Environmental issues series | No 9

Information tools for environmental policy under conditions of complexity

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Key words:
complex systems,
post-normal science,
ecological economics,
multicriteria evaluation,
environmental indicators.

European Environment Agency

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Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 1999

Cover: EEA

Layout: Rolf Kuchling

ISBN

Printed in

Printed on recycled chlorine-free paper

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Foreword

This report in the Expert Corner's Reports Series is a continuation of previous volumes on indicators and other tools for providing policy relevant information. While previous reports have dealt with various types of indicators and measures, the focus here is on the context of the use of these tools.

The report describes clearly the situation policy makers are facing when having to decide on cases concerning the environment where the stakes are high and the issues are complex. Uncertainty regarding the eventual effects on the environment, considerable social and economic interests, and value laden arguments being used by stakeholders are common features. There is much to recognise in this report and much to learn from it. Although sometimes long words and academic terms are used, it is practical in its approach.

It introduces the reader to alternative approaches to problem framing and solving which take account of the complexities. It provides a model for solving controversies by proposing a decision making process in which stakeholders are involved from the very beginning, even at the stage of data collection. The report makes such 'post-normal-science' accessible for a wide audience and explains how the related concepts can be used in day-to-day policy development. Finally, and that was the part of direct interest for the Agency – beyond making available the 'state of the art' in this matter – it shows the role of information and the type of information needed for policy making under conditions of uncertainty. The European Environment Agency should progressively develop the capacities to support implementation of the Precautionary Principle. Comments are most welcome on this matter.

Personally I would like to thank the main authors of the report, Sylvio Funtowicz, Joan Martinez-Alier, Giuseppe Munda and Jerry Ravetz, because of the high quality of work under difficult circumstances, since final editing to assure consistence with the EEA's publication programme, has delayed the publication. Thanks for their patience and I hope we are all rewarded by having this report published.

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Copenhagen,
August 1999

1. Introduction

In relation to policy, the environment is particularly challenging. It includes masses of detail concerning many particular issues, which require separate analysis and management. At the same time, there are broad strategic issues which should guide regulatory work, such as those connected with global climate change or more generally with sustainability. Nothing can be managed in a convenient isolation; issues are mutually implicated; problems extend across many scale levels of space and time; and uncertainties of all sorts and all degrees of severity affect data and theories alike.

This situation is a new one for policy makers. In one sense the environment is in the domain of science: the phenomena of concern are located in the world of nature. Yet the tasks are totally different from those traditionally conceived for Western science. For that, it was a matter of conquest and control of Nature; now we must manage, accommodate and adjust. We know that we are no longer, and never really were, the masters and possessors of Nature that Descartes imagined for our role in the world.

To engage in these new tasks we need new intellectual tools. A picture of reality which reduces complex phenomena to their simple, atomic elements can be very effective for controlled experimentation and abstract theory building. But it is not best suited for the tasks of environmental policy today. The scientific mind-set fosters expectations of regularity, simplicity and certainty in the phenomena and in our interventions. But these can inhibit the growth of our understanding of the problems and of appropriate methods to their solution.

In this report we shall introduce and articulate several concepts which can provide elements of a framework of environmental policy. They are all new, and still evolving. There is no orthodoxy concerning their content or the conditions of their application. We hope that this discussion of them will be useful in enabling environmental policy makers to grasp their phenomena and the issues more effectively.

The leading concept (as is reflected in the title) is complexity. This relates to the structure and properties of the phenomena and the issues for environmental policy. Systems that are complex are not merely complicated; by their nature they involve deep uncertainties and a plurality of legitimate perspectives. Hence the methodologies of traditional laboratory-based science are of restricted effectiveness in this new policy context.

The most general methodology for managing complex science-related issues is Post-Normal Science. This focuses on aspects of problem-solving that tend to be neglected in traditional accounts of scientific practice: uncertainty and value-loading. It provides a coherent explanation of the need for greater participation in science-policy processes, based on the new tasks of quality assurance in these problem-areas.

Closely related to Post-Normal Science in spirit is Ecological Economics. This is defined not only by its subject-matter, but also by its post-normal methodology. It is not so much concerned with analysing the allocation of scarce resources through market mechanisms; rather it is dedicated to contributing to the societal tasks of sustainability. Although it freely uses quantitative data and mathematical models, its concern is less with elegant mathematical exercises and more with robust and effective gauges of economic activity in relation to sustainability.

Within Ecological Economics we have chosen several methods of analysis for discussion. These include indicators, green national accounting, and physical indices of (un)sustainability. The lesson of complexity is that no single indicator can be the unique correct one. Hence the indicators must be used in a dialogue among stakeholders, rather than in a demonstration by experts. In this way, the decision-making process becomes central to the tasks of making environmental policy, along the lines indicated by Post-Normal Science. Although this report cannot engage with detailed political issues, questions of institutional structure can never be far from the focus of concern, in the study of environmental policy under conditions of complexity.

2. Complexity

Anyone trying to comprehend the problems of the environment might well be bewildered by their number, variety and complication. There is a natural temptation to try to reduce them to simpler, more manageable elements, as with computer simulations. This, after all, has been the successful programme of Western science and technology up to now. But environmental problems have features which prevent reductionist approaches from having any but the most limited useful effect. These are what we mean when we use the term complexity.

Complexity is a property of certain sorts of systems; it distinguishes them from those which are simple, or merely complicated. Simple systems can be captured (in theory or in practice) by a deterministic, linear causal analysis. Such are the classic scientific explanations, notably those of high-prestige fields like mathematical physics. Sometimes such a system requires more variables for its explanation or control than can be neatly managed in its theory. Then the task is accomplished by other methods; and the system is complicated. The distinction between science and engineering, the latter occurring when more than a half-dozen variables are in play, is a good example of the distinction between simple and complicated systems.

With true complexity, we are dealing with phenomena of a different sort. There are many definitions of complexity, all overlapping, deriving from the various areas of scientific practice with, for example, ecological systems, organisms, social institutions, or the artificial simulations of any of them. Here we adopt a more general approach to the concept. Let us take a system, a collection of elements and subsystems, defined by their relations within some sort of hierarchy or hierarchies. The hierarchy may be one of inclusion and scale, as in an ecosystem with (say) a pond, its stream, the watershed, and the region, at ascending levels. Or it may be a hierarchy of function, as in an organism and its separate organs. A species and its individual members form a system with hierarchies of both inclusion and function. Environmental systems may also include human and institutional sub-systems, which are themselves systems. These latter are a very special sort of system, which we call reflexive. In those, the elements have purposes of their own, which they may attempt to achieve independently of, or even in opposition to, their assigned functions in the hierarchy (Funtowicz & Ravetz, 1994b)

This variety of structures and relations enables us to envisage the rich diversity of environmental systems in relation to the problems of policy. We are able to see how difficult they are in principle; but also we can gain some insights on how some effective management policies are to be achieved.

First, any system is itself an intellectual construct, that some humans have imposed on a set of phenomena and their explanations. Sometimes it is convenient to leave the observer out of the system; but in the cases of systems with human and institutional components, this is counterproductive. For environmental systems, then, the observer and analyst are there, as embedded in their own systems, variously social, geographical and cognitive, with characteristic spatial and temporal scales that frame their perceptions.

For policy purposes, a very basic property of observed and analysed complex systems might be called ‘feeling the elephant’, after the Indian fable of the five blind men. Each conceived the object after his own partial imaging process; it was left to an outsider to visualise the whole. This story reminds us that every observer and analyst of a complex system operates with certain criteria of selection of phenomena, at a certain scale-level, and with certain built-in values and commitments. The result of their separate observations and analyses are not at all purely subjective or arbitrary; but none of them singly can encompass the whole system. Looking at the process as a whole, we may ask whether an awareness of their limitations is built into their personal systematic understanding, or whether it is excluded. In the absence of such awareness, we have old-fashioned technical expertise; when analysis is enriched by its presence, we have Post-Normal Science.

We can express the point in a somewhat more systematic fashion, in terms of two key properties of complex systems. One is the presence of significant and irreducible uncertainties of various sorts in any analysis; and the other is a multiplicity of legitimate perspectives on any problem. For the uncertainty, we have a sort of Heisenberg effect, where the acts of observation and analysis become part of the activity of the system under study, and so influence it in various ways. This is well known in reflexive social systems, through the phenomena of moral hazard, self-fulfilling prophecies and mass panic.

But there is another cause of uncertainty, more characteristic of complex systems. This derives from the fact that any analysis (and indeed any observation) must deal with an artificial, usually truncated system. The concepts in whose terms existing data is organised will only accidentally coincide with the boundaries and structures that are relevant to a given policy issue. Thus, social and environmental statistics are usually available (if at all) in aggregations created by governments with other problems in mind; they need interpreting or massaging to make them relevant to the problem at hand. Along with their obvious, technical uncertainties resulting from the operations of data collection and aggregation, the data will have deeper, structural uncertainties, not amenable to quantitative analysis, which may actually be decisive for the quality of the information being presented.

A similar analysis yields the conclusion that there is no unique, privileged perspective on the system. The criteria for selection of data, truncation of models, and formation of theoretical constructs are value-laden, and the values are those embodied in the societal or institutional system in which the science is being done. This is not a proclamation of relativism or anarchy. Rather, it is a reminder that the decision process on environmental policies must include dialogue among those who have an interest in the issue and a commitment to its solution. It also suggests that the process towards a decision may be as important as the details of the decision that is finally achieved.

For an example of this plurality of perspectives, we may imagine a group of people gazing at a hillside. One of them sees a particular sort of forest, another an archaeological site, another a potential suburb, yet another sees a planning problem. Each uses their training to evaluate what they see, in relation to their tasks. Their perceptions are conditioned by a variety of structures, cognitive and institutional, with both explicit and tacit elements. In a policy process, their separate visions may well come into conflict, and some stakeholders may even deny the legitimacy of the commitments and the validity of the perceptions of others. Each perceives his or her own elephant, as it were. The task of the facilitator is to see those partial systems from a broader perspective, and to find or create some overlap among them all, so that there can be agreement or at least acquiescence in a policy. For those who have this integrating task, it helps to understand that this diversity and possible conflict is not an unfortunate accident which could be eliminated by better natural or social science. It is inherent to the character of the complex system which is realised in that particular hillside.

