C H A P T E R 1

FROM MALTHUS TO SUSTAINABLE DEVELOPMENT

What do we mean by sustainability? First, we will talk about some ideas surrounding the issue articulated by various thinkers. Since a discussion of sustainability can cover a time span between now and kingdom come, we will keep our discussion within a realistic time frame. We will deal with the challenges of sustainable development, including environmental policy management and some social dimensions. And we will utilize some environmental economics, because economics is quite important in understanding some of the potentials and problems when we talk about sustainability and development.

Some Intellectual Underpinnings (and a Disclaimer)

In 1798, Thomas Malthus, an economist and a country pastor in England, wrote *An Essay on the Principle of Population*, revised in 1803 as *An Essay on the Principle of Population; or, a View of its past and present Effects on Human Happiness; with an Inquiry into our Prospects respecting the Removal or Mitigation of the Evils which it occasions*. He believed that population was held in check by *"misery, vice, and moral restraint."* Malthus maintained that *"... population, when unchecked, increased in a geometrical ratio, and subsistence for man in an arithmetical ratio."*

The debate about Malthusian limits has raged over the centuries, with many critics asking how it became possible to have a six-fold increase in global population (from one to six billion) since 1798 and still be able to more or less feed the population. As recently as 1973 a renewed burst of Malthusianism was published by the Club of Rome in a book entitled *Limits to Growth*, by Donella Meadows et al. (1972). Most if not all of the Club of Rome's predictions for the next 30 years, from 1973 to 2003, were not borne out. Another leading Malthusian, Lester Brown, has over the years regaled us with many jeremiads of gloom and doom predicting dire consequences within the next few years, which never seem to be quite fulfilled, but which are plausible based upon projecting trends. An expert on crop production, Brown set up the prolific World Watch Institute in 1974, which has provided much-appreciated summaries of the global use of natural resources and the environment, usually accompanied by warnings of imminent collapse. Brown's annual *State of the World* series and the associated working papers have been important steps in the development of the concepts on sustainability. Despite their tone of immediate collapse, the Malthusians provided a useful reminder to society and governments that continued profligate consumption could sooner or later get us into trouble.

In addition to the well-founded evidence that we had, indeed, not run out of resources as the Malthus hypothesis predicted, there arose a school of thought referred to as the *cornucopians*. The group dismisses Malthus and sees instead an ever-increasing human population enjoying ever more benefits from the planet. In contrast to Malthus, Ester Boserup (1981) believed "*necessity is the mother of invention*," and asserted that the increase in population pressure acts as an incentive to developing new technology and producing more food. Her analysis concluded that population growth naturally leads to development, at which point population pressures would decline. Writers such as Julian Simon (1981) and Wilfred Beckerman (2003) also disagreed with Malthus. Simon saw a future limited only by human ingenuity, not by mundane issues such as food and energy consumption; Beckerman sees the future as not resource limited, but limited by humans' inability to get the economic institutions right. Even as long ago as 1848 Karl Marx saw ever-expanding consumption possibilities, based surprisingly upon the enterprise of the capitalists in promoting globalization. (This was pointed out by the major cornucopian, Herman Khan (1976), in his book, *The Next Two Hundred Years.*)

More recently there has been a series of important books promoting more nuanced views of the Malthus/Cornucopian debate. Bjørn Lomborg's *The Skeptical Environmentalist: Measuring the Real State of the World* in 2001 and Jared Diamond's 2005 *Collapse: How Societies Choose to Fail or Succeed* both in their own ways look carefully at ecosystems from a historical perspective and draw mixed conclusions with, in some cases, dire consequences for societies that misbehave environmentally and adaptive survival strategies in others. Both see social and political adaptability as the major difference between catastrophe and survival.

Despite more than a generation since the resurgence of Malthusian ideas, we still do not have a consensus as to how seriously impaired the world ecosystems are, or the potential for continued development for the growing population. The United Nations (UN) and its resource agencies, UNDP, UNESCO, UNFPA, WHO, WMO, UNIDO, and the global multinational funding agencies such as the World Bank, the Inter-American Development Bank, the Asian Development Bank, the African Development Bank, and the European Bank for Reconstruction and Development all report with reasonable frequency upon the status of the environment and the ecosystems in their areas of interest. The news from the agencies is typically mixed. The good news is that we can feed more than 6.5 billion people with enough food to keep them functioning each day of the year. The bad news is that we appear to be seriously compromising our life support systems to accomplish this.

This was borne out in a special series on the "State of the Planet" in November 2003 in *Science.* The authors looked selectively at air, fresh water, fisheries, food and soil, energy, biodiversity (including human species), and climate change. As the editor of the series, H. Jesse Smith (2003), said:

> *This collection of articles is offered in the spirit of "forewarned is forearmed," not "the sky is falling." Whether we find ourselves forearmed or under the fallen sky depends upon what we choose to do about these issues over the next generation.*

Who then is to be believed and what, if anything, should be done? The irony of the debate is that Malthus wrote his original essay to counteract what he thought to be dangerous ideas about human perfectibility being propounded at that time. Nowadays most Malthusians coat their recommendations and aspirations in terms of human perfectibility. (Gus Speth's 2004 book, *Red Sky at Night*, is an example of this hortatory style.) The debate still swirls around us. What should we attempt to do? Our goal is to avoid the major intellectual perils on both sides of the coin. We must look coldly and soberly on what we know and have experienced and what is predictable in the short run and then settle on the continuum between the two sides of the issue. Intuition, if nothing else, tells us that Malthus makes sense in the long run: we just cannot keep on expanding and using resources, because something will be exhausted in the end. But in the short run, we can rely on human ingenuity to get us through the next 30 or 50 years. After that, all bets are off. Our definition, therefore, of sustainability is time-bound to a couple of human generations. Along with the journal *Science*, we believe this is the most scientifically supportable position to take.

