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Sustainable Development

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Introduction

“Sustainable development” is a concept that has quickly risen to prominence both in academic work and in policy making at all levels, particularly since 1987 when the World Commission on Environment and Development (WCED), better known as the “Brundtland Commission,” released its report promoting this approach. The report defines “sustainable development” as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” and states that “The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth.” The thinking behind the concept extends back for decades before the Brundtland report, particularly since the early 1970s with rapid rise of what is known as “sustainability science,” although the term “sustainable development” wasn’t coined until 1980. Sustainable development owes much of its political attractiveness to its vagueness, allowing hundreds of countries to sign onto international agreements that endorse the concept without fear that their development plans will be constrained. This advantage, of course, is linked to the disadvantage of allowing a “green” discourse to be used to promote just about any imaginable activity, no matter how damaging. Even countries importing toxic waste from the rest of the world claimed that they were practicing “sustainable development,” the Marshall Islands being the best known. The bibliography that follows presents some of the evolution of the concept of sustainable development and its scientific underpinnings. Two processes have proceeded in parallel: the political process of sustainable development that began with the Brundtland Report in 1987 and was extended by the UN Conference on Environment and Development (UNCED) in 1992 and the scientific process that evolved autonomously in response to the vagueness of the Brundtland definition. The sequence of international agreements associated with sustainable development has led this concept to permeate the planning of actions by governments and other entities throughout the world. Current application focuses on the 17 “sustainable development goals,” or “SDGs,” which were agreed at the UN Sustainable Development Summit in 2015, together with their 230 individual indicators and 169 targets. A clear example of the challenge of moving sustainable development beyond a role as a greenwashing discourse is offered by the Climate Convention. The Kyoto Protocol requires that all projects in the Clean Development Mechanism contribute to “sustainable development,” and in 1997 when the Protocol was signed this was seen as a way to prevent climate-mitigation projects from causing untoward social and environmental impacts. However, it was later decided that there would be no international standards defining what constitutes “sustainable development,” and it would be left up to each country to decide for itself whether proposed projects in the country met that country’s own criteria. A “Designated National Authority” (DNA) in each country would certify that each project represents sustainable development, with the result that projects are virtually never blocked on this basis. In Brazil a dramatic example is the Teles Pires Dam, which was certified as “sustainable development” and now receives CDM carbon credit. The Munduruku indigenous people near the dam were never consulted, as required by International Labor Organization Convention 169 and by Brazilian Law. In 2013 the tribe's most sacred site was fist dynamited and then flooded. This was the Sete Quedas rapids, which is where the spirits of respected tribal elders go after death – equivalent to Heaven for Christians.

What Is "Sustainable Development"?

So, what is "sustainable development"? At its most basic, to be "sustainable" it should theoretically last forever (or at least for a very long time). By the definition of Holdren *et al.* 1995 "A sustainable process or condition is one that can be maintained indefinitely without progressive diminution of valued qualities inside or outside the system in which the process operates or the condition prevails." Whether economic processes are considered "sustainable" depends very much on assumptions regarding the substitutability of different resources, including substituting natural capital for natural capital. Neoclassical economics (including environmental economics) assumes that human-made capital can replace natural capital of all kinds (known as "weak sustainability"). In contrast, ecological economics considers the stock of natural resources and ecological functions to be irreplaceable (known as "strong sustainability"). To be "development" a change must increase human wellbeing (presumably of the humans living in the place being "developed"). "Development" must be distinguished from "growth," which implies increased throughput of matter and energy. "Sustainable development" transcends the pre-existing concept of "economic development," which lacks the requirement of sustainability, and often also of equity (especially infragenerational equity). As Herman Daly 1996 argues, there is a real fight to control the meaning of "sustainable development." Clearly there is plenty of scope for interpretation of both what is "sustainable" and what is "development." Sustainable development is classically considered to be supported by three "pillars": economic, social and environmental. Many human activities in, for example, the "economic" sphere have negative consequences in the "social" and/or "environmental" spheres. There is plenty of leeway in how the balance is calculated, including when, where and for whom the benefits and costs accrue in each sector.

Holdren, J.P., G.C. Daily and P.R. Ehrlich. (1995) *The meaning of sustainability: biogeophysical aspects[http://documents.worldbank.org/curated/en/328001468764998700/Defining-and-measuring-sustainability-the-biogeophysical-foundations]*. pp. 3-17 In: M. Munasinghe and W. Shearer eds., *Defining and Measuring Sustainability: The Biogeophysical Foundations*. World Bank, Washington, DC, 482 pp. ISBN 0-8213-3134-5

This chapter is a background paper for the massive volume on sustainability organized by the United Nations University and the World Bank. The volume brings together a stellar group of authors on sustainability issues. These issues include indicators, effects of scale, limits of resources, climate change, and treatments by subject area (such as agriculture, forestry, fisheries, etc.) and by geographical region.

Barbier, E. 1987. The concept of sustainable economic development. *Environmental Conservation* 14(2):101–110. https://doi.org/10.1017/S0376892900011449

This paper focuses on the Third World. The primary concern of sustainable development is seen as “ensuring that the poor have access to sustainable and secure livelihoods.” Barbier divides the problem into Biological system goals (genetic diversity, resilience, and biological productivity), Economic system goals (reducing poverty through satisfying basic needs, enhancing equity, and increasing useful goods and services), and Social system goals (cultural diversity, institutional sustainability, social justice, and participation).

Lélé, S.M. 1991. Sustainable development: A critical review. *World Development* 19(6): 607-621. https://doi.org/10.1016/0305-750X(91)90197-P

Sharachchandra Lélé provides a scathing critique of “sustainable development” (SD). He finds that “…the mainstream of SD thinking contains significant weaknesses. These include an incomplete perception of the problems of poverty and environmental degradation, and confusion about the role of economic growth and about the concepts of sustainability and participation” and that “politically expedient fuzziness will have to be given up in favor of intellectual clarity and rigor.”

Redclift, M. 1987. *Sustainable Development: Exploring the Contradictions.* Routledge, London. 297 pp. ISBN 0-203-40888-8.

Michael Redclift states in his introduction to the book that “Sustainable development seems assured of a place in the litany of development truisms, but to what extent does it express convergent, rather than divergent intellectual traditions? The constant reference to ‘sustainability’ as a desirable objective has served to obscure the contradictions that ‘development’ implies for the environment.” He then proceeds in the book to explore these contradictions and the different social meanings of “environment,” “development” and “sustainability.”

Redclift, M. 2006. *Sustainable development (1987-2005) – An oxymoron comes of age[http://www.scielo.br/pdf/ha/v12n25/a04v1225]*. Horizontes Antropológicos [Porto Alegre], 12(25): 65-84, Redclift shows that the term “sustainable development” became “a property of different discourses.” He argues that the assumptions of these discourses need to be exposed in order to clarify the choices and their consequences.

Daly, H.E. (1990) Sustainable development: From concept and theory to operational principles. *Population and Development Review* 16: 25-43. https://doi.org/10.2307/2808061

Herman Daly says it best: “…Economists' growth-bound way of thinking makes it hard for them to admit the concept of throughput of matter-energy, because it brings with it the first and second laws of thermodynamics, which have implications that are unfriendly to the continuous growth ideology. …

The growth ideology is extremely attractive politically because it offers a solution to poverty without requiring the moral disciplines of sharing and population control."

Daly, H.E. (1996). *Beyond Growth: The Economics of Sustainable Development.* Beacon Press, Boston. 264 pp. ISBN-13: 978-0807047095 ISBN-10: 0807047090

Herman Daly argues that "there is a real fight to control the meaning of 'sustainable development,' and that conventional economists and development thinkers are trying to water down its meaning to further their own ends."

Quental, N. & J.M. Lourenço. 2012. References, authors, journals and scientific disciplines underlying the sustainable development literature: A citation analysis. *Scientometrics* 90: 361–381. https://doi.org/10.1007/s11192-011-0533-4

This citation analysis of sustainable development found the most-cited institutional authors to be WCED, World Bank, European Commission, DETR (UK), IPCC, United Nations, OECD, Food and Agriculture Organization, IUCN and World Health Organization. The most-cited individual primary authors were: D. Pearce, H. Daly, R. Costanza, D.H. Meadows, M. Redclift, C. Holling, P. Fearnside, R. Ayres, L. Brown, W. Rees, R. Solow, M. Wackernagel, F. Berkes, T. O'Riordan and R. Norgaard.

Sources of Information on Sustainable Development

Studies of sustainable development involve a wide range of academic fields, and also because of the volume of work on the subject. Google Scholar currently indicates 126,000 articles with "sustainable development" in the title and 2.3 million articles with this phrase mentioned somewhere in the text. The literature review and citation study Quental and Lourenço 2012 found the top journals dealing with sustainable development to be: ***Ecological Economics**, **Science, Nature**, **World Development**, **American Law and Economic Review***, and the ***Proceedings of the National Academy of Sciences of the USA**.*

Ecological Economics[https://www.journals.elsevier.com/ecological-economics] ISSN 0921-8009

This is the journal of the International Society for Ecological Economics (ISEE) (http://www.isecoeco.org/). *Ecological Economics* has been a major venue for work on sustainable development since the ISEE and the journal were founded in 1989.

Environment and Development Economics[https://www.cambridge.org/core/journals/environment-and-development-economics] ISSN: 1355-770X

This is the Journal of the Beijer Institute of Ecological Economics (http://www.beijer.kva.se/) of the Royal Swedish Academy of Sciences. As the journal's title indicates, *Environment and Development Economics* is largely concerned with "environmental economics" (the application of traditional economic methods to environmental problems) rather than "ecological economics" (a different discipline that conceives human economies as part of an ecosystem.

Environmental and Resource Economics[https://www.springer.com/economics/environmental/journal/10640]* ISSN: 0924-6460

This is the journal of the *European Association of Environmental and Resource Economists[https://www.eaere.org/).]* (Eaere) (

Sustainable Development[https://onlinelibrary.wiley.com/journal/10991719]* ISSN: 1099-1719

This is the journal of the *International Sustainable Development Research Society[http://isdrs.org/]* (ISDRS) and is entirely devoted to sustainable development.

Journal of Cleaner Production[https://www.journals.elsevier.com/journal-of-cleaner-production]* ISSN: 0959-6526

This is a "partner journal" of the Advances in Cleaner Production Network (ACPN), which organizes regular conferences on cleaner production.

World Development[https://www.sciencedirect.com/journal/world-development]*ISSN: 0305-750X

This is a leading journal on development issues, including sustainable development.

International Journal of Sustainable Development[https://www.inderscience.com/jhome.php?jcode=ijsd]* ISSN online 1741-5268 ISSN print 0960-1406

This journal is entirely devoted to sustainable development.

Redclift, M. & D. Pearce (eds.) 1988. *Sustainable development[https://www.sciencedirect.com/journal/futures/vol/20/issue/6]*. *Futures* 20(6): 595-712. [special issue]

This special issue contains articles by leading authors on sustainable development as related to equity, the co-evolutionary paradigm, land use, the market, agricultural development, and business.

History of Sustainable Development

The concept of sustainable development and its underlying components have evolved through a long series of publications and debates, including fierce disagreements. A variety of prescriptions have been put forward for sustainability, which vary depending on the background of the proponent. One particularly inflammatory debate was that surrounding the *Limits to Growth*, a book published by Meadows and coworkers in 1972 presenting simulations of the global system's behavior modes over the next 200 years, with population growth and industrial pollution being key determining factors in a future "collapse." A series of books known as the "Blueprint Series**"** lead by David Pearce developed proposals to increase sustainability from the perspective of environmental economics. Finally, underlying processes and limitations are highlighted by the perspective of ecological economics, which differs from that of environmental economics by viewing the economic system as a component within the larger ecosystem.

Prescriptions for Sustainability

Various groups and individuals have produced a voluminous literature offering suggestions or prescriptions for sustainability. These have been important both for public understanding of and support for measures to increase sustainability. They are also important sources of inputs to official negotiations, as in the United Nations. Herman Daly has played a key role in developing the relevant concepts in ecological economics by bridging gaps between the fields of ecology and economics. He was an early voice in the contribution of the environment to maintaining human societies, which are not maintained by a circular flow of money between households and firms as envisioned by traditional "neoclassical" economics. Another part is his recognition of limits, which he frequently compared to the waterline used to define the limit for loading a ship. An important contribution was a period of years Daly spent as a senior economist in the environment department at the World Bank before returning to academia. Needless to say, challenging the assumptions of the over 3000 traditional economists employed by that institution was not guaranteed of success. The need for the theoretical framework provided by ecological economics can be seen in the multiple volumes that report the many challenges to sustainable development and the policy changes needed to counter them, such as the review by NAS 1999 and the series of books illustrated by Brown 2008 and Myers 1993.