These two key properties of complex systems, radical uncertainty and plurality of legitimate perspectives, help to define the programmes both of Post-Normal Science and of Ecological Economics. They show why environmental policy can not be shaped around the idealised linear path of the gathering and then the application of knowledge. Rather, policy formation is itself embedded as a subsystem in the total complex system of which its environmental problem is another part.

3. Post-Normal Science as a bridge between complex systems and environmental policy

The idea of a science being somehow post-normal conveys an air of paradox and perhaps mystery. By normality we mean two things. One is the picture of research science as normally consisting of puzzle-solving within an unquestioned and unquestionable paradigm, in the theory of T.S. Kuhn (1962). Another is the assumption that the policy environment is still normal, in that such routine puzzle-solving by experts provides an adequate knowledge base for policy decisions. Of course researchers and experts must do routine work on small-scale problems; the question is how the framework is set, by whom, and with whose awareness of the process. In normality, either science or policy, the process is managed largely implicitly, and is accepted unwittingly by all who wish to join in. The great lesson of recent years is that that assumption no longer holds. We may call it a post-modern rejection of grand narratives, or a green, NIMBY politics. Whatever its causes, we can no longer assume the presence of this sort of normality of the policy process, particularly in relation to the environment.

The insight leading to Post-Normal Science is that in the sorts of issue-driven science relating to environmental debates, typically facts are uncertain, values in dispute, stakes high, and decisions urgent. Some might say that such problems should not be called 'science'; but the answer could be that such problems are everywhere, and when science is (as it must be) applied to them, the conditions are anything but 'normal'. For the previous distinction between hard, objective scientific facts and soft, subjective value-judgements is now inverted. All too often, we must make hard policy decisions where our only scientific inputs are irremediably soft.

The difference between old and new conditions can be shown by the present difficulties of the classical economics approach to environmental policy. Traditionally, economics attempted to show how social goals could be best achieved by means of mechanisms operating automatically, in an essentially simple system. The 'hidden hand' metaphor of Adam Smith conveyed the idea that conscious interference in the workings of the economic system would do no good and much harm; and this view has persisted from then to now. But for the achievement of sustainability, automatic mechanisms are clearly insufficient. Even when pricing rather than control is used for implementation of economic policies, the prices must be set, consciously, by some agency; and this is then a highly visible controlling hand. When externalities are uncertain and irreversible, then there cannot be 'ecologically correct prices' practised in actual markets (with 'adequate' property rights structures) or in fictitious markets (through contingent valuation or other economic techniques). There might at best be ecologically corrected prices, set by a decision-making system. The hypotheses, theories, visions and prejudices of the policy-setting agents are then in play, sometimes quite publicly so. And the public also sees contrasting and conflicting visions among those in the policy arena, all of which are plausible and none of which admits of refutation by any other. This is a social system which, in the terms discussed above, is truly complex, indeed reflexively complex.

In such contexts of complexity, there is a new role for natural science. The facts that are taught from textbooks in institutions are still necessary, but are no longer sufficient. For these relate to a standardised version of the natural world, frequently to the artificially pure and stable conditions of a laboratory experiment. The world as we interact with it in working for sustainability, is quite different. Those who have become accredited experts through a course of academic study, have much valuable knowledge in relation to these practical problems. But they may also need to recover from the mindset they might absorb unconsciously from their instruction. Contrary to the impression conveyed by textbooks, most problems in practice have more than one plausible answer; and many have no answer at all.

Further, in the artificial world studied in academic courses, it is strictly inconceivable that problems could be tackled and solved except by deploying the accredited expertise. Systems of management of environmental problems that do not involve science, and which cannot be immediately explained on scientific principles, are commonly dismissed as the products of blind tradition or chance. And when persons with no formal qualifications attempt to participate in the processes of innovation, evaluation or decision, their efforts are viewed with scorn or suspicion. Such attitudes do not arise from malevolence; they are inevitable products of a scientific training which presupposes and then indoctrinates the assumption that all problems are simple and scientific, to be solved on the analogy of the textbook.

It is when the textbook analogy fails, that science in the policy context must become post-normal. Under such circumstances, the traditional guiding principle of research science, the goal of achievement of truth or at least of factual knowledge, must be modified. In post-normal conditions, such products may be a luxury, indeed an irrelevance. Here, the guiding principle is a more robust one, that of quality.

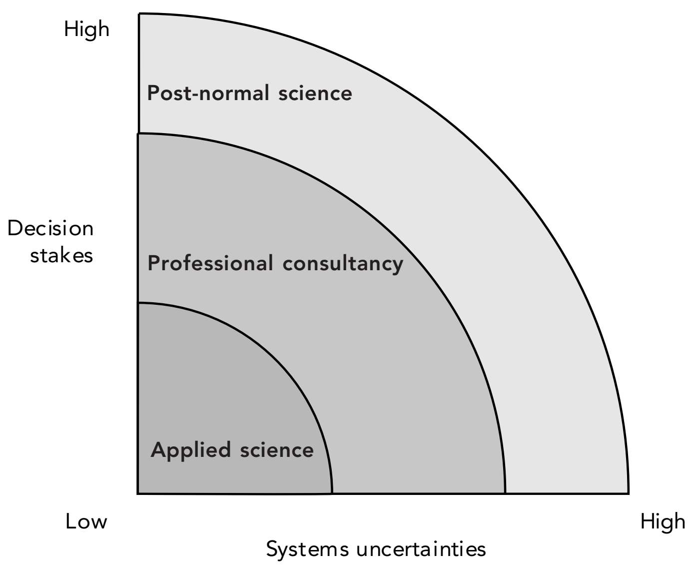
It could well be argued that quality has always been the effective principle in practical research science, but it was largely ignored by the dominant philosophy and ideology of science. For post-normal science, quality becomes crucial, and quality refers to process even more than to product. It is increasingly realised in policy circles that in complex environment issues, lacking neat solutions and requiring support from all stakeholders, the quality of the decision-making process is absolutely critical for the achievement of an effective product in the decision. This new understanding applies to the scientific aspect of decision-making as much as to any other (Wynne, 1992).

Post-Normal Science can be located in relation to the more traditional complementary strategies, by means of a diagram (see Figure 1). On it, we see two axes, ‘systems uncertainties’ and ‘decision stakes’. When both are small, we are in the realm of ‘normal’, safe science, where expertise is fully effective. When either is medium, then the application of routine techniques is not enough; skill, judgement, sometimes even courage are required. We call this ‘professional consultancy’, with the examples of the surgeon or the senior engineer in mind. Our modern society has depended on armies of ‘applied scientists’ pushing forward the frontiers of knowledge and technique, with the professionals performing an aristocratic role, either as innovators or as guardians.

Of course there have always been problems that science could not solve; indeed, the great achievement of our civilisation has been to tame nature in so many ways, so that for unprecedented numbers of people, life is more safe, convenient and comfortable than could ever have been imagined in earlier times. But now we are finding that the conquest of nature is not complete. As we confront nature in its reactive state, we find extreme uncertainties in our understanding of its complex systems, uncertainties which will not be resolved by mere growth in our data-bases or computing power. And since we are all involved with managing the natural world to our personal and sectional advantage, any policy for change is bound to affect our interests. Hence in any problem-solving strategy, the decision-stakes of the various stakeholders must also be reckoned with (Funtowicz & Ravetz 1994a)

This is why the diagram has two dimensions; this is an innovation for descriptions of

Post- normal science **Figure 1**



'science', which had traditionally been assumed to be 'value-free'. But in any real problem of environmental management, the two dimensions are inseparable. When conclusions are not completely determined by the scientific facts, inferences will (naturally and legitimately) be conditioned by the values held by the agent. This is a necessary part of ordinary research practice; all statistical tests have values built in through the choice of numerical 'confidence limits', and the management of 'outlier' data calls for judgements that can sometimes approach the post-normal in their complexity. If the stakes are very high (as when an institution is seriously threatened by a policy) then a defensive policy will involve challenging every step of a scientific argument, even if the systems uncertainties are actually small. Such tactics become wrong only when they are conducted covertly, as by scientists who present themselves as impartial judges when they are actually committed advocates. There are now many initiatives, increasing in number and significance all the time, for involving wider circles of people in decision-making and implementation on environmental issues.

The contribution of all the stakeholders in cases of Post-Normal Science is not merely a matter of broader democratic participation. For these new problems are in many ways different from those of research science, professional practice, or industrial development. Each of those has its means for quality assurance of the products of the work, be they peer review, professional associations, or the market. For these new problems, quality depends on open dialogue between all those affected. This we call an 'extended peer community', consisting not merely of persons with some form or other of institutional accreditation, but rather of all those with a desire to participate in the resolution of the issue. Seen out of context, such a proposal might seem to involve a dilution of the authority of science, and its dragging into the arena of politics. But we are here not talking about the traditional areas of research and industrial development; but about those where issues of quality are crucial, and traditional mechanisms of quality assurance are patently inadequate. Since this context of science is one involving policy, we might see this extension of peer communities as analogous to earlier extensions of franchise in other fields, as allowing workers to form trade unions and women to vote. In all such cases, there were prophecies of doom which were not realised.

For the formation of environmental policy under conditions of complexity, it is hard to imagine any viable alternative to extended peer communities. They are already being created, in increasing numbers, either when the authorities cannot see a way forward, or know that without a broad base of consensus, no policies can succeed. They are called 'citizens' juries', 'focus groups', or 'consensus conferences", or any one of a great variety of names; and their forms and powers are correspondingly varied. But they all have one important element in common: they assess the quality of policy proposals, including a scientific element, on the basis of whatever science they can master during the preparation period. And their verdicts all have some degree of moral force and hence political influence.

