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Characterizing a sustainability transition: Goals, targets, trends, and driving forces

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Sustainable development exhibits broad political appeal but has proven difficult to define in precise terms. Recent scholarship has focused on the nature of a sustainability transition, described by the National Research Council as meeting the needs of a stabilizing future world population while reducing hunger and poverty and maintaining the planet's life-support systems. We identify a small set of goals, quantitative targets, and associated indicators that further characterize a sustainability transition by drawing on the consensus embodied in internationally negotiated agreements and plans of action. To illustrate opportunities for accelerating progress, we then examine current scholarship on the processes that influence attainment of four such goals: reducing hunger, promoting literacy, stabilizing greenhouse-gas concentrations, and maintaining fresh-water availability. We find that such analysis can often reveal "levers of change," forces that both control the rate of positive change and are subject to policy intervention.

For 15 years, the notion of sustainable development has exhibited broad political appeal but has proven difficult to define in precise terms. Most definitions include concerns for development, equity, and environment. Recent scholarship has begun to focus on the concept of a sustainability transition, described by the Board on Sustainable Development of the National Research Council as meeting the needs of a stabilizing future world population while reducing hunger and poverty and maintaining the planet's life-support systems (1). We draw on the consensus embodied in internationally and regionally negotiated agreements and plans of action to identify a small set of goals, quantitative targets, and associated indicators. We then illustrate opportunities to accelerate progress toward a transition by examining current scholarship on the processes that influence attainment of four such goals. Two of the goals (reducing hunger and promoting literacy) are selected from the consensus on meeting human needs, and the other two (stabilizing greenhouse-gas concentrations and maintaining fresh-water availability) are selected from the consensus on preserving life-support systems.

Characterizing a Sustainability Transition

Defining sustainability is ultimately a social choice about what to develop, what to sustain, and for how long. As a result, we go about the job of characterizing a sustainability transition by reviewing the large, well documented body of internationally negotiated consensus on matters of development and environment. In conducting this review, we were careful to distinguish between goals, indicators, targets, trends, and driving forces. In this taxonomy, goals are broad, qualitative, statements about objectives. A statement such as the Habitat Agenda's "adequate shelter for all" is a human-needs goal (2), and that of the United Nations Framework Convention on Climate Change's "stabilization of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" is a life-support system goal (3). Indicators are quantitative measures that are selected to assess progress toward or away from a stated goal. For example, indicators of adequate shelter include measures of access to improved drinking water and improved sanitation services (4). Indicators of greenhouse-gas concentrations include measures of carbon dioxide (CO_2) and global warming potential in the atmosphere (3). Targets use indicators to make goals specific with endpoints and time tables, such as cutting in half the number of people without access to clean water or improved sanitation by 2015 (5) or reducing overall emissions of greenhouse gases by at least 5% below 1990 levels by 2008–2012 (6). Trends are changes in the values of indicators over time, and driving forces are the processes that influence trends and our ability to meet agreed-upon targets.[§]

The most striking result from our review is the differences between the consensus goals and targets for meeting human needs and reducing hunger and poverty and those for maintaining life-support systems and living resources. The agreements for meeting human needs are more clearly articulated and institutionalized. An important set of agreements, as exemplified by the Millennium Declaration of the United Nations (5), defines a specific set of goals and targets for improving health, providing education and access to water and sanitation, and reducing hunger and poverty. Only employment goals lack any specifics and targets. All of these goals are institutionalized in specialized agencies and programs of the United Nations (the World Health Organization, the United Nations Educational, Scientific and Cultural Organization, the Food and Agriculture Organization, the World Bank, the United Nations Development Program, the United Nations Human Settlements Program, and the International Labour Organization) that monitor trends, assess progress, and implement programs associated with each goal.

By way of contrast, there are literally hundreds of agreements that cover key aspects of the Earth's life-support system and living resources but little consensus. Global treaties are broadly conceived but have at best vaguely defined objectives. Treaties with clearly articulated targets, such as the Montreal and Kyoto Protocols, are the rare exceptions. The most common environmental agreements are regional in character and apply to only a small number of countries. The institutions that monitor trends, assess progress, and implement programs for these agreements are weak compared with those associated with human needs, a characteristic that ultimately diminishes our ability to maintain Earth's life-support systems and living resources. For example, the annual operating budget of the World Conservation Union is less than one-tenth that of the Food and Agriculture Organization.

