STUDIES
ON
GEORGESCU-ROEGEN'S
BIOECONOMIC PARADIGM

by

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Submitted in partial fulfillment of
the requirement of the degree of
DOCTOR OF ECONOMICS

KYOTO UNIVERSITY
KYOTO 606-8501, JAPAN
DECEMBER 1999

Acknowledgments

I first and foremost acknowledge my debt and gratitude to my teacher and mentor, the late Prof. Nicholas Georgescu-Roegen. I hope this volume will promote further research into the work and thought of one of the greatest economists of this century. I would like to thank Mr. S. Isaka for introducing me to Georgescu-Roegen's thought and thank Prof. T. Hasegawa of Nanzan University for continual moral support. I also would like to thank Prof. M. Giampietro and Prof. John M. Gowdy for permitting me to reproduce some of our joint work here.

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Chapter 1

Introduction

Nicholas Georgescu-Roegen (1906-1994) was one of the first economists to investigate rigorously the interplay between economic activity and the natural environment based on thermodynamic consideration. His achievement made him a perennial candidate for a Nobel prize in economics and the father of a new and rapidly growing school of economic thought, ecological economics. According to Georgescu-Roegen, nature consists only of just what we can perceive; beyond that are only hypothesized abstractions. His idea about the relation between nature and our perception of nature led to a particular kind of epistemology concerned mainly with valid analytical representations of relations among facts. Thus, according to Georgescu-Roegen, any theory should be a logically ordered description of a reality's mode of functioning.

The acme of Georgescu-Roegen's theoretical development is, in my view, his ambitious attempt to reformulate the economic process as "bioeconomics", a new style of dialectical economic thinking. Bioeconomics makes us bear in mind continuously the biological origin of the economic process and spotlights the problem of humans having a limited store of accessible resources that are unevenly located and unequally appropriated. Important aspects of Georgescu-Roegen's approach to the economic process can be summarized as follows:

(1). Humans changed biological evolution into a new mode of evolution in which exosomatic organs are manufactured, instead of being inherited somatically. Exosomatic production evolved into economic process. Institutions of the market, money, credit, enterprises of all sorts and internal logic inherent in these institutions emerged in response to the progressive evolution of the exosomatic nature of humankind. Human mode of existence is not dominated by biology or economics. People became completely dependent on exosomatic organs and their production, leading Georgescu-Roegen to claim that scarcity of mineral resources as well as energy shortage sets a limit on the survival of the human species on this planet. Georgescu-Roegen's profound concern for ecological salvation culiminated in his proposal for the "Fourth Law of Thermodynamics."

(2). Qualitative changes, a central theme of life sciences including biology and economics, elude arithmomorphic schematization rooted in mechanistic epistemology of neoclassical economics. Because of emergence of novelty in the economic process, Georgescu-Roegen insisted that actuality cannot be grasped only with the aid of analysis: dialectics must also be used. In J. A. Schumpeter, Georgescu-Roegen found a sympathetic mentor to share his view that the most important economic changes are qualitative, not quantitative. Schumpeter's vision of the economic process, the process of innovation in particular which anticipated biologist Richard Goldschmidt's idea of the hopeful monster, is now rediscovered by proponents of punctuated equilibrium theory in evolutionary biology.

Recent concern for sustainable issues began to attract attention to the comprehensive theory of economy, society and environment Georgescu-Roegen developed during the later phase of his career after 1960. However, Georgescu-Roegen's original and path-breaking contributions have still not received deserved attention from mainstream economists. Perusing Georgescu-Roegen's early work, particularly concerning consumer choice theory and criticism of Leontief dynamic model, reveals many innovative aspects that have never been incorporated into standard theory. These innovative aspects may give essential clues to investigating deep theoretical and policy implications for sustainability issues. Close examination of the entire spectrum of Georgescu-Roegen's work and new theoretical development based on his work are now necessary.

This thesis consists of this introductory chapter and eight chapters. Brief explanation of each chapter follows.

Chapter 2. The Foundations of Consumer Choice Theory and Environmental Valuation in View of Georgescu-Roegen's Contribution

Georgescu-Roegen is widely regarded for his important contributions to neoclassical consumer choice theory. Yet, it is rarely recognized that most of Georgescu-Roegen's contributions to consumer choice theory are a critique from within, a drastic revision of the conceptual edifice which he himself helped to build. This chapter : (1) examines his basic ideas of consumer choice theory and identifies areas that need further theoretical development; and (2)

throws new light on the relevance of his utility theory to the issue of sustainability, especially regarding the field of monetary evaluation of natural resources and environmental services.

This chapter first discusses axioms of consumer choice within the neoclassical framework of methodological individualism. Then, discussion broadens to include the social and environmental context of economic behavior. In the spirit of "consilience" proposed by E. O. Wilson, it is argued that basic assumptions of any particular science should be consistent with the basic body of knowledge understood by other sciences. Axioms of consumer choice theory when applied to environmental valuation are shown to be so unrealistic that policy recommendations based on them may not be reliable. The following topics are discussed: (1) postulates of consumer choice; (2) invariance of preferences; (3) principle of complementarity; (4) saturation point; (5) lexicographic preferences and psychological threshold; (6) hierarchy of wants; (7) marginal utility of money; (8) probalilistic binary choice; (9) economic man and methodological individualism.

Chapter 3. Information, Measurability and Physical Entropy

This chapter concerns critical evaluation of the measure of information and its relationship with entropy in physics elaborating on Georgescu-Roegen's critique.

C. E. Shannon's measure of information touching upon a historical development of the concept of information in communication engineering is introduced and three points are emphasized:

(1) the concept of information and the capacity of a communication channel should have been treated as separate concepts; (2) it is accidental that Shannon reached the function $H = -\sum p_i \log_2 p_i$ where $\sum p_i = 1$ through two different routes, an axiomatic treatment of information and a method of typical sequences; (3) Shannon misidentified a source of vernacular language with an ergodic stochastic Markov chain.

This chapter has an analysis of N. Wiener's measure of information or uncertainty on a stochastic process. Main results are: (1) any measure of uncertainty, one of which is H, is a pseudo measure and not an ordinal variable; (2) the amount of Wiener's information for all continuous distribution becomes infinite; (3) the expected amount of Wiener's information for any absolutely continuous distribution depends only on the ordinal measure adopted.

It is shown that the alleged equivalence between negative entropy and information is untenable by perusing the works of L. Szilard, E. T. Jaynes and L. Brillouin. Georgescu-

Roegen's critique of the measure of information and of the alleged equivalence between negative entropy and information is briefly related to his interest in epistemology.

Chapter 4. Georgescu-Roegen's 'Fourth Law of Thermodynamics', the Modern Energetic Dogma, and Ecological Salvation

Inputs of low entropy resources into the economic process and outputs of high entropy waste from it are two unavoidable flows of our economic activities as long as we remain bioeconomic beings. The true problem is choosing the suitable rate of increase in entropy in the long run. Tremendous rate of increase in entropy is a most troublesome characteristic of modern technological systems with respect to the resource and environmental constraint menacing human life.

First, there is a brief review of Schrödinger's theory of living things. A necessary condition for living things to continue living will be investigated. There follows an explanation of how the earth system disposes of thermal entropy increases toward outer-space in terms of the nested-hierarchical structure of open steady state systems of the second category. This chapter also deals with the "Fourth Law of Thermodynamics" proposed by Georgescu-Roegen and its implication for resource and environmental constraints: (1) Georgescu-Roegen's formulation is not compatible with the framework of thermodynamics; (2) 'Material entropy' is not entropy in physics, depending mainly on four factors: heterogeneity of matter, technological level, our multi-dimensional value system and overall availability of resources. Finally, Georgescu-Roegen's flow-fund model is used to give viability conditions of complete recycling for the macroeconomic process in terms of technological and economic parameters. It is shown that the viability conditions are too formidable to satisfy in reality.

Chapter 5. Embodied Energy Analysis, Sraffa's Analysis, Georgescu-Roegen's Flow-Fund Model and Viability of Solar Technology

The first part of this chapter is motivated by recent interest in ecological economics literature in linkages between embodied energy analysis and P. Sraffa's analysis and includes (1) comparison of the theoretical basis of embodied energy analysis from the point of view of Sraffa, a point of view not examined by Georgescu-Roegen; (2) critical examination of embodied energy analysis in terms of Georgescu-Roegen's flow-fund model; and (3) comparison of Sraffa's analysis and Georgescu-Roegen's flow-fund model.

The second part of this chapter is motivated by the fact that, despite probable exhaustion of oil in the near future, effective and drastic shift in energy resources has not been implemented. Abundant use of coal is more destructive to the environment after energy transformation and nuclear energy may be much more destructive in the long run in terms of nuclear waste management. It remains to be seen whether or not it is possible for solar technology to replace fossil and fissile fuels completely. Solar energy technology may or may not remain a 'parasite' to fossil and fissile fuels.

This second part concerns three types of aggregated reproducible flow-fund model based on solar technology. Here, flows are elements that enter, but do not come out of the process or, elements that come out of the process without having entered. Funds are elements that enter and leave the process unchanged, agents that perform the transformation of input into output flows. This analytical framework was introduced by Georgescu-Roegen, but the schematization has not received much attention. This chapter's analysis attempts to show that Georgescu-Roegen's flow-fund model is an indispensable analytical tool for examining viability of solar technology.

Chapter 6. Land: Ecological and Economic Achilles' Heel

Successful substitution of land-based resources with fossil fuels and mineral resources has supported the material structure of economic process ever since the industrial revolution and land constraint has been eased since then. But it is dangerous to claim that we have become perfectly emancipated from land constraint. This chapter suggests that we can attain only temporary emancipation from land constraint, and provides economic and thermodynamic analysis of land, mainly since the industrial revolution.

This chapter first considers the tremendous speed of matter and energy degradation which causes rapid depletion of natural resources and the destructive influence upon our environment, including land. We then reconsider the views of two great minds, Liebig and Marx, who both had prophetic visions concerning modern agriculture and its possible effect on the future economy. Thermodynamic analysis of temporary emancipation from land during the industrial revolution in England is given. The substitution of coal for wood, especially in the iron industry, and the growth of the cotton industry is featured. It is shown that temporary emancipation from land constraint in the United States is due to the vast fertile land and intensive consumption of natural resources, especially oil. Even in the United States, the food safety margin will, in the long run, be diminished by a trap of the law of the diminishing returns. Finally, to appreciate land constraint properly, there is discussion of the essential differences and similarities between farming and manufacturing processes.

Chapter 7. Another View of Development, Ecological Degradation and North-South Trade

Based on N. Georgescu-Roegen's bioeconomic paradigm, this paper reconsiders the neo-classical economic paradigm which endorses continuous global economic growth through stimulated trade. This chapter suggests that, in view of sustainability, it is fundamental to acknowledge: (1) the importance of preserving the identity and integrity of economic systems in different regions of the world through enlarging as much as possible self-sufficiency and equity assessed at national and regional levels; and (2) the importance of including respect for biospheric equilibria as one criterion for regulating world economic activity and trade. Differences and similarities of the past and present patterns of ecological degradation are examined. Two types of efficiency assess technological changes and the drive toward unsustainability. There is discussion of an entropy-based theory of North-South trade issues and three points for promotion of sustainability. Finally, the true origin of current ecological crisis is shown to lie in a deep change in the perception of the relation between humans and nature that affects the mode of technological development of modern society.

Chapter 8. Dealing with Integrated Assessments of Sustainability Trade-offs: Complexity and Its Epistemological Implications

This chapter provides a general discussion on epistemological implications of complexity in relation to the issue of governance. The challenge of Post-Normal Science (PNS) is generated by the need of modeling the process of coevolution of natural systems and human societies. Humans have to develop, within a given system of knowledge, anticipatory systems able to catch relevant features of this process. Any attempt to model the interaction between two becoming systems (which are organized over several distinct hierarchical levels) "guarantees" the insurgence of complexity. This is why, we decided to provide an overview of basic aspects of complex system theory before discussing of tools and procedures which

can be used to operationalize PNS (the subject of the second paper of this series).

In this chapter we explore first basic concepts, which are discussed both in theoretical terms and with practical examples. We believe that the work of Rober Rosen about epistemological implications of complexity represents an important linkage between PNS and complex system theory. Then we discuss the resulting epistemological predicament in relation to the issue of sustainability and governance.

Chapter 9. The challenge of Post-Normal Science: making scientific information useful for the process of decision making

This chapter discusses in practical terms the challenge of operationalizing the concept of Post-Normal Science. Accepting the idea which is impossible for scientists to provide any useful input to any practical process of integrated assessment without involving the stakeholders, then, it is important to clarify and characterize the role that scientific inputs should play in a participative processes of decision making in relation to sustainability. In this chapter we discuss the characteristics of such a scientific input. In particular, we make the point that: (i) the basic assumptions of model and goals of simulations (the structuring of the information space) should reflect the concerns found among stakeholders; (ii) the reliability of the data set and the package of models used to perform the integrated assessment should be checked jointly by scientists and stakeholders. We present examples of an analytical tool (= MultiObjective MultipleScale Performance Space) and a procedure (= Participatory Integrated Assessment based on an iterative process aimed at validating a MultiObjective MultipleScale Strategic-Problem-Structuring through its application to a specific case study) that can be used to organize scientific activities in a way more compatible with participatory processes of decision making.

Chapter 2

The Foundations of Consumer Choice Theory and Environmental Valuation in View of Georgescu-Roegen's Contribution

Until relatively recently the assumptions of neoclassical utility theory were hotly debated by economists (see, e.g., Alchian, 1953; Armstrong, 1958; Samuelson, 1952). But with the ascendance of the neoclassical synthesis in the decades following WWII most economists took the basic axioms of consumer choice as given and placed the question of 'tastes' outside the realm of economic analysis[1]. Preferences are taken to be given and constant and assumed to be adequately reflected in market choices. Armed with these axioms, economists turned their attention to applications within the neoclassical paradigm. In recent years, however, attention has returned to some of the earlier controversies in utility theory because of questions about environmental valuation, especially regarding those techniques based on neoclassical axioms of consumer choice such as the contingent valuation method (CVM).

The neoclassical theory of consumer choice describes the process by which an autonomous rational consumer allocates his/her income at the margin among an array of consumer goods. As any scientific model does, neoclassical utility theory describes some part of reality in the simplest way possible to explain the phenomena under consideration. Choice theory draws an 'analytical boundary' (Georgescu-Roegen, 1971) around an individual consumer, ignoring social and ecological context, to examine how he/she makes choices in a well-defined market. It is widely recognized that the axioms of consumer choice theory are quite restrictive, but it is argued that simplification is necessary in any analytical representation of complex reality. In this chapter, we follow the advice of E.O. Wilson (1998) who argues for 'consilience' among the sciences, that is, the assumptions of any particular science should be consistent with the basic body of knowledge understood by other sciences. We argue that the basic axioms of utility theory cannot be reconciled with current understandings in psychology, biology, political science, and other relevant disciplines.

The origin of consumer choice theory can be traced back to the English empiricists such as Bacon and Hobbes who, following the best science of their time, viewed human consciousness as a sort of a file cabinet for past experiences. Ideas are stored in a logically consistent manner to be retrieved later. These experiences may fade with time but they stay logically ordered and constitute the context in which decisions are made. As we discuss below, this view of the human mind is not supported by current scientific evidence. Other assumptions about human nature such as the impossibility of lexicographic preferences and insatiable wants are also known to be at odds with current scientific knowledge. We first discuss the axioms of consumer choice within the neoclassical framework of methodological individualism, then we broaden our discussion to include the social and environmental context of economic behavior. We also discuss the credibility of transitivity assumptions in terms of probabilistic binary choice. We conclude that the axioms of consumer choice theory when applied to environmental valuation are so unrealistic that policy recommendations based on them are not reliable.

2.1 The Axioms of Consumer Choice

Economic valuation of environmental features is based on the well-known set of axioms which constitute neoclassical theory of consumer behavior[2]. The description of the consumer as Homo oeconomicus (HO) is based on various versions (Frisch, 1926; Georgescu-Roegen, 1954b; Jehle, 1991; Mas-Colell, Whiston, and Green, 1995) of the following set of axioms[3]:

1. HO is faced with alternative combinations of various quantity-measurable commodities that involve neither risk nor uncertainty. Every point $C = (x_1, x_2, \ldots x_n)$ in the commodity space is an alternative.

2. Given two commodity bundle alternatives C^1 and C^2, HO will either prefer one to the other, or regard the two alternatives as indifferent. Indifference is a symmetric relation, but preference is not. We write C^1PC^2 for preference and C^1IC^2 for indifference.

3. The preferences of HO do not change over time.

4. There is no saturation. This is sometimes called the axiom of monotonicity. Given any C^1, C^2 is preferred to C^1 if C^2 is obtained by adding to C^1 more of at least one commodity.

5. The relation of non-preference $\overline{P}$ (the negation of P) is transitive. That is, if $C^1\overline{P}C^2$ and $C^2\overline{P}C^3$, then $C^1\overline{P}C^3$ ($C^1\overline{P}C^2$ means either C^2PC^1 or C^1IC^2).

6. If $C^1\overline{P}C^2$ and $C^1\overline{P}C^3$, then $C^1\overline{P}[aC^2 + (1-a)C^3]$ where $0 \leq a \leq 1$. It means that C^1 is not preferred to a mix of C^2 and C^3 no matter what the composition of the combination.

Although Axiom 2 allows for a region of indifference, it is not strong enough to guarantee that an indifference region actually exists. Consequently, Axiom 7, the indifference postulate, is necessary to construct a complete ordinal measure of utility.

7. A set (C^α) is called *a preferential set* if α takes all the values of an interval of real numbers and if $C^\beta PC^\gamma$ whenever $\beta > \gamma$. If the preferential set (C^α) contains C^β and C^γ, and if $C^\beta PC$ and CPC^γ, then the preferential set contains a combination indifferent to C.

2.2 Environmental Valuation and the Axioms of Consumer Choice

2.2.1 The Invariance of Preferences

Axiom 3 states that consumer preferences may be assumed to be constant over the relevant time period of analysis. Many of the criticisms of CVM by economists have centered on the ephemeral nature of consumer tastes as expressed in survey responses. Diamond and Hausman (1994), for example, criticize CVM because the responses to CVM questions depend upon the sequence in which the questions are asked. They also criticize contingent valuation because it captures a variety of 'non- market' consumer reactions including 'warm glow' effects, protest bids, and 'embedding'. The 'warm glow' criticism is that in CVM surveys individuals may be expressing support for good causes in general rather than for the specific item being evaluated. In protest bids individuals may be expressing a reaction to a recent specific environmental event such as an oil spill rather than focusing on the specific item under consideration. These criticisms of specific CVM studies can just as easily be used to critisize consumer choice theory in general. As marketing and advertising experts know, warm glow and many other feelings are embedded in almost all consumer products. Examples from CVM surveys show a mismatch between theory and reality. Responses to

CVM questions do not conform to the assumptions of the utility theory model into which they are placed. This does not necessarily mean, as neoclassical critics of CVM argue, that resonses to questionaires are not 'real', or that market choices are real.. That is, just because CVM responses do not conform to the axioms of consumer choice, this does not imply that the choices of consumers actually buying things, do conform to these axioms.

Hanemann (1994), in a defense of CVM, points out that traditional consumer choice theory assumes a 'top-down' or 'stored-rule' decision-making process. This 'filing cabinet' conception of the mind still holds sway in economics but has been abandoned by those studying how the human mind actually works (see Martin and Tesser, 1992; Bettman, 1988). Psychologists now see cognition as a constructive process depending on context and history. How choices are actually constructed depends on time, place, and immediate past experiences (Hanemann, 1994, p. 28). It has been shown that consumer choices, including those made in 'real' markets, are made using a 'bottom-up' decision process (Olshavsky and Granbois, 1979). Consumer choices are not based on a file cabinet of rational and consistent bevaioral memories but are based on rules invoked on-the-spot for each situation. This is as true of market decisions involving monetary transactions as it is of survey responses. The problem is not that CVM responses are not real, but rather that humans may not act according to the assumptions of utility theory.

2.2.2 Non-Satiation

Axiom 4 is sometimes referred to as non-satiation or monotonicity. This axiom is relevant to environmental valuation because without the assumption of non-satiation, CVM loses operational meaning as a practical tool of monetary evaluation of environmental services. This postulate has also been criticized by ecological economists because many if not most of the environmental services provided by ecosystems (water, food, oxygen, etc.) have a saturation region. For example, the composition of gases in the atmosphere must fall within a certain range to support human life. If there is too little oxygen we will die of asphyxiation; too much oxygen will cause the Earth's organic material to burn uncontrollably. Other atmospheric gases must also be present in fairly fixed amounts. The level of nitrogen, for example, is critical for the regulation of breathing in animals. As is by now well-known small changes in the level of CO_2 in the earth's atmosphere can have a dramatic effect on the earth's temperature.

Many environmental services must be present within a narrow range to support human life. Such services cannot be characterized by a single saturation point nor can the effect of changing their amounts be delineated into continuous marginal quantities. Individual preferences have some grounding in biophysical reality. Individual choices are not purely independent of the biological and social worlds surrounding the decision-maker. Many attempts to place an economic value on nature's services may be meaningless because of the lack of context of the valuation (Ayres, van den Bergh, and Gowdy, 1999; Costanza et al., 1997; Gowdy, 1997; Toman, 1998).

It should also be pointed out here that the notion that human wants are infinite is also inconsistant with evidence from a number of human societies. The craving for material goods as a dominant feature of human societies is an idea that evidently began with the agricultural revolution (Sahlins 1972, in Gowdy 1998). Indeed, in some societies the morbid craving for wealth is considered to be a serious disease (Sahlins, 1996).

A weaker version of the monotoncity or non-saturation rule is local non-statiation (Jehle, 1991; Mas-Colell, Whiston, and Green, 1995). The local non-satiation axiom rules out the possibility of having an area in which all the points are indifferent. But as discussed above, some environmental goods cannot be ruled out by the local non-satiation axiom. In addition to this difficulty, we must define a particular metric space in order to define the notion of 'vicinity'. To proceed independently of a particular metric space, a more rigorous definition is needed. So, we define a saturation point S as a point such that the direction to S is a preference direction from any non-saturation point. For simplicity's sake, we also assume that there is only one such point (in general, the set of saturation points is a convex set, but the conclusion is not affected). If we adopt this assumption, we have an integral curve which has a spiral form around a saturation point even for the two commodities case (for detailed discussion, see Mayumi and Gowdy 1999). Fig. 1 shows such curves around a saturaion point[4]. Given some amount of the first commodity, there are infinitely many values of the amount of the second commodity which result in the same utility index. Hence, we cannot build a unique index of utility in this case.

2.2.3 The Principle of Complementarity

Axiom 6 is referred to by Georgescu-Roegen (1954a) as the Principle of Complementarity. This axiom is slightly weaker than the axiom of convexity usually adopted in advanced texts

(Jehle, 1991; Mas-Colell, Whiston, and Green, 1995). In the two commodity case, The convexity axiom is equivalent to the principle of decreasing marginal rate of substitution, one of the theoretical lynchpins of utility theory. In general, indifference maps convex to the origin imply a decreasing marginal rate of substitution between any two commodities. Axiom 6 has no meaning if the commodities are only ordinally measurable. For example, 'half' of a commodity would not be uniquely defined without some notion of cardinality. Neoclassical texts usually argue that any scale is as good as another, that is, only ordinal rankings of commodity bundles are necessary. But the following example shows that this argument is not universal. The utility function $U = \sqrt{xy}$ exhibits a decreasing marginal rate of substitution. Let us adopt a new scale by the monotonic transformation: $x = e^{\frac{-1}{u}}$ for $0 \leq x \leq e^{-1}$, and $x = e^{u^2-2}$ for $e^{-1} \leq x$. We use the same transformation for y into v. We obtain the new utility function $U = e^{\frac{u^2+v^2-4}{2}}$ in the domain $u, v \geq 1$. Thus if we monotonically transform this utility function again, we obtain a new utility function whose indifference function is $u^2 + v^2 = const$. The principle of decreasing marginal rate of substitution does not hold true for this new utility function. This example shows that without Axiom 6, we cannot determine even theoretically what is an appropriate scale of monotonic transformation in the commodity space to obtain a utility index. This points to an inconsistency in the claim that ordinal utility is sufficient to construct a consistent theory of consumer choice. The axiomatic system needed for utility theory includes an axiom which is inconsistent with the ordinality claim.

What is the relevance of Axiom 6 to environmental valuation? Axiom 6 suggests that any economic law describing the structure of consumer choice depends on the special type of measure (system of mapping) used for commodities. But how can we determine one specific measure when we evaluate various environmental services in a CVM scheme? What is the relation of commodity scale and the monetary metric used in CVM? Thus even ordinal measurability does not fit in the simplest picture of a utility function. Some of these issues have been discussed in the debate over the use of 'willingness to pay' versus 'willingness of accept' measures. Which measure to use depends not only on whether Hicksian or Marshallian demand curves are assumed, but also on human psychology. Humans feel a greater loss when something they have is taken away than they do if that same thing (object, situation, or feature) is given to them as something 'extra' (Bromley, 1989 and 1990).

2.2.4 Lexicographic Preferences

Ordinalists used to believe that Axioms 1, 2, 3, 4, 5, and 6 are sufficient to build a utility function (or an ophelimity index) which is an ordinal measure of the preference of HO. But suppose we drop Axiom 7 and retain all the others. It can be demonstrated that without Axiom 7 we have a case where we cannot obtain an ordinal measure of utility. In fact, Axiom 7 is necessary to preclude a lexicographic ordering of preferences. Lexicographic preferences mean that even if alternatives can be compared, this does not imply that an ordinal measure can be obtained.

Lexicographic choice is reflected in the hierarchy of choice of human wants, termed by Georgescu-Roegen as The Principle of Irreducibility of Wants. Lexicographic preferences imply that consumers are not necessarily willing to substitute one commodity for another. Everyday observations, as well as empirical tests, show that this ordering is ubiquitous: bread cannot save someone dying of thirst; life in a luxurious palace cannot substitute for food (Georgescu-Roegen, 1954b). Lexicographic ordering implies that it is impossible to represent a variety of wants in terms of one linear, dimension-preserving, order which is a utility index. Mathematically, lexicographic ordering is not a linear continuous series. A linear continuous series satisfies the following three postulates (1) the Dedekind postulate, (2) the Density postulate, and (3) the Linearity postulate. It has been long known that lexicographic ordering does not satisfy the linearity postulate (Huntington, 1917). This fact prevents us from establishing an ordinal measure.

Lexicographic preference is more than a theoretical curiosity. Such preferences are pervasive in CVM surveys (Gowdy, 1997). Spash and Hanley (1995) argue that valuation methods which elicit bids for biodiversity preservation fail as measures of welfare changes due to the prevalence of lexicographic preferences. They found that a significant number of respondents refuse to make trade-offs between biodiversity and market goods. Stevens et al. (1991) also found evidence for lexicographic preferences in a study estimating the value of wildlife in New England. Forty-four percent of respondents agreed with the statement 'preservation of wildlife should not be determined by how much money can be spent'. Sixty-seven percent agree with the statement '[a]s much wildlife as possible should be preserved no matter what the cost' (Stevens et al., 1991, pp. 398-99).

As Arrow (1997) points out, lexicographic preferences need not be inconsistent with neoclassical utility theory if marginal valuation is possible. For example, we may place an infinite value on our own lives, but we may accept an increased risk of death for a price. The neoclassical explanation of lexicographic preferences would be that high risks do not have a monetary equivalent (Arrow, 1997). Another explanation is that in cases where people are willing to risk their lives, the risk is perceived to be so small it is assumed to be zero. The problem of lexicographic ordering revolves around the appropriateness of marginal valuation.

2.2.5 The Hierarchy of Wants

The seven axioms of consumer choice do not reflect the hierarchical ordering of human wants or the evolution of preferences over time. The existence of a hierarchy of wants is necessary to explain the Principle of Decreasing Marginal Utility. Different levels of needs have different degrees of importance to us. But we should note that what can be generally described as the hierarchy of human wants involves several other principles. The satisfaction of every want 'lower' in the scale creates a desire of 'higher' character. That is, the satisfaction of a lower want permits the higher want to manifest itself. In a way, the satisfaction of lower wants enhances the perception of wants higher in the hierarchy. Georgescu-Roegen (1954b) terms this the Principle of Subordination of Wants. We know that as a rule humans must usually reach satiety before the next different want can manifest itself. Irrespective of whether or not we accept the idea that wants have an intensity, we cannot deny the existence of another related principle listed by Georgescu-Roegen (1954b), The Principle of Satiable Wants. Due to the fact that the hierarchy of wants is open-ended we know also that as soon as humans manage to get close to the satiation of a new want, there is always another want higher on the ladder. This is the Principle of the Growth of Wants which is tantamount to the absence of absolute saturation of human ability to want more. Of course, this principle has an evolutionary character as well as being culturally specific. It should be noted, however, that marginal utility theory has ignored basically all these principles except the Principle of Satiable Wants which is the essence of the Principle of Diminishing Marginal Utility.

Economic valuation assumes the existance of a common essence of all wants, a unique want into which all wants can be merged into a mono-dimensional definition of utility. As a consequence of this procedure, very important issues which cannot be answered without addressing some of the ignored principles, were gradually moved into the category of ignored questions. Economists could argue that since their theory is in this way basically transformed into 'choice theory', which no longer uses the utility concept, these arguments are

not appropriate. Unfortunately, the metamorphosis from utility theory to consumer choice theory was based on a progressive focus on relations among goods themselves and on the axiomatic aspects of the formulation. Arguments for the plausibility of the existence of a common denominator (in terms of utility or ultimately in terms of money as a possible encoding for the quality to be mapped) have never been seriously made, perhaps because in real-world markets everything is reduced to a common denominator. In fact, close examination shows that theories of choice were only axiomatic molds of utility theories and retained all the consequences of the belief in the reducibility of all wants into money. This is against the common sense view, which, in our view is the essence of multidimensional value systems. That is, according to Georgescu-Roegen's view, would represent the Principle of the Irreducibility of Wants (1954b). Martinez-Alier, Munda, and O'Neill (1998) argue that the assumption of commensurability of wants is the key thing that separates neoclassical from ecological economics (see the discussion by Arrow (1997) and Radin (1996)).

2.2.6 CVM and The Marginal Utility of Money

The basic ideas of CVM go back to the Dupuit-Marshall consumer surplus principle (Georgescu-Roegen, 1968), that is, the money which a person would just be willing to pay for something rather than go without it, is the economic measure of the satisfaction to him or her. In practical terms, this means taking for granted that utility can be satisfactorily measured by money. Thus in the Dupuit-Marshall or the CVM schemes, the utility of the money that the individual has to pay for each additional 'util' must always increase. This is due to the fact that money is drawn away from increasingly important uses. But CVM must assume (as Marshall did) that the marginal utility of money is quasi-constant. Is this an acceptable hypothesis? Marshall's aim was to analyze the economic reality of his own time and place. According to Georgescu-Roegen's analysis (1968) the assumption of quasi-consistency of the marginal utility of money is compatible with a society consisting of urban Western 'middle class individuals', typical of developed countries where a substantial part of personal income is spent on mere conveniences. That is, the bulk of these items are marginal expenditures in relation to the entire income. In this situation, a variation in income causes one of these items either to disappear from the budget or to become a new entry in the list of expenditures. When dealing with these conditions, it is reasonable to assume that the utility of money among convenience items can be considered the same: individuals find it difficult to decide whether to buy one items or the other. However, this is another of the assumptions needed to use CVM. One question is then, is it reasonable to evaluate, by using CVM, the value of environmental services in developing countries where only a minimal part of the consumer budget is spent on mere conveniences?

2.2.7 Economic Man and Methodological Individualism

Much of the criticism of neoclassical economics centers on the notion of humans as rational calculating individuals. Economic Man lies at the heart of the impotant issues in concumer coice theory. Kenneth Arrow (1997, p. 760) recalls a skit that graduate students performed at the University of Chicago in the late 1940s 'the leading character' was the Rational Economic Man. He stood with a slide rule prepared to answer all questions. He was asked 'How much would you charge to kill your grandmother?'. After some calculations he looked up and asked, 'Do I have to dispose of the remains?'. The fact that this was taken by the audience to be a satire shows that economists are, down deep, aware of the limits of the rationality assumption. Still, economists place the individual pleasure and pain calculator at the center of the universe. Social welfare is merely the sum of the welfare of each individual.

Economists elevate the notion of individual self-interest to a moral position. Each individual knows what is best for him or her and any attempt to circumvent individual choice by any form of collective action is met with charges of totalitarianism. As Randall (1988, p. 217) puts it, 'The mainstream economic approach is doggedly nonjudgmental about people's preferences: what the individual wants is presumed to be good for that individual'. Georgescu-Roegen was eloquent on the point that what is good for an individual with a finite lifespan, acting at a particular point in time, may not be best for society as a whole.

> It is utterly inept to transpose to the entire human species, even to a nation, the laws of conduct of a single individual. It is understandable that an individual should be impatient (or myopic), i.e. to prefer an apple now over an apple tomorrow. The individual is mortal. But the human species or a nation has no reason to be myopic. They must act as if they were immortal, because with the immediate horizon they are so. The present turning point in mankind's evolution call for the individual to understand that he is part of a quasi immortal body and hence must get rid of his myopia. (Georgescu-Roegen, 1976, p. xix)

In standard utility theory, only individual perceptions count. There is no social, biological or physical reality outside the individual, only the subjective feelings of unconnected utlity maximizers. Even arguments for the well-being of future generations, as for example, in CVM measures, must be couched in terms of 'utility' not absolute requirements. Bromley (1998, p. 233), among others, has pointed out the narrowness of this position: 'In blunt terms, the atmosphere must be kept free for breathing, not because it would be useful for future generations to be able to breathe but because future generations will otherwise suffer a loss of utility'.

2.3 Probabilistic Binary Choice and Environmental Valuation

Any type of experiment designed to directly test the validity of Axiom 7 seems impossible because there are no means for testing assertions involving the continuum. In a sense, the questions involved in Axiom 7 cannot be settled solely in terms of observable facts. This confronts us with the more difficult question as to whether or not indifference could be defined in such a way as to avoid all references to introspection so as to base the definition only on direct observation. Axioms 2, 3 and 7 exclude the psychological threshold, thus making HO an absolutely perfect choosing instrument. What will happen if these three axioms are dropped? Here the psychological threshold is the area out of which HO can make a perfect choice without any doubt. If we accept the presence of this type of threshold, the choice between C^1 and C^2 may not always show the same preference ordering.

Because the evaluation of environmental services involves many types of risk and ignorance on our part, introduction of the psychological threshold is necessary. Hence, we introduce a New Homo oeconomicus (NHO).

Following Georgescu-Roegen's scheme (1936 and 1958, pp. 159-160), we adopt the following set of axioms for NHO:

1. Given two points, $A(a_1, a_2, \ldots, a_n)$ and $B(b_1, b_2, \ldots, b_n)$ in the commodity space, $w(A, B) + w(B, A) = 1$, where $w(A, B)$ is the probability that A be chosen.
2. If $A \geq B$, then $w(A, B) = 1$.[5]
3. The probability $w(X, A)$ is a continuous function of X, except for $X = A$, where $w(X, A)$

can take any value in the closed interval [0, 1].

4. If $A \leq B$, then $w(A, C) \leq w(B, C)$, the equality sign holding only if $w(A, C) = 1$ or $w(B, C) = 0$.

5. Pseudo-Transitivity: If $w(A, B) = w(B, C) = p \geq 1/2$, then $w(A, C) \geq p$.

6. General Principle of Persisting Non-Preference Direction: If $C = \lambda A + (1 - \lambda)B$, with $0 < \lambda < 1$, then $w(A, B) \leq w(C, B)$.

A simple model with two parameters, p and d, satisfying this set of axioms, can be constructed.[6] The following one-parameter family of differential equations satisfy the classical conditions of indifference directions (convexity) and $\frac{\partial}{\partial p}(-\frac{dx_2}{dx_1}) > 0$.

$$px_1^{p-1}x_2^{1-p}dx_1 + (1-p)x_1^p x_2^{-p}dx_2 = 0. \tag{2.1}$$

We can solve this equation to obtain the two-parameters family of integral curves (equation(3)). Assuming that $x_1^p x_2^p < (x_1^*)^p(x_2^*)^{1-p}$ for $(x_1, x_2) < (x_1^*, x_2^*)$, the other values of $w(X, A)$ can be defined according to the following rules:

(a). $w(X, A) = p$, if either $x_1^p x_2^{1-p} = d$, or $x_1^{1-p}x_2^p = d$, and $x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} > d$ when $1/2 < p < 1$;

(b). $w(X, A) = p$, if either $x_1^p x_2^{1-p} = d$, or $x_1^{1-p}x_2^p = d$, and $x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} < d$ when $0 < p < 1/2$;

(c). $w(X, A) = 1$, if $x_1 \geq d$, $x_2 \geq d$, and $x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} > d$;

(d). $w(X, A) = 0$, if $x_1 \leq d$, $x_2 \leq d$, and $x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} < d$.

It is relatively easy to show that this model satisfies the set of axioms for NHO. In Fig. 2, the curve $\overline{A}_2AA_3$ represents the locus with $w(X, A) = p$ where $1/2 < p < 1$. The threee curves, $\overline{A}_1AA_1$, $\overline{A}_2AA_2$, and $\overline{A}_3AA_3$ represent the following three equations in turn;

$$x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} = d, \tag{2.2}$$

$$x_1^p x_2^{1-p} = d, \tag{2.3}$$

and

$$x_1^{1-p}x_2^p = d. \tag{2.4}$$

The case in which $0 < p < 1/2$ can be depicted in a similar way. We should note that the case for which either $w(X, A) = 1$ or $w(X, A) = 0$ is reresented by the area either D_1AD_2O or E_1AE_2. The limiting lines relative to A ($x_1 = d$ and $x_2 = d$) can be obtained if p approaches either 0 or 1 in equation (3). The area either E_1AD_1 or E_2AD_2 may be termed as *hesitation region* relative to the point A in which $w(X, A)$ is neither 0 nor 1: for all price lines within this angle, NHO can only attach some probability of selecting a direction from the initial position A. In Georgescu-Roegen's words: we 'should also be aware of the possibility of interpreting as 'indiffernt states' those which man cannot order without a great deal of hesitation or without some inconsistency. Such cases are the symptoms of imperfections in the mechanism of choice caused by a psychological threshold which is absent'(Georgescu-Roegen, 1954b, p. 522) in HO. This is not indifference but rather an inability to choose, as in the case of Buridan's ass, which starved to death between two identical piles of hay (Georgescu-Roegen, 1973, p. 322).

The three different regions of this model are shown in Fig. 3. If we take any path moving toward a preferred ($w(X, A) = 1$) or non-preferred ($w(X, A) = 0$) direction, the choice in these two regions are consistent, i.e., transitive. However, in hesitation region choice is not transitive in general. This situation is shown in Fig. 3 where we might move from A to J and from J to L, but L is preferred to A. The lack of transitivity with respect to hesitation is obvious because there is a probability of choice between any two commodities in the case of hesitation. We encounter this type of hesitation whenever a new situation is given to a consumer. So, in a sense, the state of mind described by indifference in neoclassical economics is rather strange. We share the view of Georgescu-Roegen that the states of mind which could be called indifference should be those which we cannot order without a great deal of hesitation or without some inconsistency. The behavior described by NHO shows exactly these sorts of indifferent states with great hesitation rather than the states of mind willing to trade described by the CVM. The notion of hesitation region discussed in this section can be regarded as a consequence of our inability to visualize an imaginary situation exactly as we will feel it after many experiences of the situation.

2.4 Conclusion

Following the triumph of neoclassical theory after WWII utility theory was more or less relegated to a secondary field of inquiry. Criticisms of the basic axioms of consumer choice were more or less limited to those outside the mainstream of the economics profession. Economists were for the most part satisfied with Stigler and Becker's position (1977) that tastes were not a matter of dispute and with Friedman's argument (1953) that the realism of the assumptions of economic theory was not a matter of concern as long as the theory could be used to make accurate predictions. With the weakening of economic orthodoxy following the energy price shocks of the 1970s and the global financial instability in the 1980s and 1990s, some of the basic tenets of economic theory are under attack as never before. Within the field of environmental economics major crises such as global climate change and the worldwide loss of biodiversity have called into question the theoretical foundations of the basic tools of economic analysis used in environmental policy. A number of environmental policy failures have led to new approaches. The failure of fisheries policies based on economic models has triggered a number of studies of common property (as opposed to open access) management systems. Daniel Bromley (1989), Susan Hanna (1997), Elinor Ostrom (1990), and many others argue for the reformulation of institutions for democratic collective action as a means to manage environmental resources. In the past, a number of methodological breakthroughs in economics have been the direct result of policy failures, a notable example being Keynes' *General Theory*. It is our hope that some of the current controversies surrounding environmental valuation will convince economists of the importance of reconciling economic theory with basic knowledge in other sciences (Wilson, 1998). It is our belief that some of the fundamental assumptions of neoclassical utility theory, non-satiation, the indifference postulate, the commensurability of wants, and indeed methodological individualism itself are not only unrealistic but also have had unforeseen and unfortunate consequences for environmental and social policy.

Footnotes

* Previous versions of this chapter were presented and discussed at Georgescu-Roegen's Scientific Work, in Strasbourg, France, November 6-8, 1998, and the Fifth Interntional Conference of International Society for Ecological Economics, in San Diego, Chile, November 15-19, 1998.

1. G. S. Becker extended the neoclassical utility maximizing approach to endogenous preferences, including personal and social capital (e.g., Becker, 1996; Stigler and Becker, 1977). According to Becker, this extended utility function remains the same over time and the same for different individuals included addictive, siocial, advertizing capital as arguments. However, Becker's analysis does not consider the issue of relevant choices of the axioms underlying utility theory as discussed in this chapter.

2. There have been many interesting modifications of neoclassical theory since the basic postulates of consumer choice were laid out decades ago. Game theory and rational expec-

tations, for example, have enriched the standard paradigm. These approaches, however, are still grounded in a system of optimal allocation in near-to-equilibrium framework. Some promising work is currently being done under the general topic of the economics of complexity which promises to move economic theory to a more general out-of-equilibium framework (e.g., Arthur, 1999). But it is beyond the scope of this chapter to discuss such approaches.

3. When Georgescu-Roegen discussed this particular set of axioms (1954b), he did not consider its relationship to environmental valuation.