Daly, H.E. 1991. **Steady State Economics*[http://pombo.free.fr/daly1991.pdf]*. Island Press, Washington, DC. 288 pp. ISBN: 1-55963-072-8

This updates Daly's classic 1977 first edition of this book and builds on the tradition of his 1973 book *Toward a Steady-State Economy* [W.H. Freeman, San Francisco. 332 pp. ISBN: 0716707993 9780716707998 0716707934 9780716707936]. Recognizing that humans are part of an ecosystem that, as a whole, must remain in steady state has implies the need for profound changes in what kind of "development" can be pursued. Development needs to improve wellbeing without requiring more "throughput" of energy and materials.

Daly, H.E. 2008. *Towards a Steady-State Economy[https://is.muni.cz/el/1423/jaro2015/ENS242/um/55677449/3_Daly_2008_Towards_a_Steady_State_Economy.pdf]*. Essay commissioned by the Sustainable Development Commission, UK.

This short essay encapsulates Daly's teaching on the need for a steady-state economy. As he says, "The closer the economy approaches the scale of the whole Earth the more it will have to conform to the physical behavior mode of the Earth. That behavior mode is a steady state—a system that permits qualitative development but not aggregate quantitative growth."

IUCN (The World Conservation Union), UNEP (United Nations Environment Programme) and WWF (World Wide Fund for Nature). 1991 **Caring for the Earth: A Strategy for Sustainable Living*[https://portals.iucn.org/library/efiles/documents/cfe-003.pdf]* IUCN, Gland, Switzerland. 228 pp. ISBN 2-8317-0074-4;

This volume includes chapters on a wide range of topics, covering issues of environment and development in different parts of the world and different spheres of activity. I recommend the chapter on "Keeping within the Earth's carrying capacity."

NAS (National Academy of Sciences). 1999 **Our Common Journey: A Transition toward Sustainability*[https://www.nap.edu/download/9690]*. National Academy Press, Washington, D.C. 363 pp. ISBN 0-309-06783-9

This volume presents the work of a committee convened by the US National Academy of Sciences. It identifies the various trends that threaten sustainability and proposes goals for a transition to a more sustainable world, as well as priorities for both research and action.

Brown, L. 2008 **Plan B 3.0: Mobilizing to Save Civilization*.[http://www.earth-policy.org/images/uploads/book_files/pb3book.pdf]*. WW Norton, New York. 398 pp. ISBN 978-0-393-33087-8.

Lester Brown has produced a score of books on sustainability issues, including the "Plan B" series. During his presidency at the Worldwatch Institute and then at the Earth Policy Institute he contributed to many other writings that were produced at these institutions.

Myers, N. 1993 *Ultimate Security: The Environmental Basis of Political Stability*. WW Norton, New York. 308 pp. ISBN 0-393-03545-X.

Norman Myers has produced a long series of books related to sustainability issues, mostly related to tropical deforestation and biodiversity. *Ultimate Security* is an expansion of his contributions to the Brundtland Report, and deals with the link between environmental degradation and security, both at the national and at other levels.

The Limits to Growth Debate

The publication of the *Limits to Growth* by Meadows *et al*. 1972 marked a turning point in terms of public and political engagement with sustainability issues. The book also provoked a backlash of criticism that continues to the present day. The authors have defended their model and updated its results multiple times. The basic result of the World 3 model presented in the book was one of "overshoot and collapse." While more information and changed circumstances modify how and when this pattern emerges, the basic message of the existence of limits and the consequences of ignoring them remains. As Donella Meadows pointed out on various occasions, people have been declaring Malthus to be wrong for 200 years, but if there weren't a grain of truth in what he had to say he would have been forgotten long ago. Sustainable development is often seen as a new, more optimistic (and pragmatic), environmental paradigm that transcends the doom-laden Neo-Malthusian paradigm. However, Meadows and coworkers did not view doom as inevitable, but rather saw their catastrophic projections as a warning to shock society into changing course. The subsequent political process promoting sustainable development was, in part, a reflection of heightened concern that the *Limits to Growth* helped to ignite. Meadows *et al*. 1992 provided an update 20 years after the original book, Meadows *et al*. 2004 provided their "30-year" update. Controversies are illustrated by the attack on *Limits to Growth* by Cole *et al*. 1973 and by the reply by Meadows *et al*. in that volume. Dasgupta and Heal 1979 consider the treatment of substitutability in *Limits to Growth*. Applications of the *Limits to Growth* analyses to sustainable development are explored by Randers 2000 and Colombo 2001. Comparisons of *Limits to Growth* projections to subsequent history are made by Cole and Masini 2001 and Turner 2008.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens III, W. W. 1972. *The limits to growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books, New York. 205 pp. ISBN 0-87663-165-0

This is the book that was translated into 30 languages and sold over 30 million copies. In contrast to the sequence of voluminous institutional reports on sustainable development, *Limits to Growth* was actually read by millions of people, giving it an impact on a different scale. Undoubtedly it had an important role in pushing sustainability issues into the realms of politics and policy making.

Meadows, D.H., Meadows, D.L., Randers, J., 1992. *Beyond the Limits: Global Collapse or a Sustainable Future*. Earthscan Publications Ltd, London. 300 pp. ISBN 1-85383-131-X.

This update 20-years after *The Limits to Growth* shows that the world had already overshot some of its limits. The book offers a series of suggestions on how to avoid the future collapse foreseen by the World 3 model.

Meadows, D.H., Randers, J., Meadows, D.L. 2004. *Limits to Growth: The 30-Year Update* (3rd Edition). Chelsea Green Publishing, Chelsea, Vermont, USA. 338 pp. ISBN 193149858X 978-1931498586

This second update offers more modeling insights and comparisons with real-world trends. It also offers policy suggestions.

Cole, H.D.S., C. Freeman, M. Jahoda and K.L.R. Pavitt (eds.). 1973. Models of Doom: A Critique of the Limits to Growth. Universe Books, New York. 244 pp. ISBN 0-87663-905-8.

This volume mounts an attack on Meadows *et al.* 1972 and also includes a response by these authors. The critique is not only of the *Limits to Growth* but also of what Cole *et al*. consider to be a "neo-Malthusian" outlook in general, which is viewed as a license for the rich to prey upon the poor. Meadows *et al.* counter both the technical and the philosophical criticisms.

Dasgupta, P. and Heal, G. 1979. *Economic Theory and Exhaustible Resources*. Cambridge University Press, Cambridge, UK. 501 pp. ISBN: 0-521-22991-X

This book examines the place of natural resources in economic systems. It takes issue both with the lack of price mechanisms and substitutability in the *Limits to Growth* analysis and with the assumption of many economists that exhaustible resources do not constitute a problem because substitutes will always be found as a resource grows scarce and its price rises.

Randers, J. 2000. From limits to growth to sustainable development or SD (sustainable development) in a SD (system dynamics) perspective. *System Dynamics Review* 16(3): 213-224. https://doi.org/10.1002/1099-1727(200023)16:3<213::AID-SDR197>3.0.CO;2-E

This article compares outputs of the World3 models of Limits to Growth with 30 years of history. The model's feedback structures are reexamined and their relevance to sustainable development is explained. "Leverage points" in the model are identified that could be used to guide the world system towards sustainability.

Cole, S. and Masini, E.B. (eds) 2001 *Limits beyond the millennium: a retroprospective on The Limits to Growth[https://www.sciencedirect.com/journal/futures/vol/33/issue/1]*. *Futures* 33(1): 1–90. [special issue]

This special issue of Futures presents a series of articles on progress in modeling and on the course of history in the first 25 years after the Limits to Growth was published, largely confirming the conclusions of Meadows *et al*. 1972.

Colombo, U. 2001 The Club of Rome and sustainable development. *Futures* 33(1): 7-11. https://doi.org/10.1016/S0016-3287(00)00048-3

This article in the *Futures* special issue deals with the implications of the *Limits to Growth* for sustainable development. The recognition of limits is obviously fundamental.

Turner, G.M. 2008 A comparison of The Limits to Growth with 30 years of reality. *Global Environmental Change* 18: 397–411. doi:10.1016/j.gloenvcha.2008.05.001

This paper compares the simulations of Meadows *et al*. 1972 with subsequent real-world trends. The historical trends compare favorably with the Limits to Growth ‘‘standard run’’ (business-as-usual) scenario that shows a collapse of the global system in the mid- 21st century, but do not compare well with the scenarios that assume stabilization through technology or behavioral change.

<u>The Blueprint Series</u>

David Pearce (1941-2005), the most highly cited individual author on sustainable development according to Quental and Lourenço 2012, produced an important series of books exploring the economics of sustainable development, particularly the value of biodiversity and its services. This “blueprint series” has provided many inputs taken up in the official documents and negotiations on sustainable development under the aegis of the United Nations. The series begins with Pearce *et al*. 1989 focusing on economic valuation, then proceeds in Pearce *et al*. 1991 to focus on challenges, in Pearce 1992 on the global commons, in Pearce 1993 on political and institutional dimensions, in Pearce 1995 on “global bargains”, and in Pearce *et al*.1996 on the theory of sustainable development, including carrying capacity and resilience.

Pearce, D., Markandya, A. & Barbier, E.B. 1989. *Blueprint for a Green Economy.* Earthscan, London. 192 pp. ISBN 1 85383 066 6. Replaced by an expanded version: Pearce, D. & E.B. Barbier. 2000. *Blueprint for a Sustainable Economy.* Earthscan, London, 287 pp. ISBN 1853836826, 1853835152

This is the original “blueprint” volume and deals with economic valuation of environmental goods (and bads), including cost-benefit analysis. It discusses valuation methodologies, including both revealed and stated preference techniques. It discusses the causes of environmental degradation and argues for greater use of incentives to encourage sustainability, rather than depending solely on regulatory measures.

Pearce, D., Barbier, E.B., Markandya, A., Bennett, S., Turner, R.K. & Swanson, T. 1991. *Blueprint 2: Greening the World Economy*. Earthscan, London. 232 pp. ISBN 1 85383 076 3

This volume deals with such sustainability issues as the challenges of the “global commons,” population growth, climate change, tropical deforestation, biodiversity conservation, aid to the “third world,” and ethics.

Pearce, D. 1992. Green economics. *Environmental Values* 1(1): 3-13
https://doi.org/10.3197/096327192776680179

This paper looks at how to modify market signals by means such as environmental taxes and tradeable pollution certificates such that self-interest will guide economic behavior, thus avoiding the loss of human liberties implied by relying on command-and-control to achieve the same ends.

Pearce, D. 1993. *Blueprint 3: Measuring Sustainable Development.* Routledge, London. 240 pp. https://doi.org/10.4324/9781315070414 eBook ISBN 9781134163540

This volume continues from the previous volumes, giving special attention to the conditions for sustainable development and its political and institutional dimensions. It also deals with air and water quality, hazardous waste, transport, agriculture and forestry.

Pearce, D. 1995. *Blueprint 4*: *Capturing Global Environmental Value*. Routledge, London. 212 pp. https://doi.org/10.4324/9781315070421 eBook ISBN 9781134163823

This volume deals with a variety of sustainability issues, including the challenge posed by the "global commons," climate change, the ozone layer, biodiversity, population, poverty, overconsumption and international trade. The book looks for "global bargains" where self-interest could motivate all parties to improve the environment. The final part of the book examines global institutions that could facilitate capturing environmental value.

Pearce, D., K. Hamilton and G. Atkinson. 1996. Measuring sustainable development: progress on indicators. *Environment and Development Economics* 1(1): 85-101. https://doi.org/10.1017/S1355770X00000395

This paper argues that a theory of sustainable development should guide the choice of sustainability indicators. "Weak" sustainability is represented by aggregative indicators such as green national income, while "strong" sustainability is indicated by genuine savings (i.e. savings adjusted for loss of assets), thus giving greater priority to conservation. Two approaches are discussed: carrying capacity and resilience, and the authors conclude that the former is currently best developed, resilience requires more research on its link to sustainable development.

Ecological Economics and Environmental Economics

"Ecological economics" refers to a relatively new field that views the human economy as a part of the larger ecosystem. The traditional neoclassical economic paradigm doesn't consider the natural environment at all, the economy being a function of money circulating between firms and households in isolation – money making more money out of nothing. Modifications to this to incorporate the environment almost always consider the environment as a small component added on to the dominant monetary economy, rather than the other way around. "Environmental economics" is a much older field than ecological economics, and refers to applications of traditional economic methods to environmental problems. Ecological economics is increasingly central to debates on sustainable development, although greater recognition of the ecosystemic nature of sustainability issues would be a welcome evolution. Pearce and Turner 1990 apply environmental economics to sustainable development, while Costanza 1991 and Costanza *et al*. 2015 do the same applying ecological economics. Goodland and Ledec 1987 criticize neoclassical economics for overlooking or undervaluing the economic values of environmental services, ignoring intangible benefits such as many of those from biodiversity, making no distinction between reversible and irreversible environmental effects, heavily discounting economic costs and benefits such that projects with short-term benefits and long-term costs are favored (often with severe environmental impacts), and using Gross National Product to measure development, thus encouraging rapid overexploitation of a country's natural resource base. Hawken *et al*. 1999 present “natural capitalism” as a solution to some of these ills. Norgaard 1988, 1994 presents a co-evolutionary framework for shifting human society to a course consistent with sustainability requirements based on ecological economics. Kates *et al*. 2001 presents sustainability science and Turner *et al*. 2003 present a framework for vulnerability analysis in sustainability science in order to identify ways to achieve resilience as a part of sustainable development.

