eEnvironment: the Role of Information and Technology in Improving Environmental Performance

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Abstract. The term "eEnvironment" is a neologism that represents a branch of science and technology in which advanced information-age techniques are developed and used to serve environmental purposes. Information technologies could enhance many of our present approaches to pollution control and natural-resource management. Computers, the Internet, advanced communications devices, sensors, and other innovations will make it easier and cheaper to address many existing sources of regulatory and management failure. Better data and analysis will mean that decision-makers face fewer technical uncertainties. From another, complementary point of view, informatics breakthroughs may also create new problems in the environmental domain and may exacerbate existing policymaking pathologies, due for instance to the need of heavy investments that not all nations can afford. Human cognitive limitations will remain an issue for some time, too. But, in general, a more data-driven approach to environmental protection may provide some powerful new tools in terms of refined governmental capacity to manage complexity.

1 Introduction

The term "eEnvironment" is a neologism that represents a branch of science and technology in which advanced computer-science techniques are developed and used to serve environmental purposes. Given the many facets of the concept "environment", the new term cannot be directly expanded (as normally happens) into "electronic environment", "online environment", "cyber environment", "virtual environment" or "Web environment", without losing part or all of its meaning. Better ways to expand the new term are possibly: "electronic environmental-management", "computer-aided environmental-management" or "information-age environmental protection". The term is also related to the concept of "environmental informatics" [2], which can be considered to be the science and art of turning environmental data into information and understanding or also the research and system development focusing on the environmental sciences relating to the creation, collection, storage, processing, modeling, interpretation, display and dissemination of data and information.

Important work that falls under the eEnvironment label includes work towards an improved and shared information infrastructure about environmental issues to allow better use and reuse of environmental data; work to provide better access to environmental data supporting more effective implementation and management practices, including decision-making tools and assessment of policies; work to enable provision of more harmonized and higher-quality environmental data; application of artificial-intelligence (AI) techniques to environmental-impact assessment, environmental modeling and forecasting, decision-support systems and environmental management.

1.1 Motivations in the eEnvironment Domain

In many cases, basic motivations behind work in eEnvironment are the challenges of reaching an equitable and sustainable ecosystem management at local and global levels, but also the simple lack of reliable data. A report by the World Resources Institute, the World Bank and the United Nations [21], analyzing the *best* available environmental data, reached the following conclusions:

1. A number of ecosystems are fighting to survive under the impact of human activity.
2. Ecosystems in the future will be less able than in the past to deliver the goods and services human life depends upon, which points to unsustainability.

According to the report, despite many positive signs, the challenge of defining and reaching equitable and sustainable ecosystem management at a global level should not be minimized. It includes asking ourselves such difficult questions as:

- How can we manage watersheds and water resources in the face of potential increases in demand of up to 50 percent for irrigation water and up to 100 percent for industrial water by year 2025 [18]?
- Even if irrigation water can be found, how can we intensify our agriculture enough to feed future populations without increasing the damage from nutrient and pesticide runoff or without continuing to convert forests and other ecosystems to croplands?
- How can we continue to supply the roughly 1 m^3 of wood products per year that the average person consumes without decimating existing forests? And what if wood demand doubles in the next 50 years, as some project [20]?
- How can we reduce the impacts of urban areas (from sprawl to water use to air pollution and solid waste generation) on surrounding ecosystems as urban populations rise to an estimated 5 billion by 2030 [19]?

Of course, to know what is truly sustainable, reliable data are needed, while available environmental information is today often incomplete or missing altogether. Information gaps and uncertainties exist at the heart of many persistent pollution and natural resource management problems [8].

2 Do we have Sufficient Environmental Data-sets?

Information gaps badly affect environmental decision-making from the household level to the global scale [13]. The U.S. Environmental Protection Agency (EPA) has repeatedly recognized significant shortcomings in the core data sets on which regulatory decisions depend [6] [7]. Information problems are a fundamental issue holding society back from better results in pollution control and natural resource management [9], [10], [12].

From a theoretical point of view, the importance of good data and solid analytic information to sound environmental decision-making is clear. Without basic data, externalities cannot be identified and internalized. As a consequence, information gaps lead to market failures, legal-system breakdowns, and regulatory difficulties [5]. Nevertheless, much of the academic literature on how to improve environmental performance has approached information issues only indirectly or in passing, while significant work has been done in contiguous domains. For instance, many sources of environment-related regulatory failure have been studied, including:

- Distortions in policymaking;
- Questions concerning which level of government should assume environmental responsibilities;
- Risk-perception problems.

While data gaps are sometimes indicated as an issue, pervasive uncertainties are simply assumed by most researchers to be part of the framework within which environmental management has to operate [15], [16]. There are a few exceptions to this pattern:

1. A school has emerged around the concept of "information regulation" [3], but much of its analysis focuses on EPA's Toxic Release Inventory (TRI) and the disclosure of environmental information as a means for changing corporate behavior [11].
2. Other researchers have emphasized the value of providing information to citizens in their role as consumers.

