Readings in Sustainability Science and Technology

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Robert W. Kates, Editor

CID Working Paper No. 213
December 2010

Working Papers

Center for International Development
at Harvard University

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Abstract

This Reader is one possible set of materials for advanced undergraduate and beginning graduate students of sustainability science. It consists of links to 93 articles or book chapters from which appropriate readings and internet sources can be chosen. These are organized around three major domains of sustainability science: Part 1: an overview of sustainable development; Part 2: the emerging science and technology of sustainability; and Part 3: the innovative solutions and grand challenges of moving this knowledge into action.

The Readings begins with the history of sustainable development and its many concepts (1.1). Among these are the dual goals of sustainable development—the promotion of human development and well-being while protecting the earth's life support systems. Thus, the current status, long-term trends, and impacts of nine essentials for human well-being (1.2) and seven of the essential life support systems (1.3) are examined. Part 1 concludes with the interactions of human society and the life support systems as these have been sketched—simply, realistically, and imaginatively (1.4).

Part 2 of the Reader focuses on what, why, and how to do sustainability science and technology. It begins with three essential qualities of the emerging science: its use or needs orientation, focus on human-environment systems, and goal of integrated understanding (2.1). As a science in support of a sustainability transition, it is clearly value-driven and a second section of this Part considers the science of identifying and analyzing values and attitudes (2.2). The third and fourth sections examine the current practice of the science, the analyses undertaken (2.3), and the distinctive methods and models used (2.4).

The distinctive knowledge created by sustainability science is use-inspired and, at its best, provides solutions to real-world, often place-based, problems encountered for the needs of a sustainability transition. Thus, the Reader ends with linking knowledge systems and action (3.1); examples of both global and local solutions to the needs of human well-being and the earth's life support systems (3.2); and three critical needs that constitute grand challenges: poverty, climate change, and peace and security (3.3).

Keywords: sustainability science, sustainable development, environmental policy, sustainability education, environment and development

JEL subject codes: Q01, Q56, Q57, I32, J11

This paper may be cited as: Kates, Robert W., ed. 2010. Readings in Sustainability Science and Technology. CID Working Paper No. 213. Center for International Development, Harvard University. Cambridge, MA: Harvard University, December 2010. It is available at http://www.hks.harvard.edu/centers/cid/publications/faculty-working-papers/cid-working-paperno.-213. Comments are welcome and should be directed to: sustsci_reader@hks.harvard.edu.

Preface

Sustainability science has emerged in recent years as a vibrant field of research and innovation. Like agricultural science and health science, it is a use-driven field of work. Its motivations lie in what the World Commission on Environment and Development characterized as the transcendent challenge of our age: 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 (p.8)."[1] Its foundations build on the natural and social sciences, on engineering and medicine, and on the multiple knowledges of practice. Its methods are integrative and translational, seeking to link knowledge with action in the spirit of what Donald Stokes dubbed "Pasteur's Quadrant" where "basic science and technological innovation" meet and interact.[2]

The literatures of sustainability science have been growing exponentially, with contributors spread across the developed and developing world. The number of publication venues devoted in part or in full to the field have also increased rapidly. But the sustainability science literature today remains dispersed across multiple publication venues. Moreover, the relative youth and rapid growth of the field mean that there are as yet no comprehensive textbooks available. This situation poses major challenges for the increasing number of individuals, programs, and institutions that are trying to learn and teach sustainability science: How can its content be organized? What are the seminal papers? How do individual works fit into the larger picture of the field?

I first encountered the notion that some of these questions might be usefully addressed by a "Reader in Sustainability Science and Technology" a decade ago during preparations for the World Summit on Sustainable Development. A series of regional workshops had been organized by the international Initiative on Science and Technology for Sustainability (ISTS), the Academy of Sciences of the Developing World (TWAS), and the International Council for Science (ICSU) for the purpose of articulating local priorities for research needed to support sustainable development.[3] Participants had many different suggestions, but were virtually unanimous in their requests for recommended readings that they could use to supplement their own favorites from their own areas of expertise. An initial response to these requests was organized through the virtual *Forum on Science and Innovation for Sustainable Development* now hosted by the American Association for the Advancement of Science (AAAS) on behalf of TWAS and ISTS (http://sustainabilityscience.org). More recently, course syllabi in sustainability science have begun to appear around the world with reading lists of their own.

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1 World Commission on Environment and Development (WCED). 1987. *Our Common Future.* Oxford: Oxford University Press. p. 8.
http://en.wikipedia.org/wiki/Our_Common_Future

2 Stokes DE. 1997. *Pasteur's Quadrant : Basic Science and Technological Innovation.* Washington, D.C.: Brookings Institution Press.
http://books.google.com/books?id=xbztTkGKOHEC&lpg=PP1&ots=qgVBjXdAUe&dq=Pasteur's%20quadrant%20%3A%20Basic%20science%20and%20technological%20innovation&pg=PP1#v=onepage&q&f=false

3 International Council for Science, Initiative on Science and Technology for Sustainability, and Third World Academy of Sciences. 2002. Science and Technology for Sustainable Development. ICSU Series on Science for Sustainable Development, No. 9. Paris, France.
http://www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/70_DD_FILE_Vol9.pdf

Nonetheless, no systematic introduction to the key literatures of sustainability science has been widely available.

Bob Kates' *Reader in Sustainability Science and Technology* meets this need as a timely and welcome addition to the field. The *Reader* is several things. First, Kates offers an intellectual structure for the field of sustainability science, including the basic science of human-environment systems, the challenges of sustainable development that motivate that science, and the applications to specific problems that show its utility. This is not the only structure possible, but it is a deep and powerful one that many of us who "test piloted" the *Reader* have found to be enormously useful in ordering our own thinking. Second, Kates has populated his map of sustainability science with a carefully selected set of individual readings, most published during the last decade but also including some of the classics that constitute the foundations of the field. Finally, he has provided invaluable context and connections through his narrative introductions to his structuring of the field and his commentaries on the individual papers he has selected. The result is an original creation of great value and wisdom from which all interested in the field of sustainability science will benefit for years to come.

Bob Kates is the only person I know who could have created this *Reader*. He was introduced to the form in one of his first professional publications for a then new interdisciplinary field of resource management.[4] His subsequent work immersed him in a wide a cross section of the intellectual streams from which sustainability science has grown: the study of human response to natural disasters, the analysis of technology as hazard, interdisciplinary research on environment and development in Africa, pioneering efforts to reduce world hunger, and philosophical explorations of the proper human use of the earth. By the 1990s, Kates had emerged as one of the founders of the sustainability science movement, first as leader of the US National Academy of Science's seminal study *Our Common Journey: A transition toward sustainability*, then as an architect of the report in *Science* on the international workshop at Friibergh Manor that did so much to frame the current conceptualization of the field.[5] Over the last decade, through his research, writing and public service, Kates has been the most articulate and consistent voice for a truly transformative sustainability science: one that is remorselessly pluralist in its methods, balanced in its treatment of the human and environmental components of the earth system, and passionate in its insistence on using science and technology to create a better world.

This first edition of the *Reader* is a work in progress. That work is being supported by the Sustainability Science Program at Harvard University which I co-direct, with financial backing provided by the Italian Ministry of Environment, Land and Sea. This edition is freely available through the world-wide web; users are invited to redistribute it widely for unrestricted use in

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[4] Burton, Ian, and Robert W. Kates, eds. 1965. *Readings in Resource Management and Conservation*, Chicago: University of Chicago Press.

[5] National Research Council. Policy Division. Board on Sustainable Development. 1999. *Our Common Journey: A Transition toward Sustainability*. Washington, D.C.: National Academy Press. http://www.nap.edu/openbook.php?record_id=9690&page=1

Kates, Robert W., William C. Clark, Robert Corell, J. Michael Hall, Carlo C. Jaeger, Ian Lowe, James J. McCarthy, et al. 2001. Sustainability science. *Science* 292 (5517): 641-2. http://www.sciencemag.org/content/292/5517/641.summary educational or research contexts. Subsequent evolution of the *Reader* may include a published version with copies instead of merely citations of its component papers, or a web-based version with links to its articles that are accessible to all at little or no cost. More ambitiously, we hope that future editions will incorporate feedback and suggestions from its users for better or additional papers. Such comments can be submitted through sustsci_reader@hks.harvard.edu. Updates on subsequent editions of the *Reader* will be announced on the web sites of the Sustainability Science Program (http://www.hks.harvard.edu/centers/cid/programs/sustsci) and on the above-noted *Forum on Science and Innovation for Sustainable Development.*

William C. Clark
Professor and Co-director, Sustainability Science Program
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Program and Editor Acknowledgements

Robert Kates trained as a geographer and taught geography for many years at Clark University in Worcester, Massachusetts, USA. He also participated in interdisciplinary programs addressing both environment and development at the University of Dar as Salaam in Tanzania, at Clark University, and at the World Hunger Program at Brown University in Providence, Rhode Island, USA. Kates now serves as a Senior Research Fellow at Harvard, co-convener of the Steering Group for the Initiative on Science and Technology for Sustainability, and Presidential Professor of Sustainability Science at the University of Maine. Kates served as co-chair for the National Academy of Sciences' report, *Our Common Journey: A Transition toward Sustainability*. His current research is on community resilience, adaptation to climate change, and long-term trends, values, attitudes, and beliefs affecting a sustainability transition. Much of his writing can be found on http://rwkates.org. He is a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and Academia Europaea. In 1991 he was awarded the National Medal of Science for his work on hunger, environment, and natural hazards. He now lives and works as an independent scholar in Maine.

The Sustainability Science Program at Harvard's Center for International Development harnesses the University's strengths to promote the design of institutions, policies, and practices that support sustainable development. The Program addresses the challenge of sustainable development by: advancing scientific understanding of human-environment systems; improving linkages between research and policy communities; and building capacity for linking knowledge with action to promote sustainability. The Program supports major initiatives in policy-relevant research, faculty research, training of students and fellows, teaching, and outreach. See http://www.hks.harvard.edu/centers/cid/programs/sustsci.

Editor Acknowledgements

I am very grateful for the considerable assistance of William Clark, Nancy Dickson, and Elizabeth Reinhardt, and the helpful review and commentary of Mark Anderson, , Ruth Defries, Niyi Gbadegesin, Lisa Butler Harrington, Akin Mabogunje, Pamela Matson, Pim Martens, Mohan Munasingh, and Tom Parris, and the thoughtful comments of students in the Sustainability Science distributed graduate seminar. I am appreciative of the administrative support provided by Nora O'Neil and Aparna Das at Harvard University. Special thanks to Ellie Kates and my family for their extreme patience and encouragement during the four years it took to put the Reader together.

Support from the Sustainability Science Program at Harvard's Center for International Development and the Italian Ministry for Environment, Land, and Sea is gratefully acknowledged.

Readings in Sustainability Science and Technology
Robert W. Kates, editor[6]

Table of Contents

Sustainability science is science, technology, and innovation in support of sustainable development—meeting human needs, reducing hunger and poverty, while maintaining the life support systems of the planet. As such, it is an active pursuit of the scientific community and a rapidly expanding international research activity. But increasingly, it is also a focus for education as courses and degree programs in sustainability, sustainable development, and sustainability science proliferate. For these newly designed courses and programs, and for the many more scholars and scientists who want to explore the inclusion of sustainability science in their ongoing educational activities, there is need for organized teaching materials.

This Reader is an effort to provide such materials for advanced undergraduate and beginning graduate students at low cost (no cost in developing countries) in formats that take advantage of electronic media and are readily revisable given the rapid development of such a new interdisciplinary activity. It consists of links to 93 articles or book chapters from which appropriate readings and internet sources can be chosen. These are organized around three major domains of sustainability science: Part 1- an overview of sustainable development; Part 2 - the emerging science and technology of sustainability; and Part 3 - the innovative solutions and grand challenges of moving this knowledge into action. Each topic begins with an introductory paragraph followed by the recommended reading(s).

1 SUSTAINABLE DEVELOPMENT

Sustainability science aspires to contribute to sustainable development and the Readings begin with the history of sustainable development and its many concepts (1.1). Among these are the dual goals of sustainable development—the promotion of human development and well-being while protecting the earth's life support systems. Thus, we examine nine of the essentials for human well-being (1.2) and their current status, long-term trends, and impacts on the environment. In turn, we consider the current quality, long-term trends, and impacts on human well-being of seven of the essential life support systems (1.3). We conclude with the interactions of human society and the life support systems as these have been sketched—simply, realistically, and imaginatively (1.4).

1.1 CONCEPTS/ HISTORY

The definition of sustainable development that has wide acceptance is: "Humanity has 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." [7] The definition is actually creatively ambiguous and has encouraged alternative concepts of what is to be developed and what is to be sustained.

Reading:

Kates, Robert, Thomas M. Parris, and Anthony A. Leiserowitz. 2005. What is sustainable development? *Environment* 47 (3): 9-21.

http://www.environmentmagazine.org/Editorials/Kates-apr05-full.html

> The Reading explores the different definitions, goals, indicators, values, and practice that, taken together, seem to explain what is meant by sustainable development, beginning with a brief history.

1.2 PROMOTING HUMAN WELL-BEING

The well-being of the future global population of 9 billion depends on enhancing health, reducing poverty, improving habitation, and attaining peace with sustained access to needed resources of food and fiber, energy and materials, and water. For each of nine essentials of human well-being, we consider their current state, future trends, and challenge to a sustainability transition.

1.2.1 Population

World population is estimated at 6.9 billion as of 2010, with an annual growth rate of about 1.1%, adding about 77 million per year. Growth rates have declined since the peak rate of about 2.2% per year that occurred in the early 1960s. Long-range population projections suggest that the world's population could ultimately stabilize at about 9 billion people. While all regions of the world show declining fertility, almost all the projected growth will take place in developing countries. The population of Africa is projected to grow by a billion people even with the AIDS/HIV epidemic. Thus, the major population challenge is to meet the human needs of 2.1 billion more people, house and employ 4 billion new urban residents, while limiting the environmentally damaging impacts of such growth and urbanization. At the same time, the continued global fertility decline leads to an increasing ageing of the population. A growing population need is to care for ageing populations in industrialized and newly industrializing countries and to absorb the migrants those societies will require.

Reading:

U.N. Economic and Social Council, Commission on Population and Development. 2009. *World Demographic Trends: Report of the Secretary-General*. 1-22. New York: United Nations E/CN.9/2009/6.