We can offer at least three complementary explanations for these differences in the goals, targets, and institutions for meeting human needs and reducing hunger and poverty and those for maintaining life-support systems and living resources. First, efforts to address human needs were firmly embedded in the Charter of the United Nations signed in 1945 and rapidly institutionalized in specialized agencies (7). In contrast, environment did not really emerge as an international issue until the 1972 United Nations Conference on the Human Environment (8), a period in which countries have been reluctant to establish major new intergovernmental organizations (9). Second, although human needs are seen as universal, many environmental issues were identified initially as local problems, and they were seen later as transboundary problems best addressed with

Abbreviation: GDP, gross domestic product.

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§A more detailed treatment of this section can be found in ref. 52.

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Table 1. Priority human-needs goals, targets, and indicators

Goal	Indicator	Target	Quality of reporting and assessment
Improve health	Childhood mortality	Reduce to 1/3 of 1990 rate by 2015 (10)	A
Provide education	Literacy	Reduce illiteracy to 1/2 of 2000 rate by 2015 (10)	A
	Male–female secondary enrollment rates	Eliminate gender disparities in primary and secondary education by 2005 (10)	A
Reduce hunger	Prevalence of undernourishment	Reduce prevalence to 1/2 of 2000 levels by 2015 (5)	C
	Prevalence of vitamin A deficiency	Virtual elimination of vitamin A deficiency and its consequences, including blindness, by 2000 (53)	D
Reduce poverty	Poverty rate	Reduce the proportion of the world's people whose income is <$1/day to 1/2 of 2000 rate by 2015 (5)	C
Provide housing	Access to improved sanitation services	Ensure that 75% of the urban population are provided with on-site or community facilities for sanitation by 2000 (4)	B

regional institutions. Global environmental issues have only emerged slowly over time in response to genuinely global atmospheric problems or ubiquitous concerns such as water or biodiversity. Third, a consensus is more difficult to reach for the environment because of the divergence between concerns for and understanding of natural systems versus more limited anthropocentric concerns that focus on just those aspects that most immediately serve human needs. For example, most fisheries treaties feature goals and targets to maintain sustainable yields of specific economically valuable species as opposed to nurturing the marine ecosystems in which these select species live.

Goals, Indicators, and Targets

From the well documented set of goals, indicators, and targets for meeting human needs and reducing hunger and poverty, we have identified five goals and seven targets presented in Table 1. None of these targets have been obtained, and most will not give current rates of progress (10). Although early targets originally established for 2000 have been reaffirmed by the Millennium Declaration of 2000 or the World Summit on Sustainable Development in 2002, the target dates are pushed forward usually to 2015.

For these goals and targets, we sought a small set of indicators that can be used to mark the achievement of the goals and targets and collectively plot progress toward or away from a sustainability transition. We reviewed the extensive work on sustainable development indicators (11–17) and were cautioned by the Board on Sustainable Development finding that "there is no consensus on the appropriateness of the current set of indicators or the scientific basis for choosing them. Their effectiveness is limited by the lack of agreement on what to develop, what to sustain, and for how long" (1). However, by focusing on "output" indicators such as "childhood mortality" or "undernourishment" instead of the frequently used "input" indicators such as "immunization rates" or "food-aid expenditures" and eliminating highly correlated indicators, we identified seven indicators that effectively map progress toward the targets. The chosen indicators are not equally well measured, reported on, or assessed on a global level. Thus, in the last column of Table 1, we grade the quality of reporting and assessment for each indicator. Indicators that have been measured, reported, and assessed routinely on a global basis sufficient to establish a long-term trend receive a letter grade of "A." A "B" indicates that the indicator is being measured currently and is likely to be so in the future. Indicators receive a "C" when not measured directly but only estimated through extensive modeling and extrapolation, and they receive a "D" when only rough contemporary estimates using proxies are available.

It is more difficult to extract an international consensus from the many individual environmental agreements. To do so, we use the common themes that appear in regional agreements as likely forerunners of more comprehensive international agreements for maintaining Earth's life-support systems and living resources. As shown in Table 2, the goals of this consensus are primarily structured by environmental media: atmosphere/climate, oceans, fresh water, land use/land cover, terrestrial biodiversity, and toxics. With three exceptions, global targets are lacking, which provides further evidence for a weaker environmental consensus.