In any case, even these two schools just try to manipulate the policy structure through revised information flows and fail to capture the important role of information, and especially information gaps, as a theoretical matter and as a fundamental source of both environmental regulatory and management failures. Certainly, the AI community captured the importance of information in environmental issues [4], [17], but its general approach has been to stretch the capacity of reasoning on poor-quality and low-quantity data to extreme limits, instead of seriously seeking more basic-information collection.

One of the most ambitious efforts on a global level to improve environmental-data collection and distribution is the Millennium Ecosystem Assessment (MA), an international work program designed to meet the needs of decision makers and the public for scientific information concerning:

- The consequences of ecosystem change for human well-being;
- The options for responding to those changes.

The MA (whose results will be released in early 2005) was launched within the U.N. in 2001 and it will help to meet assessment needs of the Convention on Biological Diversity, the Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species, as well as needs of other users in the private sector and civil society. In particular, the goal of the MA is to improve the management of ecosystems and their contribution to human development. The main desired outcomes of the project related to data collection and eEnvironment issues include to:

- Significantly increase understanding of the linkage between ecosystems and the goods and services they provide in a manner that will facilitate the integrated decision-making required to pursue more sustainable paths of development;
- Develop methodologies to undertake interdisciplinary assessments and to effectively integrate information across scales from the local to the global;
- Strengthen the influence of international environmental agreements and improve environment-related decisions of national governments by arming decision makers with scientifically-credible information about the current condition of ecosystems and the economic, public health, and environmental consequences of different actions.

Without this baseline of scientifically-credible information, not only research will suffer, but, even more importantly, government will not be able to make sensible decisions on environmental policy. Fortunately, we are now in a position such that a revolution in environmental data collection can take place, because of computing power, satellite mapping, remote sensing, advanced artificial-intelligence techniques and information-technologies pervasion.

The collection of good data would have benefits that transcend the environmental domain, such as helping markets to work more robustly. For example, US's pioneering system to cap-and-trade emissions of sulphur dioxide (a toxic, colorless gas used for many industrial and agricultural purposes), was made possible by advanced equipment capable of monitoring emissions in real time. And now the EU is following with an emissions trade scheme modeled after the US's one. Furthermore, information technology can also help to secure property rights and so to prevent overexploitation of the commons, thanks, for example, to tracking and monitoring devices.

It is important to note that the use of advanced technology should not be confined to rich countries and, in this sense, there are already good signs coming from poor nations. Conservationists in Namibia, for example, already use satellite tracking to keep count of their elephants. Farmers in Mali receive satellite updates about impending storms on portable radios. It is hoped that the day is not far off when such technology, combined with ground-based monitoring, will help Africans and Latin Americans to measure trends in deforestation and soil erosion, and assess the effects on their local environment [14].

2.1 Information Needs

Given the dynamic nature of environmental problems and the fast pace at which knowledge evolves in the ecological sciences and in informatics. each element in environmental management has to be constantly reexamined and refined. Changes in circumstances (increased population density. greater scarcity of resources. shifts in the underlying scientific knowledge base. or technological breakthroughs) will often alter the models that have been previously created. A whole set of issues has therefore to be taken into account. of which Table 1 gives an example referred to the *pollution* domain [8].

Table 1. Information needs in eEnvironment problem-solving (simplified from [8])

Problem identification	- Is P emitting E? - Does E cause harm? - Can V perceive E?
Causal specification	- Does P's E affect V?
Impact evaluation	- Does E harm V? - If so. how? - What dose of E affects V? - Do V's symptoms come from exposure to E' as well as E? - Do V's symptoms come from the interaction of E with E'? - Are there other factors that aggravate or mitigate E's impact on V?
Harm valuations	- Who should undertake the valuation? - Is technical expertise required? - Whose values and valuations should be used? The pollutee's? Society's? - Should we fully compensate victims who are unusually susceptible to harm (e.g.. those with weak respiratory or immune systems)? - Should we fully compensate those, whose own behavior (e.g. smoking) creates the risk of injury or worsens the damage? - How do we discipline exaggeration or other strategic behaviors? - How much value should we place on the effects of P's E on V?
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Where: X = harm; P =polluter; V = pollutee; E and E' = pollutants	

Rights delineation	- Have the relevant property rights been established? - Are the parties aware of who holds the rights? - Are the boundaries clear? - Has there been an infringement on these rights? - Can the rights holder tell? - Are the rights easily enforced?
Implementation	- Is the intervention selected implemented effectively and efficiently? - How can administrative costs be minimized?
Monitoring and enforcement	- Did those assigned to reduce harm X do what they were supposed to do? - How do we best track compliance with our program of E control?
Updating and refinement	- Has anyone come up with a better way to deal with the harm? - Does this knowledge breakthrough change our assumptions about: · the existence of X? · fate and transport of E causing X? · epidemiological or ecological effects of E? · evaluation to be placed on X? · who holds the relevant property rights? · intervention options for dealing with X? · how best to monitor compliance with E abatement efforts?
Where: X = harm; P =polluter; V = pollutee; E and E' = pollutants	

3 Downsides of the Emergence of Digital Technologies

Digital (or information) technology can bring new data, but to extract information from them it will require heavy investments in both sophisticated hardware and basic information infrastructure. As the poor world clearly cannot afford to pay for all this, the rich world has to assist: simply with the selfish aim of discovering in good time whether any global environmental calamities are in the making.