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[7] World Commission on Environment and Development. 1987. *Development and International Economic Co-operation: Environment*. Report of the World Commission on Environment and Development. New York: Oxford University Press, p.8.
http://www.un-documents.net/wced-ocf.htm

http://www.un.org/Docs/journal/asp/ws.asp?m=E/CN.9/2009/6

The Reading provides a global overview of these and other demographic trends including migration and population policies.

1.2.2 Health and well-being

The overall health of people has substantially improved over the last sixty years. The average life expectancy for a newborn child has been extended from 46 to 69 years. Much of this improvement is from reductions in infant and child mortality for which immunization, and improved water, sanitation, and nutrition have played major roles. But major health problems persist both with the spread of infectious diseases, characteristic of developing countries, and the chronic diseases of industrialized countries. Human development, a major component of well-being, refers to the attainment of a long and healthy life, a rise in knowledge and education, and a growth in economic productivity. In addition to health, other measures of human development also show improvement as adult illiteracy has been cut in half since 1970, and GDP/capita (purchasing power parity) has quadrupled since 1980. Global trends, however, often mask the plight of those that are left in persistent poverty that is maintained by growing inequality, shrinking entitlements, and reduced environmental services. The very opportunity of life may be denied due to child mortality, the AIDS pandemic, and reemergent infectious diseases. For example, a child born in Africa has 25 years less life expectancy than one in Europe, a difference that has not changed in more than a century. Narrowing that difference is a central challenge of health and well-being.

Reading:

World Health Organization. 2009. *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks,* 1-31. Geneva: WHO.

http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

The Reading is a comprehensive assessment of leading risks to global health. It provides detailed global and regional estimates of premature mortality, disability and loss of health attributable to 24 global risk factors.

1.2.3 Poverty and affluence

Affluence, although measured imperfectly by GDP/per capita (purchasing power parity), has quadrupled over the last 30 years. Extending a modicum of affluence to the poorer portions of the world and especially to the poorest of the poor is a major need. Almost 1 billion people (18%) were living on less than $1.08/day in 2004 and 2.5 billion people (48%) on less than $2.15/day. But these numbers for poverty and similar figures on hunger are declining. For example, the proportion of most impoverished people, living on less than $1 a day, declined in a quarter of a century by half, from two-fifths to one-fifth of the world population. This reduction has varied by region. East Asia has made the most progress, while South Asia and Latin America have had only modest improvement. But there has been no improvement in sub-Saharan Africa where the numbers of very poor almost doubled between 1981 and 2004. Thus, the principle poverty challenge in the world is that of sub-Saharan Africa, the region that has shown little or no improvement, or even worsening, in all the key indices of health, well-being, food security, and economic growth. A secondary challenge is for the newly-industrializing countries, such as Brazil, China, and India, to translate their rapid economic growth into improved well-being for their may impoverished citizens.

Reading:

Kates, Robert W., and P. Dasgupta. 2007. African poverty: A grand challenge for sustainability science. ***Proceedings of the National Academy of Sciences*** **104 (43): 16747-16750.**

http://www.pnas.org/content/104/43/16747.full.pdf

> The Reading is an introduction to a set of articles focusing on poverty in sub-Saharan Africa and summarizes definitions, causes, and proposed poverty polices in that region.

1.2.4 Habitation and transportation

An estimated half of the world's population now live in cities, and this number will continue to expand until probably 85% of the world will live in cities, as they currently do in Australia, Chile, and Denmark. Additionally, with the worldwide emergence of the use of the cell phone and the internet, even rural dwellers now have access to virtual cities with the urban services, information, and entertainment that not only inform, but also create, expectations for urban lifestyles. To accommodate the 4 billion new urban residents the equivalent of nearly 400 great cities will need to be built in and around existing cities. Most of this expansion will be in developing countries. Time is running out for sustainable cities—cities that are habitable, efficient, and environmentally friendly. Habitable cities must meet minimal basic needs for housing, education, jobs, and health for all its residents. Efficient cities provide economically services, material needs, governance, and employment opportunities. Environmentally friendly cities pursue clean air, water, green space, and an ecological footprint that preserves the life support systems of the planet. Thus urban growth provides a unique opportunity for energy and material efficiency, green building, and public transportation as well as for jobs, education, and health. But the failure to use this opportunity will, in the next fifty years, lock us into the urban infrastructure of the last 50 years that could perpetuate the current energy-intensive, transport-gridlocked, and slum-infested cities of today.

Reading:

Satterthwaite, D. 2007. The urban challenge revisited. ***Environment*** **49 (9): 3-18.**

http://www.environmentmagazine.org/Archives/Back%20Issues/November%202007/Satterthwaite-full.html

> The Reading reflects on the urban challenge posed in *Our Common Future*, the Brundtland Report on sustainable development, and what has transpired in cities since its publication in 1987.

1.2.5 Peace and security

The antitheses of peace and security - war, conflict, crime, and corruption - are major threats to sustainable development. Directly, they destroy human lives, capital, infrastructure, and the environment, and indirectly, they divert needed productive resources and increase exploitation of natural resources. Overall, war is as destructive to the environment as it is to society, but ironically, conflict-forced or defense-related land abandonment often leads to natural restoration. Since the end of WW II, there was a steady increase in the incidence of armed conflict around the world, often as proxy battles of the Cold War or from a legacy of unresolved colonialism. Perhaps 25 million died directly from this violence, equal to all military deaths in World War II. At its peak in 1992, a third of the countries of the world contained violent conflicts and there were over 40 million refugees and displaced persons. Since then, despite the continued warfare in Afghanistan and Iraq, organized conflict has declined, including terrorism, state, and non-state conflict. Violent crime is the leading fear for personal security in most countries, although it is probably more greatly feared than actually occurring. These fears have encouraged the creation of gated communities that further separate people and increase isolation. Notwithstanding improving trends, war, conflict, crime, and corruption still pose an exceptional challenge.

Reading:

Human Security Centre. 2005. Part 1 The changing face of global violence. In *Human Security Report 2005: War and Peace in the 21st Century*, 13-60. New York: Oxford University Press.

http://www.resdal.org/ing/ultimos-documentos/human-security-report05_i.html

> The Reading documents these trends in global and regional political violence (armed conflicts, genocides and international terrorism), since the end of World War II. Its findings challenge conventional wisdom.

1.2.6 Energy and materials

Over the second half of the 20th century, while world population more than doubled, food production almost tripled, energy use more than quadrupled, and the overall level of economic activity quintupled creating a paradox for sustainability. To meet human needs, the world needs a growing economy and increased energy and material production, while coping with the threats to the planet that such affluence poses. For some time, industrialized countries have evidenced dematerialization, a decrease in harmful consumption per unit of value of product; however, increases in the overall consumption of energy and most materials more than offset such gains. In industrializing countries and in urban areas in developing countries, energy and materials consumption is growing rapidly with little or no signs of slowing. For the poorest people and least developed countries, consumption is grossly inadequate with unmet needs for energy and materials for food production, housing, consumer goods, transportation, and health. But in both rich and poor countries alike, making and selling things to each other, including things we might not need, is the essence of current economic systems. Thus, the major challenge is how to shift to the less harmful but most needed energy and material production and consumption.

Reading:

Ausubel, Jesse H., and Paul E. Waggoner. 2008. Dematerialization: Variety, caution, and persistence. *Proceedings of the National Academy of Sciences* 105 (35): 12774-12779.

http://www.pnas.org/content/105/35/12774.full.pdf

> The Reading documents recent trends in dematerialization for a number of countries for energy and material goods and for production improvements that make more from less.

1.2.7 Food and fiber

In the last half of the 20th century per capita world food production rose by 22%, even as population doubled; real food prices fell by half; and the proportion of hungry people declined by half. These trends were interrupted by a number of crises particularly in the 1970s, and sub-Saharan Africa was always a clear exception. Nonetheless, these trends had been so pronounced that the UN Food and Agriculture Organization in 2000 confidently forecast that they would continue into the future. Yet, these important trends in food and fiber production, declining prices, and reduced hunger may be coming to an end. Increases in yields have stagnated and investment in research has declined. Beginning in 2006, food prices surged and the numbers of hungry rose, as food production declined from adverse weather or shifts in production to biofuels and costs rose especially for fuel. Agriculture and food security in Africa has always been a central challenge. Now the challenge may be becoming worldwide.

Reading:

Webb, Patrick. 2010. Medium- to long-run implications of high food prices for global nutrition. *Journal of Nutrition* 140 (1): 143S-147S.

http://jn.nutrition.org/cgi/content/abstract/140/1/143S

> This Reading explores how high food prices during the financial crisis of the great recession and related impoverishment of the poor could persist because of growing demand and dietary change, cross-commodity prices, biofuels, environmental shocks to the food system, and public policy.

1.2.8 Water and sanitation

Freshwater is one of the fundamental building blocks of life and is required for drinking water, sanitation, agricultural, and industrial production. While freshwater is widely available, it is unevenly distributed. Many places in the world suffer local shortage or diminished quality from pollution and salinization. Water stress is widespread in a third of the world where withdrawals exceed 20% of available supply. In the last century, water withdrawals increased by over six times, more than double the rate of population growth. A new trend may also be beginning as per capita water withdrawals have now declined in some industrialized countries. The most significant challenge is the unmet need for household water use, with 1.2 billion people in developing countries lacking access to a safe and reliable supply and 2 billion people lacking access to sanitation.

Reading:

Gleick, Peter. H. 2003. Water use. *Annual Review of Environment and Resources* 28 (1): 275-314.

http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.040202.122849

> The Reading documents these and other long-term trends in water use, including ways to improve regional and sectoral water use efficiency and productivity.

1.2.9 Disasters

Disasters are non-routine, occurrences in societies, regions, or communities that experience extensive human harm and social disruption and are usually initiated by a combination of physical, biological, and social events. (See also 2.3.2.1) These occurrences include natural disasters (hydrometeorological, geological, or biological), technological disasters (accidental or intentional), and social (economic, cultural, conflict). They provide major challenges to sustainable development by reducing populations and health through large numbers of deaths and injuries and diminishing economic and social development through loss of income, property and employment. The best-studied disasters are so-called natural disasters. Over a century, deaths from these have declined substantially while the number of disasters and their economic losses has grown, especially in recent decades. Between 300 and 400 natural disasters are recorded annually. The overwhelming number of deaths in the last 15 years occurred in developing countries (90%) while the greater proportion of economic losses are in developed countries (63%). But the proportional impacts of the economic losses in developing countries are much greater ranging in the top 50 countries (all developing) from seven to several hundred per cent of gross domestic product.

Reading:
United Nations Development Programme. 2004. Chapter 1 Development at risk. In *Reducing Disaster Risk: A Challenge for Development,* 9-28. New York: UNDP.
http://www.undp.org/cpr/disred/documents/publications/rdr/english/chapter1.pdf

> The Reading introduces the global disaster-development relationship by examining the trends in disaster deaths and losses; their impact on achieving sustainable human development- (specifically the Millennium Development Goals) and the challenge of incorporating disaster risk in development planning.

1.3 PROTECTING THE EARTH'S LIFE SUPPORT SYSTEMS

Many of the essentials of human well-being require the production and consumption of needed energy and materials, habitation and transport, food and fiber, and water. For all of these, the processes of production and consumption threaten and impair essential life support systems. Of all these threats, only global climate and stratospheric ozone are truly systemic, namely that actions taken anywhere that affect them, affects the global system. Threats to the land we live on, the air we breathe, the water we use, the oceans we draw food from, the diversity of living things, and the services that ecosystems provide are essentially local and regional but become global problems in the sense that they are ubiquitous and occur in many parts of the world at the same time. These systems are also interlinked and it is difficult to separate them. Thus for example, human-induced climate change is linked to other systems of air, water, land, oceans, biodiversity, and ecosystem services. Despite this difficulty, we address each of these in turn and consider their current state, future trends, and challenge to a sustainability transition.

1.3.1 Global climate and stratospheric ozone

The major systemic global life support threats are the destruction of the stratospheric ozone layer and human-induced climate change, though through very different processes. During the 1980s, scientists observed that the stratospheric ozone layer that protects life on earth from the sun's harmful ultraviolet (UV) radiation was getting thinner, mainly from the use of chlorofluorocarbons that deplete the ozone layer. With the implementation of the Montreal Protocol to reduce emissions of ozone-depleting substances, the ozone layer has not grown thinner over most of the world and appears to be recovering. In contrast, the major radiatively active "greenhouse" gasses (GHGs: carbon dioxide, nitrous oxide, methane, and halocarbons) continue to increase at rates greater than projected in the most recent global assessment. The last decade has been the warmest since records began in 1861, and the last half-century has probably been the warmest in the last 1,300 years. Sea level rise, decreases in snow and ice, increases in areas affected by drought, heat waves, intense rainfalls, and changes in the numbers, health, and behavior of plants and animals are already evident. Global GHG emissions, particularly carbon emissions from the consumption of fossil fuels, will continue to grow at least over the next quarter-century further endangering food security, raising sea-level, and increasing the intensity of natural disasters, species extinction, and the spread of vector-borne diseases. More serious and abrupt climate changes are possible making climate change one of the most critical global challenges of our time.

Reading:

Intergovernmental Panel on Climate Change. 2007. Summary for policymakers. In *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. Geneva: IPCC.
http://www.ipcc.ch/publications_and_data/ar4/syr/en/spm.html

> The Reading is the major summary of the fourth global assessment of climate change undertaken by the Intergovernmental Panel on Climate Change (see also 2.4.3.4.3). It is the authoritative report on global and regional climate change, its impacts on ecology and society, and potential actions to prevent change or to adapt to it.

1.3.2 Land

Some 30% of the earth constitutes land and 89% of the land is ice free. In a novel human-environment classification of anthropogenic biomes, the mosaic of human population, land uses, and land covers of the ice free earth is divided into dense settlements (1%), villages (6%), croplands (21%), rangelands (30%), forests (19%), and wildlands (23%).[8] These land uses are in transition from wildlands, initial clearing, subsistence and small-scale farming, to urban settlement and intensive agriculture; all of these stages going on concurrently somewhere in the world. Over time, the area of original forest has been cut in half. Currently the area of tropical forests continues to decline, but temperate forest areas have been increasing. In part this is due to agricultural intensification as arable land per person has been cut from 0.42 ha to 0.23 ha while food production rose 160% over the last half-century. These changes have had major environmental impacts: to the land itself (soil erosion, salinization, desertification); to other life support systems (greenhouse gas emissions, biodiversity, aquifer depletion, freshwater pollution, human health), and to ecosystem services, increasing some but decreasing many.