Why Sustainability?

Sustainability is the term chosen to bridge the gulf between development and environment. Originally it came from forestry, fisheries, and groundwater, which dealt with quantities such as "maximum sustainable cut," "maximum sustainable yield," and "maximum sustainable pumping rate." How many trees can we cut and still have forest growth? How many fish can we take and still have a fishery functioning at the end of the time period? How much ground water can we draw and still have a viable aquifer at the end of the pumping period? Even when these "maximums" are observed, the ecosystem itself is not necessarily sustainable, as these are just the components of the overall ecosystem. Furthermore, sustainability can often be achieved in the short run, but not necessarily in the long run.

The attempt now is to apply the concept of all aspects of development simultaneously. The problem is, we experience difficulties in defining sustainable development precisely or even defining it operationally.

The major discussion initiating sustainable development is found in the report of the World Commission on Environment and Development (WCED), a body created by the UN General Assembly in 1983. This Commission was headed by Gro Brundtland, then prime minister of Norway and later head of the World Health Organization. The Commission's 1987 report, often referred to as the Brundtland Commission Report, defined "sustainable development" as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."

How is sustainable development to be achieved? This question harkens back to the sustainable fishery concept. What is a sustainable fishery? Should we ask what number of whales is sustainable? Many think that having more whales is probably better than having fewer whales. And we do not really need to eat whale meat. We have domesticated animals that we could use for that purpose.

Robert Repetto focuses his discussion of sustainable development on "... increasing long-term wealth and well-being." In his 1986 book, *World Enough and Time*, Repetto wrote that "the core idea of sustainability is that current decisions should not impair the prospects for maintaining or improving future living standards. This implies that our economic systems should be managed so that we can live off the dividends of our resources." By "resources" Repetto includes natural and otherwise, considering both as an endowment fund. As he was connected at the time with the World Bank, it is understandable that Repetto's definition relies heavily on economic concepts.

Herman E. Daly, who was also with the World Bank, suggested an ethical concept. In 1987 he talked about requiring an "increase in moral knowledge or ethical capital for mankind."

John C.V. Pezzey, another former World Bank official, listed (Rogers et al. (1997) p. 44) 72 definitions of sustainable development, commencing as long ago as 1972. Mohan Munasinghe (1993) drew the "...distinction between 'survivability,' which requires welfare to be above a threshold in all periods, and 'sustainability,' which requires welfare to be non-decreasing in all time periods." Pezzey suggests that *survivability* means that you are always above some threshold at all points in time, whereas *sustainability* takes a sort of millennial view that things are getting better all the time in a monotonic way. Our sense of this definition is that survivability is what we may have in our future rather than sustainability.

In 1993, Mohan Munasinghe discussed (Rogers et al. (1997) p. 44) three approaches to sustainable development:

- economic – maximizing income while maintaining a constant or increasing stock of capital;
- ecological – maintaining resilience and robustness of biological and physical systems; and
- social-cultural – maintaining stability of social and cultural systems.

Munasinghe, an economist from the World Bank, offers a somewhat precise definition for his economic approach to sustainable development. However, his discussion of ecological approaches that maintain resilience and robustness of biological and physical systems does not tell us what resilience and robustness mean in biological systems. We have some notions of that, but we do not have good operational definitions. And then in the social-cultural domain, he calls for maintaining stability of social and cultural systems. While this is desirable, he is not clear; besides, how can one actually calculate such stability? We are left to wonder.

Nine Ways to Achieve Sustainability

In the 1997 book entitled *Measuring Environmental Quality in Asia*, by Peter P. Rogers, Kazi F. Jalal, et al., indicators for environmental development are discussed. Nine ways to achieve sustainability are described (Box 1-1).

Box 1-1. Nine Ways to Achieve Sustainability

- Leave everything in the pristine state, or return it to its pristine state.
- Develop so as to not overwhelm the carrying capacity of the system.
- Sustainability will take care of itself as economic growth proceeds (Kuznets).
- Polluter and victim can arrive at an efficient solution by themselves (Coase).
- Let the markets take care of it.
- Internalize the externalities.
- Let the national economic accounting systems reflect defensive expenditures.
- Reinvest rents for nonrenewable resources (weak and strong sustainability).
- Leave future generations the options or the capacity to be as well off as we are.

First, leave everything in a pristine state, or return it to its pristine state. While that sounds nice, it is not going to happen. Nobody is going to do that, not when people are living, because it would involve a tremendous amount of pain and anguish.

Second, develop so as not to overwhelm the carrying capacity of the system. Again, what is the carrying capacity of the globe? Does anybody want to hazard a guess in terms of the number of people that might constitute the carrying capacity of the globe? The current global population is estimated at 6.3 billion. Is the carrying capacity of the world 6.3 billion people? If the standard of living to be achieved is the equivalent of current United States (US) standards, the carrying capacity is probably about 1 billion, based on our indicators. A carrying capacity of 6.3 billion people is possible at some greatly reduced standard of living below the US standard, but certainly not at the US standard. Carrying capacity is a difficult concept to define. And if we decided that we have exceeded our carrying capacity, what should we do about it? That is another complex question.