Digital technology will deliver the possibility to have a reliable assessment of the health of the planet, but we will *still not be able to answer the broader question of whether current trends are sustainable or not*. Actually, negative issues exist about the emergence of digital technologies that might require policy intervention in the next few years.

The frightening scenario of China and India turning into resource-guzzling USAs raises at least two questions:

- Will the world use up all its resources?
- Supposing it does not, could the growing affluence of developing nations take us to a global environmental disaster?

Apart from new pollution threats that may emerge from developing nations, other steps backward might happen from unexpected and negative consequences arising within environment-related policymaking or decision-making processes [8]:

1. Unintended cross-fertilization that creates super-weeds or other ecological contamination problems due to the introduction of genetically-modified organisms.
2. New waste streams due to the disposal of old computers and other electronic devices.
3. Increased energy demand across society as microprocessors are embedded in more and more household and commercial appliances.
4. Broad-based increase, especially in rich nations, in consumer buying power and consumption, with the prospect of many more cars on the road, energy consuming appliances in houses, and other pollution impacts from increased consumption.
5. Raw data which are not translated into useable knowledge due to deficient information-transport channels or information overload.
6. Environmental decision-making processes vulnerable to a complex disinformation environment, such as the Internet, which offers a whole set of ill-structured and entirely unscientific data-sets, on which, nevertheless, more and more people are relying.
7. Existing technologies and software that become de facto standards and deter innovation.
8. Policymaking vulnerable to manipulation by special interests through exposure to misinformation and dialogue among the uninformed.
9. Creation of a *digital divide* that leaves some citizens out of the decision-making loop.

4 Reasons to be Hopeful about the Use of Digital Technologies

The existence of such many problematic issues cannot lead us to forget that a few decades ago, and in part still today, the limit-to-growth school argued that the world might soon run out of oil, and that it might not be able to feed the world's exploding population; yet there are now more proven reserves of oil than three decades ago and the amount of food produced is undergoing an explosion similar to the one of population. Fears of oil scarcity encouraged investment that led to better ways of producing oil, and to slightly more efficient engines. In food production, in the past 50 years, technological advances have dramatically shrunk the amount of land required to feed a person. It has been calculated by the Program for the Human Environment of the Rockefeller University [1] that, if the world farmer reaches the *average* yield of

1998's US corn grower, ten billion people will need only half of 1998's cropland while they eat 1998's US calories. The land spared exceeds the Amazonia. This sparing will happen by approximately 2060 if farmers maintain the yearly 2.1% worldwide increase in grains-growth achieved in 1960-1996. In other words, if innovation and diffusion continue as usual, *feeding people* will not stress resources. Even if the rate of improvement falls to half, an area the size of India, globally, could be reverted from agriculture to woodland or other uses[1]. The idea of an absolute limit to natural resource availability is indefensible when the definition of resources changes drastically and not much predictably over time.

It can be argued that, even if we are not going to run out of resources, using ever more resources could still do irreversible damage to fragile ecosystems, increasing human *ecological footprint*, which, on a global scale, is determined by three factors:

1. Population size;
2. Average consumption per person;
3. Technological innovation.

According to environmentalist groups and economic schools, population size (which is reducing) and average consumption per person (which is rising) approximately balance themselves, giving the technological innovation factor a fundamental role in the evolution of the footprint. And, considering the strong historical trend by which current prevailing technologies will be replaced by future *greener* ones, this is an important reason for hope.

5 Conclusions

The domain of eEnvironment is a complex one in which environmental management and technological solutions combine together under the influence of fundamental social, legislative and economic factors. Technology can be used to avert environmental damage, to work towards an improved and shared information infrastructure about environmental issues, to provide better access to environmental data supporting more effective implementation and management practices, to enable provision of more harmonized and higher-quality environmental data, to improve decision-support in environmental management. But none of these techniques, or a combination of them, is going to eliminate the threat of ecological degradation in a straightforward way. That will require first of all a better understanding of the current situation, and the collection of more and better data. Given the dynamic nature of environmental problems and the fast pace at which knowledge evolves in the ecological sciences and in informatics, that will also require each element in environmental management to be constantly reexamined and refined.

Substantial steps backward might happen from unexpected and negative consequences arising, within policymaking or decision-making processes, with relation to

[1] As a curiosity, a widespread vegetarian diet of 3,000 calories/day would halve the difficulty or double the land spared.

the entrance of environmental management in the digital era, starting from serious, new pollution-threats that may emerge from developing nations. Nonetheless, the historical trend by which prevailing technologies in environmental management are constantly replaced by greener ones is a reason to think that the overall impact of the "e" on eEnvironment will be positive.

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