Reading:

DeFries, Ruth, Gregory P. Asner and Jonathan Foley. 2006. A glimpse out the window: What landscapes reveal about livelihoods, land use, and environmental consequences. *Environment* 48 (8): 22-36.
http://www.informaworld.com/smpp/content~db=all~content=a925412017~frm=abslink?words=window|defries|environment&hash=3748265063

> The Reading details the land use transition, compares it to other transitions (see also 2.3.1), the specific land uses in each stage, their locations, the environmental consequences at each stage, and the tradeoffs between short-term gain and long-term consequences.

[8] Ellis, E.C. and N. Ramankutty, 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and Environment 6(8): 439–447

1.3.3 Atmosphere

The atmosphere is an ever-changing mixture of gasses and small particulates from both human and natural sources. While essential for the maintenance of the biosphere, some gasses and particulates are also pollutants and are threatening to both human and ecosystem health. The major atmospheric threats to human health are sulfur dioxide, ozone (itself a product mainly of the interaction of nitrogen oxide and volatile organic compounds), and fine particulate matter. Over time, most industrialized countries have seen major drops in sulfur levels, but persistent levels of ozone, and increased concern with small particulates. It is in the rapidly growing cities of the newly industrializing world where the full range of pollutants are rapidly increasing and air quality is the central environmental problem both indoors and outdoors.

Reading:

Molina, Mario J., and Luisa T. Molina. 2004. Megacities and atmospheric pollution. *Journal of the Air and Waste Management Association* 54 (6): 644-680.

http://secure.awma.org/journal/pdfs/2004/10/crdiscussion04.pdf

> The Reading documents these changes, including impacts on health, ecosystems, and regional climate, for the cities of the world with populations of ten million or more. Nine of these cities are selected as case studies.

1.3.4 Water

Freshwater in rivers, lakes, and the ground, essential to all life (see also 1.2.8), contains a variety of substances of both natural and human origin, some of which is harmful to people, biota, and ecosystems. These include sediments (chemicals, soils, rocks) washed off the land or contained in groundwater, chemicals from agriculture and industry, and microbes harmful to living things. In most industrialized countries, microbial pollution is rare in drinking water, sewage is treated, and chemical pollutants from direct (point) sources in cities and industry have been substantially reduced. But indirect (non-point) sources of pollution persist from urban, agricultural, accidental, and atmospheric deposition. Water pollution is a major problem in rapidly growing urban areas in Africa, Asia, and Latin America, and infectious water-borne disease claims lives of millions, especially children.

Reading:

Postel, Sandra. 2005. From the headwaters to the sea: The critical need to protect freshwater ecosystems. *Environment* 47 (10): 8-21.

URL not available

> The Reading addresses freshwater ecosystems, the services they produce, and the growing effort to maintain and protect them.

1.3.5 Oceans

The oceans constitute some 70% of the earth‘s surface. They store and move much of its heat, produce 50% of its oxygen, 20% of its animal protein, and contain perhaps half of its species. As many as 40% of the world’s people live within 100 kilometers of the sea, a billion people have seafood as their major protein source, and many millions secure their livelihood from the sea. The physical, biological and socio-economic character of the oceans have naturally varied, but major stresses emanate from human exploitation of its resources and dispersal of waste, nutrients, and pollutants from land and air. Leading these is the long-term depletion of marine resources both at the top and the bottom of the food chain primarily from fishing practices, habitat destruction, and ocean temperatures. Some 41% of the oceans show high human-induced impacts on marine ecosystems, with the highest impacts in coastal regions. Over the long-term, climate change affecting sea levels, temperatures, currents, and acidification may emerge as the most serious of human-induced stresses on the oceans.

Reading:
Lotze, Heike K., Hunter S. Lenihan, Bruce J. Bourque, Roger H. Bradbury, Richard G. Cooke, Matthew C. Kay, Susan M. Kidwell, Michael X. Kirby, Charles H. Peterson, and Jeremy B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312 (5781): 1806-1809.
http://www.sciencemag.org/cgi/content/short/312/5781/1806

> The Reading details the very long-term trends and causes of depletion of marine species and habitats in 12 estuaries and coastal regions in Europe, the U.S., and Australia.

1.3.6 Biodiversity

Biodiversity, a contraction of the term "biological diversity," describes the variety of all forms of life, from genes to species to ecosystems. This variety, a central component of earth's life support systems, differs across the globe, with the greatest variety found in the tropics and diversity diminishing towards the poles. But this general pattern is punctuated by local concentrations or hot spots. The most frequent measure of biodiversity is number of species, which probably underestimates the importance of landscapes and seascapes as a whole. In any event, the number of species on earth is unknown, but the estimate from the reading for the total number of species of eukaryotic organisms (plants, animals, fungi) lies in the 5–15 million range (with a best guess of 7 million) and with a much larger number of microorganisms (bacteria, viruses, blue-green algae). Multi-cellular diversity grew over the past 4 billion years but was punctuated by 5 mass extinctions and recoveries. A sixth may now be underway as biodiversity is increasingly threatened by human action in the forms of habitat destruction and fragmentation, excessive harvesting, invasive species, and pollution. Recent recorded extinctions reveal rates of extinction much larger than those found in the fluctuation of the fossil record.

Reading:
Dirzo, Rodolfo, and Peter H. Raven. 2003. Global state of biodiversity and loss. *Annual Review of Environment and Resources* 28 (1): 137-167.
http://www.bio-nica.info/biblioteca/Dirzo2003Biodiversity.pdf

> The Reading documents global and regional biodiversity, including natural, domestic, and novelty species, and current and projected losses.

1.3.7 Ecosystem services

Ecosystem services are the benefits people obtain from ecosystems. These include *provisioning services*, the commodities that people use such as fiber, food, timber, and water; *regulating services* that affect climate, disease, floods, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* that assist in soil formation, photosynthesis, and nutrient cycling. The Millennium Ecosystem Assessment completed in 2005 found that overall people have made greater changes to ecosystems in the last half of the 20th century than at any time in human history. Overall these changes have enhanced human well-being, but have been accompanied by ever increasing degradation. For some people and some regions, the effects of these changes already outweigh the benefits. Reversing the ongoing ecosystem degradation, while meeting the increased demand for ecosystem services, is a major challenge of sustainable development.

Reading:
Millennium Ecosystem Assessment. 2005. Summary for decision makers. In *Ecosystems and Human Well-being: Synthesis*, 1-24. Washington, D.C.: Island Press.
http://www.maweb.org/en/Synthesis.aspx

> The Reading is the major summary of the Millennium Ecosystem Assessment, the authoritative report on the causes of global and regional ecosystem change, consequences for nature and human well-being, and ways of ameliorating or adapting to such change.

1.4 HUMAN-ENVIRONMENT INTERACTIONS

The dual goals of sustainable development—the promotion of human development and well-being while protecting the earth's life support systems—come together as human-environment interactions. We introduce some of the interactions of human society and the earth's life support systems as three sets of sketches: simple characterizations, more realistic processes, and more imaginative visions.

1.4.1 Simply sketched interactions

Simple sketches, some would say overly simple sketches, are brief, memorable characterizations of some distinctive aspect of human-environment interactions. We have chosen seven of these from the past forty years that have met the test of time along with much critique and controversy.

1.4.1.1 Human dominion

Are we part of or apart from the natural world? One set of answers, the grant by God of human dominion over nature, is derived from the Judeo-Christian tradition. Genesis, 1:28 proclaims: "…and God said unto them: [men and women] Be fruitful and multiply, and fill the earth, and subdue it; and have dominion over the fish of the sea, and over the fowl of heaven, and over every living thing that moveth upon the earth." But for some religionists, dominion also carries responsibility for what is now the "stewardship" tradition. Genesis 2:15 also says it: "God takes the newly created human, ... and placed him in the garden of Eden, to cultivate it and to guard it."

Reading:
White, Lynn, Jr. 1967. The historical roots of our ecological crisis. *Science* 155 (3767): 1203-1207.
http://www.sciencemag.org/content/155/3767/1203.extract

> This Reading by a medieval historian was a talk given to the 1966 meeting of the American Association for the Advancement of Science (AAAS). Its central theme is how the grant of dominion underlies the ecological crisis, but it is also remarkably perspicacious about the current ecological crisis.

1.4.1.2 Tragedy of the commons

Aristotle said it: "For that which is common to the greatest number has the least care bestowed upon it." Nineteen centuries later, Hardin applied this powerful metaphor of human interaction with the environment to the common resources shared by much of the earth's life support systems. That the commons is endangered is widely accepted, but that institutions, beyond privatization, evolve to rule the commons and prevent tragedy is a subject of much research [9] (see also 2.3.3.5.2).

Reading:
Hardin, Garrett. 1968. The tragedy of the commons. *Science* 162 (3859): 1243-1248.
http://www.sciencemag.org/content/162/3859/1243.full.pdf

> The Reading describes commons problems, beginning with the example of a town common overgrazed by the residents' sheep, to current pollution disposal, and even human reproduction. This class of problems, Hardin argues, can only be solved by doing away with the commons itself, either through government regulation or private ownership.

1.4.1.3 Limits to growth

Success in human endeavor is often measured by growth—bigger is better. The conjunction of environmental message and analytic methods came together to create this simple model that explored the interactions of five characteristics of global human-environment systems that were growing exponentially: world population, food production, industrialization, resource depletion, and pollution. With the cachet of a first globally-integrated world model, the essence of their argument that growth has limits persist despite being repeatedly criticized, especially by economists.[10]

Reading:
Meadows, Donella H., Dennis Meadows, Jorgen Randers, and William W. Behrens III. 1972. *The Limits to Growth: A Report to the Club of Rome's Project on the Predicament of Mankind.* New York: Universe Books.
http://www.amazon.com/Limits-growth-Project-Predicament-Mankind/dp/0876631650

> The Reading is an extended abstract of the original study that used a globally-integrated world model to argue that growth has limits. Modeling the interactions of world population, food production, industrialization, resource depletion, and pollution, the authors conclude that growth will be limited and both population and industrial capacity will decline within a century.

1.4.1.4 I=PAT

Forty years ago, three wise men—Barry Commoner, Paul Ehrlich, and John Holdren—recognized that growth in population (P), in affluence (A), and in technology (T) were jointly responsible for environmental problems. However, they spent half a decade or more, arguing over their relative importance. Today, there is a general consensus among scientists that growth in population, wealth, and technology are jointly responsible for environmental problems. This has become enshrined in a widely used, albeit overly simplified, identity known as I=PAT, where environmental impacts (I) are a function of (PAT). Various efforts have made it more

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[9] National Research Council. Committee on the Human Dimensions of Global Change. 2002. *Drama of the Commons*. Washington, DC: National Academy Press. http://www.nap.edu/catalog.php?record_id=10287

[10] Nordhaus, William D. , Robert N. Stavins and Martin L. Weitzman. 1992. Lethal Model 2: The Limits to Growth Revisited. *Brookings Papers on Economic Activity* 1992(2): 1-59. http://books.google.com/books?id=i7oEpzgycC8C&lpg=PA1&ots=iSNxMI9m8X&dq=Lethal%20Model%202%3A%20The%20Limits%20to%20Growth%20Revisited.%20Brookings%20Papers%20on%20Economic%20Activity&pg=PA1#v=onepage&q&f=false

analytical (see for example section 2.4.3.2). I=PAT is limited to environmental impacts, thus a version for a development identity is needed.

Reading:
Ehrlich, Paul R., and John P. Holdren. 1972. One-dimensional ecology. *Bulletin of the Atomic Scientists* 28 (5): 16, 18-27.
http://books.google.com/books?id=pwsAAAAMBAJ&lpg=PA5&pg=PA16#v=onepage&q&f=false

> The Reading, essentially a critique of Commoner's assertion of the importance of technology as the main cause for the environmental crisis, actually lays out the case for I=PAT and gives a flavor to the original argumentation.

1.4.1.5 GAIA

In 1972, James Lovelock postulated the Gaia hypothesis (named after the Greek earth goddess) that the living organisms of earth do not just adapt to the planet, but act upon the planet to make it fit for life, keeping its temperature and atmosphere appropriate for its inhabitants. Together, the physical and chemical environment of Earth and its living organisms form a system that embraces the whole Earth. While attractive to many, this vision has been widely debated by the scientific community.[11]

Reading:
Lovelock, James. 1986. Gaia: The world as living organism. *New Scientist* 112 (1539): 25-31.
http://books.google.com/books?id=1Il4qYVVJO0C&lpg=PA25&ots=2Ug3tTm4EF&dq=%22new%20scientist%22%201986%20%22The%20world%20as%20living%20organism%22&pg=PA25#v=onepage&q&f=false

> The Reading published 14 years after the original hypothesis includes new evidence and the modeling of a simple daisy world to support the hypothesis.

1.4.1.6 Wealth and capital

In 1995 the World Bank released a first report in which it attempted to measure wealth as three forms of capital: produced assets, natural resources, and human resources. Originally, the intent was also to include social capital, but this was apparently dropped given the problems of measurement. These forms of capital represent an economic approach to human-environment interactions that yield very different indicators of wealth than that of standard GNP of goods and services.

Reading:
Dasgupta, Partha (Lead Author); S. Niggol Seo (Topic Editor). 2008. Natural capital and economic growth. In *Encyclopedia of Earth,* ed. Cutler J. Cleveland. Washington, D.C.: Environmental Information Coalition, and National Council for Science and the Environment. [First published in the *Encyclopedia of Earth* May 18, 2007; Last revised August 21, 2008; Retrieved February 25, 2009].
http://www.eoearth.org/article/Natural_capital_and_economic_growth.

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[11] Schneider, James R. Miller, Eileen Crist and Penelope J. Boston. 2004. *Scientists Debate Gaia The Next Century*. Cambridge: MIT Press.
http://mitpress.mit.edu/catalog/item/default.asp?tid=10317&ttype=2

The Reading demonstrates that an economy's productive base includes not only its capital assets (stocks of manufactured, human, and natural capital), but also its knowledge and institutions and shows how accounting for natural capital can make a substantial difference to our conception of the development process.

1.4.1.7 Millennium Development Goals

At the turn of the century the General Assembly of the United Nations adopted some sixty goals that addressed peace, development, environment, human rights, the vulnerable, hungry, and poor, Africa, and the United Nations. Many of these contained specific targets for human-environment systems, such as cutting poverty in half or insuring universal primary school education by 2015. For the eight major goals currently monitored by international institutions, many countries will fall short in meeting them at recent rates of progress, particularly in Africa. Yet the goals still seem attainable by collective action both by the world community and by national governments.