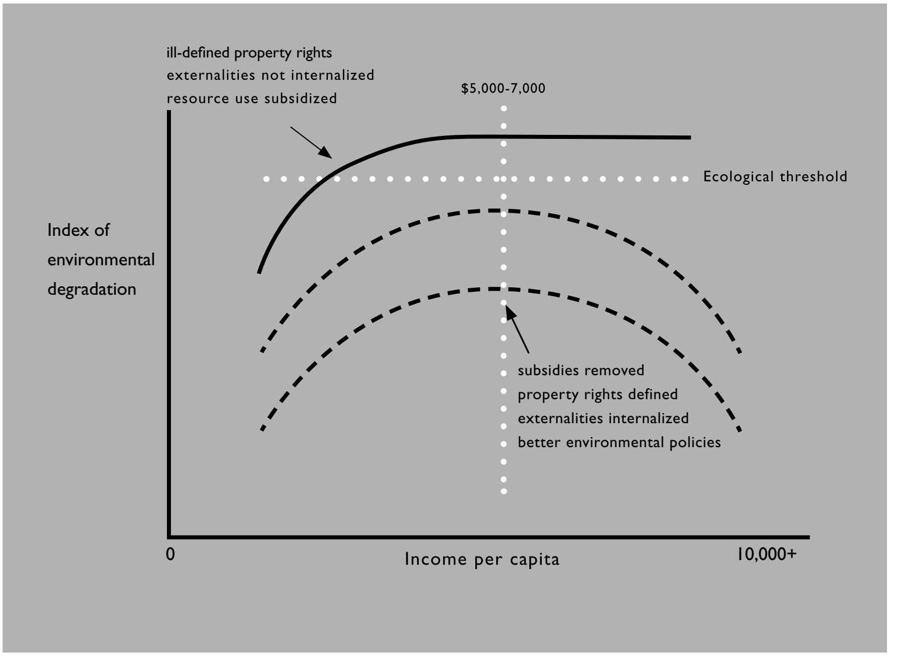
Third, sustainability will take care of itself as economic growth proceeds. This is sort of a cornucopian view and it is attributed to the economist Simon Kuznets, (ADB, *Emerging Asia* (1997), pp. 213-215), though he was already dead when the idea was attributed to him, so he could not complain about it. Basically his followers pointed out that as per capita income rises, people tend to take better care of the environment. When you are very poor, you are concerned about surviving and getting along at any cost. As you obtain more and more income, you can achieve environmental sustainability through the production of superior goods and services because you would then start to divert income to such purposes as air quality.

Consider the US in the 1960s, when the income per capita rose to about $6,000. Americans started to spend a lot of money on reducing the levels of air and water pollution. Despite current reports of gloom and doom in the newspapers, the ambient air quality in the US has greatly improved over what it was in the 1960s. That does not mean that it is perfect, but the US peaked on the parabolic curve relating environmental damage with per capita income, as Kuznets followers suggested (see Figure 1-1). The figure also suggests some arguments based upon property rights and ecological thresholds as to why and how the Kuznets hypothesis might work.

The implication of Kuznets' thinking is to develop as quickly as possible. We see this hypothesis at work in the People's Republic of China (PRC): develop quickly, as rapidly as possible, and the environment will take care of itself. However, those who have been to the PRC or India notice that the environment is not doing very well right now under this particular hypothesis, because the proponents would say, we will just wait a while, when the per capita income gets up to about $6,000, and then things will start to improve. The current per capita income in the PRC and India is probably about $3,000 to $4,000, so they have got quite a way to go before that would be possible. Meanwhile, we can expect a continuously deteriorating environment.

Fourth, Ronald Coase suggested that the polluter and the victim can arrive at an efficient solution by themselves. Under the Coase theorem (discussed in more detail in Chapter 10), everyone should get together and decide on an efficient level of pollution and on an efficient level of degradation of

Figure 1-1. Causes of Environmental Degradation



Source: Modified from T. Panayotou, ADB, *Emerging Asia* (1997), p. 213

the environment. Coase won a Nobel Prize in economics mainly for this particular theorem, which seems to work fairly well in small-scale situations. However, it is hard to imagine it working with a large number of people, because the transaction costs could be very high.

Fifth, let the markets take care of it. This is another economic solution. If one prices pollution and permits trading of pollution rights along with similar market operations, then sustainability can be achieved. Many people believe in this solution.

Sixth, internalize the externalities, which would provide an elegant solution. According to the 1997 Asian Development Bank (ADB) *Guidelines for the Economic Analysis of Projects* (1997), an "externality" is defined in part as the

> *[e]ffects of an economic activity not included in the project statement from the point of view of the main project participants, and therefore not included in the financial costs and revenues that accrue to them. Externalities represent part of the difference between private costs and benefits, and social costs and benefits.*

To internalize an externality, the ADB publication continues, "[e]xternalities should be quantified and valued, and included in the project statement for economic analysis." Of course it is a good thing to internalize the externalities, because people will then see in fact the real cost of activities, such as driving automobiles, and realize the damage caused by such activities. When we think of the cost of running an automobile, we think of the cost of gasoline at about $3 a gallon. But if we think about the environmental damage arising from the use of automobiles, it is equivalent to another $3 per gallon. Those of us who drive automobiles are taking a free ride on the environment for the equivalent of about $3 a gallon. We do not internalize these costs. If we were to internalize those externalities, then fewer people would use automobiles, or they would be driving much more fuel-efficient types of automobiles.

Seventh, perhaps we could have the national economic accounting system reflect defensive expenditures. This suggests that we worry about making sure that when we do our accounting, we do it correctly from the point of view of resource accounting. Most people probably do not realize that a good way of increasing gross domestic product (GDP) is to have lots of pollution and lots of sewage treatment plants, because GDP measures expenditures for all goods and services. This is why building more prisons with more prisoners is good for GDP; the same holds with building more schools. However, far more money is spent per prisoner than per student. But then more prisons means that GDP increases. Is this a real measure of what we want in terms of sustainability? Since prison expenditures are defensive expenditures, perhaps we should reflect such expenditures in some other way.

Eighth, reinvest the rents from nonrenewable resources (sometimes referred to as the Hartwick Rule, which is discussed more in Chapter 10.) Under this hypothesis, if we are using petroleum resources, then we should take the revenues resulting from such resources and invest them in some other way of dealing with the environment, for example, improving mobility, if use of gasoline is the issue. Some of the big oil companies are now using the profits from the oil to invest in a renewable resource such as solar technologies.