4. Equation (27) (p. 561 in Georgescu-Roegen's *QJE* paper in 1936), cannot be spiral forms as Georgescu-Roegen (1936) believed. He adopted a wrong transformation of the original equation (24) into (27). There are infinite number of values for y_2 in the transformation $x_2 = y_2 x_1$ near the saturaion point. Actually, for a suitable transformation using Jordan canonical form, a solution for Equation (24) can be obtained when $\phi^0_{12} \neq \phi^0_{21}$. A solution is, with a suitable change in axes, $X_1 = c_1 e^{\mu t} \cos \nu t$ and $X_2 = c_2 e^{\mu t} \sin \nu t$ $(\mu \neq 0)$. The detailed mathematical discussion is omitted here.

5. $A \geq B$ means iff $a_i \geq b_i$, $i = 1, \ldots, n$ and $a_j > b_j$ for at least one j.

6. The parameter p is taken as probability $w(X, A)$ given the point A.

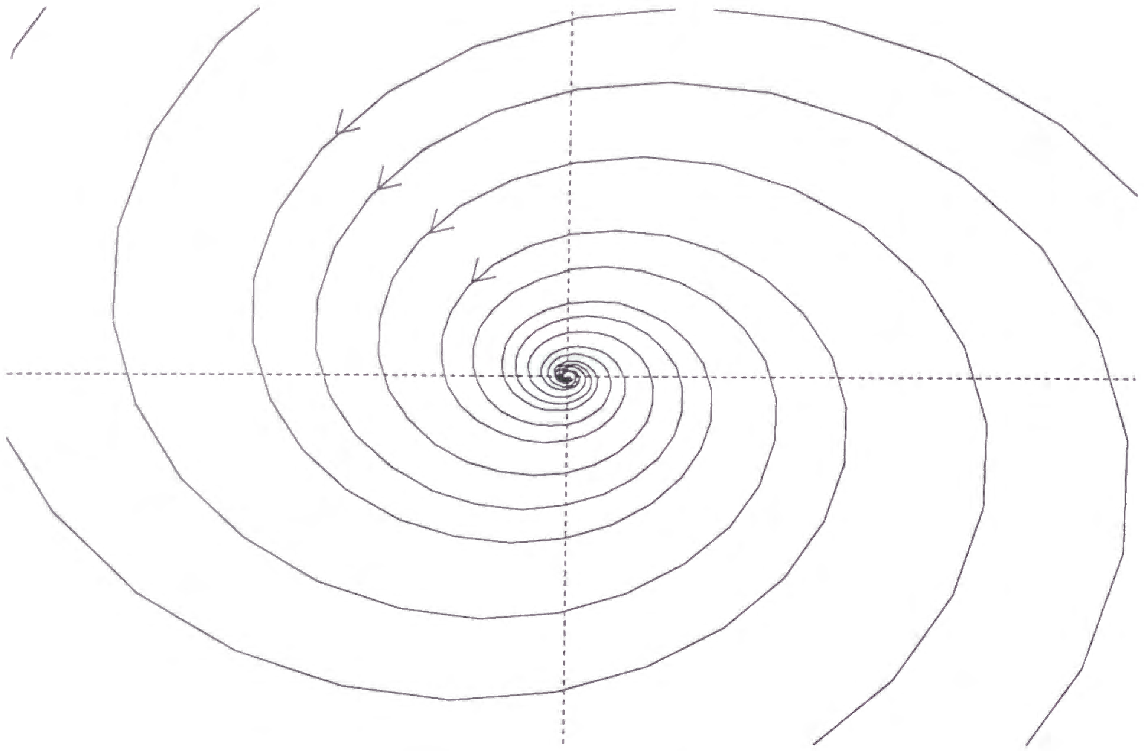
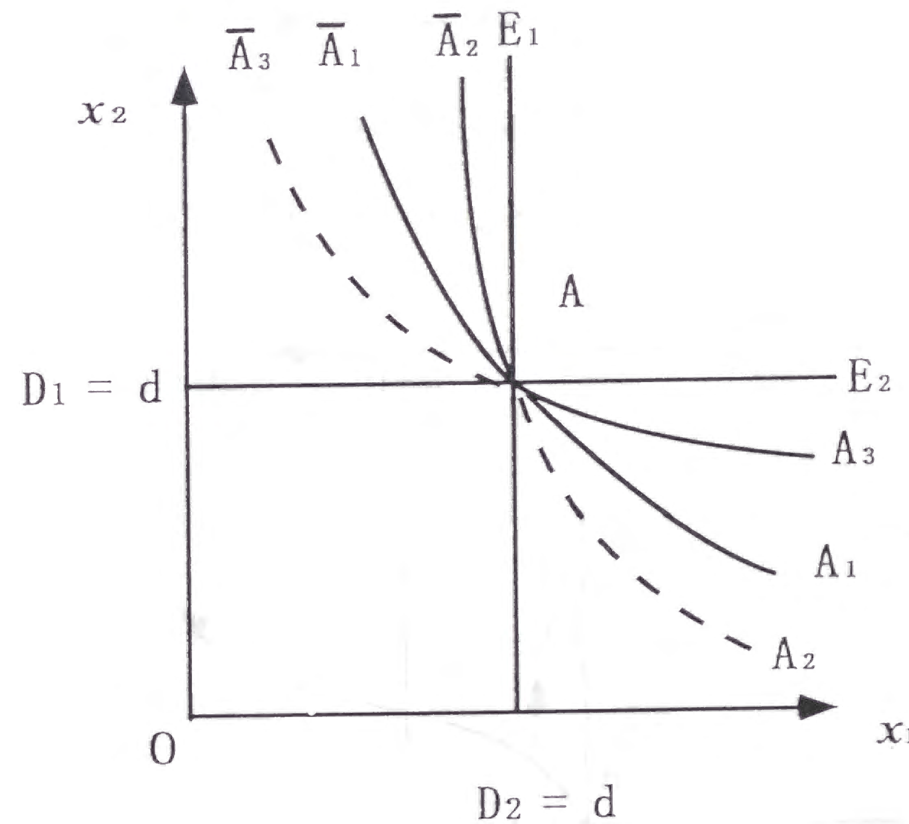


Figure 2.1: Integral Curves around the Saturation Point



$$\bar{A}_1AA_1 : x_1^{1/2} x_2^{1/2} = d$$

$$\bar{A}_2AA_2 : x_1^{p} x_2^{1-p} = d$$

$$\bar{A}_3AA_3 : x_1^{1-p} x_2^{p} = d$$

Fig. 2

Figure 2.2: Binary Choice Mapping

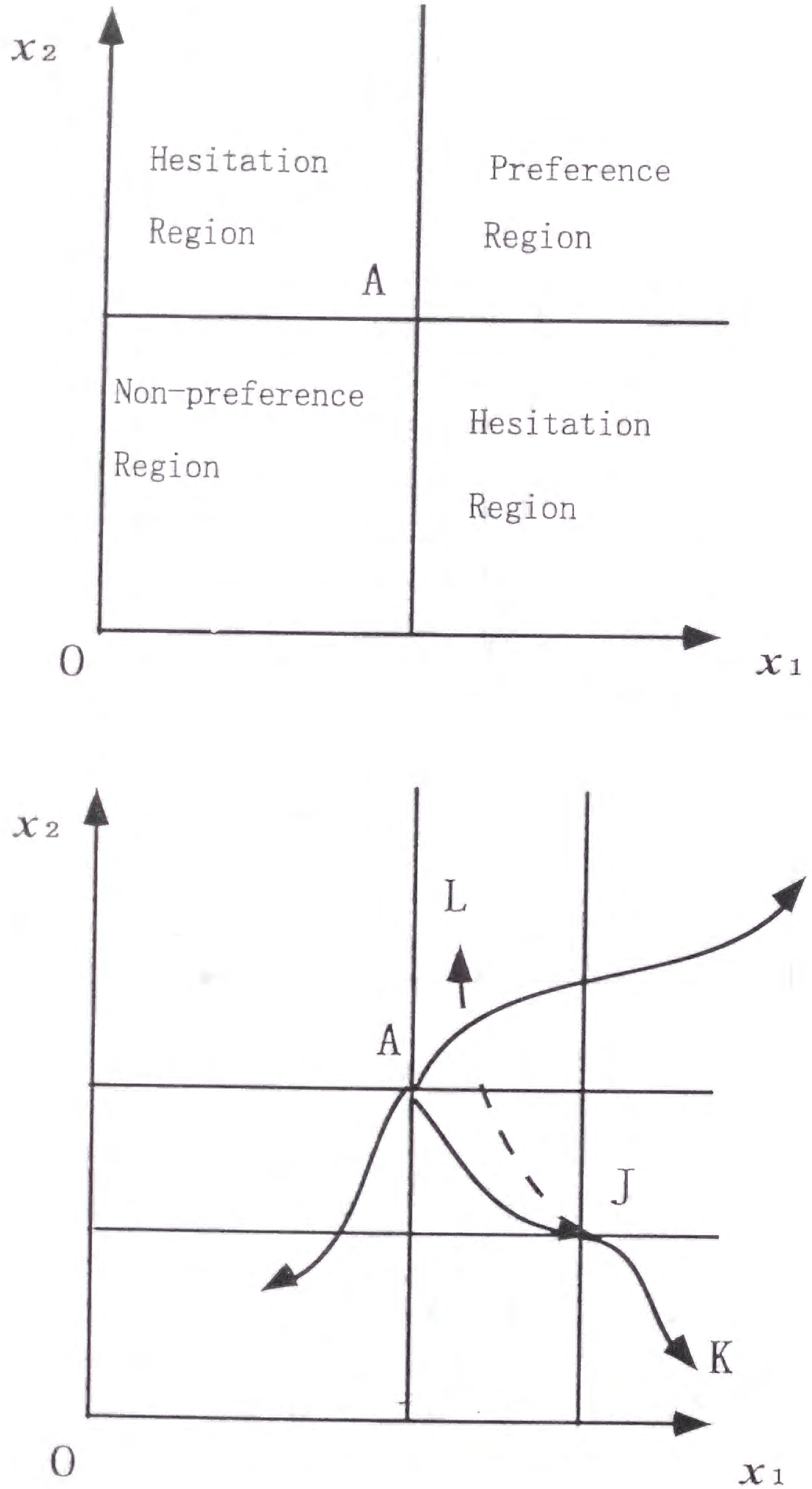


Fig. 3

Figure 2.3: Hesitation Region and Violation of Transitivity

Chapter 3

Information, pseudo measures and entropy: an elaboration on Nicholas Georgescu-Roegen's critique

3.1 Introduction

When new concepts are introduced in science, each of them is usually identified by a new name. However, these new concepts are sometimes labeled either by using words taken from common vocabulary or adopting a name which is already used in other fields. The term, information is an example of the first case, and the use of the term, entropy in information science and cybernetics is an example of the second case.

Information is a highly ambiguous term. Thus this name turned out to be a continuous source of misunderstandings (Bar-Hillel, 1955; Tillman and Russell, 1965). As N. Georgescu-Roegen (1977, p. 189) aptly remarked, "the meaning of "information" shifts freely among that of "messages," "choice," "uncertainty," to be finally confused with that of "knowledge" in the academic sense of this term." This aggravated situation led none other than C. E. Shannon to lament that the concept of information originally set out in communication engineering has been "ballooned to an importance beyond its actual accomplishments" and that "the basic results of the subject are aimed in a very specific direction, a direction that is not necessarily relevant to such fields as psychology, economics, and other social sciences" (Shannon, 1956).

On the other hand, negative entropy in information science is mathematically similar to Ludwig Boltzmann's famous formula for statistical entropy. The purely algebraic relationship between the two concepts has led many scholars to claim that negative entropy and information are essentially identical (e.g., Lewis, 1930; Brillouin, 1951b; Tribus and McIrvine, 1971;

Ayres, 1994). It is beyond doubt that some connections and similarities between entropy and information exist: "no information [in the broadest sense] can be obtained, transmitted, or received without the expenditure of some free energy" and "like free energy (negentropy), information is subject to degradation" (Georgescu-Roegen, 1971, p. 405). However, these connections and similarities cannot justify by itself the alleged equivalence between the two concepts (Mayumi, 1993).

The aim of this chapter is twofold: (1) to clarify some of the issues related to the concept of information based on Georgescu-Roegen's critique of the measure of information; (2) to examine the claim of the alleged equivalence between negative entropy and information elaborating on Georgescu-Roegen's analysis (1971 Appendix B, 1977 and 1990).

In Section 2 we introduce Shannon's concept of information and discuss related issues, together with a historical development of the concept of information in communication engineering. In Section 3 we evaluate critically N. Wiener's concept of information and uncertainty. Any measure of uncertaity is shown to be not an ordinal variable, but a pseudo measure in the sense that two pseudo measures of the same variable can yield entirely different rankings. It is also shown that the expected amount of information for a continuous distribution cannot be obtained by a passage to the limit from that for a discrete distribution as in mathematical analysis. In Section 4 the alleged equivalence between negative entropy and information is shown to be physically baseless through close examination of the works of L. Szilard, E. T. Jaynes and L. Brillouin. In Section 5, the final section, Georgescu-Roegen's epistemological position (1976 and 1992) is connected with his critique of the measure of information and of the alleged equivalence between negative entropy and information.

3.2 Shannon's concept of information: a case of misnomer

Shannon's concept of information has its roots in a classical paper by H. Nyquist (1924). Nyquist used the term, "intelligence", instead of "information", in the sense of military intelligence during wartime. Nyquist considered two fundamental factors—signal shaping and choice of codes—for improving the speed of transmission of signal elements by telegraph. Nyquist then derived a formula for the speed of transmission of intelligence. His approach makes perfect sense from one of the objectives of communication engineering, i.e., to transmit signal elements as speedy as possible.

However, Georgescu-Roegen (1977) correctly indicated that a serious and regrettable imbroglio was introduced into communication engineering from the beginning by Nyquist, R. V. L. Hartley (1928), and later by Shannon (originally published in 1948), followed by many writers. They, Shannon in particular, regarded two different concepts—the number of messages to be transmitted and the capacity of a communication channel—as equivalent and called them as information.

To explain more clearly the issue here, let us consider a channel capable of transmitting n distinct signal elements and assume that there are M distinct messages. In order to represent M messages by the codified n^N sequences of signal elements of the same duration we must choose N, the number of signal elements in each message, to satisfy the following inequality:

$$n^{N-1} < M \leq n^N. \tag{3.1}$$

In this inequality there are two distinct concepts: one is the totality of messages, M and the other, the number of different sequences of signal elements with a given length N, n^N. The latter is a measure of the capacity of the corresponding channel. Shannon as well as other communication engineers should have treated these concepts as distinct ones. Capacity is a characteristic of a communication channel adopted and varies with technological progress. On the other hand, the totality of messages to be transmitted is independent of the type of communication systems used. Both Shannon and other scholars should have coined a name, *capacity of channel transmission*, instead of information, in my view.

From the engineering view points it is perfectly reasonable to regard the capacity of a communication channel with s identical channels, for example, s times as many as the capacity of a channel of the same type. Thus, the following definition on the capacity of channel transmission using the logarithmic function makes perfect sense:

$$\textit{Capacity of channel transmission} = \log_2 n^N = N \log_2 n(bits). \tag{3.2}$$

We can obtain capacity of channel transmission per signal element independently of the length of a message:

$$\textit{Capacity of channel transmission per signal} = \log_2 n. \tag{3.3}$$

Because of the confusion of the totality of messages with the capacity of a channel, one might say that $\log_2 n$ measures the amount of information per signal element. However, this interpretaion should not have been adopted. Without careful discrimination between the two concepts Hartley and Shannon 'defined' information. Hartley wrote:

> What we have done then is to take as our practical measure of information the logarithm of the possible number of symbol sequences [$\log_2 n^N$] (Hartley, 1928, p. 540).

Shannon regarded $\log_2 M$ as a measure of information in one place:

> If the number of messages in the set is finite then this number or any monotonic function of this number [$\log_2 M$] can be regarded as a measure of the information (Shannon, 1964, p. 32).

But in another place Shannon defined H as a measure of information, even though H is actually capacity of channel transmission per signal for a stochastic case to be shown later:

> Quantities of the form $H = -\sum p_i \log_2 p_i$ play a central role in information theory as measures of information (Shannon, 1964, p. 50).

Let us consider a source which produces n independent signal elements with probability p_i $(i = 1, 2, \ldots, n)$. The number of different sequences of signal elements with a given length N, which supplies again a measure of the capacity of the corresponding channel in a stochastic case, is given by the combinatorial formula

$$W = \frac{N!}{N_1! N_2! \ldots N_n!} \tag{3.4}$$

where

$$N_i = N p_i, \sum_{i=1}^{n} p_i = 1. \tag{3.5}$$

Using Stirling's asymptotic formula equation (3) becomes

$$\textit{Capacity of channel transmission per signal} = \lim_{N \to \infty} \frac{\log_2 W}{N} = H(bits), \tag{3.6}$$

for a stochastic case. Shannon interpreted H not as a coefficient related to the number of some special categories of signals but as a measure of "information, choice, and uncertainty" (Shannon, 1964, p. 50).

There is another issue that can hardly be overemphasized: Shannon reached the function H not through the procedure above but through two different routes. One is an axiomatic

treatment based on three formal conditions. The other is based on the idea of typical sequences. Let us examine here only the second route. Shannon called any message in which signal elements appear with their expected relative frequencies as typical (1964, p. 54). The probability of this particular message is roughly

$$p \doteq p_1^{p_1 N} p_2^{p_2 N} \ldots p_n^{p_n N}. \tag{3.7}$$

From this equation Shannon arrived at the function H

$$-\frac{\log_2 p}{N} \doteq H = -\sum p_i \log_2 p_i. \tag{3.8}$$

According to his definition H is the information per signal (which is a wrong interpretation in the present author's view). However, a close examination shows that the information per signal in any typical sequence becomes zero as N approaches to infinity because it can be shown by using Stirling's asymptotic formula that

$$\lim_{N \to \infty} \frac{\log_2 (Wp)}{N} = 0. \tag{3.9}$$

Let us turn to the final issue in this section. Even though Shannon himself admitted that "there is still considerable sampling error in these figures due to identifying the observed sample frequencies with the prediction probabilities (1951, p. 64), he nevertheless tried to identify a source of vernacular language with an ergodic stochastic Markov chain (1951 and 1964). The appearance of each character in any language is subject to some kind of "mechanism" inherent in the language and not independent of the roots of the language, its syntax and so many other factors. Naturally those factors can not be treated in the framework of stochastic chain. The frequency of each character thus can never be identified with a random mechanism conceived by Shannon. On this issue Georgescu-Roegen's right verdict is:

> We must note however that this position, by now traditional in the so-called statistical interpretation of many phenomena, glosses over the fundamental difference between statistical probability and the ergodic limit in a nonstochastic sequence, such as the sequence of the decimal digits of 1/7, for example (Georgescu-Roegen, 1977, p. 193).

3.3 Wiener's concept of information and related issues

In contrast to the concept of information investigated by Nyquist, Hartley and Shannon, Wiener's information concept is *ab initio* related to the knowledge that *a certain stochastic event has occurred.* Wiener defined the measure of information (information$_w$ for short following Georgescu-Roegen's notation) as $-\log_2 p_A$, knowing that some event A with probability p_A has occurred (1961, p. 61). Wiener's excellent idea recalls G. L. S. Shackle's idea of a measure of surprise in the face of uncertainty (1955). Because the smaller is the ex ante degree of belief in a stochastic event, the greater is our ex post surprise at the knowledge that the event has actually occurred, we can in general regard any positive decreasing function with respect to p_A as a measure of information$_w$:

$$\textit{Amount of information}_w = F(p_A). \tag{3.10}$$

If we introduce probability distribution of a stochastic event into Wiener's original framework, we can obtain the expected amount of information$_w$ in the following:

$$\textit{Expected amount of information}_w = \sum_{i=1}^{n} p_i F(p_i). \tag{3.11}$$

The function H is a member of this general form. The general form can also be regarded as a measure of uncertainty. But if we want to regard the general form, $\sum_{i=1}^{n} p_i F(p_i)$ *only* as a measure of uncertainty, what conditions should be imposed on this general form? Any measure of uncertainty should have this property: it attains the maximum value when all the outcomes of a stochastic distribution are equally probable and reaches the minimum value when one outcome is absolutely certain. Georgescu-Roegen derived a necessary and sufficient condition for the general form to have this property: the function $pF(p)$ be a concave function over [0,1] (Georgescu-Roegen, 1971). Besides the function H, there are many instances of the general form of uncertainty one of which is Octav Onicescu's informational energy (Georgescu-Roegen, 1977, p. 203):

$$\textit{Informational energy} = G = 1 - \sum_{i=1}^{n} p_i^2. \tag{3.12}$$

The general measure of uncertainty represented by $\sum_{i=1}^{n} p_i F(p_i)$ was called pseudo measures by Georgescu-Roegen (1971). The pseudo measures are not ordinal variables because they do not necessarily stand in the same ordinal relationship with each other if the variable basis changes. As Georgescu-Roegen mentioned, "because of the dialectical nature of the pseudo measures, there is no way of eliminating the cases in which two pseudo measures of the same variable yield entirely different rankings" (1971, p. 389). By taking total differentiation of H and G, for instance, we can easily show that for $n > 2$, there are cases in which dH and dG do not necessarily have the same sign for some combination of dp_i's. Georgescu-Roegen (1964) established an interesting result related to the issue of measurability: the Archimedean Axiom is not a sufficient condition for an ordinal set to be ordinally measurable. In plain terms the Archimedean property is in essence tantamount to the example presented by Georgescu-Roegen: if the water in a reservoir is to be measured with the aid of a pail, we must be able to empty the reservoir by removing a finite number of pails of water (1964, p. 239).

Up to this point we considered only the cases of discrete distributions. However, Wiener defined a measure of information for continuous distributions (information$_{wc}$ for short) based on the analogy of discrete disributions, $\sum_{i=1}^{n} p_i F(p_i)$ without considering serious and problematic issues (1962, p. 61),

$$\textit{The expected amount of information}_{wc} = \int_{-\infty}^{\infty} f(x) \log_2 f(x) dx, \tag{3.13}$$

where

$$\int_{-\infty}^{\infty} f(x) dx = 1. \tag{3.14}$$

First of all, because the probability that a stochastic variable, X, for example, is equal to any value x in a given domain is zero; *Prob*$(X = x) = 0$, we obtain

$$\textit{Information}_w = F[\textit{Prob}(X = x)] = F(0). \tag{3.15}$$

Acccording to Wiener's idea of defining information, $F(0)$ should be infinite: we never imagined this event to occur but it actually occurred. In fact Wiener's function, $-\log_2 x$, becomes infinite as x approaches to zero.

Secondly, it is 'possible' for us to think that *Prob*$(X = x_1)$ is greater than *Prob*$(X = x_2)$ if $f(x_1) > f(x_2)$. Hence it seems 'reasonable' to replace the definition of information$_w$ by

$$\textit{Information}_{wc} \textit{ of } (X = x) = F[f(x)]. \tag{3.16}$$

Wiener's definition on his information for continuous distribution is based on the idea that by a passage to limit we can obtain the formula for the information for continuous cases, i.e., $\lim_{n\to\infty} \sum_{i=1}^{n} p_i F(p_i)$ is equivalent to $\int_{-\infty}^{\infty} f(x) F[f(x)] dx$. Wiener should not have adopted his definition for continuous case.

To see this, following Georgescu-Roegen (1971, 397) let us assume that $h(p) = pF(p)$ is strictly concave and that $h(0) = 0$. Under these assumptions we obtain

$$h(x) \geq \frac{y-x}{y}h(0) + \frac{x}{y}h(y) > \frac{x}{y}h(y) \tag{3.17}$$

where

$$0 < x < y. \tag{3.18}$$

Hence, the following relation holds for any x, $0 < x < y$,

$$F(x) > F(y). \tag{3.19}$$

Let us assume further that

$$\int_{-\infty}^{t} f(u)du \tag{3.20}$$

is absolutely continuous where $f(u)$ is a probability density. We can then find n intervals $-\infty < x_1 < \ldots < x_{n-1} < +\infty$ such that the probability over each of these intervals is $1/n$. For this way of dividing the stochastic field we have

$$\Phi_F(\vec{p}) = \sum_{i=1}^{n} p_i F(p_i) = F(1/n). \tag{3.21}$$

From Equation (19) $F(1/n)$ has a limit, finite or infinite for $n \to \infty$

$$\lim_{n\to\infty} \Phi_F(n) = \lim_{p\to 0} F(p). \tag{3.22}$$

Thus "*the expected amount of information for an absolutely continuous distribution depends only of the ordinal measure adopted–more exactly, on the limF(p) for p → 0–and not on the distribution itself*" (Georgescu-Roegen, 1971, p. 398).

For $F(p) = -\log p$, we obtain

$$\lim_{n\to\infty} \Phi_F(n) = +\infty. \tag{3.23}$$

Hence it is proved that Boltzmann's H function cannot be extended to a continuous distribution and that Wiener's definition on information given by (13) is not acceptable. And it is also proved that Wiener's concept of information has nothing to do with entropy in physics. Boltzmann made a similar mistake when he introduced his H-function, by using the Stirling formula (1964, pp. 55-62).

3.4 The alleged equivalence between information and negative entropy

There can be no doubt about the fact that to receive, store, and transmit information in general, we need some available energy. Just like available energy, information of any kind is subject to degradation during the process of transmission, for example, in the sense that the meaning of messages might sometimes change because of errors of recording. Thus there exist some connections and similarities between information and negative entropy. However, some scholars have gone beyond these: "it is now established to the satisfaction of virtually all physicists that information is the reduction of uncertainty and that uncertainty and entropy are essentially identical (not mere analogs)" (Ayres, 1994, p. 36).

There were three principal researchers regarded as responsible for the alleged equivalence between information and negative entropy: Szilard (1964, originally published in Germany in 1929), Jaynes (1957) and Brillouin (1950; 1951a; 1951b; 1953; 1962). Let us examine their works closely in sequence.

Szilard (1929) considered several inanimate devices which can achieve the same essential result as would be achieved by the intervention of intelligent beings like Maxwell's demon. Let us introduce briefly one of these devices to examine his idea. At a given time a piston is inserted into a cylinder. Then a given molecule is caught in the upper or lower part of the cylinder. The molecule bounces many times against the piston and in this way it does a certain amount of work on the piston (the work corresponding to the isothermal expansion of an ideal gas). The piston moves up or down until reaching the top or bottom of the cylinder, depending on whether the molecule is caught in the lower or upper half of the cylinder devided by the piston. After the piston has reached the top or the bottom of the cylinder, the piston is then removed. This procedure can be repeated as many times as desired. In his device the intervention of the man (ignoring his or her biological phenomena) consists only in the coupling of a coordinate x (determining the altitude of the molecule) with another coordinate y (the value of which is either 1 or -1, determining the position of the lever by which an upward or downward motion is imparted to the piston). Szilard derived some conditions on the magnitudes of entropies produced by the measurements if the law of entropy is not to be violated:

$$e^{-S_1/k} + e^{-S_2/k} \leq 1 \tag{3.24}$$

where S_1 is produced when during the measurement y assumes the value 1 and S_2, when y

assumes the value −1. k is the Boltzmann-Planck constant. Szilard showed that as long as the entropies S_1 and S_2 satisfy the inequality (24), the expected decrease of entropy caused by the later utilization of the measurement is fully compensated, thus the second law of thermodynamics is not violated.

However, A. Tsuchida, a Japanese physicist, devised a similar mental apparatus in order to show that Szilard's apparatus as well as Tsuchida's one is not compatible with the framework of statistical thermodynamics (Tsuchida, 1992). Let us explain this based on Tsuchida's idea (Fig. 1). A molecule is inside a container and two weights are tied with a piston with a small hole. There are four catches fixed on the container so that the piston stays inside a preassigned area of the container. Suppose that the molecule is on the left hand of the piston, the molecule bounces against the piston so many times and the piston moves to the right until touching two of the catches. After some time the molecule could pass into the right hand of the piston, and then the piston begins to move to the opposite direction. This procedure can continue indefinitely. Only thing that we should take care of is an adjustment of the size of the hole on the piston: the mean stay time of the molecule on the right or left of the piston should be sufficiently long compared with the duration in which the molecule bounces against the piston. Thus we can obtain a perpetual motion of the second kind without any measurements or 'information'!

Then what is wrong with Szilard's idea? The concept of irreversibility (or entropy) is the cornerstone in classical thermodynamics. But in quantum mechanical systems there is a principle called the principle of detailed balancing: "in equilibrium the number of processes which destroy a situation A and produce a situation B will be equal to the number of processes which produce A and destroy B" (Haar, 1954). According to this principle all phenomena should be reversible. To derive irreversibility statistical thermodynamics is constructed on this principle and the other 'compromising' principle[1]: statistical thermodynamics approaches should be applied to physical systems with 'many' molecules at least like Avogadro's number. In Szilard's model the molecule can move between the left and right

[1]However, L. D. Landau, a Nobel prize winner in physics, conjectured the quantum mechanical origin of irreversibility: "quantum mechanics does in fact involve an important non-equivalence of the two directions of time. This appears in connection with the interaction of a quantum object with a system which with sufficient accuracy obeys the laws of classical mechanics, a process of fundamental significance in quantum mechanics. If two interactions A and B with a given quantum object occur in succession, then the statement that the probability of any particular result of process B is determined by the result of process A can be valid only if process A occurred earlier than process B.... Thus in quantum mechanics there is a physical non-equivalence of the two directions of time, and theoretically the law of increase of entropy might be its macroscopic expression" (Landau and Lifshitz, 1980, p. 32).

part of the container with an equal probability because of the principle of detailed balancing. But his model unfortunately violates the other priciple of statistical mechanics. The concept of entropy, for example, should not be applied to a system with not many molecules like Szilard's model. Thus Szilard's model has been not compatible with the framework of statistical thermodynamics from the beginning.

Jaynes proposed a scheme of maximum-entropy inference (1957). For the sake of brevity we consider the simpliest formulation of Jaynes' idea. Jaynes' concern was how to find a probability assignment with no bias based on the expectation value of a given function: finding a probability assignment to maximize (25) subject to the constraints (26) and (27).

$$H(p_1 \dots p_n) = -\sum_{l=1}^{n} p_l \ln p_l. \tag{3.25}$$

$$\overline{f(x)} = \sum_{l=1}^{n} p_l f(x_l). \tag{3.26}$$

$$\sum_{l=1}^{n} p_l = 1. \tag{3.27}$$

Jaynes called H entropy or uncertainty. Introducing Lagrange multipliers λ and μ in the usual way, we obtain the following result:

$$p_l = e^{-\lambda-\mu f(x_l)}, \tag{3.28}$$

$$\overline{f(x)} = -\frac{\partial}{\partial\mu} \ln Z(\mu), \tag{3.29}$$

$$\lambda = \ln Z(\mu), \tag{3.30}$$

where

$$Z(\mu) = \sum_{l=1}^{n} e^{-\mu f(x_l)}. \tag{3.31}$$

However, Jaynes' formulation is essentially identical with a problem in statistical thermodynamics (Schrödinger, 1957). The problem is "to determine the distribution of an assembly of N identical systems over the possible states in which this assembly can find itself, given that the energy of the assembly is a constant E" (Schrödinger, 1957, p. 1). Let a_l be the number of systems out of N belonging to the state l whose eigenvalue of energy is ϵ_l. Mathematically the problem is maximization of (32) subject to (33) and (34).

$$\ln P = \ln[\frac{N!}{a_1!a_2!\dots a_l!\dots}]. \tag{3.32}$$

$$\sum_l a_l = N. \tag{3.33}$$

$$\sum_l \epsilon_l a_l = E. \tag{3.34}$$

a_l/N and E in Schrödinger's formulation correspond to p_l and $\overline{f(x)}$ in Jaynes' respectively.

It is true that Jaynes' formulation is mathematically identical with Schrödinger's based on Gibbs' idea. But there are two things in Schrödinger's formulation which are decisively different from that of Jaynes from physical points of view.

First, the interaction between the possible states is so weak that the energy of interaction can be disregarded. Thus we can safely speak of the 'private' energy of every state and that the sum of their 'private' energies is equal to E. As Schrödinger aptly remarked, the "distinguished role of the energy is, therefore, simply that it is a constant of the motion" (Schrödinger, 1957).

Secondly, a much more important point is related to one of the two fundamental principles in statistical thermodynamics. Because of the enormous largeness of the number N, the total number of distributions is very nearly exhausted by the sum of those P's whose number sets a_l do not deviate appreciably from the set which gives P its maximum value subject to the two constraints. This assumption is rigorously correct for $N \rightarrow \infty$ corresponding physically to an 'infinite' heat-bath. Even though the phrase, the enormous largeness of the number N is dialectical, the use of Shannon's measure of uncertainty cannot be justified because the number of elements usually considered in communication systems is too small.

There is another point we should notice. Even though Jaynes considered the function, $-\sum p_i^2$ as one of other candidates for uncertainty measure, he did not seem to realize that the measure of uncertainty is not ordinal variable and that there is a host of other measures for uncertainty represented for example, by $\sum p_i F(p_i)$ where $pF(p)$ is a concave function over [0, 1].

To be fair to Jaynes, however, we should notice that he himself admitted the following: the "mere fact that the same mathematical expression $-\sum p_i \log p_i$ occurs both in statistical mechanics and in information theory does not in itself establish any connection between these fields" (Jaynes, 1957, p. 621). Jaynes' contribution should be regarded as a construction of a new type of statistical inference rather than a proof of the equivalence between information and negative entropy.

Now let us turn to Brillouin's position. Brillouin proposed several measures of information (e. g., Brillouin, 1950). However, Brillouin claimed the equivalence only between negative entropy and *bound information*. Let us introduce Brillouin's definition on bound information (1951b, 1953 and 1962). We consider a physical system with initially P_0 different states, all of them having equal *a priori* probabilities. With the information (or some constraints upon the system), the number of possible states is reduced to P_1. Then the bound information is obtained:

$$Bound\ information = K \ln \frac{P_0}{P_1} = decrease\ in\ entropy, \tag{3.35}$$

where K is a constant.

There are several points to show how dubious the equivalence between bound information and negative entropy (Brillouin calls negentropy) is.

First, Brillouin used the concept of "complexions", the term introduced by Max Planck (1959, p. 122). According to Brillouin, a "quantized physical system is able to take *a number of discrete microscopic structures*, which Planck calls the distinct "complexions" of the system" (Brillouin, 1953, p. 1152, italics added). To use the concept of "complexions", we must consider a physical system with a very large number of molecules in the framework of statistical thermodynamics. In this case the constant K is equal to k, the Boltzmann-Planck constant. Then what Brillouin defined as bound information is nothing but entropy with a negative sign in physics. It seems that his definition on bound information is truly superfluous.

Secondly, there is an issue concerning dimension (Mayumi, 1993). It is impossible to place the same dimension of entropy in physics on a purely mathematical number, bits. What Brillouin did is that he just equated information with negentropy (which is impossible because of the difference in dimension of the two concepts), and *then* tried to measure these quantities with the same units. To wit:

> Another unit system will be introduced when we compare "information" with thermodynamical "entropy" and *decide to measure both quantities with the same units*. ..., we may go step further, and *decide to choose our units in such a way that both entropy and information will be dimensionless and represent pure numbers* (Brillouin, 1962, p. 3, italics added).

Thirdly, Brillouin 'devised' a demon with an electric torch by which the demon can see molecules in a system. Brillouin stated that the torch "pours negative entropy into the system. From this negative entropy the demon obtains "information" " (Brillouin, 1951a, p.

334). The present author does not understand how the torch could possibly pour negative entropy into the system, even if we accept that the torch is the source of single photons. Hence, Brillouin's statement does not make sense physically. Maxwell's original idea about his demon is how to create a difference of temperature from equilibrium. In the same paper, however, Brillouin assumed the conclusion—a difference of temperature to be obtained—he should have proved. To wit:

> We may *assume* that, a certain time, the demon has been able to obtain a difference of temperature (Brillouin, 1951a, p. 335, italics added).

Fourthly, Brillouin tried to calculate the lower limit of energy required for reading ammeters (1951a and 1953). Brillouin referred to G. Ising's work (1926) as an starting point for this limit saying that an additional energy $4kT$ is required for reading ammeters. However, a perusal of Ising's work shows that the coefficient 4 in Ising's paper has an entirely different meaning. Ising tried to estimate the least deviation of an instrument (denoted by $(\overline{\delta x})_{min}$; the overline means the root-mean-square value of δx) like galvanometer caused by change in a physical quantity (current intensity, for instance). Ising concluded that the least deviation descernible with confidence, as being really caused by the change in the physical quantity and not a mere Brownian fluctuation, was about $4\delta x$ where δx is "absolute" units (cms, radians, etc.). According to Smoluchowsky quoted by Ising, the following relation between the mean kinetic energy ϵ and the deviation δx holds true.

$$\frac{1}{2}A\overline{\delta x^2} = \epsilon, \tag{3.36}$$

where A is a directional force. Thus it is now clear that the coefficient 4 has nothing to do with the lower limit of required energy.

Brillouin 'proved' that the lower limit is $k \ln 2$ considering a harmonic oscilator of frequency ν with quantized energy levels $E_n = nh\nu$. The reason that Brillouin obtained this result is simple. He intentionally defined a vacuous concept, i.e., a median quantum number, m. All the energy levels equal to or greater than $E_m = mh\nu$ have probability 1/2. Thus if we accept a 50 percent of error, we obtain his result. But why Brillouin desparately wanted that value, $k \ln 2$? From the inequality (24) of Szilard's model we can see that the mean value of the quantity of entropy produced by a measurement is exactly $k \ln 2$ even though Szilard's model violates one of the two fundamental principles of statistical physics already shown.

We have followed three principal scholars' works regarded as responsible for the alleged equivalence between information and negative entropy. Now it is clear that this alleged equivalence is physically baseless.

3.5 Conclusion

True, information theory has developed as one of the youngest branches of applied probability (McMillan, 1953; Khinchin, 1957; Rényi, 1970). Information theory may have many fields of applications in the future. However, as Shannon warned us, "the establishing of such applications [of information theory to other fields] is not a trivial matter of translating words to a new domain, but rather the slow tedious process of hypothesis and experimental verifications" (Shannon, 1956, p. 3).

Despite Shannon's caveat against the bandwagon of information theory (Shannon, 1956) and Georgescu-Roegen's critique of the prevailing epistemological temper among scholars, "a pseudoscientific outgrowth of pure symbolism and empty verbalism" seems to be "a dominant article of scientific faith" (Georgescu-Roegen, 1977), thus leading finally to the alleged equivalence between information and negative entropy. Georgescu-Roegen was one of the brightest minds who tackled sincerely the epistemological basis of information theory, and its relation to entropy in physics. Georgescu-Roegen's epistemological attitude was influenced particularly by Karl Pearson and Joseph A. Schumpeter (Mayumi, 1995). For Georgescu-Roegen a theory of any kind should be a logically ordered description of a reality's mode of functioning. He had always been concerned with the problem of valid analytical representation of the relations among facts. One of the examples, in which Georgescu-Roegen showed his keen interest in epistemology, is a paper dedicated to P. C. Mahalanobis (1964) related to the discussion of measures of information in the present chapter. He constructed an axiomatic basis for cardinal measurability based on the idea that any kind of measure *must* reflect some physical properties or possible actual operations. His epistemological taste obliged him, in my view, to examine the meaning of information and its possible relationship with physical entropy. The present chapter is an attempt to reinforce his arguments concerning these issues as one of his former students.

Acknowledgements

I would like to thank Dr. Herman Daly for taking the initiative in editing this special issue for the late Prof. Georgescu-Roegen. Dr. Mario Giampietro kindly examined the first version of this chapter and gave the author many helpful suggestions. I am also grateful to the two referees, Dr. Malte Faber and Dr. John Proops for their constructive criticism and detailed comments on previous version of this chapter. However, I alone am responsible not only for any remaining errors but also for the views expressed in the chapter.

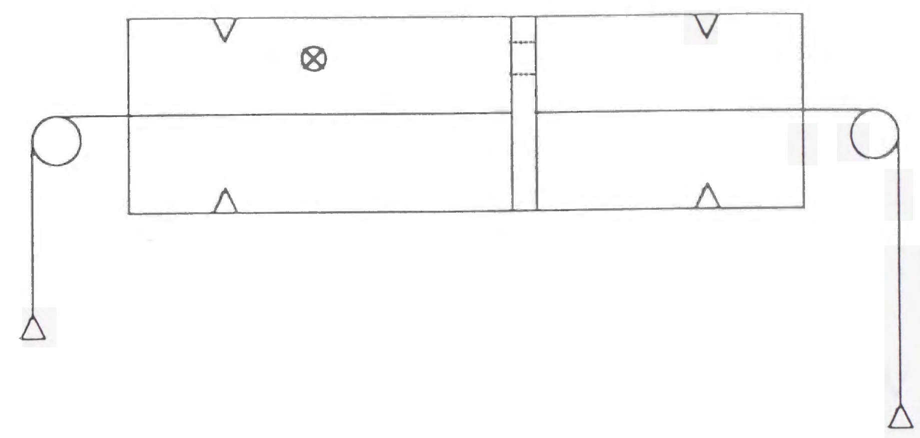


Figure 3.1: Tsuchida's Apparatus

Chapter 4

Georgescu-Roegen's 'Fourth Law of Thermodynamics', the Modern Energetic Dogma, and Ecological Salvation

4.1 Introduction

As far as transformations of matter and energy are concerned, the economic process consists of two parts: one is production in which raw materials are transformed into useful economic goods, and the other is consumption in which low entropy inputs are utilized, ultimately resulting in high entropy wastes. Accordingly matter in bulk, various metals in particular, as well as energy, is indispensable to the economic process. However, the familiar bias only in favour of energy seems to have been accentuated ever since the oil embargo in 1973. At first sight this is understandable because "matter,... can be seen as a form of energy" [Alfvén, 1969], from a purely theoretical point of view. The Einsteinian equivalence between mass and energy, $E = mc^2$, is basis for Alfvén's claim. The most salient example of this kind of view is represented by Seaborg: it is possible "to recycle almost any waste,... to extract, transport and return to nature when necessary all materials in an acceptable form, in an acceptable amount, and in an acceptable place so that the natural environment will remain natural and will support the continued growth and evolution of all forms of life" [Seaborg, 1972]. We call this view as the modern energetic dogma.

On the other hand, as the founder of bioeconomics, Georgescu-Roegen emphatically raised objection against the equivalence between energy and matter in bulk, paying attention to a peculiar character of the modern economic process: "the substantial dissipation of matter caused not by purely natural phenomena but by some activities of living creatures, of mankind's, above all" [Georgescu-Roegen, 1979].