Reading:

Munasinghe, Mohan. 2010. Section 1.4 Millennium development prospects and worldwide status. In *Making Development More Sustainable* (2nd Edition), 26-31. Colombo, Sri Lanka: Munasinghe Institute for Development.

http://www.mohanmunasinghe.com/pdf/Sust-SecEd-Ch01-Overview-v5rF-S.pdf

The Reading sets out the author's view of the disappointing progress in achieving the Millennium Development Goals in reducing hunger, achieving health, educating children, and sustaining the environment at the two-thirds mark leading to 2015.

1.4.2 Realistically sketched interactions

Realistic sketches seek to go beyond the simple characterization to capture human-environment interactions as processes, by considering more qualities, interacting dynamically, and extending across scales of time and space. We illustrate these with five examples that range from the most specific to the general: places, syndromes, wellbeing and services, socio-ecological systems, and human-environment research paradigms.

1.4.2.1 Long-term place-based interactions

The most realistic human-environment interactions are place-based and long-term, capturing, over time, the processes of specific peoples engaging with their distinctive environment. Yet, the number of places that have actually been recurrently studied as human-environment systems over periods of a decade or longer are few and narrowly focused (see also 2.4.1.1).

Reading:

Matson, Pamela, Amy Luers, Karen Seto, Rosamond Naylor, and Ivan Ortiz-Monasterio. 2005. People, land use and environment in the Yaqui Valley, Sonora, Mexico. In *Population, Land Use, and Environment,* eds. B. Entwisle and P. Stern, 238-264. Washington, D.C.: National Research Council.

http://www.nap.edu/openbook.php?record_id=11439&page=238

The exceptional Yaqui Valley studies are place-based, interdisciplinary, and bring together researchers, practitioners, and land users. Now in their fifteenth year, they seek to understand land use in this NW Mexico region, the consequences of land management decisions, and ways to harmonize environment and development.

1.4.2.2 Syndromes

A more abstract but realistic sketch is based on identifying complexes of non-sustainable processes, symptomatic of failing human-environment systems, and characteristic of either multiple places in different regions or of larger regions. Realism is provided by decomposing the dynamics of human use of nature with underlying natural processes.

Reading:

Lüdeke, Matthias K. B., Gerhard Petschel-Held, and Hans-Joachim Schellnhuber. 2004. Syndromes of global change: The first panoramic view. *GAIA* 13 (1): 42-49.

http://www.pik-potsdam.de/~luedeke/panview.pdf

> Analogous to medical practice with syndromes as a collection of symptoms indicative of sickness, the Reading describes some 16 identified syndromes of unsustainable global environmental and social change.

1.4.2.3 The Environmentalist's paradox

If human environment systems are closely coupled, then a decline in one system should affect the other; yet, environmental decline as measured by a decline in ecosystem services does not appear to influence human well-being at a global level—thus, the environmentalist's paradox. Long-term data sets add realism towards the exploration of the paradox.

Reading:

Raudespp-Hearne, Ciara, Garry Peterson, Maria Tengo, Elena Bennett, Tim Holland, Karina Benessaiah, Graham MacDonald, and Laura Pfeifer. 2010. Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? *Bioscience* 60 (8): 576-589.

http://www.bioone.org/doi/abs/10.1525/bio.2010.60.8.4

> The Reading uses human well-being and ecosystem services as the outputs of the coupled human-environment system and poses and evaluates four alternative hypotheses to explain the paradox.

1.4.2.4 Major dynamical patterns

At even more abstract levels, there are efforts to create theory. Thus, realism is provided by the attempt to integrate the essence of ecological, economic, and social theory to explain the functioning of socio-ecological systems across spatial and temporal scales.

Reading:

Holling, C. S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems* 4 (5): 390-405.

http://www.tsa.gov/assets/pdf/PanarchyorComplexity.pdf

> The Reading's author borrows from Einstein, stating that efforts to create theory should be "as simple as possible, but no simpler." This resilience project is currently one of the most frequently employed theoretical lens through which ecological scientists attempt to understand complex human-environment systems.

1.4.2.5 Human-environment research paradigms

Long-term case studies, syndromes, theory and other sketches come together in research paradigms that frame how human-environment systems are perceived, how understanding is sought, and how useful knowledge is created.

Reading:
Turner II, Billie L., and Paul Robbins. 2008. Land-change science and political ecology: Similarities, differences, and implications for sustainability science. *Annual Review of Environment and Resources* 33: 295-316.
http://www.annualreviews.org/doi/abs/10.1146/annurev.environ.33.022207.104943

> The Reading focuses on two research subfields with differing paradigms. They converge in the identification of the complexity of human-environment interactions and the importance of context in land-change outcomes, although differing in significant ways.

1.4.3 Imaginatively sketched

Then there are sketches of human-environment systems that are more the product of imagination than of observation or theory. This is especially true in contemplating a sustainable future, which, by definition, must go beyond the realism of past or present. Most linked to that reality are scenarios, most powerful are metaphors, and most imaginative is fiction.

1.4.3.1 Scenarios

Analytic efforts to describe human-environment futures vary between two poles of push or pull: projecting the past and present into the future (push) and moving the present towards desired or away from feared futures (pull). As products of science, these scenario efforts are often simply sketched but rooted in long-term models, trends, and observations (see also 2.4.3.3). Yet, they are also highly imaginative in their assumptions as to future events, processes, and probably most important, values.

Reading:
Raskin, Paul D., Christi Electris, and Richard A. Rosen. 2010. The century ahead: Searching for sustainability. *Sustainability* 2: 2626-2651.
http://www.mdpi.com/2071-1050/2/8/2626/pdf

> The Reading, updates an earlier study from the Global Scenario Group[12], which included scenario-creators from both the North and the South. These scenarios have both the push of "business as usual" and policy reform projections, and imaginative pulls of hope and fear.

1.4.3.2 Metaphor

More powerful than detailed scenarios are metaphors because they serve as an illustrative short hand for sustainable or unsustainable futures. Indeed many scenarios are given metaphorical titles such as "Fortress World" or "Great Transition" as in the previous reading (1.4.3.1) or "Adapting Mosaic" or "Technogarden" as in the Millennium Ecosystem Assessment (2.4.3.3).

Reading:

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[12] Raskin, Paul, Tariq Banuri, Gilberto Gallopín, Pablo Gutman, Al Hammond, Robert W. Kates, Rob Swart. 2002. Where are we headed; Where do we want to go? In *Great Transition: The Promise and Lure of the Times Ahead*. Paul Raskin, Tariq Banuri, Gilberto Gallopín, Pablo Gutman, Al Hammond, Robert W. Kates, Rob Swart, Chapters 2-3, Boston: Stockholm Environment Institute.
http://www.eoearth.org/article/Great_Transition%3A_The_Promise_and_Lure_of_the_Times_Ahead_%28e-book%29

Carson, Rachel. 1962. A fable for tomorrow; And no birds sing. In *American Earth: Environmental Writing Since Thoreau*, ed. B. McKibben, 366-376. New York: Library of America, reprinted from *Silent Spring*, 1-3, 103-126. Cambridge, MA: Houghton-Mifflin.
http://books.google.com/books?id=HeR1l0V0r54C&lpg=PP1&dq=intitle%3Asilent%20intitle%3Aspring&pg=PA1#v=onepage&q=a%20fable%20for%20&f=false
and
http://books.google.com/books?id=HeR1l0V0r54C&lpg=PP1&dq=intitle%3Asilent%20intitle%3Aspring&pg=PA103#v=onepage&q=no%20birds%20sing&f=false

> Probably the most powerful metaphor of human-environment interactions, this Reading poses the possibility of a "Silent Spring" to serve as a powerful parable of the dangers of extensive use of pesticides. That there never was a "Silent Spring" is not testimony to the failure of the author's imagination, but rather to the success of her vision that motivated a major societal effort to regulate and control pesticide use.

1.4.3.3 Fiction

Fiction, especially science-fiction, has always been the most imaginative genre for exploring futures. Utopian novels, such as Bellamy's *Looking Backward: 2000-1887*, are major examples.

Reading:
Callenbach, Earnest. 1975. *Ecotopia: The Notebooks and Reports of William Weston,* 1-37. New York: Bantam Books.
http://books.google.com/books?id=KWOdE2cK7f4C&lpg=PP1&dq=intitle%3AEcotopia&pg=PP1#v=onepage&q&f=false

> The Reading, taken from a 1975 novel, continues to influence learning and thinking today. The novel is still widely read in college classrooms and the west coast region it describes is still a front-runner for U.S. state-led environmental leadership.

2 SUSTAINABILITY SCIENCE AND TECHNOLOGY

"Sustainability science has emerged over the last two decades as a vibrant field of research and innovation. Today, the field has developed a core research agenda, an increasing flow of results, and a growing number of universities committed to teaching its methods and findings. Like "agricultural science" and "health science," sustainability science is a field defined by the problems it addresses rather than by the disciplines it employs. In particular, the field seeks to facilitate what the National Research Council has called a "transition toward sustainability," improving society's capacity to use the earth in ways that simultaneously "meet the needs of a much larger but stabilizing human population, . . . sustain the life support systems of the planet, and . . . substantially reduce hunger and poverty."[13]

This Part of the Reader focuses on what, why, and how to do sustainability science and technology. It begins with three essential qualities of the emerging science: its use or needs orientation, focus on human-environment systems, and goal of integrated understanding. As a science in support of a sustainability transition, it is clearly value-driven. A second section of this

[13] Clark, William C. 2007. Sustainability science: A room of its own. *Proceedings of the National Academy of Sciences* 104 (6): 1737-1738.
http://www.pnas.org/content/104/6/1737.full.pdf

Part considers the science of identifying and analyzing values and attitudes. The third and fourth sections examine the current practice of the science, the analyses undertaken, and the distinctive methods and models used.

2.1 EMERGING SCIENCE AND TECHNOLOGY

Much important research is done within the framework of the distinctive environmental or developmental sciences, so what seems to be different about sustainability science? It is, first of all, committed research, seeking solutions to problems posed by the needs of a sustainability transition. Second, it seeks integrated understanding of closely-coupled human-environment systems. Finally, it is as concerned with moving knowledge into action as with creating knowledge itself (this feature is explored in Part 3 of the Reader).

2.1.1 Use-inspired research

As a field that is defined by the problems it addresses rather than by the disciplines it employs, sustainability science is use-inspired research, in contrast to curiosity-driven research, so-called basic science, or inventive technology with little science. Drawn to problems encountered for the needs of a sustainability transition, sustainability scientists and engineers use, as appropriate, basic science where understanding is lacking, and applied science, as needed, to create solutions.

Reading:

Clark, William C. 2010. Sustainable development and sustainability science. In *Toward a Science of Sustainability*, eds. Levin, Simon A. and William C. Clark. Report from Toward a Science of Sustainability Conference, Airlie Center, Warrenton, Virginia, November 29, 2009 – December 2, 2009, 55-65. Princeton, NJ: Center for Biocomplexity, Environmental Institute, Princeton University and Cambridge, MA: Sustainability Science Program, Center for International Development, Harvard University.

http://www.nsf.gov/mps/dms/documents/SustainabilityWorkshopReport.pdf

> The Reading, a background paper to a 2009 conference on a science of sustainability, links the previous section on sustainable development to the emerging science and technology of sustainability science. Along with other issues, it describes use-inspired basic research, which is neither basic nor applied research, but rather a dynamic bridge between the two.

2.1.2 Human-environment systems

Human beings are both *part* of and *apart* from the natural world. They are apart both by their consciousness of their difference with nature and by the remarkable and unique impact that human action has on the natural world. But they are part of the natural world, both by their aspiration to be so and their dependence on its goods and services. Beginning in the 19th century with the work of Marsh on human action on the natural world and Haeckle and others on the relationship of living organisms to their environment, the notion of dual systems evolved into the complex, closely-coupled, human-environment systems that we study today. These combine terms such as man, human, people, society with nature, ecology, ecosystem, environment, either separated by hyphens or joined together, reflecting the ambiguity of both part and apart. Our preferred term is “human-environment systems.”

Reading:

Liu, Jianguo, Thomas Dietz, Stephen R. Carpenter, Marina Alberti, Carl Folke, Emilio Moran, Alice N. Pell, Peter Deadman, Timothy Kratz, Jane Lubchenco, Elinor Ostrom, Zhiyun Ouyang, William Provencher, Charles L. Redman, Stephen H. Schneider, William W. Taylor. 2007. Complexity of coupled human and natural systems. *Science* 317 (5844): 1513 – 1516.
http://www.sciencemag.org/cgi/reprint/317/5844/1513.pdf

> This Reading illustrates both the diversity of coupled human-environment systems and their complex interactions. The six case studies are drawn from five continents and include urban, semi-urban, and rural areas in both developed and developing countries.

2.1.3 Integrative understanding

If coupled human-environment systems are the focus of sustainability science, and use-inspired research its practice, then integrated understanding is its goal. Sustainability science seeks to integrate many sources of knowledge: the research of scientists and technologists, the work of practitioners, and the experience of users of knowledge. Increasingly, research transcends the major disciplines as interdisciplinary, multidisciplinary, and transdisciplinary efforts. In interdisciplinary research, scientists collaborate by asking how their disciplinary skills and understanding can contribute to the research, whereas in multidisciplinary research, they collectively undertake the research. In the transdisciplinary research of sustainability science, they frame the research questions together in ways that transcend their disciplinary origins and require new integrative understanding. Valuable knowledge is also resident in the skills and tacit understanding of practitioners, be they from the many professions of agriculture, engineering, and health, or resident in the traditional knowledge of farmers, builders, and healers.

Reading:

Clark, William C., P. J. Crutzen, and H. J. Schellnhuber. 2004. Science for global sustainability. In *Earth Systems Analysis for Sustainability*, eds. H. J. Schellnhuber, P. J. Crutzen, W. C. Clark, C. Martin and H. Hermann, 1-28. Cambridge, MA: MIT Press.
http://mitpress.mit.edu/books/chapters/0262195135chap1.pdf

> The Reading illustrates the search for integrated understanding, beginning with a base in the earth sciences. Some 23 questions are posed for global sustainability, requiring new integrated approaches.

2.2 VALUES AND ATTITUDES

Sustainability science is rooted in values. The commitment to use our skills and understanding in support of a sustainability transition reflects the dual values of human solidarity and ecological sensibility. Many proposed sustainable development solutions depend on the values of potential users. Thus, part of the emerging science is the science of identifying and analyzing values and attitudes, as well as actions. While having many meanings, it is helpful to conceive of values as abstract ideals, such as freedom, equality, and sustainability that are often valued in terms of good or bad, better or worse, or desirable or avoided. Attitudes often derive from and reflect abstract values but refer to the evaluation of a specific object, quality, or behavior. Actions are the concrete behaviors taken by individuals and groups, which are often rooted in and reveal underlying values and attitudes. We present three approaches to identifying values from philosophy, ecological economics, and survey research.

