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Multi-Objective Integrated Representation (MOIR): an innovative tool for farming system analysis

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You cannot observe a wave without bearing in mind the complex features that concur in shaping it and the other, equally complex ones that the wave itself originates. ... And so the wave continues to grow and gain strength until the clash with contrary waves gradually dulls it and makes it disappear, or else twists it until it is confused in one of the many dynasties of oblique waves slammed against the shore. ... Mr. Palomar goes off along the beach, tense and nervous as when he came, and even more unsure about everything.

From "*Reading a wave*"
in "Palomar", by Italo Calvino

Preface

This thesis resumes the results of years of field work and theoretical work dealing with rural development and integrated analysis of farming systems and agro-ecosystems.

While based at Padua University, I have been involved in two research projects, one dealing with: (i) an analysis of the sustainability of agriculture development in central China, and (ii) implementation of rural development policies for the Vietnamese uplands. All together I spent one and a half year in Asia carrying on field work for these two projects. Later on, when already a student at the Universitat Autonoma de Barcelona (UAB, Spain), I got a research fellowship at the Istituto Nazionale per la Ricerca sugli Alimenti e la Nutrizione (I.N.R.A.N, Rome, Italy), within another research project concerning socio-economic transition of four South East Asia countries (Vietnam, Laos, Thailand, Philippines). For this project I carried on theoretical work having as aim the development of tools for multi-criteria analysis of farming system and agro-ecosystem under the guidance of Dr. Mario Giampietro (Director of the Unit of Technological Assessment at INRAN and at that time visiting professor at UAB).

All these experiences enriched me greatly both personally and professionally. They made me aware of the importance of personal interactions in science. Only in this way, in fact, it becomes possible to exchange ideas and knowledge with different people, taking advantage of the knowledge developed in different fields in order to gain a richer perception of the emerging complex problems of our time.

Eventually, my task was no longer that of providing the stakeholders with “the right solution” to their problems (as I no longer believe in the existence of it). Rather my task became that of providing a clear, honest and as much as possible useful representation of their problems. Put in another way, my task became that of developing procedures and tools useful for a sound and effective integrated representation of the performance of farming systems. The adjective "sound" here indicates an integrated representation which helps stakeholders to share meanings about the data and analytical models used as basis for discussion. The enhancing of mutual understanding about how to evaluate the incommensurable trade-offs that any decision implies should be considered a crucial step in this sense. The Multi-Objective Integrated Representation (MOIR) for farming systems analysis presented in this work, is then intended as a tool to facilitate stakeholders participation both in the model construction and in the decisional process. Therefore the goal of this thesis is not that of offering best solutions for the sustainability predicament. Rather it suggests an approach aimed at enabling an informed search for *satisfying solutions* for the problems faced by farming systems.

The discussion of these topics is carried out within the context of rural development and environmental management. The thesis starts from the acknowledgment that at present we are facing problems that are not addressed by the set of standard solutions offered by traditional approaches. That is, humankind is facing new challenges, which require new tools and a fresh way to frame narratives (the account of “facts” according to different perspectives). In relation to this goal, hierarchy and complexity theory offer a theoretical background, that, along with the rationale of multicriteria analysis, can be used to gain new insights for a more effective system analysis.

I am well aware of the difficulties that constructing a satisfying integrated representation of the reality implies. For example, when discussing of sustainability the number of relevant criteria and indicators and their relative importance can never be decided in a substantive way, whenever in presence of conflicting interests and goals. Data and figures are also, often (if not always) arguable. The case studies presented in this work, for instance, deal with farming system analysis in countries as diverse as China, Vietnam and Italy. Countries in which it is hard enough to grasp just the surface of "facts", and where many socio-economic and environmental facts are missing or purposefully manipulated, where even some of the most simple indicators, such as population and GNP are highly fuzzy and arguable. Furthermore, in order to improve our understanding of farming systems (as any other human activity), I consider it necessary to contextualize the activity of the farming system under analysis within the historical, cultural, socio-political as well as environmental dimension of the society to which it belongs.

Should this approach be presented as a new paradigm? I wish not to enter in such an issue. At present, in fact, the number of new paradigms, a term made famous by Kuhn's book "*The structure of scientific revolutions*" (1962), is growing impressively in all fields, as fast as they disappear soon after the publication (Cohen, 1999). It has to be noted that although often authors refer to paradigm "*in Kunhnan sense*", Kuhn himself had troubles to precisely define the term. He even commented that a reader found that in his book the term is used in at least twenty-two different ways (Kuhn quoted in Cohen, 1999).

Should this approach be considered as something able to handle the conventional predicament of sustainability? To this question the answer is a clear no. Rather I consider this approach as misleading. In fact, while from one side it generates dangerous myths (infinite growth on limited resources), on the other while showing a bright future ahead it avoids to face some "remote" but still crucial problems of our time (e.g. vested interests, extended social exclusion, media control, concentration of economic power). This is like a doctor who, facing an ill patient, discusses about the best way to give him eternal life without bothering to deal with the actual problem that the patient is suffering now. Would not be better for the patient that the doctor forgets about the search for eternal life to carry on a good and honest check-up in order to understand what the patient is suffering from and how to remove the causes of his disease?

The goal of this work may be included in a new discipline. A discipline that studies how to deal with the challenge implied by "*surfing complexity*". I heard this definition from Mario Giampietro (see also Giampietro, 2004), and I find that this is an appropriate way to represent what he and I are trying to do (and I would extend the concept to the idea of "*surfing life*"). It well addresses the dynamic and evolving nature of living systems. They require a continuous tailoring of models, tools, procedures as well as exploring new concepts and ideas to deal, in real time, with the complex nature of a becoming world.

The procedure required to generate a MOIR, as presented in this thesis, has three main objectives: (1) structuring multiple narratives (reflecting the legitimate perspectives of multiple stakeholders) required to organize the discussion of development scenarios (e.g. comparative integrated analysis of freshwater aquaculture presented in chapter 6); (2) contextualizing the performance of farming systems within their higher supra systems, (e.g. regional, national, international level) – benchmarking - or lower subsystems, (e.g. technical characteristics of the farming system, biophysical properties of the farmland) – characterization of technical constraints; and (3) supplying effective tools for analysis of development to check the robustness of assumptions (e.g. ex-post evaluation of the implementation of a policy of rural development in Vietnam in chapter 7).

I just hope that what is presented in this work can be useful to generate new ideas and tools to improve our way to deal with farming systems analysis, and more broadly with the issues concerning human development and environmental management.

Acknowledgement

Events in our life, including the possibility to achieve our goals, are always a matter of a mixture of will, stochastic events and a lot of luck. A huge amount of small details, most of which unnoticed, bring us (willing or unwilling) where we are.

My family gave me the opportunity and the support (both material and moral) to pursue my scientific hobby all along the way. Professor Dario Colombera (former professor of genetics and human biology at Padova University), made me aware that this path was worth to be pursued (notwithstanding all), and introduced me to the art of Go, a Sino-Japanese board game, that was for me the first insight to complex thinking (the interested reader can visit the web page <http://gobase.org> for a comprehensive overview on this game). Dr. Maurizio G. Paoletti (Padova University) offered me the chance from where to start, and move on, allowing me to run into Dr. Mario Giampietro. Such a lucky event drove me into the field of modelling and multicriteria (complex) thinking, as well as to this Ph.D. thesis. Professors Juan Martinez-Alier and Giuseppe Munda, then, welcomed me at the Universitat Autonoma de Barcelona, to spend two great years of my life. I wish to thanks professor Martinez-Alier also for his valuable work in reviewing the final manuscript of the thesis and his helpful comments. Time to time, along the way, professor Kozo Mayumi (Tokushima University, Japan) provided moral support and encouragement (as well as some key literature).

I feel deeply in debt with all of them. Everyone was crucial in getting me here. However, I wish to express a very special thank to Mario Giampietro for his teaching and help in the last 10 years, as well as for his invaluable work in reviewing this dissertation. Without his long lasting support this work would have not be possible. I wish to underline, though, that the limits of this work are just my own responsibility and reflects my own shortcomings.

I wish also to thank all the friends and people I met on my way, who contributed in a way or another to the accomplishment of this work. In particular:

For chapter 6, I thank Professor Han Chunru and Dr. Long Muhua at Beijing Agricultural University and Cai Lie Wan and Xu Jin Ze at Quenjiang county, Hubei province, for their assistance to and collaboration during my fieldwork in China. I am indebted to professor L. Colombo, Dept. of Biology, Padua University, and Dr. A. Perolo, President of the Association Piscicoltori Italiani (API), for providing helpful information on freshwater fish aquaculture in Italy.

For chapter 7, I gratefully acknowledge the work carried out by Barbara Vinceti and Alessandra Gribaldo who along with me took part in the field work in Vietnam. I also acknowledge Professors Davide Pettenella, Paolo Palmieri, Paolo Faggi and Maurizio G. Paoletti, from University of Padova, Italy, for their support. A special thank goes to Professor Nguyen van So and Dr. Phan Trieu Giang, and to the team members of the Thu Duc University of Agriculture and Forestry (Ho Chi Minh City), the Xuan Mai Forestry College (Hanoi), and one representative of the University of Hue who shared the field activity in co-operation with the Italian research team. Finally, a special thank is due to the people of Thuong Lo and Phong Du communes, for their warm welcome, patience, and teaching.

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Summary

Part 1 The complexity of the challenge associated with an integrated analysis of sustainability in agriculture

This part is made of three chapters. It has the goal to introduce the main issue: why it is necessary to look for innovative tools when analyzing agricultural development.

* **Chapter 1** introduces the basic issue addressed by this thesis. (1) The effects of human activity associated to economic growth over the planet reached a size and an aggregate effect that requires a complete rethinking of the foundations and system of belief for social development. The case of technological progress in agriculture is one in which this problem is more evident because of its growing negative impact on the environment, on the efficiency of resources use and on the stability of rural socio-economic systems. (2) The analytical tools used to assess agriculture and farming system performance, which are still based on the Neo-classical economic paradigm, are, in my view, evidently inappropriate to deal with the complex problems of our time, especially when considering environmental or social issues. In the case of agriculture it is urgent to recognizing the multifunctional role and the complex meaning of agriculture systems and to develop effective analytical tools based on these concepts.

* **Chapter 2** introduces new concepts, theories and narratives developed in the field of complex systems thinking that I think very useful for dealing with an effective analysis of farming systems and rural development. The field is still in an early stage of development, and very few analysts address deep epistemological issues. In any case it is important to be aware of new concepts developed in this field since they can provide the basic rationale for the development of innovative analytical tools such as those presented in part 3.