Pearce, D. and Turner, R. 1990. *Economics of Natural Resources and the Environment*. Johns Hopkins University Press, Baltimore, Maryland, USA. 396 pp. ISBN-10: 9780801839870 ISBN-13: 978-0801839870

This book presents environmental economics (application of traditional economic methods to the environment) as related to sustainable development. The text is meant for teaching sustainability, and presents ten concepts, each representing a specific domain or a field that is related to sustainability.

Costanza, R. (ed.). 1991 *Ecological Economics: The Science and Management of Sustainability*. Columbia University Press, New York. 525 pp. ISBN-10: 9780231075633 ISBN-13: 978-0231075633

This edited volume contains chapters discussing root causes of the problems facing humanity, problems of discounting and valuation, the role of uncertainty, accounting, modeling, and analysis of ecological economic systems, environment as capital, national income accounting, resource scarcity, needed institutional changes, perverse incentives, methods to alter incentives, intergenerational transfers and the role of education. There is also a series of chapters presenting case studies, including questions of tropical forest management.

Costanza, R., J.H Cumberland, H. Daly, R. Goodland, R.B Norgaard, I. Kubiszewski and C. Franco. 2015. *An Introduction to Ecological Economics*, 2nd ed. CRC Press, Boca Raton, Florida, USA. 356 pp. ISBN-13: 978-1566706841 ISBN-10: 9781566706841

This textbook updates the original, published in 2000. The book explains the development of the field and its roots in both economics and ecology. The various challenges that face society are explained,

these being the interdependent environmental, economic, and social issues that face efforts to move towards sustainable development.

Norgaard, R.B. 1988. Sustainable development: A co-evolutionary view. *Futures* 20(6): 606-620. https://doi.org/10.1016/0016-3287(88)90003-1

Richard Norgaard argues that we are shifting from a mechanical to a co-evolutionary understanding of systems, and that this helps explain why development has been unsustainable and what we must do to attain sustainability.

Norgaard, R.B. 1994. *Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future*. Routledge, New York. 296 pp. ISBN-13: 978-0415068628 ISBN-10: 0415068622

Ecological economist Richard Norgaard offers a co-evolutionary paradigm as an alternative to the path that the global economy has been following towards ecological collapse. He portrays development is as a co-evolution between cultural and ecological systems that can allow sustainability based on a patchwork of cultures.

Goodland, R., and G. Ledec, 1987 Neoclassical economics and principles of sustainable development. *Ecological Modelling* 38(1-2): 19-46. https://doi.org/10.1016/0304-3800(87)90043-3

This paper explains the shortcomings of traditional neo-classical economics, the prescriptions from ecology that conflict with those of traditional economics, and the need for applying the perspective of ecological economics. Examples from the World Bank’s experience are used as illustrations of these problems.

Hawken, P., A. Lovins, L.H. Lovins. 1999. *Natural capitalism: Creating the next industrial revolution*. Little & Brown, New York. ISBN-13: 978-0316353007 ISBN-10: 9780316353007

This book addresses “natural capitalism” and how this can counter the “poor design” inherent in the traditional version of capitalism. Climate change is an example of how the present capitalism is not working as needed. The book develops a set of four principles for a transition to natural capitalism.

Kates, R.W., W.C. Clark, R. Corell, J.M. Hall, C.C. Jaeger, I.Lowe, J.J. McCarthy, H.J. Schellnhuber, B. Bolin, N.M. Dickson, S. Faucheux, G.C. Gallopin, A. Grübler, B. Huntley, J. Jäger, N.S. Jodha, R.E. Kasperson, A. Mabogunje, P. Matson, H. Mooney, B. Moore III, T. O'Riordan and U. Svedin. 2001. Sustainability science. *Science* 292: 641-642. https://doi.org/10.1126/science.1059386

This paper explains what “sustainability science” is and how this new field can help understand the “nature-society system” and how it reacts to stresses.

Turner, B.L. II, R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, J.X. Kasperson, A. Luers, M.L. Martello, C. Polsky, A. Pulsipher and A. Schiller. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the USA* 100 (14): 8074-8079; https://doi.org/10.1073/pnas.1231335100

“Vulnerability” is a function of the sensitivity and resilience of socio-ecological systems to perturbations. As such, vulnerability analysis is a potentially important tool for studies of sustainability and sustainable development.

Pearce, D. 2002. An intellectual history of environmental economics. *Annual Review of Energy and Environment* 27: 57–81. https://10.1146/annurev.energy.27.122001.083429

This review presents the environmental-economics perspective and traces the history of this field, including “recent perspectives on the political economy of choosing policy instruments and the philosophy of sustainable development.”

UN Commissions and International Negotiations

Sustainable development became a guiding theme in UN commissions and international negotiations beginning with the 1987 report of the World Commission on Environment and Development, better known as the Brundtland Commission. Prior to that, groundwork had been laid by the UN Conference on the Human Environment held in Stockholm in 1972, which focused on global environmental problems but neglected the needs of developing countries for economic development. This failing led to the Brandt Commission (officially the “Independent Commission”) and its report in 1980, which dealt with issues of poverty and of intergenerational equity. More specific recommendations for sustainable development were put forward in the Agenda 21 document that was negotiated in 1992 and endorsed by the United Nations Conference on Environment and Development” (UNCED) in Rio de Janeiro in June of that year. In December of the same year the United Nations Commission on Sustainable Development (CSD) was established by the UN General Assembly to ensure effective follow-up of UNCED. The United Nations Division for Sustainable Development, which administers this commission, has provided a structure for the ongoing series of meetings and international negotiations on sustainable development. In 2005 the Millennium Ecosystem Assessment included discussion of ecosystem services and developed the Millennium Development Goals (MDGs). In 2015 the United Nations the UN Sustainable Development Summit adopted the Sustainable Development Goals (SDGs), which represent the current structure for global efforts to attain sustainable development.

The Brundtland Commission

World Commission on Environment and Development 1987, known as the “Brundtland report”, contains several controversial points. One is its treatment of intergenerational equity. The report specifies only that present activities must not deprive future generations of the ability to solve their own problems when they arise – but with the unspoken assumption that those future generations will be wealthier, better educated and with better technology, and that those generations will therefore not need as much help from nature to maintain their level of development. Another controversial point is the caveat concerning non-renewable resources such as minerals. Activities like mining can be considered "sustainable" if the monetary proceeds are invested in ways that will provide employment in other kinds of activity for the people who have been supported by the extraction of the non-renewable resource. Not only is this employment transition unlikely in practice in most cases when minerals are exhausted, the minerals themselves are not necessarily substitutable with other materials. Sneddon *et al.* 2006 review the report, the criticisms of it, and its role in the 20 years of history following its release.

World Commission on Environment and Development. 1987. **Our Common Future*[https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf]*, Oxford University Press, Oxford.

> The report of the World Commission on Environment and Development (WCED), better known as the "Brundtland Report" has been the subject of both praise and criticism. Although the term "sustainable development" was raised at the 1972 environment meeting in Stockholm, it was the Brundtland Report that put this into the mainstream of international discussions and the sequence of negotiations and reports leading up to our current "sustainable development goals."

Sneddon, C., R.B. Howarth, and R.B. Norgaard. 2006. Sustainable Development in a Post-Brundtland World. *Ecological Economics* 57: 253-268. https://doi.org/10.1016/j.ecolecon.2005.04.013 ·

> This paper provides a good review of the Brundtland report and of the criticisms and progress in the first two decades after the report was published.

The 1992 Earth Summit and Agenda 21

Prior to the June 1992 "Earth Summit" in Rio de Janeiro, officially titled the "United Nations Conference on Environment and Development" (UNCED), a long series of meetings produced United Nations 1992, which is an internationally agreed document known as "Agenda 21." UNCED made an important contribution to the political process of sustainable development by extending it to cover developed countries as well as developing countries (with Agenda 21 being its blueprint for action), and by embedding the concept of sustainable development in the "Rio Conventions" on climate and biodiversity.

United Nations. 1992. *United Nations Conference on Environment and Development—Agenda 21[https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf]*. United Nations Division for Sustainable Development, New York. United Nations Department of Economic and Social Affairs (DESA) 351 pp.

This is the negotiated report known as “Agenda 21.” More information is available online at *DESA[[http://www.un.org/esa/sustdev/agenda21.htm]*

Millennium Development Goals (MDGs)

The Millennium Ecosystem Assessment was carried out between 2001 and 2005, involving a long series of meetings and the work of many volunteer scientists, in a manner similar to the working of the Intergovernmental Panel on Climate Change. The report was important in establishing ecosystem services as a paradigm for considering impacts on the world’s ecosystems and for rewarding the environmental benefits that ecosystems provide to humans. Ecosystem services were divided into four groups, described as “*provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling.” The eight “Millennium Development Goals” (MDGs) “aim to improve human well-being by reducing poverty, hunger, child and maternal mortality, by ensuring education for all, by controlling and managing diseases, by tackling gender disparity, by ensuring environmental sustainability, and by pursuing global partnerships.” The member governments agreed to a total of 15 targets to be achieved by 2015, varying between 1 and 8 targets for each MDG. The eight MDGs were (1) Eradicate extreme poverty and hunger, (2) Achieve universal primary education (3) Promote gender equality and empower women (4) Reduce child mortality (5) Improve maternal health (6). Combat HIV/AIDS, malaria and other diseases (7) Ensure environmental sustainability, and (8) Develop a global partnership for development. The Millennium Development Goals were mainly framed within the old concept of economic development and so gave limited coverage to the environment. This failing was later reversed in the Sustainable Development Goals.

Millennium Ecosystem Assessment. 2005. **Ecosystems and Human Well-Being: Synthesis*[https://www.millenniumassessment.org/documents/document.356.aspx.pdf]*. Island press, Washington, DC. 137 pp. ISBN 1-59726-040-1

The Millennium Ecosystem Assessment presents a wealth of information on the world’s ecosystems, their current state and the threats they face, as well as the consequences of allowing the present rapid loss of ecosystem services to continue. The report discusses the eight “Millennium Development Goals” (MDGs) that were adopted by the United Nations in 2000, prior to the beginning of the assessment.

Sustainable Development Goals (SDGs)

After another long series of meetings, in 2015 the United Nations adopted 17 Sustainable Development Goals (SDGs) at the UN Sustainable Development Summit. The UN also created a Sustainable Development Knowledge Platform with detailed information on the goals and on the 230 individual indicators and 169 targets

United Nations 2015 **Transforming our world: the 2030 Agenda for Sustainable Development*[https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf]*. United Nations, New York. 41 pp. (https://sustainabledevelopment.un.org/post2015/transformingourworld)

This document presents a brief summary of the UN's plans for sustainable development through the year 2030. *UN Sustainable Development Summit[(https://sustainabledevelopment.un.org/)]*

United Nations 2016 Final list of proposed Sustainable Development Goal indicators[https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf]. United Nations, New York. 25 pp.

This document presents the official list of indicators for the sustainable development goals.

Scientific Underpinnings of Sustainable Development

Sustainable development cannot be achieved without addressing the issues raised by its scientific underpinnings. These include the limits imposed on human population and human consumption by carrying capacity. The "ecological footprint" expresses the same relation as area per capita rather than as population per unit area. Such limits are among the features of human societies and the ecosystems of which they are a part that have been studied through the optics of energy and embodied energy and of the laws of thermodynamics, especially entropy. The concept of resilience has provided a useful approach to defining and quantifying sustainability. Another approach to defining and quantifying sustainability is natural capital, which, like human-made capital, can be depleted with resulting loss of sustainability. Human-made capital cannot always substitute for natural capital, and the two together (i.e., total capital) must not decline if a system is to be sustainable. A series of ethical issues and social choices determine how resources are shared and used, and whether the result can be considered "sustainable development" both in terms of its durability over time and its moral acceptability (i.e., whether it represents an improvement in human wellbeing – a defining characteristic of "development"). One such issue is the use of "commons," which range from those used by societies with social mechanisms that assure nondestructive exploitation to those that are "open access" and therefore subject to the "tragedy of the commons". Ethical considerations have defining roles in the choices to be made in pursuing sustainable development, as is especially evident in the controversies surrounding climate change. These include the value of human life, the treatment of equity (both intergenerational and infragenerational), the value of time, and the criteria for permanence and uncertainty.