2.2.1 The human use of the earth

What ought to be the human use of the earth may be the central value question of sustainability science. Yet, by its very framing it suggests a centrality for human use and questions only its kind and degree. Even widely used current concepts, such as ecosystem services, are framed in terms of services to humankind. What of the other components of nature and their values?

Reading:

Grey, William. 1993. Anthropocentrism and deep ecology. *Australiasian Journal of Philosophy* 71 (4): 463-475.

http://www.informaworld.com/smpp/content~db=all~content=a739201324~frm=titlelink

> The Reading describes the two poles of philosophical orientation: anthropocentrism and deep ecology. Each pole implies an answer to the question "what is to be sustained?," distinguishing between natural resources and ecosystem services valued for their contribution to human well-being or the natural world valued for itself.

2.2.2 Valuing people and nature

Both people and nature are continuously evaluated every time we say, "I like someone or some place." Comparative evaluations require a common standard and these may be aggregated, as in approval ratings for government leaders, or individualized, as in test results for college entrance. One common standard for evaluation is monetary, giving answers to such questions as, "how much is it worth?" For items where there are extensive markets, average prices can serve as values. And while objectionable to many, monetary values are placed on human life, as in the setting of compensation for loss of life and injury. Some benefits of nature in the form of productive ecosystem services are marketed, but most are not, and a lively interdisciplinary field of ecological economics seeks to value nature to encourage its sustainability.

Reading:

Daily, Gretchen C., Tore Soderqvist, Sara Aniyar, Kenneth Arrow, Partha Dasgupta, Paul R. Ehrlich, Carl Folke, AnnMari Jansson, Bengt-Owe Jansson, Nils Kautsky, Simon Levin, Jane Lubchenco, Karl-Goran Maler, David Simpson, David Starrett, David Tilman, and Brian Walker. 2000. The value of nature and the nature of value. *Science* 289 (5478): 395-396.

http://www.sciencemag.org/cgi/content/summary/289/5478/395

> The Reading addresses both the need to value nature and how to do it. Valuation requires the identification of alternate ways of providing needed services from institutions, technologies, and ecosystems; the costs and benefits of each in terms of human well-being; and comparable means for estimating these when much is unknown or uncertain.

2.2.3 Sustainability values, attitudes, and actions

Sustainable development requires changes in human values, attitudes, and actions. However, relatively little is known about these, both because of the essential ambiguity of the concept (see 1.1) and the limited effort to identify and survey values, attitudes, and actions comparatively across the globe.

Reading:

Leiserowitz, Anthony A., Robert W. Kates, and Thomas M. Parris. 2006. Sustainability values, attitudes, and behaviors: A review of multinational and global trends. *Annual Review of Environment and Resources* 31 (1): 413-444.
http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.31.102505.133552

The Reading draws upon five documentary efforts from which one might infer sustainability values and from the existing multinational attitudinal surveys that report on the worldwide prevalence of different dimensions of these values.

2.3 ANALYSIS: CAUSES, CONSEQUENCES, PROCESSES

"Research relevant to the goals of sustainable development has long been pursued from bases as diverse as geography and geochemistry, ecology and economics, and physics and political science. Increasingly, however, a core sustainability science research program has begun to take shape that transcends the concerns of its foundational disciplines and focuses instead on understanding the complex dynamics that arise from interactions between human and environmental systems. Central questions include the following: How can those 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?"[14] This section's Readings feature work related to these questions, except for the last one, which is discussed in Part 3 of the Reader.

2.3.1 Long-term trends and transitions

"Some long-term trends in nature and society serve as currents along which we can navigate directions towards a 21st century sustainability transition. This transition is seen as one where a stabilizing world population meets its needs and reduces hunger and poverty, while maintaining the planet's life support systems and living resources. "Bending the curve"—accelerating favorable trends, slowing harmful trends, understanding complex trends, and noting changes in direction and inflection that constitute significant departures—is a grand challenge of sustainability science. A core question of sustainability science asks: "How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?" [15] Scientists who address this question study long-term trends in nature and society to understand them, to integrate them in models and scenarios, to identify indicators and policies that move towards sustainability, and to understand transitions as general phenomena with changes in phase or state.

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[14] Clark, William C. 2007. Sustainability science: A room of its own. *Proceedings of the National Academy of Sciences* 104 (6): 1737-1738.
http://www.pnas.org/content/104/6/1737.full.pdf+html

[15] Kates, Robert W., and Thomas M. Parris. 2003. Long-term trends and a sustainability transition. *Proceedings of the National Academy of Sciences* 100 (14): 8062-8067.
http://www.pnas.org/content/100/14/8062.full.pdf

Reading:

Kates, Robert W., and Thomas M. Parris. 2003. Long-term trends and a sustainability transition. *Proceedings of the National Academy of Science* 100 (14): 8062-8067.

http://www.pnas.org/content/100/14/8062.full.pdf

> This Reading describes 26 long-term global and regional trends, some of which make a sustainability transition more feasible, while others make a transition more difficult. The potential is considered to slow or accelerate the trend to encourage a sustainability transition.

2.3.2 Interactions, impacts, response

The most common integrated analysis of human-environment systems takes the form of a linear forcing model or causal chain. It begins with changes in interactions between nature and society that impact human-environment systems and yield a set of consequences to which the systems may respond. The most common analyses tend to favor the initial elements, focusing first on changes, then on impacts, and only in limited ways, responses. An alternative form is to begin the analysis towards the end of the chain, asking, “how vulnerable are societies and ecosystems to possible change?”; “how resilient might they be to such pressures?”; and “how large is their capacity to adapt?” These linear models are further complicated by other interactions, for two of which we provide Readings. One set of interactions can tip a human-environment system into another phase that the original analysis cannot explore. A second set of poorly understood interactions take place across scales of space and time.

2.3.2.1 Vulnerability, resilience, adaptiveness

Concepts such as vulnerability, resilience, and adaptiveness are still being explored and debated. Understanding the differential vulnerability and resilience of people, places, and activities is a very active research activity. For example, consider resilience: The most common meaning of resilience is drawn from the engineering sciences, as the capacity to absorb disturbances and to return to a prior (relatively stable) state. An alternative meaning is drawn from the ecological sciences, where resilience is both the capacity to absorb disturbance and to reorganize into a system that still retains its previous functions. (See also 1.4.2.4.) Some interdisciplinary scientists use the term resilience to describe specific responses (adjustments, adaptations, coping actions, or adaptive capacity) used to reduce vulnerability to some threat. Sustainability scientists tend to use all three of these concepts, including the capacity to absorb perturbations and return to previous states, and beyond these, the capacity to reorganize in order to move toward a state better than the previous state.

Reading:

Turner II, Billie L., Roger E. Kasperson, Pamela A. Matson, James J. McCarthy, Robert W. Corell, Lindsey Christensen, Noelle Eckley, Jeanne X. Kasperson, Amy Luers, Marybeth L. Martello, Colin Polsky, Alexander Pulsipher, and Andrew Schiller. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences* 100 (14): 8074-8079.

http://www.pnas.org/content/100/14/8074.full.pdf

> The Reading provides a widely-accepted framework to examine vulnerability, resilience, and adaptiveness in human-environment systems. Vulnerability of people or places is a product of exposure to perturbations in human-environment systems, differential sensitivity to this exposure, and varied capacity to cope with or adapt to such exposure.

2.3.2.2 Limits, boundaries, thresholds, and tipping points

In nature, rapid phase transitions are common, as in the tiny increment of cooling that turns water into ice. In human-environment systems, rapid phase transitions are feared, especially if they are poorly understood. So a search for limits (see also 1.4.1.3), dangerous thresholds, and tipping points consume a significant set of scientific attention. A search for "safety" limits for the earth's life-support and ecological systems are long-standing and widespread. Much of it has taken the form of identifying "carrying capacity" that limits the use of the earth (see also 1.4.1.3); "critical loads" that overburdens air or water systems; or "minimal doses" that cause harm from radiation or chemical pollutants. Akin to the phase transition is the concern with tipping points, beyond which systems spiral into irreversible change.

Reading:

Lenton, Timothy M., Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans J. Schellnhuber. 2008. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences* 105 (6): 1786-1793.
http://www.pnas.org/content/105/6/1786.full.pdf

> The Reading illustrates this search for limits, thresholds, and tipping points in the global climate system. Nine tipping elements are identified as extensive components of the earth system, subcontinental in size, affected by human-induced climate change, and with potential that a small change across a threshold can trigger a substantial qualitative change. These changes are in ice sheets, ocean circulation, and vegetation.

2.3.2.3 Interactions across scale

To understand the interactions of large and small and fast and slow is one of the great scientific queries of our age in a wide array of sciences. Whether one ponders the scale differences and interactions between quanta and galaxies, cells and organisms, consumers and economies, the problems are similar. So it is for a sustainability transition, in spatial scale differing by local peoples, places, communities, ecosystems, but subject to the pressures and opportunities of globalization, regional culture, national polity and economy, or the mass movement of people. In the temporal scale, there is special need to understand how nature changes through the interaction of fast and slow processes that both sustain or threaten our life support systems.

Reading:

Clark, William C. 1987. Scale relationships in the interaction of climate, ecosystems, and societies. In *Forecasting in the Social and Natural Sciences,* eds. K. C. Land and Steven H. Schneider, 337-378. Dordrecht: D. Reidel.
https://springerlink3.metapress.com/content/q523w45513mr4023/resource-secured/?target=fulltext.pdf&sid=4aoj4jedrb55ao3ptpgnjs2l&sh=www.springerlink.com

> The Reading is a classic exploration of these differences in scale and the challenges they pose in understanding climate change, the impacts on nature and society, and adaptation to such change.

2.3.3 Guidance: Interventions, institutions and governance

Here we consider the ways to guide interactions between nature and society towards a sustainability transition, beginning with an overview of interventions in human-environment systems. These include the three classic instruments of policy: regulation, economic incentives, and information / persuasion. While the three instruments are classic, they are not pure. Most incentives and much information also requires some regulation. Achieving larger policy goals such as providing clean drinking water or maintaining ecosystem services requires a balance of all three. How these interventions are balanced to ensure that they work well is a major issue for policy. Who undertakes such balancing is an issue as well. The section ends with a consideration of governance for sustainable development, common property resources, and issues of power and equity.

2.3.3.1 Interventions

Human-environment systems are complicated, and where to intervene to best encourage a sustainability transition is not obvious. Often the choice is made by a combination of precedent (improve on what was done before), ease of implementation (simplicity, low cost, existing program), or recent experience (especially of extreme events). In general, interventions are rarely made in underlying human-environment processes, but rather to ameliorate consequences or to undertake adaptive responses.

Reading:

Meadows, Donella. 1999. *Leverage Points: Places to Intervene in a System*. Hartland, VT: Sustainability Institute.

http://www.sustainabilityinstitute.org/pubs/Leverage_Points.pdf

> The Reading, by an early proponent of systems analysis as well as a policy advocate for sustainability, provides a generic list of leverage points for effective interventions. Leverage points that emphasize the nature and purpose of systems are most powerful; followed by those that address institutions, norms, and rules; then, the many characteristics of flows; and finally, the material content of stocks.

2.3.3.2 Regulation

Regulations are edicts, laws, norms that seek to control some aspect of human, institutional, or societal behavior. They are enacted by the various institutions of governance, most commonly government, but also by corporations, communities, civil society, and indeed cultures. Over time, formal regulation by government tends to displace other institutions, but there is lively interest in hybrids, such as "cap and trade" regulations, that require corporate action or commons regulations that give authority to traditional user groups.

Reading:

Dasgupta, Susmita, Ashoka Mody, and David Wheeler. 1995. Environmental regulation and development: A cross-country empirical analysis. *Policy Research Working Paper 1448*. Washington, D.C.: World Bank.

http://papers.ssrn.com/sol3/papers.cfm?abstract_id=620638

> The capability to develop, implement, enforce, and evaluate formal regulations roughly varies with development, but large differences are found. This early Reading demonstrates this in examining environmental regulation and policy in 31 countries as related to economic development.

2.3.3.3 Economic incentives

If regulations seek to command and control behavior, economic incentives seek to encourage behavior by making it economically worthwhile. Actions that aid a sustainability transition can be undertaken because "they pay." For example, many energy efficiency actions have a profitable cost benefit ratio; they reduce the cost of electricity more than the cost of the actions. In the case of health, the cost of many preventive health measures is much lower than the cost of suffering and treating the illnesses they are designed to prevent. For many actions, incentives are required to either lower the cost of the action or to raise the cost of not undertaking the action. Bribes, subsidies, or generosity, for example, may guarantee markets and prices for renewable energy, provide free anti-malarial bed nets, or give payments for ecosystem services. On the other hand, charges, taxes, and fines can make the cost of not doing so higher. Still, many incentives require regulation as well, as in "cap and trade" systems to reduce pollution or carbon emissions (2.3.3.2).

Reading:
Jack, B. Kelsey, Carolyn Kousky, and Katharine R. E. Sims. 2008. Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences* 105 (28): 9465-9470.
http://www.pnas.org/content/105/28/9465.full.pdf

> The Reading uses extensive experience with various incentive programs to assist in the development of incentive payments for ecosystem services. The design for such payments should depend on the ecological, socioeconomic, and political context, and the varying intent to increase ecosystem services, improve livelihoods, and reduce costs.

2.3.3.4 Information/persuasion

A basic assumption of sustainability science is that use-inspired knowledge can lead to action. A corollary is that user-friendly information based on that knowledge can encourage or persuade individuals and institutions to take such action. Common are efforts to encourage specific actions. Social marketing uses popular forms of advertisement, theater, music, and multimedia to encourage behaviors such as vitamin A ingestion, smoking cessation, or material recycling. Formal efforts to create problem-solving information often take the form of decision support tools (see 2.4.2.3) that provide information to choose among desired actions. Information technology, especially the internet, and increasingly cell phones in developing countries, not only makes instantly available multiple sources of desired information, but motivates users to seek them.

Reading:
Fung, Archon, and Dara O'Rourke. 2000. Reinventing environmental regulation from the grassroots up: Explaining and expanding the success of the toxics release inventory. *Environmental Management* 25 (2): 115-127.
http://www.springerlink.com/content/rat9902qaqmggb09/fulltext.pdf

> The Reading explores the U.S. Toxics Release Inventory, a frequently cited success of information as persuasion. Firms above a minimum size were required to report each year, beginning in 1988, information on disposal or other releases (and other waste management activities) for over 650 toxic chemicals from industrial sources. Significant and continuing reductions in the use and release of toxics have taken place.