* **Chapter 3** provides an overview of complex system theories and introduces the perspective of complex system theory as developed by Robert Rosen (one of the few theoreticians which dared to address the issue of complexity in terms of the characteristics of the observer/observed complex). This chapter introduces a few concepts required to understand the philosophy of the approach MOIR presented in Part 3: modelling relation, essence, identity, attributes and indicator.

Part 2 An overview of existing graphic tools and the procedure for Multi-Objective Integrated Representation of farming systems

This part is made of 2 chapters. It has the goal of presenting innovative procedures for structuring the representation of scientific information used in a process of decision making about development. In particular it deals with the integrated use of indicators belonging to non-reducible descriptive domains (e.g. environmental, social, economic, cultural). More technically this means using in parallel variables referring to observable systems qualities, which are defined at different scales (e.g. households, local community, nation; local ecosystem, watershed, global system), or referring to system attributes associated to incompatible definitions of identity for the same system (e.g. farming land aiming at

maximizing biomass harvest vs. preserving natural ecosystem and its biodiversity). In particular:

*** Chapter 4** provides an overview of graphic tools that are currently used for integrated analysis in the fields of rural development, environmental management and development policy (in general coupled to Multi-Criteria Analysis). The overview includes also an appraisal of the various methods in terms of pros and cons.

*** Chapter 5** presents a procedure that can be used to perform Multi-Scale integrated analysis. That is, a multi-objective representation based on package of indicators and covering perception of relevant aspects of the reality referring to different space-time scales and to a diversity of social actors. The various tools illustrated in this chapter are referring to farming system analysis.

Part 3 Applications of Multi-Objective Integrated Representation (MOIR)

This part is made by 2 chapters and has the goal to show the feasibility and flexibility of the procedure and analytical tools proposed in Part 2. In particular case studies are used to verify the usefulness of such an approach in providing new insights in the issues considered (by helping the sharing of meaning among stakeholders). In particular the two case studies proposed refer to different typologies of problems defined at different scales:

*** Chapter 6** presents an analysis of the performance of system of production of aquaculture. In particular the approach of Multi-Scale Integrated Analysis is applied to characterize systems of production operating in two completely different socio-economic and ecological contexts: (i) low-tech rural areas of China; (ii) high-tech rural areas of Italy. The approach makes it possible to compare these two systems, but at the same time to define benchmark values, constraints and opportunities of these two systems in relation to their relative socio-economic contexts.

*** Chapter 7** presents the application of MOIR to an ex-post analysis of the implementation of a FAO project in a village in the Vietnamese uplands: As a way to characterize the various effects, options and constraints that could be expected in this project when a multicriteria, multiple scales approach is adopted.

Conclusions

*** Chapter 8** briefly summarizes the most important lessons that can be driven home from what has been presented in this thesis.

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Part 1

The complexity of the challenge associated with an integrated analysis of sustainability in agriculture

This part is made of 3 chapters. It discusses the need to rediscover the complex meanings of agriculture and introduces new concepts developed in the field of complex systems thinking. In particular:

Chapter 1: Rediscovering the complexity of agriculture: new concepts (e.g. multifunctionality) call for new analytical tools (e.g. multi-scale integrated analysis)

It introduces the basic issue addressed by this thesis. (1) The effects of human activity associated to economic growth over the planet reached a size and an aggregate effect that requires a complete rethinking of the foundations and system of believes for social development. The case of technological progress in agriculture is one in which this problem is more evident because of its growing negative impact on the environment, on the efficiency of resources use and on the stability of rural socio-economic systems. (2) The analytical tools used to assess agriculture and farming system performance, which are still based on the Neo-classical economic paradigm, are, in my view, evidently inappropriate to deal with the complex problems of our time, especially when considering environmental or social issues. In the case of agriculture it is urgent to recognizing the multifunctional role and the complex meaning of agriculture systems and to develop effective analytical tools based on these concepts.

Chapter 2: Acknowledging the complexity revolution: an overview of concepts, theories and narratives

It introduces new concepts, theories and narratives developed in the field of complex systems thinking useful for dealing with the analysis of sustainability. The field is still in an early stage of development, and very few analysts address deep epistemological issues. In any case it is important to be aware of new concepts developed in this field since they can provide the basic rationale for the development of the innovative analytical tools presented in part 3.

Chapter 3: Introducing innovative concepts derived from complex systems thinking “à la Rosen”: modeling relation, essence, identity, attributes and indicators

It introduces the perspective of complex system theory as developed by Robert Rosen (one of the few theoreticians which dared to address the issue of complexity in terms of the characteristics of the observer/observed complex). This chapter introduces a few concepts required to understand the philosophy of the approach MOIR presented in Part 3: modelling relation, essence, identity, attributes and indicators.

Chapter 1

Rediscovering the complexity of agriculture: new concepts (e.g. multifunctionality) call for new analytical tools (e.g. multi-scale integrated analysis)

> *Perhaps the most serious obstacle impeding the evolution of a land ethic is the fact that our educational and economic system is headed away from, rather then toward, an intense consciousness of land.*
> Aldo Leopold[1]

> *The difficulty lies not in new ideas, but in escaping from the old ones*.
> John Maynard Keynes[2]

> *You can't defeat a measure or a candidate simply by pointing to defects and inadequacies. You must offer an alternative*.
> Herbert Simon[3]

Summary

This chapter introduces the basic issue addressed by this thesis. (1) The effects of human activity associated to economic growth over the planet reached a size and an aggregate effect that requires a complete rethinking of the foundations and system of beliefs for social development. The case of technological progress in agriculture is one in which this problem is more evident because of its growing negative impact on the environment, on the efficiency of resources use and on the stability of rural socio-economic systems. (2) The analytical tools used to assess agriculture and farming system performance, which are still based on the Neo-classical economic paradigm, are, in my view, evidently inappropriate to deal with the complex problems of our time, especially when considering environmental or social issues. In the case of agriculture it is urgent to recognizing the multifunctional role and the complex meaning of agriculture systems and to develop effective analytical tools based on these concepts.

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[1] In: Leopold (1966), p. 261.

[2] In: *The general theory of employment, interests and money,* (1936, p. viii), quoted in Meyer (1993, p. 881).

[3] In: Lecture to the memory of Alfred Nobel, December 8, 1978 (p. 366).

1.1 Introduction: Reaching the limits to externalization

Since the beginning of human history the limit posed by the availability of solar energy (along with some others basic resources) constrained how much humans could produce or import. Time to time humans overcame scarcity by finding new ways to increase production. Time to time the past achievement was overtaken by a larger population to be fed. This raised the cost to be paid for the maintenance of novel complex social structures that had to be created to manage the challenge to boost production itself - e.g. extending the land under culture, intensification of production by means of irrigation works, supporting technological shifts (Tainter, 1988; 1996; Allen *et al.*, 2003). Then limits were met again and further geographical expansion was needed to keep an inflow of resource capable of meeting the demand of a larger and larger population and a more and more complex social organization. This is the standard framing of the technical progress in agriculture (Carter and Dale, 1974; Boserup, 1981; Tainter, 1988; 1996; Diamond, 1997). With this solution, however, problems were continuously "externalized" to neighborhood ecosystems and societies.

With the industrial revolution and the fossil energy era, boundaries of the biophysical process of production and consumption seem to disappear (Odum, 1971; Georgescu-Roegen, 1975; Mayumi, 2001). Food and goods can be produced and traded cheaply and fast overcoming, (at least temporarily - Mayumi, 2001), the traditional biophysical limits of shortage of land, labor and resources. But relying on a huge stock of energy, which is now available for a part of humankind, did not solve old problems and generated new ones.

Intensification of crop production reached a limit in every sense and it is not that sure that further intensification, thanks to an higher energy investment (e.g. irrigation, desalinization of sea water) and new technologies (e.g. genetically engineered crops), could bring us more goods then worst (Doyle, 1986; Smil, 1987; 1993; Postel, 1998; Pimentel and Pimentel, 1996; Altieri and Rosset, 1999; Giampietro, 2002; 2004); and when dealing with risk in case of the food system we are warned that: "*…at the world level, there is no option to import food from elsewhere.*", (Giampietro, 2004, p. 330). Further to that, the genetic base of the present day cultured crop is so narrow to present a threat of considerable damage by insects, diseases or growing conditions (Doyle, 1986), (e.g. from 50 to 70% of the hybrid corn in the USA Northern Corn Belt comes from just one parent line, of the about 10,000 varieties of apple named and recorded in history just a dozen make up the 95% of the entire commercial production - Doyle, 1986).

The impressive achievements that came along with industrial revolution, left most scholars on human well-being (mainly economists) to believe that the expansion of human activity and increasing of wealth, could occur "*at infinitum*" (Pretes, 1997). This, under the implicit assumption that natural resources and ecosystem services supply were abundant and free, and that technology would have helped to solve any problem and overcome any constraint. For centuries the warnings of those who believed otherwise remained neglected (Martinez-Alier, 1987). Until problems could be externalized to somebody else, there was not need (nor the will), to be concerned with these issues.

At present we are being confronted with: (1) a dramatic speed of growth in both population and level of human activity per capita. The combined effect of these two different types of growth is now heavily interfering with natural ecological processes (Odum, 1971; Pimentel and Hall, 1984; Vitousek *et al.*, 1986; Smil, 1987; Giampietro and Pimentel, 1994; Postel, 1998; Giampietro, 1999); (2) the increasing "efficiency" of human technology enlarged the domain of action of human control to a point that it is now impossible to "externalize" any further without seriously compromising environmental and human health (Giampietro and Bukkens, 1992; Pimentel and Pimentel, 1996; Giampietro, 1999; Gunderson and Holling, 2002; Wilson, 2002); (3) the increasing number and level of conflicts and confrontations among social groups and populations for limiting resources. All these factors combined are generating a new challenge for humankind. As noted by Ostrom *et al*., 1999, (p. 282): "*Today, we have less leeway for mistakes at the local level, while at global level there is no place to move*".

From the graph reported in **Figure 1.1** it should be quite clear that the conventional technical solution of further intensification of crop production sooner or later will have to meet limits.