Thus it is not surprising that only one of the suggested indicators is operationally produced on a global basis: overall emissions of greenhouse gases. This exception suggests that when viewed as truly important, indicators could be economically produced on an operational basis with modest investments. In the meantime, most of the other indicators such as land-use/cover-change or consumptive fresh-water withdrawals are produced sporadically by individual scholars or groups subject to the whims of scientific funding agencies. Some indicators such as ocean biological community condition require additional basic research.

Table 2. Priority life support system goals, targets, and indicators

Goal	Indicator	Target	Quality of reporting and assessment
Reduce emissions of atmospheric pollutants	Greenhouse gas emissions	Reduce overall emissions of greenhouse gases by at least 5% below 1990 levels by 2008–2012 (6)	A/B
	SO_x emissions	Reduce SO_x emissions (target varies by agreement) (54–57)	C
Stabilize ocean productivity	Biological community condition	Not stated	D
Maintain fresh water availability	Consumptive fresh water withdrawals	Not stated	D
Reduce land use/cover change	Land use/cover change	Not stated	C
Maintain biodiversity	Land use/cover change in biodiversity hotspots	Not stated	D
Reduce emissions of toxic substances	Dioxin and furan emissions	Reduce or eliminate releases from unintentional production as measured by toxic equivalency units	D

A technical problem for such research is the need to develop indicators that aggregate multiple, conceptually related trends to a common scale. Common scale indicators are substantially different from composite indices that arithmetically combine disparate measures into a single overall score such as the Environmental Sustainability Index (14) and the Ecosystem Well Being Index (13). Common scale indicators use scientific methods to establish equivalencies to a common unit of measure, whereas composite indices use subjective methods to define an overall grade with no associated units. Past experience with the Montreal Protocol on Substances That Deplete the Ozone Layer and the Kyoto Protocol to the United Nations Framework Convention on Climate Change is instructive. By aggregating the many different trace gases involved as ozone-depleting potential or global warming potential, the resulting simplifications seemed to play an important enabling role in the negotiation and implementation of each agreement. With the exception of SO_x emissions, all the life-support system and living resource indicators proposed above are aggregated indicators. Even with SO_x, a method for aggregating emissions of multiple tropospheric air pollutants to a common measure would be welcome.

Although the basic goals of a sustainability transition (meeting human needs, reducing hunger and poverty, and maintaining life-support systems) are largely consistent across scale, the relative importance, specific indicators, and targets can vary widely. To capture such variability as well as to use existing national sources of data, analysts frequently use countries as a unit of analysis. To capture first-order variability, we think it is more productive to analyze sustainability transitions regionally, where each region consists of multiple countries as defined by a "peer" relationship such as geography, income, or some other factor. Regionalization prevents analysts from ignoring some important geographic variation while minimizing the likelihood that specific countries will opt out of the measurement process for fear of being singled out because of low scores on a particular indicator.

Driving Forces

What forces and the processes that underlie them are the principal drivers toward or away from sustainability goals and targets? How may favorable forces be accelerated and harmful forces slowed? Using as examples two each of human needs and preserving life-support systems we review current scholarship to identify the major forces that serve as principal drivers toward or away from sustainability goals.

Reducing Hunger. There are three major types of hunger: chronic household hunger, episodic hunger, and special-needs hunger. Each seems driven by somewhat different forces. The most widely used measure of chronic household hunger is the number living in households with insufficient income or its equivalent to provide for health, children's growth, and ability to work. Current global estimates find 800–900 million chronically hungry people, with the largest number in Asia and the greatest proportion of population in Africa (18).

The number of chronically hungry people can be estimated by using four variables: the size of the population, the average income per person, the distribution of income across the population, and the definition of a hunger line of income or its equivalent, below which the population is thought to be hungry. Considering the forces that drive these variables, it is possible to readily define ways to accelerate the positive trend in reduced population numbers and growth in income and less readily to slow the harmful trends in income distribution and requirements.

