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Reducing Our Ecological Footprints

William E. Rees

During Global Forum '94, an international convention for urban planners, Professor Rees presented the results of his eco-economic studies. At the center of his thesis is the concept of ecological footprints – essentially the amount of land each of us needs to maintain a certain standard of living. His ideas, which stand in contrast to the views of classical economists, are sure to provoke plenty of discussion.

For the first time in the three million year history of our species we have acquired the power if not the wisdom to alter the course of planetary evolution. It is true that human beings have long been able to alter the face of the Earth, but such 20th Century phenomena as human-induced atmospheric change and ozone depletion affect the entire ecosphere and pose an unprecedented threat to global stability.

The human enterprise has grown exponentially since the beginning of the 19th Century and the growth rate itself has accelerated through the 20th Century. In fact, the global economy has doubled and more than doubled again just since the end of World War II and at prevailing growth rates (3% to 4%) will repeat this performance in the next half-century.

One result is an unprecedented level of material and energy exchange between the economy and the ecosphere. Within the lifetime of the reader, this expanding material flow has elevated human beings from minor shareholder status to the point where we have a nominal controlling interest in nature's economy. People are now the major consumer species in all the significant ecosystems of the world. By 1986, humankind, one species among millions, was appropriating or otherwise diverting more than 40% of the products of terrestrial photosynthesis to its own use, and the demand for non-renewable resources was rising apace. At the same time, the laws of energy conservation and mass balance dictate that the entire energy and material flux through the economy must return in altered form as pollution and waste to the ecosphere.

The problem is that the sheer volume of these human-induced flows is accelerating the deterioration of major ecosystems and is now capable of disrupting life support functions essential to the maintenance of life itself. This sobering conclusion is no longer exclusively that of nervous ecologists, deep greens, and the professional radical fringe. As Professor Terry Barker of the University of Cambridge points out "it is the scientific, political, and economic consensus as expressed by the United Nation's Intergovernmental Panel on Climate Change, The Brundtland Report, the (U.N.) Conference on Environment and Development in Rio de Janeiro, the Business Council for Sustainable Development, and the World Resources Institute," and many independent analysts.

In effect, global change signals the virtual convergence of the economy with the ecosphere and implies a new type of constraint on the expansion of the human enterprise. Indeed, to the extent that material consumption is tied to economic growth, even one more doubling (expected within 23 years) would see human beings commandeering virtually the entire output of nature. Moreover, material consumption during that 23 years would be equivalent to total consumption during all previous doubling periods combined! The diminishing prospects for ecological stability in these circumstances has prompted economist Herman Daly to argue that we must begin the transition from "empty-world to full-world economics," a shift in worldview that he terms "an historical turning point in economic development." Daly's full-world economics implies a more ecological economics.

Toward Ecological Economics

There can be little doubt that few political leaders and international development institutions acknowledge or understand the new eco-economic reality. Environmental policies in most countries, and even recent international environmental accords, still reflect the prevailing expansionist worldview that humankind has mastered nature and that "the environment" can be engineered at will to satisfy almost any level of human demand. This traditional perspective contrasts sharply with the emerging ecological worldview as revealed by their respective economic models.

Expansionist thinking is well reflected in neoliberal (neoclassical) market-based economics which has come to dominate the world economy in recent years. This model, based on ideas bor-

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rowed from classical mechanics, treats the economy as a self-sustaining system of circular flows, separate from, and essentially independent of nature. According to this perspective, human ingenuity, stimulated by rising prices, will enable technology to substitute for depleted natural resources, while pollution-related damage is avoided through full cost pricing and other measures to "internalize the externalities." The economy, unconstrained by environmental factors, is thus free to grow indefinitely. Accordingly, the shortest route to sustainability is through freeing up markets, liberalizing trade, and reducing government intervention in the marketplace. This will stimulate a new round of global economic expansion generating the money wealth needed both to alleviate poverty and to provide the surpluses needed to husband the natural environment.

By contrast, ecologically-minded economists argue that humans continue to depend on nature. Far from existing in splendid isolation, the human economy is seen to be a functionally integrated, completely contained, wholly dependent, growing, open subsystem of the materially closed, non-growing ecosphere. As such, economic activity is governed not by mechanics but by the same thermodynamic laws that govern material and energy transformations in the rest of the natural world. From this perspective, the most important flows in the economy are not the circular flows of money, but rather the unidirectional and irreversible flows of energy and materials from nature through the economy and back to nature in degraded form.