Historically speaking, in the case of agriculture, Liebig emphasized the importance of material circulation in the agricultural fields. The principle of his agronomy (the law of compensation) consists in his view that the circulation of matter in the agricultural fields must be maintained with manure as long as most of agricultural products are consumed in cities, and fundamental elements of soils are never returned back. Liebig wrote about the law of compensation:

> The Chinese husbandman has, for thousands of years past, made it a practice to restore to his fields the mineral constituents removed from them in the produce, and the fertility of his land has accordingly kept pace with the increase of the population.
>
> The law of compensation, which makes the recurrence or permanency of effects dependent upon the recurrence or permanency of the conditions which produce them, is the most universal of the law of nature; it governs all the production of man's industry [Liebig, 1959, pp. 205–206].

Georgescu-Roegen proposed the 'Fourth Law of Thermodynamics' through his sincere concern with the ecological salvation. This law states that in a closed system, the ' material entropy' must ultimately reach a maximum value or all matter must ultimately become unavailable. He defines the perpetual motion of the 'third kind' as a thermodynamic system that can perform work indefinitely at a constant rate. He then claims that perpetual motion of the 'third kind' is impossible. An equivalent formulation of the 'Fourth Law' is more transparent: *complete recycling is impossible in a closed system.*

Cloud [Cloud, 1977] and Bormann [Bormann, 1972] strongly support Georgescu-Roegen's ecological concern. According to them, if current rates of consumption of useful metals continue, about half of the known reserves might be exhausted by 2050s.

In this chapter, first we show the following: (a) Georgescu-Roegen's formulation is not compatible with the framework of thermodynamics. (b) The 'material entropy' is not entropy in physics and dependent mainly on four factors, that is, heterogeneity of matter, technological level, our multi-dimensional value system and the overall availability of resources. Then we give viability conditions of complete recycling for the macroeconomc process in terms of technological and economic parameters by utilizing Georgescu-Roegen's flow-fund model,

and show that the viability conditions are too formidable to satisfy in actuality. Finally we touch on the alleged equivalence between 'negentropy' and information.

4.2 Is Georgescu-Roegen's Formulation Compatible with the Framework of Thermodynamics?

First let us review the impossibility of the classical motions of the first and of the second kind [Planck, 1945] to see what is wrong with Georgescu-Roegen's formulation of the 'Fourth Law'.

The first kind: "it is impossible to construct an engine which will work in a cycle and produce continuous work, or kinetic energy, from nothing."

The second kind: *it "is impossible to construct an engine which will work in a complete cycle, and produce no effect except the raising of a weight and the cooling of a heat-reservoir."*

Planck selected this formulation of the second kind because of its technical significance. After these two classical perpetual motions, Georgescu-Roegen defines the perpetual motion of the 'third kind' as a closed thermodynamic system that can perform work at a constant rate *forever* or that can perform *forever* work between its subsystems. He then claims that perpetual motion of the 'third kind' is impossible.

Georgescu-Roegen's formulation is not compatible with the theoretical framework of thermodynamics in the following way.

In the two classical cases it is *implicitly accepted* that it takes an infinite time to achieve any finite movement. This theoretical trick is quasistatic process, an imaginary limiting process without friction. Thus time (the term, forever or indefinitely) should not be explicitly intoduced into Georgescu-Roegen's formulation as far as the theoretical framework of thermodynamics is concerned. Furthermore, the boundary between the system and its environment is ambiguous in Georgescu-Roegen's formulation, because he considers his motion of the 'third kind' *in* a closed system. Whether work is done on another object in the closed system or on the environment is not so clear. In thermodynamics it should be clear whether the system can do work *on* its surroundings or the surroundings can do work *on* the system. If the theoretical framework of thermodynamics is strictly followed, it is relatively easy to reach the following result; it is *possible* to construct a *closed* engine which will work in a complete cycle, and produce no effect except the raising of a weight, the cooling of a heat-reservoir at a higher temperature, and the warming of a heat-reservoir at a lower temperature. This is nothing but a Carnot engine. The Carnot engine (with a fluid) is a closed system because heat can be exchanged during two isothermal processes (expansion and compression) through the base of the cylinder.

We have the meteorite fall onto the earth. But it consists of highly unavailable form of dust. The amount of particles that escape the gravitational field is also negligible. The amount of heat produced by consumption of fossil fuels is about one twenty thousandth of the amount of the solar radiation reaching the earth. The amount of geothermal heat is about one six thousandth. Therefore these can be ignored at the global level [Koide and Abiko, 1985]. Hence if our economic process is set aside, the earth, our abode, can be regarded as a big (closed) Carnot engine with the sun (a heat-reservoir at a higher temperature) and the outer space (a heat-reservoir at lower temperature).

4.3 Are There Two Types of Entropy in Physics?

The answer to this question is, of course, no!

We briefly review and examine the physical logic of equivalence between entropy of energy (heat) diffusion and entropy of matter diffusion. Let us take a case of matter diffusion from classical thermodynamics (Figure 1). 1 mole of an ideal gas is stored in a container (which has volume of V_1) and then allowed to expand freely into another container (V_2) after opening a nozzle. What is the increase in entropy then? To calculate it, compress the ideal gas in the container 2 isothermally into the container 1 by moving a piston. In this process of isothermal compression, the work done on the system, W, is

$$W = RT \ln \frac{V_1 + V_2}{V_1}. \tag{4.1}$$

Because the process is isothermal compression and the gas is ideal, all the work, W, will come out of the system as heat, Q. That is

$$Q = W. \tag{4.2}$$

Entropy of mechanical work is zero, so the increase in entropy through the work done is also zero. The entropy flow as heat from the system, S, is

$$S = \frac{Q}{T} = R \ln \frac{V_1 + V_2}{V_1}. \tag{4.3}$$

S corresponds to the entropy increase due to diffusion of matter. Hence if 1 mole of an ideal gas expands N times as large as the initial volume, increase in entropy is $R \ln N$.

Three equations, (1), (2), and (3), show clearly that entropy of matter diffusion is perfect substitute for entropy of energy diffusion in classical thermodynamics. Decrease in entropy of matter is accomplished by the same amount of increase in entropy of heat diffusion. Therefore from a purely physical point of view there is no essential difference between a closed system and an open system.

On the other hand, the procedure mentioned above transparently shows the limitations of applicability of purely thermodynamic consideration to ecological issue. Georgescu-Roegen's following remarks are worth keeping in mind for the people who concern the future of our planet:

> the Van't Hoff reaction box describes in an ideal way a procedure for unmixing gases... No similar device, however, has been thought up yet for mixing of liquids or solids (and from what we know now, none seems reliable) [Georgescu-Roegen, 1982, p. 16].

It seems that we cannot apply the concept of entropy direcly to "phenomena of the macrolevel, that is, of the level of our direct senses".

4.4 What is the Entropy Degradation of Matter (the 'Material Entropy') in Georgescu-Roegen's Formulation?

The analysis in the previous section suggests that the concept of entropy is, in essence, tantamount to entropy of energy diffusion. Therefore the degradation of matter in bulk at the level of our direct senses cannot be treated in terms of entropy in thermodynamics. As Fermi stated correctly, thermodynamics "is mainly concerned with the transformations of heat into mechanical work and the opposite transformations of mechanical work into heat" [Fermi, 1956]. Then what is the 'material entropy' Georgescu-Roegen proposed?

Let us quote several passages from Georgescu-Roegen's writing:

> All over the material world there is rubbing by friction, cracking and splitting by changes in temperature or evaporation, there is clogging of pipes and

> membranes, there is metal fatigue and spontaneous combustion. Matter is thus continuously displaced, altered, and scattered to the four corners of the world. It thus becomes less and less available for our own purposes... In the economic process it is not mass such that counts. What counts is matter in bulk (and, of course, energy) [Georgescu-Roegen, 1979, p. 1034].

As several Japanese physicists and engineers [Ozaki, 1983, Takamatsu, 1983, Tsuchida, 1985] suggested, the degradation of matter in bulk in our daily life—just like Georgescu-Roegen's favorite example of broken pearls—does not give rise to increase in entropy treated in physics. Nevertheless the concept of 'material entropy' will be critically important for our ecological salvation.

However, Georgescu-Roegen aptly remarked, "to arrive at an entropy formula seems impossible at this stage". Energy is a homogeneous substance so that energy conversion from one form into another can be easily accomplished. On the other hand, matter is highly heterogeneous and every elemant has some unique physico-chemical properties. This feature of matter explains the reason that the practical procedures for unmixing liquids or solids differ from case to case and consist of many complicated steps. Very probably we will not have a general blueprint applicable for unmixing all the liquids and solids without distinction.

The only possible way, it seems, to reach a quantitative measure of 'material entropy' is to calculate *indirectly* the amounts of matter and energy in order to recover the initial state of matter in bulk in question given the present technological level. The proper initial state of matter in bulk is deeply related to our multi-dimensional value system: to what state we should transform the degraded matter? Because the amounts of matter in bulk and energy required for recovering depend on the present technological level, they will contain some factors of uncertainties to predict. Still further, Georgescu-Roegen stated, because matter in bulk and energy are not convertible into each other, we cannot judge which one of two equivalent recovering technologies, one with more energy and less matter, and the other with less energy and more matter, is ecologically préferable without taking account of the overall availability of energy and mineral resources.

As Georgescu-Roegen pertinently remarked, we need a general quantitative flow matrix representing a macro-global and micro-local economic system in terms of Georgescu-Roegen's flow-fund model [Mayumi. 1991b] to tackle these formidable issues.

4.5 Clausius' Disgregation Revisited

It is none other than Clausius who tried to get a quantitative measure of dissipation of matter, the disgregation, in 1862. This concept is perfectly forgotten and has been a museum piece nowadays. After reaching the Clausius' inequality in 1854, Clausius tried to investigate the possibility of extending the equivalence of transformations (not restricted to cyclic processes), instead of introducing immediately the new state function, entropy [Yamamoto, 1987].

Clausius stated:

> Accordingly, since, in my former paper, I wished to avoid everything that was hypothetical, I entirely excluded the interior work, which I was able to do by confining myself to the considerations of *cyclic processes*—that is to say, operations in which the modifications which the body undergoes are so arranged that the body finally returns to its original condition. In such operations the interior work... neutralizes itself, so that nothing but exterior work remains [Clausius, 1867, p. 216].

The original formulation made by Clausius in 1862 is as follows:

$$dQ = dH + AdI + AdW, \tag{4.4}$$

where dH (H is not the enthalpy) is the heat added to the quantity already present in a body (im Körper wirklich vorhandene Wärme [Wärmeinhalt]), AdI is the heat expended in interior work (A is the thermal-equivalent of a unit of work), and dW is the exterior work performed by the heat during the change of condition of the body.

Clausius introduced a new assumption (whose validity is still ambiguous): the maximum work, interior plus exterior, which *can* be done by heat during any change of the arrangement of a body is proportional to the absolute temperature at which this change occurs. Under this assumption equation (4) can be rewritten:

$$dQ = dH + TdZ, \tag{4.5}$$

where $dI + dW = KTdZ \qquad (K = 1/A)$.

Clausius stated:

> Now the effect of heat always tends to loosen the connexion between the molecules, and so to increase their mean distances from one another. In order to

> be able to represent this mathematically, we will express the degree in which the molecules of a body are separated from each other, by introducing a new magnitude, which we will call the ***disgregation*** of the body [dZ], and by help of which we can define the effect of heat as simply *tending to increase the disgregation* [Clausius, 1867, p. 220].

His aim was to extend the transformation between heat and exterior work into the transformation between heat and increase in volume under the assumption above and to allot the equivalence-value, dZ, to the transformations in which heat does not give rise to exterior work in actuality.

Under the assumption above Clausius showed that H is a function of the temperature alone, that is $Tf(T)$. In fact it can be easily shown that the assumption is equivalent to the following: H depends only on its temperature and not on the arrangement of its constituent particles. In the case of an ideal gas,

$$\frac{dH}{T} = \frac{C_V dV}{T}, \tag{4.6}$$

$$dZ = \frac{RdV}{V}. \tag{4.7}$$

These quantities correspond to each term in the following well known relation.

$$S(T, V) = C_V \ln \frac{T}{T_0} + R \ln \frac{V}{V_0}. \tag{4.8}$$

Finally Clausius reached the following relation.

$$\int \frac{dQ}{T} = S - S_0, \tag{4.9}$$

$$S = Y + Z, \tag{4.10}$$

$$S_0 = Y_0 + Z_0, \tag{4.11}$$

$$\int \frac{dH}{T} = Y - Y_0, \tag{4.12}$$

$$\int dZ = Z - Z_0, \tag{4.13}$$

where Y is the transformation-value of the body's heat, estimated from a given initial condition and Z is the disgregation, which is the transformation-value of the existing arrangement

of the particles of the body. Physically Y corresponds to the entropy of thermal diffusion and Z, the entropy of matter diffusion.

Klein, a science historian, claimed that "Clausius saw the disgregation as a concept more fundamental than the entropy, since entropy was to be interpreted physically with the help of disgregation" [Klein, 1969, p. 140]. Georgescu-Roegen stated:

> On what *operational* basis can the loss of matter availability be treated as being the same essence as the loss of energy availability? In other words, why should the sum of the two entropies [Entropy of Energy Diffusion and Entropy of Matter Mixing] have one and the same meaning regardless of its distribution among two terms? [Georgescu-Roegen, 1977b, pp. 301–302].

The following opinion raised by Planck seems to support Georgescu-Roegen's idea:

> The real meaning of the second law has frequently been looked for in a "dissipation of energy." This view, proceeding, as it does, from the irreversible phenomena of conduction and radiation of heat, presents only one side of the question. There are irreversible processes in which the final and initial states show exactly the same form of energy, *e.g.*, the diffusion of two perfect gases, or further dilution of a dilute solution. Such processes are accompanied by no perceptible transference of heat, nor by external work, nor by any noticeable transformation of energy. They occur only for the reason that they lead to an appreciable increase of the entropy. In this case it would be more to the point to speak of a dissipation of matter than of a dissipation of energy [Planck, 1945, pp. 103–104].

The convection of the air and water cycle constitutes, as it were, an atmospheric heat engine which guarantees the existence of life on earth by continually discarding *thermal* entropy to outerspace [Murota and Tsuchida, 1985]. On the other hand, because the earth is a closed system, wasted matters tend to remain on the earth unless there is any effective mechanism in which wasted matters are transformed into thermal entropy. Furthermore the economic process depends not only on biological organs but also, to a much greater extent, on exosomatic organs. Unfortunately, we do not have any effective devices to recycle wasted matters to maintain the structure of the economic process. The flows of dissipated matter in bulk increase with the size of the economic process. We should recognize difficulty in maintaining the large scale material structures in the present industrial society. In these respects Georgescu-Roegen's concern—the distribution of entropy among two terms matters ecologically—is a matter of vital importance for our ecological salvation.

4.6 Viability Conditions and Georgescu-Roegen's Flow-Fund Model

According to Georgescu-Roegen, "a viable technology is a complex of techniques that can support the life of the associated biological species as long as some specific "fuel" is forthcoming." For us humans, a technology is viable, if and only if our economic system represented by it can go on steadily as long as the environmental flows of available energy and matter are forthcoming in the necessary amounts. In this section we give the viability conditions of complete recycling for the aggregated economic process in terms of technological and macroeconomic parameters. Then these conditions are shown to be too formidable to satisfy in actuality.

Let us represent the economic process according to the energetic dogma—it claims that complete recycling is possible with a sufficient amount of energy—by the flow-fund matrix of Table 1. Fund elements (the agents) refer to those components which are used (but unchanged) during the process such as Ricardian land, tools and workers. On the other hand, flow elements are those undergoing transformation. Let us assume that the energetic dogma does not go so far as to claim that actual processes require no material scaffold at the macro-level. In this matrix the outflows of any kind are represented by positive coordinates, the inflows by negative coordinates. The whole reproducible economic process (one period is t) is reduced to the following consolidated sectors and aggregated categories for the purpose of the present argument [Georgescu-Roegen, 1981]:

P_1: transforms energy in situ, ES, into controlled energy, CE, ultimately resulting in a form of dissipated energy, DE;

P_2: produces maintenance capital, MK;

P_3: produces consumer goods, C;

P_4: recycles *completely* the material wastes, W, of all processes into recycled matter, RM;

P_5: maintains the population, H;

In this representation a flow of energy in situ, e_1, is the only environmental support of

the economic process. For the aggregated economic process to be reproducible, the following equalities must always hold good on the basis of the conservation laws at the macro-level:

$$d_1 = e_1 - x_{11}, \tag{4.14}$$

$$d_i = x_{1i} \qquad (i = 2, 3, 4, 5), \tag{4.15}$$

$$w_1 = x_{21}, \tag{4.16}$$

$$w_2 = x_{42} - x_{22}, \tag{4.17}$$

$$w_3 = x_{23} + x_{43} - x_{33}, \tag{4.18}$$

$$w_4 = x_{44} - x_{24}, \tag{4.19}$$

$$w_5 = x_{25} + x_{35}. \tag{4.20}$$

On the other hand, for our aggregated economic process to be viable, the entire population should be maintained at least at the minimum standard of living, x^0_{15}, x^0_{25} and x^0_{35}. Hence the following inequalities should prevail:

$$x_{i5} \geq x^0_{i5} \qquad (i = 1, 2, 3). \tag{4.21}$$

The following well-known relations are also satisfied:

$$x_{11} = x_{12} + x_{13} + x_{14} + x_{15}, \tag{4.22}$$

$$x_{22} = x_{21} + x_{23} + x_{24} + x_{25}, \tag{4.23}$$

$$x_{33} = x_{35}, \tag{4.24}$$

$$x_{44} = x_{42} + x_{43}, \tag{4.25}$$

$$w_4 = w_1 + w_2 + w_3 + w_5. \tag{4.26}$$

From the relations above we can easily obtain the folloing inequalities:

$$w_5 \geq x^0_{25} + x^0_{35}, \tag{4.27}$$

$$x_{14} + x^0_{15} \leq e_1 \left[\frac{x_{11}}{e_1} - \frac{x_{12} + x_{13}}{e_1}\right], \tag{4.28}$$

$$x_{24} + x^0_{25} \leq x_{42} \ [\frac{x_{22}}{x_{42}} - \frac{x_{21} + x_{23}}{x_{42}}]. \quad (4.29)$$

Inequality (27) implies that the amounts of material wastes matter resulted from P_5 necessarily increase with the amounts of both maintenace capital and consumer goods in P_5 . In other words, the material wastes will be accumulated in the environment if they do not circulate harmoniously in the environment. This plain fact is theoretically rooted in the law of conservation of matter: before and after any transformation of matter and energy, the number of nucleons (protons and neutrons) are preserved. Consequently, if an artificial product does not circulate harmoniously in the ecosystem, there might be serious environmental damage in the long-run with increase in its stock in the environment. Some ecologists confuse the economic system with ecological and geological systems. The economic systems depends heavily on "exosomatic" organs for which we do not have any effective devices to recycle wasted matters completely. Thus the following comments may lead to the wrong policy implication in the economic process.

> it is thoroughly demonstrated by ecological systems and geological systems that all the chemical elements and many organic substances can be accumulated by living systems from background crustal or oceanic concentrations without limit as to concentration so long as there is available solar or other source of potential energy [Odum, 1991, p. 29].

Two inequalities (28) and (29) represent a dual relationship between energy and material transformations in the macroeconomic process. The inequality (28) implies that increase in the controlled energy consumption in P_4 can be accomplished at the expense of decrease in that in P_5 if the structures of P_1, P_2 and P_3 are not changed. On the other hand, the inequality (29) implies that increase in the maintenance capital consumption in P_4 can be accomplished at the expense of decrease in that in P_5 if the structures of P_1, P_2 and P_3 are not changed. x_{14} and x_{24} usually increase with w_5. Thus a secured supply of controlled energy and maintenance capital will be prerequisite for complete recycling if the structures of P_1, P_2 and P_3 are not changed.

4.7 'Negentropy', Information and Photosynthesis

Photosynthesis is often described as "a transition from a state of higher to lower entropy, at the expense of solar negentropy" [Bianciard, et. al., 1992]. However, Tsuchida [Murota and Tsuchida, 1987] showed that photosynthesis consists of two processes: production (carbon dioxide + water + light ⇒ glucose + oxygen gas) and consumption (liquid water ⇒ water vapor). Thus far only the production side of photosynthesis has been investigated. "Plants transpirate water by 200~400 times as much as [the weight of] the photosynthetic product." That is, water plays a crucial role in extracting heat of higher entropy produced in the process of photosynthesis. Then why do some scintists attribute the sun to the source of 'negentropy'? This is probably the influence of Schrödinger's book [Schrödinger, 1967] on the minds of scientists. He described the sunlight as the "most powerful supply of negative entropy." He also stated that a living organism "feeds upon negative entropy." Up to this point, there was no problem. However, in 1950 L. Brillouin [Brillouin, 1950] equated information with 'negentropy'. As Georgescu-Roegen pertinently remarked [Georgescu-Roegen, 1990], Brillouin only showed "the *algebraic* identity of Boltzmann's and Shannon's formulae." Brillouin did not give any physical proof of this identity. On this point, Tsuchida stated:

> But as Fast makes it crystally clear, a purely mathematical number called bit should not, in a general context, be placed on the same dimension as entropy [Tsuchida and Murota, 1987].

The temptation to equate information with 'negentropy' can be traced back to Szilard's paper, now available in English [Szilard, 1964]. But with perusal of his paper, it is clear that he investigated a certain condition under which the Second Law not be violated.

He stated:

> If we do not wish to admit that the Second Law has been violated, we must conclude *that the intervention which establishes the coupling between y and x, the measurement of x by y, must be accompanied by a production of entropy* [Szilard, 1964, p. 306].

The concept of information was introduced as "the measure of the capacity of a code to represent different messages, whether meaningful or not." Jaynes acknowledged that the "mere fact that the same mathematical expression $-\sum p_i \log p_i$ occurs both in statistical mechanics and in information theory does not in itself establish any connection between these two fields" [Jaynes, 1957, p. 621]. Thus the equivalence between information and negentropy has no physical meaning whatsoever.

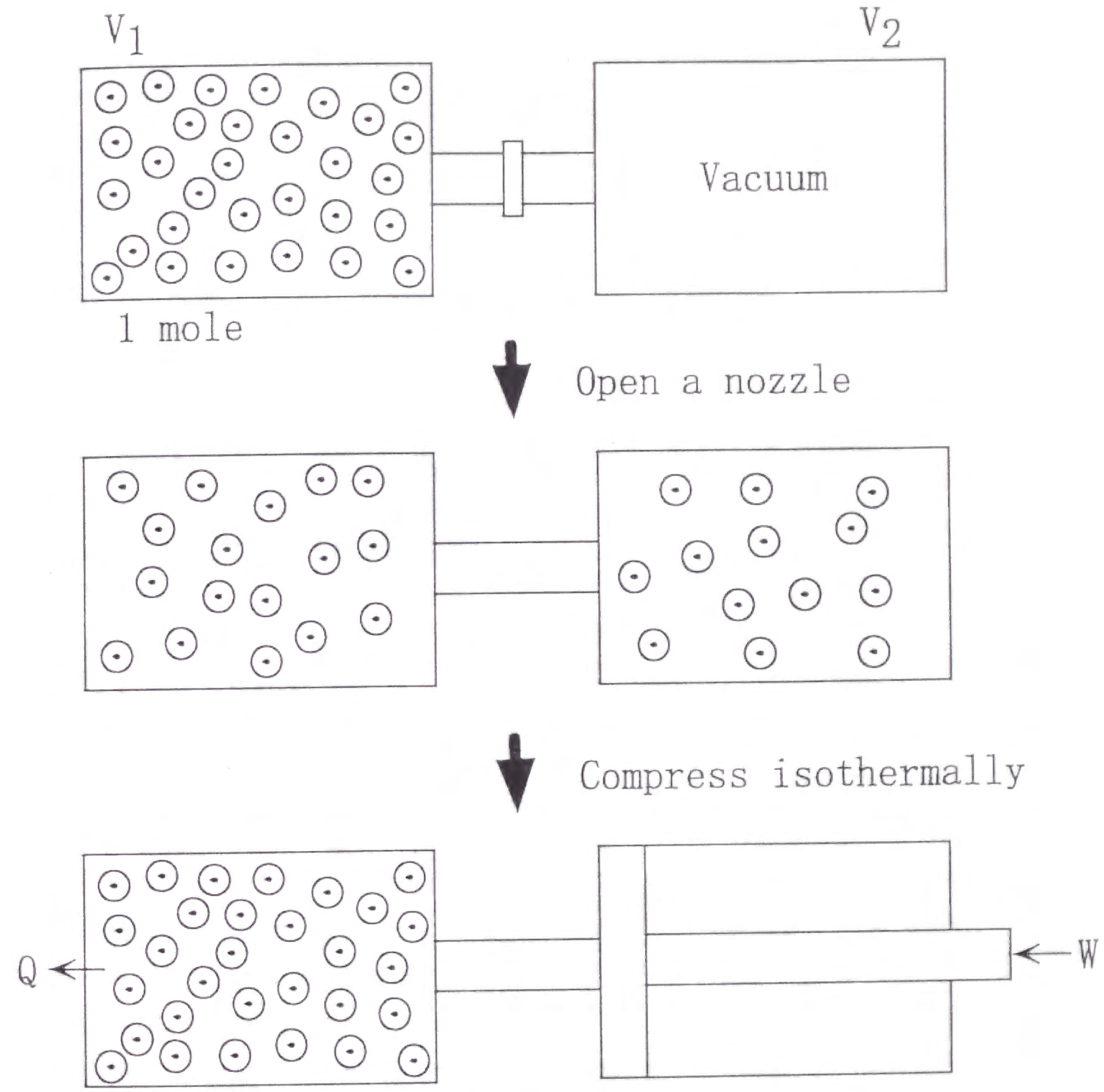


Figure 4.1: Diffusion of Matter. Source: Compiled by the Author.

Elements	P_1	P_2	P_3	P_4	P_5
Flow Coordinates					
CE	x_{11}	$-x_{12}$	$-x_{13}$	$-x_{14}$	$-x_{15}$
MK	$-x_{21}$	x_{22}	$-x_{23}$	$-x_{24}$	$-x_{25}$
C	*	*	*	*	$-x_{35}$
RM	*	$-x_{42}$	$-x_{43}$	x_{44}	*
ES	$-e_1$	*	*	*	*
W	w_1	w_2	w_3	$-w_4$	w_5
DE	d_1	d_2	d_3	d_4	d_5
Fund Coordinates					
Capital	K_1	K_2	K_3	K_4	K_5
People	H_1	H_2	H_3	H_4	H_5
Ricardian land	L_1	L_2	L_3	L_4	L_5

Table 4.1: The Aggregated Economics process

Chapter 5

Embodied Energy Analysis, Sraffa's Analysis, Georgescu-Roegen's Flow-Fund Model and Viability of Solar Technology

5.1 Introduction

Peak energy prices triggered by 1970s oil crises caused great interest in energy analysis and created several schools of thought, including Embodied Energy Analysis (EEA). Simply put, EEA is a cost of production theory in which all costs can be ultimately calculated according to the amount of solar energy necessary to produce commodities directly and indirectly. According to Robert Costanza, a proponent of the theory, '[an] embodied energy theory of value ... makes theoretical sense and is empirically accurate only if the system boundaries are defined in an appropriate way' (1980, p. 1224). Nicholas Georgescu-Roegen (1982) assesses Costanza's thesis in relation to the crucial role played by mineral resources and fund element (an agent transforming input into output in the economic process). In view of viability conditions, Georgescu-Roegen (1979) argues against overoptimism in direct use of solar energy technology because such technology is still a 'parasite' to fossil and fissile fuels.

The present investigation is motivated by recent interest in possible linkages between energy analysis and Sraffa's analysis (SA) (e.g., England 1986; Christensen 1987; Judson 1989; Patterson 1996).

The first part of the present chapter: (1) compares the theoretical basis of EEA from the point of view of Piero Sraffa, a point of view not examined by Georgescu-Roegen. ; (2) examines EEA critically in terms of Georgescu-Roegen's flow-fund model; and (3) compares

SA and Georgescu-Roegen's flow-fund model. The second part of the present chapter is a theoretical analysis of the viability conditions of solar technology which : (1) introduces three models in sequence; (2) analyses and compares the three models.

5.2 Embodied energy analysis, Sraffa's analysis and the flow-fund model

5.2.1 Embodied energy analysis and Sraffa's analysis: no-joint production case

One system of equations in SA (Sraffa 1960, p. 11) does not consider joint production.

$$(1+\mathrm{r})\mathrm{A^t p} + \mathrm{P_H H} = \hat{\mathrm{A}}\mathrm{p} \tag{5.1}$$

$p = {}^t(p_1, p_2, \ldots, p_n)$: the value vector of commodities (t denote the transpose) and p is determined together with the wage P_H and the rate of profit r;

A: a matrix and element A_{ij} is the commodity i used in the process j (i *or* $j = 1, 2, \ldots n$);

$\hat{A}$: a diagonal matrix and elements A_1, A_2, ..., A_n form the diagonal where A_i is the total quantity of commodity i ($i = 1, 2, \ldots n$) annually produced;

H: a vector and element H_j is the fraction of the total annual labour of society employed in the process j ($\sum_{j=1}^{n} H_j = 1$).

Sraffa assumes that the system of Equation (1) is in a self-replacing state, so the following inequality should hold true:

$$\mathrm{A_{1j} + A_{2j} + \ldots + A_{nj} \leq A_j \quad (j = 1, 2, \ldots, n).} \tag{5.2}$$

Sraffa first examines the case in which $r = 0$ and $P_H = 1$.

$$\mathrm{A^t p + H} = \hat{\mathrm{A}}\mathrm{p}. \tag{5.3}$$

The system of equations (3) is the same as that used in EEA for static analysis (Costanza 1980; Costanza and Hannon 1989; Brown and Herendeen 1996).

$$\mathrm{X^t}\epsilon + \mathrm{E} = \hat{\mathrm{X}}\epsilon \tag{5.4}$$

X: a matrix and element X_{ij} is input of commodity i to the process j;

$\hat{X}$: a diagonal matrix and elements X_j form the diagonal;

E: a vector and element E_j is the external direct energy input to sector j;

ϵ: a vector and element ϵ_j is the embodied energy intensity per unit of X_j.

It is important to discuss formal similarity between EEA and SA without joint production because the roles played in economic process by labour and by energy input are the same in both analyses. According to IFIAS (cited in Brown and Herendeen 1996), EEA is the process of determining energy required directly and indirectly to allow a system (usually an economic system) to produce commodities. EEA claims that 'with the appropriate perspective and boundaries, market-determined dollar values and embodied energy values are proportional' (Costanza 1980, p. 1224). In SA without joint production, relative commodity values and labour cost have the same proportional relationship: 'the relative values of commodities are in proportion to their labour cost, that is to say to the quantity of labour which directly and indirectly has gone to produce them' (Sraffa 1960, p. 12). At first sight, EEA and SA without joint production seem to agree on the role played by net energy input in EEA and by labor in SA because each unit of external energy input has the same embodied energy intensity in EEA and each unit of labour input receives the same wage in SA. However, the two analyses have entirely different aspects of the role played by energy and labour.

Except when $r = 0$ and $P_H = 1$, proportionality of commodity values to labour cost does not hold. The case of $r = 0$ and $P_H = 1$ is a preliminary step for Sraffa to set up the concept of the Standard Commodity and the Standard System. The Standard Commodity is a composite commodity in which various commodities are represented among its aggregate means of production in the same proportions as various commodities among its products. The Standard System consists of a set of equations which produce the Standard Commodity. Sraffa clearly states that 'in the Standard system the ratio of the net product to the means of production would remain the same whatever variations occurred in the division of the net product between wages and profits and whatever the consequent price changes' (1960, p. 21).

In EEA, energy is the only net input to the economic system, but it is unclear whether or not Sraffa treats labour as net input to the system. However, Sraffa recognizes two different characteristics of labour: (1) wages consisting of necessary subsistence of workers as basic product defined by Sraffa (a commodity enters into the production of all commodities[1]); (2) a share of the surplus product. Sraffa treats labour only as a share of the surplus product and follows the traditional wage concept, despite noticing drawbacks of this procedure (1960,

p. 10). Georgescu-Roegen's flow-fund approach tries to evade Sraffa's dual nature of labour by establishing an economic sector which maintains all labour power in which subsistence character of labour is treated.

5.2.2 Embodied energy analysis and Sraffa's analysis: joint production case

The circular nature of joint production causes theoretical treatments of joint production to be complicated. Both EEA and SA face two central epistemological issues when investigating the case of joint production. (1) since each commodity is produced by several processes, if commodity Γ enters only one of two different processes and commodity Γ is produced in both processes at the same time, it is difficult or impossible to be sure whether or not commodity Γ enters directly into the production process; (2) if commodity Δ is produced by two different processes and different commodity Γ enters one of these processes as a means of production, it is difficult or impossible to be sure whether or not different commodity Γ enters indirectly into the production process.

In the case of joint production, there is no operational meaning of 'direct' or 'indirect'. EEA further complicates issues because energy and material flows in ecosystems are measured in different physical units. To examine the issue of dimension in EEA, the following equations apply to the case of joint production (Hannon et al. 1986; Costanza and Hannon, 1989).

$$\mathrm{q} = \mathrm{Ui} + \mathrm{w}, \tag{5.5}$$

$$\mathrm{q} = \mathrm{V^t i}, \tag{5.6}$$

and

$$\mathrm{g} = \mathrm{Vi} \tag{5.7}$$

q = commodity output vector;
g = process output vector;
w = net system output vector;
i = vector of 1's;
U = use matrix (commodity × process) giving use of commodities by the processes;
V = make matrix (process × commodity) giving production of commodities by the processes.

Rewriting Equation (5),

$$\mathrm{q} = \mathrm{U\hat{g}^{-1}\hat{g}i} + \mathrm{w} \tag{5.8}$$

$\hat{g}$: a diagonal matrix with elements of g as the diagonal.

Substituting from Equation (7),

$$\mathrm{q} = \mathrm{U\hat{g}^{-1}Vi} + \mathrm{w} \tag{5.9}$$

and rewriting,

$$\mathrm{q} = \mathrm{U\hat{g}^{-1}V\hat{q}^{-1}\hat{q}i} + \mathrm{w} \tag{5.10}$$

Defining $U\hat{g}^{-1} = F$ and $V\hat{q}^{-1} = D$,
gives

$$\mathrm{q} = \mathrm{FDq} + \mathrm{w}. \tag{5.11}$$

For simplicity, the issue of dimension is explained in terms of a system of 3 commodities and 2 processes. T_1, T_2, and T_3 in matrices indicate dimension (not strictly physical dimension). Number 1 in matrices indicates no dimension.

$$\mathrm{U} = \begin{pmatrix} T_1 & T_1 \\ T_2 & T_2 \\ T_3 & T_3 \end{pmatrix} \tag{5.12}$$

$$\mathrm{V} = \begin{pmatrix} T_1 & T_2 & T_3 \\ T_1 & T_2 & T_3 \end{pmatrix} \tag{5.13}$$

$$\mathrm{q} = \mathrm{Ui} + \mathrm{w} = \mathrm{V^t i} = \begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} \tag{5.14}$$

To transform g into dimensionless quantity, the following path is adopted.

$$\mathrm{g} = \mathrm{Vi} = \begin{pmatrix} T_1 & T_2 & T_3 \\ T_1 & T_2 & T_3 \end{pmatrix} \begin{pmatrix} T_1^{-1} \\ T_2^{-1} \\ T_3^{-1} \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \tag{5.15}$$

$$\mathrm{U\hat{g}^{-1}} = \begin{pmatrix} T_1 & T_1 \\ T_2 & T_2 \\ T_3 & T_3 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} T_1 & T_1 \\ T_2 & T_2 \\ T_3 & T_3 \end{pmatrix} = \mathrm{F} \tag{5.16}$$

$$\mathrm{V\hat{q}^{-1}} = \begin{pmatrix} T_1 & T_2 & T_3 \\ T_1 & T_2 & T_3 \end{pmatrix} \begin{pmatrix} T_1^{-1} & 0 & 0 \\ 0 & T_2^{-1} & 0 \\ 0 & 0 & T_3^{-1} \end{pmatrix} = \mathrm{D} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \tag{5.17}$$

Forming FDq

$$\mathrm{FDq} = \begin{pmatrix} T_1 & T_1 & T_1 \\ T_2 & T_2 & T_2 \\ T_3 & T_3 & T_3 \end{pmatrix} \begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} = \begin{pmatrix} T_1^2 + T_1T_2 + T_1T_3 \\ T_2T_1 + T_2^2 + T_2T_3 \\ T_3T_1 + T_3T_2 + T_3^2 \end{pmatrix} \tag{5.18}$$

Dimensions in Equation (11) are not consistent with dimensions in Equations (14) and (18), making untenable the claim: 'it is indirectly applicable by assuming a set of weights to allow the formation of g and then investigating the properties of these weights' (Hannon et al. 1986, p. 395).

Sraffa's aim of introducing the case of joint production provides the major difference between EEA and SA. Sraffa describes (Chapter VIII) the case of two products jointly produced by two different methods, implying that the same machine at different ages should be treated as being different products with different prices. Thus, the partly worn-out, older machine emerging from the production process may be regarded as a joint product with the year's output of a commodity.

It is important to consider the concept of non-basic and basic commodities[2]. In a system of n productive processes and n commodities (whether or not produced jointly) a group of m $(1 \leq m < n)$ linked commodities are non-basics if the rank of matrix of n rows and $2m$ columns is less than or equal to m (Sraffa 1960, p. 51). All other commodities are basics.

A system of equations of production system can be transformed into a system of equations without non-basic commodities. This transformation produces a set of positive and negative multipliers which, when applied to the original n equations, allows reduction of the original equations to a smaller number of equations equal in number to basic products. This new system of equations is called the Basic equations. In each of the smaller number of equations, quantity of a non-basic is cancelled by an equal quantity of opposite sign, so only basics are included. Sraffa introduces the Basic equations to show that the relation between relative values of basic commodities and the rate of profit is independent of relation between relative values of non-basic commodities (if any) and the rate of profit.

A system of equations similar to the Basic equations in SA may contain negative quantities as well as positive quantities. This is a logical problem, but not a problem of insufficient data as claimed by some energy analysts who insist that ' such negative values are mainly a result of flaws in the original data acquisition and aggregation and can be eliminated by judicious further aggregation, or by better data' (Hannon et al. 1986, p. 397, the same view is found in Costanza and Hannon, 1989, p. 99).

5.2.3 Embodied energy analysis and Sraffian system: a comparison with the flow-fund model

Table 1 considers aggregated economic process:

P_0: transforms matter in situ (MS) into controlled matter (CM);

P_1: transforms energy in situ (ES) into controlled energy (CE);

P_2: produces maintenance capital goods (K);

P_3: produces consumer goods (C);

P_4: recycles garbojunk (GJ) into recycled matter (RM);

P_5: maintains population (H).

Flows are elements that enter but do not exit the process or, conversely, elements that exit without having entered the process. Funds (capital, people and Ricardian land[3]) are elements that enter and exit the process unchanged, transforming input into output flows. DM is dissipated matter and DE is dissipated energy. Refuse (RF) consists in part of available matter and available energy, but RF is in a form not potentially useful to us at present.

Georgescu-Roegen's critique of EEA considers double counting of labour. Assuming energy equivalent of labor service (e_L), these equations follow:

$$\mathrm{Yf} - \mathrm{e_L H} = \mathrm{e} \tag{5.19}$$

and

$$\mathrm{Y^t} = \begin{pmatrix} x_{00} & * & -x_{02} & -x_{03} & -x_{04} \\ -x_{10} & x_{11} & -x_{12} & -x_{13} & -x_{14} \\ -x_{20} & -x_{21} & x_{22} & -x_{23} & -x_{24} \\ * & * & * & x_{33} & * \\ * & * & -x_{42} & -x_{43} & x_{44} \end{pmatrix}. \tag{5.20}$$

Y: transposed matrix of the first five rows and five columns of Table 1;

f: column vector of gross energy equivalents ${}^t(f_0, f_1, f_2, f_3, f_4)$;

e: column vector ${}^t(0, e_1, 0, 0, 0)$;

H: column vector ${}^t(H_0, H_1, H_2, H_3, H_4)$.

In a static perspective, there must normally be one monetary equality:

$$\text{Total Receipts} = \text{Total Cost} \tag{5.21}$$

Total cost equals cost of input flows plus payments for fund service. So,

$$B_i = P_H H_i + P_K K_i + P_L L_i \quad (i = 0, 1, 2, 3, 4). \tag{5.22}$$

B: column vector ${}^t(B_0, B_1, B_2, B_3, B_4)$;

p: column vector of prices ${}^t(p_0, p_1, p_2, p_3, p_4)$ of physical commodities produced by processes (P_i).

The system that prices must always satisfy independently of other constraint is

$$Yp = Re + B. \tag{5.23}$$

R: price of energy in situ corresponding to conventional royalty income.

If embodied energies are proportional to prices, the factor of proportionality must be R, so

$$p_i = Rf_i. \tag{5.24}$$

Combining Equations $Yf - e_L H = e$ (19), $Yp = Re + B$ (23) and $p_i = Rf_i$ (24) produces an absurd result:

$$Re_L H = B. \tag{5.25}$$

Thus, e_L should be deleted to avoid double counting of labour. Equation $Yf - e_L H = e$ (19) should be replaced by

$$Yf = e. \tag{5.26}$$

Combining Equations $Yp = Re + B$ (23), $p_i = Rf_i$ (24) and $Yf = e$ (26) produces

$$B = 0. \tag{5.27}$$

Equation $B = 0$ (27) is absurd, based on the flow complex of EEA without fund element. Flow complex $B = 0$ is similar to that adopted by neoclassical economists dealing with energy analysis (Huettner 1976). B must be a strictly positive vector in any economic system, even in a socialist system which includes at least some wages and interest.

Georgescu-Roegen never compares his approach with Sraffa's approach, but such comparison is worthwhile because recent research (e.g., England 1986) in sustainability issues indicates possible applicability of SA to sustainability issues.

First of all, Sraffa and Georgescu-Roegen have decidedly different views about the economic process. Sraffa does not consider the creation of the production process. Sraffa claims that his investigations is 'concerned exclusively with such properties of an economic system as do not depend on changes in the scale of production or in the proportions of factors' (1960, p. v). On the other hand, Georgescu-Roegen (1974, p. 251) reports that: 'commodities are <u>not</u> produced by commodities, but by processes. Only in a stationary state is it possible for production to be confined to commodities'[4]. Georgescu-Roegen (1974, p. 252) maintains that 'it is this Π-sector [process production] ...that consititutes the fountainhead of the growth and further growth'.