2.3.3.5 Governance

The choice of policies is a task of governance, but governance is more than the government of political bodies. It can be thought of as the set of processes, customs, policies, laws, and institutions affecting the way a societal body (state, corporation, or civil society) is directed, administered, or controlled. Here we consider three aspects of governance for sustainable development: an overall framework, the distinctive tasks of governing common resources, and the issues of power and equity.

2.3.3.5.1 Environment and development

Given the varieties of governance, what distinguishes governance for sustainable development? At the very least it addresses both environment and development, what is to be sustained and what is to be developed, and the tradeoffs between them.

Reading

Van Zeijl-Rozema, Annemarie, Ron Corvers, Rene Kemp, and Pim Martens. 2008 Governance for sustainable development: A framework. *Sustainable Development* 16 (6): 410-421.

http://onlinelibrary.wiley.com/doi/10.1002/sd.367/abstract

> The Reading explores the dimensions of governance for sustainable development, the continuum between ecological sustainability and human quality of life, and between hierarchical and deliberative forms of governance.

2.3.3.5.2 Common resources

The air we breathe, the sea we fish in, and much of the land we dwell on are common resources—open to all, used by many, and the individual property of none. Simply sketched (1.4.1.2), it is a tragedy, but its reality is much more complex.

Reading:

Dietz, Thomas, Elinor Ostrom, and Paul Stern. 2003 The struggle to govern the commons S*cience*. 302 (5652): 1907-1912.

http://www.sciencemag.org/cgi/content/abstract/302/5652/1907?siteid=sci&ijkey=RHYs.uM0u.bkU&keytype=ref

> The Reading reviews governance of common resources from the local to the global, eliciting a set of principles and requirements for adaptive governance.

2.3.3.5.3 Power and equity

For many analysts, the institutions of governance, the interventions they employ, and the knowledge systems that support these choices reflect sources and differences in power and equity. This is in contrast to such prevailing assumptions that efficiency, improved technology, and rational decision-making guide sustainability actions.

Reading:

Lebel, Louis, Antonio Contreras, Suparb Pasong, and Po Garden. 2004. Nobody knows best: Alternative perspectives on forest management and governance in Southeast Asia. *International Environmental Agreements: Politics, Law and Economics* 4 (2): 111-127.

https://springerlink3.metapress.com/content/k35155pw82741j36/resource-secured/?target=fulltext.pdf&sid=bp4jiwmqijbfhve1gn4xuxmv&sh=www.springerlink.com

> The Reading illustrates different degrees of power and equity in contrasting perspectives of state, markets, international environmental groups, and local resource users in the governance of tropical forest management.

2.4 INTEGRATIVE METHODS AND MODELS

Sustainability science is developing a set of transdisciplinary methods and models to provide integrated understanding of closely-coupled human-environment systems. Such understanding can be acquired from place-based studies, systematic monitoring, observations, summary indicators, and a variety of analytic methods and model building.

2.4.1 Place-based studies

In one sense, all sustainable development is place-based. What to sustain and what to develop differ from place to place by the distinctive human-environmental systems found there. There are, of course, thousands of case studies of coupled human-environment systems engaged in sustainability-related activities; but there are relatively few that are long-term or that are systematic case-study comparisons.

2.4.1.1 Long-term place-based studies

Most human-environment case studies are snapshots of place and time. To observe and understand change and process requires longer term observation, which has been common in natural and social systems but less so in coupled ones. Individuals and small groups of scholars, primarily in anthropology, ecology, geography, and history, have done so, usually as part of their research careers. Larger, interdisciplinary research groups are less common (see also 1.4.2.1). An international organization of long-term ecological research systems now links networks in some 40 countries, but these have only recently begun to explore the social as well as ecological dimensions of their sites.

Reading:

Turner II, Billie L. 2008. The Southern Yucatan Peninsular Region (SYPR) project: Deforestation and land change in a season tropical forest and economic frontier. *GLP News: Newsletter of the Global Land Project International Project Office* 3: 8-10.
http://www.globallandproject.org/Newsletters/GLP08_03_high.pdf

> The Reading describes an exemplary effort over the last 13 years in the Southern Yucatán Peninsular Region by over 40 researchers in the ecological, social (especially geography and economics), and Geographic Information Science (GIS) sciences. The project has addressed the dynamics of the forest, biota, and soil nutrients, farming household decision making, and both econometric and agent-based models of land changes.

2.4.1.2 Case studies comparisons

The thousands of existing short-term place-based case studies offer opportunities to bring sets of such studies together to ask larger questions of sustainability science. However, great difficulty is experienced in making comparisons, because the definition of place, initial purposes of the study, data collected, and analytic methodology differ so much and the contextual information provided is often so limited.

Reading:

Geist, Helmut J., and Eric F. Lambin. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52 (2): 143-150.
http://caliber.ucpress.net/doi/abs/10.1641/0006-3568%282002%29052%5B0143%3APCAUDF%5D2.0.CO%3B2

The Reading illustrates the use of 154 case studies to explore the causes of tropical deforestation. The analysis refutes common notions of single causes, e.g. shifting cultivation, population growth, as well as suggestions of irreducible complexity.

2.4.2 Observations, indicators and monitoring

Observations, data, and experiments are the substance of much scientific endeavor and not uniquely sustainability science. Some methods of aggregating or analyzing these, especially integrating or monitoring observations from both the natural and social sciences, are skills or approaches all sustainability scientists should be familiar with. Readings on aggregated indicators, analysis using geographic information systems, and methods for decision support and community participation follow.

2.4.2.1 Indicators

To move to a sustainability transition, societies need to establish or change direction, assess progress, and obtain warnings of unsustainability. Quantitative indicator systems relevant to the sustainability transition, such as institutional audits, integrated "sustainability" metrics of cities or regions, or global accounts of carbon, populations, or ecosystems, were early products of sustainability efforts. Despite, or perhaps because of, upwards of 500 efforts, no sets of indicators have achieved the widespread use and credibility of such indicators as gross domestic product (GDP)/capita or the human development index (HDI).

Reading:

Parris, Thomas M., and Robert W. Kates. 2003. Characterizing and measuring sustainable development. *Annual Review of Environment and Resources* 28: 559-586.
http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105551?journalCode=energy

The Reading reviews the diverse efforts to measure and to characterize sustainable development by examining twelve selected efforts. It then proposes an analytical framework that clearly distinguishes among goals, targets, and indicators of sustainable development and related trends, driving forces, and policy responses.

2.4.2.2 Geographic information systems

For a place-based science, observations are essentially geospatial or spatiotemporal "facts," established at a specific place or time. Acquiring, storing, processing, analyzing, and visualizing such geographic data are the tasks of geographic information systems, an essential tool for a science of the human environment.

Reading:

Goodchild, Michael F. 2003. Geographic information science and systems of environmental management. *Annual Review of Environment and Resources* 28: 493-519.
http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105521?journalCode=energy

The Reading provides an introduction to the state of the science, its analytic systems, and some environmental applications. Trends that will affect the use of GIS in human-environment management include increasing interoperability of systems, mobility to collect and analyze data in the field, and the continuing improvement in modeling.

2.4.2.3 Decision support methods

Sustainability science aspires to move scientific knowledge into action. One class of actions is the key sustainability decisions made by people and institutions. Such decisions range from a farmer's choice of seed to a global compact on climate change. Decision support methods are bundles of data, tools, and information products that meet the needs of the potential users of such information. Such methods also include the identification of such needs through direct interaction with users, practitioners, and scientists (see 2.4.2.4).

Reading:

National Research Council, Panel on Strategies and Methods for Climate-Related Decision Support. 2009. Effective decision support: Definitions, principles, and implementation. In *Informing Decisions in a Changing Climate*, 33-69. Washington, D.C.: National Academies Press.

http://books.nap.edu/openbook.php?record_id=12626&page=33

> The Reading explores what might constitute effective decision support for climate change decisions. Effective decision support efforts should begin with users' needs, emphasize processes for learning that link information producers and users, build connections across disciplines and organizations, and provide institutional homes for the effort.

2.4.2.4 Participatory approaches

Increasingly, proponents of moving knowledge into action understand the need for the participation of all actors in the creation, dissemination, and utilization of such knowledge. Such participatory approaches may begin with identifying the knowledge, values, and attitudes of the user groups, then learning together with researchers through the co-production of knowledge, and finally, sharing in decision-making and implementation actions.

Reading:

Lynam, Timothy, Wil de Jong, Douglas Sheil, Trikurnianti Kusumanto, and Kirsten Evans. 2007. A review of tools for incorporating community knowledge, preferences, and values into decision making in natural resources management. *Ecology and Society.* 12 (1): 5.

http://www.ecologyandsociety.org/vol12/iss1/art5

> The Reading reviews participatory tools suitable for the various stages of informing, learning about, and managing resources. Such tools elicit views of resource systems, of system stakeholders, and possible causal relationships and dynamics within systems.

2.4.3 Analytic methods

While methods of integrating and presenting observations and other data contain considerable analysis, some methods focus primarily on analysis: identifying causes and consequences of a sustainability transition and projecting, assessing, and modeling the long-term transition. In this section we examine four clusters of methodologies: portfolios of tools for integrated analysis, driving force analysis, scenario creation, and assessments.

2.4.3.1 Portfolios

Major problems arise in analyzing causes and consequences in human-environment systems. These include defining what process is to be explained in the system, whether to use proximate or ultimate causes, and how these are to be defined. There are also issues of observations, data, or case studies: how many to use and can these be compared. Because of all these problems and the complexity of such systems, the likelihood of drawing the wrong conclusions is an ever-present problem. Thus, unlike much specific disciplinary research, there may be no specific preferred analytic method, as in, for example, econometrics.

Reading:
Young, Oran R., Eric F. Lambin, Frank Alcock, Helmut Haberl, Sylvia I. Karlsson, William J. McConnell, Tun Myint, Claudia Pahl-Wostl, Colin Polsky, P. S. Ramakrishnan, Heike Schroeder, Marie Scouvart, and Peter H. Verburg. 2006. A portfolio approach to analyzing complex human-environment interactions: Institutions and land change. *Ecology and Society* 11(2): 31.
http://www.ecologyandsociety.org/vol11/iss2/art31

> The Reading argues a portfolio of approaches may be more helpful in analyzing causes and consequences in human-environment systems. Techniques include standard statistical analyses, pattern comparisons and meta-analyses of case studies, counterfactuals, narratives, and systems analysis and simulations.

2.4.3.2 Driving forces

A specific approach in analyzing causes and consequences is to focus on driving forces those activities that seem to affect long-term trends (2.3.1). Here, the problems of separating proximate versus ultimate causes and how to define and measure these are especially important.

Reading:
York, Richard, Eugene A. Rosa, and Thomas Dietz. 2003. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impact. *Ecological Economics* 46: 351-365.
http://ireswb.cc.ku.edu/~crgc/NSFWorkshop/Readings/STIRPAT_%20IPAT%20and%20ImPACT.pdf

> The Reading examines analytic methods for making the simply sketched and widely used driving force explanation for environmental impacts, I=PAT (1.4.1.4), more rigorous and scientific. These are illustrated by applications to carbon emissions and a more general energy footprint.

2.4.3.3 Scenario analysis

Behind the imaginatively sketched story lines of most scenarios (1.4.3.1) lies a formal analytic process by which scenarios are created, described, compared, and evaluated. This begins with projections for push scenarios or backcasting for pull scenarios, based on a coherent and internally consistent set of assumptions about key relationships and by the incorporation of simulation models of long-term trends and major driving forces.

Reading:
Alcamo, Joseph, Detlef van Vuuren, Claudia Ringler, Wolfgang Cramer, Toshihiko Masui, Jacqueline Alder, and Kerstin Schulze. 2005. Changes in nature's balance sheet: Model-based estimates of future worldwide ecosystem services. *Ecology and Society* 10 (2): 19.
http://www.ecologyandsociety.org/vol10/iss2/art19

> The Reading illustrates this analytic process in the creation of four alternative scenarios of the demand for ecosystem services that were used in the Millennium Ecosystem Assessment (MEA). The scenarios variously emphasized global trade, technology,

diversified gated communities, or ecosystem development. However, the formal process may still be limited by the final narrative selection, (see for example Granger and Keith, 2008).[16]

2.4.3.4 Assessments

The term "assessment" is widely used in sustainability science, always implying a scientific assessment of a problem. Three important usages are the assessments of risks or hazards, the integrated assessment of human-environment problems and systems, and global assessments of transnational problems. Many assessments include all three of these usages.

2.4.3.4.1 Risk assessments

Many analytic methods address the causes and consequences of threats from physical, chemical, and biological agents, from human activities as well as natural events. Risk assessment specifically asks what the likelihood of the occurrence of such threats is and what their consequences would be. Such assessment is also part of a larger virtual discipline of risk analysis that also includes risk characterization, communication, management, and policy.

Reading:

National Research Council, Committee on Risk Characterization. 1996. Summary. In *Understanding Risk: Informing Decisions in a Democratic Society*, eds. Paul C. Stern and Harvey V. Fineberg, 1-10. Washington, D.C.: National Academies Press.
http://books.nap.edu/openbook.php?record_id=5138&page=1

> The Reading uses risk characterization to address the major questions of understanding, assessing, and characterizing risk. It both advocates and assumes that the risk characterization is to be used within an analytic-deliberative process.

2.4.3.4.2 Integrated assessments

An assessment is seen as integrated when it incorporates methods and data from many disciplines and practitioners. The term was first made popular to describe models addressing climate change with physical, biological, and socio-economic dimensions. It has subsequently been applied to a variety of human-environment problems and systems.

Reading:

Ostrom, Elinor, and Harini Nagendra. 2006. Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory. *Proceedings of the National Academy of Sciences* 103 (51): 19224-19231.
http://www.pnas.org/content/103/51/19224.full.pdf

> The Reading effectively integrates data and understanding from remote sensing, field studies, laboratory experiments, and from the natural and social sciences, to examine forest management under different tenure arrangements.

2.4.3.4.3 Global assessments

Most ambitious are global assessments - efforts to bring together knowledge, primarily scientific, to address major issues, problems, or concerns that are transnational. Those most related to

[16] Morgan, M. Granger, and David W. Keith. 2008. Improving the way we think about projecting future energy use and emissions of carbon dioxide. *Climatic Cha*nge 90: 189-215.
http://www.springerlink.com/content/p113h768w74215p6/fulltext.pdf

sustainability address resources, such as water or ecosystems; problems, such as climate change; or concerns, such as health or education.