Figure 1.1 *(see p. 4a) Trends in human history: (i) human population, (ii) arable land per capita, and (iii) energy consumption (after Giampietro and Bukkens, 1992)*

The critical fact that makes the actual challenge different from the previous ones is that now humans are left with no more room to expand and to externalize. The various socio-economic systems and the various ecosystems operating on this planet are more and more connected because of the action of humans which is expressing patterns at the global level. This implies that rather than having a series of local collapses (the mechanism that regulated human expansion in the past), humankind is risking to experience a collapse at a large scale. It should be noted, however, that this view is not shared by the various scientists dealing with the issue of sustainability (see, for instance, the debate Myers versus Simon in Myers and Simon, 1994).

1.2 Changing perspective: Recognising the multifunctional role and the complex meaning of agriculture

The assessment of agricultural production is still based on the old way of calculating specific ratio, such as tons of crop, or heads of livestock produced per hectare, or land tilled per hour of labour, or other indicators of technical efficiency. There is energy input-output in the biophysical assessment, and cost-benefits analysis in the economic assessment. To this regard, the question I want to pose in this section is the following one: to what extent an efficiency approach, that implies the focus on a specific ratio at time to be optimized, without making clear the context in which such an optimization is applied, is of any use?

A sound technical assessment based on the efficiency approach, would require a previous, and clear definition of at least three sets of characteristics (Giampietro and Pastore, 2001; Giampietro, 2004):

(1) the *assumptions on which the assessment relies* – that is, related to the optimizing strategies adopted by the farmer or by the society in which the farming system is operating, (e.g. maximization of return versus minimization of risk);

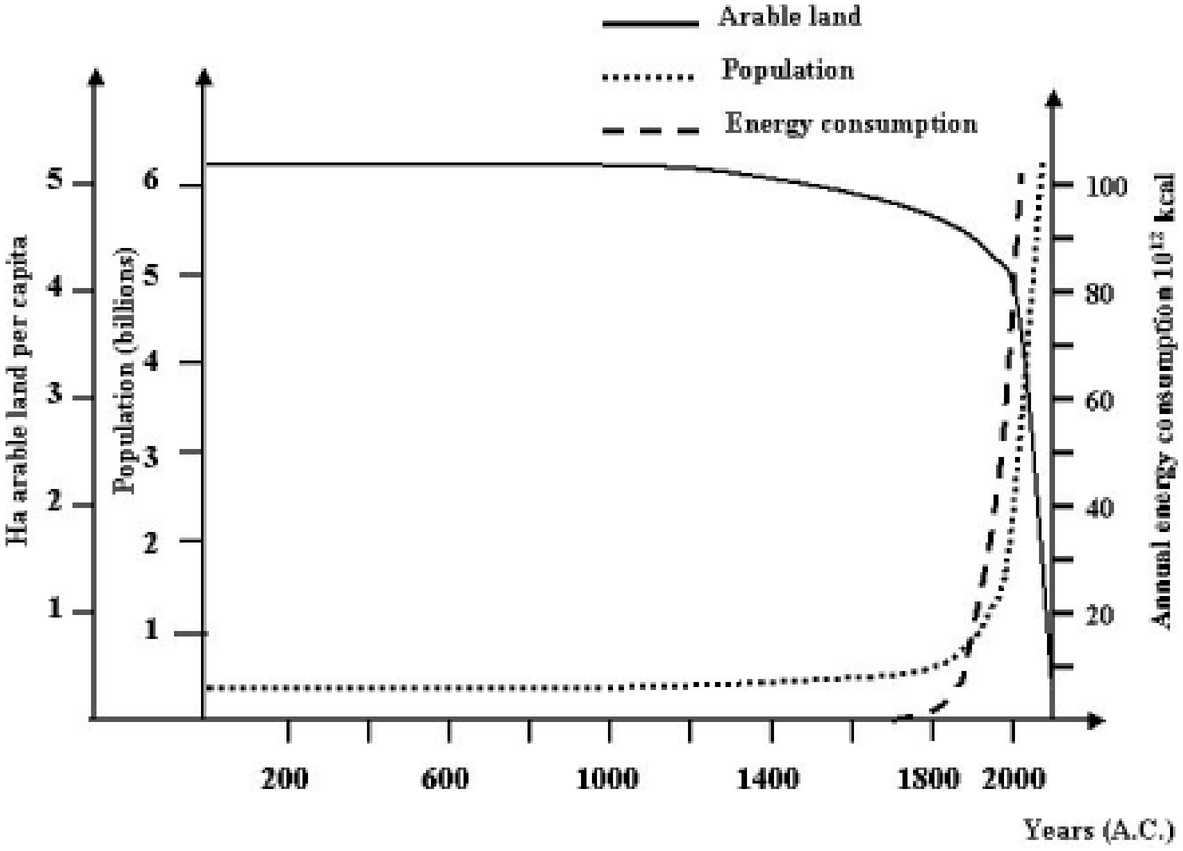

Figure 1.1 *Trends in human history: (i) human population, (ii) arable land per capita, and (iii) energy consumption (after Giampietro and Bukkens, 1992).*

(2) *boundaries at which the system of production is analyzed* (as stated by Georgescu-Roegen – quoted in Mayumi (1991, p. 50): “*no boundary, no process*”);

(3) *the characteristics of the agricultural production system under study* – that is the characteristics of the society in which the system is operating and the characteristic of the natural system (ecosystem) that is altered to carry out a given productive activity.

In the case of agriculture and the agro-food system, it is becoming more and more evident how much a re-thinking of an approach based on optimization is needed. The main issue in fact, is to recognize that agro-food systems are *complex systems* (Allen and Starr, 1982; Altieri, 1987; Conway, 1987; Beets, 1990; Giampietro, 1994a; 1994b; 2004; Röling, 1994; 1997; Pretty, 1995; Wolf and Allen, 1995; Pearson and Ison, 1997; Bland, 1999; Gliessman, 2000; 2001; Giampietro and Pastore, 2001; Sinclair, 2001). That is agro-food systems are made up by many different components (e.g. biophysical, socio-economical, cultural) and agents (e.g. species, ecosystems, households, social communities, scientists, policy makers) operating on different scales (e.g. local, national, global) and pursuing different (and possibly contrasting) objectives.

This is to say that an adequate representation of a farming system requires a *multidimensional*, or *multicriteral*, approach, where many dimensions and levels of analysis have to be taken into account (e.g. economic, environmental, social, cultural), and many perspectives associated to stakeholders (e.g. farmers, consumers, citizens) have to be represented (Beets, 1990; Röling, 1994; 1997; Skop and Schou, 1999; Kropff *et al*., 2001; Giampietro, 2004; López-Ridaura *et al*., 2003).

The implications of this new fact for governance, are at least twofold (Giampietro, 2004): (1) on the scientific capability of providing useful representations and structuring of these new management problems; and (2) on political capability of providing adequate mechanisms of governance. This implies a major shift: from chrematistic (efficiency) to multicriteria approach, from development strategies focusing on one criterion at the time (e.g. economic growth) to those focusing on the integrate management of social and environmental systems; from unidirectional decisional processes (either top-down or bottom-up) to more complex procedures for decision making (based on negotiation and iterative exchange of information across relevant social actors). In the last decades the awareness about the need for new approaches and tools to deal with the complex problems of modern development is increasing worldwide (an overview of the literature in this field is provided in the next chapters). It seems, then, that the time is ripe for a paradigm shift. This calls for the development of more effective analytical tools to be tested in the field.

1.3 Understanding the complex nature of agricultural activity

Agriculture is the management of natural environment in an attempt to its domestication, in order to provide humankind with a controlled, reliable and stable source of food and fiber. Agriculture deals with the management of living systems at many scales.

1.3.1 Agricultural systems as adaptive, self-organizing systems

Agriculture is an activity that has its basis on: (i) living beings as relevant actors on the short term; and (ii) species co-evolution as the underlying process guaranteeing sustainability in the long term (biodiversity at large). The sustainability of agriculture is guaranteed through ecosystems functioning (e.g. stabilization of energy and matter flows, robustness of trophic webs) in relation to the existence of many biophysical constraints (e.g. solar irradiation, climate, soil, landscape structure), which are operating at different scales. Co-evolving species are posing constraints and modifying each other. This integrated process is occurring at many different space-time scales. For example, green plants, when appearing for the first time on this planet, started to generate free oxygen, an element that before was not there in large quantities. Actually oxygen at the beginning was perceived as a poison (pollutant) by the majority of living organisms. Now it makes up about 20% of the atmosphere mass and it is the key element which makes possible life for the large majority of living beings. Thanks to oxygen, in billions years, shells and corals could made up kilometers thick strata of carbonate rocks.

Obviously, agriculture is also characterized by the fact that human activity plays a crucial role in controlling and managing the biological activity of living organisms and ecosystem functioning. Because of this, we should expect that the characteristics of an agricultural system tend to reflect the characteristics of the human society at large to which the farming system belongs (e.g. human work, social organization, technology, culture).

Being on the interface of human societies and ecosystems, agriculture is a dynamic, adaptive and evolving system (*self-organizing becoming system*) just like the previous two (detail on these definitions will be provided in chapter 2). Agriculture is subject to changes reflecting both the changes occurring in its physical and social context: (i) changes of external constraints, both posed by the environmental system (e.g. biodiversity, landscape, climate) and socio-economic systems (e.g. demography, cost of labor, technological innovation): and (ii) changes in internal characteristics (reflecting cultural, social and technical innovations). This is why, like any other living system, agricultural systems do not adapt in a passive way, rather they act as ***self-organizing systems***.

Ridley (1993), in his classical textbook on evolution, states that: “*Adaptation has to be understood historically.*”, (Ridley, 1993, p. 345). And follows: “*In summary: the adaptation of organisms are a set of trade-offs between multiple functions, multiple activities, and the possibility of the present and the future. If a character is viewed in isolation it will often seem poorly adapted; but the correct standard for assessing an adaptation is by its contribution to the organism's fitness in all the functions it is employed in, through the whole of the organism's life.*”, (Ridley, 1993, p. 346). From another classic textbook on evolutionary biology, Futuyma, (1986, p. 19), states that: "*... it is not an exaggeration to say that by virtue of past evolution, species create their own environments. ... Not only the past evolution of a species determines its environment, so do its present activities, for species deplete resources, release toxic metabolites, and alter their surroundings in numerous other ways. Thus species and environment alter each other reciprocally. It is an error to think of species simply as passive sufferers of harsh external fate; they are active participants in a dialectical interchange between organism and environment.*” This can easily hold true for humans and agriculture activity.