Sraffa considers depreciation of capital fund in order to preserve the same efficiency of capital for reproduction of the process. But SA is essentially a static analysis. Georgescu-Roegen considers the case of stationary process in which fund element is intact. Of course Georgescu-Roegen recognizes the invalidity of this assumption in the long run because of the entropy law: '[a] process by which something would remain indefinitely outside the influence of the Entropy Law is factually absurd. But the merits of the fiction are beyond question'(1971, p. 229).

Sraffa treats mineral resources and land as non-basic commodities which are not included in the Standard System and having marginal importance. Georgescu-Roegen's approach holds mineral resources to be vital elements for the survival of human beings.

Georgescu-Roegen sees a fundamental difference between flow and fund element in the economic process because p_2 is not equal to P_K. p_2 is the price of various maintenance items and P_K is the price proper (e.g., renting an automobile). If the rate of profit $r = 0$, approaches of both Sraffa and Georgescu-Roegen are identical in a stationary state. The following equation obtained by Sraffa (1960, p. 66) for the case of capital illustrates the point.

$$\mathrm{Mp}\frac{\mathrm{r}(1+\mathrm{r})^{\mathrm{n}}}{(1+\mathrm{r})^{\mathrm{n}}-1} + (\mathrm{C_1p_1} + \ldots + \mathrm{C_kp_k})(1+\mathrm{r}) + \mathrm{P_HH_g} = \mathrm{G_gp_g} \tag{5.28}$$

M: the number of machines of a give type to produce G_g of a commodity.

If r approaches zero, the following equation holds.

$$\frac{\mathrm{Mp}}{\mathrm{n}} + (\mathrm{C_1p_1} + \ldots + \mathrm{C_kp_k}) + \mathrm{P_HH_g} = \mathrm{G_gp_g} \tag{5.29}$$

$C_1p_1 + \ldots + C_kp_k$: flow cost; Mp/n: fund cost;

G_gp_g: total receipts.

Equation (29) is essentially the same as Georgescu-Roegen's for reproduction system.

5.3 Viability of solar technology and the flow-fund model

Three types of aggregated reproducible flow-fund model based on solar technology are in Tables 2, 3 and 4. Analytical framework of these tables is introduced by Georgescu-Roegen (1978), but little attention has been paid to the schematization[5]. The present chapter attempts to show Georgescu-Roegen's flow-fund model to be an indispensable analytical tool for examining viability of solar technology.

5.3.1 Three flow-fund models

Georgescu-Roegen (1978) identifies a feasible recipe as being any known procedure for manipulating the material environment for some given purpose. 'Technology' can be defined as a set of feasible recipes containing at least one feasible recipe for every commodity necessary

for maintaining any fund element involved. A technology is viable, if and only if the economic system it represents can operate steadily as long as environmental flows of available energy and matter are forthcoming in necessary amounts (Georgescu-Roegen 1978;1986).

Table 2 is a flow-fund matrix based on direct use of solar energy:

Process P_1: collecting solar energy (SE) with the help of collectors[6] (CL) and other maintenance capital (MK);

Process P_2: producing collectors with the help of solar energy and capital equipment;

Process P_3: producing capital equipment with the aid of energy.

For the case of Table 2, it is appropriate to define flow-fund matrix of strong viability as a matrix where any flow coordinate except collectors has surplus:

$$\mathrm{x_{11} - x_{12} - x_{13} > 0, -x_{21} + x_{22} = 0, and - x_{31} - x_{32} + x_{33} > 0.} \tag{5.30}$$

For the case of Table 2, it is appropriate to define flow-fund matrix of weak viability as a matrix where only solar energy produces surplus:

$$\mathrm{x_{11} - x_{12} - x_{13} > 0, -x_{21} + x_{22} = 0, and - x_{31} + x_{32} + x_{33} = 0.} \tag{5.31}$$

Table 3 concerns a case in which energy made available by solar collectors more than suffices for reproduction of the system itself, but capital equipment has to be produced by Process P_3^* using fossil energy (FE). Thus another process is required:

P_4^*: producing FE.

In Table 3, a_1 a_2 are technological parameters and because of the type of technology considered, it is safe to assume that $a_1 < 1$ and $a_2 > 1$. In these tables, identical characters with identical subscripts and superscripts represent identical values.

Table 4[7] represents the actual case of solar collectors:

Process P_2^*: producing collectors with the help of fossil energy and capital equipment;

Process P_5^*: corresponding to P_3^* in Table 3;

Process P_6^*: corresponding P_4^* in Table3.

Due to the type of technology in question, it is safe to assume that $a_3 > 1$.

5.3.2 Analysis and comparisons

Table 2 gives four results:

First, direct calculation shows that

$$\det X = x_{22}(x_{11} - x_{12} - x_{13})(x_{31} + x_{32}) + x_{22}(x_{33} - x_{31} - x_{32})(x_{11} - x_{12}) > 0. \quad (5.32)$$

X: flow coordinates matrix of Table 2.

Hence, according to Theorem 4 (Georgescu-Roegen 1966, p. 323), the following system has a positive solution $p^t = (p_1^1, p_2^1, p_3^1) > 0$ (p is column vector of flow prices in Table 2.)[8]:

$$X^t p = B. \quad (5.33)$$

$B =^t (B_1, B_2, B_3) > 0$;

$B_i = P_K K_i + P_H H_i + P_L L_i$;

P_K: price of capital service;

P_H: price of labour;

P_L: price of Ricardina Land.

Thus for any strong viable technology and for any fund prices, there exists a set of positive prices for flow coordinates (Georgescu-Roegen 1979).

Secondly, there exisits a case in which Equation (33) has a positive solution, even when the technology is not viable. Prices of flow coordinates may be calculated using the following example,

$$X = \begin{pmatrix} 4 & -2 & -3 \\ -1 & 1 & 0 \\ -1 & -2 & 5 \end{pmatrix}. \quad (5.34)$$

Direct calculation shows the following results for prices of flow coordinates,

$$p_1^1 = 5(B_1 + B_2) + 3B_3 > 0, \quad (5.35)$$

$$p_2^1 = 2p_1^1 + 2p_3^1 + B_2 > 0, \quad (5.36)$$

and

$$p_3^1 = 3B_1 + 3B_2 + 2B_3 > 0. \quad (5.37)$$

Third, curiously, when technology is not viable ($x_{11} < x_{12} + x_{13}$ and $x_{33} < x_{31} + x_{32}$), the price of solar energy is negative! In this case p_3^1, price of maintenance capital can also be negative[9].

Fourth, it is easily shown that the price of solar energy in a strong viable case is lower than in a weak viable case. Prices of solar energy for cases in Table 2 and Table 3 are easily calculated, assuming weak viability,

$$p_1^1 = \frac{B_1 + B_2 + B_3}{x_{11} - x_{12} - x_{13}} \quad (5.38)$$

and

$$p_1^2 = \frac{B_1 + B_2 + cB_3}{a_1 x_{11} - x_{12}}. \quad (5.39)$$

$cB_3 = B_3^2 + B_4^2$ (c is a parameter);

$B_3^2 = P_K K_3^2 + P_H H_3^2 + P_L L_3^2$;

$B_4^2 = P_K K_4^2 + P_H H_4^2 + P_L L_4^2$.

Line segment AE in Figure 1[10] is represented by the equation

$$a_1(B_1 + B_2 + B_3)x_{11} - cB_3(x_{11} - x_{12} - x_{13}) - (B_1 + B_2)(x_{11} - x_{13}) - B_3 x_{12} = 0 \quad (5.40)$$

Figure 1 shows two regions Ω_1 and Ω_2: $p_1^1 < p_1^2$ in Ω_1 and $p_1^1 > p_1^2$ in Ω_2.

If c is greater than D, $p_1^1 < p_1^2$ holds true, regardless of the magnitude of a_1. To produce maintenance capital with the help of fossil fuels is not efficient, so the price of solar energy based on that energy alone is cheaper than the price of solar energy with capital equipment produced through use of fossil energy. If c is less than D, for each value of c, there exists a lower limit of a_1, above which $p_1^1 < p_1^2$ holds true. The price of solar energy based on solar energy alone is cheaper because Process P_1 produces solar energy efficiently.

The price of solar energy in the case of Table 4 is

$$p_1^3 = \frac{B_1 + B_2 + a_3 B_3^2 + (a_3 + x_{12}/x_{44}) B_4^2}{a_1 x_{11}}. \tag{5.41}$$

The equation of hyperbola MJ in Figure 2[11] can be obtained from (39) and (41),

$$a_3 = 1 + z_1 + \frac{z_2}{a_1 - x_{12}/x_{11}} \tag{5.42}$$

where

$$z_1 = \frac{x_{12} B_4^2}{x_{44}(B_3^2 + B_4^2)} \tag{5.43}$$

and

$$z_2 = \frac{x_{12} x_{44}(B_1 + B_2 + B_3^2 + B_4^2) + 2x_{12}^2 B_4^2}{x_{11} x_{44}(B_3^2 + B_4^2)}. \tag{5.44}$$

There are two regions Γ_1 and Γ_2: $p_1^3 > p_1^2$ in Γ_1 and $p_1^3 < p_1^2$ in Γ_2.

If a_3 is less than G, $p_1^3 < p_1^2$ always holds true, independently of the value of a_1. When the amount of fossil fuels for producing maintenance capital is small, the price of solar energy in the mixed technology of Table 4 is cheaper.

As a_1 approaches x_{12}/x_{11}, the range of a_3 in which $p_1^3 < p_1^2$ holds true becomes wider. As efficiency of producing solar energy becomes lower, price of solar energy in the mixed technology of Table 4 is cheaper.

The prices of collectors in Table 2 and 3 are:

$$p_2^1 = z_3 + \frac{(B_1 + B_2 + B_3)(x_{11}x_{32} + x_{12}x_{31})}{x_{22}(x_{31} + x_{32})(x_{11} - x_{12} - x_{13})} \tag{5.45}$$

and

$$p_2^2 = z_3 + \frac{(B_1 + B_2 + cB_3)(a_1 x_{11} x_{32} + x_{12} x_{31})}{x_{22}(x_{31} + x_{32})(a_1 x_{11} - x_{12})} \tag{5.46}$$

where

$$z_3 = \frac{B_2 x_{31} - B_1 x_{32}}{x_{22}(x_{31} + x_{32})} \tag{5.47}$$

The equation of hyperbola SR in Figure 3[12] is

$$c = 1 + z_4 - \frac{z_5}{a_1 + (x_{12}x_{31})/(x_{11}x_{32})} \tag{5.48}$$

where

$$z_4 = \frac{(B_1 + B_2 + B_3)(x_{12}x_{31} + x_{12}x_{32} + x_{13}x_{32})}{(x_{11} - x_{12} - x_{13}) B_3 x_{32}} \tag{5.49}$$

and

$$z_5 = \frac{(B_1 + B_2 + B_3)(x_{11}x_{32} + x_{12}x_{31})^2 x_{12}}{(x_{11} - x_{12} - x_{13}) B_3 x_{11}^2 x_{32}^2}. \tag{5.50}$$

Figure 3 depicts a case where $x_{31}/x_{32} < 1$. To produce collectors requires more maintenance capital than to produce solar energy with the help of collectors.

There are two regions Δ_1 and Δ_2: $p_2^1 < p_2^2$ in Δ_1 and $p_2^1 > p_2^2$ in Δ_2.

If c is greater than R, $p_2^1 < p_2^2$ holds true independently of the value of a_1. To produce maintenance capital with solar energy is efficient enough, so the price of collectors produced by solar energy is cheaper. If c is less than R, for each value of c there exists a lower limit of a_1, above which $p_2^1 < p_2^2$ holds true. The price of solar collectors based on solar energy alone is cheaper because Process P_1 produces solar energy efficiently.

5.4 Conclusion

A recent report in *Oil and Gas Journal* (Campbell 1997, p. 37) indicates that by close to the year 2015, real physical shortage of oil supply will begin. Despite possible exhaustion of oil in the near future, effective and drastic shift in use of energy resources has not been and is not being implemented. Abundant coal is more destructive to the environment after energy transformation. Nuclear energy may be much more destructive, considering long-term nuclear waste management. It remains unclear whether or not solar technology can completely replace fossil and fissile fuels. It is an open question as to whether or not solar energy technology will remain a 'parasite' to fossil and fissile fuels.

Our analysis thus far reinforces Georgescu-Roegen's arguments about the issue of solar energy viability; "viability of a technology requires only that its material scaffold be self-supporting" (1979, p. 1052). The next issue is to examine viability of candidates for direct use of solar energy, particularly viability of photovoltaic cells.

Notes

1. This definition is not precise for the case of joint production to be introduced later in this chapter.

2. Manara (1980) and Steedman (1980) adopt another definition of basic and non-basic commodities. Their definition is based on the fact that the definition adopted by Sraffa may result in the case of no solution or the case of multiple solutions. The present author follows Sraffa's definition because that definition should not be changed purely for analytical convenience. Pasinetti (1980) gives yet another definition.

3. In this representation, outflows of any kind are represented by positive coordinates, inflows by negative coordinates.

4. The meaning of commodities adopted by Georgescu-Roegen is slightly different from that of Sraffa. Sraffa considers the worn-out machine as a commodity with an appropriate age.

5. An exception is Morroni (1992). Applications of the flow-fund matrix to recycling are seen in Mayumi (1991 and 1993).

6. Collectors are devices of any kind used by presently known feasible recipes for direct use of solar energy.

7. $K_3^3 = a_3 K_3^2$, $H_3^3 = a_3 H_3^2$, and $L_3^3 = a_3 L_3^2$. $K_4^3 = (a_3 + x_{12}/x_{44})K_4^2$, $H_4^3 = (a_3 + x_{12}/x_{44})H_4^2$, and $L_4^3 = (a_3 + x_{12}/x_{44})L_4^2$. a_2 and a_3 are related to each other by the equation; $x_{44}x_{34} + a_2 a_3 x_{33} x_{44} - a_2 x_{33} x_{44} = a_3 x_{34} x_{44} + x_{34} x_{12}$.

8. Vector notation $\lambda > \mu$ means $\lambda_i > \mu_i$ for every i.

9. $p_1^1 = [B_3(x_{31} + x_{32}) + (B_1 + B_2)x_{33}]/[x_{33}(x_{11} - x_{12}) - x_{13}(x_{31} + x_{32})]$ and $p_3^1 = [B_3(x_{11} - x_{12}) + (B_1 + B_2)x_{13}]/[x_{33}(x_{11} - x_{12}) - x_{13}(x_{31} + x_{32})]$.

10. $A = [(B_1 + B_2)(x_{11} - x_{13}) + B_3 x_{12}]/(B_1 + B_2 + B_3)$ and $D = 1 + [(B_1 + B_2 + B_3)x_{13}]/[B_1(x_{11} - x_{12} - x_{13})$.

11. $F = x_{12}/x_{11}$, $G = 1 + Y$ and $Y = x_{12}[x_{44}(B_1 + B_2 + B_3^2 + B_4^2) + (x_{11} + x_{12})B_4^2]/[(x_{11} - x_{12})x_{44}(B_3^2 + B_4^2)]$.

12. $S = -x_{12}x_{31}/(x_{11}x_{32}) + z_6/z_7$, $z_6 = (B_1 + B_2 + B_3)(x_{11}x_{32} + x_{12}x_{31})^2 x_{12}$, $z_7 = [(x_{11} - x_{12} - x_{13})B_3 x_{32} + (B_1 + B_2 + B_3)(x_{12}x_{31} + x_{12}x_{32} + x_{13}x_{32})]x_{11}^2 x_{32}$, $Q = 1 + z_8/z_9$, $z_8 = (B_1 + B_2 + B_3)[(x_{12}x_{31} + x_{12}x_{32} + x_{13}x_{32})x_{11}x_{31} - (x_{11}x_{32} + x_{12}x_{31})^2]$, $z_9 = (x_{11} - x_{12} - x_{13})B_3 x_{11} x_{31} x_{32}$, and $1 < R < Q$.

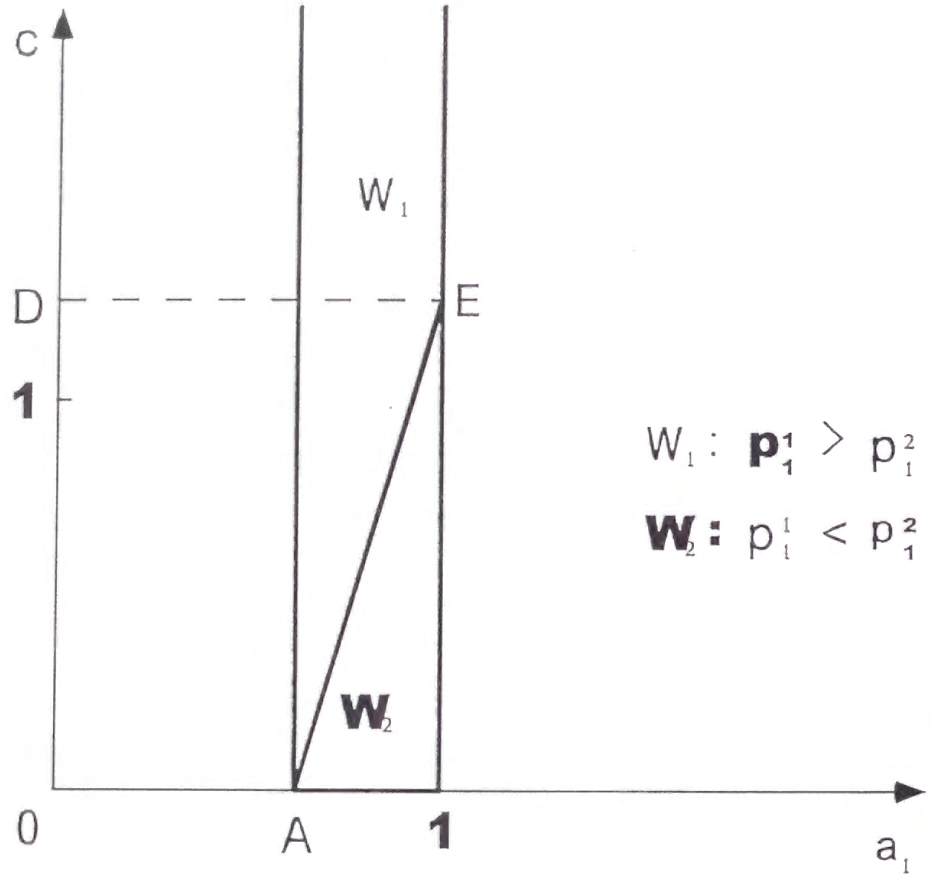


Figure 5.1: Comparison of Solar Energy Prices for Cases in Table 5-2 and Table 5-3.

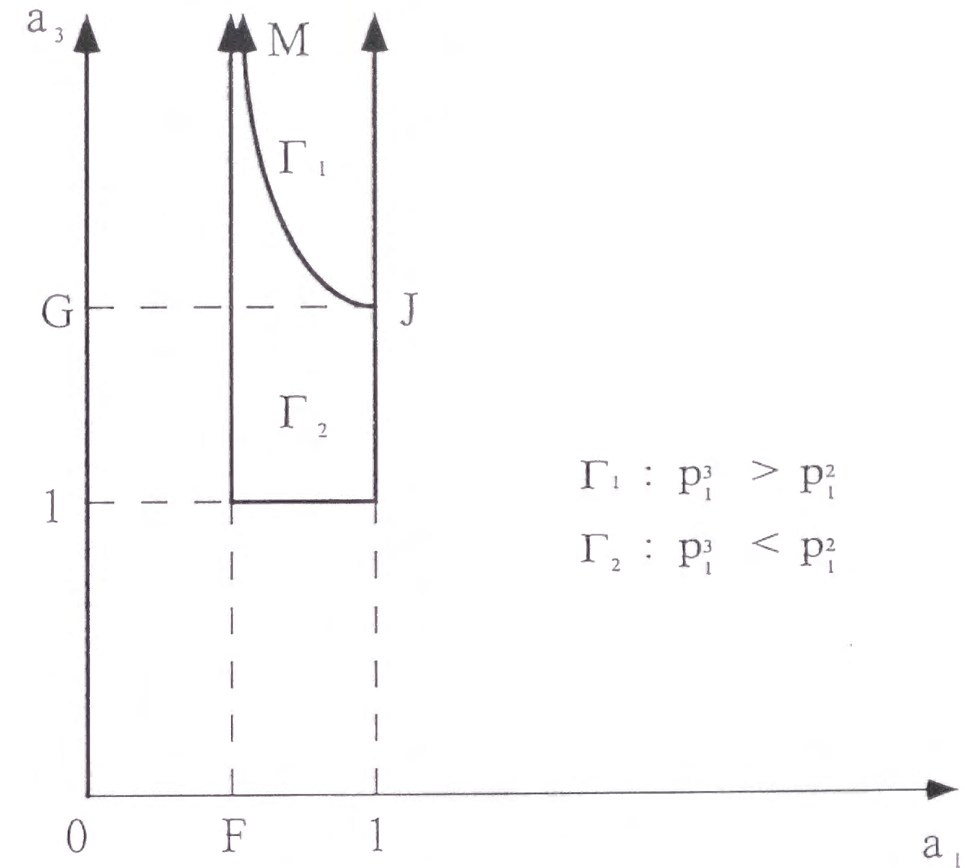


Figure 5.2: Comparison of Solar Energy Prices for Cases in Table 5-3 and Table 5-4.

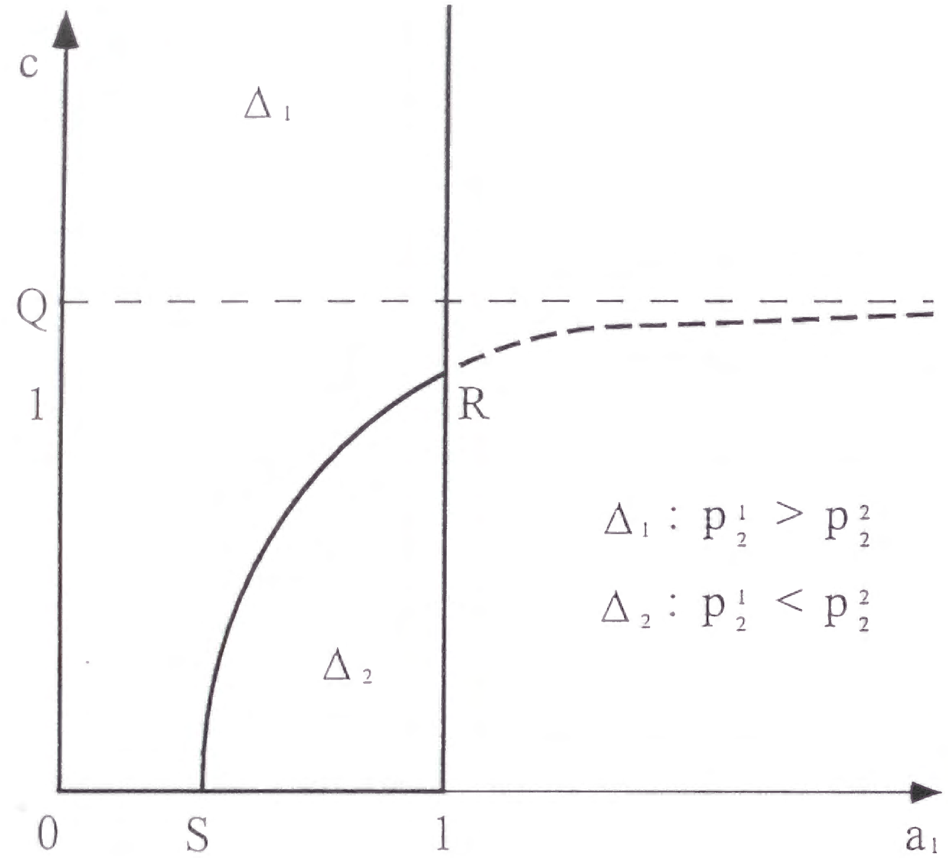


Figure 5.3: Comparison of Collectors' Prices for Cases in Table 5-2 and Table 5-3.

Elements	P_0	P_1	P_2	P_3	P_4	P_5
Flow Coordinates						
CM	x_{00}	*	$-x_{02}$	$-x_{03}$	$-x_{04}$	*
CE	$-x_{10}$	x_{11}	$-x_{12}$	$-x_{13}$	$-x_{14}$	$-x_{15}$
MK	$-x_{20}$	$-x_{21}$	x_{22}	$-x_{23}$	$-x_{24}$	$-x_{25}$
C	*	*	*	x_{33}	*	$-x_{35}$
RM	*	*	$-x_{42}$	$-x_{43}$	x_{44}	*
ES	*	$-e_1$	*	*	*	*
MS	$-M_0$	*	*	*	*	*
GJ	W_0	W_1	W_2	W_3	$-W_4$	W_5
DM	s_0	s_1	s_2	s_3	$-s_4$	s_5
DE	d_0	d_1	d_2	d_3	d_4	d_5
RF	r_0	r_1	r_2	r_3	r_4	r_5
Fund Coordinates						
Capital	K_0	K_1	K_2	K_3	K_4	K_5
People	H_0	H_1	H_2	H_3	H_4	H_5
Ricardian land	L_0	L_1	L_2	L_3	L_4	L_5

Table 5.1: Aggregated Economic Process

Elements	P_1	P_2	P_3
Flow Coordinates			
SE	x_{11}	$-x_{12}$	$-x_{13}$
CL	$-x_{21}$	x_{22}	*
MK	$-x_{31}$	$-x_{32}$	x_{33}
Fund Coordinates			
Capital	K_1	K_2	K_3
People	H_1	H_2	H_3
Ricardian land	L_1	L_2	L_3

Table 5.2: Flow-Fund Matrix of A Viable Solar Technology

Elements	P_1	P_2	P_3^*	P_4^*
Flow Coordinates				
SE	a_1x_{11}	$-x_{12}$	*	*
CL	$-x_{21}$	x_{22}	*	*
MK	$-x_{31}$	$-x_{32}$	a_2x_{33}	$-x_{34}$
FE	*	*	$-x_{43}$	x_{44}
Fund Coordinates				
Capital	K_1	K_2	K_3^2	K_4^2
People	H_1	H_2	H_3^2	H_4^2
Ricardian land	L_1	L_2	L_3^2	L_4^2

Table 5.3: Flow-Fund Matrix of Solar Collectors Produced by Solar Energy

Elements	P_1	P_2^*	P_5^*	P_6^*
Flow Coordinates				
SE	a_1x_{11}	*	*	*
CL	$-x_{21}$	x_{22}	*	*
MK	$-x_{31}$	$-x_{32}$	$a_2a_3x_{33}$	$-x_{34} - a_2(a_3 - 1)x_{33}$
FE	*	$-x_{12}$	$-a_3x_{43}$	$a_3x_{44} + x_{12}$
Fund Coordinates				
Capital	K_1	K_2	K_3^3	K_4^3
People	H_1	H_2	H_3^3	H_4^3
Ricardian land	L_1	L_2	L_3^3	L_4^3

Table 5.4: Flow-Fund Matrix of the Present Mixed Solar Technology

Chapter 6

Land: Ecological and Economic Achilles' Heel

6.1 Introduction

Successful substitution of landbased resources with fossil fuels and mineral resources has been supporting the material structure of economic process ever since the industrial revolution. It is true that the land constraint has been eased since the revolution. However, can we claim that we have perfectly become emancipated from the land constraint? The message of this study is that we can never attain emancipation from land except in a temporary sense. This study provides an economic and thermodynamic analysis concerning land mainly from the period of the industrial revolution to our time.

In this introductory section we discuss one of the characteristics of present world, i.e., the tremendous speed of matter and energy degradation which causes the rapid depletion of natural resources and the destructive influence upon our environment including land. In Section II we reconsider the views of two great minds, Liebig and Marx, who both had prophetic visions concerning this characteristic of modern agriculture and its possible outcome in the future economy. Section III gives a thermodynamic analysis of temporary emancipation from land during the the industrial revolution in England. The substitution of coal for wood, especially in the iron industry, and the growth of the cotton industry will be featured. Section IV shows that the temporary emancipation from land in the United States is due to the vast quantity of fertile land and to the intensive consumption of natural resources, especially of oil. Even in the United States, the food safety margin will be diminished by a trap of the law of the diminishing returns in the long run. Section V briefly examines four proposed methods to secure food supply. We will show that these methods can be temporary remedies, but not permanent ones. Section VI discusses the essential differences and similarities between farming and manufacturing processes to appreciate the land constraint properly. Section VII gives some concluding remarks.

6.2 Two Types of Efficiency in Physical Terms

While the importance of the disposal of entropy within a system has been emphasized thus far, *the time rate of increase in entropy* (dS/dt, S is entropy) has not been introduced. In this section, the speed of entropy increase will be discussed. Georgescu-Roegen's emphasis on a large amount of resources required in the economic process, especially on matter in bulk, can be best grasped in terms of the dreadful speed of increase in entropy. The speed of increase in entropy on the earth has been increasing recently so that it is not sufficient to talk about an increase in entropy alone. The speed at which entropy increases characterizes the destructive aspects of modern technology. While it is virtually impossible to measure the speed of increase in entropy exactly for each actual case, we can obtain the general tendency of entropy increase.

In order to discuss the speed of entropy increase in modern civilization, especially after 1960s, two types of efficiency in physical terms must be defined in the following way.[8]

1. Efficiency of Type 1 (EFT1): EFT1 refers to the ratio of output to input. EFT1 leaves time required out of consideration.

2. Efficiency of Type 2 (EFT2): EFT2 refers to output per unit time. EFT2 leaves the amount of inputs out of account.

If we regard the thermal efficiency of an ideal Carnot engine (which has neither friction nor heat loss) as output in this case, EFT1 is less than one because of the entropy law. If we regard the speed of a piston of the ideal Carnot engine as output, EFT2 is an infinitesimal amount, actually zero. If we try to raise EFT2 beyond a certain limit during the transformation process of matter and energy, we end up with a smaller EFT1. For example, if we keep raising the speed of a car beyond an ecónomical speed, we consume gas at a higher rate. Even though most drivers know this fact, they prefer to drive fast. That is, they prefer EFT2 in terms of speed of the car to EFT1 in terms of gas consumption.

There are three fundamental substances, i.e., fossil fuels, concrete and iron, which play very important roles in supporting the material structure of modern urban life. With regard to fossil fuels, these are the results of past photosynthesis made by plants and animals during

the Palaeozoic era. They are the products made over several hundred million years (EFT2 was tremendously small) on a grand scale of land so that they guarantee the present high EFT2. Limestone, a main element of concrete, was made from the debris of lime algae. Iron ore is mined from piled ore deposits which were formed through activities of iron bacteria. These three material bases for urban life are low entropy resources made with low EFT2 in the past. We are now enjoying high EFT2 by consuming these vast amounts of past bonanza. Therefore we can perhaps say that it is very difficult to maintain our civilization without the support of low entropy resources saved in the ecosystems. There is an optimal combination of EFT1 and EFT2 under some technical criterion. However, the present state of technology appropriates EFT2 much more than EFT1 and high level of EFT2 is guaranteed by low entropy resources stored in the past. Therefore dS/dt necessarily becomes bigger and bigger.

To put it differently, we shall take a case of an electric power generation plant. An electric power plant is usually constructed in order to satisfy the demand for electricity at a peak load so that the size of the facilities becomes bigger and bigger. The quantity of matter and energy to maintain the facilities and to operate this plant necessarily becomes bigger than that for the previous plant. Therefore dS/dt has a tendency to increase even within this plant system. Still worse, matter and energy required to construct this plant reduce the availability of resources for a whole system, including this plant. And also, as the quality of matter and energy entered into this plant system decreases. At the same time, unbalanced inputs of matter and energy may cause other harmful interplays with the environment, since the increased inputs remain in the environment and create other physical, chemical, and biological interactions with elements in the environment. This is the general picture of modern technology.

Finally let us take another example of the bias of EFT2 over EFT1 on land problem [Carter and Dale, 1974, p. 237–8]. There are chemical substances such as Krilium, Loamium and other "miracle" compounds that are supposed to make productive loam out of heavy clay subsoil. These chemicals have only temporary effects (EFT2 complex) without raising the fertility of land, and eventually cause the soil particle to cohere—i.e., granulation. This granulation will speed up oxidation of the minute organic matter and render the soil in worse condition than previously.

6.3 The Farsighted Views of Liebig and Marx on EFT2 Complex of Modern Agriculture

The natural tendency of increase in entropy is equivalent to saying that available matter and energy will end up in a diffused form. The diffusion speed of matter and energy has tremendously increased due to our EFT2-mania.

There were two great minds, Liebig and Marx, who appreciated the diffusion of matter and energy due to EFT2-mania, especially in agriculture and worried about the possible outcome of it.

Liebig called agricultural methods in Europe at his time *a spoliation system* because these methods contributed only to the agriculturists' further exploitation of the total sum of elements from the soils. These methods were directed to produce more in a given time period [Liebig, 1859]. He had an insight into the essential characteristic of modern agriculture—EFT2 complex. Why did the agriculturists do farming based on a spoliation system where they ignored the importance of the maintenance of land fertility? Because the agriculturists at that time sought to obtain the maximum amount of crops with minimum labour input and a large amount of fertilizers in a shorter time [Liebig, 1859]. Liebig's agronomical view was entirely different from that of the agricultural economists at that time, because, first, Liebig clearly grasped the fact that the basic cause of degradation of land fertility is due to the sales of agricultural products and the expansion of the sewage system in urban areas without returning the residues of agricultural products and excreta to soils. Second, the contemporary agricultural economists in Europe did not pay sufficient attention to the importance of circulation of matter in order to maintain land fertility in the long run. Their interest was to increase the amount of crop yields in a short span of time. Liebig's position is clearly seen in his writings:

> Hence, little "Japhet in search of his Father," the poor child called "Mineral Theory," was so ill-used and ridiculed, because he was of the opinion that the big purse at least be emptied, by always taking out money without putting any in. But who could have thought twenty years ago, when there was plenty of manure, that it would ever occur to these obstinate and wilful fodder plants to produce no more manure, and no longer to *spare* and *enrich* the ground? The soil is naturally not the cause of this; for they teach that it is inexhaustible, and those still enough believe that the source from which it is derived will always flow. Truly, if this soil could cry out like a cow or a horse which was tormented to give the maximum quantity of milk or work with the smallest expenditure of fodder, the earth would become to these agriculturists more intolerable than Dante's infernal regions. Hence, the advantageous prosecution of this system of modern agriculture is only possible on large estates, for the spoliation of a small one would soon come to an end [Liebig, 1859, pp. 130–1].

In short, the critique of Liebig was based on his view that land and its natural power are the source of wealth for nations and of wealth for the human species as a whole. His scientific thought, which placed human beings in a natural existence with great cycles of nature going on without much intervention, enabled him to posit his view and to part from the type of agricultural economics which treated nature as human property.

There is tremendous degradation of nature and land by the rapid development through industrialization everywhere, in socialist countries as well as in capitalist countries. Strangely enough, the Marxian economists, who are supposed to inherit Marx's genius, did not seem to appreciate his view on nature and man properly. Throughout the industrial revolution, there began to occur the separation between cities and farm villages [Parsons, 1977]. In this regard Marx, clearly influenced by Liebig, writes:

> The capitalist mode of production extends the utilization of the excretions of production and consumption. By the former we mean the waste of industry and agriculture, and by the latter partly the excretions produced by the natural exchange of matter in the human body and partly the forms of objects that remains after their consumption. In the chemical industry, for instance, excretion of production are such by-products as are wasted in production on a smaller scale; iron filings accumulating in the manufacture of machinery and returning into the production of iron as raw material, etc. Excretions of consumption are of the greatest importance for agriculture. So far as their utilization is concerned, there is an enormous waste of them in the capitalist economy. In London, for instance, they find no better use for the excretion of four and a half million human beings than to contaminate the Thames with it at heavy expense [Marx, 1959, p. 100].

The picture drawn by Marx has much worsened ever since. He succinctly grasped the fundamental cause of destruction of nature–in our society man's dialectical relationship with nature (material circulation between man and nature) is executed through the exchange of economic goods.

Marx writes about Liebig in several places:

> To have developed the point of view of natural science, the negative, *i.e.*, destructive side of modern agriculture, is one of Liebig's immortal merits. His summary, too, of the history of agriculture, although not free from gross errors, contains flashes of light [Marx, 1936, p. 555].

His comments on Liebig can be seen in his letter to Engels:

> I had to wade through the new agricultural chemistry in Germany, especially Liebig and Schönbein, who are more important in this matter than all the economists put together [Marx, 1979, pp. 205 and 207].

Liebig's influence on Marx is often seen in Marx's writings in Capital:

> It [Capitalist production] disturbs the circulation of matter between man and the soil, *i.e.*, prevents the return to the soil of its elements consumed by man in the form of food and clothing; it therefore violates the conditions necessary to lasting fertility of the soil [Marx, 1936, p. 554].

Moreover, he keenly grasped the syndrome of EFT2 complex of modern agriculture in the following passages:

> All progress in capitalistic agriculture is a process in the art, not only of robbing the labour, but of robbing the soil; all progress in increasing the fertility of the soil for a given time, is a progress towards ruining the lasting sources of that fertility. The more a country starts its development on the foundation of modern industry, like the United States, for example, the more rapid is this process of destruction. Capitalist production, therefore, develops technology, and the combining together of various processes into a social whole, only by sapping the original sources of all wealth—the soil and the labourer [Marx, 1936, pp. 555–6].

Marx also reached a deep understanding about the difference between agriculture and manufacturing:

> It is possible to invest capital here successively with fruitful results, because the soil itself serves as an instrument of production, which is not the case with a factory, as a place and a space providing a basis of operations ... The fixed capital invested in machinery, etc., does not improve through use, but on the contrary, wears out [Marx, 1959, pp. 761–2].

Marx also mentioned the similar characteristics between large-scale industry and large-scale mechanized agriculture:

> Large-scale industry and large-scale mechanized agriculture work together. If originally distinguished by the fact that the former lays waste and destroys principally labour-power, hence the natural force of human beings, whereas, the latter more directly exhausts the natural vitality of the soil, they join hands in the further course of development in that the industrial system in the country-side also enervates the labourers, and industry and commerce on their part supply agriculture with the means for exhausting the soil [Marx, 1959, p. 793].

From the discussion above, it has become clear that Marx effectively evaluated and appreciated the development process of agriculture and the destructive aspect of modern industry in terms of the circulation of matter between nature and man as presented by Liebig.

We close this section with Marx's concern for the forest problem:

> The long production time (which comprises a relatively small period of working time) and the great length of the periods of turnover entailed made forestry an industry of little attraction to private and therefore capitalist enterprise, the latter being essentially private even if the associated capitalist takes the place of the individual capitalist. The development of culture and of industry in general has ever evinced itself in such energetic destruction of forests that everything done by it conversely for their preservation and restoration appears infinitesimal [Marx, 1957, p. 244].

6.4 Four Variations of the Law of Diminishing Returns

In the previous two sections, the tremendous speed of increase in entropy was explained in terms of EFT2 fetishism of modern industrial society. The following explanation of four variations of the law of diminishing returns will give us a window through which we can see the true picture of our economy due to the present EFT2 fetishism. First we define the four types of the law of diminishing returns (LDR).

1. LDR of Stock Type 1 (for short LDRST1): LDRST1 refers to a situation where the maintenance or expansion of output level becomes more difficult as the accumulated output or accumulated consumption of resources increases. We leave the quality of resources out of consideration for LDRST1. The amounts of available land and resources decrease as the accumulated output or consumption increases, since we have only a finite amount of energy and matter available to humans.

2. LDR of Stock Type 2 (LDRST2): LDRST2 states a situation where the maintenance or expansion of output level becomes more difficult as the quality of resources gets worse and worse, even though there are the same amounts of resources available. If the quality of resources worsens, we need a greater amount of resources to obtain the same level of output than before because we have to reduce the higher entropy of the original resources. Furthermore, during the transformation of low-grade resources, the polluting rate of the environment necessarily accelerates and finally the output level will decrease. Two different types of force work toward the same direction to reduce the output level.

3. LDR of Rate Type 1 (LDRRT1): LDRRT1 refers to a situation where an increase in some varying input relative to other fixed inputs will make output increase at a decreasing rate after some point. We leave the quality of inputs, and other chemical, physical, and biological interplays of varying input with some other factors, including environment, out of consideration. This type is a ubiquitous one, and is discussed in most textbooks of standard economics.

4. LDR of Rate Type 2 (LDRRT2): LDRRT2 states a situation where both LDRRT1 and also other interplays operate, since the greatly increased input may remain in the environment and create other physical, chemical, and biological interplays with substances in the environment.

Four points should be noticed here before we presents three applications of these laws.

First of all, the four variations of the law of diminishing returns in this section are expressed in physical or technological terms, not in terms of economic cost.

Second, it is true that Historical Increasing Returns (HIR for short)—the shift of a whole production curve upward into a new position over time by technological progress—has been ubiquitous in the past one hundred years or so, but this fact does not prove at all that

"*there is no law of decreasing returns to technological progress*" [Schumpeter, 1954, p. 263], as Schumpeter claimed. We should remember the fact that the phenomena of HIR and technological progress have been supported both by a change in the cost structure benefited through the unsurpassed bonanza of fossil fuels and mineral resources and by our EFT2 fetishism. Georgescu-Roegen stated on this point:

> This exceptional bonanza by itself has sufficed to lower the real cost of bringing minerla resources *in situ* to the surface. Energy [cost] of mineral resource thus becoming cheaper, substitution-innovations have caused the ratio of labor to net output to decline. Capital also must have evolved toward forms which cost less but use more energy to achieve the same result. What has happened during this period is a modification of the cost structure, the flow factors being increased and fund factors decreased. By examining, therefore, only the relative variations of the fund factors during a period of exceptional mineral bonanza, we cannot prove either that the unitary total cost will always follow a decreasing trend or that the continuous progress of technology renders accessible resources almost inexhaustible—as Barnett and Morse claim [Georgescu-Roegen, 1975, p. 362].

Third, LDRST1 and LDRST2 are deeply related to the entropy law:

> the amounts of low entropy within our environment (at least) decreases continuously and inevitably, and second, *a given amount of low entropy can be used by us only once* [Georgescu-Roegen, 1966, p. 94].