Many of these critical flows are simply invisible to conventional analysis. Thus, ecological economists argue that while markets may work adequately to monitor the state of familiar, mostly non-renewable resources, the conventional system of costs, prices, and market incentives fails absolutely to warn of scarcity in the case of essential ecological goods and services for which there are no markets and for which there may be little possibility of technological substitution (e.g., the ozone layer).

Thermodynamic laws make sustainability a much more complicated issue for ecological economists than it is for their neoclassical colleagues. In particular, the Second Law suggests that all highly-ordered, complex systems maintain their internal order and remain in a dynamic non-equilibrium state by continuously dissipating available energy/matter extracted from their host environments. Since the economy is a subsystem of the ecosphere, this model predicts that beyond a certain point increases in the human population and the stock of manufactured capital must inevitably result in the depletion of so-called "natural capital," reduced biodiversity, air/water/land pollution, atmospheric change, etc – and overwhelming pollution. Such symptoms of the progressive disordering of the ecosphere are, in fact, a distinguishing feature of our age.

Conserving Natural Capital

On the positive side, global change has forced environmental and ecological economists to stop treating ecosystem processes and natural resources as mere "free goods of nature." They now recognize that natural resources represent a special class of productive capital capable of producing flows of valuable goods and services indefinitely into the future. Sustainability considerations have therefore elevated natural capital to the same theoretical status as the more familiar manufactured or human-made capital (physical plant, machinery, infrastructure, etc.) and human/social capital (knowledge, skills, social infrastructure, etc.).

To illustrate, consider a forest, a fishery, or arable land. These are examples of natural capital that can provide a tangible yield that is potentially sustainable year after year. As eco-economists Robert Costanza and Herman Daly have noted, the stock that produces this continuous flow is the "natural capital" and the sustainable flow derived from it can be thought of as "natural income." Certain forms of natural capital also provide intangible services such as waste assimilation, flood control, and protection from ultra-violet radiation, which are also counted as natural income.

Natural capital falls into three broad categories: Renewable natural capital includes living species and ecosystems that are self-producing and self-maintaining using photosynthesis. The second class includes replenishable natural capital (e.g., ground water and the ozone layer). Although non-living, these systems are often ultimately dependent on the solar engine for renewal. The third category comprises non-renewable natural capital such as fossil fuels and minerals. These stocks are more like inventories: any use implies liquidating part of the stock.

There is general agreement that no development path is sustainable if it depends on reducing productive assets. From the perspective of capital theory, society can be said to be economically sustainable if it passes on an undiminished per capita stock of capital from one generation to the next. Ecologists and economists are therefore debating various interpretations of a "constant capital stock" condition for sustainability in which the major bone of contention is the degree to which manufactured capital can be substituted for natural capital.

Mainstream economists and most development planners assume close substitutability and favor a weak sustainability criterion in which the aggregate stock of manufactured and natural capital must be held constant. By this criterion, it is of little consequence if natural capital assets are depleted as long as part of the returns are invested in creating an equivalent value of manufactured capital.

On the other hand, ecological economists regard natural and manufactured capital as complements rather than substitutes. More fishing boats, for example, are no substitute for a depleted fish stock. In addition, there is little possibility that technology could ever substitute for certain essential life-support services. The ecologically-minded therefore support a strong sustainability criterion in which both natural and manufactured capital are held intact separately. This more risk-averse version of the constant capital stocks criterion for sustainability can be stated as follows:

Each generation should inherit per capita stock of both manufactured and self-producing natural assets no less than the stock of such assets inherited by the previous generation.

Manufactured capital aside, this version of the constant capital stocks criterion implies that humankind has no choice but to live on the income generated by remaining (or enhanced) stocks of essential natural capital. These physical flows are related to Hicksian (or "sustainable") income, that is, the level of consumption that can be maintained from one period to the next without reducing real wealth.

The Ecological Footprint of the Human Economy

The primary question for ecological economics is whether remaining stocks of natural capital are adequate to supply the resources required and assimilate the wastes produced by a global economy supporting twice the present human population into the next century while simultaneously maintaining the life-support functions of the ecosphere. In other words, does the Earth have sufficient carrying capacity to sustain indefinitely the anticipated demand of the total human enterprise?