Along with this regulatory, evaluative function of extended peer communities, another, more intimately involved in the policy process, is springing up. Particularly at the local level, the discovery is being made, again and again, that people not only care about their environment but also can become ingenious and creative in finding practical, partly technological, ways towards its improvement. Here the quality is not merely in the verification, but also in the creation; as local people can imagine solutions and reformulate problems in ways that the accredited experts, with the best will in the world, do not find natural.

None can claim that the restoration of quality through extended peer communities will occur easily, and without its own sorts of errors. But in the processes of extension of peer communities through the approach of Post-Normal Science, we can see a way forward, for science as much as for the complex problems of the environment.

A sort of manual for Post-Normal Science practice has recently been produced by the UK Royal Commission on Environmental Pollution. In its 21st Report, on Setting Environmental Standards, makes a number of observations and recommendations reflecting this new understanding.

Thus, on uncertainty, we have:

- 9.49: No satisfactory way has been devised of measuring risk to the natural environment, even in principle, let alone defining what scale of risk should be regarded as tolerable;

on values:

- 9.74: When environmental standards are set or other judgements made about environmental issues, decisions must be informed by an understanding of peoples values. ...;

and on extended peer communities:

- 9.74 (continued): Traditional forms of consultation, while they have provided useful insights, are not an adequate method of articulating values;

and on a plurality of legitimate perspectives:

- 9.76: A more rigorous and wide-ranging exploration of peoples values requires discussion and debate to allow a range of viewpoints and perspectives to be considered, and individual values developed (1998).

The inadequacies of the traditional 'normal science' approach have been revealed with tragic clarity in the episode of 'mad cow' disease. For years the accredited researchers and advisors assured the British government that the risk of transfer of the infective agent to humans was low. They did not stress the decision-stakes involved in the official policy in which public alarm and government expense were the main perceived dangers. Then infection of humans was confirmed, and for a brief period the government admitted that an epidemic of degenerative disease was a 'non-quantifiable risk'. The situation went out of control, and the revulsion of consumers threatened not only British beef, but perhaps the entire European meat industry. At this stage there had to be a hard decision to be taken, on the number of British cattle to be destroyed, whose basis was a very soft estimate of how many cattle deaths would be needed to reassure the meat-eating public. At the same time, independent critics who had been dealt with quite harshly in the past were admitted into the dialogue, even trading citations with the President of the Royal Society. Without in any way desiring such an outcome, the Ministry of Agriculture, Forests and Fisheries has created situation of extreme systems uncertainty, staggering decision stakes, and a legitimated extended peer community.

The Post-Normal Science approach need not be interpreted as an attack on the accredited experts, but rather as assistance. The world of 'normal science' in which they were trained has its place in any scientific study of the environment, but it needs to be supplemented by awareness of the 'post-normal' nature of the problems we now confront. The management of complex natural systems as if they were simple scientific exercises has brought us to our present mixture of triumph and peril. We are now witnessing the emergence of a new approach to problem-solving strategies in which the role of science, still essential, is now appreciated in its full context of the uncertainties of natural systems and the relevance of human values.

4. Ecological economics: the study and assessment of (un)sustainability

The idea of an Ecological Economics was born in the later 1980s out of dissatisfaction with the dominant trends in the economics discipline, in which ecology seemed to be neglected. Since then, work done under that title has grown steadily in vigour and influence. There are many ways of describing Ecological Economics. The simplest is that it is the discipline which attempts to bridge the gap between economics and ecology. However, such a bridge must have connections on both sides, and harmonising the two approaches and world-views of conventional economics and of ecology is a far from simple task. Ecology is itself a strongly contested name. Rather than delving into a conceptual study, we will approach the characterisation of Ecological Economics through the theory of complex systems.

When we look at the problems of environmental policy, we ask, how much can we simplify those complex systems and still have both a realistic vision and effective policies? At one extreme, we are urged to keep in mind the welfare of all future generations and all other species. At the other, we are subjected to the overriding political objectives of economic growth, job creation, and global free trade. To find an appropriate perspective in between, we might ask: how much complexity must we assume in the reality out there; and how much uncertainty should we assimilate in our assessments and recommendations?

For our theoretical basis, at one extreme we have the core model of mainstream economics, which is one of total simplicity. There is a marketplace, with individual buyers and sellers, in perfect knowledge of their (simple, quantified) desires, and in perfect knowledge of the curves describing the equilibrium behaviour of the market. This model has been elaborated and enriched in many ways, such as in admitting imperfect competition and using non-quantified gauges of utility. But the issues of most concern for the environment still tend to be described in terms of externalities (as they are not part of the core monetary transactions) or of market failure (since they occur even when the market mechanism is working well for its own purposes). Hence we are justified in seeking for methods which are complementary to those of mainstream economics, in their function and design.

For environmental problems, once we admit complexity in the sense defined above, the aims of scientific analysis, economic or other, must be modified. Just as in case of the classical physics on which it was modelled, in neo-classical economics it is possible to produce elegant and powerful mathematical theories describing the structural properties of the phenomena under study. When we admit complexity, with its plurality of perspectives and deep uncertainties, such an articulated mathematical science becomes unfeasible. But this is not to say that an ecological economics is inferior, any more than (say) engineering is inferior to physics. The mathematics of Ecological Economics describes different objects, and performs different functions, and is therefore designed around different criteria.

In keeping with its assumption of complexity, Ecological Economics does not present its results as a full description or definite prescription. Each measure serves as an indicator into one aspect (or a few aspects) of the complex system, rather than as a measuring rod of a simple, linear quantity. Their function is as an aid to dialogue. Some of the indicators may seem to be objective, but others, as the multi-criteria methods, clearly have their meaning only in the context of dialogue (Funtowicz & Ravetz, 1994c).

We can use the framework of Post-Normal Science to explain the nature and role of these techniques of measurement. In one sense they are normal science, particular puzzles to be solved within an accepted paradigm or framework of assumptions and methods. But, unlike in traditional normal science, the guiding framework is not adopted implicitly and uncritically. The practitioners, in dialogue with other stakeholders, should be fully aware of the functions of their techniques, their limits, and the pitfalls in their interpretation. With that consciousness of uncertainties and value-loading, even the routine technical work of research becomes post-normal in spirit.

Considering Ecological Economics as a whole, some have imported a policy-driven concept to characterise the discipline. This is sustainability, a goal which commands universal assent while yet (hopefully) escaping vacuity. Ecological Economics is then defined as the science and management of sustainability (Costanza 1991). However, giving operational content to sustainability turns out to be extremely difficult; for reaching that goal, our present socio-technical system is not really a good starting point. So some have re-phrased the definition, as the study and assessment of (un)sustainability. This negative characterisation is highly paradoxical; but this should be seen as a virtue in illuminating the nature of the problem, and of the need for new approaches to its solution. Ecological Economics, like Post-Normal Science, is essentially a reflexive activity; and its reflections must concern such contradictions and paradoxes which arise from the complex systems which are its objects of concern.

5. Taking nature into account: the incommensurability principle

Environmental Policy deals with reflexive phenomena, involving awareness and purposes of agents. In order to be realistic, an economic assessment should consider not merely the measurable and contrastable dimensions of the simple part of the system that may be technically simulated even if complicated. It should deal as well with the higher dimensions of the whole complex system, those in which power relations, hidden interests, social participation, cultural constraints, and other 'soft' values, become relevant. These variables strongly (but not deterministically) affect the possible outcomes of the strategies to be adopted.

A mathematical model of e.g. an ecosystem, although legitimate in its own terms, cannot be sufficient for a complete analysis of its reflexive properties, which include the human dimensions of ecological change and the transformations of human perceptions along the way. The learning process that takes place while analysing the issue and defining policies is itself influencing perceptions and altering significantly the decisional space in which alternative strategies are chosen. At the other end, institutional and cultural representations of the same system, also legitimate, are on their own insufficient for specifying what should be done in practice in any particular case. The various dimensions are not totally disjoint; thus the institutional perspective can be a basis for the study of the social relations of the scientific processes. To take any particular dimension as the true, real or total picture, amounts to reductionism, whether physical or sociological.

As a consequence, any attempt to fit the real world in a closed mathematical model leads to a simplification, to a violence to the description of reality. In most cases the sacrificed dimensions are precisely the reflexive properties of the systems. These characterise the problem in a fundamental way but are hardly identifiable and measurable. For example, in conventional economics only the monetisable quantitative properties and a single perspective, i.e. economic efficiency are considered (Castells and Munda, 1996). However, the environment is a site of conflict between competing, perspectives, values and interests, and the different groups and communities that represent them. How are such conflicts to be resolved? Conventional economics assumes the existence of value commensurability. Is that assumption justified? In the following we argue that it is not.

From a philosophical perspective, it is possible to distinguish between the concepts of strong commensurability (common measure of the different consequences of an action based on a cardinal scale of measurement), weak commensurability (common measure based on an ordinal scale of measurement), strong comparability (there exist a single comparative term by which all different actions can be ranked) and weak comparability (irreducible value conflict is unavoidable but compatible with rational choice employing practical judgement) (O'Neill, 1993).

For a simple example, students in a class may be ordered according to how well they have performed in an exam. There might be a cardinal scale of measurement (strong commensurability), by which one student gets '10', another one gets '8.5', the next one gets '7', etc. Or there might simply be an ordering, as 'first', 'second', 'third'... (weak commensurability). But there may be other criteria of value to be considered. Candidate X might be the best student in her class, but from the fact that all students are persons, we may not infer that she is the best person in her class. If someone is 'good' or if something is 'valuable', we must ask, in which type of value?