Human Carrying Capacity

One of the most basic requirements for sustainability is that the existence of limits is recognized and that limits are respected. These include limits on population, consumption, pollution in various forms (including greenhouse gases), and standards regarding inequality, poverty (i.e., minimum per-capita consumption), minimum acceptable risks (of various types) and assurance of respect for human rights and various individual freedoms. The perceptions of what is acceptable clearly vary among societies and change over the course of time. While the existence of limits might seem obvious, this has been and continues to be denied both explicitly (i.e., by “cornucopian” advocates) and, more commonly, implicitly by the actions of much of humanity. Fearnside 1986 presents a study of human carrying capacity in Brazilian Amazonia and Fearnside 1997 discusses this concept as a basis for sustainable development. Cohen 1995 provides an extensive review of human carrying capacity studies and their implications for global population. Vitousek *et al*. 1986, Arrow *et al*. 1995, Rees 1996 and Steffen *et al*. 2004 present a series of limitations on human use of the biosphere and consequent implications for carrying capacity.

Fearnside, P.M. 1997. Human carrying capacity estimation in Brazilian Amazonia as a basis for sustainable development. *Environmental Conservation* 24(3): 271-282. https://doi.org/10.1017/S0376892997000350

> This paper explains the relation of carrying capacity and sustainable development in Brazilian Amazonia based on the modeling results of Fearnside 1986. Carrying capacity is clearly central to sustainable development, since both sustainability and development require that population and consumption remain within these limits of carrying capacity, while preventing a decline in the carrying capacity of an area requires that productive systems implanted through development be sustainable. Research needs are identified.

Fearnside, P.M. 1986. *Human Carrying Capacity of the Brazilian Rainforest*. Columbia University Press, New York, NY. 293 pp. ISBN 0-231-06104-8

> This book discusses the importance and challenges of estimating human carrying capacity and presents modeling results for a settlement on Brazil’s Transamazon Highway. The estimation uses stochastic model that includes the variability in many variables affecting land use, agricultural productivity and the composition and behavior of the Transamazon Highway colonist population. Carrying capacity is defined in terms of a relationship between population density and the probability of colonist “failure” (i.e., failure to achieve defined levels of per-capita consumption).

Cohen, J.E. 1995. *How Many People can the Earth Support*. WW Norton, New York. 531 pp. ISBN 0-393-31495-2

> This book reviews the question of human population and how human carrying capacity has been approached. The reality of limits is inescapable. While these limits are not fixed, the tendency to exceed them has been a pattern throughout history. While populations can expand as production increases through technological improvements and by spatial expansion when areas are available, passing carrying capacity can degrade resources with disastrous consequences for the populations that depend on them.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.-O. Jansson, S. Levin, K.-G. Mäler, C. Perrings and D. Pimentel. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520-521. https://doi.org/10.1126/science.268.5210.520

> Kenneth Arrow (1921-2017), in addition to being a major figure in neo-classical economic theory, recognized the existence of limits. Arrow *et al*. 1995 argued that carrying capacity is surpassed when economic growth increases resource use and waste emissions beyond the capacity of the environment to supply the resources or assimilate the wastes. As these limits approached, societies become more sensitive to external shocks.

Steffen, W., Sanderson, A, Tyson, P.D., Jager, J., Matson, P.M., Moore, B. III, Oldfield, F., Richardson, K., Schnellnhuber, H.J., Turner, B.L. II, Wasson, R.J. 2004 *Global Change and the Earth System: A Planet under Pressure*. Springer-Verlag, New York. 336 pp. ISBN 978-3-540-26607-5

> This book describes the various human-caused changes that threaten the sustainability of the Earth's capacity to support human the human population. The book describes the "Earth System," how its complex interactions are at risk, and how these risks might be countered.

Vitousek, P., P.R. Ehrlich, A.H. Ehrlich and P. Matson. 1986. Human appropriation of the products of photosynthesis. *Bioscience* 36(6): 368–373. https://doi.org/10.2307/1310258

> Peter Vitousek and collaborators calculated that human consumption currently being appropriated approximately 40% the biosphere's total net terrestrial primary production. This calculation has been widely used as an indication of the scale that human influence on the Earth system has now reached.

Rees, W.E. 1996. Revisiting carrying capacity: Area-based indicators of sustainability. *Population and Environment* **17(1)**: 195–215. https://doi.org/10.1007/BF02208489

> This article dispels the myth that human carrying capacity is infinitely expandable through technology and hence should not be a concern for demography or for development planning. Recognizing carrying capacity is presented as fundamental to assuring that stocks of natural capital are sufficient to support the human economy in the coming years.

<u>**Ecological Footprint**</u>

The “ecological footprint” expresses essentially the same limits as human carrying capacity, but viewed from the opposite direction. Rather than focusing on the number of people per unit of area, the units are area per person, the area being what is needed to supply the various kinds of resources the person consumes. This has the advantage of making clear the individual responsibility of the small fraction of the population of the Earth (and also the small fraction of the population within most countries) that consume most of the resources. The book by Wackernagel and Rees 1996 is the principal reference on the ecological-footprint approach. Wackernagel *et al*. 1999 use the footprint approach to address natural capital accounting, and this is extended by Monfreda *et al*. 2004 to include trade. Wackernagel and Yount 1998 explain the relation of the ecological footprint to carrying capacity and regional sustainability.

Wackernagel, M. and Rees, W. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Philadelphia, PA. 160 pp. ISBN: 0-86571-312-X.

> Wackernagel and Rees have made an important contribution in bringing the “ecological footprint” into policy discussions on sustainability and into the popular consciousness. This book lays out the Earth’s litany of problems of overconsumption, overpopulation, inequality, waste, damaging technologies and environmental destruction. It shows the unsustainability of human society’s current course and uses the ecological footprint paradigm to suggest ways to “reduce human impact on the Earth.”

Wackernagel, M., L. Onisto, P. Bello, A.C. Linares, I.S.L. Falfán, J.M. García, A.I.S. Guerrero and M.G.S. Guerrero. 1999. National natural capital accounting with the ecological footprint concept. *Ecological Economics* 29: 375–390. https://doi.org/10.1016/S0921-8009(98)90063-5

> Wackernagel and coworkers explain how the ecological-footprint approach offers an alternative way to account for natural capital. Energy and resource throughput are translated into the biologically productive areas necessary to produce these flows, that is, the “ecological footprint.” Such calculations have been applied to 52 countries. The authors claim that “With this framework … human consumption can be compared with natural capital production at the global and national level, using existing data.”

Wackernagel, M. and J.D. Yount. 1998. The ecological footprint: An indicator of progress toward regional sustainability. *Environmental Monitoring and Assessment* 51(1-2): 511–529. https://doi.org/10.1023/A:1006094904277

> Wackernagel and Yount “define regional sustainability as the continuous support of human quality of life within a region's ecological carrying capacity.” Human resource use and waste discharge are compared to a region's ecological carrying capacity, and “to achieve global sustainability, the sum of

all regional footprints must not exceed the total area of the biosphere." This paper presents progress on standardizing the footprint methodology for nations and regions.

Monfreda, C., M. Wackernagel and D. Deumling. 2004. Establishing national natural capital accounts based on detailed ecological Footprint and biological capacity assessments. *Land Use Policy* 21(3): 231-246. https://doi.org/10.1016/j.landusepol.2003.10.009

This paper presents a number of improvements in the ecological-footprint methodology to improve its detail and reliability and to distinguish such features as primary and secondary production. These improvements make the method capable of analyzing the Ecological Footprint embodied in trade.

Energy and Embodied Energy

Howard T. Odum (1924-2002) founded a school of thought that analyzes environmental and social systems on the basis of energy. In the 1950s he developed a modeling methodology and accompanying "electrical circuit" diagramming conventions to represent energy flows in natural ecosystems. In Odum 1971 he applied this methodology to human socioeconomic systems. Odum 1983 elaborated on this. Odum 1988 explains "embodied energy," which he termed "emergy" (spelled with an "m") to represent living and non-living components of socioeconomic systems in terms of the energy that had been transformed to create these components, as opposed to the energy they contain that could be measured by burning them in a calorimeter. This "currency" provides a different sort of analysis than what is achieved by economists using money as the means of measuring stocks, flows and the equivalences of different items. Energy as a currency has advantages in allowing conversions among items ranging from species to human institutions to information. It also can be criticized, as with other currencies, in ignoring other types of value, the impediments that exist in the real world preventing many types of conversion, and the surprises that emerge from the tremendous diversity in both natural ecosystems and human societies. Like all modeling, simplification means that omission of important aspects can distort the conclusions, but, on the other hand, the simplification allows basic principles (such as the existence of limits) to be made clear. Currencies have advantages in allowing conversions and transactions, but excluding everything that can't be expressed through the currency can have serious consequences. In a capitalist economy, money is the currency and prices are a function of supply and demand. This mean that what is abundant, such as the air or the oceans, has no value and is not cared for until it becomes scarce. A perennial challenge to sustainable development is the bulk of economic decisions omitting any consideration of the "externalities" that fall outside of the market system, such as the loss of the regulating environmental services. Other currencies also have problems: the labor theory of value of Karl Marx, which holds that the value of everything should be proportional to the human labor required to obtain it, means that natural ecosystems have no value. H.T. Odum left a large group of disciples who continue to apply and promote his methods. Mark Brown is prominent among these. Brown and Ulgiati 2004 review Odum's work. Hall 1995 provides an edited the volume presenting a wide variety of applications of

Odum's methods. Several of Odum's former students, such as Robert Costanza, have gone on to become important contributors to work on sustainability issues. Braat and Streetskamp 1991 apply Odum's methods at the regional level, and Braat 1995 at the global level.

Odum, H.T. 1971 *Environment, Power and Society*. Wiley, NY. 331 pp. ISBN: 0-471-65275-X.

This volume marks H.T. Odum's shift from studying natural ecosystems to applying his methodologies to human societies and the ecosystems in which human societies are embedded. The methodology involves extreme simplifications (what Odum calls "macroscopic minimodels") that make basic messages very clear. Such simplification has been criticized for leaving out so much of the complexity of real systems that the result becomes an expression of the modeler's impressions, often compared to an impressionist painting.

Odum, H.T. 1983 *Systems Ecology: An Introduction*. Wiley, NY. 644 pp. ISBN: 0-471-65277-6. [succeeded by *Ecological and General Systems*. University Press of Colorado, Boulder, CO. 644 pp. (1993; revised ed. 1994). ISBN-10: 087081320X ISBN-13: 978-0870813207]

This is H.T. Odum's textbook presenting his methodology and how to use it, with many examples.

Odum, H.T. 1988 Self organization, transformity, and information. *Science* 242: 1132-1139. https://doi.org/10.1126/science.242.4882.1132

H.T. Odum distinguishes different kinds of energy by introducing a new quantity, the "transformity" (energy of one type required per unit of another). Transformities are used as energy-scaling factors for the hierarchies found in ecosystems, including human economies embedded within them. They include both living organisms, nonliving components such as manufactured goods, and information. Resource contributions multiplied by their transformities are proposed as a value system for human service, environmental mitigation, foreign trade equity, public policy alternatives, and economic vitality.

Braat, L.C. and I. Streetskamp. 1991. Ecological economic analysis for regional sustainable development. pp. 269-288. In: Costanza, R. (ed.). *Ecological Economics: The Science and Management of Sustainability*. Columbia University Press, New York. 525 pp. ISBN-10: 9780231075633 ISBN-13: 978-0231075633

This chapter examines sustainable development at the regional level, which is more complicated than at the global level because it is open system. H.T. Odum's methods are applied. Sustainable development at the regional level requires treatment as an open system.

Braat, L.C. 1995. Systems ecology and sustainable development: Links on two levels. Pp. 164-174. In: C.A.S. Hall (ed.) *Maximum Power: The Ideas and Applications*. University Press of Colorado, Boulder, CO. 393 pp. ISBN: 0-87081-362-5.

Bratt explains how Odum's methods can be applied to sustainable development at the global level, that is, as a closed or "semi-closed" system. Odum's traditional systems-ecology methods applied to the global system have results "quite similar" to those of the more complex models used by Meadows *et al*. 1972 in *Limits to Growth*. A new concept, the "resource regenerative system." is applied to the sustainable use of natural resources.

Brown, M.T. & S. Ulgiati. 2004 Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. *Ecological Modelling* 178(1–2): 201-213. https://doi.org/10.1016/j.ecolmodel.2004.03.002

This reviews H.T. Odum's later work in which embodied energy (emergy) is used to understand systems, particularly those that include humans.