Fourth, the physiological basis of LDRRT1 is the Law of the Minimum established first by Liebig and later refined by E. A. Mitscherlich. E. Lang stated:

> Mitscherlich himself had already early recognized the fact that plant yield is dependent not only on the vegetative factor present, according to Liebig, in minimum, but also on all other vegetative factors so far as these are present in quantities varing from the optimum during the vegetative period, which may always be the case in any combination in nature [Lang, 1924, p. 133].

The four types of the law of diminishing returns will give us a better guide to evaluate the possible outcome of EFT2 fetishism in the modern world and to pave the way for reconstructing modern technology. In this respect these laws in physical terms *ultimately* ordain the law of diminishing returns in terms of economic cost. We must appreciate the prophetic view of Georgescu-Roegen regarding this point:

> To suggest further that man can construct at a cost a new environment tailored to his desires is to ignore completely that cost consists in essence of low entropy, not of money, and is subject to the limitations imposed by the natural laws [Georgescu-Roegen, 1975, p. 359].

Let us examine how these laws work during the process of matter-energy transformation in modern agriculture and manufacturing. We shall give three examples here. The third example concerns land and water.

1. Greenhouse Effect: carbon dioxide in the atmosphere allows the sun's ultraviolet and visible radiation to penetrate and warm the earth, but absorb the infrared energy the earth radiates back into the atmosphere. By blocking the escape of this radiation, CO_2 effectively forms a thermal blanket around the earth. To rebalance the incoming and outgoing radiation, the earth's temperature must increase. Increases in atmospheric CO_2 (LDRRT1) mainly derive from the use of fossil fuels (LDRST1 and LDRST2). Increases in CO_2 cause the temperature to rise (LDRRT2) and are likely to be accompanied by dramatic changes in precipitation and storm patterns, and a rise in global average sea level.

2. A Project for Taking ^{6}Li from the Sea [Shimazu, 1984, pp. 216–9]: the only type of fusion which may be materialized is the tokamak type. Contrary to the common sense view, only ^{6}Li is the fuel for this fusion. The estimated amount of ^{6}Li used for one fusion power plant (1 million kw) during its lifetime is 580 tons. We need to transform 16.2 billion tons of sea water (0.15 g of ^{6}Li in one ton of sea water). We obtain 1.3 billion tons of NaCl (salt) and 3.0 million tons of KCl as by-products. We need electric power amounting to 1.6×10^{14} kcal which turns out to be an amount of electric power 32 fusion power plants of the same size produce per year (LDRST1). The amount of NaCl is 16 times as much as the consumption of all Japanese people annually (LDRST2 and LDRRT2). In addition to this we need more energy for producing tritium from ^{6}Li as well as other elements, Ni and He, for example (LDRST1 and LDRST2).

3. Nitrogen Fertilizer [Commoner, 1971, pp. 84–5 and 152]: because of low economic cost farmers use nitrogen fertilizer in order to increase production. In Illinois, the increment of 20 bushels per acre in yield was the result of an increase in fertilizer of about 100,000 tons per year between 1945 and 1958. But only 25 bushels per acre were added after 300,000 tons of fertilizers were used (LDRRT1). This implies that a good deal of nitrogen must have dissipated somewhere. Subsequently, there appeared a significant increase in the nitrate levels in a number of rivers in Illinois (LDRRT2). This indicated a hazard to their water supply (LDRST1 and LDRST2) in the long run which will reduce farm output level as well as the quality of farm products (LDRST1 and LDRST2). Also, under the impact of intensive use of nitrogen fertilizer, the nitrogen-fixing bacteria originally living in the soil may not survive, or even if they do, they may mutate into nonfixing forms (LDRST2 and LDRRT2).

6.5 The Industrial Revolution in England

When Liebig and Marx indicated the deteriorative effects of sales of crops and of the sewage system on land fertility and worried about the future land situation, the industrial revolution, which was a temporary relief from the land constraint, had already begun in England. This was toward the end of the eighteenth century. In this section let us begin with the situation of European land, especially of England, before the revolution in order to understand the historical background properly.

While nowadays the influence of the civilization of Western Europe is strong, its history has been influential only for one thousand years. With respect to the land situation in Western Europe most of the agricultural land has been cultivated for less than nine centuries. The climate is conducive to soil conservation in most part of Western Europe. The mild rains and mists, with few torrential downpours and snow that protects the cultivated fields during winter from erosion, are crucial characteristics of the climate. While the Romans exploited most of the region in Western Europe in the first century B. C., most of the land in Western Europe recuperated by the time of the Dark Ages. Most of the land, north and west of the Alps, was nearly as productive as it had been before the Phoenician and Greek civilization came to the region as early as 500 B. C. Modern Western civilization developed rapidly during the eleventh century. During the eleventh through thirteenth centuries, the amount of cultivated land tripled or quadrupled over most parts of Western Europe, encouraged mostly by the feudal lords. This practically amounted to a recolonization of the whole region in Western Europe. As feudal power collapsed, and the king's power began to exert influence, the present nations of Europe began to form. By the middle of the fourteenth century, a substantial part of the tillable land of the region was cultivated through the emancipation of the serfs encouraged by the kings. Although one fourth of all people in Europe died of the

Black Death in the fourteenth century, they invented the modern systems of crop rotation, manuring, liming, and other soil-building methods in order to preserve land fertility. Thus modern European agriculture made it possible for the urban population of a region to exceed the rural population for the first time in human history, because one farmer could produce more than enough to feed his own family and *another family* in the city [Carter and Dale, 1974].

However, as the population in cities grew more and more, and organic raw materials including food became more and more scarce, the pressure generated by the land shortage began to emerge. In England, the pressure was more powerful than on the continent, particularly in Germany and France, because the feudal system in England ended long before that of Germany and of France. Feudalism in Germany, for instance, "did not disappear until the Prussian kings came to power about the middle of the seventeenth century" [Carter and Dale, 1974, p. 179]. How, then, did England manage to escape this pressure by the industrial revolution up to the end of eighteenth century?

The most dramatic change in raw material provision which took place during the industrial revolution was the substitution of inorganic for organic sources of supply, especially landbased resources [Wrigley, 1962]. As R. G. Wilkinson described the situation in England before the industrial revolution:

> The supply of food and drink depended on agricultural land, clothing came from the wool of sheep on English pasture, and large areas of land were needed for extensive forest: almost all domestic and industrial fuel was firewood, and timber was one of the most important construction materials for houses, ships, mills, farm implements etc. In addition, the transport system depended on horses and thus required large areas of land to be devoted to grazing and the production of feed. Even lighting used tallow candles which depended ultimately on the land supply [Wilkinson, 1973, p. 112].

Therefore land became increasingly scarce with increase in population. The crisis can be seen from the fact that England became a net importer of wheat instead of a net exporter from the late 1760s except 1785–89 [Wilkinson, 1973].

The substitution of coal for wood had the most dramatic influence on the progress of the English Industrial Revolution. In some cases, coal was substituted for wood without serious technical difficulties. Where substances were kept separate from the fuel in industries such as smiths, limeburners, salt-boiling, dyeing, soap-boiling, the preparation of alum, copperas, saltpetre and tallow candles etc., it was quite easy to substitute coal for wood [Wilkinson, 1973]. However, where coal was in direct contact with the raw materials, especially in iron-smelting, the difficulty remained unsolved until Abraham Darby I succeeded in using coke to smelt native ore at his works of Coalbrookdale in 1709 [Armytage, 1961].

The quality of coke pig iron was not as good as that of charcoal pig iron because wood is a raw material of low entropy. Therefore the refining process was still dependent on charcoal. In addition, coke furnaces required a site which was near coal and iron mines, and water mills on a large scale. Still worse, coal mining reached depths at which then existing methods of drainage became impracticable [Wilkinson, 1973].

A secured supply of water was a prerequisite for building water mills on a large scale; a lot of water was necessary to turn water mills by using Newcomen's engine. However, Newcomen's engine had an overall thermal efficiency of 0.2% only. Therefore a water shortage problem began to emerge. Watt's steam engine with thermal efficiency of 2% succeeded in solving the problem of drainage in coal mines and enabled people to construct water mills independently of location and seasonal variation in water flow. Thanks to the increase in thermal efficiency of Watt's steam engine, the difficulty of transportation of raw materials and final goods was eased dramatically so that it became possible to construct iron works in areas remote from the site of coal mines and consuming cities.

By this development, the English iron industry shifted to coke furnaces (blast furnace) and subsequently established industrial supremacy for one century. During this period, the refining process was also transformed to use cokes. This was made possible by the puddling process patented by H. Cort in 1783 [Armytage, 1961].

It was a reverberatory furnace. In this process, pig iron was heated indirectly so that the impure elements in coal did not diffuse into iron. However, the reduction in thermal efficiency due to indirect heating was a burden, although there was plenty of coal available. A dramatic improvement in the balance of thermal efficiency was achieved by the Siemens-Martin process in 1865 [Armytage, 1961].

The development process of the (coke) blast furnace can be regarded as a typical example of resource substitution. First, there occurs a scarcity problem of low entropy resource (for example, wood). A substitutable resource is of high entropy (coal) so that a roundabout process is needed to remove mixing entropy due to the poor quality of the raw material (coal). Unless a new resource itself is of low entropy (oil, for instance) or there is another low entropy material available to reduce the entropy of the new resource of high entropy, the new resource would never be available to mankind via technological progress. We can not expect technology to produce something from nothing because technology is a catalyst, as it were, to induce the latent ability of a resource to emerge.

Another important technological aspect of the industrial revolution came from a change in the transportation system. The secure supply of raw materials is a key to carrying out a large scale production. As E. A. Wrigley indicated, "production of the former (mineral production) is a punctiform; of the latter (vegetable and animal production) areal" [Wrigley, 1962, p. 3]. The expansion of the transportation system was necessary due to increase in population in England. To put it differently, it became impossible for a growing eighteenth century population within a local area to sustain an adequate standard of living. Canals and the later development of steam railways became major means of transportation instead of horses.

The growth of the cotton industry, one of the dominant features of the revolution, posed a different aspect of raw material supply. The shift from the wool industry to the cotton industry benefited from two land-saving factors in England. First, while cotton was also a landbased resource, England could exploit land in India and America. Therefore it was relatively easy for the cotton industry to expand its production without causing the problem of land shortage in England. Second, while the wool industry had a process; solar energy + water ⇒ meadow ⇒ wool, the cotton industry had a process; solar energy + water ⇒ cotton [Kawamiya, 1984]. In the cotton industry a part of the roundabout process, i.e., meadow ⇒ wool, is not necessary. However, as the production of cotton began to expand dramatically, the necessary working hours increased greatly because more labour was required to process cotton into a piece of cloth. At the same time there were only water mills and horse power available as a source of motive power before the invention of the steam engine. The mechanization by utilizing steam engines solved these problems successfully so that the rapid expansion of the cotton industry became possible afterwards.

The foundation of the industrial revolution in England was supported by two thermodynamic improvements and changes—one is the transition from organic materials, especially wood, of scarce and of low entropy, to coal of high entropy in abundance, and the other, the transition from wool of good quality (but dependent on land in England) to cotton of poor quality (but abundant in India and America) [Kawamiya, 1984].

The English industrial revolution seemed to ease the land problem perfectly and forever.

However, two points have to be noticed. First, coal itself is a landbased resource. We are consuming a past heritage or bounty created by plants over a long period of time. In this sense we are still perfectly dependent on land. Second, there is a common characteristic between the scarcity of wood before the revolution and the resource problems facing mankind in the near future. The resource transition from wood (charcoal) to coal in the iron industry means the transition from a "clean" (low entropy of mixing) to a "dirty" (high entropy of mixing) resource. We now have the same problem, because oil and natural gas are superior to coal, in this respect. An intensive utilization of oil began in 1960s all over the industrial nations. It should be noted that this rapid shift of a fundamental resource in the modern world is an unusual event in the history of mankind because the transition from coal to oil means the transition from a "dirty" to a "clean" resource. One of the features of modern technologies is an intensive use of oil which was produced on land in the past. The consumption of oil has increased exponentially during 1860s–1980s. The doubling period was about ten years [Tsuchida, 1982, p. 76]. We are now using up oil at an accelerated rate. It is true that we temporarily escaped the land shortage by shifting from wood to coal in the process of the industrial revolution. But it would be absurd to claim that we can overcome the present crisis based on the past success.

6.6 The Temporary Emancipation from Land: in the Case of the United States

"It is the quantity of the land, not its quality, which is decisive here," [Marx, 1959, p. 656] for the development of America in the colonial times, as Marx correctly indicated. Carter and Dale write:

> The area now known as the United States contained nearly two billion acres of land. Two-thirds of the country was covered with magnificent forests or lush grass, wildlife of all types abounded, rainfall was adequate for agriculture over more than one-half the area, and all this land was occupied by less than two million people [Carter and Dale, 1974, p. 222].

A peculiar aspect of the American Revolution is that after the establishment of independence America's only competitors for the tremendous amount of land were American Indians. At first, successive American Presidents obtained land by entering into treaties with the

American Indians. During these early years, most parts of the middle and the western lands were the American Indians' territory. However, the colonists then started their expansion westward violently with the tacit consent and support of the American government. With respect to the land situation of the United States at that time, Liebig stated:

> As men began to till the soil, and as fast as they exhausted one locality of such elements of God's bounty as were in a condition, from their solubility, to act as food for plants, they moved to new places rather than to properly work or fertilize old ones. They were not the servitors of their grandchildren, but with a vast country before them they chose to skim it, and as they drove the Red Men westward, they found new fields for planting, and they "skimmed" the land. Here the great mistake was made, that of overrunning the soil to reap a few good crops that ended in impoverishing it, and this bad example has followed to the present day. Thus the Atlantic slope became a depleted expanse, and unprofitable with the modes of culture in practice [Liebig, 1859, p. 243].

With respect to the tendency of a decrease in yields, Liebig writes:

> A writer in the 'Year Book of Agriculture for 1855', on the 'Alarming Deterioration of the Soil' referred to various statistics of great significance in connection with this subject. Some of them regarded Massachusetts, where the hay crop declined *twelve* per cent. from 1840 to 1850, notwithstanding the addition of 90,000 acres to its mowing lands, and the grain crop absolutely depreciated 6,000 bushels, although the tillage lands had been increased by the addition of 60,000 acres [Liebig, 1859, p. 243].

Marx, who fully understood that the sales of agricultural products to remote areas without returning the residues of crops stressed the natural circulation of matter and caused the land fertility to decrease, paid special attention to J. F. W. Johnston's *Notes on North America: Agricultural, Economical, and Social* and called him the English Liebig [Marx and Engels, 1982, p. 476]. Because Johnston reached a similar conclusion about American agriculture, as Liebig did–that exporting of large quantities of agricultural products was nothing but the export of land fertility itself without compensation, and that the virgin lands in America did not have infinite fertility, while a vast stretch of land enabled America to export a large quantity of agricultural products *temporarily*. Johnston writes:

> The power of exporting large quantities of wheat implies neither great natural productiveness, nor permanently rich land. . . . And yet, such a country as I have described—like the interior uplands of western New York—will give excellent first crops, even of wheat, and will supply, to those who *skim the first cream off the country*, a large surplus of this grain to send to market (italics added) [Johnston, 1851, pp. 223–4].

Johnston predicted the situation of America in the following way:

> When a tract of land is thinly peopled—like the newly settled districts of North America, New Holland, or New Zealand—a very defective system of culture will produce food enough not only for the wants of the inhabitants, but for the partial supply of other countries also. But when the population becomes more dense, the same imperfect system will no longer suffice [Johnston, 1847, p. 4].

Mistreatment of land in the United States continued until the end of World War I, in the shipping of furs and skins of wildlife, exporting as much timber as foreign markets would take and burning much that was not wanted, and transferring the fertility of soils in the form of tobacco, cotton, wheat, corn, beef, pork, and wool. The people of the United States tried to extract the products of land as quickly as possible. They caused ruin in a shorter time—EFT2 complex—than any people before them because they had more land to exploit and better tools with which to exploit it [Carter and Dale, 1974]. This situation did not change much until "agribusiness" came to the temporary rescue after World War II. According to B. Commoner:

> agribusiness is founded on several technological developments, chiefly farm machinery, genetically controlled plant varieties, feedlots, inorganic fertilizers (especially nitrogen), and synthetic pesticides. But much of the new technology has been an ecological disaster; agribusiness is a main contributor to the environmental crisis [Commoner, 1971, p. 148].

The environmental crisis, especially the erosion and degradation of land, is the result of the EFT2 complex, a typical characteristic of modern industry, including agriculture. That is, agribusiness' interest is to increase crop yields as much as possible within a very short span of time, instead of increasing total agricultural produce by maintaining the land fertility for the future generations. The continued abuse of land by agribusiness contributed to exhausting the land and to making it still more unproductive for future crops. Agribusiness misunderstood the meaning of culture, as H. Maron, who visited Japan in the last days of the Tokugawa shogunate as a member of the Prussian East Asian Expedition, correctly understood:

> If by 'culture' is meant the capability of the soil to give permanently high produce, by way of *real interest on the capital of the soil*, I must altogether deny that our farms (with perhaps a few exceptions), can properly be said to be in a satisfactory state of culture. But we have by excellent tillage and a peculiar method of manuring, put them in a condition to make the entire productive power of the soil available, and thus to give immediately full crops. It is not, however, the interest that we obtain in such crops, but the capital itself of the soil upon which we are drawing. The more largely our system enables us to draw upon this capital, the sooner it will come to an end [Liebig, 1972, pp. 369–70].

Before investigating some characteristics and suggested solutions for modern agriculture, the intensive petroleum utilization and some consequences of it will be discussed.

A general phenomenon in the history of resource substitution, except perhaps for iron ore, is to move to resources of high entropy after exhausting resources of low entropy. A typical example is gold ore. While pure gold was mined in ancient times, at present gold ore of seven ppm (several grams of gold out of 1 ton) is usually mined. The transition from wood to coal during the industrial revolution was the same type of resource substitution. However, the transition from coal to oil is an entirely different substitution. It is an exceptionally rare case of the substitution of a main resource which support the motive power of the whole industrial system [Kawamiya, 1984].

Oil has three distinctive characteristics. First, oil is made of hydrocarbons of high purity and its mixing entropy is very low. In this respect, oil is superior to coal. Second, oil is liquid and has low entropy *per unit volume*. In this respect, oil is better than natural gas because larger scale equipments are required for transportation and storage of natural gas. Third, the environmental pollution when burned is relatively mild. In this respect oil is superior to coal and to nuclear energy [Kawamiya, 1984].

Oil is excellent as a raw material in the manufacturing industry. Oil products such as plastics and polythenes have provided an important group of new materials as substitutes for wooden products. Wilkinson stated: "Polythene sheet is replacing cellophane and paper (both made from wood pulp) for bags and wrapping as well as for a number of other uses, and heavier plastics are being substituted for wood in moulding where rigidity and heat resistance are unnecessary" [Wilkinson, 1973, p. 185]. These are only a few examples of substitution of minerals for landbased resources. The most important distinction between the technology of modern times and that in the era of the industrial revolution is that the substitution of minerals for landbased resources is happening now at an accelerated rate both in scale and in variety.

To see the intensive use of energy, especially oil and oil related products, in modern agriculture, in 1973, D. Pimentel, et al. examined the energy balance in corn production in the United States. They regarded the energy required for production of agricultural machines, fertilizers, pesticides, and other management tools as indirect input to corn production. Between 1945 and 1970, while corn yield increased from 3.4 billion kcal to 8.2 (238%), the total energy inputs increased from 0.9 billion kcal to 2.9 (312%). As a result, the ratio of return kcal to input kcal was reduced from 3.70 to 2.82.

While the United States seems to have escaped the land trap ever since colonial times by the intensive use of machinery and chemicals, the law of diminishing returns on land had already begun to work. B. Commoner writes:

> Between 1949 and 1968 total United States agricultural production increased by about 45 per cent. Since the United States population grew by 34 per cent in that time, the overall increase in population was just about enough to keep up with population; crop production *per capita* increased 6 per cent. In that period, the annual use of fertilizer nitrogen increased by 648 per cent, surprisingly larger than the increase in crop production [Commoner, 1971, p. 149].

Why, then, cannot the modern agricultural method escape the trap of the law of diminishing returns? To this question, basically Liebig gave an answer. His theory is called *Gesetz des Minimums (the Doctrine of Minimum)*. According to him:

> every field contains a *maximum* of one or several, and a *minimum* of one or several other nutritive substances. It is by the *minimum* that the crop are governed, be it lime, potash, nitrogen, phosphoric acid, magnesia, or any other mineral constituent; it regulates and determines the amount or continuance of the crops [Liebig, 1972, p. 207].

When a soil is abundantly provided with one of the mineral constituents, for instance, nitrogen, the amount of nitrogen removed by the crops is such a small fraction of the soil so that the effect of the law of diminishing returns temporarily does not express itself. Therefore, the intensive use of several chemicals can keep the soil from suffering from the trap of the law of diminishing returns of the rate type, but only temporarily (Mayumi, 1990) However, other elements, especially the elements whose amounts are minimum, are removed with crops at the same time. A relative decrease in amounts of those elements has a profound influence on the succeeding crop yields and results in decrease in land fertility itself. That is to say, the law of diminishing returns of the stock type for those elements begins to emerge so that the crop yields will decrease dramatically in the long run. Therefore, we should fully know the condition and composition of the soil at hand. However, the ironic aspect is that the condition and composition of the soil vary in different fields. We cannot apply a general principle to different soils. The condition and composition of the soil depend on geography, precipitation, temperature, etc. Hence, we have to revalue the blind application of machinery and chemicals with respect to different soils.

6.7 Examination of Some Suggested Remedies

There are several technological proposals for an ever increasing food supply: artificial photosynthesis, hydroponics, ocean farming, and artificial loam.

Let us examine the possibilities of these suggested remedies briefly. 1. Artificial photosynthesis: apart from the health problems due to these artificial proteins, an extravagant amount of energy is required to synthesize them. Worgan [Worgan, 1975] examined an artificial synthesis for increasing food supplies. Ef is the number of times the energy inputs are greater than the energy value of the food produced. If we produce food via total chemical synthesis, the total energy requirement for the synthesis of food is estimated at 33 Ef. According to Worgan: "to provide the diet in the USA this input would be more than 100,000 kcal *per capita*/day or nearly 50% of the total energy requirement of an advanced technological society" [Worgan, 1975, p. 190]. Some people say that the artificial synthesis of protein is a method to produce protein only from water and air. Worgan clearly showed this to be a myth.

2. Hydroponics: this is a method to produce plants in tanks filled with sand or gravel and proper chemical solutions. We have two difficulties here in applying this technology to the actual situation. In the first place, we do not know exactly which elements and what proportion of these chemicals are necessary in the solution. Secondly, the amounts of chemical elements and energy will be tremendous, just like in the case of artificial photosynthesis. The chemical elements must be mined and processed, and a large number of tanks must be constructed. These material requirements give a further burden to the scarcity of matter and energy, while the pressure on the food supply may be eased temporarily. This method will never be practical for growing a major part of the food for several billion people.

3. Ocean farming: some scientists advocate the use of potentially vast amounts of minerals in the sea water to grow various types of plants that could be transformed into human food through laboratory processes. This can not be a practical substitution for soil conservation. Similar objections to artificial photosynthesis and hydroponics can be applied to ocean farming. There are additional obstacles. First, the concentration of minerals in the sea water is very thin. A lot of electric power would be needed to obtain a sufficient amount of minerals for plants. At the same time, we end up with tremendous amount of by-products such as salt, potassium chloride. Second, contrary to common understanding, the place where the primary activities of sea life take place is within only 10 meters in depth in the sea. Economic activities of present human beings consist of transporting and transforming materials of 10 billion tons such as fossil fuels (6 billion tons), minerals, woods, food etc., and one trillion tons of water resources. If this situation continues even with zero growth rate for another five hundred years, waste matter of 5 trillion tons will be accumulated in our environment. This quantity would be equivalent to spreading 500 kg of waste matter per m^2 over the United States. We have already had the problem of pollution by DDT, mercury, or other poisons, sewage, oil spills, etc. One the other hand, in the process of natural photosynthesis, carbohydrates are synthesized by concentrating 2 million times as much as the original concentration of carbon dioxide of 0.03% in the air. Biological activities and concentration of a specific substance are inseparably related to each other so that we cannot separate only polluted substances during the process of concentration. Ocean farming is not a solution for the future food supply, but a further source of environmental disaster.

4. Artificial loam: substance such as Krilium, Loamium, etc. are used to make productive loam out of heavy clay subsoil. However, these drugs are only temporary remedies because they cause the granulation of the soil. The granulation will accelerate oxidation of the little organic matter that remains in the treated soils. This implies that after a temporary respite, the soil will be in worse condition than before. Also, these drugs do not help land that is

already badly gullied. Most dealers are said to have stopped producing these drugs.

All these four possibilities can be temporary remedies, but not permanent ones. Eventually we will find that we have despoiled or consumed our good land through poor land management.

6.8 Conclusion

We seem to forget the fact that our present material structure and EFT2 complex have been supported by the bonanza of fossil fuels and mineral resources during the last one hundred years. Georgescu-Roegen stated:

> Now, economic history confirms a rather elementary fact—the fact that the great strides in technological progress have generally been touched off by a discovery of how to use a new kind of accessible energy. On the other hand, a great stride in technological progress cannot materialize unless the corresponding innovation is followed by a great mineralogical expansion. Even a substantial increase in the efficiency of the use of gasoline as fuel would pale in comparison with a manifold increase of the known, rich oil fields.
>
> This sort of expansion is what has happened during the last hundred years. We have struck oil and discovered new coal and gas deposits in a far greater proportion than we could use during the same period. Still more important, all mineralogical discoveries have included a substantial proportion of *easily* accessible resources [Georgescu-Roegen, 1975, p. 362].

We also seem to forget the fact that fossil fuels (especially oil and coal) are contributions made by animals and plants in vast stretches of land over several thousand million years so that they can guarantee the essential merits of modern industry, i.e., land and time saving, and support EFT2 complex. We must remember that we still depend on land completely in manufacturing as well as in farming. If it were not for fossil fuels such as oil and coal, which provide our civilization with a basis for motive power and transportation, production on a large scale would never be carried out, even though other mineral resources are available in abundance.

We cannot follow the past pattern of civilizations. "The pattern of the past–use up the natural [landbased] resources and move to new land–is no longer an adequate solution. The time has arrived when all peoples must take stock of their resources and plan their future accordingly" [Carter and Dale, 1974, p. 23]. In the United States alone, an estimated 50 million acres are going to erode in the next 25 years. In 1970 the United States was said to have about 400 million acres of cropland [Carter and Dale, 1974]. Even in the most powerful country, the United States, the food safety margin will have grown thin at the end of this century. We should build an economic system on the earth which does not stress land so much in the long run.

Chapter 7

Another View of Development, Ecological Degradation and North-South Trade

7.1 Introduction

Economic growth and advance of science and technology bring positive effects like increased production and consumption but also negative side effects. These negative side effects include: (i) natural resource depletion and environmental degradation such as deforestation, soil erosion, pollution; and (ii) increasing disparity between rich and poor both within and across national borders. The most conspicuous ecological degradation is in Third World nations:

[T]he last thirty years have been the most disastrous in the history of most, if not all, Third World countries. There has been massive deforestation, soil erosion and desertification. The incidence of floods and droughts has increased dramatically as has their destructiveness, population growth has surged, as has urbanization, in particular the development of vast shanty-towns, in which human life has attained a degree of squalor probably unprecedented outside Hitler's concentration camps (Goldsmith 1985: 210).

Ecological degradation is today most catastrophic in Third World countries. Developed countries cannot face the unpleasant fact that the environmental problems in the Third World are also problems for developed countries. One important cause of environmental crisis in the Third World lies in the political and economic structure of North-South trade. Developing countries produce mainly raw materials and monocultural products for export to developed countries. Monocultured lands are agro-ecosystems similar to ecological communities in early stages of ecological succession. In modern agriculture human beings are forced to create the early stages of ecological succession artificially. We favor a simple ecological community. We want fertilizers to have a large effect on productivity. Thus, we try to take advantage of those characteristics of the early stages of succession that we are able to. However, these states are characterized by some troublesome features: (1) the weights of plants per unit of land area are relatively small, hence, we cannot expect large yields during these stages; (2) both flora and fauna are simplified during the early stages. Hence, the number of some special group of herbivora tends to become larger because of favorable conditions for the growth of these herbivora; (3) the early stages of ecological succession are not stable, easily succumbing to disturbances from the environment.

We attempt to increase the weights of plants by the use of fertilizer and the improvement of plant breeding. Then, a special group of herbivora becomes more and more dominant. The frequent occurrence of harmful insects is due in part to the intensive use of chemical elements. In traditional agriculture, matter and energy within a particular area circulated in ways such that little waste matter was produced. In modern agriculture, however, most matter and energy are introduced from outside the land under cultivation. Also, this matter and energy are difficult to circulate productively within the cultivated area, so that waste matter and pollutants flow inside as well as outside the cultivated land, resulting in high risk of long-term land deterioration.

Present North-South trade boosts the risk of land deterioration and accelerates degradation of ecosystems in the Third World. In fact, large-scale land abuse in developing nations results from the current structure of North-South trade. Developing countries interacting with more advanced socioeconomic systems must abandon traditional, mainly subsistence economic systems (Martinez-Alier 1996). Unfortunately, the abandonment of traditional economy is happening very quickly with devastating loss of ecological viability and cultural heritage in the Third World.

This chapter reconsiders the neoclassical economic paradigm of growth through trade and suggests that, in view of sustainability, it is important to acknowledge: (1) the importance of preserving the identity and integrity of economic systems in each region of the world by enlarging as much as possible self-sufficiency and equity of their economic systems assessed at national and regional levels; and (2) the importance of biospheric equilibria as one criterion to be used to regulate world economic activity. Section 2 discusses differences and similarities of past and present ecological degradation. Two types of efficiency are introduced to assess technological changes and the drive toward unsustainability. Section 3 first touches on standard theory of international trade and then presents an entropy theoretical approach to North-South trade issues and three points for promotion of sustainability. Section 4 examines the historical relationship of humans with nature, showing that the ecological crisis is rooted in the extraordinary acceleration of exosomatic mode of human evolution. Dramatic acceleration of economic activity started by the Industrial Revolution has not been accompanied by adequate cultural controls on human development. Cultural, scientific and economic paradigms are much slower to evolve than material processes of production and consumption. Section 5 uses a hierarchy theory to touch on the problem of perception of ecological decline.

7.2 Ecological Degradation and Drive toward Unsustainability

Ancient people felt "[i]ntimacy with nature and sensitivity to its cycles [and they felt] more direct dependence on the natural world" (Hughes 1975). This attitude toward nature dramatically altered when there was a switch from the endosomatic mode of evolution to the exosomatic mode of evolution. "[Man] transgressed the biological evolution by entering into a far faster evolutionary rhythm [exosomatic evolution]—the evolution in which organs are manufactured, instead of being inherited somatically" (Georgescu-Roegen 1986: 249). Dramatic change in the mode of human evolution together with the rise of "Western Materialism" since the seventeenth century led to rapid depletion of mineral resources and fossil fuels (Norgaard 1995: 478) and to serious global environmental damage. In thermodynamic terms, the present situation is characterized by tremendous increase in the rate of entropy generation of modern economies (Mayumi 1992). Presently, annual economic activity consists of transporting and transforming six billion tons of fossil fuels, four billion tons of minerals, wood, etc., and one trillion tons of water. If this situation continues for another five hundred years, even with zero growth rate, waste matter of 5 trillion tons will accumulate in our environment. This quantity is equal to spreading 500 kg of waste matter per square meters all over the United States (Kawamiya 1983: 9). Tremendous speed of matter and energy degradation causes rapid depletion of natural resources and heavy stress on our environment.

To understand better the speed of current matter and energy degradation, it is useful to introduce two types of efficiency. "Type 1 efficiency" is the output/input ratio and does not consider the time required to obtain one unit of output. "Type 2 efficiency" is the output obtained per unit of time (the speed of throughput) and does not consider the amount of input required to obtain one unit of output.

Thermodynamic consideration indicates which type of efficiency is optimized by social and economic systems. A lower input requirement, implied by an increase in "Type 1 efficiency," has beneficial effects on the stability of the boundary conditions. This lower requirement of input is ecologically benign, since it decreases depletion of natural resources and stress on the environment. A higher speed of throughput, implied by increase in "Type 2 efficiency," has beneficial effects on the ability to maintain more complexity and hierarchy in society. This higher speed is benign to the economic process, since it can be related to a higher level of production and consumption of goods and services.

"Type 1 efficiency" is related to the scale of the system (e.g., the size of economic system is compared with ecosystems having activities of production and consumption). Therefore, "Type 1 efficiency" should be considered more carefully when "natural capital" becomes a limiting factor in economic growth (Daly 1995). In thermodynamic terms, "Type 1 efficiency" is concerned with the energy throughput needed for a particular structure and/or function in society. Clearly, all living systems and social and economic systems are dissipative (Glansdorff and Prigogine 1971; Nicolis and Prigogine 1977). Systems must be open and exchange flows of energy and matter with their environment. The higher the "Type 1 efficiency," ceteris paribus the lower the quantity of input taken from the environment (less depletion of natural resources) and the less waste released into the environment (less environmental pollution).

On the other hand, lowering the flow of throughput can imply lowering of the complexity that can be sustained within the system (for example, a lower standard of living in economic systems) and an increased risk of collapse in case of perturbations. Consequently, even in ecological theory, increase in "Type 2 efficiency" in energy terms has been proposed as one of the general principles of evolution for self-organizing systems, such as Lotka's maximum energy flux (Lotka 1956: 357).

It is the balancing of these two types of efficiency that generates the formation of hierarchical structures within ecological systems (Giampietro 1994a). Unfortunately, when short-term economic objective is aimed only at growth of GDP, the main concern is increase in "Type 2 efficiency" (the speed of throughput in terms of production and consumption);

there is little concern with "Type 1 efficiency" (less depletion of natural resources and less environmental pollution). Hence, the modern economies may be said to exhibit "Type 2 efficiency fetishism" (Mayumi 1991). The definition of value is generated by the system itself such as when humans are concerned with their standard of living. Such definition of value ignores long-term environmental effects, especially when costs and benefits for the environment are not easy to define (Giampietro 1994a). The final result of the optimization is a myopic rule: the higher the speed of throughput (e.g., GDP), the better.

In The Coal Question of 1865, William Stanley Jevons discussed the trend of future coal consumption and argued against contemporary predictions about future reduction in the consumption of coal due to technological progress. He explained an intrinsic human addiction to the comfort offered by exosomatic instruments related to "Type 2 efficiency fetishism": increase in efficiency in using a resource leads to increased use of that resource rather than to a reduction in its use. This can be termed "Jevons' paradox" (Jevons1990).

"Jevons' paradox" proves true not only regarding demand for coal and other fossil energy resources. Doubling the efficiency of food production per hectare over the last fifty years (due to the Green Revolution) did not solve the problem of hunger. Increase in efficiency worsened hunger because of the resulting increase in population (Giampietro 1994b). In the same way, building new roads did not solve the traffic problem because increasing use of personal vehicles was encouraged (Newman 1991). More energy efficient automobiles resulted from rising oil prices, but Americans increased leisure driving (Cherfas 1991). The number of miles driven increased and car performance improved. Now, Americans are driving bigger and more sophisticated vehicles such as mini-vans, pick-up trucks and four-wheel drive vehicles. Similarly, technological improvement in efficiency led to bigger refrigerators (Khazzoom 1987).

In economic terms, increase in supply combined with higher efficiency boosts demand. Technological improvement in the efficiency of a process (e.g., increase in miles traveled per unit of gasoline) represents improvement in intensive variables. However, when technological improvement occurs, there is usually room for expansion in the size of the system (e.g., more people make more use of their cars). Expansion in the size of the system represents a change in extensive variables, the dimension of the process. Unless there is a comprehensive analysis of change induced by technological improvement, there is possible misunderstanding caused by counter-intuitive behavior of evolving complex systems.

The limited ability of controlling energy and matter flows prevented early tool-making societies from encountering the "Jevons' paradox" or "Type 2 efficiency fetishism." Still, pre-industrial societies faced environmental decline in a form analogous to modern environmental decline, the only important difference being the scale of such predicament. Earlier civilizations caused stress on natural ecosystems, but were unable to disturb, on a global scale, bio-geochemical cycles such as water and nitrogen cycles or the composition of the atmosphere such as accumulation of green-house gases. Nevertheless, study of the past can teach us how to formulate better policy for sustainable use of natural resources and environmental management.

Until the transition to agricultural society about 10,000 years ago, "a combination of gathering foodstuffs and hunting animals" had been a basic form of subsistence with little damage to the environment in part due to "a number of accepted social customs" (Ponting 1991). This transition to agriculture made possible the emergence of complex and hierarchical societies. In fact, agriculture made possible increase in population density and accumulation of sufficient surpluses to sustain armies and administrators (Tainter 1988).

As in the past, despite technological advance, modern civilization still depends on the ecological viability of agricultural base. More than 98

As in ancient times, "it is in the area distant from the centers of powers ...... the first indicators of ecological catastrophe become apparent" (Weiskel 1989). Areas remote from power are characterized by weaker economies and often by more fragile ecosystems. In those remote areas, environmental degradation is an early warning signal indicating lack of respect for the stability of biospheric equilibria. Even in the 1990s, a major reason for conflict between Bangladesh and India has been the dispute over land and water, crucial renewable resources (Homer-Dixon et al. 1993). Arguments over land and water cause many local conflicts throughout the Third World.

7.3 North-South Trade and Ecological Crisis

The character of ancient trade is still debated by anthropologists. For example, K. Polanyi emphasizes institutionalized reciprocity and redistribution. R. McC. Adams reevaluates innovative, risk-taking, profit-motivated behavior of traders (Adams 1992). Free trade dogma based on international specialization supported by comparative advantage is a cornerstone of standard economics. It is used to argue, e.g. that England established world supremacy

through overseas commerce. Standard economics teaches that "free trade in goods between different regions is always to the advantage of each trading country, and therefore the best arrangement from the point of view of the welfare of the trading world as a whole, as well as of each part of the world taken separately" (Kaldor 1980: 85). Thus, Friedrich List's infant industry argument is an exception to the standard theory (ROpke 1994). The traditional theory of free trade is refined theoretically in Heckscher-Ohlin theory and the Stolper-Samuelson theorem (Kaldor 1980; Ropke 1994).

The General Agreement on Tariffs and Trade (GATT) shows a fundamental commitment to unrestricted trade based on the free trade dogma of standard economics. Three central principles of the GATT system provide the framework for international trade: (1) non-discrimination; (2) reciprocity; (3) general prohibition of non-tariff trade measures (Watkins 1992). But, N. Kaldor states (1980) that standard trade theory "rests on a number of artificial assumptions." Free trade is subject to actual conditions and the case of increasing returns in the field of manufactured goods led to concentration of industry in developed countries—a polarization process. This polarization resulted in the present world situation in which "differences in wealth and living standards became considerably larger" (Kaldor 1980). Developing Arthur Lewis' argument, Graciera Chichilnisky (1986) also shows that the policy of export expansion in the South leads to lower terms of trade and to lower export revenues in the South. Several important issues, not properly treated within the traditional framework of standard theory including "forced specialization" and "absolute advantage" of developed countries (Daly 1993; ROpke 1994), are not discussed here. Our concern is rather biophysical and sustainable issues resulting mainly from North-South trade.

Basically, North-South trade may be considered with the following entropy theoretical approach. If a system absorbs low entropy from its environment and releases high entropy of matter and heat, the system can maintain a quasi-steady state. Suppose we divide this system into A and B subsystems. If subsystem A extracts low entropy resources from subsystem B and releases high entropy waste into its environment including B, entropy saturation in A can be avoided, at least locally and temporarily, at the expense of B. There is some "freedom" for subsystems to share total entropy production in the whole system and exchange entropy with their environment. Thus, to picture the world economy, we have to specify subsystem relationships.

The case of Japan's trade with the rest of the world reinforces this theoretical approach. Japan imports some 80 million tons of forest and agricultural resources such as timber, fodder and foods. Since about 500 tons of water is usually required to produce one ton of carbohydrate, in a sense, Japan imports 40 billion tons of water resources, more than the water required in all Japanese cities (Kawamiya 1983: 23). Thus, Japan exploits low entropy resources from exporting countries. When a country subsystem (e.g., USA) produces monocultural products for Japan, relying on intensive use of oil-based inputs, that country subsystem experiences as a side effect increased deterioration of its land (Pimentel et al. 1995). Recall that monocultural agricultural systems are based on an excessive simplification of agro-ecosystems which imitate early stages of ecological succession. When a country subsystem (e.g., a timber exporter in Southern Asia) cuts and exports forest resources at competitive prices for Japan, that country subsystem experiences as a side effect loss of habitats and biodiversity, soil erosion and other environmental damage (Farber 1995).

Without transfer of capital and trade, developed countries would accelerate their own environmental crisis. With autarky, high standard of living coupled with high population density in developed countries would encounter environmental constraints. For example, the need to mechanize agriculture and rely heavily on petrochemicals for food production could exacerbate even more the ecological predicament of developed countries. As R. U. Ayres (1995) correctly observes, with the current rapid international capital movement, developed countries such as Japan export part of the production process as well as export industrial wastes to developing countries. In this way, developed countries escape the negative environmental side effects and high entropy generation (see J. Martinez-Alier (1996) for a splendid account of NAFTA issues). Liebig's criticism of land abuse by excessive export of crop yields is relevant:

Can it be imagined that any country, however rich and fertile, with a flourishing commerce, which for centuries exports its produce in the shape of grain and cattle, will maintain its fertility, if the same commerce does not restore, in some forms of manure, those elements which have been removed from the soil, and which cannot be replaced by the atmosphere? (Liebig 1843: 112).

Unfortunately, no GATT articles impose trade restrictions for biophysical and sustainability reasons. In addition, GATT outlaws "use of trade controls, such as import tariffs and quotas, designed to prevent cheap food imports" from developed countries into developing countries (Watkins 1992: 69). A difficult situation is created:

In the North, the energy intensive production systems which have sustained economic growth and trade expansion have contributed to industrial pollution, global warming and

ozone depletion. These problems now constitute a profound threat to the future welfare of the citizens of developed and developing countries alike. In the South, the lethal combination of debt-service obligations and falling commodity prices has deepened a more immediate ecological crisis. Forced to export an ever increasing volume of commodities to compensate for declining prices, many countries, as the 1985 Brundtland Report noted, have over-exploited fragile ecological bases, sacrificing long-term sustainability for short-term trade gains (Watkins 1992: 98–99).