At the University of British Columbia's School of Community and Regional Planning my students and I have developed a method to estimate natural capital requirements based on a novel definition of carrying capacity. Ecologists usually define carrying capacity as the maximum population of a given species that can be supported indefinitely in a particular habitat without permanently damaging that habitat or ecosystem. However, most conventional analysts reject this definition when applied to humans. After all, why should the growth of any population or economy be constrained by resource limitations when trade can relieve local shortages and technology can substitute for more universal scarcities?

Good point. However, we can subvert this objection simply by inverting the standard carrying capacity ratio. Rather than asking what population a particular region can support sustainably, the relevant question becomes: How large an area of productive land is needed to sustain a defined population or economy indefinitely, wherever on Earth that land is located? Regardless of trade and technological wizardry, everyone uses some resources from somewhere and thus imposes a measurable load on the Earth.

Our approach uses land area as a proxy for natural capital. Since many forms of natural income are dependent on terrestrial ecosystems and associated water bodies, it should be possible to estimate the area of land/water required to produce sustainably the quantity of any resource or ecological service used by a defined population or economy at a given level of technology. The sum of such calculations for all significant categories of consumption would give us a conservative area-based estimate of key natural capital requirements for that population or economy. We refer to this aggregate land area as the rele-

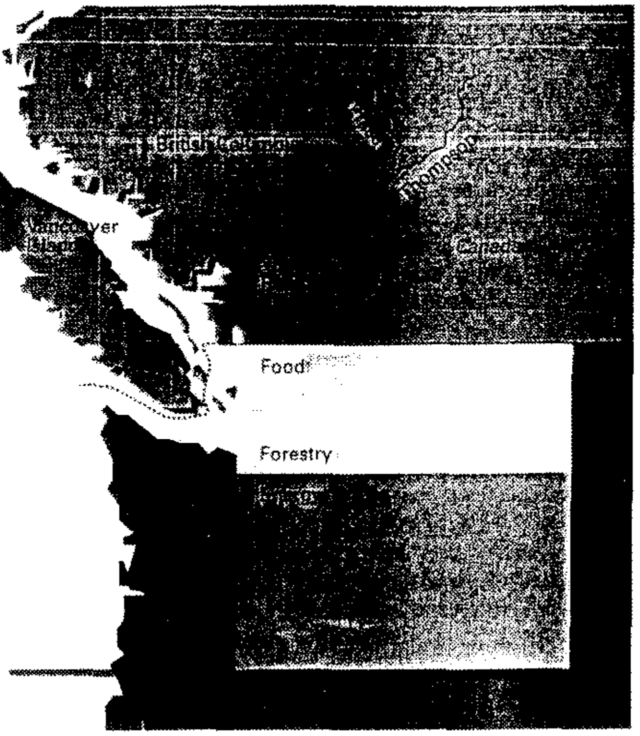


Fig. 1
To sustain its current standard of living, the Vancouver-Lower Fraser Valley requires the ecological output of an area at least 19 times its size. This natural income is obtained by exploiting local natural capital, through trade, and by appropriating flows from natural bio-geochemical cycles.

vant economy's de facto "ecological footprint" on the Earth.

To illustrate this idea, consider any modern city of your choice. First, imagine what would happen to your city as defined by its political boundaries, the concentration of socioeconomic activities, or the area of built-up land, if it were enclosed in a glass hemisphere that admitted light but prevented material of any kind from entering or leaving. This means that the physical health and functional integrity of the entire human system so contained would depend entirely on whatever was initially trapped within the hemisphere. It is obvious to most people that such a city would cease to function and its inhabitants would perish within a few days. The population and the economy contained by the capsule would have been cut off from vital resources and essential waste sinks leaving it both to starve and to suffocate at the same time! In other words, the ecosystems contained within our imaginary human terrarium would have insufficient carrying capacity to service the ecological load imposed by the contained human population. Our mental model reminds us rather abruptly of humankind's continuing ecological vulnerability.

Now let's assume that our experimental city is surrounded by a diverse terran landscape in which cropland and pasture, forests and watersheds, all the different ecologically productive land-types, are represented in proportion to their actual abundance on the Earth, and that adequate fossil energy is available to support current levels of consumption for the foreseeable future. Let's also assume our imaginary glass enclosure is elastically expandable. The question now becomes: How large would the hemisphere have to become before the city at its center could sustain itself indefinitely and exclusively on the land and water ecosystems contained within the capsule? In other words, what is the total area of terrestrial ecosystems needed on a continuous basis to generate the resources consumed and assimilate the wastes produced by the people of your city going about their day to day lives? The answer to this question would provide an estimate of your city's actual (if invisible) "ecological footprint." Its size would depend on the city's population, on the values and life-styles of the people, on the efficiency of their technologies, and on the sophistication of their land/resource management practices.