When there are different types of value in play, we speak not of commensurability but of comparability, either weak, or perhaps of incomparability of values. Quite often, in cost-benefit analysis there is strong commensurability, even going beyond an ordinal ranking of alternatives. Thus, in project evaluation, there can be strong commensurability of values in cost-benefit analysis, when the situations are all valued in the same numeraire (present value in money terms of costs and benefits, including of course externalities). In contrast, in some forms of multi criteria evaluation, there is irreducibility among the different types of value. In that case, there is at most only weak comparability. In our view, Ecological Economics rests on a foundation of weak comparability of values, but it also includes (in appropriate cases) other approaches (contingent valuation, or energy analysis, or 'ecological footprint' analysis in terms of land requirement), which imply strong comparability and even strong commensurability (Martinez-Alier et al., 1996).

The arguments about economic commensurability and its place in decision making about the environment are not new to economic debate. It was precisely the relation between rational decision-making and economic commensurability which was the main point in the opening stage of the famous debate of the 1920s and 1930s on economic calculus in a socialist economy. The debate, started in central Europe (Hayek, ed. 1935, repr. 1970), focused on disagreement on how an economy could work, when the means of production were socialised, and therefore were not in the market. The question seemed practically relevant in the aftermath of the War of 1914-18 because of the wave of revolutions in central and eastern Europe.

The philosopher and social theorist Otto Neurath (the leader of the positivist Vienna Circle) explained the essence of economic incommensurability by means of the following example (Neurath, 1919). Let us consider two capitalist factories, achieving the same production level of the same type of product, one with two hundred workers and one hundred tons of coal, the second one with three hundred workers and only forty tons of coal. Both would compete in the market, and the one using a more 'economic' process would achieve an advantage. However, in a socialist economy (where the means of production are socialised), in order to compare two economic plans, both of them achieving the same result, a present value should be given to future needs for coal (and, we would now add, a present value should be given also to the future impact of carbon dioxide emissions). We must not only decide, therefore, a rate of discount and a time horizon, but also guess the changes in technology: use of solar energy, use of water power, use of nuclear power. In Neurath's own words [1928, p. 263], the answer to whether coal-intensive or labour-intensive methods should be used, 'depends for example on whether one thinks that hydraulic power may be sufficiently developed or that solar heat might come to be better used. If however one is afraid that when one generation uses too much coal thousands will freeze to death in the future, one might use more human power and save coal. Such and many other non-technical matters determine the choice of a technically calculable plan... we can see no possibility of reducing the production plan to some kind of unit and then to compare the various plans in terms of such units...'. Elements in the economy were not commensurable, hence the need for what he called a Naturalrechnung - or natural accounts. It is interesting that the turn to ecological thinking in economics, with a full awareness of both incommensurability and uncertainty, was stimulated by the debate over the possibility of an economic order which did not rely on the market mechanism for the allocation of resources. (Martinez-Alier, 1987, 1992).

6. Multicriteria evaluation as a tool for environmental policy under complexity

Cost-Benefit Analysis (CBA) is the traditional evaluation instrument used in economics both at a micro and macro level of analysis. It is based on the neo-classical maximisation premise on behaviour of neo-classical economics, which is that rational decisions are identical with utility maximisation. Thus, it becomes possible to base the validity of a decision procedure either on a notion of approximation (i.e. discovering pre-existing truths) or on a mathematical property of convergence (i.e. does the decision automatically lead, in a finite number of steps, to the optimum a*?). The existence of a solution to the mathematical optimisation problem depends on a number of assumptions, which can be criticised on the grounds of their correspondence with the real world of economic activity. Moreover, in the framework of environmental policy, CBA can be further criticised (Munda 1966):

1. In practice, issues of efficiency, equity and sustainability cannot be separated. But in the mathematics of CBA, it is possible to optimise only one objective at a time, with the first taking precedence over the second, etc. Hence such a monocriterion optimisation is not objective and value-free, but reflects the aspect of the complex problem which is chosen as dominant.

2. The optimisation and compensation models do not aim at achieving a better environmental quality, but only at incorporating the environmental impacts in the traditional price and market system. Since the objective is to keep utility constant, complete substitution between environmental quality and economic growth is always allowed. This takes no account of irreplaceable resources or irreversible change.

3. There are strong distributive impacts of any model, which are concealed in the range of its numerical parameters. Future generations are affected by the choice of social discount rate; with (e.g.) a rate of 7%, their interests are halved in value every ten years, being worth only one-sixth as much, one generation into the future. The monetary values of negative externalities, if calculated by comparative incomes, effectively treat the poor as disposable.

In contrast, during the last two decades, more support has emerged for the view that welfare is a multidimensional concept, thus the conventional complete commensurability principle can be questioned. Weak comparability can be considered to be the philosophical base of multicriteria evaluation. Multicriteria evaluation methods based on the ‘incommensurability principle’ are an evaluation methodology alternative to traditional CBA.

A typical multicriteria problem (with a discrete number of alternatives) may be described in the following way: A is a finite set of n feasible actions (or alternatives); m is the number of different points of view or evaluation criteria g_i i=1, 2, ... , m considered relevant in a decision problem, where the action a is evaluated to be better than action b (both belonging to the set A) according to the i-th point of view if $g_i(a)>g_i(b)$. In this way a decision problem may be represented in a tabular or matrix form. Given the sets A (of alternatives) and G (of evaluation criteria) and assuming the existence of n alternatives and m criteria, it is possible to build an n x m matrix P called evaluation or impact matrix whose typical element p_{ij} (see Table 1) (i=1, 2 , ... , m; j=1, 2 , ... , n) represents the evaluation of the j-th alternative by means of the i-th criterion. The impact matrix may include quantitative, qualitative or both types of information (Munda et al., 1994; Munda 1995).

In general, in a multicriteria problem, there is no solution optimising all the criteria at the same time and therefore the decision-maker has to find compromise solutions. In the absence of a unique ‘correct’ policy as the product, the focus is on the quality of the process.

In designing models for environmental and resource policy-making the following three main types of policy objectives may be distinguished (Van den Bergh, 1995; Braat and Van Lierop, 1987; Dietz and Van der

Straaten, 1992; Faucheux et al., 1994; Hafkamp, 1984):

1. nature conservation objectives, e.g. ‘minimum exploitation of natural systems’, ‘optimum yield’;
2. socio-economic objectives, e.g. ‘maximum production of goods and services’;
3. mixed objectives, e.g. ‘maximum sustainable use of resources and environmental services at minimum (private and social) cost’.

Such formulations are vague, until such time as constraints and performance criteria are defined. But, it is clear that in policy-relevant economic-environmental evaluation models, socio-economic and nature conservation objectives are to be considered simultaneously. Consequently, multicriteria methods are in principle an appropriate modelling tool for environmental decision-making issues: a compromise solution, taking into account different conflictual values, can in principle be identified.

As a tool for conflict management, multicriteria evaluation has demonstrated its usefulness in many environmental management problems (Beinat & Nijkamp 1998). From an operational point of view, the major strength of multicriteria methods is their ability to address problems marked by various conflicting evaluations. Multicriteria evaluation techniques cannot solve all conflicts, but they can help to provide more insight into the nature of conflicts and into ways to arrive at political compromises in case of divergent preferences so increasing the transparency of the choice process. In this way it contributes to the quality of the process, along the lines of Post-Normal Science.

Multi-criteria Evaluation has clearly shown its effectiveness in the exploratory study of water resources scarcity at Troina, in Sicily. A decision problem that seemed totally intractable, with a mass of conflicting interests, has been transformed into the beginnings of a community dialogue. Recognising that a ‘product’ in the form of a decision was very far away regardless of the approach, the facilitators made their focus on its necessary foundation, the ‘process’. In this, the various interests would become aware of themselves, of their neighbours, and of the common problem. Whatever “product” may eventually emerge, it will be the outcome of an organic community process. It will then have a legitimacy and a resilience that no imposed solution, however impeccable its scientific credentials, could expect.

Example of an impact matrix **Table 1.**

Alternatives					
Criteria	**Units**	**a_1**	**a_2**	**a_3**	**a_4**
g_1		$g_1(a_1)$	$g_1(a_2)$		$g_1(a_4)$
g_2					
g_3					
g_4					
g_5					
g_6		$g_6(a_1)$	$g_6(a_2)$		$g_6(a_4)$

In Troina, the situation seemed particularly intractable, partly because of the diversity of interests, and even also because of confusion over the perceived problem. It had to do with water shortage, which is common almost everywhere else in Sicily, but not exclusively. There were many resentments about the behaviour of the water company in building a large dam which then became inaccessible to the public, conflicting interests among different sorts of water users, a general concern with the decay of the historic centre of the town, and finally the dominating presence of a large private organisation running a health-care establishment, the creation of an ageing priest. The investigators used both formal (multicriteria) methods and sociological techniques, including institutional analysis, in-depth interviews and surveys. This methodology of triangulation provided their research with greatly enhanced robustness and also credibility in the community. Through a process of iteration, they came up with two successive sets of proposals, ranked by their attractiveness to various coalitions in the community. One of these (an exhibition about the water problem) caught the popular imagination, and a community dialogue was launched (O’Connor et al., 1998).

7. Imprecise and fuzzy information: The NAIADE method

It has been argued that the presence of qualitative information in evaluation problems concerning socio-economic and physical planning is a rule, rather than an exception (Munda et al., 1994; Nijkamp et al., 1990). Thus there is a clear need for methods that are able to take into account information of a 'mixed' type (both qualitative and quantitative measurements). An example of a multicriteria method that may use mixed information is the so-called REGIME method; this method is based on pairwise comparison operations; from this point of view it has something in common with outranking methods (Hinloopen and Nijkamp, 1990).