Forces driving these four variables were considered in a scenario study prepared for the Board on Sustainable Development of the National Research Council study in which the basic reference scenario of current forces was compared with a hunger and carbon-reduction scenario. The desired hunger reduction was to cut chronic household hunger in half in each of two generations: by 2025 and again by 2050. Various combinations of population and income growth, income distribution or equity, and income required to abate hunger were explored with an effort made to keep within the range of the possible if not the probable. A key as might be expected was income redistribution. Thus by using an assumed scale of the world economy close to the reference scenario, population slightly lower and average global income slightly higher, hunger could be cut in half by a more equalitarian distribution of income. Within countries, income distribution would need to be close to that of Europe today, and between countries the 7-fold difference in per capita incomes between rich and poor countries in 1995 would need to shrink to 3-fold in 2050 (1).

Trends in episodic hunger and special-needs hunger can be addressed more directly by international and national policies. Episodic hunger is caused by famine that arises from natural hazard or war and from entitlement shifts, triggered by changes in the relative value of labor or products, financial crises, or structural adjustment efforts that decrease social services and programs. The reduction of famine-determined hunger from natural hazards is a great success story of a global emergency food-aid system that relies both on public and private efforts, and famine-inspired hunger exists only where war and violent conflict persist. Thus national and international policies that favor emergency food aid and provide support for the poor and their incomes and products and assistance to civilians in time of conflict help to reduce this type of hunger.

For special-needs hunger, global efforts to address major causes of child undernutrition have helped to reduce the rate of wasting and stunting of children and the major micronutrient deficiencies of iodine, vitamin A, and iron deficiencies. Current efforts in immunization and child feeding and provision of micronutrients can all be accelerated (19).

Promoting Literacy. Education[¶] is a major human need, valued both for its intrinsic need and its role as a driving force for other goals relating to poverty, equality, and health. Educational progress is most widely measured in terms of inputs such as gross primary or secondary school enrollment and outputs such as literacy, primary and secondary school completion, and improved female attendance. Net primary school enrollment has risen slowly from 80% in 1990 to 84% in 1998. At the same time, the gap in primary school enrollment between males and females has fallen from 8% to 7% (20). However, primary school completion (the percentage of children reaching grade 5) has remained stagnant at 76% for 1990–1995 and 75% for 1995–1999 (21, 22). Gross secondary school enrollment has risen from 27% in 1960 to 55% in 1990 and 64% in 1997 (23).

Literacy is one of the first skills learned in formal or nonformal education programs. The most commonly used definition of literacy is a person's ability to "with understanding both read and write a short simple statement about his/her everyday life" (24). The national (or regional) adult literacy rate is a strong predictor for primary school attendance but a weaker one for secondary school attendance. We use adult literacy as our main educational indicator of an "educational transition" and consider its major driving forces.

Most countries are in the process of an education transition to full literacy and perhaps to universal full primary and secondary education achievements for all adults. Global adult illiteracy rates have fallen from $\approx$37% in 1970 to $<$21% in 2000 (25). However, there is great global disparity; adult literacy rates in 2000 ranged from 16% in Niger to $>$99% in Latvia (26). Nonetheless, it seems that all nations with incomplete literacy are moving along a similar sigmoid path toward a universal ability to read and write (see Fig.

¶This section is largely drawn from ref. 27.

1, which is published as supporting information on the PNAS web site, www.pnas.org). For two thirds of the countries, the rise from 10% adult female literacy to 90% takes from 55 to 100 years or three to four generations and longer for the remaining third of the countries (27). The rise from 10% adult primary education (and even less secondary) to 90% secondary education among adults takes ≈150 years or seven generations.

There are a number of countries that show exceptionally fast literacy increases. These countries (and the date of their relevant census) are Botswana (1993), Tanzania (1988), Brunei (1981), and China (1993). Countries with the lowest literacy increases are Bangladesh (1991), Nicaragua (1971), Seychelles (1971), Guyana (1982), and South Africa (1980). How might a literacy transition be speeded up?

The main key to rising adult literacy historically has been child school enrollment, with adult-education programs being a secondary force. Three forces seem to drive the enrollment rate: a low, but sufficient level of basic school expenditure per child of school age [in nonsocialist countries the threshold was ≈$500 in gross domestic product (GDP) per capita in 1997]; the proportion of adults who have secondary education; and how many of these well educated adults choose to or are able to become teachers. At any given level of child enrollment rates, the probability that a child will attend school is positively related to small family size, household income, parental education, male gender, and urban residence.