Most devastated is Africa, which imported "two-fifths of its food supply and [where] about a third of its people depended wholly or partly on imported food" in 1985, resulting in complete loss of self-sufficiency (cited in Weikel 1989). The only choice appears to be a global reallocation of existing wealth, if aggregate growth beyond carrying capacity is unsustainable in the long-run and the poor are harmed more by both resource depletion and environmental decline (Daly 1992; Colby 1991). However, the reality is: "a political attempt to move the ecological agenda away from the issue of Raubwirtschaft by the wealthy. Thus, in the wake of the Brundtland Report, the study of poverty as a cause of environmental degradation has become more fashionable than the study of wealth as the main human threat to the environment" (Martinez-Alier 1991: 123).

Modern agriculture based on Green Revolution technology is not a solution for the famine problem in the Third World, particularly in tropical areas (Norgaard 1981). Green Revolution technology depends on massive petro-chemical products, imposing a financial burden on Third World governments and creating a wide range of health hazards. Due to possible oil shortage, development schemes based on Green Revolution technology can probably not be sustained indefinitely (Weiskel 1989). Yet Third World nations faced with short-term food shortage must rely on Green Revolution technology in order to avoid the Malthusian population growth trap, even though such reliance is not sustainable in the long-term (Giampietro and Bukkens 1992). Three points deserve attention in promoting sustainability in developing countries:

(1) It is necessary to empower local communities with the principle of distributional equity in the decision making process, avoiding so called "top-down" decision making process. In developing countries, traditional socioeconomic systems are affected by a powerful drive toward dramatic social change. This drive is generated by interaction with socioeconomic systems of more highly developed societies. Huge disparities in the standard of living between developed and developing nations generate friction that pushes less developed societies to

rapid change of their internal organization. Socioeconomic systems in developing countries must adapt as quickly as possible to the new set of risks and opportunities. Obviously, more privileged social groups are first to be involved in this modernization process. Later, further friction within the socioeconomic system occurs at the national level. Social changes tend to pass from upper class to lower class.

Through this social change, expansion of the way of thinking of developed world threatens diversity of cultural experiences, values, knowledge, and alternative economic paradigms. The developed world is everywhere propagating and amplifying its value systems. Ironically, the loss of cultural diversity occurs precisely when developed countries themselves discover that their own value systems might not achieve sustainability.

Therefore, it is vital to preserve respect for different cultural identities. Actions to promote sustainable development should enhance the preservation of socioeconomic systems that can counter the strong driving force toward unsustainability.

To repeat, an effort must be made to empower local communities in the decision making process. Approaches based on grassroots development schemes together with help from NGOs deserve top priority, allowing local people to use indigenous farming knowledge and inherent natural resource management skills (Altieri and Masero 1993). Such approaches, implemented at local levels by NGOs, can increase pressure on governments of both developed and developing countries, leading to more altruism in trade negotiations (ROpke 1994).

To implement a development project requires resolution of "discount rate dilemma": "natural resources are most likely to be over-exploited at high discount rates than at low ones, whereas low discount rates discriminate against projects with an environmental dimension that have a long gestation period" (Barbier and Markandya 1990: 668).

There are also additional issues of environmental risk and irreversible nature of impacts (Markandya andPearce 1988; Barbier and Markandya 1990).

(2) It is necessary to reorient the world economy toward increased local self-sufficiency and social equity defined and assessed at the level of national and regional economic systems. This implies abandoning a myopic view of growth through unlimited trade. John Gowdy aptly remarks that "a regionally based economy is not a sufficient condition for sustainability" (Gowdy 1995: 494). But an effort must be made to increase self-sufficiency and social equity of economic systems at national or regional levels as a prerequisite for sustainability. There are several reasons why:

(i) Reducing the space-time scale for making decisions about sustainability makes it easier to involve local people in the decision-making process and to increase the responsibility of local communities for resources management (note 1) (ROpke 1994). Except when resources available to a community are well below some threshold level, decisions related to sustainability should be made as close as possible to the local people and with participation of all major stake-holders. This would allow local people to utilize their own indigenous knowledge in the decision making process;

(ii) Internalizing most external services on which economic systems rely makes it easier for the system to respond quickly to intricate changes and the variety of signals from surrounding ecosystems (Norgaard 1981);

(iii) The goal of harmonizing energy and material circulation with local ecosystems is achievable. However, the space-time range of production and consumption in the socioeconomic system should be similar to the space-time range of the material cycles occurring in local ecosystems. Energy expenditures for transportation from distant ecosystems can be justified only if there is no sufficient access to energy resources in the area. So, it is necessary to assess directly possible negative effects of increased trade on the stability of the biosphere and on the integrity of local socioeconomic systems.

(3) It is necessary to amend GATT's articles to promote sustainability on a global level by reducing the impact on the biosphere caused by rapid expansion of world economy. To enhance the integrity of national and regional economies and the degree of self-sufficiency and equity at the national and regional level, GATT's articles need to be amended (Watkins 1992).

(i) restrictions on the volume of trade of defined commodities should be considered in view of environmental protection;

(ii) developing countries should have subsidies and "ad hoc" regulation imposing a minimum level of processing of natural resources before export;

(iii) tariff systems should retain as much as possible of the value in developing countries to slow the trend of excessive exploitation of natural resources (e.g., tropical timber).

7.4 The Relation of Humans to Nature

Natural systems tend to evolve by balancing the two goals of (i) increasing their complexity (the activity of their process of self-organization); and (ii) increasing their stability by harmonizing internal activities with environmental boundary conditions (Odum 1971). On the other hand, modern people seem more concerned with only the first of these two goals ("Type 2 efficiency fetishism").

Sudden departure from sustainable pattern of socioeconomic activities may be due to a progressive change in perception of the relation that humans should have to nature. That is to say, an excessive priority on industrial activities is based on a world view that perceives humans, nature and environment, as separate. Those parts of nature useful for human activity (e.g., parts that provide raw materials for economic consumption) are viewed as resources and therefore as belonging to economy, and not belonging to nature.

According to Lynn White (1967), the first clear change in the perception of humans and nature occurred in the latter 7th century A. D., with the introduction of new technology for plowing. At that moment, the ability of socioeconomic systems to generate surplus for self-organization changed them from being part of nature to being exploiters of nature. The advent of monotheistic religions like Judaism, Christianity and Islam in the Mediterranean basin—the heart of western civilization—accentuated such an anthropocentric view. Humans viewed themselves as "special" creatures of God, distinct from the environment in which they operate. This view, sharply contrasting with pagan animism, legitimized exploitation of nature for improvement of human life. This anthropocentric view of technical development was further reinforced by the Baconian creed: "scientific knowledge means technological power over nature" (White 1967: 1203). Marx commented on changes in human view of nature:

[F]or the first time, nature becomes purely an object for humankind, purely a matter of utility; ceases to be recognized as a power for itself; and the theoretical discovery of its autonomous laws appears merely as a ruse so as to subjugate it under human needs, whether as an object of consumption or as a means of production. In accord with this tendency, capital drives beyond national barriers and prejudices as much as beyond nature worship, as well as all traditional, confined, complacent, encrusted satisfactions of present needs, and reproductions of old ways of life (Marx 1973: 410).

Western hedonism is partly responsible for the modern ecological crisis, since "for more complex forms of society a dynamic equilibrium is stabilized only at a high level of energy [and mineral resources] expenditure per capita" (Giampietro and Bukkens 1992: 45). Hence, the current ecological crisis has been generated not only by changes in the perception of the relation of humans to nature, but also by sudden access to immense stocks of fossil energy made possible by the Industrial Revolution. As Georgescu-Roegen stated:

The fossil-fuels bonanza of the past century has raised the exosomatic production to a miraculous level in the developed nations, and somewhat indirectly a little in the rest of the world as well" (italics added) (Georgescu-Roegen 1986: 273).

7.5 Conclusion: Perception, Hierarchy, and Ethical Aspects of Environmental Degradation

According to Georgescu-Roegen (1977), the exosomatic mode of human evolution brought about three predicaments: (1) There is a "ratchet effect" that implies Malthusian instability in exosomatic consumption. Addiction to comfort offered by exosomatic instruments and existing gradients of wealth in socioeconomic systems imply that technological improvements will always be used to increase material standard of living. Technological improvement is not used to reduce the pressure on ecosystems and resources; (2) There are social conflicts which are caused by positive feed-back loops in the exosomatic compartment. These feed-back loops generate imbalances in wealth distribution within socioeconomic systems faster than institutional change can cope with such imbalances; (3) There are gradients of development among countries and world regions. In fact, nonlinear behavior in the process of development based on autocatalytic loops of energy production implies that historical accidents, differences in natural resource allocation, geographical characteristics give to certain regions an initial advantage in the process of development. Initial advantages are then amplified during the process, resulting in ever increasing gaps between developed and developing countries if corrective policies are not applied. Evolving systems follow the law, "the survival of the first," identified by Hopf (1988). Through stimulated trade developed countries with favorable terms of trade can actually increase rather than decrease the existing gap.

The three human predicaments identified by Georgescu-Roegen are typified in North-South trade issues. Environmental impacts caused by local people in developing countries are relatively low compared to those caused by developed countries. People faced with aggravated environmental conditions are forced to exploit immediate economic benefits at the expense of long-term sustainability of livelihood. Barbier and Markandya (1990: 668) write: "one of the consequences of deforestation and the depletion of fuelwood supplies is that it forces poor households to divert dung for use as fuel rather than for fertilizer. The 'present value' of the dung as fuel is higher than its value as a oil nutrient."

The basic difficulty in coping with ecological decline lies in the problem of perception.

For example, deforestation of tropical areas affects both local weather and global climatic conditions. At present, the Third World suffers most ecological degradation. But problems in the Third World are problems of the developed world. The present situation in West Africa mirrors a coming anarchy that will soon confront the developed countries as well (Kaplan 1994).

Giampiertro and Bukkens state the essential point correctly:

The separation between the developed and developing worlds is mainly due to the perception/description of Western socioeconomic culture; in biophysical terms these two worlds are linked together by the existence of a hierarchical structure. When dealing with a hierarchical system, the essential ethical problem is the correct definition of the boundaries and therefore of the goals of the system. This definition, together with the knowledge of the constraints operating in the system, may then allow discussion of the mechanism with which decisions should be made (Giampietro and Bukkens 1992: 49).

Each level of hierarchy—individual, societal (local, national and international) and biophysical—must be analyzed scientifically and ethically in relation to the other levels, allowing us to assess overall issues of sustainable development.

Notes

1. The Indian village is characterized by an access system, called nistar different from the notion of a commons. In this system the masses who controlled no land still had access to the residual—to road sides, to ditchbanks, and to other areas too poor or too isolated for effective control and cultivation. For a case study of nistar system in this direction, see (Bromley and Chapagain 1984).

Acknowledgments

We would like to thank two anonymous referees for detailed comments on a previous version of this chapter and for stylistic advice. We have benefited from Prof. John B. Davis's editorial help and stylistic advice. We also express our sincere thanks to Mr. Don Sturge for his encouragement to improve the English of the chapter. We alone are responsible for any errors and misconceptions.

Chapter 8

Dealing with integrated assessments of sustainability trade-offs: complexity and its epistemological implications

8.1 Dealing with the complexity of reality and its representation

"The ontological relationship between simple systems (= all formal systems that are logically consistent) and complex systems (= all natural systems) is unformalizable in any absolute sense. The only true type of simple systems is the class of conceptual systems that we as humans have developed to make sense of the world. All natural systems are complex in that there is stratification of the system's reality into levels. Here, we mean that levels have the property that all relevant interaction occurs within the level. The gaps are classed epistemic gaps. Evidence for the gaps are in the form of pi-numbers such as the constants in physics. Some complex (natural) systems allow a very useful and close matching to simple formalisms. Most natural systems do not". Paul Prueitt (1999).

This quote of Prueitt is a useful starting point for discussing of the epistemological implications of complexity. Here the concept of complexity is used according to the theoretical framework proposed by Robert Rosen (1977; 1985; 1991). In Rosen's view complexity implies the impossibility to fully describe the behaviour of a given system by using a single model (or a finite set of reducible models) of it. This impossibility derives from the existence of logically independent ways of modeling the behaviour of any adaptive nested hierarchicalsystem. In turn this is determined by the existence of: (i) different relevant space-time differentials that can (and should) be considered to describe and explain such a behaviour, and (ii) various possible relevant qualities - linked to the behaviour of interest - which require the adoption of encoding variables belonging to non-equivalent descriptive domains. Put it in another way, the usefulness of any scientific representation of a complex system cannot be defined 'a priori', without considering the goal for which this representation has been generated. As a general principle we can say that by increasing the number of reciprocally irreducible models used in parallel for mapping its behaviour we can increase the richness of any scientific representation. The good news implied by this concept is that: (1) it is often possible to catch and simulate relevant aspects of the behavior of a complex system by using an incomplete but consistent knowledge of it. The bad news is that: (2) any "perspective" on a complex system (comprehensive and consistent knowledge - interpretation of the system,such as a modeling relation) will see some of the elements and/or relevant relations in the system, but at the same time miss others. That is, scientific models of complex systems (even if extremely complicated) imply the unavoidable generation of errors in the resulting models (due to the unavoidable neglecting of some relevant relations referring to events - or patterns - detectable only on distinct space-time scales or in different systems of encoding). In more technical jargon Rosen refers to this fact as the unavoidable existence of bifurcations in any mapping of complex systems (Rosen, 1985; 1991).

We can reduce the effect of these errors by using in parallel various mutually irreducible "perspectives" (by generating "mosaic effects" in our scientific representation - Prueitt, 1998). However, this solution: (i) does not solve completely the problem; (ii) introduces another source of arbitrarity in the resulting analysis. In fact, the very concept of complexity implies that a virtually infinite number of mutually irreducible "perspectives" (modeling relations) can (and depending on the objective of the analysis) should be considered to fully describe the behaviour of a "real" system. Therefore, any selection of a limited set of mutually irreducible perspectives to be used in an integrate assessment (= a multicriteria description able to generate a mosaic effect and based on a finite set of criteria) can only be based on a subjective decision about the relative relevance of the selected set of perspectives (why should we limit the analysis only to the selected set of criteria ?). For example, when selecting an airplane pilot, it is her/his zodiacal sign (or her/his religious belief) one of the relevant criteria to be considered ? Probably a commercial airline would definitely exclude these two criteria from its screening process. On the other hand, it could very well be that an eccentric millionaire (or an integralist religious group) when looking for a pilot for her/his/their private jet could decide to include one (or both) of these criteria among the relevant pieces of information to be considered in the process of selection.

Everytime we are dealing with a decision about the relevance or irrelevance of the set of criteria to be considered in the integrated assessment we cannot expect to find general algorithms which will make possible to escape "value judgments". The irreducibility of possible perspectives that should be considered as relevant when structuring the description of a natural system (= determining the selection of variables used in the modeling relation) implies that there is a "logical independence" among the relative "qualities" of the system. That is, it is only after deciding (and how ?) the set of relevant qualities to be considered in the scientific analysis which is possible to discuss about encoding variables and consequently about models to be developed.

This fact has also another important consequence. When dealing with non-equivalent, alternative models which can be used to represent the behaviour of a given complex system, we cannot check or compare their "validity" by focusing only on a single aspect of system behaviour at the time. The "validity" of a given model is not simply related to its ability to make good simulations and consequently predictions. Even when the predictions of a model are supported by experimental evidence in relation to a certain quality, this does not guarantee that: (i) such a quality is relevant for the solution of the problem; (ii) the modeling relation valid at the moment under a given "ceteris paribus" hypothesis will retain its ability to model the same system again in the future when some conditions and characteristics (external and/or internal to the system) will change. We can remember here the example of the broken analogic clock that happens to indicate the right time twice a day versus the clock which looses a minute every day that will never indicate the right time in the next year (here being able to be perfectly right "sometimes" do not coincide with the ability of being useful); and last but not least (iii) nobody cheated in collecting the data used to validate the model. This observation carries a completely new domain of quality controls to be added to the evaluation process.

In this section, we presented the "core" of the argument in a very condensed form. We provide in the next two sections a few practical examples which touch upon the same points but using a more "relaxed" narrative. A final section of conclusions, hopefully, should provide a list of points to be driven home from these examples.

Nested hierarchical systems require the use of non-equivalent descriptive domains

All natural systems of interest for sustainability (e.g. biological systems and human systems when analyzed at different levels of organization and scales above the molecular one) are "dissipative systems" (Glansdorf, P., and Prigogine, I.; 1971; Nicolis, G., and Prigogine, I. 1977; Prigogine, I., and Stengers, I. 1981). That is they are self-organizing, open systems, operating away from thermodynamic equilibrium. In practical terms, in order to remain alive they have to be able to stabilize their own metabolism within their given context (e.g. living systems have to make available to themselves an adequate amount of food, economic systems have to make available to themselves an adequate amount of added value). Because of this forced interaction with their context they are necessarily open-systems and therefore "becoming systems" (Prigogine, 1978). This implies that in turn they: (i) are operating in parallel on several hierarchical levels (= various patterns of self-organization can be detected only by adopting different space-time windows of observation) and (ii) will change their identity in time (but at different speeds) over their various levels of organization. Put it in another way, the very concept of self-organization in dissipative systems (the essence of living and evolving systems) is deeply linked to the idea of: (i) parallel levels of organization on different space-time scales, and (ii) evolution.

Actually this view has been suggested as the very definition of hierarchical systems by O' Neill (1989): a dissipative system is hierarchical when it operates on multiple spatio-temporal scales - that is when different process rates are found in the system. Another useful definition of hierarchical systems refers to another important point for our discussion: "systems are hierarchical when they are analyzable into successive sets of subsystems (Simon, 1962; p. 468) - in this case we can consider them as near-decomposable. Another definition of hierarchical systems related to the topic of this section is: "a system is hierarchical when alternative methods of description exists for the same system" (Whyte et al. 1969). Put it in another way, the existence of different levels and scales at which a hierarchical system can be analayzed implies the unavoidable existence of non-equivalent descriptions of it.

For example, we can describe a human being at the microscopic level to study the process of digestion of nutrients within her/his body. When we look at a human being at the scale related to the level of an intestine cell we can even take picture of it with a microscope (Fig. 1a). However, this type of description is not compatible with the description which

would be required to catch the quality "face" of the same human being - e.g. needed when applying for a driving licence (Fig. 1b). No matter how many pictures we will take with a microscope of a defined human being, the type of "pattern recognition" of that person which refers to the cell level (obtained at its relative space-time window with a microscope - Fig. 1a) is not equivalent to the description of human beings ("pattern recognition") required to catch the quality "face" (Fig. 1b). The ability to detect the identity of the face of a given person, in fact, is an "emergent property" linked to a description which is in turn linked to a defined space-time window. Not only the face cannot be detected using a description linked to a very small space-time window (the scale good for looking at individual cells), but also when using a description linked to a larger scale (that good for looking at the social relation of our system - Fig. 1c). It should be noted here, however, that the term "emergent property" of the system, used earlier for defining the pattern recognition of the face can be misleading. The emergent property, in fact does not refer to the analyzed system it-self but rather to the need of getting a **pattern recognition in relation to an assigned goal for the description**. When dealing with a system organized hierarchically it does not make sense to speak of pattern recognition "per se". In fact, there is a virtually infinite number of patterns overlapping across scales waiting for being recognized within every self-organizing adaptive hierarchical system (such as living and human-made systems). We will take a picture able to detect a face when we are looking for an input for a driving licence (Fig. 1b) otherwise we will take a picture able to detect a synusite when we are looking for an input in a medical investigation (Fig. 1d). In the reality, the 4 recognizable patterns shown in Fig. 1 are all present in parallel at any time overlapping. It is our choice of looking at the system in a way rather than another that will focus on just one of them rather than the others.

Human societies and ecosystems are generated by processes operating on several hierarchical levels over a cascade of different scales. Therefore, they are perfect examples of dissipative hierarchical systems that require a lot of non-equivalent descriptions to be used in parallel in order to analyze their relevant features in relation to sustainability (Giampietro 1994a; 1994b; Giampietro et al. 1997; Giampietro and Pastore, 1999). Using the epistemological rationale proposed by Kampis (1991) to define a system as "the domain of reality delimited by interactions of interest" (pag. 70), we can introduce here the concept of descriptive domain in relation to the analysis of a system organized on nested hierarchical levels. A descriptive domain is the domain of reality resulting from an arbitrary decision to describe the system in relation to: (i) a defined set of encoding variables (to catch the selected relevant qualities); (ii) a defined space-time horizon determined by the resulting relevant space-time differential (= the differentials needed to detect and characterize the behaviour of interest over a particular hierarchical level).

To clarify this concept we can use again the 4 views of the same system given in Fig. 1 using a metaphor to better explore the relation between analysis linked to sustainability and the need of using non-equivalent descriptive domains. Let's imagine that the 4 non-equivalent descriptions presented in Fig. 1 were referring to a country (e.g. the Netherlands) rather than to a person. In this case, we can easily see how the parallel use of different descriptive domains is required to obtain an integrated analysis of its sustainability. For example, by looking at socio-economic indicators of development (Fig. 1b) we "see" this country as a beautiful woman (i.e. satisficing levels of GNP, good indicators of equity and social progress). This is good to keep low the stress on social processes. However, if we look at the same system (same boundary), but using different encoding variables (e.g. biophysical variables) - Fig. 1d in the metaphor - we can see the existence of a few problems not detected by the previous selection of variables (i.e. a synusite and a few dental troubles). In the metaphor this picture can be intepreted as an assessment of accumulation of excess of nitrogen in the water table, growing pollution in the environment, excessive dependency on fossil energy and imported resources for its agricultural sector. This is bad when considering the biophysical dimension of sustainability. Comparing Fig. 1b and Fig. 1d we can see that even maintaining the same physical boundary for the system (looking at the same head) a different selection of encoding variables can generate a different assessment of the performance of the system. Things become much more difficult when we decide to use other assessments of performance which must be referred to descriptive domains based on the use of different space-time scales. For example, an analysis related to lower levels components of the system (= which require for their description a smaller space-time relevant differential) - Fig. 1a. In the Dutch metaphor, this could be an analysis of technical coefficients (e.g. input/output) of individual economic activities. Clearly, this knowledge is crucial to determine the viability and sustainability of the whole system (= the possiblity to improve or to adjust the overall performance of Dutch economic process if and when changes are required). In the same way, an analysis of the relations of the system with its larger context can imply the need of considering a descriptive domain based on larger scale pattern recognition (Fig. 1c). In the Dutch metaphor this could be an analysis of institutional settings, historical entailments, or cultural constraints over possible evolutionary trajectories.

In conclusion, when dealing with the sustainability of complex adaptive systems the existence of irreducible "relevant" behaviours expressed in parallel over various relevant space-time differentials implies the need of using in parallel different descriptive domains. This in turn implies that: (i) it is impossible for practical reason to handle the virtually infinite amount of information which would be required to describe in this way the sustainability problems; (ii) it is impossible for theoretical considerations to collapse the complexity of an adaptive system organized over several relevant hierarchical levels into a simple model based on a single formal inferential system (= it is impossible to reduce into a single descritpive domain these non-equivalent models).

Non-equivalent descriptive domains entail the existence of legitimate contrasting scientific truths (or legitimate non-equivalent "structurings" of the same problem)

The intriguing definition of complexity for a system given by Rosen (1977 - p. 229) focusses on the fact that "complexity" is a property of the appraisal process rather than a property inherent to the system: "a complex system is one which allows us to discern many subsystems . . . (a subsystem is the description of the system determined by a particular choice of mapping only a certain set of its qualities/properties) . . . **depending entirely on how we choose to interact with the system**" (emphasis is our).

That is, the concept of complexity is attributed to the representation we are adopting of a natural system and not to the natural system itself. This means also that the attribute of complexity is generated by the existence of different relevant dimensions (perspectives that can not be all mapped by the same system of encoding) of our possible relations (potential interactions) with the natural system. A stone can be a simple system for a person kicking it when walking and an extremely complex system for a geologist examining it during an investigation of a mineral site (Rosen, 1977).

Three examples are now given before discussing the implications of this point:

Example 1 - contrasting but legitimate scientific assessments about the orientation of the coastal line of Maine

In a famous article, Mandelbrot (1967) makes the point that it is not possible to define the length of the coastal line of Britain, if we do not first define the scale of the map we will use for our calculations. The smaller the scale (the more detailed the map) the longer will result the length of the same segment of coast. The example provided below is based on Mandelbrot idea and wants to prove that the description of multilevel hierarchical systems necessarily generate legitimate but contrasting scientific assessments.

Imagine now that we need to define the orientation of a tract of shore of Maine. According to Fig. 2a we can safely state that Maine is located on the East coast of the USA. We can imagine an experiment to prove it [= calling 500 Maine resident randomly selected on a phone book from London and Los Angeles at a given day-time and ask them what time is it. Calculating the time difference and using a globe including the representation of time zones we can safely state that Main is on the East cost of the USA].

However, if we analyze the system at a lower hierarchical level, for example the County level, we find that Lincoln County, which is in Maine, has its coastal line directed toward the south (Fig. 2b). Lets imagine that someone who is preparing computerized maps of Maine by using satellite images actually makes such a statement, when describing the orientation of the coast of Lincoln County, on a scientific journal. We are now within a scientific fight, there are scientists who have proved that Maine has its coast oriented toward East (with the phone book experiment) and others that says that the coast is oriented toward South (with the computer elaboration of satellite pictures).

Scientific controversies tend to attract scientists from other field, therefore we will sooner or later find other scientists willing to have a look to this problem from their own perspective. So the controversy can get the attention of scientists operating with encoding variables and descriptive domain referring to a smaller scale. Another reduction of hierarchical level (Fig. 2c) shows that the village of Colonial Pemaquid, in Lincoln County, in Maine, has actually its coastal line facing west. Also in this case we can easily "scientifically prove" this fact by studying the lay-out of the houses (again a random sample of a few hundred houses would do it. However, since the issue is controversial, and in Pemaquid it is not possile to get all these houses, we will have to work on a larger sample - studying the differences found on the trunk of at least 1,000 trees). It should be clear to the reader, at this point, that this new scientific inquiry performed by a different type of scientists operating within a different academic discipline (using a representation of the coastline referring to a different scale) can only add confusion to the controversial issue rather than clarifying it.

In fact, the process of changing scales can go on for ever. In out hypothetical growing scientific debate on the orientation of the coastal line of Maine it is unavoidable (even in our imaginated chain of events) to get into the step of the "common sense" approach: "I don't believe all these scientists using their sophisticated models and statistical analyses for assessing the thruth, I believe only what I see . . .". That is, it is almost unavoidable that some common sense scientist will therefore coming out proposing a "down to the Earth" approach. He will go on a particular beach in Colonial Pemaquid and put her/his feet into the water perpendicular to the water front holding a compass in her/his hands in order to "see" what the "real" orientation is. If she/he does it on Polly Beach - Fig. 1d - she/he will find that actually all the others are wrong. He is the only one that see the thruth, "Maine" has its shore oriented toward North !

This example shows how the hierarchical structure of a system can generate contrasting assessments that can resist scientific testing (unless a carefull definition of the "terms" used in scientific statements is performed in relation to the hierarchical structure of the system). Probably, this explain why reductionistic scientists do not like getting into theoretical discussions about foundations of their respective disciplines. Geographical connotations (as representative of the largclass of fractal objects - Mandelbrot, 1967) are entities that change their identity according to the particular space scales at which they are described. These scales in turn depend on the hierarchical level chosen to describe the system. If we do not carefully acknowledge this process, we may end up with scientifically correct but misleading assessments. For example, the assessment that Maine is on the East coast can be misleading for a person interested in buying a house in Colonial Pemaquid with a porch facing the sun rising from the sea. At the same time this it is the right information for the same person to determine the time difference between Los Angeles and Colonial Pemaquid (when making a phone call). When the system under investigation is operating on more spatio- temporal scales, it is important to understand the whole hierarchical structure of the system, before relying on indications from scientists describing the system at one particular level. It is fundamental to define where we stand with our definition and how the information obtained by adopting a particular description integrates with the views resulting from the adoption of different spatiotemporal scales

Example 2: contrasting but legitimate policy reccomendations based on sound scientific analyses

A list of 6 policy suggestions presented by different panellists at a conference on the Sustainability of World Food Security is given in Fig. 3. Three pairs of contrasting statements are listed within the following fields: (1) food policies within countries, (2) international trade policies; (3) social policies dealing with the role of women. It should be noted that each one of these statements (including the contrasting pair made within each of the three fields) is perfectly sound and legitimate (a quick discussion of the various points is given in the notes of Fig. 2). That is, the list presented in Fig. 3 provides us with an example in which contrasting suggestions and policy reccomendation are given by reputable scholars that are perfectly right in defending their points (a short sion of the validity of each one these points is given in the note section of Fig.3).

Two other observations should be made before leaving this example: (1) when confronted with the fact that the information given by the panel was contrasting (one journalist attending the conference actually made such an obvious remark) the invited scientists could not figure out, why this was happening. They actually started to defend their theses AGAINST the others (under pressure none of the panelists even considered the possibility that legitimate but contrasting scientific truths can coexist); (2) looking at the different conclusions reached by the scientists it becomes clear that scientists coming from different social contexts (e.g. developed countries versus developing countries) based their analysis on choices of descriptions that generate different "structuring of the problem" (= choice of relevant variables, dynamics used for modeling, determination of the scientific inputs in relation to possible policies) which was reflected into the set of different recommendations. Scientists operating in developed societies were suggesting policies aimed at preserving current steady-state (keep prices low, stop trading, keep cultural diversity at any cost); whereas scientists coming from less developed countries were suggesting policies aimed at changing as fast as possible current situation of steady-state (boost the evolution rate of the system). Probably, this clear-cut division at that conference has been generated by chance (the particular combination of invited speakers and topics assignment in that conference). However, it is sure that a different perception of a given problem (strongly determined by the social context) tends to select a description of the system (structuring of the problem) focused more on keeping the steady-state rather than on the evolutionary perspective (and/or viceversa).

Example 3: non-equivalent scientific explanations of the same event

This example follows the same line or reasoning of the previous one, but addresses more explicitely the political implications of the choice made when deciding to describe an event

at a particular space-time scale. A list of 4 non-equivalent scientific explanations given to the same event is provided in Fig. 4. The event to be explained is the possible death of particular individual and the explanation provided will be used as an input for the process of decision making.

- Explanation 1 refers to a very small space-time scale at which the event is described. This is the type of explanation generally looked for when dealing with a very specific problem (=when we have to do something according to a given set of possibilities as perceived here and now = a given and fixed associative context for the event). Such an explanation tends to look for maximum efficiency (we want to do as good as we can, assuming as valid and available a closed and reliable information space). In political terms, these "scientific explanations" tend to reinforce current selection of goals and strategies of the system. Maximization of efficiency implies not questioning basic assumptions and the established information space used for decision making.
- Explanation 2 refers again to a small space-time scale at which the event is described. This is the type of explanation generally looked for when dealing with a class of problems that have been framed in terms of the HOW question. We have an idea of the HOW (of the mechanisms generating the problem) and we want to both fix the problem and understand better (fine tuning) the mechanism according to our scientific understanding. A gain we assume that the basic structuring of the available information space is a valid one, even though we assume that we can add a few improvements to it;
- Explanation 3 refers to a medium/large scale. The individual event here is seen through the screen of statistical descriptions. This type of explanation is no longer dealing only with the HOW question but also, in an indirect way with the WHY question. We want to solve the problem, but in order to do that we have to mediate between contrasting views found in the population of individuals to which we want to apply policies (e.g. in this particular example, dealing with the trade-offs between individual freedom of smoking and the burden of health- costs for the society generated by heavy smoking). We no longer have a closed information space and a simple machanism to determine optimal solutions. Such a structuring of the problem requires an input from the stakeholders in terms of "value judgment" (= for politicians this could be the fear of loosing next elections);

- Explanation 4 refers to a very large scale. It should be observed, that this explanation is often perceived as "humoristic" within a scientific context. Whenever this slide is presented at conferences or lessons, usually the audience starts laughing when the explanation "humans must die" is listed among possible scientific explanations for the death of an individuals. Probably this reflects a deep conditioning to which scientists and students have been exposed in the last decades. Obviously, such an explanation is perfectly legitimate in scientific terms when framing such an event within an evolutionary context. The question then becomes why it is that such an explanation tends to be systematically neglected when discussing of sustainability ? The answer is already present in the list given in Fig. 4. Such an explanation would force the scientists and other users of it to deal explicetely and mainly with "value judgment" (why ? what for ?) rather than with the how question. This type of questions seem to be considered not "scientifically correct" according to western academic rules.

Also in this second example we find the same pattern seen in the previous one: the validity of using a given scientific input depends on the compatibility of the process which generated it with the context within which such an information will be used. A discussion about pros and cons of various policies restricting smoking would be considered unacceptable by the relatives of a patient in critical conditions in an emergency room. In the same way, a physiological explanation on how to boost the supply of oxygen to the brain would be completely useless in a meeting discussing the opportunity of introducing a new tax on cigarettes.

Implications of these examples

- Scientific assessments can be formally correct (consistent with a declared set of axioms and protocols) but still providing only a very limited and biased view of the reality. When dealing with complex systems operating in parallel on several hierarchical levels the existence of contrasting "correct" scientific assessments is not only possible but rather unavoidable (the same system assumes different identities according to the choices used when structuring the scientific representation on a particular space-time scale).

- Any discussion related to sustainability, which is based on assessments and models related to a single descriptive domain (a particular system of scientific mappings referring to a pattern recognition linked to a single relevant space-time differential) is necessarily: (1) misleading, (2) dangerous, and, it goes without saying, also (3) totally useless, to clarify and to structure sustainability problems about which we want to make a decision. Put in another way, we cannot discuss of the effect on the environment of an energy tax, or about expected changes in the ecological footprint of a city derived from a technical innovations, if we are using only one single system of mapping to describe the pros and cons of this changes (e.g. only money values such as US Dollar of 1988 or only biophysical variables such as Mega Joules or hectars of productive land). Without an integrated assessment able to consider at the same time other non-equivalent descriptions of the same problem (able to reflect other relevant perspectives and able to catch side-effects occurring on different scales) there is only one very probable outcome: any reductionistic analysis trying to collapse complex behaviours into simple models "see" improvements on a certain scale and according to certain encoding variables (e.g. households paying less taxes), which will result bad when "seen" adopting another scale and other encoding variables (e.g. community getting less revenues for investing in social services). In a real world made up of adaptive systems, any proposed change which generates winners tends to generate also loosers. Whenever loosers are not detected by the proposed model of analysis, we can only assume that the structuring of the problem (the scientific representation of the complex behaviour) used to get the integrated assessment is neglecting some side effects. That is, before going ahead looking for the resulting win-win solution it would be wise to check how important are possible neglected side effects.

- When dealing with the issue of sustainability there are not "optimal solutions" (optimal for whom ? optimal for how long ?), but rather changes which imply trade-offs. Any sound system of indicators (scientific representation) to be used to discuss of sustainability must be able to reflect this fact. Methods of analysis which make possible to clearly define a solution as "better" than another, should be regarded with suspect. Sustainability has to do with the tragedy of change (you have to loose something in order to gain something else), which is reflecting basic principles on which life works. Claims of technological fixes which are generating win/win/win solutions are often based on the ignorance (or, even worse, conscious neglecting) of negative side-effects occuring in dimensions or scales not considered in the description (model) of system performance (since they are not considered relevant by the modelers). Moving from the search for "optimal solutions" toward the search for "satisfying solutions" (following Simon's suggestion - Simon 1976) implies moving the scientists out from their cocoon of self-proclaimed neutrality. Not only such a search implies to define trade-offs functions rather than optimizing functions, but also it implies: (i) a discussion of what are the criteria to be included as the most relevant in the multicriteria performance space; (ii) a continuous process of adjustment of the weights given to the various irreducible criteria used in the integrated assessment; (iii) a "quality control" on the process which is generating the integrated assessment, which implies inputs such as political will of negotiate with other stakeholders, trust, fairness, reciprocity.

- There is an unavoidable hidden "political dimension" in any scientific description. That is, the original decision on how to structure the problems in the first place (what is the system ? what the system is doing ?) which is then reflected into the selection of qualities of the system to be encoded with variables. Such a decision has nothing to do with the claimed "objectivity" of science. It is simply not possible to define a standard scientific protocol determining "a priori" how to define "the system under analysis" (what is the boundary, what are the relevant behaviours and relevant dynamics to be considered). Actually, when dealing with the sustainability of complex adaptive systems, we can be sure of the opposite. The same system will exhibit non-reducible behaviours that can only be catched by adopting different boundaries and different relevant space-time differentials. In the reality of scientific investigations, it is not even clear **who is that wants to investigate the system and why** (who is entitled to decide about the definition of the set of most relevant criteria of performance to be considered in the analysis ? are we sure that this is an issue that it is dealt with in current scientific investigations over sustainability ?). This unescapable "value- loaded" input which is introduces in any numerical assessment obtained through scientific mapping implies the existence of an unavoidable political or epistemological 'bias' in any number used in the following discussion. That is, any scientific description depends on a set of previous 'value- calls' related to the following basic structuring questions: (i) what is the identity of the system ? (ii) what does the system do ? and (iii) what qualities (and therefore variables) should be considered as relevant for describing its behavior ? (iv) what is the life- span of the investigated behavior which has been considered of interest ? (e.g. do we agree with the asumption given by radical neo-classical economists that in the long-run we are, in any case, all dead ?). The arbitrarity implied by this series of choices has to be addressed very carefully in order to make the relative scientific input more useful and "transparent".

- the impasse often experienced by scientists struggling with sustainablity (such as the panellists at the conference in example 1) is often generated by the fact that scientists coming form different disciplines tend not to specify either the assumptions under which their analysis can provide valid indications or the goals that generated the choice of that particular type of analysis in the first place. Both (assumptions and goals) are usually taken as granted (or not relevant for the validity of the conclusions). Actually, this can be used as a definition for reductionistic scientists. Those that: (i) not even bother to explicitly acknowledge the fact that their representation and structuring of the problem through the use of numerical indicators (scientific mappings) is heavily dependent on their personal assumptions and goals; (ii) seem not to realize that scientists working in different fields are using different assumptions in order to be able to map the complexity of the reality into simple numerical models. Basic differences in the assumption result into mappings that cannot be reducible to each other; (iii) seem not to be aware that the applicability of their analysis to a given problem is directly related to the relevance of the set of qualities encoded by the selected variables and the modeling relation considered in the inferential system (= the selected set of simplifications used in the model).

The three simple examples given above point at the obvious fact that the choice of a particular type of description (the scientific structuring of a problem) is generated in any case by the social context within which the scientist is operating. That is any selection of encoding variables and models reflects both perceptions of the reality and interests of the scientists, which, in turn, is reflecting their social, political and cultural context. Therefore, everytime we deal with contrasting views determined by **different interests** and social contexts, we cannot expect to work out these differences by confronting their validity against an absolute "objective" referent. When two different mappings are chosen for the same natural system the resulting numerical assessments are no longer necessarily supposed to be related - in the same logical way - to that natural system. That is they are no longer reducible or commensurable with each other. For example, imagine to compare the size of capital cities:

London, U.K., would result larger than Reykjavik, Iceland in terms of population, however, by changing the choice of encoding variable for the "quality" size, London would result smaller than Reykjavik in terms of number of letters making up the name [e.g. when such a ranking is performed by a company making road signs]. Using Rosen's theory of errors (Rosen, 1985)- the occurrence of this logical independency of mappings should be considered a bifurcation in the system of mappings used for representing the same natural system. The crucial point here is that bifurcations are generated by the existence of different interests in the population of mapping users and not by intrinsec characteristics of the natural system mapped. That is there is nothing bad about the existence of bifurcations, on the contrary they simply reflect the fact that life is complex. Meaning that the larger is the number of non-equivalent perspectives (logically independent useful mappings) that we can use to represent and model the behaviour of a natural system, the richer will be our understanding of the reality. On the negative side, a large number of non-equivalent representation will make more difficult to handle the resulting information space. How to deal with this unavodiable dilemma between "relevance" and "compression" is the ficus of Part 2.

8.2 Moving from the concept of "Substantive Sustainablity" to that of "Procedural Sustainability"

It is often stated that Sustainable Development is something that can only be grasped as a "fuzzy concept" rather than expressed in terms of an exact definition. This is due to the fact that Sustainabe Development is often imagined as a formal, static concept that could be defined in general terms without the need of using, any time we are applying it to a specific situation, several internal and external semantic checks. The only way to avoid the "fuzzy trap" implied by such a substantive concept of sustainability is to move from a definition which is of general application (it does not depend on the specific perception of the characteristics of the specific context in which we are operating but it is related to some predefined optimizing function related to a standard associative context) to a definition which is based on (and implies the ability of performing) internal and external semantic "quality checks" on the correct use of adjectives and terms under a given set of special conditions (at a given point in space and time). These "quality checks" should be able to reflect the various perceptions of the stakeholders found within a defined context. Clearly, these perceptions depend on the particular point in space and time at which the application

of general principles occurs (this implies also a strong dependency on the history of the local system - e.g. cultural identity of various social groups, existing institutions and power structure, existence of shared goals and trust among stakeholders).

The main point here is that a definition of Sustainable Development can be given (see below) but only after assuming that within a given society it is possible to obtain these semantic checks. In this case we can say that the concept of Sustainable Development can be referred to as: "**the ability of a given society to move, in a finite time, between satisficing, adaptable, and viable states**".

Such a definition implies that sustainable development has to do with a process (procedural sustainability) rather than with a set of once-and-for-all definable system- qualities (substantive sustainability) [note: we are using the distinction between substantive and procedural rationality proposed by Simon (1976)]. Put in another way sustainability implies the following points:

1. governance and adequate understanding of present predicaments - as indicated by the expression: "the ability to move, in a finite time,";

2. recognition of legitimate contrasting perspective related to the existence of different identities for stakeholders (implying the need of: (i) an adequate integrated scientific representation reflecting different views; and the possibility of having: (ii) istitutionally organized processes for negotiation within the processof decision making) - as indicated by the expression: "satisficing";

3. recognition of the unavoidable existence of uncertainty and indeterminacy in our understanding, representation and forecasting of future events - as indicated by the expression: "adaptable". When discussing of adaptability (= the usefulness of a larger option space in the future): (i) reductionistic analyses based on "ceteris paribus" hypothesis have little to say; and (ii) incommensurability implies that optimal solutions cannot be detected applying algorithmic solutions (the information space needed to describe the performance of the system is expanding and therefore cannot be catched by any closed formal inferential systems);

4. availability of sound reductionistic analyses able to verify within different scientific disciplines the "viability" of possible solutions in terms of existing technical, economic, ecological and social constraints - as indicated by the expression: "viable".