Reading:
Clark, William C., Ronald B. Mitchell, and David W. Cash. 2006. Evaluating the influence of global environmental assessments. In *Global Environmental Assessments: Information and Influence*, eds. R. B. Mitchell, W. C. Clark, D. W. Cash and Nancy M. Dickson, 1-28. Cambridge, MA: MIT Press.
http://mitpress.mit.edu/books/chapters/0262633361chap1.pdf

> The Reading, while focusing on how to evaluate the influence of global environmental assessments, defines and describes the range of recent assessments. These include global assessments of climate change, water management, and biodiversity.

2.4.4 Models

Models are approximations of real-world objects, phenomena, or systems, described as narratives, visualized as small objects, drawn as diagrams, expressed as mathematical equations, or animated by computer simulations. Sustainability science models seek to explore human-environment systems, simulate trends in the sustainability transition, and provide solutions for sustainability problems.

2.4.4.1 Structure

These sustainability models try to detail or reproduce the essential structure and functions of the human-environment system under study. In general they contain at least three basic elements: a human sub-system, an environmental sub-system, and the interactions, links, and feedbacks between them. Designers of such models often struggle between the desire to provide detail, sufficient to capture the verisimilitude of the real world, and the need to simplify, sufficient to make the model both operational and understandable.

Reading:
Schaldach, Rudiger, and Jorg A. Priess. 2008. Integrated models of the land system: A review of modeling approaches on the regional to global scale. *Living Reviews in Landscape Research* 2.
http://www.livingreviews.org/lrlr-2008-1

> The Reading illustrates these with eight recent models of the "land system" at various spatial scales. All contain human and the environment sub-systems and these are linked by the effects of changing land-use patterns on environmental factors and processes.

2.4.4.2 Agent

While structural models are still the most common, there is increasing application of agent-based models to sustainability problems. The agents are people, communities, institutions, and living organisms, each of whom make decisions or take actions autonomously, while interacting with other agents and the environment. Typically, the agents take action based on the application of a few simple rules of interactive behavior. The outcomes of these agent-based models are often tested against some empirical observations to see how well they reproduce observed change.

Reading:
Janssen, Marco A., and Elinor Ostrom. 2006. Empirically based, agent-based models. *Ecology and Society* 11 (2): 37.

http://www.ecologyandsociety.org/vol11/iss2/art37/

The Reading explores the construction of agent-based models using four types of empirical data: large numbers of observations, case studies, role-playing games, and laboratory experiments.

2.4.4.3 Complex and cross-scale

Complex human-environment systems have many interacting components, some of which behave in non-linear and/or adaptive ways. Thus, changes in the system are not simply predictable from the original state of their components. These emergent properties may increase or reduce vulnerabilities across temporal and spatial scales.

Reading:

Levin, Simon. 2010. Complex adaptive systems and the challenge of sustainability. In *Toward a Science of Sustainability*, eds. Levin, S. A. and William C. Clark. Report from Toward a Science of Sustainability Conference, Airlie Center, Warrenton, Virginia, November 29, 2009 – December 2, 2009, 83-86. Princeton, NJ: Center for Biocomplexity, Environmental Institute, Princeton University and Cambridge, MA: Sustainability Science Program, Center for International Development, Harvard University.

http://www.nsf.gov/mps/dms/documents/SustainabilityWorkshop2009Report.pdf

The Reading, a background paper to a 2009 conference on a science of sustainability, identifies a set of scientific needs for understanding complex and cross-scale adaptive systems. These include new theories, early warning signals of change, the roles of fluctuations in conditions, and the contagious spread of information, materials, or disturbances.

3 KNOWLEDGE INTO ACTION

The distinctive knowledge created by sustainability science is use-inspired and, at its best, provides solutions to real world, often place-based, problems encountered for the needs of a sustainability transition. Thus, this Reader ends with linking knowledge systems and action, with examples of both global and local solutions to the needs of human well-being and the earth's life support systems, and with three critical needs that constitute grand challenges.

3.1 MOVING KNOWLEDGE INTO ACTION

Use-inspired knowledge still needs to be used, and a central task of sustainability science is to help move such knowledge into action. Knowledge for sustainability should be *salient* for user needs and problems, *credible* both to other scientists, practitioners, as well as users, and seen as *legitimate* by all in the process that produced it. Meeting all of these three criteria is difficult and knowledge systems often include institutions capable of spanning the boundaries of difference, mediating between interests, and communicating to all necessary participants.

3.1.1 Knowledge transfers

Moving knowledge into action requires a transfer of such knowledge from the knowledge producers to the users or practitioners of that knowledge. Three basic models exist. In the first, science is curiosity-driven: the best of basic science may or may not have practical use, but will eventually trickle down into practice. An alternative model is translational: it assumes that much scientific knowledge is useful, but it needs to be translated into language and applications that practitioners can use. For example, major efforts in health emphasize translation, and new scientific journals are devoted to the topic. The third model is interactive: knowledge and utility transfers move back and forth, leading, at their best, to the coproduction for sustainability of knowledge and actions.

Reading:

Van Kerkhoff, Lorrae, and Louis Lebel. 2006. Linking knowledge and action for sustainable development. *Annual Review of Environment and Resources* 31 (1): 445-477.
http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.31.102405.170850

> The Reading examines the conventional views and critiques of knowledge transfers and efforts to improve the process of linking knowledge to action. It seeks to understand the relationships between research-based knowledge and action as areas of shared responsibility that are embedded within larger systems of power and knowledge that evolve and change over time

3.2 SEEKING SOLUTIONS: GLOBAL AND LOCAL

The most salient knowledge provides real-world solutions to support a sustainability transition. In Part 1 of the Reader we examined the problems posed for the essentials of meeting human needs and preserving the life support systems of the planet. In this and the following sections, we review projected solutions for the problems posed. As noted, sustainable development is also place-based: the problems may be global, in the sense that they are expressed in many places, but they are also often different in their local expression. Thus, for each of the reviewed global essentials, we include a second Reading, describing examples of regional or local solutions.

3.2.1 Stabilize population numbers

The major sustainable development population challenges are to meet the human needs of 2.3 billion more people; house and employ 4 billion new urban residents; care for ageing populations of industrialized and newly industrializing countries; and absorb the migrants those societies will require for such care while limiting the environmentally damaging impacts of such growth and urbanization. All of these tasks would be lessened with smaller numbers of people, and solutions that accelerate current trends in fertility reduction are to be welcomed. The three major sources of high fertility and continued rapid population growth are the unmet need for contraception; the still sizeable desired family size; and the large number of young people entering reproductive age. While more needs to be known, solutions, both global and local, are available to address each of these.

Readings:

Bongaarts, John. 1994. Population-policy options in the developing world. *Science* 263 (5148): 771-776.
http://www.sciencemag.org/cgi/content/short/263/5148/771

> The Reading presents an early paper outlining the problem of continued rapid population growth and the three major sources of high fertility. Solutions include measures to: reduce unwanted pregnancies by energized family planning programs; reduce the demand for large families by improved human development; and address population momentum by increasing the age of child-bearing.

Phillips, James F., Ayaga A. Bawah, and Fred N. Binka. 2005. Accelerating reproductive and child health program development: The Navrongo Initiative in Ghana. In *The*

***Population Council, Policy Research Division Working Papers*, 29. New York: The Population Council.**
http://www.popcouncil.org/pdfs/wp/208.pdf

The Reading describes an experiment in Ghana to reduce fertility while increasing child health. Linking these two needs together began as a pilot project in 1994, evolved into a carefully designed experiment and, by 2005, was in place in 20 districts of Ghana.

3.2.2 Improve health

A central challenge for health and well-being is to narrow the difference in health and well-being between that of Europe and most developing countries, where a child born in Africa has 25 years less life expectancy than one born in Europe. Three clusters of solutions are available: accelerating the reduction in infant and child mortality and morbidity through immunization and improved water, sanitation, and nutrition; broadening efforts to both prevent and treat the major diseases of AIDS, malaria and tuberculosis, and the large set of regional tropical diseases; and implementing these solutions through appropriate and sustainable community health institutions.

Reading:

Gates Foundation. 2009. Successes in global health; Progress against malaria; Progress against tuberculosis; Progress against HIV/AIDS; Progress against neglected tropical diseases; Progress against polio; Progress towards immunization; Progress towards maternal, newborn and child health; Progress towards nutrition. In *Living Proof Project.*
http://www.gatesfoundation.org/livingproofproject/Pages/progress-sheets.aspx.

The Readings consist of succinct reviews of proposed solutions, actions, and successes in health needs from the leading foundation that is pursuing global health. These include addressing HIV/AIDS, malaria, polio, tuberculosis, and neglected tropical diseases, as well as progress towards immunization, maternal and child health, and nutrition.

Kisinza, W. N., J. K. Kisoka, P. P. Mutelemwa, J. Njau, F. Tenu, T. Nkya, S. P. Kilima, and S. M. Magesa. 2008. Community directed interventions for malaria, tuberculosis and vitamin A in onchocerciasis endemic districts of Tanzania. *Tanzania Journal of Health Research* 10 (4): 232-239.
http://www.bioline.org.br/request?th08036

The Reading describes a recent effort in Tanzania to bring together usually separate community-directed health interventions against malaria, onchocerciasis, tuberculosis, and vitamin A deficiencies.

3.2.3 Provide water and sanitation

The most pressing water and sanitation challenges are the unmet need for household water use, with 1.2 billion people in developing countries lacking access to a safe and reliable supply and 2 billion lacking access to sanitation. The shame being, that while three decades of global campaigns to bring water to all have failed, the technological and behavioral solutions have always been at hand. Beyond this immediate challenge is the growing water stress in a third of the world, where withdrawals already exceed 20% of available supply and will grow with increased demand and climate change. For this challenge, a large array of solutions need to be sought or pursued, regionally and activity-specific, including reducing demand, shifting or reducing use, and increasing storage and supply.

Reading:

Gleick, Peter H. 2003. Global freshwater resources: Soft-path solutions for the 21st century. *Science* 302 (5650): 1524-1528.
http://www.sciencemag.org/cgi/content/abstract/302/5650/1524

The Reading describes solutions that do not require building massive infrastructure to solve water problems. These include lower-cost community-scale systems, decentralized and open decision-making, water markets and equitable pricing, application of efficient technology, and environmental protection

Funke, Nikke, Karen Nortje, Kieran Findlater, Mike Burns, Anthony Turton, Alex Weaver, and Hanlie Hattingh. 2007. Redressing inequality: South Africa's new water policy. *Environment* 49 (3): 10-23.
http://www.environmentmagazine.org/Archives/Back%20Issues/April%202007/Funke-full.html

The Reading is a soft path solution addressing the very distinctive geography and history of water provision and use in South Africa. The national water legislation adopted in South Africa is unique in the world, as not only legislating water provision and use, but also serving as a tool for social and environmental justice.

3.2.4 Intensify agriculture and food security

Until recently agricultural production has outpaced population growth, reduced hunger, and improved diets almost everywhere except in Africa. Thus, the central challenge for agriculture and food security has been to reverse the decline in agricultural capability in sub-Saharan Africa. This is still true, although recent trends in food prices, energy, climate, and agricultural production suggest a growing food security problem worldwide. Increasing agricultural production through soil and plant selection, water, and fertilizers is clearly feasible, along with opportunities to market food products. However, production increases are not synonymous with increased food security. In many cases food is available, but is still beyond the means of poor people. Thus, increased food security also requires income and other entitlement enhancement opportunities.

Reading:

Conway, Gordon. 2000. Food for all in the 21st century. *Environment* 42 (1): 8-18.
http://www.informaworld.com/smpp/content~db=all~content=a920346469~frm=abslink

The Reading argues for a "doubly green revolution" for the 21^{st} century, combining the needed productivity of the original green revolution and the greening of conservation, resource management, and energy. A key to the success of such a revolution is the involvement of farmers as analysts, designers, and experimenters.

InterAcademy Council. 2004. Realizing the promise and potential of African agriculture: Executive summary, xvii-xxx. Amsterdam: InterAcademy Council.
http://www.interacademycouncil.net/Object.File/Master/8/397/Africa%20-%20A2%20Executive%20Summary.pdf

The Reading proposes solutions to the specifics of Africa's 17 specific farming systems. Four of these – maize-mixed, cereal/root crop mixed, irrigation, and tree crop systems – have the most potential to improve livelihood and food security.

3.2.5 Modify consumption

One of the biggest challenges to sustainable development arises from the desire of so many people for lifestyles requiring much larger flows of energy and materials. Such consumptive flows can increase climate change, degrade the environment, diminish ecosystem services, and deplete natural resources. Practical solutions seek to remove the most resource-depleting or environmentally-damaging consumption from general consumption and to shrink the amounts of environmentally-damaging energy and materials used in the production of consumable products (dematerialization). Another alternative is to alter lifestyles by substituting high energy and material products with low energy and material products such as services, education, information, and leisure. The global spread of cell phone use, satellite TV, and internet access suggest that much of that shift in information-rich, low-material consumption is already underway. Ironically, such use of information technology also fuels high consumption aspirations with their images of developed nations' lifestyles.

Reading:

Kates, Robert W. 2000. Population and consumption: What we know, what we need to know. *Environment* 42 (3): 10-19.

http://www.rwkates.org/pdfs/a2000.01.pdf

> The Reading substitutes consumption for affluence in the I=PAT identity and examines generic ways of modifying impacts. These include slowing population growth and reducing per/capita consumption and impacts from harmful consumption.

Moreira, Jose R., and Jose Goldemberg. 1999. The alcohol program. *Energy Policy* 27 (4): 229-245.

http://www.sciencedirect.com/science/article/B6V2W-3WWKN5N-M/2/9a8b96eed9c787db521bf21ac6ae252d

> The Reading describes the Brazilian program to substitute ethanol made from sugar cane for gasoline that demonstrated that a massive alternative and renewable fuel program can be carried out and implemented in less than 10 years.

3.2.6 Create sustainable cities

Urban growth taking place primarily in developing countries provides a unique opportunity for more sustainable cities with energy and material efficiency, green building, and public transportation, as well as with jobs, education, and health. But the failure to meet this challenge will lock us into the current urban infrastructure that will perpetuate the energy-intensive, transport-gridlocked, and slum-infested cities of today. To move urban areas toward sustainability, new urban forms, infrastructure, technologies, and environmental management are needed and new behaviors, institutions, and policies are required to innovate and implement them. Thus we will need to bring together the science and technology of habitability, efficiency, and environment with the practice of planning, building, and financing cities.

