SCIENTIFIC JUSTIFICATION FOR ENVIRONMENTAL AND ECOLOGICAL SUSTAINABLE DEVELOPMENT

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Summary

This article shows that science and technology will play a central role in working toward sustainable development. Scientific research will be crucial to better understanding how human activity affects the environment. The sciences, like new technologies, should continue to provide for an improvement in the efficiency of resource utilization and in developing new practices, resources, and alternatives. Thus, the sciences are increasingly being understood as an essential component in the search for feasible pathways towards sustainable development.

Meeting scientific research needs in the environment and development field is only the first step in the support that the sciences can provide for sustainable development. Finally, the article introduces the changes of technology associated with the energy systems of the far future.

1. Introduction

In working toward sustainable development, science and technology must play a central role. Scientific research will be crucial to better understanding how human activity affects the environment. New technologies hold the promise of resolving many current problems if they are properly applied and disseminated.

In particular, biotechnology, the science of changing the genetic code in plants, animals, and microbial systems to create useful products and technologies, is quickly emerging as having great potential and pitfalls. However, with proper management, biotechnology can make significant contributions to sustainable development in a variety of areas, including health, agriculture, and pollution reduction, and the clean up of toxic chemicals. Countries need the ability to access, generate, and utilize knowledge in order to achieve sustainable development and join the dialog among the scientific and technical communities.

Scientists are improving the understanding of areas such as climatic change, growth in rates of resource consumption, demographic trends, and environmental degradation. Changes in those and other areas need to be taken into account in working out long-term strategies for development. A first step towards improving the scientific basis for these strategies is a better understanding of land, oceans, and atmosphere and their interlocking water, nutrient, and biogeochemical cycles and energy flows, which all form part of the earth's system. This is essential if a more accurate estimate is to be provided of the carrying capacity of the planet and of its resilience under the many stresses placed upon it by human activities. The sciences can provide this understanding through increased research into the underlying ecological processes and through the application of modern, effective, and efficient tools that are now available, such as remote-sensing devices, robotics monitoring instruments, and computing and modeling capabilities. The sciences are playing an important role in linking the fundamental significance of the earth's system as life support to appropriate strategies for development that build on its continued functioning. The sciences should play an increasing role in providing for an improvement in the efficiency of resource utilization and in developing new practices, resources, and alternatives. There is a need for the sciences constantly to reassess and promote less intensive trends in resource utilization, including less intensive utilization of energy in industry, agriculture, and transportation. Thus, the sciences are increasingly being understood as an essential component in the search for feasible pathways towards sustainable development.

Meeting scientific research needs in the environment and development field is only the first step in the support that the sciences can provide for the sustainable development process. The knowledge acquired may then be used to provide scientific assessments or audits of the current situation and for a range of possible future conditions. This implies that the biosphere must be maintained in a healthy state and that losses in biodiversity must be slowed down.

2. Technology and Energy Systems of the Future

Of the technological changes associated with the deep future energy system, among the most important will be the decline of combustion technologies to close their fuel cycle of fossil carbon oxidation through the atmosphere. The remaining combustion processes will operate on hydrogen, sustainable biomass, or biomass-derived hydrogen-rich fuels. Of course, by the mid twenty-first century numerous additional environmental technologies will have enriched the technology options. Carbon scrubbing and fossil-sourced hydrogen-rich fuel production may well eke out the fossil era. In any case, technological invention and innovation, in part stimulated by revised energy market prices that reflect their full social costs, will ensure a high degree of technology diversity.

The alternatives to fossil fuels are many, and they have all been explored and tested: wind energy, tidal energy, hydropower (though our uses of it have challenged the sustainability of salmon and other wildlife), geothermal, biomass, solar hydrogen gas, solar photovoltaics (P.V.), and so on. What we haven't assessed is how these alternatives compare in terms of real costs to the real costs of fossil fuels and their use.

The deep future energy system has the structure of a quasi zero-pollution energy system based on the single premise that local air-quality issues in the short run, and greenhouse gas emissions in the longer run, mandate the restructuring of the energy system to eliminate the use of fossil-energy-sourced carbon. If this premise stands the test of time, the configuration of the future energy system will be determined by the forces that render the current system obsolete. Most importantly, the future energy system will need to eliminate the unacceptable burdens that the present system places on the environment, and will ultimately be based on sustainable non-fossil sources and non-carbon currencies. However, the transition phase to the zero-carbon energy system will probably last a century or more.Before the beginning of the industrial revolution, some two centuries ago, human activities—on the average—were not really incompatible with a healthy and sustainable biosphere. The vast majority of people lived and worked on farms. Land was the primary source of wealth. Horses and other animals, supplemented by windmills, sail, and waterwheels, provided virtually all power for plowing, milling, mining, and transport. The sun, either directly or through photosynthesis, provided virtually all energy except in a few coal-mining regions. Metals were mined and smelted (primarily by means of charcoal), but their uses were almost exclusively metallic rather than chemical. Recycling was normal.

By the end of the twentieth century, humans were far more numerous and they were wealthier (on average) than two centuries before. In particular, those countries that industrialized first are now comparatively rich. In the rich countries, most people live in cities. Land is no longer the primary source of wealth. Energy (except food) is largely derived from the combustion of fossil fuels (coal, oil, and gas). Power for machines is obtained mainly from engines driven by heat from (internal or external) combustion of fossil fuels. (Nuclear and hydroelectric power, together, account for a relatively small percentage of the total.) However, one key attribute of this recent rise to wealth is critical for the future of humankind: what we have achieved so far has been done by exploiting an endowment of natural capital, especially topsoil and minerals. For some material resources, technology can offer viable substitutes. For other resources in the natural endowment—notably the biosphere and its functions—no substitute is likely.