Ninth, leave future generations the options or the capacity to be as well off as we are, which comes from Robert Solow (1991). We are not quite sure how to do that. We keep on doing more of the same, although it is a truism, certainly in the western, industrialized nations, that generally each generation is better off than the last one. We are better off than our parents were, and so on. But whether we can continue with this progression, and how we can actually ensure it, is not obvious.

Sir John Hicks, an early twentieth-century English economist, defined income as "the maximum value that a person can consume in a period of time and still expect to be as well off at the end of the period as he was at the beginning." This has been redefined in the context of sustainable development as "sustainable social net product," which is a measure of a sustainable national income (see Box 1-2). Thus for a nation, sustainable social net product is the net national product (net national product equals GNP minus consumption of fixed capital) minus defensive expenditures to protect the environment minus the depreciation of natural capital. This means that we cannot chop down all the trees in the forest and count them as income, but that we can only use the amount of trees that are going to grow during the time period of such use.

Box 1-2. Sustainable Social Net Product

Sustainable social net product is based on Sir John Richard Hick's definition of income (i.e., maximum value that a person can consume in a period of time and still expect to be as well off at the end of the period as he was at the beginning) as net national product minus defensive expenditures minus the depreciation of natural capital:

SSNP = NNP – DE – DNC

Source: Daly (1996)

That is a prudent definition, and one would hope that we would all behave that way. However, it seems that a great deal of current behavior does not conform to this line of thinking. When the net national product is measured without taking into account defensive expenditures and depreciation of natural capital, we tend to overestimate how well we are doing (this is discussed more in Chapter 11). In *Measuring Environmental Quality in Asia* (Rogers et al., 1997), measures of environmental quality are developed, including a cost of repair approach, which emphasizes measurement of defensive expenditures. This suggests that if we have damaged the environment, we should be concerned with what it would cost to repair it, which means what it would cost to get it back into the condition in which we would like to have it.

Savings is the key to sustainability. The formula in Box 1-3 is also a sentence, which in English says, savings, as a percentage of GDP, should be greater or equal to the sum of the depreciation of human knowledge plus the depreciation of human-made capital plus the depreciation of natural capital.

Box 1-3. Savings: Key to Sustainability

A simple rule for sustainability would be:

$$\frac{S}{y} \geq \frac{\delta_H K_H}{y} + \frac{\delta_M K_M}{y} + \frac{\delta_N K_N}{y}$$

Savings as Percentage of GDP	≥	Depreciation of Human Knowledge	+	Depreciation of Human-made Capital	+	Depreciation of Natural Capital

Human Capital (H), Man-made Capital (M), and Natural Capital (N).
Weak sustainability requires: Sum of all forms of capital constant or increasing over time
Strong sustainability requires: Each is constant or increasing over time

Source: Modified from Pearce and Atkinson in Rogers et al. (1997), p. 52

Weak sustainability requires that the sum of all capital be constant or increasing over time. In other words, it implies the possibility of substitutions among human-made capital, human knowledge, and natural capital. Strong sustainability requires that each of these three types of capital be increasing over time. Most of the literature basically thinks in terms of weak sustainability, meaning that we can substitute between natural capital, human-made capital, and human knowledge, but there are many counter-examples to this assumption. For example, how can we substitute human-made capital for an extinct species such as the dodo bird?

Economics as the Dismal Science

Why is economics considered the dismal science? It is because of the relationship of decreasing returns to scale, posited by Malthus and the English economist David Ricardo, among geometric population growth, the arithmetic depletion of resources, and the expansion to ever-declining quality of resources. Both did not paint a very pretty picture of what was going to happen to the world, and so economics earned the appellation, "the dismal science," and they are considered its fathers.

Boxes 1-4 and 1-5 are often referred to as the "rule of seventy." It is a useful trick to help remember the time taken for a number to double when the number is constantly increasing at a certain percent. If a number, such as the number of people in a population, is increasing at r percent per year, then after one year the number will equal the original number times one plus r, or (1.0 + r), percent, which is the rate of growth. After two years, the number of people in the population equals the original population times one plus r squared, or $(1.0 + r)^2$, because we are compounding the increase in the number. After t years, the total population is equal to the original population multiplied by (1.0 + r) to the power of t $(1.0 + r)^t$.

The formula also applies to calculating increases in the value of money invested at R percent per annum. Such calculations may be more interesting to most laypersons as they indicate how much money can be made by a particular investment over a period of time. If we use exponentials we can do these computations quickly. For instance, the time taken for a number to double is shown in Box 1-4 as 0.6931/r. This means that the doubling time is close to 70/r where R is expressed in percentage terms.

Box 1-4. Geometric Growth: The Foundations of the Dismal Science

If the growth rate of a population is r percent per annum, an initial population of N_0 becomes N_1 after one year, or

$$N_1 = N_0 (1+r)$$

and after two years,

$$N_2 = N_1 (1+r) = N_0 (1+r)^2$$

and after t years,

$$N_t = N_0 (1+r)^t$$

So for a population of 100 persons growing at a rate of 2% per annum, after 1 year the population will be 102 persons. After 2 years the population will be 104.02.

The same holds true for money invested at r percent per annum.

Continuous compounding can be expressed as

$$N_t = N_0 e^{rt}$$

This is a very useful form to compute. For instance, the time taken for N_0 to double is

$$N_t / N_0 = 2$$

or

$$2 = e^{rt}$$
$$\ln 2 = rt$$
$$t = (\ln 2)/r = 0.6931/r$$

For r as a percentage the doubling time is close to 70/r.