This exercise illustrates that as a result of high population densities, the enormous increase in per capita energy and material consumption made possible by (and required by) prevailing technology, and universally increasing dependencies on trade, the modern city or industrial region is dependent for maintenance and growth on a vast and increasingly global hinterland of ecologically productive landscapes.

Data from my home region, the lower Fraser River Valley of British Columbia, Canada, serve as an example. This urbanizing agricultural valley extends inland from the seaport city of Vancouver to the town of Hope approximately 155 km to the East and has a population density only slightly less than that of the Netherlands. Considering only three important categories of consumption, domestic food, forest products, and fossil energy, is sufficient to illustrate the major strengths of ecological footprint analysis.

The average Canadian requires nearly one hectare of crop and grazing land under current land management practices to produce his/her high meat protein diet and about 0.5 ha for wood and paper products. Canadians are also among the world's highest fossil energy consumers with an annual carbon emission rate of 4.2 tonnes carbon (15.4 tonnes CO_2) per capita (data corrected for carbon content of trade goods). Therefore, at a carbon sequestering rate of 1.5 tonnes/ha/yr, an additional 2.8 ha of middle-aged North temperate forest would be required as a continuous carbon sink to assimilate the average Canadian's carbon emissions (assuming the need to stabilize atmospheric carbon dioxide levels).

These three categories of resource consumption and waste assimilation alone contribute 4.2 ha to the individual footprint of a typical Canadian. On this basis, the 1.8 million people living in the Lower Fraser Valley require, conservatively, 7.6 million ha of temperate land for their exclusive use to maintain their current consumption patterns (assuming such land is being managed sustainably). However, the area of the valley is only about 4000 km² (400,000 ha). This means that the regional population "appropriates" the productive output of a land area nearly 19 times larger than its home territory to support its present consumer lifestyles (Fig. 1).

Nor is the Vancouver area unique. Some entire countries have a similar dependency on external ecoproductivity. For example, our estimates show that the Netherlands requires a land area at least 14 times larger than the country itself to support current domestic consumption. Dutch government data reveal that for food alone (including food "produced" in the Netherlands for export) the Netherlands "imports" 100,000 to 140,000 km² of agricultural land, mostly from the Third

World. This is five to seven times the area of agricultural land in the country (or three to four times the area of the entire country).

In conventional accounting terms both of these highly developed regions would be regarded as economic success stories with positive current account and trade balances. However, physical flow analysis shows that each is running a massive unaccounted ecological deficit with the rest of the planet.

Sustaining Development with Phantom Planets?

One of the current objectives of international development is to raise the Third World to the material standards enjoyed by the First World. The Brundtland Commission pointed out that this would depend on "more rapid economic growth in both industrial and developing countries" and suggested that "a five to ten fold increase in world industrial output can be anticipated by the time world population stabilizes some time in the next century."

These development goals force us to consider the first axiom of ecological footprint analysis: on a finite planet, not all countries or regions can be net importers of carrying capacity.

If just the present world population ot 5.7 billion people were to achieve current Canadian ecological standards (4.2 ha/person), a conservative first approximation of their total productive land requirements would be 24 billion ha (assuming present technology). However, there are only about 13 billion ha of land on Earth, of which only 8.8 billion are ecologically productive cropland, pasture, or forest (1.5 ha/person). In short, we would need an additional two planet Earths to accommodate the increased ecological load of people alive today. If the population were to stabilize at between 10 and 11 billion in the next 40 or 50 years, five additional Earths would be needed, all else being equal and this only to maintain the present rate of ecological decline. However astonishing this result may seem, it probably represents a considerable underestimation because the five phantom planets result is based on only three categories of natural income. Such is the "sustainability gap" being generated by prevailing technologies and development policies.