Hall, C.A.S. (ed.). 1995. *Maximum Power: The Ideas and Applications*. University Press of Colorado, Boulder, CO. 393 pp. ISBN: 0-87081-362-5.

Most academics have students, H.T. Odum has disciples. These have promoted Odum's methodology around the world and applied it to many environmental problems. This is a collection of some of their writings.

Entropy

Nicholas Georgescu-Roegen (1906-1994) considered sustainable development to be "snake oil," but is work has been fundamental as an underpinning for this concept. He focused on energy, particularly the second law of thermodynamics that holds that energy is dissipated in the form of entropy at each transformation, and that this ultimately leads to degradation of natural resources by human activities. He also created what is often called the "fourth law of thermodynamics," namely that matter is also needed for all energy transformations, and that matter also is degraded and is lost from the perspective of human economies. Georgescu-Roegen 1971 explains the fundamental importance of entropy in economic systems. The edited volume by Daly1997 offers a series of applications and a review of Georgescu-Roegen's contributions to ecological economics.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Progress*. Harvard University Press, Cambridge, MA. 457 pp. ISBN 9780674281653

Georgescu-Roegen explains the importance of the laws of thermodynamics and criticizes traditional economics for its assumptions of infinite substitutability of different resources. He also criticizes traditional economics for its assumption of unlimited growth of material consumption, and inaugurated the concept of “de-growth.”

Daly, H.E. (ed.). 1997 *The Contribution of Nicholas Georgescu-Roegen[https://www.sciencedirect.com/journal/ecological-economics/vol/22/issue/3]*. *Ecological Economics*, 22(3): 171-312. [special issue].

Herman Daly, who was a student of Nicholas Georgescu-Roegen, organized this special issue of the journal *Ecological Economics* to host a debate between ecological economists and some of the traditional economists that Georgescu-Roegen (and also Daly) had criticized.

Resilience and Sustainability

The term “Resilience” has been used in two ways: one referring to the speed with which a system returns to the previous equilibrium following a disturbance, and the other referring to the magnitude of disturbance needed for the system to shift to a different equilibrium. As Arrow *et al.* 1995, who use the second of these definitions, have pointed out, economic activities are sustainable only if the life-support ecosystems on which they depend are resilient. Resilience was identified by Levin *et al.* 1998 as the best way to approach sustainable development. Work on resilience owes a great debt to the efforts of C.S. Holling, who was instrumental in founding the Resilience Alliance and the journal *Ecology and Society* . Walker *et al*. 2004 explain four components of resilience: “latitude, resistance, precariousness, and panarchy.” “Adaptability,” which is the “capacity of actors in the system to influence resilience” means that sustainability studies need to change their focus from seeking optimal states and the determinants of maximum sustainable yield to “resilience analysis, adaptive resource management, and adaptive governance.” Pimm 1984 defines resilience as the time for a perturbed ecosystem to return its original state. .As Perrings 1998 points out, this definition refers to the properties of the system near some stable equilibrium (i.e. in the neighborhood of a stable focus or node), whereas others, such as Holling 1973, use “resilience” to refer to how much perturbation the system can withstand before shifting to a different equilibrium state.

Perrings, C. (ed.). 2006. *Resilience and sustainable development[https://www.cambridge.org/core/journals/environment-and-development-economics/issue/E1D4444EFD7589A7BB232B357024BDDD]*. *Environment and Development Economics* 11(4): 411–551. [special issue].

This special issue treats “resilience” in both of its definitions: the speed of return to equilibrium following perturbation (Pimm, 1984), and the size of a disturbance needed to dislodge a system from its stability domain (Holling, 1973). In addition to an important opening article on “Resilience and sustainable development” by editor Charles Perrings, the special issue contains papers on resilience of agricultural systems, pest control, soil conservation, pollution thresholds, landholding fragmentation, and the diversity of firm sizes.

Holling, C.S. 1973. *Resilience and stability of ecological systems[https://www.annualreviews.org/doi/abs/10.1146/annurev.es.04.110173.000245]*. *Annual Review of Ecology and Systematics* 4: 1-24.

This is the classic review of resilience and stability.

Gunderson, L. and Holling, C. (eds.) 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, Washington, DC. 536 pp. ISBN-13: 978-1559638579 ISBN-10: 1559638575

This edited volume by participants in the Resilience Alliance explores the importance of "Panarchy" which refers to the structure in which systems are interlinked. It is sometimes portrayed through the metaphor of a stability landscape.

Walker, B., C.S. Holling, S.R. Carpenter and A. Kinzig 2004,* Resilience, adaptability and transformability in social–ecological systems[http://www.ecologyandsociety.org/vol9/iss2/art5/]*. *Ecology and Society* 9(2): 5.

This paper traces the evolution of the concept of resilience since C.S. Holling's 1973 seminal paper. The paper discusses social–ecological systems in terms of three key attributes: resilience, adaptability, and transformability. Resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks."

Carpenter, S.R., B.H. Walker, J.M. Anderies, and N. Abel 2001. From metaphor to measurement: resilience of what to what? *Ecosystems* 4: 765–781. https://doi.org/10.1007/s10021-001-0045-9

This paper considers resilience of socioecological systems and the different characteristics that contribute to it. These include abilities of a system to remain in a given "domain of attraction" in the face of slowly changing variables, the ability to self-organize, and the ability to evolve or learn.

Perrings, C. 1998. Resilience in the dynamics of economy-environment systems. *Environmental and Resource Economics* 11(3-4): 503–520. https://doi.org/10.1023/A:1008255614276

This paper examines linkages between resilience and the stability of dynamical systems, particularly linkages between resilience, biodiversity and the sustainability of alternative states. The authors suggest using a Markov process for analyzing change in the system, as the transition probabilities between states offer a natural measure of resilience.

Pimm, S.L. 1984. The complexity and stability of ecosystems. *Nature* 307: 321–326. https://doi.org/10.1038/307321a0

The relation of ecosystem complexity to stability has long been a subject of debate in ecology. Stuart Pimm relates this to resilience. Pimm's definition of "resilience" is different from that of other authors. He considers resilience to be measured by the time it takes for an ecosystem to return to the state from which it was perturbed.

Levin, S.A., S. Barrett, S. Aniyar, W. Baumol, C. Bliss, B. Bolin, P. Dasgupta, P. Ehrlich, C. Folke, I-M Gren, C.S. Holling, A.-M. Jansson, B.-O. Jansson, D. Martin, K.-G. Mäler, C. Perrings, and E. Sheshinsky. 1998. *Resilience in natural and socioeconomic systems[https://www.cambridge.org/core/journals/environment-and-development-economics/article/resilience-in-natural-and-socioeconomic-systems/AC6374D11513248CC521C3FAC3E5E1E4#fndtn-information]*. *Environment and Development Economics* 3(2): 221-262.

This paper explains resilience and proposes it as the best way to approach sustainable development. The paper considers sustainability to be most relevant to stochastic rather than the deterministic systems that dominate economic analyses. Economists usually consider sustainability as achieved in an equilibrium state in a deterministic system. Levin *et al*. consider sustainability is instead best measured by system resilience either at or away from the equilibrium state.

Berkes, F., Folke, C. and Colding, J. (eds.) 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience.* Cambridge University Press, Cambridge, UK. 476 pp. ISBN: 0521785626, 9780521785624

This edited volume presents 12 case studies showing how resilient ecosystems are linked to people and technology, local ecological knowledge, and property rights. Lessons are drawn from the case studies for how to better manage socio-ecological systems for resilience.

Gunderson, L.H. and C.S. Holling (eds). 2002. *Panarchy: Understanding Transformations in Systems of Humans and Nature*, Island Press, Washington D.C. 536 pp. ISBN-13: 978-1559638579 ISBN-10: 1559638575

"Panarchy" refers to the structure in which systems are interlinked. These systems include both "natural" ecosystems and those dominated by humans. The interlinked systems encompass a wide range of scales both in time and in space, and they are characterized by continual cycles of growth, restructuring, and renewal. Study of these cycles can reveal the points at which a system can change to increase resilience and sustainability.

Natural Capital and Sustainable Development

The field of economics normally deals only with money and with “built” infrastructure implanted by humans. However, the natural components such as forests, rivers and oceans are essential parts of the socio-ecological systems that include the human population and that must be sustained. The term “capital” in economics traditionally refers to stocks that are “produced” (manufactured) and serve as a means of production. As explained by Costanza and Daly 1992, in more general terms, “capital” means "a stock that yields a flow of valuable goods or services into the future." “Natural capital” means that the stock has come from nature rather than manufacture, and is divided into two types: renewable or active natural capital and nonrenewable or inactive natural capital. Examples of renewable natural capital would include a population of trees in a forest that yields a flow of timber or a population of fish in the ocean that yields a flow of seafood. Ecosystems are renewable natural capital and produce “regulating” ecosystem services such as preventing soil erosion, pollinating flowering plants and maintaining climate stability. Examples of nonrenewable natural capital would include deposits of fossil fuels or minerals. Costanza and Daly 1992 emphasize the "constancy of total natural capital" rule and distinguish between “growth” (material increase in size) and “development” (improvement in organization without size change), and make clear that there is no such thing as sustainable growth, but there can be sustainable development. They also discuss methodological issues concerning the degree of substitutability of manufactured for natural capital, quantifying ecosystem services and natural capital, and the role of the discount rate in valuing natural capital.

Costanza, R. and Daly, H. 1992. Natural capital and sustainable development. *Conservation Biology* 6(1): 37-46. https://doi.org/10.1046/j.1523-1739.1992.610037.x

This paper provides a good explanation of natural capital and its relation to sustainable development. If natural capital is depleted, the risk of losing the benefits it produces for humans increases. Therefore “maintaining natural capital stocks is a prudent and achievable policy for insuring sustainable development.”

Pearce, D. W. and Atkinson, G. 1993 Capital theory and the measurement of sustainable development: An indicator of “weak’’ sustainability. *Ecological Economics* 8(2): 103-108. https://doi.org/10.1016/0921-8009(93)90039-9

This develops the idea that a minimum criterion for “weak” sustainability is that the level of overall capital stock should be non-decreasing. Overall capital stock includes both natural and manufactured capital. A country’s economy is “sustainable” if it saves more than the depreciation of its man-made and natural capital. Eight countries ranked. “Sustainable” countries are almost all industrialized, “unsustainable” ones are all developing, and two are “marginally sustainable”: Mexico and the Philippines.

Prugh, T., H. Daly, R. Goodland, J.H. Cumberland and R.B. Norgaard. 1999. *Natural Capital and Human Economic Survival*, Second Edition. Lewis Publishers, Boca Raton, Florida. 208 pp. ISBN: 1-56670-398-0

This book critiques conventional economics from the standpoint of ecological economics. The book explains natural capital and how it is being degraded by humans. Policy options are offered such as green taxes, and suggestions are made for personal action.

Sustainable Development and the Commons

Few have provoked such long and impassioned controversy as Garett Hardin (1915-2003) did with his "tragedy of the commons" paper. Hardin 1968 draws an analogy between a "commons" for grazing sheep – a long tradition in the British Isles – where villagers can graze their sheep in a pasture that is shared by all. The outcome, according to the parable, is that each individual will continue to add sheep to the pasture even though this degrades the resource to the eventual ruin of all. This is because all of the benefit of each sheep that is added accrues to its owner, whereas the loss by reducing the productivity of the overgrazed pasture is spread among all. Hardin's use of the term "commons" has often been criticized because the salient aspect is that of "open access," not the distinction between joint and individual control. Resources held in common can be managed sustainably, as shown by Elinor Ostrom 1990. Elinor Ostrom (1933-2012) winning the Nobel Prize in economics in 2009 was a landmark, not only as the first woman to win this prize in economics but also in showing recognition of the social issues underlying sustainability.

Hardin, G. 1968. The tragedy of the commons. *Science* 162: 1243-1248. https://doi.org/10.1126/science.162.3859.1243

This is the classic paper initiating the "The tragedy of the commons" debate. Hardin used the commons parable to argue for controlling human population growth, but the pernicious effect of individual gain versus diffuse impacts is shared by many other issues underlying sustainable development.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge, UK. 180 pp. ISBN 0 521405998

Ostrom's work on the commons shows that collective management can produce sustainable outcomes, provided that institutional and customary arrangements prevent the proverbial individual-level struggle. Her examples show that resources such as fisheries, forests and water for irrigation can be managed by the individuals who use the resources without the disastrous outcome of the "tragedy of the commons."