Another issue related to the available information concerns the uncertainty contained in this information. Ideally, the information should be precise, certain, exhaustive and unequivocal. But in reality, it is often necessary to use information which does not have those characteristics, so that one has to face the uncertainty of a stochastic and/or fuzzy nature present in the data. If it is impossible to establish exactly the future state of the problem faced, a stochastic uncertainty is created. This type of uncertainty is well known; it has been thoroughly studied in probability theory and statistics. Alternatively, a 'qualitative analysis' of the quantitative information may be undertaken (Funtowicz & Ravetz, 1990).

Another framing of uncertainty, called fuzzy uncertainty, focuses on the ambiguity of information in the sense that the uncertainty does not concern the occurrence of an event but the event itself, which cannot be described unambiguously (Zadeh, 1965). This sort of situation is readily identifiable in complex systems. Spatial-environmental systems in particular, are reflexive complex systems characterised by subjectivity, incompleteness and imprecision (e.g., ecological processes are quite uncertain and little is known about their sensitivity to stress factors such as various types of pollution). Fuzzy set theory is a mathematical theory useful for modelling situations of such a sort. It aims to portray some of the indeterminacies of the socio-ecological system under study in terms of fuzzy uncertainty (Munda, 1995).

Zadeh (1965) writes: 'as the complexity of a system increases, our ability to make a precise and yet significant statement about its behaviour diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics'. Therefore, in these situations statements as 'the quality of the environment is good', 'the unemployment rate is low' are quite common. Fuzzy set theory is a mathematical theory for modelling situations, in which traditional modelling languages which are dichotomous in character and unambiguous in their description cannot be used. Human judgements, especially in linguistic form, appear to be plausible and natural representations of cognitive observations. A linguistic representation of an observation may require a less complicated transformation than a numerical representation, and therefore is less subject to distortion.

In traditional mathematics, variables are assumed to be precise, but when we are dealing with our daily language, imprecision usually prevails. Ordinary language is intrinsically incapable of precise characterisation at either the syntactic or semantic level. Therefore, a word in our ordinary language can technically be regarded as a fuzzy set. Fuzzy sets as formulated by Zadeh are based on the simple idea of introducing a degree of membership of an element with respect to some sets. The physical meaning is that a gradual instead of an abrupt transition from membership to non-membership is taken into account.

NAIADE (**N**ovel **A**pproach to **I**mprecise **A**ssessment and **D**ecision **E**nvironments) is a discrete multicriteria method whose impact (or evaluation) matrix may include either crisp, stochastic or fuzzy measurements of the performance of an alternative with respect to an evaluation criterion. It is very flexible for real-world applications. The aggregation procedure of NAIADE is based on a pairwise comparison of all the policy alternatives, involving both the number of criteria in favour of each alternative and also the intensity of the preference. More technical information can be found in

Munda (1995). The ranking can be a complete preorder (among the alternatives only relations of preference or indifference exist) or a partial preorder (incomparability relations may also exist). Some indicators of the uncertainty and compensability introduced in the aggregation process are also used.

Equity and distribution issues in NAIADE are introduced by means of conflict analysis procedures, which are to be integrated with the multicriteria results. This is to enable policy-makers to seek for decisions that could reduce the degree of conflict (in order to reach a certain degree of consensus), or that could have a higher degree of equity among different interest groups. NAIADE uses a fuzzy conflict analysis procedure. Starting with a matrix showing the impacts of different courses of action on each different interest/income group, a fuzzy clustering procedure indicating the groups whose interests are closer in comparison with the other ones is used. Summarising, NAIADE can give the following information:

1. ranking of the alternatives according to the set of evaluation criteria (i.e. compromise solution/s);
2. indications of the distance of the positions of the various interest groups (i.e. possibilities of convergence of interests or coalition formations);
3. rankings of the alternatives according to actors' impacts or preferences.

One should note that sometimes, a serious divergence between the multicriteria ranking and the equity ranking may exist. This mainly because the information provided by these rankings is different in nature (otherwise they would be redundant).

The multicriteria ranking can be considered more 'technical'. That is, for instance in an integrated environmental assessment problem, some alternative options can be evaluated according to a set of socio-economic and environmental criteria. These criteria should have been chosen so that they reflect actors' values (or preferences or interests) or they could even have been chosen directly by the affected actors. However, in principle the determination of the criterion scores is independent of their preferences. For example, an interest group can accept the use of a criterion measuring the effects of the various alternatives on the employment, but the determination of the figure cannot be (at least completely) controlled by them (the same applies e.g. to environmental impact indicators). Moreover, the ranking is a consequence of all the criteria considered simultaneously (in search of the compromise solution).

On the contrary, the impact score of each alternative to each interest group is much more direct. Such a score should be determined by the group itself (or anyway it should be a direct consequence of its preferences). Unreconcilable conflicts may exist between different coalitions or even between single groups. The policy analysis can be conditioned by heavy value judgements such as, have all actors the same importance (i.e. weight)? Should a socially desirable ranking be obtained on the grounds of the majority principle? Should some veto power be conceded to the minorities? Are income distribution effects important? And so on.

Once more we would like to stress that formal evaluation tools cannot *solve* the conflicts, what they can do is to help in providing more insight into the nature of conflicts (so improving the understanding of the negotiation process itself) and into ways of arriving at policy compromises, so increasing the transparency of the evaluation process. They can also be considered as learning tools helping the actors to become aware of their own assumptions and preferences as well as those of the other actors.

8. Environmental policy tools (1)

Choice of indicators, target-setting and cost-effectiveness

This section deals with an important issue in environmental policy, the setting of environmental standards and their implementation through green taxes or marketable permits or other instruments. In microeconomics, strong commensurability is assumed when externalities are internalised into the price system. Thus, the definition of a Pigovian tax as the value of the externality at optimum pollution level, implies strong commensurability. In our view, genuine 'cost effectiveness' implies weak commensurability only, as the tolerable levels of pollution which are to be achieved most cheaply in money terms, are themselves socially negotiated.

In conventional environmental economics, 'external' effects are given present money values. For instance, if a power station produces SO_2, NO_x and CO_2 as by products, then such externalities are measured in money terms. The external costs, which will depend on the amount of electricity produced, are then compared (in the same numeraire: money) to the profits obtained by producing and selling electricity, attempting to reach the 'optimum' amount of pollution by such a comparison. This is a starting point for many textbooks in environmental economics (e.g. Pearce and Turner, 1990). The analysis requires counting the value of the damages, or of remediation work, or of preventive measures. For instance, if the power station works with nuclear energy, then we would have to give money values to radioactive waste. Since some of these will require attention for millennia into the future, how is the present cost to be calculated? At which rate of discount should future negative (or positive) impacts be discounted, in order to obtain present values? Therefore, the valuation of future, uncertain, irreversible externalities is not always convincing.

Turvey's diagram (Turvey, 1963) which compares marginal private profits and marginal external costs, in order to determine the 'optimum' amount of pollution, is called in economics a 'partial' equilibrium analysis. It is based on the assumption of strong commensurability. One critique, from inside economic analysis, is that the modification of prices in one branch or in one firm of the economy (i.e. the 'internalisation' of externalities into the cost structure), will modify to some extent the pattern of prices in the whole economy. Therefore, what is required (always inside the strong commensurability straitjacket) is a 'general' equilibrium analysis. Another critique is that in some cases it is just too difficult to assign money values to 'external' effects, and that economists should settle down for something more modest than an 'optimum' amount of pollution. The chosen approach is called 'cost effectiveness'.

'Critical loads' express whether discharges are harmful, and they are similar to fishing quotas, or to limits to water extraction, or to standards of air quality, in that such norms are not set by the calculus of marginal costs and marginal benefits but they are set from outside the economy. Then, the economists come back into the scene in order to discuss the policy instruments which could be used in order to adjust the economy to such environmental norms. Instruments could be charges or taxes, or marketable permits, or voluntary agreements, for instance. The cheapest instrument is then called the most 'cost effective' instrument.

Let us see one concrete example. A 'critical load' approach to the amounts of SO_2 and NOx emitted by power stations is used in the European RAINS model, which divides Europe into a grid of squares. It determines how much acidifying load each square can take without damage, and how much it is actually taking (and where it is coming from). The model is based on the maximum amount of acidifying substances which can be received without damage (the 'critical load'). Such critical loads are different in different parts of Europe, depending for instance on whether the soils are more or less calcareous. The scientific question is how to reduce emissions so that critical loads are not exceeded, and how to achieve such reductions in the cheapest, most 'cost effective' way? In the political reality, in the last round of negotiations in the UN-ECE, it was decided to close only one part of the gap between the present situation and the desired situation of strict compliance with the 'critical load' norms, so that negotiations were on the 'gap closure' percentage, and on which policy instruments to choose in order to achieve this new norm.

Therefore, even when 'critical loads' exist, the norm accepted might be less ambitious than full compliance. Moreover, critical loads can be contested. Ecological economists are interested not only in the economics of policy instruments but also in researching how such norms are set. The notions of 'post normal' science and 'extended peer reviews' will again apply. Thus, choosing another example, to accept as a 'safe' limit of CO_2 concentration in the atmosphere of 300 ppm (which is already exceeded), 400 ppm, 500 ppm or 600 ppm (or any number in between), is largely a matter of political choice. Here it is obvious that there are several environmental norms possible. This is explicitly acknowledged in many instances, such as water quality standards negotiated quite legally among stakeholders. So, the idea that there existed some norm, limit or standard or 'critical load' established from outside the economy by scientific experts (such as the IPCC), beyond which the environment is endangered, below which every thing remains green, must regrettably be abandoned in practice.

If there were an indisputable norm, then we would discuss whether in money terms (in a single scale of value, and with cardinal measurements), compliance with such a norm could be achieved by a 'cost effective' instrument A (marketable permits, for instance, with associated monetary costs of 100$), or by instrument B (say, taxes, or fines, with associated monetary costs of 200$). The context would be assumed strong commensurability despite the fact that the costs of compliance and the benefits of compliance are not compared in the same numeraire. However, if the extended expert and stakeholder 'review process' is allowed for, then what we have in practice is a combination of several different physical norms possible, where X is less strict than Y, and Y less strict than Z, and also different policy instruments.