Agriculture is a human activity (although other species, e.g. ant, are known to practice it in a very sophisticated manner - Hölldobler and Wilson, 1994). Large availability of manpower, for instance, allowed in many societies the construction of extensive irrigation systems that increased productivity. Migration and trade allowed for plants and animal species to be moved for long distances and to be introduced in new ecosystems. Social organization allowed for the defense of the crops from competitors and for the taming of new animal species (as well as humans belonging to different socio-economic systems too). This increased the amount of applied power that could be invested in working activities. Surplus of products allowed for an additional increase in population and then to a further specialization in different activities.

When referring to agriculture, then (as for any other process associated with living systems), we have to be aware that we are dealing with the analysis of a dynamic, adaptive, self-organizing complex system. Next section provides an overview of possible ways to represent it, in view of sound management.

1.3.2 Agriculture as a nested-hierarchical system

As noted earlier, agricultural systems can be usefully understood as made up of many different components defined on different levels and scales. When adopting a ***biophysical view*** we can move from the scale of the soil (with its characteristics), and its fauna (micro-organisms whose activities are essential for nutrients cycling), to arrive to the scale of crops species (and the cultured pattern). When adopting a ***socio-economic view*** we can start from the scale of the farmer, and moving up to that of the household of the rural community in which the household lives, to arrive to the scale of local, regional and national socio-economic systems. Using an ***ecological view*** we can have: the scale of the local agro-ecosystems, then the scale of the watershed, up to the natural mechanisms generating biogeochemical cycles of water and nutrients that are required to stabilize and constrain the boundary conditions of the farming activity (**Figure 1.2**).

Figure 1.2 *(see p.7a) Hierarchy in agriculture some representations (These photos are free from copyright and have been taken from the following websites: <http://www.freefoto.com> and http://www.freeimages.co.uk/)*

To better understand (in their complex nature) farming systems, they should be analyzed in parallel using different criteria and utilizing different hierarchical levels. We have to keep in mind that neither goals and/or boundary conditions do coincide for subsystems belonging to the same system but perceived and represented as operating on different hierarchical levels (Allen and Starr, 1982; Checkland and Scholes, 1990; Clark *et al.*, 1995; Wolf and Allen, 1995; Pearson and Ison, 1997; McConnell and Dillon, 1997; Giampietro and Pastore, 1999; 2001; Hall *et al.*, 2000; Giampietro, 2004). So before attempting any assessment we should pose great attention at precisely framing the context of analysis. A telling example of a non-equivalent assessment of this kind is provided by Giampietro (2004). He carried out an assessment exercise based on non-equivalent assessments concerning the question: "*How many kg of cereal were consumed, per capita, by US citizen in 1997?*" and found four different figures, all perfectly reasonable. Hereafter, two of them are provided as an example.

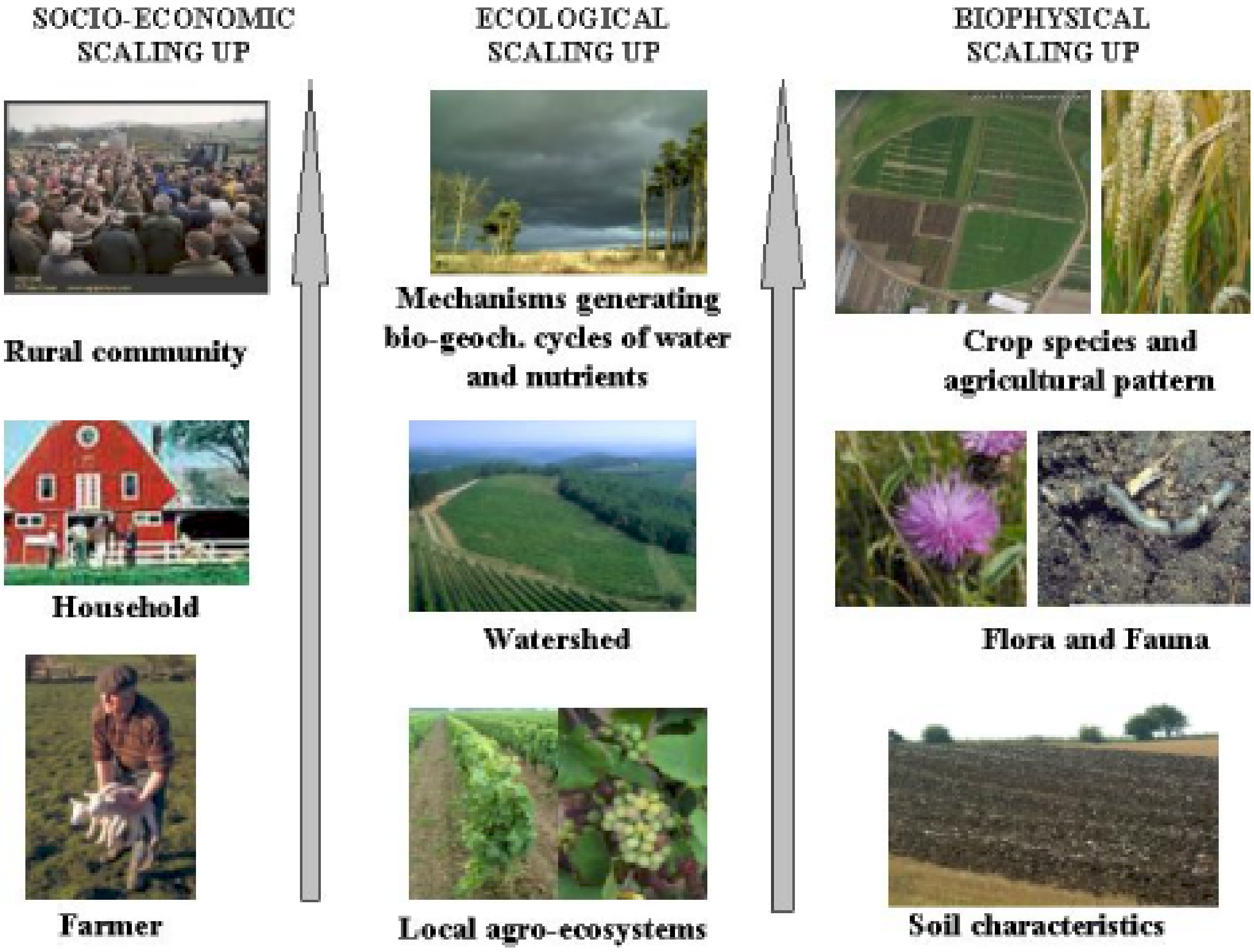

Figure 1.2 *Hierarchy in agriculture some representations.*

(These photos are free from copyright and have been taken from the following websites: <http://www.freefoto.com> and http://www.freeimages.co.uk/)

1st answer: 116 kg. Cereals per capita consumed as food, at the household level. The assessment can be done by a number of surveys at the household level, or by dividing the total amount of cereals directly consumed as food by the population of USA in that year.

2nd answer: 1,015 kg. Cereals per capita consumed as food, at the food system level. The value is obtained by dividing the total consumption of cereals in the US food system by the size of US population. (1,015 kg is obtained by 116 kg directly consumed, 615 kg fed to animals, plus almost 100 kg of barley for making beer, plus other items related to industrial processing and post-harvest losses).

The issue in this example is that before giving the right number (or any number), we must supply the proper context of reference for the meaning of the answer, which must result congruent with the meaning of the question. Without a specific definition of the context, any numerical assessment is simply meaningless.

We have also to keep always clearly in mind that agents operating at different hierarchical levels not only have different goals but also see a different reality. For instance, developing countries aiming at fast industrial growth, tend to adopt agricultural policies that provide cheap staple food for the urban population or intensify cash crop production for export. They adopt this policy in spite of the fact that the associated land use patterns and agricultural practices may result harmful both for the environment and the stability of the social fabric of rural community. A country can pose high stress on its own farmers in order to have cheap staple foods to feeds urban population. In this case agriculture policy may focus on producing mainly grains leaving little room for others crops. In addition to that low purchasing power capacity of potential consumers can pose a heavy constraint to farmers, preventing them from producing relatively more expensive items, such as vegetables and fruits. High post harvest losses, bad transportation and market facilities do the rest. It is only when a society moves to high average income, and when better infrastructures are available that farmers get the option of diversify and intensify their production.

This is to say that farming systems do not operate in a void but in a very specific biophysical environmental and socio-economic context. Such context poses constraints on what farming can do and how it can be managed.

1.4 Agriculture as a complex system: implications for policy

Agriculture operates at the same time, in parallel and on several different hierarchical levels, on the interface of two complex systems: “socioeconomic systems” and “natural ecosystems”. Because of this structural hierarchical nature, what we see in a given descriptive domain (it is to say what and how we describe a system), depends on the spatio-temporal frame we choose to adopt (Conway, 1987; Lowrance *et al*., 1986; Smil, 1987; 1993; Ikerd, 1993; Giampietro, 1994a; 1994b, 2004; Wolf and Allen, 1995; McConnell and Dillon, 1997; Bland, 1999; Brouwer and Crabtree, 1999; Giampietro and Pastore, 1999; 2001; Murray *et al*., 1999; Giampietro and Mayumi, 2000a; 2000b; Kropff *et al*., 2001; Sinclair, 2001).

This implies that in any analysis of a defined farming system, one will always find legitimate and contrasting perspectives with regard to the effects of changes in the system

(Smil, 1987; 1993; Giampietro, 1994b; 2004; Röling, 1994; 1997; Wolf and Allen, 1995; McConnell and Dillon, 1997; Bland, 1999; Giampietro and Pastore, 1999; 2001; Sinclair, 2001). For example, increasing return for farmers (e.g., intensification of crop production) can be coupled to more stress on ecological systems (e.g. loss of biodiversity and soil erosion). Similarly, "improvements" for certain social groups (e.g. lower retail price of food for consumers), can represent a step back for others (e.g. lower revenues for farmers).

Agricultural systems are then dynamic, evolving systems, existing within historical and evolving contexts, an evolutionary process that takes place at each level of the hierarchy, although at different pace (Allen and Starr, 1982; Altieri, 1987; 2002; Smil, 1987; 1993; Giampietro, 1994a; 1994b; 2004; Norgaard, 1994; Clark *et al*., 1995; Wolf and Allen, 1995; McConnell and Dillon, 1997; Giampietro and Pastore, 1999; 2001; Hall *et al*., 2000). How all this reflect on the approach to agro-ecosystem management? Embracing the complexity perspective has three major implications for policy making: (1) changes are unpredictable, (2) existence of legitimate, different, contrasting perspectives, and 3) existence of subjectivity.