For example, for an interest rate of 10%, the doubling time will be 7 years; $70/10 = 7$.

Population, Resources, Environment, and Sustainability

The above calculations can often be done in one's head. This is a useful trick and a useful tool to calculate rough values for investment returns, world population trends, north-south distribution rates, and the like.

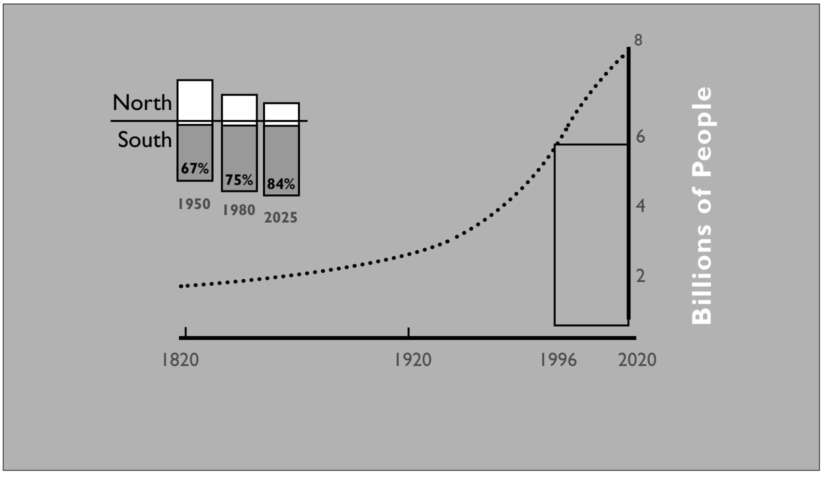
Table 1-1 shows that it took all of previous history until the 1800s before the earth had a population of one billion. The next billion was reached in 1930, or 130 years later. The next billion

Table 1-1. World Population

Number of Years to Add Each Billion	Year	Years to Add
First billion reached	1800	all of human history
Second	1930	130
Third	1960	30
Fourth	1975	15
Fifth	1987	12
	Projected	
Sixth	1998	11
Seventh	2009	11
Eighth	2020	11
Ninth	2033	13
Tenth	2046	13
Eleventh	2066	20
Twelfth	about 2100	34

Source: Population Reference Bureau (1991), United Nations and World Bank estimates for the projections

Figure 1-2. World Population Trend and North-South Distribution



Source: Modified from UNDP/HDR (1990), p. 25

people was achieved in 1960, after 30 years. And then the fourth billion took 13 years; the fifth billion, 12 years; the sixth billion, 11 years. So there has been a huge acceleration in the growth rate of the world population, and this is one reason why we have become concerned about population and resources. Figure 1-2 shows the trend in world population as of 1996, when it was less than 6 billion. It is more than 6.5 billion now, and it is still increasing. Based upon 1990 data, the UN indicated that it would increase to more than 10 billion by 2050, following their median population estimates, and that it might rise as high as 13 billion before stabilizing. Just to show how quickly population forecasts can change, as of 2002 the UN experts expected the world population to level off at between 9 to 11 billion. A difference of 2 to 4 billion is rather large, considering that the total world population in 1975 was only 4 billion.

The Ehrlich Identity

To help analyze the interaction of factors causing environmental impact, the American environmentalist Paul Ehrlich suggested the relationship, I=PAT, popularly known as the Ehrlich Identity. The identity relates in a multiplicative way population, P, affluence, A, and technology, T, to environmental impact, I. (This identity fits into a long line of "production" functions in economic analysis. The best known is the Cobb-Douglas production function, where production output, O, is related nonlinearly to capital inputs, K, and labor inputs, L, by the equation $O=K^aL^b$, where a and b are the output elasticities of capital and labor, respectively.)

Box 1-5. Ehrlich Identity: I=PAT

Environmental Impact (I) = Population (P) times Affluence [consumption per capita (A)] times Technology per capita (T)

$$I = PAT$$

A small change in each, ΔP, ΔA, and ΔT, gives the new impact

$$(I+\Delta I) = (P+\Delta P)\ (A+\Delta A)\ (T+\Delta T)$$

Dividing through by the identity I = PAT yields

$$(1+\Delta I/I) = (1.0+\Delta P/P)\ (1.0+\Delta A/A)\ (1.0+\Delta T/T)$$

where ΔI/I etc. is the percentage increase in impact, population affluence, and technology.

Ehrlich has written several books, commencing with *The Population Bomb* (1971), predicting dire consequences from the rapid growth of human population. Fortunately, so far his predictions have not been borne out, but he (like Malthus) might be right in the long run. In any event, I=PAT provides a useful way of looking at the impact of population, consumption per capita, and technology per capita. These three factors constitute some of the major influences on the environment.

For example, I=PAT can help us understand the relative causes of the impact of lead from automobiles on the environment from 1946 to 1968. During those 22 years, the US population increased by 42%. The measure of affluence in terms of vehicle miles driven per capita rose by 100%, and the measure for technology in terms of lead emitted per vehicle mile rose by 81%. Therefore, the increase in environmental impact can be described as

$$(1+\Delta I/I) = (1.0+0.42)\ (1.0+1.0)\ (1.0+0.81)$$
$$(1+\ \Delta I/I) = 5.14$$

This amounts to a 414% increase. What caused the increase? Clearly it was not simply a population effect, but the joint effect of affluence and technology working together. Fortunately, lead was phased out from gasoline in the US fuel system starting in 1973.

What is the carrying capacity of the globe? As the Ehrlich Identity suggests, the level of per capita consumption is very important in determining the impact on the environment or the carrying capacity. But then, too, technology changes and income rises, and both these changes are associated with the use of resources.