Could the three situations be compared in terms of strong commensurability? They could not, for the costs of attaining the norms are expressed in money values, but the norms them selves are in physical terms (for instance, CO2 emissions). Z is better than Y and Y is better than X in their own physical ranking, but Z is more expensive than Y and Y more expensive than X in money terms.

Cost of compliance (in money terms) with different physical norms, an imaginary example — **Table 2.**

	Physical norm X	Physical norm Y	Physical norm Z
instrument A	$ 100	$ 150	$ 200
instrument B	$ 200	$ 300	$ 400

One possible ranking of acceptable situations could be:

Situation	Physical norm	Cost
A)	Z	$ 200
B)	Y	$ 150
C)	X	$ 100

Which is better, (Z, 200$), or (Y, 150$), or (X, 100$)? Perhaps a discussion would lead to a judgement that the improvement of Z over Y is really worth the extra economic cost, and also that Y is 'better' than X, at the extra economic cost. Or perhaps the judgement could be that, given the costs of compliance, Y is better than X and X is better than Z. In both cases we would have an ordinal ranking of alternatives, i.e. weak commensurability. Perhaps, however, a consistent ranking of alternatives A), B) and C) proves impossible to achieve. Then, in this case, 'cost effectiveness' could not make it even to the weak commensurability grade, and it would 'fall down' into weak comparability only, i.e. incommensurability. Clearly, however, the analysis of 'cost effectiveness' requires further work, which should no longer be focused mainly on instruments but on the social evaluation processes and reflexive practices which lead to the choice of concrete indicators and target setting. In the next section we will extend the discussion to the macroeconomy.

9. Environmental policy tools (2)

Green national accounting and physical indices of (un)sustainability

Traditionally, Gross National Product (GNP) has been considered as the best performance indicator for measuring national economy and welfare. But if resource depletion and degradation are factored into economic trends, what emerges is a radically different picture from that depicted by conventional methods. In environmental terms, the GNP measure is plainly defective because (Faucheux and O'Connor, forthcoming):

- no account is taken of environmental destruction or degradation;
- natural resources as such are valued at zero;
- repair and remedial expenditure such as pollution abatement measures, health care, etc., are counted as positive contribution to GNP inasmuch as they involve expenditures of economic goods and services.

The purpose of 'green accounting' is to provide information on the ecological (un)sustainability of the economy. But there is no settled doctrine on how to combine different and sometimes contradictory indices in a way immediately useful for policy (in the sense that GNP or other macroeconomic statistics have been useful for policy). How to count depletion of resources, when they are not inventoried, or when no property rights exist? How to monetise non market impacts (because of trade or because of international externalities such as carbon dioxide exports) outside the European borders? Leaving money values aside, how to integrate the physical indicators themselves? Different physical indicators will sometimes show contradictory trends, and then the topic of 'aggregation' arises.

Moreover, apart from trends, there are 'dangers' or 'surprises', i.e. new technologies, or technologies gone wrong, or new social perceptions about well known phenomena. Thus, the increased greenhouse effect was interpreted favourably from Arrhenius in the 1890s until the 1950s, when the scientific and social alarm started to appear. 'Surprises' are inevitable in complex systems. Research usually reduces uncertainty. However, research into complex systems sometimes increases uncertainty. Climate change research has provided some recent examples. Sulphate aerosols (coming partly from sulphur dioxide emissions from economic activity) counteract the enhanced greenhouse effect, in the sense that they explain why temperature increase has been slower than foreseen in some models, but the amount of sulphate aerosols will change in an uncertain manner, depending on national and international policies. Also, the hypothesis of a change in ocean currents because of climate change, means that risks of an increase in temperatures now become dangers of a decrease in temperatures in some regions of the world (Western Europe, for instance). Under these conditions it becomes ever more difficult to practice normal science on such issues.

Although long words (such as 'incommensurability of values') are used in this report, our approach is most practical. Ecological Economics comprises the study of both Green Accounting and Environmental Indicators. But, are environmental indicators or satellite accounts to be translated into commensurable values by means of damage evaluation and monetisation techniques? We see Weak Comparability of Values as the foundation for the realistic assessment of (un)sustainability. For instance, the European Commission issued a communication to the Council of Ministers and to the European Parliament on Directions for the European Union on Environmental Indicators and Green National Accounting (COM(94) 670 final, June 1996) precisely on this question.

The aim of this section is to dispel confusion in the assessment of (un)sustainability, by carefully classifying and discussing, in practical terms, the proposals for Green Accounting and for physical indices of (un)sustainability. Our objective is to help create a consensus on the respective place of, and the relations among, the tools for assessing (un)sustainability. Table 3 presents a tentative classification of concepts, theories and methods of ecological economics, where the upper part of the table includes environmental and resource economics and the lower part includes physical indicators in different units (and the negotiation of physical indicators). While conventional environmental and resource economics rests on principles of compensation and substitution which sometimes might be operative, ecological economics emphasises the difficulties in substituting for the loss of environmental goods such as biodiversity (which is not even inventoried), or in

Table 3. **Concepts, theories and methods in ecological economics**

Source: (Martinez-Alier, Munda and O'Neill, 1996)

COMPARABILITY OF VALUES	MACROECONOMICS	MICROECONOMICS AND ENVIRONMENTAL POLICY	PROJECT EVALUATION
STRONG COMPARABILITY			
Strong commensurability of values	'Weak' sustainability	Internalisation of externalities at 'optimum' social level (Turvey's diagram, 1963)	Cost-benefit analysis (including Krutilla's modification of discount rates applied to 'commodities' and 'amenities')
	Solow-Hartwick rule	Coasian bargaining and fusions	
	Pearce-Turner 'constant capital stock' and 'constant natural capital stock'	Hotelling's rule (1931)	
	Green GNP (El Serafy's correction)	Renewable resource management (Gordon-Scott, etc.)	
	Green GNP (Repetto's correction)	Cobb-Douglas, CES and other standard production functions	
	Biological and physical indicators of sustainability (e.g. HANPP, MIPS, ecospace, energy cost of energy, etc.)	Contingent valuation and similar methods	
		Conventional utility theory, use value, existence value	
Weak commensurability of values	Green GNP (Hueting's correction)	Cost-effectiveness analysis (and related instruments: Markets in emission permits, etc.)	Cost-benefit analysis (with ordinal rankings only)
	ISEW (Daly & Cobb)	Lexicographic ordering of consumer's preferences	Cost-effectiveness analysis
		Industrial ecology and industrial metabolism (Ayres, Ruth, etc.)	Compensatory multicriteria evaluation based on utility functions
		Biophysical production functions	Discrepancies between WTP and WTA
WEAK COMPARABILITY			
Incommensurability of values	'Strong' sustainability (in physical accounts), 'satellite' accounts	Social evaluation of environmental limits or standards	Non-compensatory multicriteria decision aid
	Simultaneous use of monetary and non-monetary indicators by means of reflexive complexity and macroeconomic multicriteria evaluation	Integrated assessment of sectoral indicators of sustainability (in physical accounts) for urban planning, agriculture, water management, etc.	Environmental impact assessment techniques Sagoff's 'consumers' versus 'citizens'
	Co-evolution	Precautionary principle, liability rule, environmental bonds, and other methods for dealing with uncertainty and 'surprises'	
		Eco-auditing, product-life cycle analysis and other methods of physical environmental accounting at firm's level	

compensating future generations for the uncertain, irreversible negative externalities we are causing today. There are allocations without any possibility of transactions in actual or fictitious markets.

Does the expression 'Taking nature into account' imply money valuation, or rather appraisal through physical indices (which themselves might show contradictory trends)? Are European countries, regions, cities moving towards sustainability or away from sustainability? Which are the'measuring rod(s)' to be employed? For instance, statistics are available which show that the Netherlands is sustainable (in the 'weak' sense of the word), while other statistics (on environmental space) show the Netherlands occupying fifteen times their own territory, i.e. appropriating the 'carrying capacity' of a much larger territory than their own. Such inconsistencies (if such they be) also apply to Europe as a whole.

Some economists tend to claim that measurements of natural capital stock made exclusively in physical terms are problematic because of the difficulty in adding up different physical quantities expressed in different units. For this reason, for 'strong' sustainability, the main requirement would be that the total value of the natural resource stocks should remain constant in money terms. By valuing each resource stock in money terms, the total value of natural capital can be measured. One obvious problem here is that many natural resources (e.g., air, water, wilderness) do not have observable prices. Thus one would need to find implicit or shadow prices in some way. Even those prices that do exist may not be useful; they may be affected by market imperfections and taxes, and they may exclude externalities involved with the production and use of the resource. Moreover, the economic values of non-traded and traded, environmental services or of negative externalities, depend on the endowment of property rights and on the distribution of income.

There are additional problems in using market prices to value the aggregate stock of natural capital. Resource prices or net prices reflect conditions at the margin and to use these to value entire stocks can give perverse results. Although the idea of a constant capital stock is quite important and desirable (maintaining the natural capital seems to be an important prerequisite for sustainability), one should admit that the above considerations demonstrate that the development of relevant monetary indicators of sustainable development connected to this idea is quite difficult.

For instance, some believe that computation of 'weak sustainability' in money terms (equivalent to 'net capital accumulation' or to the 'genuine savings' published by the World Bank) is easily achievable, even including trade flows, once some technical difficulties are solved, but many believe that there is no methodology for assigning monetary values to future, uncertain, irreversible environmental damages. Also in macroeconomics, the proposals to correct GNP measures in a 'green' direction, as introduced by El Serafy (Yusuf, El Serafy and Lutz, 1989) the results of which in actual practice will depend more than anything else on a rate of discount or interest chosen arbitrarily , do not go beyond strong commensurability in money terms. Not all receipts from the sale of exhaustible resources should be included in GNP. Only one part should be included, 'true' income, and the rest is counted as 'decapitalisation' or the 'user cost' of such 'natural capital' which should be invested at compound interest over the period until the resource is exhausted, so as to allow the country to live at the same standard of living even when running out of the resource. This is an interesting proposal in order to correct the macroeconomic accounts. It is based on a notion of 'weak sustainability' only. But other criteria are available in order to judge whether the economy moves towards sustainability.