1.4.1 Changes are unpredictable

Zadeh (1965, quoted in Janssen and Munda 1999, p. 844) writes: "*...as the complexity of a system increases, our ability to make precise and yet significant statement about its behaviour diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics*."

Socio-economic and agricultural systems change in an inherently unpredictable way. Optimizing solutions focusing on a specific problem at time, necessarily neglect other system dynamics, as they are based on mathematical analysis that must assume the system to be in steady state (*ceteris paribus*), a state non existent in real systems (Funtowicz and Ravetz, 1990; 1991; Smil, 1987, 1993; Giampietro, 1994a, 1994b; 2004; Clark *et al*., 1995; Wolf and Allen, 1995; Rosen, 2000; Musters *et al*., 1998; Giampietro and Pastore, 1999; 2001, Holling, 2001).

This is a very dangerous mistake when dealing with evolutionary processes. In fact, solutions found under *ceteris paribus* assumptions can result not only useless for fixing the original problems but also negative factors in relation to the original problems. As Wolf and Allen (1995, p. 6) put it, "*In complex systems action at one level can have exactly the opposite important effect at other levels, importance being assigned by the investigator*". Smil (1993) argues how, even before we get to choose a course of action, we must first deal with many fundamental uncertainties about our understanding of our intents and goals. He remarks then that: "*And, of course, there is little we can do about the counterintuitive, unforeseeable consequences of our best-intentioned efforts*." (Smil, 1993, p. 153).

Scientists, then, have to be ready to deal with uncertainly and genuine ignorance (the emergence of new relevant facts, agents, mechanisms not included in the previous analytical framework). Hiding this obvious consideration translates into assigning to analytical models a "mission impossible". This is especially true in our fasting, novelty rich, society. The early concept of risk assessment (already debated in its early times, Vineis, 1990), has to be substituted with an approach that better can take into account the issues concerning uncertainty and ignorance (Funtowicz and Ravetz, 1990; Dovers and Handmer, 1995; De Marchi *et al*., 2001; Giampietro, 2002; 2004).

1.4.2 Existence of legitimate, different, contrasting perspectives

A household can be perceived as an economic unit, as a community component, as a home and as a livelihood process for a members of a family, as a component of an agro-ecosystem, etc. These different readings will imply the use of alternative criteria of observation and representation. In this situation, we have to expect the co-existence of legitimate different contrasting perspectives of what is relevant when describing households or what should be considered good for households. Different contrasting goals will be in fact associated with different perceptions. For instance, the long term necessity of preserving a forest (when using the perception of a household component of an agro-ecosystem) can clash with the short terms necessity of increasing income generation to pay debts (when using the perception of livelihood for a family). This is why cultural values may play a decisive role in shaping final policy choices (Nijkamp, 1979; Chambers, 1983; 1997; Beets, 1990; Checkland and Scholes, 1990; Funtowicz and Ravetz, 1990; 1991; Altieri and Masera, 1993; Giampietro, 1994b; 2004; Norgaard, 1994; Röling, 1994; 1997; Munda *et al*., 1994; Wolf and Allen, 1995; Bland, 1999; Giampietro and Pastore, 2001; Munda, 1997; 2004; Sinclair, 2001; Altieri, 2002).

1.4.3 Unavoidable subjectivity in any perception/representation

When dealing with the modeling of a real-world situation an important degree of subjectivity appears to be inevitable. Models that pretend to represent the reality tend rather to make the reality to fit the model, dismissing all not included in the model as "noise". However, the noise perceived by the modeler can represent relevant information for others stakeholders involved in the decisional process. Eventually, it is the "*ability and the ethical behavior of the researcher constructing the model*", (Munda *et al*., 1994, p. 111) that determine the meaning of the information used there, and in turn the effectiveness of the model in dealing with real-world problems.

1.4.4 Implication for policy: handling incommensurable trade-offs versus optimization

The points made in the previous section have very important implications for policy:

- real-world systems are not steady-state systems but highly adaptable and evolving systems, (*ceteris* are never *paribus*). Any representation of these systems depends on the observer frame;
- we can no longer search for the "optimal", or "best" solution (optimal for who and in which sense?), as there is no solution optimizing all the criteria at the same time for all the actors;
- any definition of a solution as "good" or "bad" has to be associated to the definition of "good" or "bad" for whom, in which sense, for how long, and at which cost.

See for references: Simon, (1976); Nijkamp, (1979); Checkland and Scholes, (1990); Funtowicz and Ravetz, (1990; 1991); Altieri and Masera, (1993); Giampietro, (1994b; 2004); Norgaard (1994); Munda *et al*., (1994); Clark *et al*., (1995); Wolf and Allen, (1995); Munda, (1993; 1997); Röling, (1997); Beinat and Nijkamp, (1998); Martinez-Alier *et al*., (1998); Musters *et al*., (1998); Bland, (1999); Munda and Giampietro, (2001); López-Ridaura *et al*., (2002); Altieri, (2002).

Procedures for decision making, therefore, should permit:

- a clear and transparent formulation of the questions, and structuring of the problem,
- a search for *compromise solutions* and an explicit acknowledgment of the existence of ***incommensurable trade-offs*** (as the giving up of one thing in return for another, usually as an act of compromise, cannot be formalized and assessed in substantive terms). These incommensurable trade-offs are inherent in alternative policies (they should be understood and studied during the preliminary design process, of the pros and cons of alternative approaches and/or the selection of criteria which leads to the choice);
- an explicit definition of the relevant stakeholders that should be involved in the process as well as a specification of the role and timing of their involvement in the decisional process;
- a fair behaviour of policy-makers and institutions in face of unavoidable conflicts.

1.5 Farming systems research: a brief overview of definitions, historic development, and working tools

In this section I will briefly overview farming system research. I will end by briefly introducing the multicriteria approach, that is at the basis of the MOIR.

1.5.1 Defining a farming system

First of all let's define "farm". "*A farm is any tract of land or water consisting of one or more parcel devoted to the cultivation of plants and animals under the management of the owner or the tenant. The cultivation of aquatic form can also be included in this definition*." Beets (1990, p. 725).

The definition of farming system is more difficult, as we face again a case of increase in complexity. While a farm can be individuated for its physical characteristics, farming system is more related to a system of relations and constraints which is established across space-time domains and hierarchical levels. This explains the fact that there is no a commonly used and general accepted definitions for farming system (Beets, 1990).

According to Andrews and Kassam, (1976, in Altieri, 1987), farming system refers to the cultivation patterns used in a plot and their relation with the farm, other agricultural entities, and the technology available that determine its character.

A more complex and comprehensive definition is provided by Beets (1990), for who as farming system we should understand: "*A unit consisting of a human group (usually a household) and the resources it manages in its environment, involving the direct production of plants and/or animals products. Factors such as climate and weather, land tenure, land quality, and socio-economic variables are included. It is an ecosystem in which all of the component - land, operator, hired labor, crops and cropping system, animals and machinery - are considered together to produce goods to meet the requirement for food, clothing, and shelter, to exchange for goods to meet part or all of those needs. A farming system is always part of a larger social, political, economic, cultural environment that impact on everything happening within the farming system. Thus it can be said that the next level of analysis* *upward can be a rural village, a compound, or some physical unit of space including several farming systems*.", (Beets, 1990, p. 275).

The most complex and detailed definition I found, is that provided by McConnell and Dillon, (1997). It cannot be reproduced here as it is a more than 6 page definition (from p. 5 to p. 10)! The authors use a 13 order hierarchical definition, from the Order Level (OL) 1: Uni-dimensional process systems (e.g. single fertilization element to a crop and the consequent plant response), to OL 6: Animal system (e.g. systems related to single species), and OL 7: All animal systems (the aggregation of the level 6), OL 10: Whole-farm systems (the summing up of all the previous OLs), up to Order Level 13: Village-community systems (e.g. community group systems, cooperatives).

However, as soon as the ladder of nested hierarchies is taken, there is not reason to stop at 13. In fact, key relations can also be found outside the village. For instance urban systems are also very important for farmers as they represent the end point of the agriculture supply. Why not considering also the global market then? At a higher level such as national and supranational, political systems dictate agriculture policies that eventually will determine the boundary conditions that heavily constrains farming strategies. We could also add the technology producers, often trans-national companies, and those providing energy sources, credits etc. If it is true that the hierarchical approach helps to enlarge the view, to be effectively operational we have to decide to set a focal point. Then, we must be aware of the hierarchical nature of the system in relation to such a choice. It is very interesting to note that after the complex definition of farm system provided by McConnell and Dillon, (1997), the analytical tools presented by the authors to deal with such a huge complexity are: (a) liner programming; and (b) cost-benefit analysis; aimed manly at profit maximization at the level of the farm-household. Actually, this task takes the remaining 340 pages of the book. Another observation about this book is that *farm system* and *farming system* are often used interchangeably. The authors refer to farm systems as the structure of an individual farm, intending as farming system a homogenous system made up of a single typology of farm system, e.g. wet paddy farming system of West Java, grain-livestock farming system of Sind (McConnell and Dillon, 1997).

I think that it is useful also to provide a frame on which locate farming systems within the agricultural systems of the world. To do this I refer again to Beets (1990) who distinguish three types of agriculture: Industrial, Green Revolution and Resource poor. The main characteristics are reported in **Table 1.1**.

Table 1.1 *(see p. 12a) Summary of three types of agriculture (from Beets, 1990, p. 3)*

Although **Table 1.1** is just a simple summary of a very complex issue, still I think that it is sufficient to provide the reader with an insight about the diversity of boundaries conditions, constrains, goals - often striking contrasting - that characterize framing systems. In some overpopulated, poor countries a few square meters more or less for a farm can make the difference between have sufficient food to reach the next cropping season or starving. Whereas, in some developed countries the main problem is how to stop farmers from producing costly and useless surplus. In many developed countries farmers are even paid for not farming!

1.5.2 Farming system research: a brief historic overview

In the words of Lynam (2002, p. 228): "*It was the failure of the commodity research programme to meet the needs of rainfed agriculture in the tropics, especially in Africa, that was the genesis of FSR.*", (FSR stands for Farming System Research). According to the author FSR: "… *was a response to the failure of agricultural research to generate a green revolution in the rainfed areas of the tropics.*", (Lynam, 2002, p. 227), and it started well before the Green Revolution. In fact, the change in rice production in Asia is generally attributed solely to the introduction of the high yielding varieties (HYVs). However, rice systems research plaid before an important role. It laid the basis for understanding the constraints on rice productivity. The work of Peter Jennings led to the selection methodology for appropriate plant types.