We believe that a procedural definition of sustainable development is possible (we provided our suggestion) but such a formulation implies a paradigm shift in the way scientific information is generated and organized when providing inputs to the process of decision making.

To conclude this section we quote Faucheux et al. (1997; pag. 57) commenting Simon's analysis: 'When indeterminacy or complexity prevail, decision making embodies deliberation and search, and is sensitive to the forms of representation the decision makers know about or prefer. A solution is then constructed through a heuristic process in which it is reasonable to retain "an alternative that meets and exceeds specified criteria, but that is not guaranteed to be either unique or in any sense the best". This defines as "satisfying" solution adequate to some aspiration level, which is the essence of the procedural rationality. It is no longer possible to get rid of deliberation when there is indeterminacy or complexity. The formation of human perceptions and preferences should be considered as part of the problem of decision. Decision making is influenced by the decision-maker's mind: " A body of theory for procedural rationality is consistent with a world in which human beings continue to think and continue to invent: a theory of substantive rationality is not" (Simon, 1976)'.

Complexity and Sustainability imply a new challenge for Science:

According to what said in the previous section, in order to be useful for decision making scientific information has to:

1. be able to reflect - in the representation step - the various relevant features (after defining the criteria to be used for determining if current situation is worsening or improving) found when considering the legitimate perspectives of stakeholders.

2. be able to put in perspective the various indicators resulting from the selection of relevant criteria included in the analysis (which are necessarily referring to a picture at a particular point in space and time) with possible future evolutionary paths and perturbations (trend analysis and resilience analysis). Scientific input should also include information related to strategic assessments;

3. be organized in a way that is compatible with the process of governance. Before discussing in detail how to deal with such a challenge (this is the subject of Part 2) we would like to use the rest of this section to provide two other simple examples of practical implications of the epistemological predicament (discussed in section 1) for scientific analyses related to the issue of sustainability.

8.2.1 The fuzzy nature of sustainability trade-offs

Example 1 - dealing with problems requiring the consideration of a set of incommensurable criteria

An example of integrated assessment based on the consideration of incommensurable criteria of performance is given in Figure 5. Very little explanations are needed to present this example, since the structuring of the problem of how to chose a car to buy is a quite familiar one to everyone living in the developed world. The radar-type graph (called also "spider- web" or "AMOEBA" - Brink et al. 1991) is made-up of various axis coming out of a common origin in the center. Each axis represents an indicator of performance which indicates "improvements" in relation to the quality of the system encoded by it. For example, a position more distant from the center for the indicator "Price" - e.g. that indicated by Profile 1 - implies a car which is much cheaper than that characterized by Profile 2.

Three observations about the two profiles shown in Fig. 5:

1. the shape of various profiles linking the numerical values taken by the set of indicators of performance on the graph indicates overall "satisfying solutions" for the buyer in relation to the various trade-offs considered in the multicriteria analysis of performance. How to select the most satisfying "trade-offs profile" obviously depends on a "value call" (required to weight the various performances related to incommensurable criteria). Clearly, the previous selection of the set of indicators used to assess trade-offs (e.g. why considering the Safety Devices and not the number of tires) will affect the final decision. This means that after including a new (or different) criteria in the set (e.g. the risk that the car get stolen, when the buyer is living in a place where such a risk is very high) we can expect that a different combination of satisfying values could be selected. That is, a change in the set of selected criteria (by the addition of a new one) could imply changes over the old profile of satisfying values related to the old set of 12 indicators.

2. the 4 different classes in which the various performance indicators have been clustered (Safety, Economic costs, Driving Characteristics, Aesthetic Aspects/Status Symbol) imply the existence of non-linear "threshold values" on the final decision of the buyer. That is, if the performance of the considered car - in the buyer's perception - fails

completely on only one of these 4 aspects, the car will not be purchased, no matter how well perfroming in the others. This implies that - after agreeing on the selection of crucial non-reducible aspects of the performance of a system - an integrated assessment of this type can be used to explore buyers' perception of sustainability trade-offs.

Also in this case the integrated assessment of the performance of a car (illustrated in Fig. 5) can be used as a metaphor for sustainability. A given model of a car will be "sustainable" on the market only if (1) its trade-offs profile over the various crucial and incommensurable aspects of its performance remains above minimum acceptable values over all the relevant criteria considered; (2) the given trade-offs profile is judged as satisfying by a consistent number of buyers (there is a correspondence between perceptions of buyers and performance of the car). Under this assumption, trade-offs profiles of performance of the type reported in Fig. 5 are mapping the weighting profiles given by various "types" of buyer to the set of criteria considered in the integrated assessment. We can put in relation different "satisfying trade-offs profiles" to different "buyer types" (this is what is called in marketing identification of the "consumer targets" for various products).

3. the same buyer can change its "satisfying trade-offs profile" in time. For example, Profile 1 can represent a satisfying solution for a student without a strong financial support (the basic concern is to have a car moving her/him around at a low economic cost), whereas Profile 2 can represent a satisfying solution for the same student after getting a job, married with 3 children. In this case, top priority is given to Safety and Comfort, even if this implies a higher economic cost for the car.

4. the same multicriteria performance space can generate a lot of different satisfying trade- offs profiles in relation to different typologies of buyers (this is reflected into the existence of different models of cars on the market reflecting such a diversity of trade-offs profiles). From this simple consideration it is obvious that an interdisciplinary team of scientists (no matter how smart and how interdisciplinary) cannot, even in principle, determine from their office the profile of an "optimal car". Actually, they can not even decide how to "improve" the performance of a specific car used by a specific individual in a particular point in space and time, without receiving an input from that specific individual about what would be perceived as an improvement right now.

5. as a consequence of the previous point, the co-existence of different "buyer types" in the real world (reflecting the existence of different trajectories in the evolution of perception of car perfromance of possible buyers and different local specific situations) implies that a "substantive" definition of a sustainable model of car (even if obtained by considering a very large database) does not make much sense. Clearly, the combined knowledge of buyer s' preferences and technical aspects of the performance of cars can imply the defintion of general principles. For example, we can use general trends to guess satisfying profile for class of buyers (e.g. a higher income of the buyer implies more concern for safety) and we can use our knowledge of technical aspect to explore the existence of internal links among trade-offs (e.g. more safety implies higher prices). However, we cannot expect that this better structuring of the information space related to trade-offs analysis can make possible to get away completely from the need of receiving direct information related to "location specific" characteristics (e.g. additional "special" criteria that can alter the validity of the "standard trade-offs analysis" - e.g. in place with very cold winters diesel car are not reccomended; particular colors cannot be accepted in a given society).

Example 2 - dealing with performances referring to different time windows

The example given in Figure 6 addresses explicitely the importance of considering the hierarchical nature of the system under investigation. Such a case study has been proposed by David Waltner-Toews (ref) to focus on the fact that when reading the same event on different levels (on different space-time horizons) we are forced to structure the solution to this very same problem in different ways.

The case study deals with the occurrence of a plague in a rural village of Tanzania. the plague is generated by the presence of rats in the houses of villagers. The rats moved into the houses following the stored corn, which previously was stored outside. The move of the corn inside the hhouse resulted necessary due to the local collapse of the social fabric (it was no longer safe to store corn outside). Other details of the story are not relevant here.

The term Holarchy used in Fig. 6 indicates a nested hierarchy of dissipative systems (a hierarchical system made of holons) following the terminology proposed by Koestler (1968 p. 102). A 'holon' is a component of a dissipative nested hierarchical system which has a double nature of "whole" and "part" (for a discussion of the concept see also Koestler, 1969;

and Allen and Starr, 1982, pp. 8-16). That is a holon is a whole made of smaller parts (e.g. a human being made of organs, tissues, cells, atoms) and at the same time it forms a part of a larger whole (an individual human being is a part of a household, a community, a country, the global economy). According to this definition any integrated analysis of Holarchies has to be based on the adoption of non-equivalent descriptive domains (see discussion on Fig.1).

A simple procedure to explore the implication of hierarchical level is indicated in Fig. 6. After stating the original problem defined at a given level, it is possible to explore the causal relations in the holarchy by climbing the various levels through a series of why and because (upper part of Fig. 6). When arriving to an explanation which has no implications for action we can stop. Then we can descend the various levels by answering new types of questions related to the how and when dimension (lower part of Fig. 6).

Looking at possible structurings of the problem in this way we are left with a set of questions and decisions that lead us directly into a typical "Post-Normal Science" domain:

- What is the "best" level that should be considered when making a decision about eliminating the plague? (who is entitled to decide that ?). The higher we move in the holarchy the better is the overview of parallel causal relations and the richer (more complex) is the explanation. On the other hand, this implies a stronger uncertainty about possible policies and related outcomes as well as a longer lag-time to get a fix (= prolongation of sufferance of lower level holons = those affected by the plague in the village - in this specific case, mainly women). The smaller is the scale, the easier the handling of specific projects looking for quick-fixes. However, faster and more reliable results carry the risk of curing symptoms rather than causes. That is, the adoption of a very small scale of analysis can imply the risk of "locking in" the system in the same dynamic that generated the problem in the first place (we can recall also the discussion related to the problem of how to deal with the possible death of a heavy smoker in Fig. 4).

- How to assess the trade-offs linked to the choice of a level rather than another ? When using a very short time horizon (e.g. kill the rats while keeping the society and the ecosystem totally unbalanced) it is likely to get, sooner or later, into another problem (if rats were a symptom, the cause is still there). When using a too large time horizon, the risk is related to the attempt to solve the perceived problem in the future according to present knowledge and boundary conditions (e.g. assuming shortage of fossil energy and/or water in the area). The very same problems could have a different and easy solution in 20 years (e.g. new sources of energy and/or climatic changes) and therefore different policies giving a quick relief to the suffering of the poor could have been implemented without negative side-effects. But what if current problems will not be solved ?

- Multicriteria analysis must be able to reflect existing multiple goals found in the system. The definition of priorities (relevant criteria to be considered and weighting factors among them) and the perception of effects of changes (the level of satisfaction given by a certain profile) both heavily depend on: (i) the level of the holarchy at which the system is described (if we ask the president of Tanzania or a farmer); and (ii) identity of social groups within the socio-economic system at any given level in the holarchy (e.g. farmers have often different perspectives than herders all over the world);

- Cultural mode-locking (how the past is constraining the possibility of finding new models of development) - which is clearly "space and time specific" - can play an important role in preventing the feasiblity of alternative solutions. Again, changes imply tragedy. When solving a sustainability problem the socio-economic system has to be prepared to loose something to get something else. This introduce one of the most clear dimension of incommensurability in the analysis of trade-offs (we can recall here the dilemma about the importance of preserving cultural diversity and the two different perceptions of it given by two feminist groups in the example of Fig. 3). Therefore, when working out solutions in relation to sustainability the various stakeholder should be able to reach an agreement on: (i) what do they want to keep - how important is to keep it (are they happy about what we get now ?) and (ii) what do they want to change - how important is to get away as fast as possile from current situation (what do they want to become) ? (iii) how reliable is the information space, used to translate into practical action the agreement reached about points: (i) and (ii). Clearly, an agreement over these points is certainly not easy to reach. The unavoidable existence of different perceptions about how to answer these questions can only be worked out through negotiation if we want to keep diversity in the social entity. The alternative solution - imposing a particular view point with the force (hegemonization) - beside the very high cost in human terms, carries the risk of an excessive reduction in the cultural diversity, and therefore a dramatic reduction of adaptability, in the resulting social systems. The expression "Ancien regime syndrome" proposed by Funtowicz and Ravetz (personal communcation) exactly indicates that boosting short-term efficiency through hegemonization is often paid for in terms of lack of adaptability in the long term. Such a typical pattern leading to the collapse of complex social organization has been discussed in detail by Tainter, (1988).

Implications of these two examples

- When looking at a particular problem at a particular point in space and time (when deciding to buy a car in Paris at a given date) the existence of heterogeneity of buyers implies the parallel existence of non-equivalent and non reducible "satisfying trade-offs profiles". None of them can be proclaimed as "the most satisfying" by scientific analyses, due to the heterogeneity of preferences expressed by different social types, and due to the existence of evolutionary trajectories in the preferences within each one of the existing social types. In more general terms, we can say that when looking at a particular problem using an evolutionary perspective (when considering the causal structure of a problem over various hierarchical levels) we are forced to deal with a clear case of incommensurability. This is a typical situation of sustainability analysis requiring the use of non-equivalent descriptive domains needed to represent contrasting interests found in the holarchy. These contrasting interests among holons and across levels are implied by the very existence and sustainability of holarchies (Giampietro, 1994a; 1994b; Giampietro, 1997).
- The main contribution that scientific analyses can provide to the rest of society when dealing with the issue of sustainability is related to the possibility of exploring and representing sustainability trade-offs at the various levels and scales at which the process of decision making occurs. However, dealing with sustainability trade-offs implies dealing with irreducible criteria, undeterminacy in the representation, and a strong uncertainty in the generation of scenarios. Therefore, general principles, laws, protocols, as well as databases can be usefully employed, but only after being checked within the specific context in which decision have to be made (do they make still sense within such a context ?).
- Sustainability has to do with governance [= the ability to integrate in the process of decision making: (i) current value-loaded selection of relevant criteria; (ii) available error-loaded information; (iii) existing uncertainty-loaded predictive models]. When dealing with a practical decision the society has to discuss, first of all, what are the relevant qualities and the relevant scales to be considered to discuss of "costs" and "benefits". The managing of such a discussion will determine the legitimacy (= social acceptance) of the entire process of decision making. In this delicate step, scientific analyses have to help rather than being detrimental to such a process.
- The process of globalization and the fast process of technical development occurring in these decades is generating a new class of governance problem for decision makers operating at either the local, medium and global level. Both ecological systems and socioeconomic systems operating in various parts of the world - under a wide variety of social and ecological characteristics - are now connected to each other. This over-connectedness is generating important frictions between those social and ecological systems due to the dramatic differences in their characteristics. For example, capital is moving toward socio-economic systems that have much lower labor cost generating a problem of unemployment in developed countries and possible over-exploitation of workers in developing countries. Tropical ecosystems naturaly more fragile and less protected by local regulations risk to be the big loosers of the growing integration of world economy.

In each one of these cases, the very roots of the sustainability predicament can be found in the trade-offs between economic development, enlargement of the scale of operation of the economy, environmental loadings, stress on the identity of local communities (criteria to be considered: the need of preserving cultural diversity), stress on the identity of ecological communities (criteria to be considered: the need of preseving integrity and biodiversity). The only way to analyze the nature and the effect of these trade-offs is to analyze and describe the various relevant dynamics. But this requires using complementing non- equivalent descriptive domains linked to events described on different scales. Only in this way we can attempt to reflect, when structring the representation of a sustainability problem, the various relevant perspectives.

8.3 Conclusion

In this first paper we tried to convince the reader of the following point: There is nothing trascendent about complexity, something which implies the impossiblity of using sound scientific analyses in a process of decision making about sustainability. On the other hand, complexity theory can be used to show clearly the impossibility to deal with decision making related to sustainability in terms of "optimal solutions" determined by applying algorithmic protocols to a closed information space. When dealing with complex behaviours we are forced to look for different causal relationships among events. However, the causal relations found are often reflecting our interest in the studied system (depends on the original structuring of the problem). This is due to the fact that we can only deal with the scientific representation of a hierarchical system by using a strategy of stratifications (= by using a triading reading based on the arbitrary selection of a focal space-time differential able to catch the dynamics of interest).

In order to be able to use fruitfully science when discussing of sustainability, humans should just stop pretending that their processes of decision making are based on the ability to detect the "best" of the possible courses of action (after applying standard protocols based on reductionistics analyses). This has never been in the past and will never be in the future.

The confusion has been generated by the fact that, in the last decades, in Western countries the "elites" in power, for various reasons, decided to pretend that they were taking decision based on "substantive rationality". Clearly, this was simply not true. The clash of reductionistic analyses against the issue of sustainability is clearly esposing such a fault assumption. Complex systems theory can help in explaining the reason of such a clash. Any definition of priorities among contrasting indicators of performance (reflecting legitimate non-equivalent criteria) depends on the hierarchical level at which events are described. In turn the choice of a hierarchical level to be used as basis for description depends on the priority expressed by some agent in the holarchy. We are in a classic example of chicken- egg situation which simply implies alternative methods for structuring of sustainability problems. Such a structuring cannot be done by scientists operating within the given set of assumptions of an established discipline. The only viable way out is adopting participatory techniques able to generate an iterative interaction between scientists and stakeholders (this is the subject of the second paper of this series).

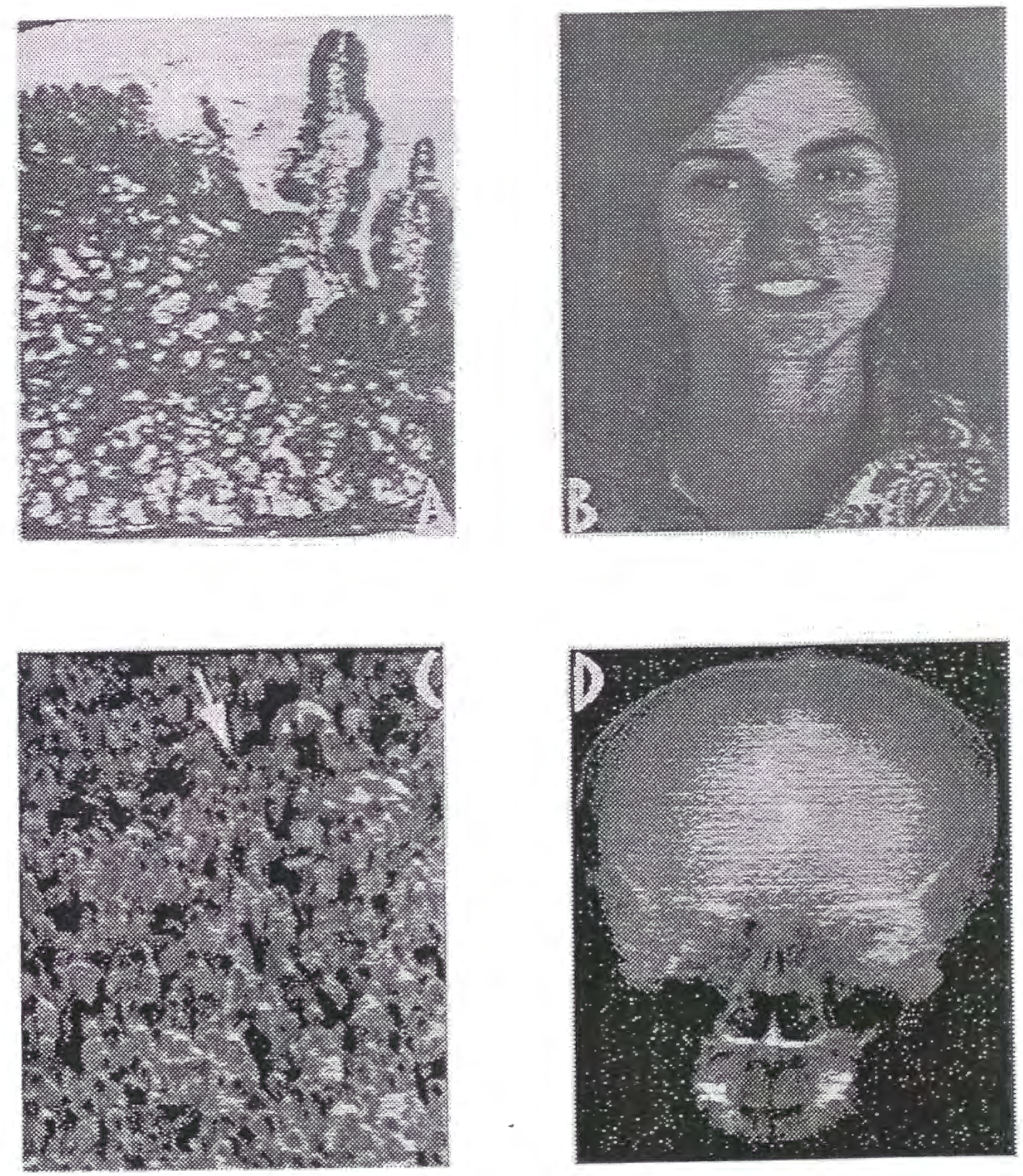


Figure 8.1: Non-equivalent descriptive domains needed to obtain non-equivalent pattern recognition in nested hierarchical systems

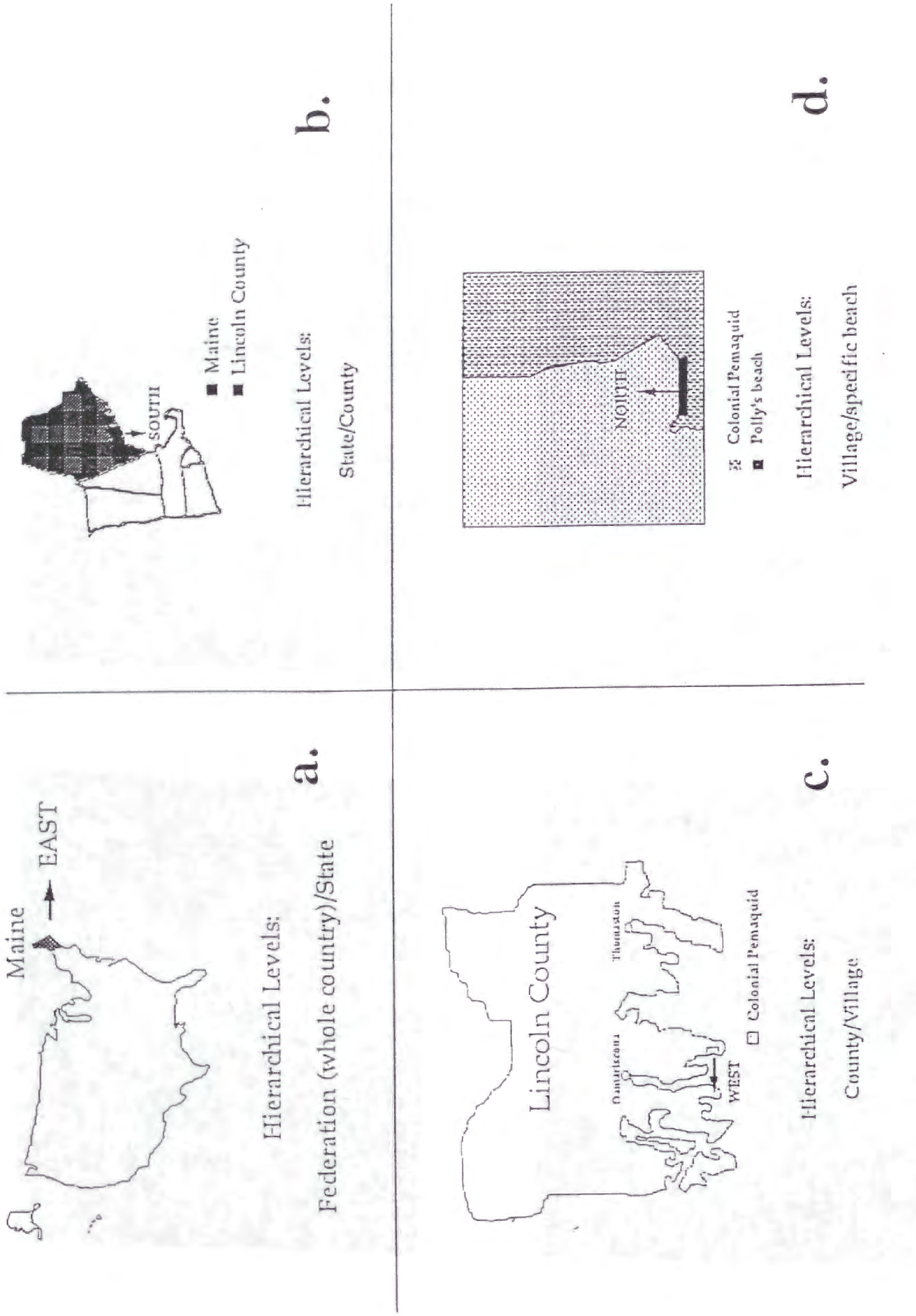


Figure 8.2: Orientation of the coastal line of Maine

Policy indications given at the International Conference on World Food Security - SAGUF -Zurich, October 9 - 10, 1996

National Policies (1)

Keep prices of food commodities LOW
(I.F.P.R.I. - U.S.A.)

Keep prices of food commodities HIGH
(**Prof. agricultural development Pakistan**)

International Policies (2)

REDUCING agricultural imports from the South
(**Wuppertal Institute - Germany**)

INCREASING agricultural imports from the South
(**Prof. agricultural economics -Ghana**)

Social analisys (women issue) (3)

PRESERVING local cultural heritage
(**NGO from Switzerland**)

FIGHTING local cultural heritage
(**sociologist from India**)

Figure 8.3: Legitimate but contrasting policy suggestions about a sustainable World Food Security

Explanation 1 → *(looking for the known HOW)*

Space-Time Scale
very small

Example of Situation
Emergency room

Explanation:
No oxygen supply to the brain

Implications for action:
apply known procedures

· strong entailment of the past on present action

Explanation 2 → *(looking for a better HOW)*

Space-Time Scale
small

Example of Situation
Medical Treatment

Explanation:
Affected by lung cancer

Implications for action:
apply known procedures & explore new ones

· entailment of the past on present, room for exploring changes

Explanation 3 → *(mixing HOW to WHY)*

Space-Time Scale
medium

Example of Situation
Meeting at the Ministery of Health

Explanation:
Individual was a heavy smoker Policy

Implications for action:
formulation mixing experience with aspirations for change

· mixed entailment of the past and "virtual future on present

Explanation 4 → *(implications of WHY)*

Space-Time Scale
very large

Example of Situation
discussion sustainability

Explanation:
Humans must die

Implications for action:
dealing with the tragedy of change

· strong entailment of the "virtual future"(passions) on present

Figure 8.4: Non-equivalent scientific explanations for a given event event to be explained: death of a particular individual

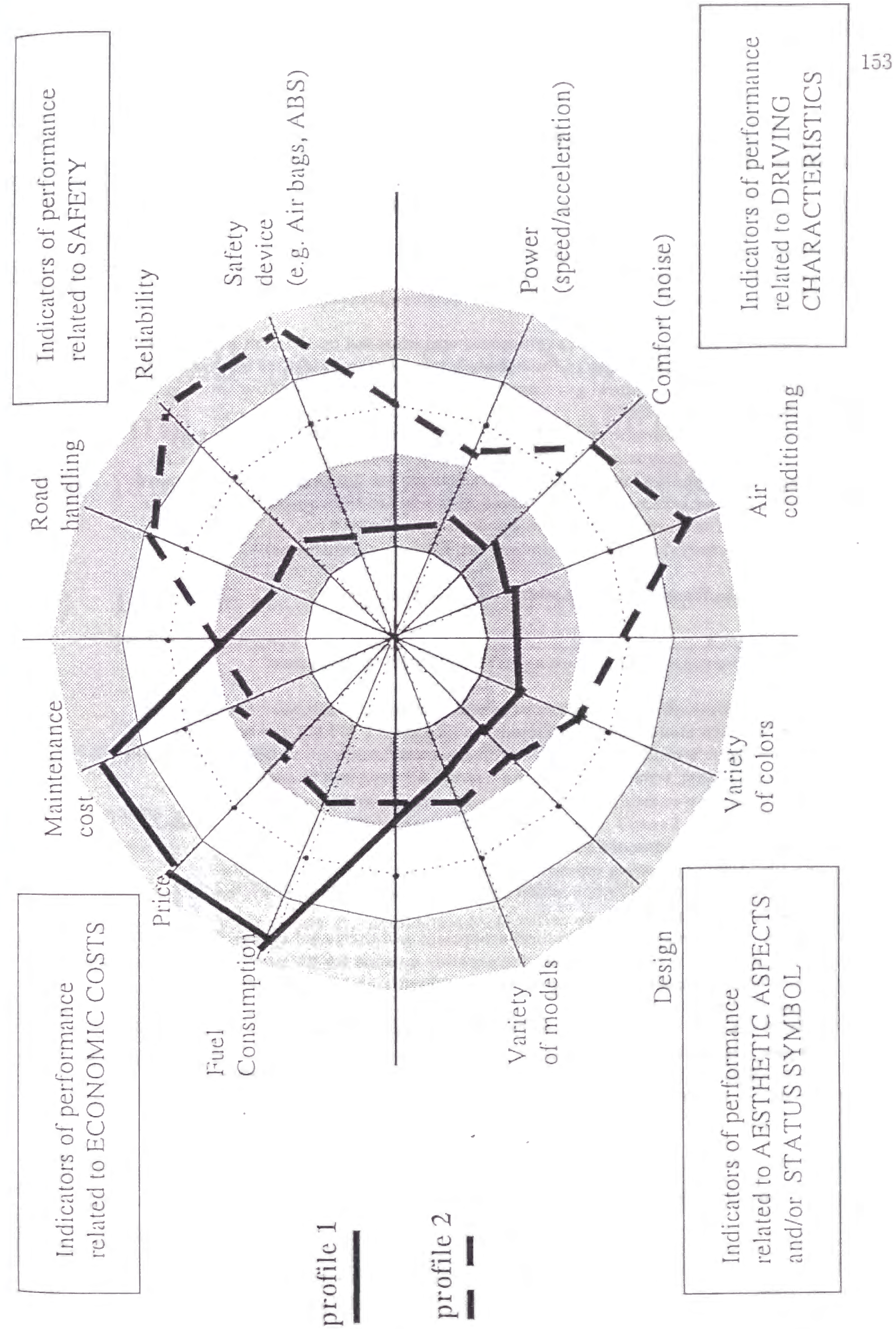


Figure 8.5: Example of integrated assessment based on incommensurable criteria of performance for a car

Specific problem to deal with: a plague in a village in rural Tanzania
(see text for more explanations)

Phase 1 - climbing the holarchy (using WHY and BECAUSE)

0. WHY there is the plague in the village ?
1. BECAUSE rats and humans interact too much - WHY ?
2. BECAUSE the traditional pattern of interaction between local society and ecosystem have been disturbed - WHY ?
3. BECAUSE an exogenous model of development was imposed on the community - WHY ?
4. BECAUSE the double asymmetry in the holarchy was broken (= lack of empowerment of local communities versus central governments which are forced to follow western models of development) - WHY ?
5. BECAUSE two socio-economic systems at a too different level of development are interacting (developing countries in the South and developed countries in the North). This is generating friction on lower level holons (changes are going so fast that the need of equipollence in the holarchy must be ignored, this implies the squeezing of those on the bottom) - WHY the North is more developed than the South ?
6. BECAUSE of a historical accident (boundary and initiating conditions)

--> this answer indicates that there is nothing we can do about it

Phase 2 - descending the holarchy by using HOW and WHEN questions

5. HOW/WHEN - How existing difference between North and South can be mediated ? (Which one of the two models of development we like most ? Which one would be possible for the entire world? = compatible with thermodynamic constraints, compatible with human aspirations); what is the lag time needed for expected changes ?
4. HOW/WHEN - can we re-establish equipollence in the holarchy in spite of differences in North and South ? (it is possible to empower local communities ? how ? what is the expected lag time to do that ?)
3. HOW/WHEN - can we generate room for expressing local aspirations within the existing constraints given by the evolutionary trajectory of the larger system to which the community belongs ?
2. HOW/WHEN - the disturbance to the local ecosystem and the social system can be reduced to acceptable levels ? what are the possible options for the people living in the village? what are the expected lag times to get results? what is the level of uncertainty on the considered options?
1. HOW/WHEN - can we eliminate the rats ? what is the expected lag time ? the costs?
2. what are possible negative side effects ?
(--> if rats are symptoms rather than causes, then, what are the possible negative side effects linked to the curing of symptoms?)

Figure 8.6: Exploring the Holarchy

Chapter 9

The challenge of Post-Normal Science: making scientific information useful for the process of decision making

9.1 Keeping separated "normative" from "descriptive" information

Resuming the major conclusions presented in the first paper of this series we can say that the scientific representation of any specific sustainability problem:

1. requires the use of various indicators of performance defined and calculable only over various non-reducible descriptive domains (e.g. considering various possible complementing views on the quality of life of individuals, various complementing indicators of economic performance at various levels, families of indicators of ecological stress at various scales);

2. is affected by an unavoidable degree of genuine uncertainty which cannot be eliminated by working out better models, hiring smarter scientists, or using more powerful computers;

3. has to be structured not only by looking at the class of problem under analysis but also by looking at the characteristics of the social entities which will be the 'information users'.

In particular, the main point to stress here is that in any process of decision making related to sustainability the information space used to discuss about "what to do" has to be generated by two distinct activities that are "qualitatively" different and that therefore should be kept clearly separated:

INPUT TYPE 1 - Participatory Integrated Assessment

The need of this activity is related to the point that an "optimization based on the standard discussion of a given class of problems" is not feasible and/or useful when dealing with special situations. This implies that we must have an input able to reflect: (i) the specificity of the situation; and (ii) the "value dependent" information required for a sound structuring of the problem.

By definition scientists **cannot and should not give** this type of input [clearly this statement is valid only when playing the role of "scientists". Off course they can and have to give such an input as member of ths society, but only when playing the role of stakeholders - e.g. as fathers, as concerned citizens, or as protector of the Panda bear]. Put it in another way, it is important that the following inputs to the process of decision making should not be given by scientific analyses either in direct (in the form of a fixed protocol) or "indirect" (= hidden in the assumptions of models) form:

1. what are the relevant criteria to be used in describing and considering options;
2. "quality control A" = a control on the reliability of data, models, and scenarios provided by the scientists for representing and structuring the problem;
3. iterative check on the validity of the integrated representation of the problem used in the discussions and negotiation in relation to the specific process of decision making. In fact, during the process of negotiation stakeholders can decide to change the original selection of relevant criteria and/or ask for additional or alternative descriptive tools to obtain a more relevant and/or reliable integrated representation;
4. final call on the "satisficing" level of the selected trade-offs profile in the multicriteria performance space (=what decision should be made).
5. "Quality Control B" = a control over the fairness in the management of various steps followed in the process of decision making [= (i) negotiation (policy evaluation according to the agreed upon structuring of the problem); (ii) decision making (policy definition according to the agreed upon organization of the information space); (iii) implementation of decisions (policy enforcement according to the agreed upon definition of the satisfying trade-offs profile)].
6. "Quality Control C" = a continuous monitoring (through feed-backs to the decision makers) - at different levels and locations - aimed at detecting unexpected consequences of previous decisions.

INPUT TYPE 2 - Multi-Objective-Multiple-Scale-Strategic-Problem-Structuring

The definition of perceptions of both risks and benefits as well as the weighting profile that should be given to the selection of relevant incommensurable criteria (a crucial component of the Input of type 1) both require that the stakeholders must have an initial knowledge/structured representation of the situation. That is, in order to provide 'value calls' stakeholders need to know in the first place something about the causal relations between changes and effects as well as pros and cons linked to possible scenarios. This implies that the process of decision making needs also the following inputs that should be given by scientists (the definition of science proposed here is related to a quality control on the reliability and consistency of the information organized to frame the representation of sustainability trade-offs):

1. a set indicators of performance belonging to various non-equivalent descriptions of the problem, which has to reflect the diversity of perceptions of "improvement" and "worsening" found among the stakeholders. These various indicators are related to the set of incommensurable evaluation criteria judged as relevant for decision making as emerged by the participatory process;
2. a set of numerical and qualitative assessments defined on various descriptive domains which refers to different space-time windows (and different hierarchical levels). This means making available various pictures of the system under investigation (to catch its behaviour) that we obtain when considering the selected set of indicators of performance;
3. a set of various models which can be used to establish causal links among relevant qualities (many of them defined and definable only on different specific descriptive

domains). These models must be able not only to verify the viability of possible options in relation to several constraints under the "ceteris paribus" hypothesis (economic viability, technical viability, social viability, ecological compatibility), but also provide strategic assessment in relation to the participatory evaluation of possible scenarios (e.g. analysis of the domain of possible evolutionary trajectories). These analyses should be able to answer questions such as: "what if", there are general principles that can be used for helping the decision making under uncertainty ? how can we expand the space of possible options ? what are the factors determining the option space ?

It is easy to recognize that when considering the relation between these two distinct set of activities we are dealing with a classic example of chicken-egg self-entailing relation. Stakeholders are supposed to provide the "Input-Type 1", but in order to do their job they need to have from the scientists an "Input-Type 2". Scientists are exactly in the same situation. However, chicken-egg situations are only bad for theoretical modelers, not for real adaptive systems. Real adaptive systems are embedded in a complex time (Rosen, 1985) and are going through this apparent dilemma every moment of their life. They are used to operate in a situation in which different hierarchical levels affect each-other. In fact, a "clear-cut" linear direction of causality is an artifact generated by the choice of a descriptive domain used to represent their behavior. A few examples can be used to clarify this point. In ecological systems, the activity of predators determine the size of the prey on one time horizon, but, at the same time, it is the size of the prey which determines the activity of the predators when a larger time horizon is considered. In the same way, the consumers choice determines what is produced in an economy, even if, when describing the process of production and consumption on a smaller time horizon, we are forced to note that the consumer can only buy a product after its production. This egg-chicken relation of causality in hierarchical systems has been called "double asymmetry" (Grene, 1969) and it is due to the existence of parallel processes affecting (or using Rosen's vocabulary "entailing") each-other on different relevant space-time differentials. In political systems, the government is ruling over citizens on the every-day time scale, but the citizens are ruling on governments when an "election time scale " is considered.

In conclusion, for real systems embedded in complex time, it is easily possible to generate an egg-chicken pattern of self-entailment. In order to do that, they have to get into an iterative processes designed for a flexible output (both the components of the systems and the rules to be followed can be changed during the process). We arrived in this way to a different view of the concept of procedural sustainability (discussed in the first paper). Procedural sustainability implies that scientists cannot organize usefully their scientific representation of a problem without getting an input from the users/decision makers. In the same way, the users/decision makers cannot develop any sound procedure/tool related to governance without getting an adequate input from a transdisciplinary team of scientists. Such a problem can only be solved by generating a iterative process of interaction among the two (Fig. 1). A practical example will be discussed in the last section of this paper.

In conclusion, in order to make the scientific representation of a problem RELEVANT for the process of decision making we have to check whether or not: (i) the organization of the information space adopted by scientists when structuring the representation of the problem is compatible with (ii) an organization of the information space which is able to reflect the concerns and the aspirations of the stakeholders. But when doing that, the very process which makes the scientific input RELEVANT implies a structuring and representation of the problem which can not be handled in a reductionistic way. That is, in order to perform such a check on "relevance" we have to mix scientific analyses needed for generating an integrated assessment with participatory techniques involving stakeholders in a quality check. Such an integrated process is crucial for generating both : (i) a meaningful discussion about the sustainability of human progress (developing collective knowledge) and (ii) sound deliberative processes related to specific problems of natural resources management.

What discussed up to now indicates also that defining the performance of a given scenario as "more satisficing" than others - in relation to stakeholders' perceptions - is just a part of the story. It is also crucial to deal with information dealing with "how to get to the state we like most". This requires that when structuring a problem and analysing the resulting scenarios, we have not only to take into account biophysical, economic, technical, ecological, and institutional constraints on the viability but also information related to policy feasibility and social acceptability of proposed solutions. However, due to the focus of this paper on how to organize the scientific input in a Participatory Integrated Assessment of sustainability trade-offs. This text does not deal with:

1. how to assess policy feasiblity and social acceptability with indicators;

2. how to involve, in practical terms, the stakeholders in a deliberative process (e.g. how to organize focus groups or people jury). Even if this dimension of the problem (how to get the input-type 1) is as crucial as the one considered here (how to get the input-type

2).

Multi-Objective Multiple-Scale StrategicProblem Structuring (MOMS-SPS)

If we accept that the organization of the information space needed for a Participatory Integrated Assessment can no longer be based on traditional (reductionistic) descriptive tools, then, we have to look for more useful descriptive tools to be employed in participatory processes. These new tools must have the goal of organizing the scientific representation of the problem in order to generate a relevant, reliable and transparent scientific input for the process of decision making. Therefore the structuring of the information space made by the scientists has to provide:

1. a set of various possible useful representations of relevant features of the system defined by stakeholders involved in Participatory Integrated Assessment (e.g. definition of a set of models which use non-equivalent identities and boundaries for the same system when represented over different descriptive domains as performing different functions);

2. a definition of the feasibility space (= range of admissible values) for each of the selected indicators of performance. Feasibility should reflect the reciprocal effect across hierarchical levels of economic, biophysical, institutional and social constraints;

3. a multicriteria representation of the performance of the system (in relation to the selected set of incommensurable criteria) by calculating in parallel the value of each indicator included in the package. This makes possible to represent: (i) what should be considered an improvement when the value of the relative variable changes, (ii) how the system compares with appropriate targets and other similar systems, (iii) what are possible critical, threshold values of certain variables where non-linear effect can play a crucial role.

4. a strategic assessment of possible scenarios done by addressing the problem of uncertainty and general evolutionary trends that can be expected. The scientific representation has no longer be based only on steady-state view (past-present entailment) and on a simplification of the reality represented according to a single dimension at a time ("ceteris paribus"). The reductionistic perspective has to be complemented by an analysis of evolutionary trends (considerations related to adaptability implying a future-present causal perspective), the crucial effects of the particular history of a system (e.g. institutional analysis) and the parallel consideration of the relations among several levels at the same time. A strategic analysis should make possible to classify the investigated system in relation to its position within the domain of possible evolutionary trajectories (by comparing it with other similar systems within the same state space used for the integrated assessment);

5. a boost in the reliability of available scientific descriptions by generating redundancy in the information space - looking for "mosaic effects" (Prueitt, 1998) based on the bridging of non-equivalent descriptions through the forced congruence of numerical assessment across scales. A sound MOMS-SPS should imply the possibility to perform a consistency check on the validity of the data base used in the step represent (and even the possibility to fill empty spaces in the data base, when gaps occur). When dealing with practical problems of sustainablity of human societies the bridge across descriptive domains can be obtained by forcing the congruence of flows of: (i) money; (ii) energy; (iii) matter; and (iv) human time, as resulting from different descriptions (choice of variables and inferential models simulating main dynamics) across hierarchical levels. The condition of congruence implies that non- equivalent descriptions adopted when generating and calculating the set of different indicators included in the package (e.g. according to microeconomic, macroeconomic, biophysical analyses, social indicators, demographic analyses, etc.) must have an internal coherence. That is, assessments coming from an analysis performed on a given level must result consistent - when scaled-up or scaled-down to a different level - with indications coming from the analysis based on a non-equivalent description performed at a different level both in terms of: (i) numerical values; (ii) known trends. A practical example of how to apply this approach is given in the last section of this paper. The generation of a "mosaic effect" can make possible the filtering out of incoherent scenarios or biased policy solutions proposed by interested scientists and/or stakeholders, as well as forcing transdisciplinarity in the step representation (Giampietro and Pastore, 1999; Pastore et al. 1999).