These factors need to be taken into account when population growth in third world countries is compared with such growth in industrialized countries. Third world countries do not consume very much. Industrialized countries have low rates of population growth but high rates of consumption of resources like energy. In many instances a person in an industrialized country consumes as much energy in six months as an Indian villager consumes in a lifetime. Per capita consumption is thus probably the most important component in such comparisons of technology change. In planning for the future we typically want per capita consumption to increase; hence, to reduce the impact on the environment the multiplicative effects of the other components need to be reduced. Perhaps we need to focus more on the third factor: technology change. Such an emphasis is the basis of much of the cornucopians' optimism about the future.

Life Cycle Analysis and Sustainability

The choice of a simple disposable coffee cup is a trivial example, but it can demonstrate how we could improve sustainability by examining each of our small life style choices—a small achievement, but an important demonstration of the power of life cycle analysis in establishing sustainability. This relates to the environmental impacts of paper cups compared with polyfoam, or Styrofoam cups. The debate over this issue goes back many years. It appears that in many quarters, paper cups have won this debate. The question is, which is the most environment-friendly of these cups? How can we ascertain which is more sustainable? Does the paper cup provide the right answer? We will have to do some analysis to find out. Consider Table 1-2 comparing some obvious features of a typical paper cup and a typical polyfoam cup.

Table 1-2. Paper Cup vs. Polyfoam Cup: An Environmental Summary I

Item	Paper Cup	Polyfoam Cup
	per cup	
Raw materials:		
Wood and bark (g)	33 (28 to 37)	0
Petroleum fractions (g)	4.1 (2.8 to 5.5)	3.2
Other chemicals	1.8	0.05
Finished weight (g)	10.1	1.5
Wholesale cost	2.5 ×	×

Source: Based on M. Hocking (1991)

When we are examining sustainability, it is important to look at the life cycle of the device in question, including production, use, and ultimate disposal. In Germany, for example, there is an attempt to make automobiles fully recyclable. This has not yet been achieved, but large portions of German automobiles are now recyclable, and greater portions will become recyclable in the future.

As indicated in the table, the raw materials in the paper cup include wood and bark, since it is made of paper. Paper cup raw materials also include petroleum. Actually, there is more petroleum used in paper cup production than in a polyfoam cup, which is made almost entirely of petroleum products. Some may find that surprising. Also, a lot of chemicals like chlorine are used to bleach the paper in the paper cups to make them look nice. Binders such as glue are used to stick paper cups together. All of these ingredients for paper cups cost about two and a half times as much as cups made of polyfoam.

Now consider the environmental impacts during production of the cups, summarized in Table 1-3.

The production of the cups requires steam, power (electricity), and cooling water. Water effluent for each cup is measured by volume, suspended solids, biochemical oxygen demand (BOD), organochlorines, and metal salts. Air emissions are measured in terms of chlorine, chlorine dioxide, reduced sulfates, particulates, chlorofluorocarbons, pentane, and sulfur dioxide. The table shows that in most cases polyfoam cup production causes much less environmental impact than paper cup production.

What about the reuse and recyclable potential and ultimate disposal of paper cups versus polyfoam cups? (Tables 1-4 and 1-5.) The ability to reuse paper cups is likely low, since they can disintegrate when reused. Very few people reuse paper cups. However, polyfoam cups are easy to wash, and reuse. Paper cups burn well, but produce a hot melt adhesive. If paper cups are not completely burned, these adhesives will linger in the environment.

Table I-3. Paper Cup vs. Polyfoam Cup: An Environmental Summary II

Item	Paper Cup	Polyfoam Cup
	per metric ton of material	
Utilities:		
Steam (kg)	9,000-12,000	5,000
Power (kWh)	980	120-180
Cooling water (m^3)	50	154
Water effluent		
Volume (m^3)	50-90	0.5-2.0
Suspended solids (kg)	35-60	Trace
BOD (kg)	30-50	0
Organochlorines (kg)	5-7	0
Metal salts (kg)	1-20	20
Air emissons		
Chlorine (kg)	0.5	0
Chlorine dioxide (kg)	0.2	0
Reduced sulfides (kg)	2.0	0
Particulates (kg)	5-15	0.1
Chlorofluorocarbons (kg)	0	0
Pentane (kg)	0	35-50
Sulfur dioxide (kg)	10	10

Source: Based on M. Hocking (1991)

Table I-4. Recyclable Potential of Paper Cups and Polyfoam Cups

Item	Paper Cup	Polyfoam Cup
	Recyclable Potential	
To primary user	Possible, though washing can destroy	Easy, negligible water uptake
After use	Low, hot melt adhesive or coating difficulties	High, resin reuse in other applications

Source: Based on M. Hocking (1991)

Table 1-5. Ultimate Disposal of Paper Cups and Polyfoam Cups

Item	Paper Cup	Polyfoam Cup
	Ultimate Disposal	
Paper incineration	Clean	Clean
Heat recovery (MJ/kg)	20	40
Mass to landfill (g)	10.1	1.5
Biodegradable	Yes, BOD to leacheate, methane to air	No, essentially inert

Source: Based on M. Hocking (1991)

Potential heat recovery from a polyfoam cup is twice that of a paper cup. The mass to landfill ratio of paper to polyfoam cup is 8 to 1. Are these two types of cups biodegradable? Polyfoam cups do not seem to be biodegradable. Walking the beaches of Massachusetts, one finds lots of old polyfoam that was not disposed of in a correct way.