"*Central tenet of FSR was to improve researcher understanding of farming system, especially in rainfed areas, so as to improve the probability of successful development and adoption of improved technology.*", (Lynam, 2002, p. 230). Collinson (in Lyman, 2002, p. 231) notes: "*FSR is an essentially operational process with a focus on the farming system and community levels in a systems hierarchy.*", FSR became a "*diagnostic process*", it is to say a basket of methods for understanding farm household.

Lately, the importance of institutional issues has been debated, and farmers participation into farming system research and extension entered in the FSR agenda (Chambers, 1983; 1993; 1997; Altieri and Masera, 1993; Lyman, 2002). The participatory approach started with the development of technique of Participatory Rural Appraisal (Chambers, 1997; Lyman, 2002).

According to Lynam (2002), however, while the FSR methodology remains focused on participatory issues and adaptive research, there is no, or little, actual research on farming or even cropping systems. The author points out that the FSR agenda has evolved to the point that it has eliminated the technical and agronomic research component. Although baskets of technological options are usually a key component of such adaptive research, there are few attempts to exploit synergistic systems interactions.

1.5.3 An overview of theories of farm management

Theories of farm management, concerning also the epistemological approach to farming system analysis, can be broadly grouped under two definition frameworks (McConnell and Dillon, 1997):

(1) Farm-system theory that conceptualize the farm as a purposeful system. It provides a checklist of aspects of the farm that should be the concern of management.

Farm-system approach derived from the development of system thinking in the 1950s, after the declining of the reductionistic approach. System thinking views the system as more then the sum of its parts, and claims that system behavior is not completely deducible by the behaviors of its parts. "*System performance must therefore be judged not simply in terms of how each part works separately, but also in terms of how the parts fit together and relate to each other, and in terms of how the system relates to its environment and to other systems in that environment.*", (McConnell and Dillon, 1997, p. 331).

"*Farm-system theory views a farm as unique goal-setting, open, stochastic, dynamic artificial (man-made), system, having a major aim of generating income for its stakeholders through agricultural production*." (Dillon, 1992 in McConnell and Dillon, 1997, p. 332).

This approach also recognizes the existence of *subsystems* and *suprasystems* of the farm system. Main ***subsystems*** are: (i) the technological system (involving cropping system, irrigation system etc.,), (ii) organizational and structural subsystem (e.g. responsibilities, task allocation) , (iii) informal structural subsystem (e.g. farm family, neighbors as well as their relations), (iv) goals and values subsystem, (v) managerial subsystem (e.g. farm manager's setting goals). Main ***suprasystems*** are of different nature and can include: (i) cultural suprasystem (e.g. historical background, ideologies, norms, values), (ii) technological suprasystem (e.g. scientific and technological development), (iii) political suprasystem (e.g. political organization, system of power), (iv) legal suprasystem (e.g. nature of legal system), (v) demographic suprasystem (e.g. flow of human resources, density, numbers), (vi) sociological suprasystem (e.g. definition of social roles, social mobility), (vii) climatic suprasystem, (viii) economic suprasystem (macro and micro).

The goals considered in farm system theory belong to three categories: (a) goals of the farm system itself (e.g. family sustenance, profit maximization), (b) social goals (such as resources conservation) imposed on (or expected from) the farm system by the society in which it operates; and (c) personal goals (such as outdoors life) held by the individual actors of the farm system. A major task of farm's management is then to harmonize these different goals. To conclude with McConnell and Dillon, (1997, p. 336): "*Hence there is logic in the traditional orientation of farm management theory to profit maximization under relevant resource and other constraints*."

(2) Theory of management by objectives that correspond to the analytical and decision making activity necessarily undertaken by the farmer in his/her role as manager.

Management by objectives is done via application of the sequential management functions of: (1) planning, [(i) what to produce? (ii) how to produce, (iii) how much to produce?], (2) organization (in the sense of administrative process). It aims at ensuring that the farm's system plan is implemented; and (3) controlling (the process of monitoring plan implementation). Being aimed at the optimal achievement of farm-system goals, the function of planning, organizing, and controlling have a normative orientation. Farm system goals will be set by the farm owner(s), or stakeholder(s) of the system. As stated by McConnell and Dillon, (1997, p. 337): "*Hence, management by objectives relates not just to final objectives or strategic goals but to the whole means-end hierarchy of objectives or goals*."

1.5.4 Assessing farming system productivity/efficiency: an overview of methods

In general, the assessment of agricultural productivity, or efficiency, is based on the calculation of specific ratios, such as kilogram of crop, or livestock produced per hectare of land tilled and/or per hour of labour, or other indicators of technical efficiency. Briefly I wish to note that according to Sanne (2000, p. 487): "*The terms* (productivity and efficiency) *are very close in meaning: a difference sometimes used is that efficiency refers to the fulfillment of a stated goal while productivity is the rate of production per unit of input. Thus a military operation may be efficient while a factory line may have high productivity*."

According to what was learned in the process of industrialization that was so successful in industrialized countries, the task of improving agriculture performance was confused with the task of industrializing agriculture. The pattern of technological progress in agriculture had to follow the pattern on technological progress in the industrial sector (extensive adaptation and economies of scales) by any means, everywhere, in spite of evident heterogeneity of social, cultural, economic, ecological characteristics of different farming systems.

The main goals of agriculture research were: (1) increase productivity of labour of farmers, and (2) increase the productivity of land (Ellis, 1996; McConnell and Dillon, 1997; Bland, 1999; Giampietro, 2004). In the words of Ellis, (1996, p. 169), (a popular textbook on the economics of farm households in developing countries where a review of main theories can be found): "*The traditional goal of policy intervention in peasant agriculture, with the exception of pure welfare policies, is to increase productive efficiency, output growth, and peasant income*." Any other criterion and/or side effect was neglected or considered negligible. Unfortunately, side effects on different criteria of performance are not negligible, and, eventually, such "nuisances" had to be faced and coped with by farmers, consumers, citizens and policy makers alike, both at the local and global level.

In the 1970s the traditional methods of farming system assessment, based on economic cost-benefits analysis (e.g. Pearce and Turner, 1990; Ellis, 1996; McConnell and Dillon, 1997), started to be integrated with others sort of evaluations. Particular importance was given to energy input-output (e.g. Pimentel and Hall, 1984; Smil, 1987; Giampietro and Pimentel, 1994; Giampietro *et al*., 1994; 1999; Pimentel and Pimentel, 1996; Hall *et al*., 2000). Lately, the many side effects resulting from the former approach, made more and more people aware that the complexity of the problems and the risks at stake were demanding a wider assessment approach. Wider means a larger variety of: (i) criteria to be included in assessment exercises; (ii) space-time dimension to be considered; (iii) assessment methods and (iv) procedures for stakeholders participation (Chambers, 1983; 1993; 1997; Smil, 1987; Edwards, 1989; Checkland and Scholes, 1990; Altieri and Masera, 1993; Giampietro, 1994b; 2004; McConnell and Dillon, 1997; Bland, 1999; Brouwer and Crabtree, 1999; Hall *et al*., 2000; López-Ridaura *et al*., 2002).

Recently, also international organization (e.g. FAO, World Bank, and other international NGOs) embraced the idea that a multicriteria approach would provide a much better (sound and effective) description of farming systems in view of its sustainability (e.g. Hardaker, 1997; McConnell and Dillon, 1997; Dixon and Gulliver, 2001; Dixon *et al*., 2001). Although this should be considered certainly a step forward, still it should be noted that in all these attempts there is still the general idea that an "overall best" can be achieved. That is, the "goblin of efficiency" still is moving behind main assumptions and problem structuring.

1.5.6 Multicriteria approach as a useful tool to deal with complex problems

Multicriteria decision analysis is a tool developed within the operational research discipline (as well as mathematical programming and scenario analysis) and offers mathematical techniques form modeling decision makers' goals and conflicts. The main advantage of multicriteria approaches, with respect to standard optimization approaches, is that they make it possible to consider a large number of data, relations and objectives (Munda, 1993; Munda *et al*., 1994; Martinez-Alier *et al*., 1998). There are many Multicritera techniques that have been developed. For a review see for instance Bana e Costa, (1990); Beinat and Nijkamp, (1998); Guitouni and Martel, (1998).

In multicriteria analysis conflicts between various criteria taken into consideration are the norm, as an action *a* may be better then a action *b* according to a criterion and worse according to another (Munda, 1993; Martinez-Alier *et al.*, 1998). Then Multicriteria analysis teaches us that a consequence of taking into account various dimensions simultaneously is that it is impossible to optimize all the objectives at the same time (Munda *et al*., 1994; Munda, 1995, 1997). This implies that rather than looking for "optimal solutions", that is to say the result of a function maximization, we should learn how to look for "compromise solutions", that is to say the balance between conflicting incommensurable values and dimensions. However, as Munda, (2004) notes: "… *in a multi-criteria framework, what really matters is the process since the problem structuring will determine the result. Thus the method as such is just a framework, which of course has to be as consistent and above all transparent as possible, but please remember a computation is not a decision.".* The decision makers, then, have to find compromise solutions. Of course Multicriteria methods cannot pretend to solve all the conflict (that is a social aspect of the decisional process) but: "… *can help to provide more insight into the nature of the conflict and into a ways to arrive at political compromises* …", (Martinez-Alier *et al.*, 1998, p. 281).

Notwithstanding the complexity of application of multicriteria evaluation, compared with the relative simplicity of usual costs-benefits analysis, still the approach is gaining attention. Multicriteria approach, in fact, allows a broader and deeper view of a problem, and the inclusion of stakeholders in the structuring process can secure better results in the long terms. Moreover, a growing body of literature dealing with the theoretical and practical issues as well as practical application is already available (see for instance the references quoted in this chapter and in chapter 4).

1.6 Conclusion

Questions like: what is produced by agriculture? What should be considered as the relevant output of "*agricultural production*"? Are crucial questions that should be answered in a sound way before starting any analysis of the performance of agriculture. More and more in the last decades is becoming evident that the answer to these questions is multifold, including a wide range of items: crop, food, food security, crop for export, health, environmental values, preservation of cultural values and identity, managing landscape, leisure for people. Therefore, when we acknowledge this multifunctional nature of agriculture, when we talk of productivity, what are we talking about? Are we maximizing the productivity of what? Productivity of crops, fibers, citizens in good health, happy agro-tourists, commodities to export, preserved landscapes, preserved traditions and values, uncontaminated water tables? Unfortunately, conventional analyses of agricultural productivity tend to focus just on profit and commodity production dismissing altogether many other important criteria (e.g. resources conservation and social issues, Altieri, 1987; 2002; Giampietro, 2004). This is why agricultural production, in standard analyses, can be represented only in terms of quantitative assessment of crops/animals per unit of investment.