The assumption that there is a maximum limit to the scale of economic activity, defined either by the regenerative or absorptive capacity of the ecosystem, leads to the concept of 'strong sustainability'. Such a definition is based on the assumption that certain sorts of natural capital are deemed critical, and not readily substitutable by human-made capital. In particular, the characterisation of sustainability in terms of the 'strong' criterion of non-negative change over time in stocks of specified natural capital provides a strong justification for development of non-monetary indicators of ecological sustainability based on direct physical measurement of important stocks and flows (Faucheux and O'Connor, forthcoming). One has to keep in mind that the very definition of sustainability depends on:

(i) what we define as identity for the system;
(ii) the time scale adopted to define the system under investigation.

For example, the recent literature on physical indicators includes:

- the Vitousek, Ehrlichs and Matson (1986) indicator based on the 'human appropriation of net biomass production (HANPP)';
- the MIPS concept (developed by Schmidt-Bleek (1994) at the Wuppertal Institut), the measurement of the energy cost of obtaining energy (Cutler Cleveland, 1991);
- the concept of Environmental Space (Opschoor, 1995), and the comparable concept of Ecological Footprint (Wackernagel and Rees, 1995).

It is interesting to reflect on how a development should be judged, in which a synthetic indicator such as MIPS improves, while HANPP deteriorates. This is a sort of macroeconomic multicriteria evaluation (Munda, 1995).

This discussion may be phrased also in the framework of recent work on the so called 'inverted U curve' (or so called 'Kuznets environmental curve' – see Selden (1994) and Arrow et al. (1995) for a critical viewpoint). For instance, as incomes grow, in urban situations sulphur dioxide emissions first increase and then decrease. But carbon dioxide emissions increase with incomes. If something improves and something deteriorates, the first reaction from the conventional economist will be to give weights or to put prices on such effects, in the pursuit of strong comparability of values. However, there is so much uncertainty and complexity involved in such situations, there are also so many distribution conflicts involved (the prices of externalities would depend on the distribution of property rights, of power, and of income), that the economists' accounts would be convincing only for the faithful. We must learn to live with weak comparability of values. The interplay between physical uncertainties, distribution issues, and temporal scales appears very clearly in the well known case of integrated economic-environmental assessment of climate change. Attempts at cost-benefit analysis of the increased greenhouse effect are not convincing because of the arbitrariness of the discount rate (Azar and Sterner, 1996), because of the inseparable links between (in)equity and efficiency, and also because many items are not easily measured in physical terms, much less easily valued in money terms (Funtowicz and Ravetz, 1994).

10. Environmental policy tools (3)

Some available physical tools for the assessment of (un)sustainability

A number of indicators and indices have been proposed in order to judge the overall impact of the human economy on the environment. We shall leave aside monetary indicators which correct GNP. These would include Cobb's and Daly's Index of Sustainable Economic Welfare. Calculating ISEW involves qualitative assessments (for instance, which expenditures to include as 'defensive expenditures', which algorithms to use in order to evaluate inequality in the distribution of income) (Daly and Cobb, 1989). In this sense, the strong comparability of the ISEW, a monetary indicator, calculated for different countries and periods, is not so straightforward as it would appear. This is why in Table 3 ISEW is classified under 'weak commensurability'. In this section, we take knowledge of 'green' corrections to GNP for granted (and also the related discussion on 'weak' and 'strong' sustainability, cf. Cabeza Gutes, 1996, O'Connor et al. 1996, Gowdy, 1996), and go on to provide a short list of some physical synthetic indicators and indices:

10.1. HANPP

(Human appropriation of net primary production) as proposed by Vitousek et al. (1986). The NPP is the amount of energy that primary producers, the plants, make available for the rest of living species, the heterotrophs. Of this NPP humankind 'co-opts' about 40 % in terrestrial ecosystems according to Vitousek et al. 's calculations. The higher HANPP is, the less biomass is available for 'wild' biodiversity. The proportion of NPP appropriated by humans is increasing because of population growth, and also because of increasing demands on land per person, for urbanisation, for growing feedstuffs, for growing timber ('plantations are not forests', is a slogan of environmental activists in the Tropics).

This indicator should be regionalised, in the world and inside Europe. Thus, in Latin America as a whole the part of NPP "co-opted" by the local population is still much lower than in Europe or in Southeast Asia. However, pressure on NPP comes from population density in the region itself, but also from pressure of exports. Therefore, HANPP and 'environmental space' (or 'ecological footprint') are related measures.

10.2. MIPS

This indicator, which has been developed at the Wuppertal Institute (Schmidt-Bleek, 1994), adds up all the materials used for production directly and also indirectly (the 'ecological rucksack'), the materials include mineral ores, the energy carriers such as coal or oil, all biomass, including the whole product 'life cycle', i.e. the disposal or recycling phases. This is the Material Input which is measured in tons. It then compares the material input, measured in tons, with the services provided, sector by sector (and in principle, for the whole economy). For instance, in order to provide the service of travel of one passenger one km, or in order to provide the service of living space of so many square metres, which is the amount of materials involved, comparing different regions in the world, or historically? Comparisons of MIPS will show whether there is really a trend toward dematerialisation of the economy. It may of course be objected that tons of materials say nothing about the toxicity of the materials used or of their residues. MIPS is a synthetic indicator, but not the only one.

10.3. The material intensity of consumption

When MIPS are calculated there are difficulties in determining the Services provided. For instance, one passenger km might be considered a clear unit of service, but perhaps travelling by car (higher MIPS) or travelling by train (lower MIPS) should be considered different life experiences. Needs and tastes are so complex that one may understand the conventional economist's temptation to consider only preferences revealed in actual or fictitious market through willingness to pay. In contrast to conventional economics, Ecological Economics adopts the principle of irreducibility of needs. There is no general principle of substitution amongst goods and services, rather some goods and services are more important, and cannot be substituted by other goods and services. There is a connection between Georgescu Roegen's early work in the 1930s on utility theory (and on what was later called lexicographic ordering of preferences), and the physical view of the economy which he developed in the 1960s and which culminated in The Entropy Law and the Economic Process (1971) (cf. Gowdy, 1992). Thus, for instance, the minimum amount of endosomatic energy necessary for human life, cannot be substituted or compensated by anything else. However, this does not mean the Ecological Economics adopts a biological, reductionist view of human needs. On the contrary, ecological economists adopt Lotka's distinction between endosomatic consumption and exosomatic use of energy (also, of materials), and we point out that the human species has no genetic instructions as regards exosomatic use. There is enormous variation in use within the world population.

To call the endosomatic consumption of food energy (of 1500 or 2000 kcal per person/day) a 'revealed preference' would betray the economist's metaphysical viewpoint. But to call either the endosomatic consumption of 1500 or 2000 kcal, or the exosomatic use of 100 000 kcal or 200 000 kcal per person/day, a 'socially constructed need, or want', and to go no further, as those with an institutional approach to economics would perhaps do, would leave aside the ecological explanations and/or ecological implications of such use of energy.

10.4. Another approach

There is another approach, which is recently becoming an important element in the study of (un)sustainability. It builds upon Maslow's work on needs from Social Psychology, also on Georgescu Roegen's 'principle of irreducibility' of needs, and on the 'basic needs' approach in Development Economics. This novel approach analyses the 'satisfactors' employed to satisfy needs. According to Max-Neef (Max-Neef, Elizalde, Hopenhayn, 1995) all humans have the same needs, described as 'subsistence', 'affection', 'knowledge'..., and there is no generalised principle of substitution among them. Such needs can be satisfied by a variety of 'satisfactors'. For instance, 'subsistence' implies, at one level, endosomatic energy intake, and in this sense there is only one possible 'satisfactor', kcal or joules, but food may come in many different fashions. There might be vegetarians by tradition, or choice, or income level, but also there might be a Veblenian conspicuous consumption of meat as in Spain or Italy in the last thirty years. The 'satisfactors' of other types of needs are still much more varied. Research by Tim Jackson (1996) has asked the following question: 'how material and energy intensive are the 'satisfactors' of non material needs?'

Instead of taking economic services as given, as in MIPS (passenger km., square metres of living space), and then computing the material inputs (in tons) throughout the whole product life cycle to provide such services, Jackson (building on Max Neef) discusses the services themselves – for instance, why is there so much travel, why is there so much new building (instead of restoration), which are the needs which are being satisfied in such material and energy intensive manner. Taking the British standard of life around 1950 as a standard of life which satisfied material needs, Jackson's research considers that there is a trend to use 'satisfactors' which are themselves very intensive in energy and materials in order to satisfy predominantly "non-material" needs. Duchin's research on household lifestyles through input output analysis (Duchin, 1996) shows the material and energy use in production in order to provide for alternative patterns of consumption.

10.5 EROI

This acronym stands for Energy Return on (Energy) Input, and it was the first physical indicator widely employed in ecological economics in the 1970s, mainly by direct or indirect disciples of Howard Odum. In fact, the idea of looking at the basic economics of human society, and particularly of agriculture, as a flow of energy, goes back to the 1880s, through Podolinsky's work, if not earlier. Clearly, for an economy to be sustainable, the energy productivity of human labour (i.e. how much energy is made available per day, by one day of human work) must be higher (or equal, if everybody is working) than the efficiency of the transformation of energy intake into human work. This is a minimum condition for sustainability. However, as Podolinsky himself wrote, the economies of hunter gatherers and of agriculturists were different from industrial economies. The energy productivity of a coal miner was much larger than that that a primitive agriculturist could obtain, but this energy surplus from fossil fuels was transitory, it was not sustainable because coal reserves were limited . We may ask, "is there a trend towards an increasing energy cost of obtaining energy? (Cleveland, 1991)."