6. a trade-offs analysis (including an assessment on the uncertainty associated to varius scenarios considered) in relation to the criteria and scenarios indicated as more relevant in the discussion. The "on-line" assistence of scientists during the discussion related to the decision making can make possible a more efficace multicriteria evaluation of

different options - over selected criteria spaces - by reflecting in a coherent way the information coming from different hierarchical levels described within various feasibility spaces. This should include also a discussion over the usefulness and validity of: (i) distinct multicriteria performance spaces that could be adopted; (ii) various hypotheses that could be used to discuss possible options over the selected multicriteria spaces.

An example of a Multi-Criteria Multiple-Scale Performance Space (MCMSPS) that can be used as an input in a Participatory Integrated Assessment is given in Fig. 2. In this example, 4 different families of indicators generated within different descriptive domains are used to represent the effects of 2 different scenarios (in this example, expected effect of Policy 1 → scenario 1; versus Policy 2 → scenario 2). The MCMSPS of Fig. 2 includes in the integrated assessment: (i) numerical values taken by the variables selected to describe the material standard of living of individual households (such as life expectancy at birth or net disposable cash); (ii) numerical values taken by variables selected to describe the economic performance of socio-economic systems analysed at different hierarchical levels (e.g. the GNP of the community or of the country within which the household is operating); (iii) values taken by variables selected to assess different types of environmental loading for the ecosystems affected by the behaviours of the socio-economic system considered (e.g. accumulation of pollutants, soil erosion, indicators of diversity of landscape- uses); (iv) values taken by variables selected to assess the validity of the "steady-state" view obtained by adopting the descriptive domains generating the assessments given in the other three quadrants (= how much the system is open and therefore how much its stability depends on the possibility of: (1) externalizing problems (such as excess of population and pollution); (2) importing resources from elsewhere (through a favourable terms of trade); (3) depleting existing stocks of resources (such as fossil energy, biodiversity, soil, undeground water) and (4) filling sinks, that is increasing the existing level of environmental loading (saturating the absorbing capacity of local ecosystems). Put in another way, this last quadrant tells us how much the assessments given in the other quadrants (by considering the system as in "quasi- steady-state") depend on current benign boundary conditions (availability of stocks of resources and sinks for pollutants, as well as the possibility of obtaining needed inputs from and externalizing unavoidable wastes to an accessible outer-space).

The choice of a multicriteiria multilevel representation of performance over distinct descritpive domains is an obliged choice when dealing with sustainability. In fact, without using a multilevel analysis is very easy to get models that simply suggest to shift a particular problem between different descriptive domains. Put in another way, "optimising models" based on a simplification of real systems within a single descriptive domain just tend to externalise the analyzed problem out of their own boundaries (e.g. economic profit can be boosted by increasing ecological or social stress, ecological impact can be reduced by reducing economic profit, and so on). This standard problem faced by monocriterial analyses is avoided by the method of analysis indicated in Fig. 2, since the use of different relevant and complementing descriptive domains makes possible to easily detect such an "epistemological cheating". Problems "externalised" by the conclusions suggested by one model (e.g. when describing things in economic terms) will reappear amplified into one of the parallel models (e.g. when describing the same change in biophysical terms or on a different scale).

9.2 Looking for procedures to be adopted in Participatory Integrated Assessment

In this last section we propose a specific example of a procedure which can be used to organize transdisciplinary analyses applied to a specific problem of governance in relation to sustainability. The proposed procedure can be used to generate a useful characterisation and integrated assessment of different scenarios of technological and organisational innovation in relation to the various dimensions of sustainability. This procedure is based on "complex system thinking" and aims at the evaluation of scenarios over a multicriteria performance space through a guided interaction of stakeholders and various scientific teams. It: (i) provides a multicriteria multiplescale assessment dealing with different aspects of possible policies (looking in parallel to economic, ecological, technical, social consequences); and (ii) boosts the reliability of analysis and simulations.

To make the life of the reader easier such a procedure is presented in relation to a real research project entitled: "Globalization and governance in 'commercial shrimp farming' versus 'mangroves': a multicriteria multilevel participative assessment of security and sustainability trade-offs". Clearly, details of the specific project are skipped here trying to focus on the general characteristics of the proposed procedure.

The first goal of the procedure is to properly start the process of interaction (resonance) between the two information input-types discussed before. As noted earlier, these two inputs are unavoidably locked into an "egg-chicken pattern" which cannot be broken. This situation should be expected any time we are dealing with complex problems with a lot of side-effects and hidden variables:

- perception of risks/opportunities -¿ selection of relevant criteria and the ranking of incommensurable trade-offs reflecting the organization of the information space found in the various stakeholders is obviously affected by a previous representation and structuring of the problem received in the past;
- in the same way, it would simply not be possible for any scientist to provide a scientific structuring of a problem without having an idea of what are the relevant criteria (= system's qualities to be mapped by the scientific model) to be considered in the first place.

For this reason the proposed procedure is based on the selection of two groups which are supposed to deal with these two different (but interdependent) tasks (that of providing input-type 1 and input-type 2) in parallel. The main goal of the procedure is to guarantee that the two groups collaborate in an useful way but without losing the specificity of their functions. We call the two groups:

1. Societal Advisory Board (SAB1) - a group of representative stakeholders (which is organized by experts in participatory/deliberative processes) which is in charge of providing the input-type 1 to the process of decision making. That is, this group has to: (i) perfrom a quality check on the scientific information; (ii) apply the scientific information to governance;
2. a Scientific Advisory Board (SAB2) - a transdisciplinary group of scientists which will be in charge of providing a tentative input of MOMS-SPS and then a continuous assistence in the iterative process of adjustment and validation. They have to deal with the problem of how to structure and represent, in scientific terms, a complex problem according to the concern and the needs expressed by Societal Advisory Board. Transdisciplinary means here: the ability to handle and use in parallel variables belonging to different descriptive domains (= encoding variables used in various modeling relations which are developed within different scientific disciplines)

The basic idea is to interface in an useful way: (1) the natural tendency of scientific knowledge to describe problems in "extensive adaptation terms" (= individuating classes of standard relations among qualities in relation to established patterns and standrad associative contexts). This is good since it provides compression and the possibility to forecast and predict possible outcomes. On the other hand, this is bad since in this way, there is a big risk of neglecting key elements related to the specificity of the case considered, and (2) the natural "local specificity" of each real situations (= representing an individual behaviour defined at a particular point in space and time). Practical problems are determined by a given history and the peculiarity of the given context considered. In a way they are all "special".

For this reason it is important to force the scientific advisory board to experience how the same set of security and sustainability trade-offs requires different methods of representation when packaged for different users. In the same way, it is important that the various groups of the societal advisory board experience how their legitimate specific perceptions of a problem have to be put in perspective with the legitimate specific perceptions of the same problem related to the different identity of other stakeholders.

To boost the richness (complexity) of the descriptive space the procedure requires that the societal and scientific advisory boards deal with a general problem [in this example a discussion and integrated assessment of sustainability trade-offs implied by the process of globalization in relation to shrimp farming versus mangroves] which is then structured in relation to different deliverables. Deliverables here are defined as "practical structuring of the problem in relation to specific contexts". That is these deliverables are required in order to make possible practical deliberative processes in relation to different information users. In our example we have 3 deliverables related to 3 information users: (1) a Government owned Bank looking for developing a protocol/procedure to be followed when assessing the funding of projects related to this issue; (2) a local community having to decide what to do with its available natural, human and economic resources in relation to the issue of shrimp-farming versus mangroves; (3) an international NGO trying to develop tools to be used for assisting local communities in their interfacing with the global market. Clearly, other or a larger number of "information users" could have been proposed in this type of procedure.

The different steps of the procedure:

1. Definition of the identity for the Societal and Scientific Advisory Boards

The selection of an indentity for the Societal Advisory Board and for the Scientific Advisory Board in relation to the problem to be tackled remains a completely open question in terms of standard rules to be followed (how to select them, who is entitled to decide about that ?). In fact, such a definition should be the result of a self-organizing process and not the result of a decision made by some agent (be a person or a group). For this reason we decide to rely, in the project, on an iterative process of improvements in the quality of the selection obtained through successive adjustments. This implies starting with a tentative solution based on past experience (based on knowledge related to similar situations). In this first tentative, the composition of the two boards can be indicated by using some expertise and common sense and then leaving open the two Boards to self-adjust if other relevant views and/or expertises should result relevant. Even though the handling of this process is everything but free from heavy implications in relation to the thematics of Post-Normal Science.

In general terms we can imagine that the Scientific Advisory Board should be always composed by two teams of scientists: (i) those working on qualitative analyses; (ii) those working on quantitative analysis. Whereas the Societal Advisory Board should include representative of key stakeholders and should be assisted by experts in participatory and deliberative processes.

2. Joint definition of a multicriteria performance space which can be useful for governance

2.1 Starting the process with an initial crossed input

The procedure have to start with a participative structuring of the problem to be dealt with. The two teams (SAB1 and SAB2) have to agree on a common structuring of the information space (= how to perform an integrated assessment of sustainability trade-offs linked to the specific problem considered). In order to do that, the interaction among the two SAB is based on their commitment to work out an integrated set of deliverables.

- Societal Advisory Board will prepare a first "draft" of their deliverables according to their own perception of relevant points to be considered [a list of deliverables is discussed below].

- Scientific Advisory Board will prepare a first input of Multi-Objective-Multi-Scale-Strategic-Problem-Structuring related to how to deal with this general problem in relation to the 3 deliverables.

2.2 "Stakeholders" and "Scientists" have to agree on how to organize the information space: joint defintion of deliverables for the two TASKS

The first input generated independently by the two Boards will be exchanged:

- the input provided by scientists is reflecting the "state-of-the-art" of the discussion about various relevant features as resulting from the past concern expressed by previous users (over a very large sample of population users).

- the input provided by stakeholders is reflecting the "location specific" conditioning of the context (e.g. lock-in, lack of knowledge of general information available for the scientists, BUT availability of location specific knowledge = a very valuable type of information which is in general not avaialble to the scientists).

In general, it can be expect that enough knowledge and expertise already exists in the two Boards (if the two groups have been wisely selected) to be able to get through this preliminary step of generation of a first input on both side in a quite short period of time. Otherwise, changes in the structure of the Boards is suggested.

The Scientific Advisory Board will have to agree on how to organize and represent a general class of trade-offs between economic, ecological and social performance applied to the particuar type of natural resources considered in the case study. In this phase there is no need for compression and filtering of redundant representations. On the other hand, the Societal Advisory Board will provide in its first input a "reality check" of what is perceived - in the specific context under analysis - as relevant for dealing with the problem.

After having exchanged their first inputs the two SAB will meet during a 3-day workshop (workshop 1). The "users" of scientific representation will react to the first input received from the scientists asking for explanations, or for a different representation (e.g. looking for more relevant or reliable analyses according to their views) of the problem. They will ask for including in the MOMS-SPS other variables or even of different models when discussing future scenarios. In the same way scientists will react to the information given by the Societal Advisory Board in terms of how to structuring the problem and choice of relevant criteria. Scientists can disagree on some of the criteria considered as relevant by the stakeholders attempting to convince them of their irrelevance (according to their views).

The exploration of possible alternative ways of representing and/or structuring the problem in relation to governance would also be enhanced by the existence of non-equivalent views within the Scientific Advisory Board. In fact, to guarantee diversity in the representation step the transdisciplinary team making up SAB2 should be selected looking for different approaches (quantitative and qualitative analysis).

The discussion should lead to a first general definition of deliverables for the groups working in the two self-entailing tasks.

A tentative list of possible deliverables is discussed below.

2.3 Using deliverables to homogenize the structuring of the problem

A tentative example of possible definitions of 3 deliverables related to the selected 3 information users include:

Deliverable A

"a governamental Bank" ↔ Scientists ↔ other stakeholders

TASK 1 - Information user 1 - Participative Integrated Assessment = Development of a protocol/procedure to assess the quality of projects to be funded in relation to the protection of mangroves and/or sustainable and equitable projects of development on coastal areas.

TASK 2 - MultiObjectiveMultipleScale-StrategicProblemStructuring = Development of a scientific analysis adequate to support the generation of the deliverable A.

This deliverable implies working on the selection of several criteria and relative indicators:

1. Viability - assessing steady-state performance, that is: assessing the economic, social and ecological effects of the project to be funded at different scales (local, medium, large);

2. Trend analysis - assessing evolutionary performance, that is: comparing present position of the system under analysis to the trajectory of other socio-economic systems which share (and/or shared) some similarities. Study variables relevant to understand current position of the system within the domain of evolutionary trajectories;

3. Selection of additional indicators of performance that can be used to reflect social and ethical concerns express within the analyzed contexst (for example):

   (a) "Environmental Justice" = are those getting the profit also getting a proportional share of negative side effects linked to higher environmental loadings ? that is, do investments and profits come from outside and go again outside the system whereas the negative side effects of higher environmental loading are the only things retained within the boundary of the system ? Indicators to address this issue can be made by tracking what happens to flows of money and to the related flows of matter and energy;

   (b) "Empowerment of local communities" does the project include the active involvement local stakeholders in the process of gathering relevant or even critical information for decision making as well as in the generation of an important input to the final decision (when defining the terms of reference of the project and the modality of its implementation) ?;

   (c) "Accounting of ecological impact" (what are the more opportune indicators that should be used to include this criteria into an integrated assessment ?);

   (d) "Gender analysis" - are there differential impacts (as well as risks and opportunities) according to gender ?

   (e) Characterization of the "robustness of governance processes" - are we sure that during and after the implementation of the project it will be done what was supposed to be done ? Are we confident that the mechanisms of control and current power structure in the area can guarantee that the original planning and written statements will be followed in the reality ? (what indicators can be used from institutional analysis, political analysis) ? If the answer is no, then what can be done to deal with such a problem ?

4. Inclusion in the multicriteria performance space of a set of conventional criteria needed by a Bank for project assessment .

Deliverable B

Local Community ↔ Scientists ↔ other stakeholders

TASK 1 - Information user 2 - Participative Integrated Assessment = local community will define a multicriteria performance space the will be used to discuss and negotiate practical decisions in relation to security and sustainability trade-offs within a participative context (e.g. people juries).

TASK 2 - MultiObjectiveMultiScaleStrategicProblem Structuring = Development of a scientific analysis adequate to support the generation of the deliverable B.

Starting from a set of practical problem proposed by the communities the project should be able to implement a joint process of Participatory Integrated Assessment using the scientists and the other stakeholders for analyzing possible future roles of available resources for the welfare of the community in relation to alternative policy tools

Deliverable C

NGO ↔ Scientists ↔ other stakeholders

TASK 1 - Information User 3 - Participative Integrated Assessment = Exploring the terms of the sustainability trade-offs in the conflict over mangroves in relation to a growing interaction of local communities, through the international market with the global economy. In this project, the specific focus will be on how to label as "satisficing products" local products that will be commercialized in developed countries within the "solidarity shops" circuit . Main questions to be answered are: what are the relevant criteria and suitable indicators to be used to perform such a labeling ? who should decide about that ?;

TASK 2 - MultiObjectiveMultiScaleStrategicIntegratedRepresentation = Development of a scientific analysis adequate to support the generation of the deliverable C.

In this deliverable, the set of general criteria to be used should basically reflect those already discussed in previous deliverable A (when defining a "quality check" for proposed projects to fund). However, the difference in focus provided by the people working in the non-profit organizations compared to those working in a Bank can determine a quite different demand for a "useful" scientific characterization of security and sustainability trade- offs. Other stakeholders included in the Societal board such as the local association of producers or local NGO defending the interests of marginal social groups (e.g. single women faimilies) can certainly play a crucial role in the working out and in the making operational negotiated solutions in the development of deliverable C.

3. Boosting the reliability of the scientific input within the MOMS-SPS

At this point the scientists, on the basis of the set of incommensurable evaluation criteria reflecting the various interests of principal stakeholders have to: (i) individuate various descriptive domains relevant for representing these problems; (ii) select an appropriate set of indicators of performance to discuss of trade-offs over the various dimension of the problem; (iii) propose a consequent set of models able to simulate the behaviour of the system in relation to changes related to these indicatore; (iv) using existing databases (with variables defined on different descriptive domains) to provide a generic representation of the basic terms of the problem in terms of a package of models making possible viability checks, comparison with similar situations and strategic assessments.

This requires a previous step dedicated to the selection of a set of existing models that can be used, in a parallel running, to generate all the indicators of performance selected in step 1 (Fig. 3). The formulation of a package of models can be used also to establish mechanisms of reciprocal constraining among the various models when running them in parallel (= a congruence check of flows of energy, money and human time).

3.1 Generating mosaic effect in the scientific information space

Going back to the application of the procedure in our practical example, the "Scientific Advisory Board" has to define 3 packages of integrated models able to generate for each of the users: (a) robust and reliable information input to characterize possible options; and (b) a set of indicators of reflecting the set of relevant criteria of performance indicated by each of the stakeholders. In particular: (1) the groups working on qualitative analyses will develop a series of parallel studies relevant to the discussion of the reliability and reasonability of the assumptions used in the models determining quantitative analyses. This would include: (i) historic analysis of social and environmental conflicts linked to shrimp farming; this will be based on a comparative analysis with similar situations; (ii) comparative institutional analysis in relation to the previous overview; (iii) socio-economic, political, anthropological analysis in relation to the root and the nature of these conflict; (iv) overview of analytical tools available to define and assess the various security and sustainability trade-offs implied by changes within the descriptive domains referring to socio-economic analyses. (2) the groups working on quantitative analysis will develop an ensemble of analytical tools able to provide a Multi-Objective-Multi-Scale Modeling of the problems selected for the "case study" (Giampietro and Pastore, 1999).

Since the ability of any model to "see" and encode some qualities of the natural world implies that the same model cannot "see" other qualities detectable only on different descriptive domains. In this step the parallel use of non-equivalent models is a necessity. However, the selected models, already validated within the scientific community, have to be organised in an integrated package. That is, on the basis of the identity of the multicriteria multiplescale perfromance space selected in Step 1, the scientists working on quantitative methods of representation have to select a set of existing models that will be used, in a parallel running, to generate all the indicators of performance required by the MOMS performance space. The various models will cover with their descriptive domains different hierarchical levels of analysis and different scientific disciplinary domains.

As already observed an integrated scientific representation over non-equivalent descriptive domains with a parallel modelling on several levels is not only required to provide a more relevant characterization of the perfromance, but also to boost the reliability of such an analysis. In the example indicated in Fig. 3 the models cover three contiguous hierarchical levels (raws of the 3X3 matrix): (i) household level, (ii) community level (iii) national level; and 3 different scientific domains of mapping (columns of the 3X3 matrix): (i) models based on socio-economic variables; (ii) models based on biophysical variables (accounting of energy and matter flows); (iii) models based on geographic characterization of analyzed processes. The level of satisfaction of various scenarios generate in such an integrated assessment is then expressed by the trade-offs profile resulting on the selected Multicriteiria Multilevel Performance Space.

According to the selection of the encoding variables for the various models the scientists can attempt to impose a series of a congruence check over the flows of energy, money and human time over the various compartments of the system considered and across its hierarchical levels. In this way, each model of the selected package will provide as output: (i) numerical values to fill part of the required set of performance indicators; (ii) numerical values that can be used to perform a congruence check with description given by non-equivalent models.

This organization of scientific activity makes possible to better interface qualitative analyses (e.g. trend and institutional analyses) to quantitative analyses, since this becomes an obliged step to deal with the insurgence of bifurcations.

The big matrix in the center of Fig. 3 represents the package of models used to perform quantitative analyses (referring to various levels and various descriptive domains). When the various models bifurcate from each other (when they produce values for output variables that are either not compatible with values taken by other variables in other models, or not compatible with what is known from trend analysis) it is necessary to perform a "semantic check" for explaining such a lack of congruence. This implies that qualitative reasoning and "value calls" made by stakeholders and other scientists will be continuously needed to check the quantitative information generated.

In this way the work of the scientists generating quantitative analyses will undergo a continuous "quality control" operated by: (i) other scientific groups working also on quantitative analyses, but in different descriptive domains; (ii) the scientific groups working on qualitative analysis (related to evolutionary trajectories and providing different trend analysis on the various relevant levels and descriptive domains); (iii) the societal advisory board providing the "ultimate" quality check of stakeholders on the entire process of scientific structuring of the problem.

Getting more in details on the type of analysis that can be perfromed in this way, Fig.4 present how it is possible to boost the reliability of scientific analyses by generating mosaic effects using in parallel non-equivalent descriptive domains and bridging different hierarchical levels (for a detailed example of scientific analysis of this type performed by bridging different descriptive domains and crossing different hierarchical levels see Giampietro and Pastore, 1999; and Pastore et al. 1999).

4. Iterative validation of the emerging MOMS-SPS through PIA (= it is actual MOMS-SPS useful when looking for solutions ?)

Next step of the procedure is to validate such an integrated package of models which can be operated only by mixing the expertise of quantitative and qualitative scientific analysts and which is reflecting the original basic structuring of the problem in terms of perception of relevant trade-offs to be considered. Obviously its validation can only be obtained in relation to its ability to facilitate deliberative processes (specific decision to be taken). This is why practical deliverables were introduced in the first place. That is, this step has to check whether or not the organization of the existing information about the problem to be tackled make possible to solve the given problems within a participatory context and by achieving satisfying solutions.

Keeping the interaction between groups working on parallel TASKS

The previous agreement on the basic organization of the information space and the reciprocal need of inputs from the other side tend to guarantee a natural level of interaction between the activities of the two Boards. However, the procedure can imply scheduled events which will force the respect of deadlines (and therefore forced compression of process of discussion, understanding and negotiation). The trade-offs between compression (decisions have to be made in a finite and often very short time) and relevance (time invested in discussions, negotiations and explanations should be considered as the most valuable output of this process, because it is when investing in these activities that social learning and trust - both crucial ingredients for procedural sustainability - are produced) is a very delicate one. Therefore, also in this case the handling of scheduled event should be kept as flexible as possible, depending on the special trajectory taekne by the specific deliberative process. In any case, other meetings can be scheduled for boosting the level of interaction between the two boards.

Additional meetings of those concerned with generating scientific representations of a complex problem and those concerned with using the scientific representations of the complex problem for governance through participatory processes should be used to exchange ideas and advice about how to do better in their relative jobs (deliverables). The two sides will have the opportunity to assess the first draft of the deliverables made by the others and check the reciprocal suitability of the relative deliverables (as an input for the other group);

The structure of the interactions in this phase of the project in relation to the various roles that the various actors will play in the running of parallel activities is given in Fig. 5. The expression "semantic check" it is not only related to the insurgence of bifurcations (discussed in the previous section) but also to a continutous monitoring of the validity of the original selection of relevant criteria, encoding variables, models, sources of data, solutions given to the problem of uncertanity and lack of information, hypotheses used to generate scenarios (deciding about reasonable assumptions, goals and targets of each simulation). That is, in this iterative process, the societal advisory board has to provide the "Quality Control" on the entire process which generated and is generating the actual MOMSSPS.

The crucial role of scientists working in participative techniques

Before closing the presentation of this practical case study it is important to stress that when the implementing such a procedure it is crucial to have a team of scientists/experts in participative and deliberative process. Such an expertise is obviously essential in keeping the iterative process together (to involve the various members of the societal advisory team into the discussion - getting inputs from and giving input to the scientific advisory team). That is for generating the "emergent properties" looked for, out of the iterative process.

It is also important to mention here another crucial expertise. That related to the design of Information Communication Technologies for interactive multistakeholders assessment. As indicated in the overall picture of the project given in Fig. 11 these technologies are needed for being able to involve the stakeholders in the various phases of the project. These can include communication technologies able to enhance the interaction among stakeholders (focus groups, people juries) and/or able to make more user friendly hard scientific models (so that various stakeholders can be more interactive with the scientific input delivered in the form of computer based models).

9.3 Conclusion

In this second paper we tried to convince the reader of the following point: Humans could already do better in organizing their processes of decision making when dealing with the issue of sustainability. In order to do so, they should rely more on multicriteria analysis linked to participatory processes. This change would require, however, a "political" commitment of: (i) decision makers; (ii) scientists; (iii) stakeholders in getting involved in new and certainly more challenging and trasparent mechanisms of governance. For each one of these three groups this would imply taking much more direct responsability. Unfortunately, such a political will (a strong demand for adopting these new tools) is not always present. On the other hand, it is also true that very often what "conventional scientists" have been offering to decision makers and stakeholders (the existing supply of decision aids) is certainly not helping much such evolution. The academic lock-in on analysis based on substantive definitions of sustainability certainly seems to play a crucial role in determining such a problem.

Participatory Integrated Assessment

Multi-Objective-Multiple-Scale Strategic-Problem-Structuring

inputs that cannot and should not be given (but needed) by scientists ⇄ **inputs that scientists can and should provide to decision makers**

(1) defining the relevant criteria to be used to represent and considered when deciding;

(2) "Quality control" on data, models and scenarios proposed as scientific input for the process of decision making;

(3) negotiation among stakeholders and iterative process within the step REPRESENT deciding whether or not the set of criteria used to represent the problem (in step 1) are really the most relevant ones;

(4) final call on the "satisficing" compromises over the examined profile of trade-offs (both in terms of short-term efficiency and long-term adaptability);

(5) "Quality control" on the various procedures used in the steps of:
(i) Negotiation (Policy evaluation);
(ii) Decision Making (Policy definition);
(iii) Implementation of decisions (Policy enforcement);

(6) Continuous monitoring (with feed-backs) at different levels and locations for detecting unexpected consequences of previous decisions

(1) identify various possible useful representations (parallel identities and boundaries for the same system when represented as doing different functions). That is, a set of relevant variables and dynamics over non-equivalent descriptive domains needed to catch the relevant features;

(2) individuating feasibility spaces (= range of admissible values) for each of the selected indicators of performance

(3) defining the overal perfromance of the system in reation to each of the selected indicators;

(4) making possible a multicriteria evaluation of different options over the selected criteria space (by providing a trade-off profile over it);

(5)boosting the reliability of scientific input by generating redundancy in the information space (looking for Mosaic Effects)

(6) filtering out poor quality data, incoherent scenarios and forcing transdisciplinarity in the step representation

inputs that cannot and should not be given (but needed) by scientists ⇄ **inputs that scientists can and should provide to decision makers**

Figure 9.1: Resonance between PIA and MOMS-SPS

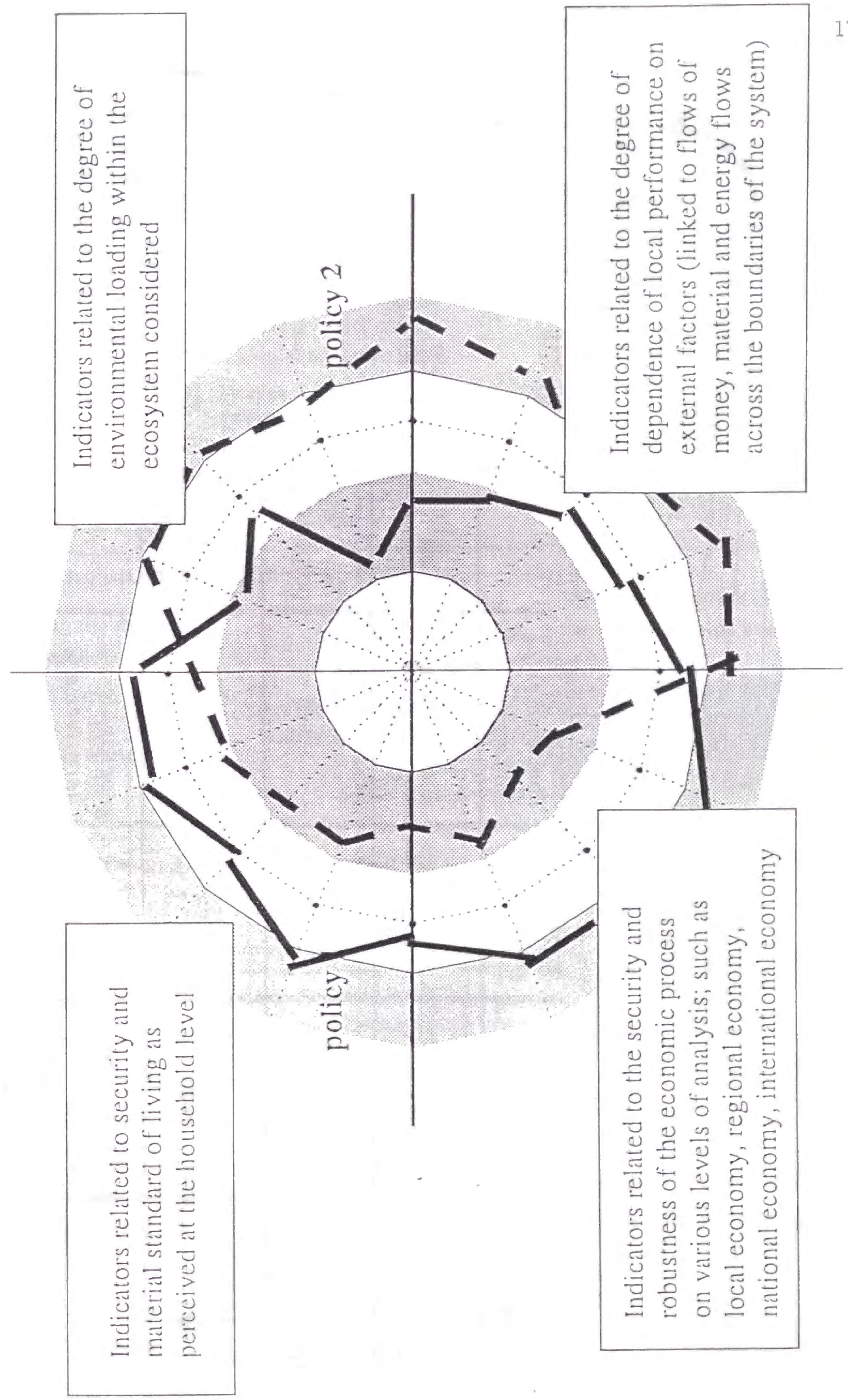


Figure 9.2: Integrated assessment over a Multi-Criteria Multiple-Scale performance space of security/sustainability trade-offs

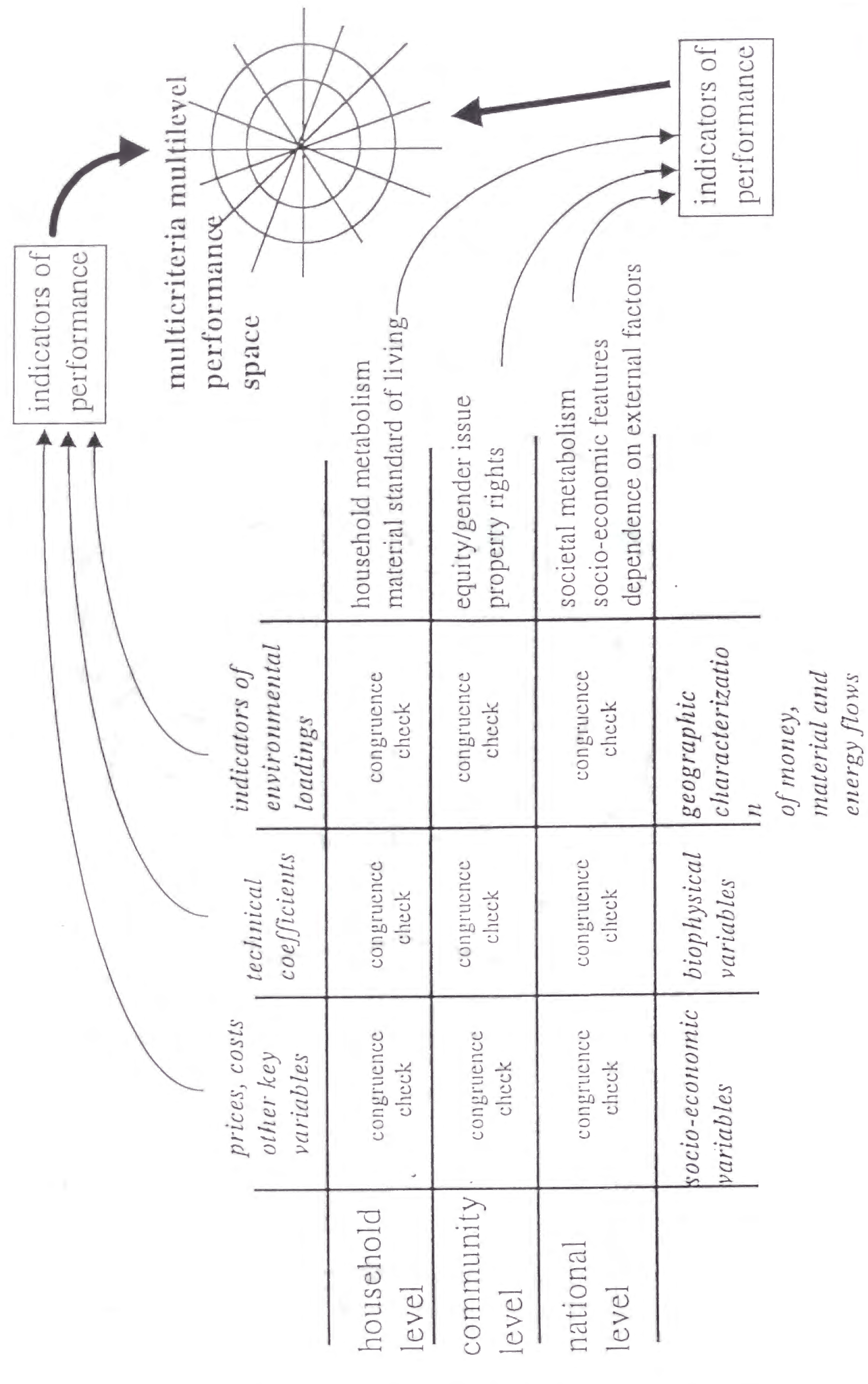


Figure 9.3: Multi-Objective Multi-Scale Strategic-Problem-Structuring using non-equivalent descriptive domains and looking for mosaic effect

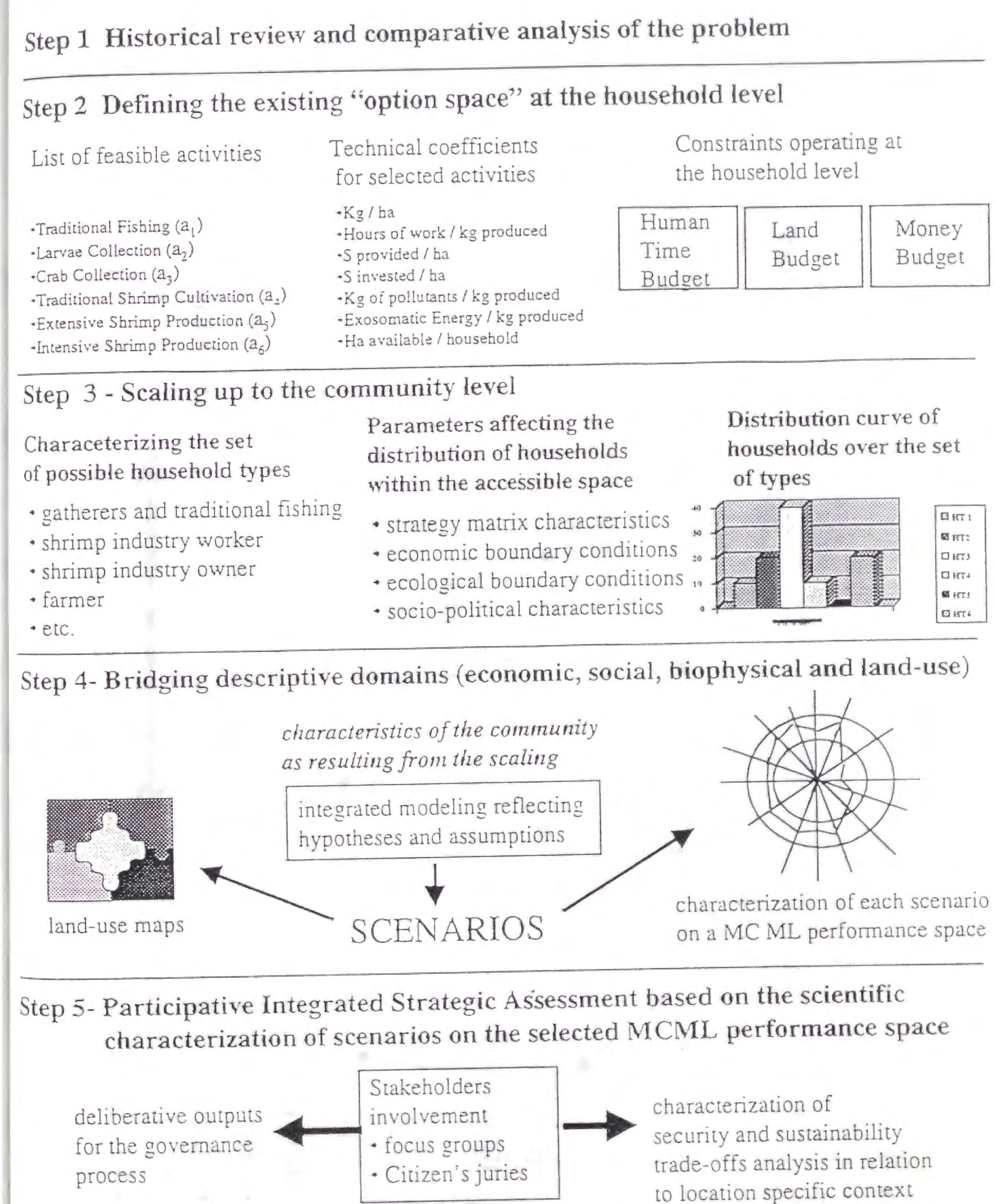


Figure 9.4: Integrated assessment based on a robust representation of security and sustainability trade-offs on Multi-Objective Multi-Level performance space

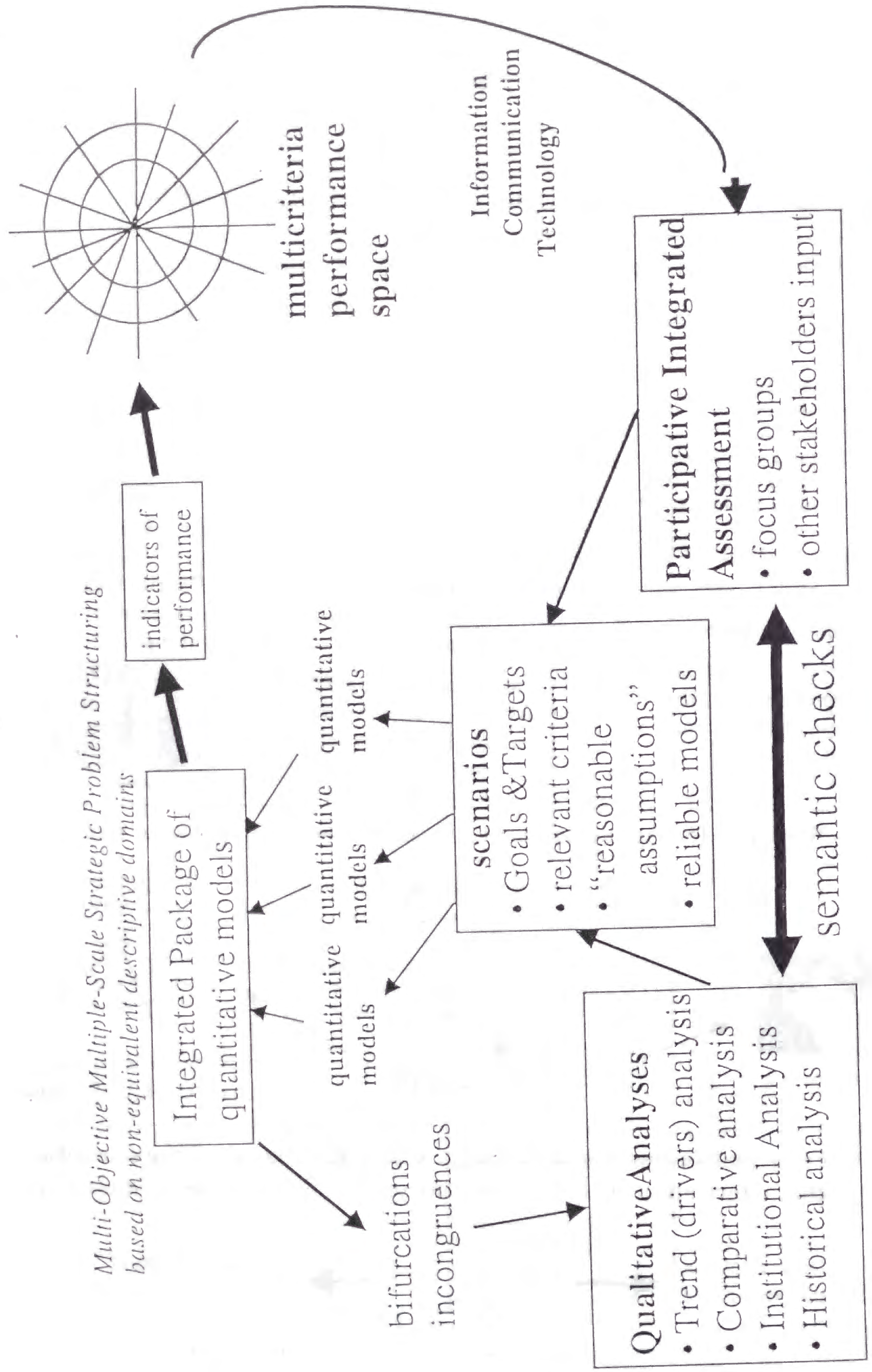


Figure 9.5: Mixing quantitative and qualitative analyses to discuss sustainability trade-offs

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