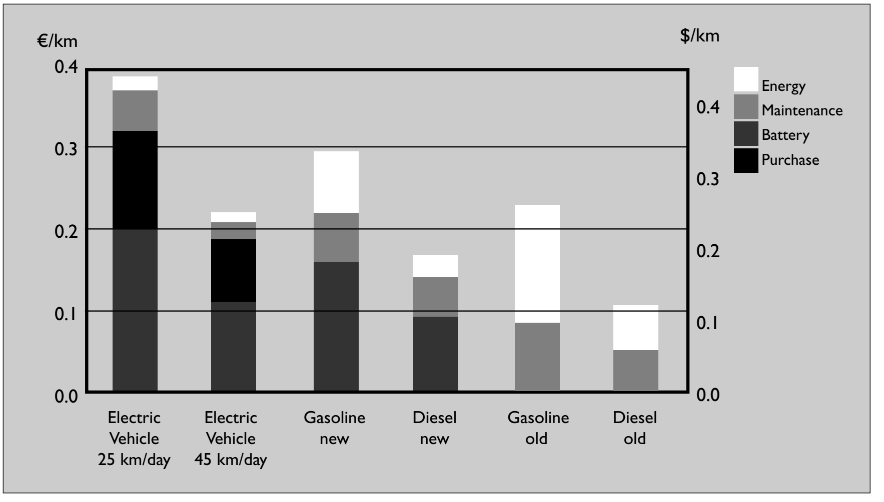
Which is the best cup depends on what we think are bad results. A lot of people seem to think that the litter of polyfoam on the beaches of the world is much worse than all of those other environmental insults produced by paper cups. If polyfoam cups were collected and disposed of properly by incineration, there would be no question about which would be preferred.

Sustainability on the Highway Produced by Three Key Sources of Energy

Comparing vehicles powered by electricity, gasoline, and diesel is a bit like comparing apples and oranges, and bananas. A comparison of these vehicles is possible only if it is based on their respective performance levels in use and over their entire life cycle. In the following example, based upon typical sized gasoline, diesel, and electric cars in France in the late 1990s before hybrids were available, the cars were assumed to be similar in all performance and travel conditions.

In this case, life cycle costs are calculated on the assumption of 45 kilometers a day. First, when all of the private costs from purchase price to energy use, maintenance, battery replacement, and the like are considered, it turns out in Figure 1-3 that the new gasoline vehicle is the most expensive, the cost of a new diesel is the least expensive, and the cost of an electric vehicle lies in between. This result is based upon very low electricity rates in France due to the large amount of nuclear electricity on the base load. In the US the new electric car would have had the highest private costs. Diesel vehicles are a lot cheaper. How would one make a choice? If one is a rational

Figure I-3. Life Cycle Costs per Kilometer: *Private Costs*



Source: Funk and Rabl (1999)

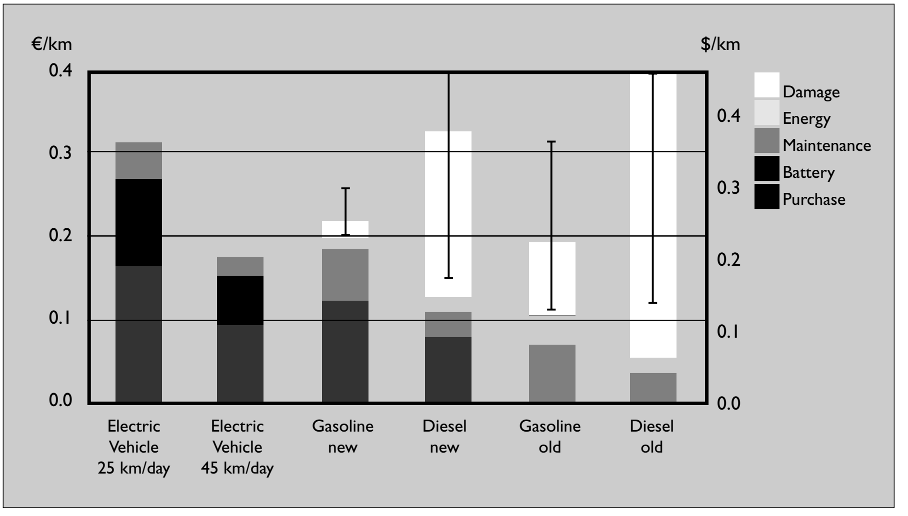
Table I-6. Calculated Damage Costs of Common Air Pollutants

Pollutant	**Damage Cost** (euro/kg)[a]
Greenhouse gases, CO_2 equivalent	0.029
Secondary pollutant, per kg of primary pollutant	
SO_2 via sulfates	10.0
NO_2 via nitrates	14.5
NO_2 via ozone	1.50
NMVOC via ozone	0.93
Primary pollutants from refineries	
PM10	15.4
Primary pollutants from cars	
$PM_{2.5}$ Paris	2190
$PM_{2.5}$ highway, Paris-Lyon	159
$PM_{2.5}$ rural France	22
SO_2 direct, Paris	28
SO_2 direct, highway, Paris-Lyon	2.2
SO_2 direct, rural France	0.3
CO_2 Paris	0.02
CO_2 highway, Paris-Lyon	0.002

[a] 1€ = $1.16

Source: Funk and Rabl (1999)

Figure 1-4. Life Cycle Costs: Including Social Costs



Source: Funk and Rabl (1999)

consumer, focusing on the overall cost of running and owning a car, one would buy a new diesel car or an old diesel car, because either one costs less based on euros spent per kilometer.

However, use of these vehicles results in damages caused by the pollution they produce over their life cycle. To calculate these damages, we need to know the damages caused by primary and secondary pollutants. Primary pollutants are emitted from refineries and from fuel use, and secondary pollutants consist of sulfates, nitrates, and ozone generated in other parts of the life cycle. The primary pollutants from cars are provided in terms of driving in a city or driving on a highway, and greenhouse gases (use of all fossil fuels produces greenhouse gases). Table 1-6 reports the estimates used to calculate the impacts of the conventional pollutants. Also we need to add in the cost of greenhouse gases estimated at about $20 per ton of carbon dioxide (CO_2).