Notwithstanding the theoretical attempt to move ahead toward a more integrated and comprehensive view of agricultural performance, very little is done in practical applications. Better, we can say that the new challenges of this new millennium are dealt with by trying to adapt and recycle old analytical and normative tools. The tenet remains always the same: "*There are two major form of farm-operating objectives, profit maximization on market-oriented farms and household subsistence on subsistence-oriented farms.*", (McConnell and Dillon, 1997, p. 111). Although these authors and many others mention a number of additional criteria referring and reflecting the characteristics of supra and subsystems eventually the tools are always the same: input-output analysis, cost-benefit analysis leading to optimization exercises via linear programming. In this frame, yield and money remain the two most popular variables involved.

A recent publication from FAO (Hardaker, 1997), concerning the program for Sustainable Agriculture and Rural Development (SARD) - the latest, strategic, rural development program implemented by FAO – claims to pursue the goals of growth, equity, efficiency, and sustainability, and the adoption of a holistic, integrated new perspective. After a long description of the pros and cons of the different assessment techniques: (i) extended cost-benefit analysis, (ii) cost-effectiveness analysis, and (iii) multi-criteria analysis, the latter is dismissed on the following bases: "*While MCA is a flexible method that appears to be well adapted to analysis for policy planning, the complexity* ***and the demands it places on decision makers to be explicit about their objectives and values may limit its use****. This is especially so for the theoretically more valid non-linear functional forms. As a result, it may be that only the first three steps above are formalized, followed by intuitive assessment of the alternatives*" (Hardaker, 1997).

It is to wonder how cultural, political, historical issues can be accounted for in a neutral and substantive way by linear programming or cost-benefit analysis. Important is the authors' warning to the reader that: "*… any significant difference between what a farmer is actually doing and what LP* (Linear Programming) *analysis suggests he or she should be doing should not be attributed to farmer irrationality, ignorance or inefficiency. Rather, such differences should be seen as a reason to review and possibly re-specify the LP analysis*." (McConnell and Dillon, 1997, p. 228). This statement should be considered as a true step forward, away from reductionism. In the past, in fact, discrepancies between models output and farmers' behavior were interpreted against the rationality of farmers. Whenever, they behaved different from what predicted by optimizing models, they were considered to be insufficiently informed or insufficiently rationale. This was also the way to put the blame on them for the failure of development projects (Chambers, 1997; Schilizzi and Boulier, 1997). Because of this criticism, some authors (e.g. Collinson and Norman in Lynam, 2002) claim the impracticality, (if not the total irrelevance), of linear programming in farming systems research, while others (as we will see later on), dismiss the maximization-optimization paradigm to embrace a more complex but more fruitful multicriteria approach.

Chapter 2

Acknowledging the complexity revolution: An overview of concepts, theories and narratives

> *I have yet to see any problem, however complicated, which, when you looked at it in the right way, did not become still more complicated.*
> Paul Anderson[4]
>
> *There is a place where contrarieties are equally true...*
> William Blake[5]
>
> *Cambia lo superficial*
> *Cambia también lo profundo*
> *Cambia el modo de pensar*
> *Cambia todo en este mundo.*
> *Cambia el clima con los años*
> *Cambia el pastor su rebaño*
> *Y así como todo cambia*
> *Que yo cambie no es extraño.*
> *Julio Numhauser*[6]
>
> *Panta rei.*
> Eraclitus[7]

Summary

This chapter introduces concepts, theories and narratives developed in the field of complex systems thinking and hierarchy theory. The field is still in a phase of confusion, since very few analysts address deep epistemological issues. In any case it is important to be aware of the a few new (and at times very old) concepts developed in this field, since they represent the basic rationale for the development of the innovative analytical tools presented in part 2 and 3.

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[4] Nobel Prize for Physics (in New Scientist 25 Sept. 1969, p. 638).

[5] English poet (1757-1827), from the poem "Milton"

[6] Julio Numhauser, words for the song: "Todo Cambia" (Everything change), sung by the great Argentinean singer Mercedes Sosa. Translation (extract): "*It changes the superficial/ It changes also the deep/ It changes the way of thinking / Everything changes in this world/ It changes the climate with passing years/ It changes the Sheppard's herd/ And, as everything change/ That I change it is not strange*."

[7] Greek philosopher (Efeso 540 ca. - 480 ca. BC), quote translation "All flows".

2.1 Simplicity versus complexity

There is no doubt, and everybody agrees, that the development of mechanics, the science of Newton, represents one of the greatest achievements of human mind, which has been, and still is a key ingredient of science and human development. Anyway, it is very doubtful to many (and surely it was doubtful also to Newton himself), that in terms of simple mechanisms humans will be ever able to fully explain their reality. The attempt to extrapolate from the science of physics (developed to construct human artifacts and to make them to work better), laws that can be applied to social and natural life, seems to be failing in many aspects. Living things (organisms, ecosystems, societies) escape simple, mechanical descriptions. They represent, for those trying to observe and control them, a continuous flow of novelties and unexpected behaviors. They continuously challenge the validity of verified knowledge and require the generation of new explanations.

Starting the middle of the XX century some scholars (e.g. Weaver, 1948; Simon, 1962, Koestler, 1967; Rosen, 1969) began to argue that mechanics can and should be applied only to simple things (e.g. machines). Machines are systems that can be studied by splitting them into simpler parts. Complex systems (e.g. living systems) on the contrary, require a different approach for it is not possible to split them into parts without loosing their peculiar characteristics.

Etymologically the term complexity, or complex, comes from late Latin *complexus*, meaning totality: a whole made up of complicated or interrelated parts (e.g. examples found on the dictionary include: a *complex* of welfare programs, the military-industrial *complex*), or a group of obviously related units of which the degree and nature of the relationship is imperfectly known (Merriam Webster Dictionary online). By reviewing the scientific literature, however, it seems that it is not that easy to distinguish the simple from the complex, as well as among different versions of "*complexities*".

Complex systems thinking emerged during the second World War, from the attempt to manage strategic issues in warfare such as convoying troops and supplies across the Atlantic (Weaver, 1948; McCown, 2002). Warren Weaver (co-founder of information theory with Claude Shannon - Shannon and Weaver, 1949) stated that: "*The attempt to answer such broad problems of tactics, or even broader problems of strategy, was the job during the war of certain groups known as the operations analysis groups. Inaugurated with brilliance by the British, the procedure was taken over by this country, and applied with special success in the Navy's anti-submarine campaign and in the Army Air Forces*". Later on it becomes known as Operations research or Operational research, a discipline studied in engineering and economics, having to do with strategic and optimization planning (Weaver, 1948; McCown, 2002).

Operational Research ("OR"), also known as Operations Research or Management Science ("OR/MS") looks at an organisation's operations and uses mathematical or computer models, or other analytical approaches, to find better ways of doing them (see at http://www.orsoc.org.uk/). According to the association of European Operational Research Societies (EURO) (see the association website at http://www.euro-online.org): "*Though there is no "official definition" of Operational Research ("Operations Research" in the US), it can be described as a scientific approach to the solution of problems in the management of complex systems. In a rapidly changing environment an understanding is sought which will facilitate the choice and the implementation of more effective solutions* *which, typically, may involve complex interactions among people, materials and money.*", (see http://www.euro-online.org/display.php?page=what_or&). Operational Research has been used intensively in business, industry and government. Many new analytical methods have evolved, such as: mathematical programming, simulation, game theory, queuing theory, network analysis, decision analysis, multicriteria analysis, etc., which have powerful application to practical problems with the appropriate logical structure. Operational Research, in practice, is a team effort, requiring close cooperation among the decision-makers, the skilled OR analyst and the people who will be affected by the management action.

In the 1940s, in parallel, the existence of complex behaviors was recognized and explored also in others fields, from physiology (e.g. Walter Cannon, who introduced the concept of *homeostasis*), to anthropology and psychology (e.g. Gregory Bateson, Margaret Mead; Warren McCulloch), from mathematics (e.g. Norbert Wiener, John von Neumann) to engineering (e.g. Claude Shannon, Warren Weaver). This interdisciplinary attempt to study complex behaviors lead to the science of "*cybernetic*", what can probably be considered the precursor of complexity (Bertalanffy, 1968; Heims, 1991). Cybernetic was a concept introduced by Wiener (1948) and Ashby (1956) to study systems with feed-backs. Feed-back refers to a process where the input is somehow affected by the output. For at least three decades cybernetic ideas remained in use in many fields (e.g. Patten and Odum, 1981, in the field of ecology). The name given to processes of feed-back was then that of autocatalytic loops (Odum, 1971; Giampietro, 2004). Later on cybernetics evolved in system theory and then to complexity theory, and cybernetic as specific field of science, started to loose importance (Bertalanffy, 1968). For a broad review of material on cybernetic (some important books are freely available) see "Principia Cibernetica Web" at URL: <http://pespmc1.vub.ac.be/>. See also the American Society for Cybernetics at URL: <http://www.asc-cybernetics.org/>

One of the first attempts to define complexity seems to be dated back to Warren Weaver, in his 1948 paper (see also O'Neill *et al*., 1986). In his paper the author distinguished: (1) *problems of simplicity*, problems largely concerned with two-variables. They characterized physical science before 1900 – classic Newtonian physics; (2) *disorganized complexity*, problems concerned with many variables to deal with, about which scientists developed powerful techniques of probability theory and of statistical mechanics. They characterized physical science after 1900; and (3) *organized complexity*: problems concerned with "*medium-number systems*". "*They are all problems which involve dealing simultaneously with a sizable number of factors which are interrelated into an organic whole*.", (Weaver, 1948). These are the sort of systems (or problems) involved when dealing with living and evolving systems.

However, as noted by some authors (e.g. O'Neill *et al*., 1986, Rosen, 2000) the number of components may not be directly related with the complexity of a system. The problem of three bodies (only three components), in classical Newtonian physics, is a well known example that does not allows for solutions because of its complexity. But I would dare to add that Newtonian mechanics says very little also about the much simpler and still classical "two bodies" problem, when we specify to the analyst that the two bodies are those engaged in a man-woman relationship… Large number systems can also escape the predictive power of statistical mechanics as they may reveal unexpected, emergent behaviors that statistics cannot forecast (Prigogine, 1980; Prigogine and Stengers, 1984).