Sustainable Development and the Value of Human Life

Perhaps the most explosive subject in debates over sustainable development is the value of human life. David Pearce, who was found by Quental and Lourenço 2012 to be the most highly cited individual author in the area of sustainable development, was engulfed by this controversy in the 1990s. As a result he even had to install an elaborate system of locks and security devices for his offices at University College London. Pearce was convening lead author of a chapter in the Working Group III volume of the 1996 second assessment report of the Intergovernmental Panel on Climate Change (IPCC) that calculated monetary values for the impacts of global warming. Pearce *et al*. 1996 included the value of lost human life in these calculations based on a scheme explained in Fankhauser 1995 that attributed a much higher value per life lost in rich countries than in poor countries. Fearnside 1998 was among those who condemned this as morally unacceptable, proposed an alternative dual accounting system with monetary losses being accounted separately from loss of human life, which would be accounted without monetary values and with all lives being considered equal. The question of loss of human life remains a delicate subject in decisions regarding development and, unfortunately, the most common response is simply to base decisions on monetary cost/benefit calculations that ignore this impact altogether.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Velinga, P. 1996. *The social costs of climate change: Greenhouse damage and the benefits of control[https://www.ipcc.ch/report/ipcc-second-assessment-full-report/]*. pp. 179– 224. In Bruce, J.P., Lee, H. and Haites, E.F. (eds.), Climate Change 1995: Economic and Social Dimensions – Contributions of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 448 pp. ISBN 0-521-56433-6

> This chapter in the Working Group III volume of the IPCC's Second Assessment Report was the source of intense controversy because it attributed monetary values to losses of human life, with much greater value being attributed to each life lost in developed countries than in poorer countries. Pearce *et al*. give 11 times more weight to each life lost in the Organization for Economic Cooperation and Development (OECD) countries as compared to the non-OECD [i.e., poor] countries.

Fankhauser, S. 1995. *Valuing Climate Change--The Economics of the Greenhouse*. EarthScan, London, U.K. 180 pp. ISBN 185383-237-5

> Samuel Fankhauser, a student of David Pearce, calculated that ".. For developed countries … a statistical life should not be valued at less than $700,000 and should plausibly be at least $1.5 m (Pearce *et al*., 1991). For developed regions we thus assume $1.5 m … $300,000 for middle income and $100,000 for low income countries…" (pp. 47-48). This controversial estimate was used in the chapter by Pearce *et al*. 1996 o in IPCC's Second Assessment Report.

Fearnside, P.M. 1998. The value of human life in global warming impacts. *Mitigation and Adaptation Strategies for Global Change* 3(1): 83-85. https://doi.org/10.1023/A:1009640412108

This paper contests the monetary valuation of human life in Fankhauser 1995 and Pearce *et al*. 1996. It proposes an alternative dual accounting system that considers all lost human lives as equal, and accounts for them separately from monetary cost calculations.

Sustainable Development and Equity

The question of equity is fundamental to discussions of sustainable development both in terms of the ways that development decisions distribute benefits and impacts between present and future generations (intergenerational equity) and how these effects are distributed among different groups today (infragenerational equity). Most of the scientific discussion has focused on intergenerational equity, and better addressing infragenerational equity is an urgent priority. Decisions intended to contribute to sustainable development can cause injustices by their lack of equity. For example, is it sustainable development if a project to mitigate global warming by planting trees results in expelling small farmers to make room for the plantations, or if forest wood is converted to charcoal to replace mineral coal in Brazil's iron and steel industry if this is done with child labor or with "labor equivalent to slavery"? Tropical hydroelectric dams, many of which are now receiving carbon credit under the Clean Development Mechanism, cause a vast array of highly inequitable social impacts. Most dramatic are dams built in one country to supply electricity to another. The question of equity is linked to the recognition of limits, such as that represented by human carrying capacity. It is easy to rationalize not dealing with inequities if one assumes that the material economy is a "pie" that is forever growing, and that maximizing this growth will have some benefits for all parts of society. By recognizing limits one also must face the question of how to divide the pie (see section on Human Carrying Capacity).

Fleurbaey M., S. Kartha, S. Bolwig, Y. L. Chee, Y. Chen, E. Corbera, F. Lecocq, W. Lutz, M. S. Muylaert, R. B. Norgaard, C. Okereke, and A. D. Sagar, 2014: Sustainable Development and Equity. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

This chapter from the IPCC Fifth Assessment Report (AR5) contains a good review of equity issues related to climate change and climate-change mitigation.

Pearce, D. 1988. Economics, equity and sustainable development. *Futures* 20(6): 598-605. https://doi.org/10.1016/0016-3287(88)90002-X

This paper discusses equity within a generation and equity between generations in the context of sustainable development.

Hartwick, J. 1977. Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review* 67(5): 972-974.

This paper discusses the question of how the present generation invests the money it earns from exhaustible resources. Theoretically, if the rents are invested in machines rather than in consumption, this will pass on an income stream to the next generation. As with most economic literature, this appears to assuming complete inter-convertibility among resources through the use of money. Available online by subscription[https://www.jstor.org/stable/1828079]*

Kojima, S. 2006. *Reconsideration of dynamic utility optimisation and intergenerational equity in sustainable development studies[http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.454.2653&rep=rep1&type=pdf#page=26]*. *International Journal of Ecological Economics & Statistics 6(F06): 26-36.*

This paper criticizes traditional dynamic utility optimization models used in economic on the basis of their assumptions about intergenerational equity. The paper claims that “intergenerational equity in sustainable development is better represented as certain “survival conditions” rooted in physical facts instead of sustainability conditions based on value judgements. As one candidate of such survival conditions, an approach based on an ecological resilience concept is illustrated.”

Baer, P., J. Harte, B. Haya, A.V. Herzog, J. Holdren, N. E. Hultman, D.M. Kammen, R.B. Norgaard and L. Raymond. 2000. Equity and greenhouse gas responsibility. *Science* 289: 2287. https://doi.org/10.1126/science.289.5488.2287

Baer et al. argue that the allocation of greenhouse-gas emission quotas (i.e., “assigned amounts” under the Kyoto Protocol) among countries based on past emissions is unfair, and that the only ethically acceptable solution is equal per capita emissions rights,

Baer, P. 2002. *Equity, greenhouse gas emissions, and global common resources[https://epdf.tips/climate-change-policy-a-survey190d3d8174b4d14a9f2e6f478dc011a943483.html]*. pp. 393-408. In. S.H. Schneider, A. Rosencranz and J.O. Niles (eds.). Climate Change Policy: A Survey. Island Press, Washington, DC. 563 pp. ISBN 1-55963-880-X

This chapter reviews a series of issues in decisions about equity both from a political-science perspective and from an ethical perspective. These include burden sharing versus resource sharing, problems stemming from the nature of common resources, per-capita versus other allocations of emissions rights, historical accountability

Sustainable Development and the Value of Time

Time has value for reasons independent of any selfish interest on the part of the current generation. One is its link to the value of human life: delaying global warming by a given number of years, even though not permanent, saves lives over the period of the delay (and these lives represent permanent gains). The value of time is a critical factor in all decisions on development, including sustainable development. Time is normally given value in economic calculations by applying a discount rate that reduces the weight given to future costs and benefits by a fixed percentage each year. Howarth 2003 and Dasgupta 2008 explore the implications of discounting for sustainability. Fearnside 2002 presents alternative ways of giving weight to time preference, and Fearnside 1997 shows how time preference is determinant in the global-warming impact attributed to electricity generation choices. Both weighting for time preference, as by a discount rate, and the time horizon taken into consideration are critical. Although sustainable development obviously requires considering the long term, including future generations, the consequences of ignoring the short term are serious. For example, if global temperatures are allowed to continue rising over the coming decades, “tipping points” will be crossed leading to disastrous loss of ecosystems and their services and to positive feedbacks that could push global warming beyond human control, causing a “runaway greenhouse” or “hothouse Earth.” The “sustainable” aspect of sustainable development means that the long term must be considered because long time horizons allow visualization of whether the Earth system and its human component are stable, or whether they face collapse. The 200-year time horizon used by Meadows *et al*. 1972 in the *Limits to Growth* study is an example. Focus on time horizons in this range is a healthy anecdote to the prevailing focus on the few years of an election cycle or of most business plans. Long time horizons and choices on the value attributed to time (as through a discount rate) are also critical to sustainable management of renewable resources, such as ocean fisheries and tropical forests (see the section on “Impediments to sustainable development”). Unfortunately, decisions on time are not simple, either with respect to the length of the time horizon to be considered or any weighting for the value of time to be applied over the course of that time horizon (as through a discount rate). It is easy to get lost in philosophical meanderings about the far-distant future to the detriment of solving problems that are close at hand. Heal 2000 has explored the implications to time horizons for sustainability. Fearnside 2012 has reviewed controversies over choices for mitigating global warming that are heavily influenced by the value attributed to time. Kirschbaum 2006 presents arguments for giving equal weight over an infinite time horizon. This is contested by Fearnside (2008) and by Dornburg and Marland 2008.

Fearnside, P.M. 1997. Greenhouse-gas emissions from Amazonian hydroelectric reservoirs: The example of Brazil's Tucuruí Dam as compared to fossil fuel alternatives. *Environmental Conservation* 24(1): 64-75. https://doi.org/10.1017/S0376892997000118

Tropical dams produce a large emission in the first few years, followed by a much lower emission in subsequent years, whereas thermoelectric power produces emissions at a constant rate. Dams release methane whereas fossil fuels produce almost only carbon dioxide. Valuing time weighs heavily against tropical dams as mitigation. The figures for hydroelectric emissions are out of date, but the logic of the comparison is still highly relevant.

Heal, G.M. 2000. *Valuing the Future: Economic Theory and Sustainability*. Columbia University Press, New York. 224 pp. ISBN: 9780231113076

This book explores the problem of valuing time, including the interpretation of time horizons. Heal tries to reconcile the perspective of economists, for whom thirty years is a long time with that of environmental scientists, who usually consider much longer time scales. A shorter working paper summarizing the book is available free *online[http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.199.8589&rep=rep1&type=pdf]*

Fearnside, P.M. 2002. Time preference in global warming calculations: A proposal for a unified index. *Ecological Economics* 41(1): 21-31. https://doi.org/10.1016/S0921-8009(02)00004-6

This paper discusses rationales for giving value to time and the impact of this on calculations of the global-warming impact of different mitigation choices. It proposes an alternative to discounting as one of the ways that could be used to incorporate this value into decision-making on climate.

Howarth, R. B., 2003. Discounting and sustainability: Towards reconciliation. *International Journal of Sustainable Development* 6(1): 87-97. https://doi.org/10.1504/IJSD.2003.004220

This paper examines the tension between discounting and sustainability and describes a rights-based ethical framework for decision-making. Howarth holds that the time preferences of the present generation are trumped by duties to posterity where discounting favors uncompensated depletion of resource stocks.

Kirschbaum, M.U.F. 2006, Temporary carbon sequestration cannot prevent climate change. *Mitigation and Adaptation Strategies for Global Change* 11(5-6), 1151-1164.

This paper presents the argument for not granting carbon credit for temporary sequestration. See replies by Dornburg and Marland 2008 and Fearnside 2008.

Dornburg V. and G. Marland. 2008. Temporary storage of carbon in the biosphere does have value for climate change mitigation: A response to the paper by Miko Kirschbaum. *Mitigation and Adaptation Strategies for Global Change* 13(3): 211-217. https://doi.org/10.1007/s11027-007-9113-6

This replies to the conclusion of Kirschbaum 2006 that temporary storage of carbon in the terrestrial biosphere ‘‘achieves effectively no climate-change mitigation.” Dornburg and Marland 2008 question Kirschbaum’s model and his definition of climate-change mitigation. Dornburg and Marland show that temporary sequestration of carbon reduces reduces impacts over the course of a 100-year time horizon.

Fearnside, P.M. 2008. On the value of temporary carbon: A comment on Kirschbaum. *Mitigation and Adaptation Stategies for Global Change* 13(3): 207-210. https://doi.org/10.1007/s11027-007-9112-7

Kirschbaum 2006 bases his argument on maximum temperatures at the very end of the 21st Century, dismissing consideration of any impacts before that time. Unfortunately, those earlier impacts are severe and give value to temporary carbon. We do not have the luxury of discarding part of our arsenal in fighting against climate change: we must both reduce fossil-fuel combustion and increase biosphere carbon stocks.

Dasgupta, P. 2008. Discounting climate change. *Journal of Risk and Uncertainty* 37: 141–169. https://doi.org/10.1007/s11166-008-9049-6

This paper examines the application of social discount rates to public policy. Dasgupta shows that these rates should not be derived from market rates of return on investment, but rather from forecasts and from concerns for contemporary and intergenerational equity. He also shows that ethical paradoxes arise if future uncertainties are large and suggests modeling approaches to address these problems.

Fearnside, P.M. 2012. Brazil's Amazon forest in mitigating global warming: Unresolved controversies. *Climate Policy* 12(1): 70-81. https://doi.org/10.1080/14693062.2011.581571

This paper explains controversies over avoiding deforestation through mechanisms such as REDD (Reducing Emissions from Deforestation and Degradation). The value of time is still an important part of these debates, although some of the underlying motivations have shifted since the 1997-2001 controversies over the Clean Development Mechanism.