The rate at which rising school enrollments translates into adult literacy rates is strongly conditioned by the age structure of the population. The larger the percentage of young people represented in the overall population, the more rapidly literacy learned in school affects the overall adult literacy rate. But adult literacy can also be taught directly, and successful adult-education programs have occurred in countries where the overall literacy rate of adults is >60% and there is a focused government commitment to eradicate illiteracy in a short period.

Some of the above-mentioned factors are amenable to immediate policy or social intervention; others are not (such as the proportion of adults with secondary education). Strengthening those factors, which can be changed in the short run, would accelerate the transition to full or 90% adult literacy. Those factors are reducing family size (through family-planning programs), ensuring sufficient funds for primary schools, hiring a large number of teachers (even if the pool of well educated adults is small), and a focused, 1- to 10-year limited commitment to adult literacy programs if overall literacy is >60%. There indeed is some tension between the observations that both small families and young populations promote a literacy transition. However, the advantage of young populations is only relevant in the context of school enrollment rates, where there is little opportunity to acquire literacy as an adult. Given that population growth is a major driving force that limits our ability to make progress on other sustainability goals, it clearly makes more sense to complement policies encouraging small families with focused adult literacy campaigns than to encourage the formation of large families.

Stabilizing Concentrations of Greenhouse Gases. Efforts to manage the rate and magnitude of future climate change will involve managing the increasing atmospheric concentrations of greenhouse gases and aerosols. Since 1900, CO_2 emissions from fossil fuels have risen by a factor of >11, methane emissions by a factor of 3, and nitrous oxide emissions approximately doubled (28). Sulfate aerosols (SO_x) that reduce warming have grown by a factor of >5.5 from their levels in 1900 (29). However, they appear to have peaked in 1989 and declined by 2.6% from 1990 to 2000 (30). Much less is known about global trends in other radiatively active agents such as emissions of black carbon (soot) or the formation of tropospheric ozone. In aggregate from 1850 to 2000, anthropogenic activities are estimated to be responsible for a net climate forcing of ≈1.2 W/m^2 or 0.8 W/m^2 per century (31). For the well mixed gases (CO_2, CH_4, chlorofluorocarbons, and N_2O), the rate of climate forcing peaked in 1980 at almost 5 W/m^2 per century. Although this figure has declined to ≈2 W/m^2 per century in 2000, primarily because of the phase-out of substances that deplete the stratospheric ozone layer, it is still 2.5 times the rate from 1850 to 2000 (31). Current growth in climate forcing is driven by increasing concentrations of CO_2, with much smaller contributions by CH_4 and N_2O. Although there are large uncertainties regarding the role of black carbon, recent estimates rank its overall effect as greater than that of CH_4 (32). Additional future forcing is expected as terrestrial carbon sinks saturate and emissions of sulfates that reduce forcing decline because of concern over acidifying deposition. Estimates of net climate forcing in 2100 range from 4 to 9 W/m^2 (growth rates of 2.8–7.8 W/m^2 per century) depending on assumptions about population, economic growth, equity, and technology (33). Scenarios for stabilizing climate forcing call for some combination of reducing CO_2 emissions, carbon-sequestration technology, and reductions in air pollution (black carbon and ozone).

Anthropogenic CO_2 emissions are driven by energy production and consumption [6.4 petagrams of carbon (PgC)/year in 2000] and to a lesser degree by land-use/land-cover change (2.1 PgC/year in 1990) (33). Future emissions will depend on the complex interactions among population growth, economic growth, and technological innovation. The lowest of generally accepted projections estimate that global population will reach ≈8 billion people by 2050, a 25% increase over current levels. Population, in turn, is influenced most heavily by total fertility rates, which in turn are influenced by education, income, and opportunities for women and health (34). Economic growth, as measured by GDP in constant dollars, has outpaced population growth but by a declining margin over time. Average annual growth in world GDP per capita shrank steadily from 3.3% per year in the 1960s to 0.95% per year in the 1990s (23). The forces driving long-term economic growth are poorly understood. Current literature suggests important roles for education (i.e., the quality of the labor force), investment in infrastructure and research and development, and institutional factors such as the quality of governance and the rule of law (30). If we are to meet our goal of halving the number of people living in poverty and at the same time stabilize climate, then future economic growth needs to be targeted toward those who need it most and toward less emission-intensive activities. From a technology perspective, the long investment cycles for expensive capital equipment required to improve overall efficiency (CO_2 emissions/unit energy) will limit the speed at which many industrialized countries will be able to reduce energy-related emissions (35–37). Newly industrializing countries may be better positioned to take advantage of more efficient technologies as did China, where recent fossil fuel emissions have declined steadily from 824 million metric tons of C in 1997 to 775 million metric tons of C in 2000 despite continued population and economic growth (38). Some have also suggested the possibility of a "Kuznets" curve in which emissions decline beyond a certain degree of affluence (GDP per capita). If true, this effect is not expected to be significant until levels of affluence well beyond the current levels of the richest nations are achieved (39). CO_2 emissions from anthropogenic land-use/land-cover change are driven primarily by net deforestation rates, a topic we address in our companion article (59).