Different vehicular activities have different damage costs based on health damages (mortality damages were not considered). Figure 1-4 shows what the relative attractiveness of the automobile choice is now when these externalities are factored in. An old diesel vehicle, which is really cheap to buy and use based upon the private costs, has high social costs because it produces a great many particulates that are very damaging to human health. If all of these costs are added together, the life cycle cost per kilometer, including social costs, is high. Many consumers, however, do not wish to be concerned with social costs; they wish to pay only private costs. However, a policy designed to find a solution that takes into account everyone in a community, not just those who purchase low-cost vehicles, will encourage the purchase and use of electric vehicles. Indeed, electric vehicles, which can be driven 45 kilometers per day, become competitive with old gasoline vehicles after taking into consideration average values of damages.

How can we make consumers respond to social costs rather than the private costs? Some would suggest manipulating costs, particularly fuel costs, and removing direct and indirect subsidies, in order to make the private cost look more like the real social cost. When attempting full life cycle analysis, social as well as private life cycle costs have to be considered. We must also factor in the damage to the environment. Each of these three points of view may provide entirely different answers, all of which are important to achieve sustainability.

By looking behind the numbers and ascertaining the impacts, we could start modifying motor vehicle technology. For example, sports utility vehicles (SUVs) were often considered the worst vehicles from the sustainability point of view because they were big and consumed a great deal of fuel. Ford has now produced a new, small, hybrid SUV powered by gasoline and electricity. As advertised, the new SUV has improved fuel efficiency by 81% and reduced emissions by 60%, and this SUV is now enjoying brisk sales. Americans often prefer bigger mid-sized vehicles than Japanese consumers. So now American consumers can buy an SUV and feel better about it from the environmental point of view. From the environmental point of view, however, everyone should be driving small cars or taking public transportation, if such is available.

On the public transit side there are also potential moves towards sustainability. For example, Seattle recently bought 235 new diesel electric buses, each with a hundred seats. Compared with previous buses, these have a potential improved fuel economy of 60% and reduced particulates of 90%. Also note that Seattle has many tunnels where these buses will be used, powered only on electric cycle in the tunnels. The ability to drive significant distances on only electricity has other significant advantages in stop-and-go traffic, because most of the emissions come from low-speed driving.

Recall the I=PAT identity and note that we are now rapidly changing the technology we use, which will lead at the same time to reducing consumption. These are major technical improvements with major potential for changing per capita use of petroleum resources. How long does it take to roll over from one type of vehicle in the United States—ten years or 15 years? If these new technologies do indeed catch on, then we can expect that US petroleum demand by 2020 could be substantially lower than currently projected.

One important reason to believe that we are due for such an accelerated change of technologies in the direction of more sustainability is the current and growing competition for petroleum-based fossil fuels. In 2004, the PRC imported about 90 million tons of petroleum products, while the US imported about 400 million tons. By 2020, the PRC will import 400 million tons. Also India imported about 90 million tons of oil products last year, and India's demand in 2020 will be significant, though not as high as the PRC's. The world market for oil may not be able to supply these amounts at reasonable prices. Something has to give. Unless there is a radical shift in the availability of fossil fuels, we are heading for one of those proverbial train wrecks. To avoid such disaster, we are already starting to see the adoption of alternative-fueled vehicles. This suggests that we will muddle through because we are smart enough to figure out that we do not want to be wiped out by such a train wreck. The two examples of new technologies for hybrid SUVs and Seattle's purchase of new hybrid buses are quite hopeful. If other parts of the world such as India, where there are several hundred thousand buses, take similar initiatives, major environmental and social improvements can be achieved. However, without a radical technology shift, we will face significant problems. The good news is, people are actually buying and using new technologies.

Life cycle analysis of every proposed change is imperative to achieve sustainable development. We often fall short, because most of our analyses are based purely on private costs, on manufacturing costs, and on costs to purchase goods and services in the marketplace without sufficient attention to what is important. Why were little plastic bags filled with air designed for packing purposes? Not so long ago Germany required all packaging to be returned to the manufacturer. Before this change, US producers were flying thousands of computers packed with Styrofoam to Germany. With this new requirement the Styrofoam had to be flown back to the US. While flying computers packed in Styrofoam is probably a profitable activity, flying Styrofoam-filled 747s back to the US for disposal clearly is not. Manufacturers had to find a new way of packing the computers. Because bags full of air are a lot cheaper to bring back home than bulky Styrofoam, they were rapidly adopted.

These changes in technology for packaging were induced by environmental concerns, new legal requirements, and resulting economic costs, as suggested by the above example of the electric vehicle, which was superior, but only if based on the social costs.

A Look Forward

This introductory chapter has explored many of the key issues to be confronted in achieving sustainable development, including the triple bottom line of environmental, social, and economic considerations in the face of such global environmental issues as population growth, consumption, production, pollution, effects of legal requirements, as well as some of the causes and effects of poverty. The book will consider other issues, including sustainable development indicators; environmental assessment and management trends; international law, including multilateral environmental agreements; and national environmental accounts.

The book concludes with a review of what international financial institutions and others are doing to achieve sustainable development, together with a quick look into the next 50 years. The Epilogue focuses on the challenges posed by terrorism, climate change, the global food system, and globalization. It will be argued that the most serious indicators of losing our path to a sustainable 2050 would be an increase in absolute levels of poverty in the world, increasing gaps between the rich countries and the poor countries, and increasing gaps between specific countries. Since sustainable development requires social sustainability as well as economic and environmental sustainability, we believe that increased polarization between the rich and the poor could lead to increased terrorist violence, failed states, further deterioration of the environment, and mass migrations for economic survival and environmental reasons. To avoid such consequences and provide for a better world, we all need to work toward achieving sustainable development throughout the world.