Needed: A "Factor-10" Economy

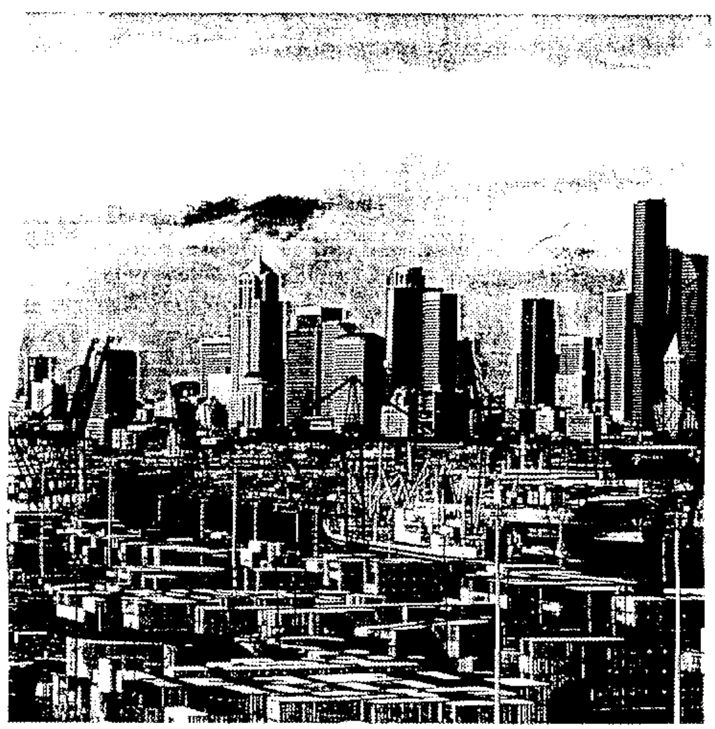
There is no getting around the fact that material consumption is at the heart of the sustainability crisis. With the world economy already running an ecosphere deficit, there is clearly insufficient natural capital to sustain even present demand. Since rapid economic growth, particularly in the developing world, is deemed the only politically feasible way to address this conundrum, scientists and economists in many countries are exploring potential mechanisms for, and policy implications of, reducing the energy/material throughput of so-called advanced economies. Researchers such as Ernst von Weizsäcker, Friedrich Schmidt-Bleek and colleagues at Germany's Wuppertal Institute, Paul Ekins and Michael Jacobs of Cambridge University, J.B. Opschoor and colleagues of the Netherlands' Advisory Council for Research and Environment, as well as Washington's Worldwatch Institute and the Business Council on Sustainable Development have determined that material intensity per unit of consumption must be reduced by a factor of up to ten to accommodate the needed growth in both rich and poor countries.

Clearly, achieving a "factor 10" economy will require wrenching changes in industrial strategy, fiscal and taxation policy, and consumer-corporate relations. However, if managed properly, the net effect of this transformation should be less consumption and waste as well as more jobs and increased regional self-reliance. It is also important to emphasize that those countries and businesses that act first to develop new energy/material efficient technologies and processes will gain the competitive upper hand. The richest opportunities lie in materials science, alternative energy, clean production technology (including industrial ecology), transportation, and communications.

Ecological Taxes for Sustainable Development

It is an economic axiom that under-pricing leads to overuse. Much of the sustainability crisis derives from the fact that today's prices do not reflect the resource depletion or pollution damage costs of economic goods and services. Ecological and economic sustainability requires the restructuring of economic incentives and taxation policy to encourage material and energy conservation. A major objective should thus be to decouple the profitability of commercial firms from the throughput of energy and material and tie profitability to the provision of services. Many analysts, including representatives of the Commission of the European Communities, argue that this can best be achieved by replacing present fiscal and environmental subsidies with a system of resource use and depletion taxes, and marketable quotas, off-set by corresponding reductions in other taxes, particularly on labor.

Fig. 2
Because most people in the industrialized world live in cities, strategies to reduce urban energy and materials consumption would have a high "sustainability multiplyer" effect.



Because they reduce throughput, resource use and depletion levies may also be as effective at reducing pollution as are comparable existing pollution charges. (Indeed, much of the pollution abatement and control effort of recent years, estimated to be costing industry in Europe and North America U.S. $150 billion per year, may be misspent because it is directed at the wrong end of the materials stream.) Ernst von Weizsäcker argues that if such ecological taxes were introduced as part of a fundamental tax reform, they would have to be 50 or even 100 times higher than the special environmental charges presently set in some jurisdictions. Such high levels may be necessary to bring about the rapid and fundamental restructuring of the economy required to attain sustainability.