As for the other greenhouse gases, CH_4 emissions are primarily driven by rice and cattle farming, N_2O emissions are primarily driven from agricultural application of fertilizers, the anthropogenic production of tropospheric ozone is primarily driven by electrical power generation and transportation uses of fossil fuel, and emissions of black carbon are additionally driven by household heating and cooking (31). Tropospheric ozone and black carbon are addressed more easily than the agricultural uses and byproducts associated with CH_4 and N_2O.

Maintaining Fresh-Water Availability. Although the hydrologic cycle is a global system, the availability of fresh water has primarily been managed as a local issue that is driven by local demand, availability, transportation costs, and many other features of the hydrologic cycle that vary by scale. However, so many localities are either experiencing water stress or are likely to experience it in the near future that a growing consensus finds that fresh water needs to be analyzed in a global context. Between 1900 and 1995, global water withdrawals for irrigation, industry, and domestic use increased by over six times, more than double the rate of population growth (40, 41). At the same time, water pollution has degraded the available fresh-water supply. To help supply this water, dams have increased the standing stock of water in river systems by 700% since 1950, albeit accompanied by the forced movement of people, the destruction of wetlands and nutrient provision, and needed river-channel and -flow regulation (42).

The forces driving water consumption vary by sector with nearly 70% of fresh-water withdrawals and 87% of consumptive withdrawals used for agricultural applications, primarily irrigation (43). The effect of these withdrawals is amplified by agricultural water pollution due to runoff of nutrients (e.g., nitrogen) and toxics (e.g., pesticides and herbicides) and salinization as well as the destruction of wetlands. Agricultural demand for irrigation, in turn, is driven by the need to feed a growing population with rising nutritional expectations and the fact that irrigated agriculture has significantly higher yields than rain-fed agriculture. Demand for grains tends to rise with income as more affluent populations consume more grain-intensive meat products. This trend has reversed in some high-income countries such as the United States, where consumers have reduced beef consumption in favor of poultry products (44). Evolving agricultural technologies such as drip irrigation, precision farming methods, and genetically modified crops can reduce the amount of water consumed per unit of production.

Domestic fresh-water consumption is driven by a wide range of factors including income, settlement patterns, infrastructure, and relative availability (43). Although household fresh-water consumption is positively correlated to income per capita (45), there is some evidence that this trend begins to reverse at very high levels of income (46). However, rapidly growing cities in semiarid regions (e.g., Phoenix, AZ, and Chennai, India) outstrip the local renewable supply, creating demand for large-scale water storage and transportation infrastructure. In developing countries, it is estimated that approximately one half of the water withdrawn for domestic use in developing countries is lost because of leakage, illegal hookups, and vandalism (41). Rapid urbanization without adequate investment in sanitation infrastructure adds stress to downstream fresh-water supplies through increased pollution. In the poorest countries, domestic water provision is inadequate, and the poor are burdened both by disease from unclean water and very high costs for delivered water.

Industrial fresh-water consumption has two major components, manufacturing and energy conversion. Within manufacturing, different geographic regions and individual sectors exhibit vastly different patterns of consumption. For example, the states of the former Soviet Union use $\approx$89 m^3/\$1,000 value added, whereas Western Europe uses 19 m^3/\$1,000 and China uses 5 m^3/\$1,000. Similar geographic variation exists for energy conversion. It is also estimated (based on U.S. data) that iron and steel production uses roughly four times as much water per unit value added than does chemical production (43). The great variations in water withdrawal and use for similar purposes suggest great opportunity to increase efficiency in use and supply and to create closed cycles of use, more effective means of preventing and controlling water pollution, and more appropriate water pricing (1).