In the 1970s there were a number of studies on energy flow in agriculture, of which the best known were those of Pimentel (Pimentel et al., 1973) showing the decreasing energy efficiency in maize cultivation in the United States. The human labour input had become very small, but energy inputs in the form of fuel for machinery, pesticides, fertilisers, increased in proportion more than the energy in the crop. Perhaps in Europe the trend towards decreasing energy efficiency in agriculture was halted in the 1970s because of the increase in oil prices (Bonny and Dauce, 1989, cit. by Passet, 1996:179). In any case, a fruitful new field of research was opened by such studies (historic and cross section) on the efficiency of the use of energy in different sectors of the economy, including the energy sector itself.

Naturally, although all kinds of energy can be counted in the same units, not all sources of energy have the same meaning from other points of view. In use, some forms of energy are more versatile than others. In origin, some arise from non renewable resources and/or in their use they have more negative impacts than other sources. There have been attempts at giving equivalencies between types of energy (aside from their energy contents) but the ratios for transforming the values of different types of energy seem to be based (in our view) on ad hoc decisions.

The analysis of energy flow, which is a constant feature of ecological economics since its beginnings over one hundred years ago, does not imply the 'energy dogmas' denounced by Nicholas Georgescu Roegen. It is true that in the 1970s there was a strong belief that economic and social policy advice could be based on the study of energy efficiencies (Odum, 1971, Slesser, 1979), coming close to a revival of the 'social energetics' of 1900. Figures of use of energy (mainly, EROI) are one more indicator (macroeconomic, or sectorial), which does not supersede other indicators, such as material balances in 'industrial ecology' or in the study of 'industrial metabolism' (Ayres, 1989, 1994). Such interesting contradictions among the trends of physical indicators and indices are grist for the mills of Multi-Criteria Evaluation.

It is relatively easy to reach consensual figures on energy efficiency, but the economic meaning of such figures is a different question. Max Weber, in 1909, wrote that Wilhelm Ostwald's discussion of economic history in terms of a) an increased use of energy, b) also, an increased efficiency in the use of energy, was irrelevant, because the adoption of new industrial processes or new products had little to do with energy efficiency, it had to do with price relations. Nowadays we interpret Ostwald's propositions in the sense that energy relations sometimes point in a contrary direction to price relations because energy is 'too' cheap as a result of the discrepancy between bio-geo-chemical time and economic time. The economy discounts the future.

10.6. Ecospace and Ecological Footprint

Both these concepts, with similar contents, address the following issue: 'which is the demand for natural resources which an economy makes, expressing this demand in terms of space?'

The authors who have developed the ideas on environmental space, ecospace, or the ecological footprint (Opschoor, Rees) would concur on the crucial importance of time in ecological economics. However, for practical purposes, they chose to give a spatial representation of the environmental load of the economy. Rather than asking what population a particular region or country can support sustainable, which would depend not only on its geography and resources but also on its average level of exosomatic consumption of energy and materials, on the material and energy intensity of the technologies employed, on the ecological terms of trade (i.e. whether the region is a victim of, or profits from ecologically unequal exchange), the question of carrying capacity becomes: how large an area of productive land is needed in order to sustain a given population indefinitely, at its current standard of living, and with current technologies? (Rees, 1996:203). In German, the discussion on ecospace makes use of the word Umweltraum, which philologically is similar to the word Lebensraum that came from scientific ecology and then was taken over by the Nazis. Although Umweltraum as used today does not refer to a space which a people claims a 'natural' right, still it reminds us that someone has appropriated a carrying capacity which in principle belongs to somebody else. Environmental space (e.g. Buitenkamp et al. 1993) is a notion related to Ecological Footprint, or appropriated carrying capacity, and also to the notion by Dassman, applied to India by Gadgil and Guha (1995), of 'Ecological Trespassers' vs. 'Ecosystem People': the contrast between people living on their own resources, and people living on the resources of other territories and peoples.

The main categories of land use for the calculation of the Ecological Footprint would be as follows:

- crop and grazing land required to produce the current diet (the sea area could also be included);
- land for wood plantations for timber and paper;
- and occupied or degraded or built over, as urban land;
- land needed to absorb CO_2 emissions through photosynthesis, or alternatively;
- land required to produce the ethanol equivalent to current fossil energy consumption.

In Rees' hometown of Vancouver, the respective figures for these four items, per person, would be 1 hectare, 0.6 has., 0.2 has., and 2.3 has. (of middle aged Northern temperate forest), i.e. over 4 hectares per person. Notice that only CO_2 is translated into a land requirement, and not other wastes, such as domestic waste, or other greenhouse gases, or radioactive waste, not for any reason of principle, but because of difficulty of computation. Notice also that the water catchment area, and the waste water disposal area, are not included. (For more details, Wackernagel and Rees, 1995).

Similar computations, not for cities or metropolitan regions (whose 'ecological footprint' is hundreds of times larger than their own territories) but for whole countries, show that some densely populated European countries (assuming per capita eco footprints of only 3 has.) or Japan or Korea (with per capita eco footprints of only 2 has.) occupy eco-spaces ten times larger (for the Netherlands, fifteen times larger) than their own territories.

10.7. Ehrlich's approach: I = PAT

Why so many different indicators – it may be asked - when there could be a unique physical indicator of whether human impact on the environment is excessive, simply by using the concept of Carrying Capacity, as defined in Ecology: the maximum population of a given species (frogs in a lake for instance) that can be supported sustainably in that given territory, without spoiling its resource base. The answer is that this definition of carrying capacity is irrelevant for humans, for several reasons.

First, the human ability to establish large differences in exosomatic use of energy and materials means that one first question should be, maximum population at which level of consumption? Second, human technologies change at a much quicker pace than in other species; thus, an early objection to the use of carrying capacity was Boserup's thesis, according to which changes in agricultural systems defined as shortening of rotation period were seen as responses to increases in population density, turning the tables on the Malthusian argument. Boserup's thesis of endogenous technical change is relevant for the development of agriculture until the change in techniques around 1840 in industrial countries, when outside inputs into agriculture became the defining trait of the technology based on the new knowledge of agricultural chemistry. Third, the territories occupied by humans are not given. We compete with other species, which are pushed into corners as shown by the Vitousek, Ehrlich et al.'s (1986) indicator of Human Appropriation of the Net Primary Production of Biomass. Also, inside the human species, territoriality is socially and politically constructed. This is why migration from Sweden to Spain, or vice versa, is nowadays free inside the European Union, while many people die at sea every year trying to cross illegally but not unnaturally from Morocco into Spain.

There is still another reason why the notion of carrying capacity is not directly applicable to humans, in any particular territory. This is international trade. Trade may be seen indeed as the appropriation of the carrying capacity of other territories, as we have seen in the discussion on the Ecological Footprint and Ecospace. Between the two extremes of globalisation of production based on the growth of trade, and no trade at all, there is room for an ecologically sensible middle position. Even from a strict bio-regional point of view, it might be argued (Pfaundler, 1902), that if one territory lacks one very necessary item which is abundantly present in another territory, then Liebig's law of the minimum would recommend exchange. Therefore, the joint carrying capacity of all territories would be larger than the sum of the carrying capacity of all such autarchic territories. This point of view links up with recent proposals for Fair and Ecological Trade, coming from non governmental organisations.

Authors who come from a background in Biology and from an emphasis on population growth, such as Paul Ehrlich and his collaborators, have over the years become aware of the shortcomings of the notion of Carrying Capacity applied to humans. This is why they proposed the formulation I = PAT, where I is the human impact on the environment, P is human population, A is affluence, and T is technology. Compared to the physical indicators mentioned in the previous section, all of which may be calculated with a reasonable amount of consensus on computation, the formula I=PAT has not (to our knowledge) been applied in practice. T stands for the effects of technology on the environment per unit of affluence, but in terms of material intensity? in terms of energy intensity? in terms of impact on biodiversity? A stands for affluence, presumably per capita income, but do we take measures of income as they are? The formula I=PAT is best understood as a symbolic device, or a teaching metaphor (Duchin, 1996, p. 289), rather than as a research tool. But if it raises awareness without misleading anyone, then in the spirit of Post-Normal Science it should be accepted as another sort of contribution to the dialogue.

11. Conclusion

The array of assessment methods discussed above is a proof that Ecological Economics can be as rigorous and quantitative as any other branch of the discipline. We believe that they also demonstrate how environmental policy is to be framed and assessed, under the conditions of complexity that now prevail.

As we have seen, no single indicator captures the whole problem. Nor can any combination of indicators ever do this, however much improvement is made in data collection or computational capacity. In any given problem there are a multiplicity of attributes and criteria; and formally or informally any decision procedure must respect that essential feature of environmental policy making. The diversity of aspects, and the plurality of legitimate perspectives, will ensure that such indicators will serve as aids to dialogue and decision. They are to be assessed not by their 'truth', but by their quality, their fitness for their particular functions. The search for a single numeraire, characterising the optimum behaviour of a simple economic system under automatic control, is not for this study.

In some ways this might seem to be an admission of defeat. How much more tidy the world would be if there were some experts who, in possession of the appropriate applied science, could tell us what to do in the cause of sustainability. But there is no point in regretting the non-existence of a world which could never happen outside a textbook. For those involved in environmental assessment and policy making, the outlook is actually more optimistic. For with the extended peer communities as defined in Post-Normal Science, there is an opportunity to bring new energies to the whole process of governance in relation to the environment. Sustainability in our sense is not, and cannot be, a purely physical property of simple technological systems. It involves the quality of life for all the earth's inhabitants. With the help of the sort of perspective that is developed in this respect, that work is now underway.

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