Reading:

McGranahan, Gordon, and David Satterthwaite. 2003. Urban centers: An assessment of sustainability. *Annual Review of Environment and Resources* 28 (1): 243-274.

http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105541

> The Reading is an overview of cities and sustainability that concludes with extensive

discussion of strategies for implementing sustainable development. These include important synergies between healthier, safer city environments and reduced depletion of natural capital.

Solecki, William D., and Robin M. Leichenko. 2006. Urbanization and the metropolitan environment: Lessons from New York and Shanghai. *Environment* 48 (4): 8-23.
http://www.informaworld.com/smpp/content~db=all~content=a925411839

The Reading contrasts the opportunities for sustainable development found in the historic transformation of New York City and in the current transformation of Shanghai. During periods of major urban transformation contradictions arise, as in efforts to both encourage decentralization and to bring together metropolitan regions or to both increase economic development and to create social improvement and environmental enhancement.

3.2.7 Maintain biodiversity

Reversing the ongoing ecosystem degradation, while meeting the increased demand for ecosystem services, is a major challenge of sustainable development. Solutions for maintaining biodiversity are region- and biome-specific and range between "species approaches," designed to preserve key or endangered species, and broader "habitat approaches," designed to preserve entire habitats that are the homes of biodiverse mixtures of living plants and animals. Adding more complexity to the range of solutions is how to deal with invasive species and climate change.

Reading:

Soberón, M. Jorge. 2004. Translating life's diversity. *Environment* 46 (7): 10-20.
http://www.informaworld.com/smpp/content~db=all~content=a920531524~frm=abslink

The Reading reviews the efforts to preserve biodiversity globally and using mainly Mexican and other Latin-American examples, emphasizes translator (or boundary) institutions that make biodiversity knowledge amenable to users of that knowledge.

Timmer, Vanessa, and Calestous Juma. 2005. Taking root: Biodiversity conservation and poverty reduction come together in the tropics. *Environment* 47 (4): 24-44.
http://www.informaworld.com/smpp/content~db=all~content=a925412020~frm=abslink?words=environment|timmer|juma&hash=2700256236

The Reading explores a variety of solutions for the linking of biodiversity conservation with poverty reduction found in the Equator Prize winners. While encouraging, the search for joint solutions of conservation and poverty reduction must grapple with such realities as whether these proposed solutions can reconcile the differing interests of the actors, the problems associated with transferability between places, and with scaling-up.

3.2.8 Preserve ecosystem services

For the most part problems of ecosystem services relate to how to maintain their flow in the face of human action that diminish or degrade them. The provisioning services that provide the commodities that people use such as fiber, food, timber, and water differ from the ecosystem regulating, cultural, and supporting services. Sustaining or increasing provisioning always entails large levels of human management and ecosystem modification, in contrast to the limiting of human action and ecosystem change to sustain or increase the other services. Solutions appropriate to specific regions or places that can provide the entire range of services are most needed.

Reading:
Millennium Ecosystem Assessment. 2005. What options exist to manage ecosystems sustainably? In *Ecosystems and Human Well-Being: A Synthesis*, 92-100. Washington, D.C.: Island Press.
http://www.maweb.org/documents/document.356.aspx.pdf

The Reading reviews available options to manage ecosystems to provide needed services, including management, policy, technological, behavioral, and institutional actions.

Tomich, Thomas P., David E. Thomas, and Meine van Noordwijk. 2004. Environmental services and land use change in Southeast Asia: From recognition to regulation or reward? *Agriculture Ecosystems and Environment* 104 (1): 229-244.
http://www.worldagroforestrycentre.org/sea/Publications/files/book/BK0067-04/BK0067-04-5.PDF

The Reading considers the experience with management options to control rapid land use change in Southeast Asia. It assesses the effectiveness of regulations and the alternative interests in rewards (usually economic or infrastructure incentives) and negative rewards (taxes, penalties, etc.)

3.2.9 Clean air and water

In most industrialized countries a common sequence occurring over a century consisted of increased air and water pollution, followed by limitation and remediation. Thus, most industrialized countries have seen major limits placed on indoor air pollution and witnessed large declines in atmospheric sulfur levels, but they are still grappling with persistent levels of ozone and small particulate pollution. Similarly, most drinking water is safe; sewage is treated; and chemical pollutants from cities and industry have been substantially reduced; yet, they are still grappling with urban, agricultural, accidental discharge, and atmospheric deposition non-point sources. But most developing and newly industrialized countries are still in the increasing pollution stage. Thus, the central focus for needed solutions is whether they can with our current knowledge limit air and water pollution along with increases in production, consumption, and population.

Reading:
Longhurst, J. W. S., J. G. Irwin, T. J. Chatterton, E. T. Hayes, N. S. Leksmono, and J. K. Symons. 2009. The development of effects-based air quality management regimes. *Atmospheric Environment* 43 (1): 64-78.
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH3-4TN0M20-D&_user=10&_coverDate=01%2F31%2F2009&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1569262117&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=9af9b713bec2b16acaefb21b1d372568&searchtype=a

The Reading surveys the evolution of air quality management, primarily in the United Kingdom, but also in other industrialized countries. It describes the movement away from emissions based regulations by adding a health effects-based, risk management approach built upon the existing technology-based controls.

Bai, Xuemei, and Peijun Shi. 2006. Pollution control in China’s Huai River Basin: What lessons for sustainability? *Environment* 48 (7): 22-38.

http://www.informaworld.com/smpp/content~db=all~content=a925412083~frm=abslink?words=environment|bai&hash=2822389587

> The Reading considers the lessons learned from efforts to control water pollution in the Huai River Basin in China. Beginning in 1994 major efforts were made with limited success to shut down small major polluters, require treatment by major industrial polluters, and create municipal waste treatment plants for all the basin.

3.2.10 Restore marine resources

Currently, the most severe diminution of replaceable natural resources is marine resources. The major challenges are to maintain and restore marine resources and to control deposition of waste, nutrients, and pollutants from land and air into the oceans. In the longer term climate change, affecting ocean temperatures, sea levels, currents, and acidification, may emerge as the most serious challenge. The ongoing depletion of marine resources arises primarily from fishing practices, habitat destruction, and rising ocean temperatures. Two main strategies in restoring fisheries are to address wild capture or to substitute aquaculture for wild sources. To control wild capture single-species management limits the size of fish, area for catching, and time for fishing, tries to reorder the economic incentives for fishermen, and to increase the demand for sustainable products. Increasingly, there is a focus on ecosystem management leading to better solutions.

Reading:

Roberts, Susan J., and Kenneth Brink. 2010. Managing marine resources sustainably. *Environment* 52 (4): 44-52.
http://www.environmentmagazine.org/Archives/Back%20Issues/July-August%202010/managing-marine-abstract.html

> The Reading addresses the sustainability of wild capture fisheries and aquaculture and the solutions being used, as well as the impacts of nutrient enrichment runoff from land areas.

Lejano, Raul P., and Helen Ingrahm. 2007. Place-based conservation: Lessons from the Turtle Islands. *Environment: Science and Policy for Sustainable Development* 49 (9): 18-27.
http://www.environmentmagazine.org/Archives/Back%20Issues/November%202007/LejanoIngram-abstract.html

> The Reading illustrates how the distinctiveness of place-based sustainability differs from global generalities of conservation. The case involves the Turtle Islands of the Philippines and Malaysia, the major green turtle rookery in Southeast Asia, where female turtles return each year to lay eggs that are also marketed as gourmet food.

3.2.11 Increase resilience to disaster

The earthquakes in China and Haiti, the floods in Pakistan, the hurricanes in the United States are dramatic reminders of the challenge of 3-400 natural disasters annually and their negative impact on human development. In one sense, resilience, the ability to withstand or overcome pressures that lead to disaster, is the opposite of disaster. There are at least four key activities to increase resilience at regional or community levels of social organization. These include: anticipating significant multi-hazard threats; reducing the community's overall vulnerability to hazard events; and responding to and recovering from specific hazard events when they occur. In developed countries, there is some effort to implement all of these, but often in fragmented ways with the least attention given to reducing vulnerability (see also 2.3.2.1) or planning for recovery.

Even modest efforts have not been undertaken in many developing countries as they grapple with their overwhelming everyday problems.

Reading:

United Nations Development Programme. 2004. Chapter 3 Development: Working to reduce risk. In *Reducing Disaster Risk: A Challenge for Development*, 57-95. New York: UNDP.

http://www.undp.org/cpr/whats_new/rdr_english.pdf

> The Reading examines the disaster-development relationship in two key factors related to vulnerability: urban growth and agricultural land use and the key pressures of globalization, climate change, conflict, disease, governance, and social capital. While further explicating the causes of disaster below the global level, many examples of good practice solutions to reduce disaster vulnerability are identified.

Colten, Craig E., Robert W. Kates, and Shirley B. Laska. 2008. Three years after Katrina: Lessons for community resilience. *Environment: Science and Policy for Sustainable Development* 50 (5): 36-47.

http://www.rwkates.org/pdfs/a2008.01.pdf

> The Reading uses 290 years of New Orleans history to examine the four resilience activities of anticipation, disaster response, recovery, and vulnerability reduction to identify lessons that can be learned and applied to other communities.

3.3 ADDRESSING GRAND CHALLENGES

In Part 3 of the Reader we have been addressing the challenges posed by long-term trends in major human needs and life support systems with proposed solutions, both global and local. Here, we identify three of these as grand challenges, exceptional both in the magnitude of the problem and in the need for transformative, rather than just incremental solutions. Reducing poverty in Africa, slowing climate change, and limiting war and crime seem to pose exceptional challenges. These grand challenges are large and difficult and, when transformative solutions are studied or offered, they are risky. As research topics, the research will often fail, and as offered solutions, they may never be implemented. To help them be researchable, grand challenges seem to require a specificity best characterized as the middle range—neither so general as to be all inclusive, nor so specific as to be trivial. To encourage their implementation, solutions need to be sought after by those who might use them.

3.3.1 Reduce poverty in Africa

There are two major poverty challenges in the world, the most serious being in sub-Saharan Africa, the region that has shown little or no improvement, or even worsening, in all the key indices of health, well-being, food security, and economic growth. Another challenge involves the very large newly-industrializing countries such as Brazil, China, and India, which have yet to translate their rapid growth into rapid improvement in well-being for their half-billion extremely poor citizens. Efforts to address poverty generally take one of three approaches: trickle down, redistribution, and social innovation. The first approach assumes that economic growth is a key to poverty reduction and that poverty-oriented growth is even more effective. The second approach seeks to redistribute some portion of societal wealth through increasing the entitlements of the poor—the bundle of income, natural resources, familial and social connections, and societal assistance that help limit hunger and poverty. The third is a bottom-up approach that seeks to improve the ability of the poor to create new livelihood opportunities, to improve their existing livelihoods, or to strengthen their ability to influence growth and redistribution policies.

Reading:
Collier, Paul. 2007. Poverty reduction in Africa. *Proceedings of the National Academy of Sciences* 104 (43): 16763-16768.
http://www.pnas.org/content/104/43/16763.full.pdf

> The Reading explores the causes of poverty in Africa, concentrating on three geographic differences in resource-richness, scarcity, and access to the sea. Each of these poses different challenges and requires different solutions.

Mabogunje, Akin. 2007. Tackling the African poverty trap: The Ijebu-Ode experiment *Proceedings of the National Academy of Sciences* 104 (43): 16781-16786.
http://www.pnas.org/content/104/43/16781.full.pdf

> The Reading reports on a grassroots poverty reduction effort in a Nigerian town. Utilizing the extensive home town social capital, the effort brings together the traditional ruler, local governmental organizations, and the diaspora.

3.3.2 Slow climate change

Human-induced climate change is endangering food security, raising sea-level, accelerating erosion of coastal zones, and increasing the intensity of natural disasters, species extinction, and the spread of vector-borne diseases. More serious and abrupt climate changes are also possible making climate change one of the most critical global challenges of our time. The main approaches to reducing this threat includes policies and technologies that reduce greenhouse gas emissions (mitigation) and those that improve the capacity of nature and society to adapt to inevitable climate changes (adaptation). Another approach, just being discussed and explored, seeks to change fundamental processes such as photosynthesis or the radiative balance affecting climate change (geoengineering).

Reading:
Socolow, Robert, Roberta Hotinski, Jeffery B. Greenblatt, and Stephen Pacala. 2004. Solving the climate problem. *Environment* 46 (10): 8-19.
http://www.princeton.edu/mae/people/faculty/socolow/ENVIRONMENTDec2004issue.pdf

> The Reading addresses climate change through fifteen alternatives, each of which reduces greenhouse gasses by a billion tons of carbon per year. They include energy conservation, renewable energy and fuels, enhanced natural sinks, and carbon capture and storage. Seven of these would be required for stabilizing emissions over the next fifty years.

Wilbanks, Thomas J., J. Timothy Ensminger, and C. K. Rajan. 2007. Climate change vulnerabilities and responses in a developing country city: Lessons from Cochin, India. *Environment* 49 (5): 32-33.
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> The Reading explores adaptation by responding to the particular vulnerabilities found in an Indian coastal city. Solutions should link climate change adaptations to current needs for urban sustainability: waste management, drainage, inland waterways and other assets

for significant growth in tourism and land use.

3.3.3 Limit war, conflict, crime, and corruption

War, conflict, crime, and corruption are major threats to sustainable development - directly destroying human lives, capital, infrastructure, and the environment, and, indirectly, by diverting resources from development, increasing exploitation of natural resources, and encouraging personal security concerns to dominate the common good. There is evidence that conflict is reduced by equitable economic growth, increased state capacity, and inclusive democracy. Development seems to be a necessary condition for security, as is the reverse. In the short term the many initiatives at conflict prevention, peace-making, and post-conflict peace-building pursued by the United Nations, the World Bank, donor states, a number of regional organizations and thousands of NGOs, working closely with UN agencies, have been and can be effective. Yet, amidst these efforts, a grand challenge is the recurrent "natural resources curse."

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The Reading explores this link between natural resource endowment and conflict, and what can be done about it.

Aspinall, Edward. 2005. Aceh/Indonesia: Conflict analysis and options for systemic conflict transformation. Prepared for the Berghof Foundation for Peace Support. Berlin: BFPS.
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The Reading examines opportunities to reduce a conflict in Indonesia, where differences over resources is one of several causes of the conflict. Written just after a peace agreement that followed the tsunami of 2004, the fragile peace it describes is still holding five years later.

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