Common Features of Driving Forces. Three sets of forces driving human impact on life-support systems and living resources are common to most analysis: population, affluence or income, and technology, the so-called $I = PAT$ identity (47, 48). For example, studies of energy-related carbon emissions are structured by using the Kaya identity, where CO_2 emissions are a function of population, affluence (GDP per capita), energy intensity (units of energy/GDP), and technology (CO_2 emissions per unit of energy). Further decompositions account for differences among economic sectors (e.g., agriculture versus transportation) and energy technologies (e.g., nuclear, coal, oil, natural gas, and renewables). Sophisticated analysts are careful to recognize that the variables in such decompositions are not fundamental driving forces in and of themselves and are not independent from one another (30, 49).

A similar approach can be applied to human needs with an expanded concept of both income and institutional equity substituting for technology. In addition to commonly cited economic measures of equity (e.g., the GINI coefficient, poverty rate, and poverty gap), there are also institutional components of equity that are difficult to measure in economic terms. Examples include access to and quality of health care, education, housing, and employment. Depending on the context these factors of "institutional equity" will be influenced by the extent and character with which access is provided by government as a public good (i.e., entitlements) and various forms of explicit or implicit discrimination.

In the case of chronic household hunger, current estimates explicitly consider the population, the average income per person, the distribution of income across the population, and the definition of a hunger line of income or its equivalent below which the population is thought to be hungry. Similarly, primary and secondary school enrollment have been modeled in terms of school-age population, national expenditures per school-age person, household income, family size, and parental education. In this context household income is a direct measure of within-country inequality, whereas family size and parental education are related to inequality one generation prior. Together, these two case studies suggest the possibility of a generic relationship between development and the interactions between the target population (e.g., school-age population), affluence (GDP per capita), and equity (percent of the relevant population in households above an income or entitlement threshold) that can be expressed as $D = PAE$. As with $I = PAT$, it is essential to realize that the population, affluence, and equity are not fundamental driving forces, nor are they independent from one another.

Each of the four reviews of driving forces also reveals potential "levers of change," variables that both control the rate of change and are subject to policy intervention. The one such variable that is consistent across all four cases is population. There is no question that the increasing world population makes progress on all aspects of sustainability more difficult. However, population growth is susceptible to policy intervention. Indeed, concerted policies and programs can achieve a 10% reduction in the size of the population now projected for 2050 (34). In the same vein, education is not only an important goal in and of itself, but is an important prerequisite for long-term gains in poverty reduction and technological innovation. The availability of teachers is a key factor that limits the rate of educational progress (27). Policies to overcome this barrier include importing teachers from donor countries, voluntary and mandatory public service programs, and adult literacy campaigns. Opportunities for reducing hunger are most likely to be found in programs for reducing income inequality through a combination of entitlements and poverty reduction.

After accounting for population, the levers of change for critical trends in life-support systems tend to focus on technology. The capital investment time horizon seems to be the limiting factor for decreasing emissions of greenhouse gases. This time horizon can be shortened through a combination of investment incentives and taxes or regulations that provide disincentives for continued operation of inefficient capital equipment. Similarly, the rate of future consumptive water withdrawals is most likely to be influenced by the rate at which farmers invent and adopt water-efficient agricultural technologies and practices. This rate can be accelerated through the use of economic and regulatory incentives along with aggressive public and private extension services.

There are also a number of tantalizing, although anecdotal, cases that suggest changes in consumer preferences can alter future scenarios significantly for the better (48, 50). Some of these stories are classic examples of the Kuznets hypothesis. For example, altruistic consumer willingness to pay a premium for shade-grown coffee is reducing pressure for certain types of deforestation. Others such as the substitution of poultry for beef in the United States are driven by self-interested health concerns (51).

Finally it should be noted that the minimal consensus goals and targets that currently characterize a sustainability transition and the forces that affect their attainment will surely change over time. Success in achieving these modest goals will raise the global aspiration level, whereas continued sluggishness will lower it. Thus perhaps the most powerful lever of change is the concerted willingness of governments, business, and civil society to press ahead with the well understood actions needed to achieve the current 2015 goals of the Millennium Declaration and the World Summit for Sustainable Development.

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