It has been widely recognized that there is a very real conflict between meeting human needs and desires and the possibility of satisfying those expectations by the middle of the twenty-first century. It will be exceedingly difficult simultaneously to satisfy the objectives of environmental preservation, on the one hand, and accelerated economic development of the undeveloped world based on current population trends and energy–material intensive technologies, on the other.

3. Defining the Environmental Threats

Experts can and do disagree on the probabilities and timing of environmental threats relative to other problems facing the human race. Some have even argued that the threats are figments of the fevered imagination of the conservationist "Greens." Arguments on these matters will probably continue for some time. However, there is increasing evidence that major changes in the global economic and industrial system may be needed if the world is to achieve a sustainable state before the middle of the twenty-first century. Even though there is not yet a scientific consensus on the extent of the needed changes, it is clear that they will involve significant technological elements, as well as major investment.

The kinds of techno-economic changes envisaged as preconditions for long-term sustainability also include a sharp reduction in the use of fossil fuels (especially coal) to minimize the danger of global greenhouse warming. Alternatives to increasing use of fossil fuels include a return to nuclear power, large-scale use of P.V., intensive biomass cultivation, large-scale hydroelectric projects (in some regions), and major changes in patterns of energy consumption and conservation. Again, there are disputes over which of these energy alternatives are the most (least) desirable, feasible, etc. However, the future of energy, from both the supply (technology) and the demand perspective, is a critical topic.

Again, the broad question is how to shift from a techno-economic trajectory based on exploiting natural resources—soil, water, biodiversity, climate—that, once lost, can never be replaced, to one that could lead to a society that preserves and conserves these resources. To facilitate this search, science approaches the problem in three stages. First, it attempts to identify the most pressing questions, especially with regard to the severity of the threat and the technical feasibility of solutions. Next, it attempts to distinguish those issues about which there is little or no scientific disagreement from those about which the evidence itself is in dispute. Thirdly, it raises the most fundamental question of all: how to get from "where we are" to "where we need to be."

Another example of increasing consensus concerns climate change. The climate is certainly an environmental resource. Even by the early 1990s there were still a number of scientists expressing serious doubts about whether the problem was "real." The major source of doubt had to do with the reliability of the large-scale general circulation models of the atmosphere used to forecast the temperature effects of a build up of greenhouse gases (e.g. carbon dioxide, methane, nitrous oxide, chlorofluorocarbon (CFC)). Since then, the models have improved significantly and it has been established fairly definitely that climate warming has been "masked" up to now by a parallel build up in the atmosphere of sulfate aerosol particles (due to sulfate dioxide emissions) that reflect solar heat and cool the earth. The two effects have tended to compensate each other. However, the greenhouse gases are accumulating (they have long lifetimes) whereas the sulfur aerosols are quickly washed out by rain. In other words, the greenhouse gas concentration will continue to increase geometrically, whereas the sulfate problem may increase only arithmetically or not at all (if sulfur dioxide emissions are controlled). In any case, the intergovernmental panel on climate change has now agreed that the greenhouse problem is indeed real. The controversy continues, however, with regard to likely economic damage and optimal policy responses.

Yet the environment is by its very nature unsuited to incremental control strategies. It is equally unsuited for reductionist "bottom-up" modes of analysis. The problem is that scientific insights are and will continue to be insufficient for predicting the detailed environmental consequences of any change or perturbation. To take a concrete instance, nobody can predict the exact physiological effects of ingestion of any chemical from knowledge of its structure. Still less can the genetic or ecological consequences of its dispersion be predicted. This uncertainty is multiplied by the enormous number of different chemical materials and mixtures (natural and synthetic alike) simultaneously manufactured and used by humans, not to mention the variety (type and intensity) of possible reaction modes and interaction effects.

Setting aside carcinogens and highly toxic or radioactive substances, only one important environmental problem has been predicted in advance from the creation or displacement of any particular material stream. This single exception was Rowland's chance recognition of the reactive potential of CFCs in the stratosphere, and the resulting possibility of stratospheric ozone depletion. This potential hazard, derided by chemical industry representatives in the 1970s as "speculative," turned out to be very real.

The "ecological" scientific criterion for sustainability admits the likelihood that some of the important functions of the natural world cannot be replaced within any realistic time frame—if ever—by human technology, however sophisticated. The need for arable land, water, and a benign climate for agriculture is an example; the role of reducing bacteria in recycling nutrient elements in the biosphere is another; the ozone layer of the stratosphere is a third. The ecological criterion for long-run sustainability implicitly allows for some technological intervention: for example, methods of artificially accelerated tree growth may compensate for some net declares in the area devoted to forests. But, apart from any plausible technological "fixes," this definition does not admit the acceptability of major climate changes, widespread desertification, deforestation of the tropics, accumulation of toxic heavy metals and non-biodegradable halogenated organics in soils and sediments, or sharp reductions in biodiversity, for instance.

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Biographical Sketch

Jun Peng graduated from Tsinghua University, Beijing, and received a master's in engineering from the Department of Engineering Physics, Tsinghua University. Jun Peng now works in the State Environmental Protection Administration.