Full-Cost Pricing Means Less Waste, More Jobs

By raising the prices of goods and services to reflect their full social costs, taxes on energy and resources create an incentive for industry to minimize material throughput. High material and energy costs encourage reuse, repair, reconditioning, and recycling, all essential components of the "optimal utilization" economy. Recycling is already widespread, but is not nearly as environmentally effective or economically efficient as reuse, repair, and remanufacturing.

Product-life extension activities partially replace capital-intensive resource extraction and original manufacturing activities with local labor- and skill-intensive shop units. According to Swiss analyst Walter Stahel, product life can be enhanced "by designing intercompatible systems with distinct functional modules, separating, for instance, structural elements (a car chassis), skin elements (bodywork), wear and tear components (engine), and control components." These structural modules can be replaced as required with new or (preferably) remanufactured units as required, without discarding other modules still in good working order. He notes that reconditioning a car to make it last a second ten years requires 42% less energy and 56% more labor than manufacturing a new car; and refurbishing and recycling of washing machines can reduce resource consumption and waste volume by 90%.

Creating incentives to redirect investment into renewable energy development and conservation has great potential for reducing consumption and increasing employment while actually improving material standards and overall quality of life. For example, research reviewed by the Worldwatch Institute reveals that:

- At the local level, energy conservation and efficiency programs create four times as many jobs as does spending on new supply, partly because reduced energy bills allow investment in other job-creating businesses.
- Investments in energy conservation, solar, and other renewable energy technologies create twice as many jobs as do investments in conventional capital-intensive energy supply projects.

A tax- or quota-induced increase in energy efficiency of just 2% per year could reduce global energy intensity by almost two-thirds over 50 years and would therefore be justified on economic grounds alone. Some industrial countries have already managed to achieve this rate of efficiency growth.

Reinventing the City

Cities are the proudest product of technological civilization; but in ecological terms they are also nodes of pure consumption, the black holes of industrial society. This means, paradoxically, that while there is no hope for the city per se to achieve sustainability independent of its vast and scattered global hinterland, it is in cities that the greatest opportunities exist to make the changes necessary for general sustainability. Most people in the industrial world live in cities, most consumption takes place in cities, and therefore strategies designed to reduce energy and materials consumption in cities could result in enormous savings because of the economies of scale inherent in high urban densities. In short, reinventing the city would have a high "sustainability multiplier" effect.

A single example will suffice. Consider the effect of reallocating a major proportion of the direct and indirect public subsidy to private automobiles (up to U.S. $2500 per year per vehicle in North America) to public transit. Over time, such a shift would contribute to better urban air quality, improved public health, reduced threat of climate change, improved accessibility, more efficient land use, more affordable housing, and the conservation of crop lands. While tampering with the seemingly inalienable rights of motorists has long been deemed to be politically infeasible, economic common sense aligned with global change should help redefine the boundaries of practicality.

Beyond Technology: The Moral Transition

So far we have discussed the transition to sustainability strictly in terms of technological innovation and the structural changes in the economy needed to bring it about. This may not be enough. Given the scale of the task ahead there may be insufficient time for technology alone to create the "ecological space" needed by the world's poor to grow. Thus, the ecological imperative also presents an ethical dilemma. At the limits of material throughput and technological adaptation, can the richest quarter of the world's people continue to lay moral claim to three-quarters of the world's wealth? To the extent that ecological and geopolitical stability depend on greater material equity, the world may have to consider mechanisms for the redistribution of income, including natural income, from North to South and from rich to poor.

This second front in the quest for global security may be interpreted as a challenge to consumerism, the growth ethic, and other fundamental values of industrial society. But just as technologies can become obsolete with improved understanding and new discoveries, so too can perceptions, beliefs, and values. If prevailing values have led us astray, reaching our destination may require a different road map. In short, perhaps the time has come to shift our collective emphasis from merely promoting growth to fostering long-term development. Growth means getting bigger, while development implies becoming better, and there is no fixed relationship between the two. Given a choice, most people would opt for a path that guarantees development with or without growth, while promoting ecological security. At the very least, this requires restoring the balance between competition and cooperation, between individual rights and social responsibility, and between the use of private (and national) property and conservation of the global commons. In the final analysis, the most viable form of sustainability may derive from investments that pay social rather than purely monetary dividends. This may prove to be the most difficult stretch on our route to global sustainability. •