Sustainable Development and Permanence

“Permanence” is the term used in discussions of mitigating climate change to indicate carbon that is held in pools that, at least theoretically, will be kept out of the atmosphere forever. Demands that mitigation efforts be restricted to those that can guarantee permanence have been a central point of controversy in debates over how to mitigate global warming, particularly the place of tropical forests in this debate. Fearnside 2001 reviews disagreements over this issue both between national governments and between environmental NGOs during the period between the signing of the Kyoto Protocol in December 1997 and the Bonn Agreement of June 2001, which excluded avoided tropical deforestation from receiving carbon credit under the Clean Development Mechanism. Permanence was a central part of arguments used for not allowing credit for avoiding deforestation, although the underlying reasons for opposition to this credit were unrelated to climate. Brazil’s diplomatic positions were guided by a belief that the countries of the world are continuously conspiring to take away Brazil’s sovereignty over its Amazon region, and that carbon credit is part of this plot. An argument used by Brazil to justify excluding forests was that some of the greenhouse gases that humans emit today will still be in the atmosphere 35,000 years in the future. Because there will be another ice age within this time period, the Amazon forest carbon stocks cannot be considered permanent. A similar rationale was employed by international environmental NGOs headquartered in Europe, for other non-climate reasons. For example, WWF argued that Amazon forest would be destroyed by droughts and fires stemming from climate change, and Greenpeace argued that only carbon sequestered for "geological" time periods has value. However, although temporary carbon sequestration has less value than permanent sequestration, temporary sequestration has significant climate benefit. Fearnside *et al*. 2000 proposed methods for accounting for this benefit. Fearnside 2002 proposed a 100-year horizon as a standard in order to eliminate the distortions from discourse based on infinite or very long horizons. However, since then it has become increasingly clear that catastrophic "tipping points" are likely to be crossed well before the end of a 100-year horizon, and that immediate measures therefore must have greater priority. For example, the 2018 IPCC special report on holding global temperature to a level 1.5°C above the pre-industrial average makes clear that this benchmark, as well as the "well below 2°C" limit of the Paris Agreement, will be passed in the coming decades. A 20-year time horizon (one of the options for greenhouse gas conversions in the IPCC's Fifth Assessment Report) would have a large effect on mitigation decisions, for example Fearnside 2015 shows how this greatly increases the impact attributed to tropical hydroelectric dams, which emit a large peak of methane in the first few years after reservoir filling.

Fearnside, P.M., D.A. Lashof & P. Moura-Costa. 2000. Accounting for time in mitigating global warming through land-use change and forestry. *Mitigation and Adaptation Strategies for Global Change* 5(3): 239-270. https://doi.org/10.1023/A:1009625122628

This paper explains two approaches to accounting for time in global warming mitigation. It shows how the benefits of temporary carbon sequestration in forests and in silvicultural plantations can have their benefits quantified and made comparable to permanent (or long-term) sequestration. Most criticism of crediting temporary carbon assumes that each ton of this carbon will have the same value as permanent sequestration, but this does not have to be the case: temporary sequestration can be a good deal for the climate with proper accounting.

Fearnside, P.M. 2001. Saving tropical forests as a global warming countermeasure: An issue that divides the environmental movement. *Ecological Economics* 39(2): 167-184. https://doi.org/10.1016/S0921-8009(01)00225-7

This paper explains the controversies over including avoided tropical deforestation in the Kyoto Protocol's Clean Development Mechanism. Many of the arguments used against including these forests were based on ignoring the value of time.

Fearnside, P.M. 2002. Why a 100-year time horizon should be used for global warming mitigation calculations. *Mitigation and Adaptation Strategies for Global Change* 7(1): 19-30. https://doi.org/10.1023/A:1015885027530

This paper proposes a 100-year time horizon for mitigation calculations and discusses distortions of the longer horizons. The proposal includes a mechanism for extending some weight to events beyond the end of the time horizon. Note that recent events make a 20-year horizon the appropriate one for staying within the limits of the Paris Agreement. We do not have 100 years to bring global warming under control (see: http://www.theglobalist.com/dams-climate-change-global-warming-brazil-paris-agreement/)

Fearnside, P.M. 2015. Emissions from tropical hydropower and the IPCC*. Environmental Science & Policy* 50: 225-239. https://doi.org/10.1016/j.envsci.2015.03.002

This paper explains how tropical dams have been treated within the Intergovernmental Panel on Climate Change (IPCC), revealing significant problems that have led to grossly understated emissions for this energy source, particularly in the tropics. Among the concerns are several regarding the value of time. One of these is the conversion used between methane and carbon-dioxide equivalents by means of the global warming potentials.

Sustainable Development and Uncertainty

Dealing with uncertainty is a critical part of decisions on sustainable development. Information is often highly uncertain, and the responses to this situation vary widely. One response is to simply ignore the information, often combined with insisting on an impossible complete “certainty” or “proof” (a common position among climate-change deniers). Another is to take measures based on the precautionary principle: if the information indicates possible catastrophic impacts it should be taken seriously until better information indicates otherwise. It is the magnitude of the impacts that determines the level of assurance that must be provided that the impacts will not happen. The amount of uncertainty that is demanded has a dramatic effect on decisions regarding mitigation of global warming. Because mitigation options that have a potentially very high reward (like a “jackpot” in gambling) also have outcomes with high uncertainty, these are eliminated of one insists on having a high level of certainty. Fearnside 1995 shows how avoiding tropical deforestation is such a high-risk, high-gain option. Fearnside 2000 argues that insisting on high certainty leads to opting for less risky choices, such as silvicultural plantations, but the expected climate benefit is much lower, that is the size of the reward multiplied by the probability of obtaining it, as in the “expected monetary value” in decision analysis. Moss and Schneider 2000 explain uncertainty as applied to the reports of the Intergovernmental Panel on Climate Change (IPCC), while Curry 2011 criticizes this approach. Schneider and Kuntz-Duriseti 2002 explain the importance of uncertainty for climate change policy. Fearnside 1997 discusses how uncertainty and risk affect limiting factors for human occupation of Amazonia, while Ludwig *et al*. 1993 discuss the implications of uncertainty for sustainable development using the example of ocean fisheries.

Moss RH and Schneider SH 2000 *Uncertainties in the IPCC TAR: recommendations to lead authors for more consistent assessment and reporting[http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.399.6290&rep=rep1&type=pdf]*. pp. 33–51. In: Pachauri R, Taniguchi T and Tanaka K (eds) *Guidance papers on the cross cutting issues of the third assessment report of the IPCC*. World Meteorological Organization, Geneva, Switzerland.

This guidance paper lays out the methods used by the Intergovernmental Panel on Climate Change (IPCC) to classify and express uncertainties. These have been used by the beginning with the 2001 Third Assessment Report.

Curry, J. 2011 Reasoning about climate uncertainty. *Climatic Change* 108: 723-732. https://doi.org/10.1007/s10584-011-0180-z

This article criticizes Moss and Schneider 2000 as oversimplified and argues for a “concerted effort” to generate alternative ways to address the problem based on evidence-based logical hierarchies.

Schneider, S.H. and K. Kuntz-Duriseti. 2002. *Uncertainty and Climate Change Policy[https://stephenschneider.stanford.edu/Publications/PDF_Papers/Ch02ClimatePolicy.pdf]*. pp. 53-87 In. S.H. Schneider, A. Rosencranz and J.O. Niles (eds.). Climate Change Policy: A Survey. Island Press, Washington, DC. 563 pp. ISBN 1-55963-880-X

This chapter provides a good review of uncertainty and its relation to climate-change mitigation policies. Particularly important is the treatment of climate “surprises,” which are defined by the IPCC as “rapid, nonlinear responses of the climatic system to anthropogenic forcing,” such as the collapse of the “conveyor” belt circulation in the North Atlantic Ocean or rapid deglaciation of polar ice sheets.

Fearnside, P.M. 1997. *Limiting factors for development of agriculture and ranching in Brazilian Amazonia[http://philip.inpa.gov.br/publ_livres/1997/Limiting%20Factors.pdf]*. *Revista Brasileira de Biologia* 57(4): 531-549.

This paper explains the relation between the magnitude of potential impacts and the amount of certainty needed to assure that they do not occur. Deforestation in Brazilian Amazonia provides a good example of this because continued deforestation could cross a ‘tipping point” leading to catastrophic consequences, which makes defining the limits to allowable additional deforestation an urgent matter.

Fearnside, P.M. 1995. Global warming response options in Brazil's forest sector: Comparison of project-level costs and benefits. *Biomass and Bioenergy* 8(5): 309-322. https://doi.org/10.1016/0961-9534(95)00024-0

This paper provides illustrative calculations of the effect of uncertainty on choices of options for climate-change mitigation. The large payoff if avoided deforestation is successful gives this option a strong argument for priority. The paper also presents effects of what is now known as "leakage" (a term that was coined in 1996).

Fearnside, P.M. 2000. Uncertainty in land-use change and forestry sector mitigation options for global warming: Plantation silviculture versus avoided deforestation. *Biomass and Bioenergy* 18(6): 457-468. https://doi.org/10.1016/S0961-9534(00)00003-9

Insisting on high certainty for climate-change mitigation projects eliminates high-payoff options like avoided deforestation in favor of more certain by low reward options. The effect is similar to the dilemma of type I and type II certainty in statistics: by demanding very high type I certainty (i.e., a low "p" value), one can lose sight the most meaningful conclusions because of type II uncertainty.

Ludwig, D., R. Hilborn & C. Walters. 1993. Uncertainty, resource exploitation, and conservation: Lessons from history. *Science* 260: 17-36 https://doi.org/10.1126/science.260.5104.17

These authors argue that plans for sustainable development "reflect ignorance of the history of resource exploitation." The authors use examples from ocean fisheries to show the effect of uncertainty on achieving sustainable management of the resources. They show that sustainable solutions are ignored even when technical knowledge is more than sufficient. Decisions should take uncertainty into account through available quantitative techniques for decision-making under uncertainty, and, more generally, by application of common sense.

Applications of Sustainable Development

Three groups of applications of sustainable development are discussed: climate change, regional-level studies (using Amazonia as an example) and environmental & ecosystem services. Unless global warming and other drivers of climate change are contained, human wellbeing cannot be maintained, let alone improved (i.e., "development" will be reversed in many ways). In 2018 the Intergovernmental Panel on Climate Change (IPCC) produced a special report on the question of limiting mean global temperature to 1.5°C above the pre-industrial mean, and special attention was given to sustainable development and to the consequences of mean global temperature at the 1.5°C level and also at the 2°C level. It should be remembered that the 2015 Paris Agreement commits almost all of the countries of the world to prevent global mean temperature from passing an unspecified limit "well below" the 2°C level, and to "pursue efforts" to limit warming to 1.5°C. "Climate action" is one of the UN's sustainable development goals (SDG No. 13), and it underlies many of the other goals. In addition to consideration of sustainable development at the global level, regional-level discussions are essential. These better reflect the problems in each part of the world. Here, Amazonia will be taken as an example of this literature. Amazonia has as its dominant feature the Amazon forest, which has an outsized role in supplying environmental services not only to the region itself but also to other parts of South America and globally. Ecosystems, whether or not they or "natural" or modified by humans, provide a wide array of services that are essential to humans. Some of these are in the form of products (such as timber or fish) that are extracted by humans and marketed in the existing monetary economy. These are known as "provisioning services." Other essential services are not yet included in the market economy, such as the climate regulating roles of tropical forests in storing carbon (thus avoiding global warming) and in recycling water (a role that, in the case of the Amazon forest supplies rainfall to southern Brazil, Argentina and other countries). Hydrological functions of forests avoid flooding and associated damage. Biodiversity has many values for humans, some utilitarian (such as serving as a source of information for medicinal compounds and providing pollination for neighboring agricultural crops) and some are non-utilitarian "existence" values.

Sustainable Development and Climate Change

One of the most universal challenges to sustainable development is climatic change, and there will be no sustainable development unless climate change is contained. Sixteen-year-old Swedish climate activist Greta Thunberg said it best on May 28, 2019 at the Austrian World Summit when she accused world leaders of "stealing our future and selling it for profit." Allen *et al*. 2018 provide an excellent review of the relation of climate to sustainable development. Von Stechow 2015 explore the sustainable development goal on climate-change mitigation (SDG 13), while Wright 2015 point out barriers that are preventing many of the SDGs from being achieved. Kelman 2017 and Gomez-Echeverri 2018 link SDG 13 to other SDGs and to international agreements. Finally, Maupin 2017 shows how climate mitigation in Africa offers concrete opportunities for synergies among the SDGs.

Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfeld, 2018: *Framing and Context[https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter1_Low_Res.pdf]*. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

This chapter in the IPCC special report on 1.5°C contains a good review of the relation of climate to sustainable development.

von Stechow, C., D. McCollum, K. Riahi, J.C. Minx, E. Kriegler, D.P. van Vuuren, J. Jewell, C. Robledo-Abad, E. Hertwich, M. Tavoni, S. Mirasgedis, O. Lah, J. Roy, Y. Mulugetta, N.K. Dubash, J. Bollen, D. Ürge-Vorsatz, and O. Edenhofer, 2015. Integrating global climate change mitigation goals with other sustainability objectives: A synthesis. *Annual Review of Environment and Resources* 40(1): 363–394. https://doi.org/10.1146/annurev-environ-021113-095626.

This review discusses the relation to the climate-change mitigation goals (SDG 13) and other goals such as human health and energy security. Energy demand reductions are considered to be particularly important for "realizing synergies across multiple sustainability objectives."

Wright, H., S. Huq, and J. Reeves, 2015: *Impact of climate change on least developed countries: are the SDGs possible?[http://pubs.iied.org/pdfs/17298IIED.pdf]* IIED Briefing May 2015, International Institute for Environment and Development (IIED), London, UK, 4 pp.

This short "briefing" explains how expected climate change will prevent many of the Sustainable Development Goals (SDGs) from being achieved in the Least Developed Countries (LDCs).

Kelman, I. 2017. Linking disaster risk reduction, climate change, and the sustainable development goals. *Disaster Prevention and Management* 26(3): 254–258, https://doi.org/10.1108/dpm-02-2017-0043.

This paper proposes ways to link sustainable development goals to three international agreements, including the Paris Agreement. The author advocates climate being considered inside the wider disaster-reduction framework.

Maupin, A. 2017. The SDG13 to combat climate change: An opportunity for Africa to become a trailblazer? *African Geographical Review* 36(2): 131–145. https://doi.org/10.1080/19376812.2016.1171156

This paper presents opportunities for climate-change mitigation in Africa that could make key contributions to achieving Sustainable Development Goal No. 13 (combat climate change).

Gomez-Echeverri, L. 2018. Climate and development: Enhancing impact through stronger linkages in the implementation of the Paris Agreement and the Sustainable Development Goals (SDGs). *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 3762119 https://doi.org/10.1098/rsta.2016.0444

This paper discusses the connections between two important agreements that were concluded in 2015: the Agenda for Sustainable Development or Sustainable Development Goals (SDGs) and the

Paris Agreement on climate change. The paper argues for a need for stronger linkages between the two agreements and suggests ways to maintain global temperatures below the limits agreed in Paris.

Regional-Level Studies: The Example of Amazonia

Global-level discussions of sustainable development are often so general that they lack connection to problems at the level at which decisions are made, namely by governments. Regional-level studies therefore have an important role in filling this gap. Here Brazil's Amazon region is taken as an example. The volume edited by Anthony Hall 2000 presents a range of threats to sustainability in Amazonia, while Philip Fearnside and Adriano Figueiredo 2016 consider a threat that has been rapidly increasing in recent years, namely China's influence on deforestation. The volume edited by Miguel Clüsener-Godt and Ignacy Sachs 1995 presents a series of sustainable development initiatives in Amazonia, while the one edited by Clóvis Cavalcanti 2000 addresses sustainable development and public policies, including those for environmental services.

Hall, A. (ed.) 2000 *Amazonia at the Crossroads: The Challenge of Sustainable Development*. Institute of Latin American Studies (ILAS), University of London, London, U.K. 257 pp.

This edited volume presents chapters on threats to sustainability in Amazonia and on proposals to counter these threats, including payments for environmental services.

Clüsener-Godt, M. & I. Sachs (eds.) 1995. *Brazilian Perspectives on Sustainable Development of the Amazon Region*. UNESCO, Paris, and Parthenon Publishing Group, Carnforth, U.K. 311 pp. ISBN: 1-85070-576-3

This edited volume presents chapters on sustainable development initiatives in Amazonia, such as extractive reserves for collection of non-timber forest products. The volume discusses Amazonia's role in climate and hydrology as related to strategies for "ecodevelopment," as long advocated by Ignacy Sachs.

Fearnside, P.M. & A.M.R. Figueiredo. 2016. *China's influence on deforestation in Brazilian Amazonia: A growing force in the state of Mato Grosso[http://www.anthempress.com/china-and-sustainable-development-in-latin-america-hb]*. pp. 229-265. In: R. Ray, K. Gallagher, A. López & C. Sanborn (eds.) *China and Sustainable Development in Latin America: The Social and Environmental Dimension.* Anthem Press, New York, USA. 367 pp. ISBN 978-1-78308-613-9.

The volume edited by Rebecca Ray and collaborators shows that China's influence through commodity purchases and through investments (including infrastructure) is a significant threat to sustainable development throughout Latin America. This chapter on the effect on deforestation in Brazil is part of this pattern.

Cavalcanti, C. (ed.) 2000. *The Environment, Sustainable Development and Public Policies: Sustainability in Brazil*. Edward Elgar, Cheltenham, U.K. 219 pp.

This edited volume presents chapters on a wide variety of issues affecting sustainable development in Brazil, including Amazon deforestation and the question of how environmental services can have a role in containing this process.

Environmental Services & Ecosystem Services

The terminology applied to environmental and ecosystem services is nothing if not confused and contradictory. Different authors have used these terms in different ways, and one would be wise to always provide a clear definition of what is meant when using the terms. The term "environmental services" has been used since the 1940s and is widely used in Latin America, for example by the Payment for Environmental Services program in Costa Rica. "Ecosystem services" is the term used by the 2004 Millennium Ecosystem Assessment. One distinction often made is inclusion of the "provisioning services" (such as providing timber, fish and other marketable products from natural ecosystems) as part of "ecosystem services," but not "environmental services." In some cases a distinction is in the intended use of the numbers calculated for the value of these services. For example, Costanza *et al*. 1997 calculated a monetary value for the world's ecosystem services that is far greater than all of the money in human society's monetary economy. The calculated values provide an illustration of the importance of maintaining the ecosystems that provide these services, but clearly do not carry the expectation that anyone will actually pay these amounts through any form of monetary transfer. In contrast, the proposal by Fearnside 1997 for "environmental services as a strategy for sustainable development in rural Amazonia" calculates values to be actually paid. However, these distinctions vary greatly in the literature, and there are an increasing number of projects and programs throughout the world both for "payment for environmental services" and for "payment for ecosystem services." The role of biodiversity as a provider of ecosystem services is a major theme in the classic volume edited by Gretchen Daly 1997. Fearnside 1999 discusses the potential and limits of biodiversity as a motivator for monetary flows to pay for Amazonia's role in providing these services. Fearnside 2008 discusses progress towards the recognition and compensation of Amazonia's environmental services and concludes that those related to carbon stocks and water recycling are closer to playing significant economic roles than are the region's equally important roles in maintaining biodiversity. Fearnside 2012 reviews the "theoretical battlefield" of controversies over how the magnitudes of environmental services are calculated, decisions on which have a greater impact on the resulting values than do uncertainties stemming from measurement data.

Daily, G.C. (ed.). 1997 *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC. 392 pp. ISBN 1-55963-475-8

Gretchen C. Daily’s edited volume was a landmark in sparking interest in ecosystem services, particularly those related to biodiversity.

Costanza, R., R. d' Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, M. van den Belt, 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260. https://doi.org/10.1038/387253a0

This paper by Robert Costanza and collaborators has been cited over 20,000 times. It explains the Earth’s ecosystem services in a broad sense, considering the current economic value of 17 ecosystem services for 16 biomes. The value of these services from the entire biosphere is calculated to average US$33 trillion per year, or almost double the total global gross national product of US$18 trillion per year.

Fearnside, P. M. 1997. Environmental services as a strategy for sustainable development in rural Amazonia. *Ecological Economics* 20.1: 53–70. [https://doi.org/10.1016/S0921-8009(96)00066-3][class:journalArticle]

Amazonian forests provide services in avoiding global warming, recycling water (water vapor transport from Amazonia is essential for rainfall in other parts of Brazil as well as in the Amazon region) and maintaining biodiversity. These services have much greater value than deforestation.

Fearnside, P. M. 1999. Biodiversity as an environmental service in Brazil’s Amazonian forests: Risks, value and conservation. *Environmental Conservation* 26.4: 305–321. [https://doi.org/10.1017/S0376892999000429][class:journalArticle]

The different values and uses of Amazonian biodiversity are discussed and their prospects for providing monetary flows that could counter the current financial incentives favoring deforestation. The prospects of significant flows from biodiversity on the time scale needed are much less than in the case of the forest’s environmental services in avoiding climate change. Available in Portuguese *online[http://philip.inpa.gov.br/publ_livres/2003/livro%20Floresta%20amazonica%20nas%20mudancas%20globais%202ED%20MIOLO%20web.pdf]*.

Fearnside, P. M. 2008. Amazon forest maintenance as a source of environmental services. *Anais da Academia Brasileira de Ciências* 80.1: 101–114. [https://doi.org/10.1590/S0001-37652008000100006][class:journalArticle]

Environmental services of Amazonia are reviewed together with progress in their quantification and transformation into an alternative basis for sustaining rural population and forest. Unresolved issues include accounting procedures, quantification of the benefits of different policy options, and the use of the funds generated from the services.

Fearnside, P. M. 2012. The theoretical battlefield: Accounting for the climate benefits of maintaining Brazil's Amazon forest. *Carbon Management* 3.2: 145–148. [https://doi.org/10.4155/CMT.12.9][class:journalArticle]

Reviews a series of outstanding issues in how climate benefits are counted in proposed mechanisms, such as REDD, to reward avoided deforestation. Especially important is the question of the value attributed to time in the calculations. These issues must be faced if the environmental services of Amazon forest are to provide an alternative form of development for the region's rural population.

Impediments to Sustainable Development

Sustainable development faces an imposing list of impediments. These include logical contradictions that impede important components of many sustainable-development plans, such as "sustainable" management of forests for timber. Colin Clark 1973 is the classic paper on the contradiction between biological growth rates of renewable natural resources such as fish or trees and the rates of financial rewards available from competing economic activities. Even though resources could be managed sustainably, it is more profitable to destroy them as quickly as possible and invest the returns in some other activity elsewhere. Clark 1990 develops the mathematics of this more fully. This contradiction means that supposedly "sustainable" management of Amazonian forest for timber ends in abandonment of the system despite any number of promises and policies. Fearnside 1989 proposed using the value of the forest's environmental services as a means of changing the financial incentives to make these systems sustainable. Other barriers to sustainable uses include organizational factors, such as the open access exploitation that is popularly (but inaccurately) known as the "tragedy of the commons." A wide variety of political circumstances also act as impediments to sustainable development. Fearnside 2018 reviews these impediments in Brazilian Amazonia.

Clark, C.B. 1973. The economics of overexploitation. *Science* 181: 630-634. https://doi.org/10.1126/science.181.4100.630

This is an absolutely classic work. The subtitle of the paper is "Severe depletion of renewable resources may result from high discount rates used by private exploiters." This explains why those who destroy tropical forests or the world's wild populations of fish or whales are not "short sighted," but instead are acting in a completely logical way from the standpoint of their own self-interest.

Fearnside, P.M. 1989. Forest management in Amazonia: The need for new criteria in evaluating development options. *Forest Ecology and Management* 27(1): 61-79. https://doi.org/10.1016/0378-1127(89)90083-2

This paper evolved from a conference presentation in 1985 that initiated discussion of environmental services in Amazonia. The discussion of environmental services has progressed considerably since, although much remains to be done before these services translate into significant financial flows. The

expansion of forest management has expanded greatly in Amazonia but has not faced the implications of the underlying contradiction and continues to be unsustainable in practice.

Clark, C.B. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources, 2nd ed.* Wiley, New York. 400 pp. ISBN-10: 0471508837 ISBN-13: 978-0471508830

This second edition of the book first published in 1976 presents great mathematical detail of modeling economic and biological aspects of renewable-resource management, especially the optimal use of resource stocks over time. It supports the conclusions in Clark's classic 1973 paper in *Science*.

Fearnside, P.M. 2018. Challenges for sustainable development in Brazilian Amazonia. *Sustainable Development* 26(2): 141-149. https://doi.org/10.1002/sd.1725 ISSN: 1099-1719

This paper discusses impediments that are preventing sustainable development in Brazilian Amazonia. Sustainable forms of development are inhibited by barriers such as a decision-making system with heavy influence (including corruption) from actors with interests in non-sustainable activities. These interests have driven a recent surge of legislative threats to environmental licensing. Various development paths are that would be more sustainable and better promote the wellbeing of local residents.