For instance, there was no way to predict that green plants, once spread on the earth, could transform its atmosphere in the way they did, as well as that human activities could have reached such a dimension to interfere with the biogeochemical cycles on the Earth. As well summarized by Allen and Starr, (1982) emergent properties are those: *(1) Properties which emerge as a coarser-grained level of resolution is used by the observer. (2) Properties which are unexpected by the observer because of his incomplete data set, with regard to the phenomenon at hand. (3) Properties which are, in and of themselves, not derivable from the behaviour of parts a priori.* (Allen and Starr, 1982, p. 278).

2.2 Is complexity a complex concept? A brief overview of theories of complexity

By reviewing the literature on the issue, it emerges how complex is trying to define complexity. Many definitions are attached to the term “complexity”, and the word itself stands as the basis of a flourishing, ever expanding, terminology in the field of complex system theory. A lot of terms related to complexity are actually in use in a wide range of scientific fields (ecology, economics, social sciences). Examples, taken from works of distinguished scholars, are: systems (Bertalanffy, 1968; Patten, 1978; Kampis, 1991; 1995; Checkland and Scholes, 1990; Müler, 1997), holons, (Koestler, 1967), integron (1967), Koestler, (1967), org (Koestler, 1967), holarchy (Koestler, 1967; Giampietro, 2004), panarchy (Gunderson and Holling, 2002), complex systems (Simon, 1962; Rosen, 1969; 2000; Whyte *et al*., 1969; O’Neill *et al*., 1986; Tainter, 1988; 1996; Kline, 1995; Waldrop, 1994; Holland, 1995; Allen and Hoekstra, 1992; Holling, 2001; Wolfram, 2002), holarchic systems (Koestler, 1967; Giampietro, 2004), complexity pyramid (Oltvai and Barbási, 2002), complex networks (Milo *et al*., 2002), dissipative systems (Prigogine, 1980; Prigogine and Stengers, 1984), autopoietic systems (Maturana and Varela, 1980), emergent systems (Koestler, 1967; Odum, 1971; 1988; Patten, 1978; Odum, 1983), adaptive systems (Rosen, 1991; 2000; Giampietro, 2004), anticipatory systems (Rosen, 1985; 1991; 2000), adaptive cycles (Holling, 1978; 2001), dissipative structures (Prigogine, 1980; Prigogine and Stengers, 1984), organised complexity (Weaver, 1948), holarchic complexity (Giampietro, 2004) impredicative loops (Rosen, 1991; 2000; Giampietro, 2004), autocatalytic loops (Rosen, 1985; 1991; 2000; Giampietro, 2004), complex adaptive systems (Waldrop, 1994; Holland, 1995; Levin, 1998), self-regulating systems (Bertalanffy, 1968; Odum, 1983; Odum, 1988), self-modifying systems (Kampis, 1991), self-entailing systems (Rosen, 1985; 1991; 2000; Giampietro, 2004), self-organizing systems (Prigogine, 1980; 2000; Rosen, 1985; 1991; Odum, 1988; Kauffman, 1993), self-organizing dissipative systems (Prigogine, 1980; Prigogine and Stengers, 1984), self-organizing open systems (Odum, 1988), systems’ self-organizing criticality (Bak, 1996), complex dissipative systems (Prigogine, 1980; Prigogine and Stengers, 1984; Nicolis and Prigogine, 1989), complex dissipative holarchies (Allen and Starr, 1982), hierarchical dynamic systems (Allen and Starr, 1982; O’Neill *et al*., 1986), hierarchical organized systems (Simon, 1962; Pattee, 1973; Allen and Starr, 1982; O’Neill *et al*., 1986; Gunderson and Holling, 2002), hierarchical functional structures (Clark *et al*., 1995), nested dissipative systems (Giampietro, 2004), ordinary complex systems (Weaver, 1948), emergent complex systems (Funtowicz and Ravetz, 1994b), open autocatalitic systems (Rosen, 2000; Giampietro, 2004), adaptive reflexive systems (Funtowicz and Ravetz, 1994b), emergent reflexive systems (Funtowicz and Ravetz, 1994b), nested hierarchical systems (Koestler, 1967; Allen and Starr, 1982; Giampietro, 1994b; 2004), self-replicating dissipative systems (Giampietro, 2004), asymmetric systems of constraints (Ulanowicz, 1997), self-organizing holarchic open systems (Kay *et al*., 1999), nested adaptive hierarchy of dissipative systems (Koestler, 1969). And I am sure that this is just a sample of what can be found. It would be interesting to attempt an history of complexity via reconstructing the complexity tree. Possibly by studying the evolutionary process of the various ideas (as cladistics in biology), we would get a better insight about what complexity means or stand for, for the various complexity scholars.

I wish to make the reader aware that complexity is an important concept in mathematics, although its meaning is quite different. In this field it is named *computational complexity*, and it has its foundations in logic: Turing machines, diagonalization, reductions, and the polynomial-time hierarchy (Traub and Wozniakowski, 1994; Casti, 1996). The mathematician and Nobel Laureate Gregory Chaitin (1975), defines algoritmic complexity as: "*… a measure of randomness. ... The complexity of the formal system has such an important bearing on the proof of randomness because it is a measure of the amount of information the system contains, and hence of the amount of information that can be derived from it*.". (For more information I refer the reader to Fortnow and Homer, in press) ,

Invoking "complexity" is becoming more and more on fashion in many scientific fields. Seth Lloyd (in Horgan, 1995) listed 31 different ways to define complexity, among them: entropy, information, fractal dimension, effective complexity, hierarchical complexity, grammatical complexity, thermodynamic depth, time computational complexity, spatial computational complexity, mutual information. However, often (if not in most of the cases) it is not quite clear to what is the meaning that is associated with the label "complexity", and this justify the statement of Francisco Antonio Doria, a Brazilian mathematician (in Horgan, 1995, p. 109) that: "*We go from complexity to perplexity*.". Of course, this large variety of definitions reflects the different backgrounds, approaches and goals of the different scholars proposing them. This is something quite common in science. Even key terms established long ago are still a matter of debate when coming to the exact meaning that should be associated with them, (e.g. *force* and *energy* in physic, and *gene* and *fitness* in biology). Some scholars even refuse to attempt a real definition. Per Bak (famous for his theory of "*self-organization criticality*"), for instance states that: "*I will define system with large variability as complex. ... Complexity is a Chinese box phenomenon. In each box there are new surprises. Many different definitions of complexity have been attempted, without much success, so let us think of complexity as variability: Crystals and gases and orbiting planets are not complex, but landscapes are* ." (Bak, 1996, p. 5).

The next section provides an overview of theories of complexity. This is done by quoting key definitions given by scholars in the field. I have to make clear to the reader that this is just an attempt, as the complexity issue concerns many different and difficult fields (e.g. thermodynamics, biology, information theory, computer science, cognitive science, philosophy of science), and a comprehensive account of the state-of-the-art for complexity is well beyond my capacities, research interests and expertise. However, I believe that it is useful to provide an overview of perspectives and approaches that characterize the study of complexity. This overview is necessary to better understand the theoretical foundations of the approach presented in the rest of this thesis.

I propose for this overview to use four main typologies:

(1) *Complexity as synonymous of complicatedness (the mutual interaction of many parts);*

(2) *Complexity as a whole that is more than the sum of the parts (emergent properties meaning new behaviours);*

(3) *Complexity as the properties of a system to self-organize and change in time its essence, identity and behaviour (emergence meaning new relevant attributes for the observer);*

(4) *Complexity as "dialectic process": as a property of the interaction between observer and the observed system (complexity à la Rosen).*

These typologies will be explained in the following sections.

2.2.1 Complexity as synonymous of complicatedness (mutual interaction of many parts)

The bio-mathematician Robert Rosen, resumes the early simple-complex distinction as follow: "*…von Neuman and others* (see Weaver, 1948, for instance)*, had drawn attention to a notion of complexity, which they felt was important for such a category or classification of material systems. Roughly speaking, this complexity was measured by a number, or numbers that could be effectively associated with any such system, in such a way that the system would be called "simple" if these numbers were small and, "complex" otherwise*.", (Rosen, 2000, p. 289).

An example of this approach is provided by Kline (1995). The author proposes a "complexity index", which: "*… can provide an estimation of complexity for any system or class of systems*.", (Kline, 1995, p. 49). The complexity index C he proposes is then defined as laying within the boundaries of $V + P + L < C < V * P * L$, where V = the number of independent variables needed to describe the state of the system; P = the number of independent parameters needed to distinguish the system from other systems in the same class; and L = the number of control feedback loops both within the system and connecting the system to the surroundings. This, however, is clearly an example of computational complicatedness. The same kind of definition is provided by René Passet (working in ecological economics), who states that: "*Generally, complexity is linked to the heterogeneity of the parts* (of a system), *and to the richness of their reciprocal contacts.*", (Passet, 1997, p. 356). The definition given by Passet derives from those provided by H. Atlan (1972), and J. Tonnelat (1977; 1978). It has to be said, anyway, that Passet (1997), addresses the issue of "emergent properties", as a characteristic of living systems, recognising that the idea of "emergence" was already very clear in the minds of early economists. He quotes, for instance, the great economist Alfred Marshall (1842-1924) who used to say that a cathedral is more then the sum of its stones, a person is more then the sum of its thoughts and sentiments, and a society is more then the sum of its individuals (to understand what drove economists away from this enlightened thought should be matter of reflection) .

Exploring complexity for other scholars has the goal of finding general principles, like some general physical or mathematical laws, by which to get a comprehensive explanation of the functioning of nature. Principles and laws that can be applied in every field of science, from physics to biology, from psychology to economics (e.g. Holland, 1995 and the Santa Fe Institute (http://www.santafe.edu/) approach, Back 1996; Wolfram, 2002).

The books by Lewin "*Complexity: life on the edge of chaos*" (Lewin, 1993), and Waldrop "*Complexity: the emerging science at the edge of chaos.",* (Waldrop, 1994), provide an extensive account of the history of science of complexity from the 70s onwards, with particular regards to the main theories and scholars of the Santa Fe Institute (the book by Waldrop, specifically focus on the history of the Santa Fe Institute and its people). (An interesting book telling the story of a related subject is "*Chaos: making a new sciences*" by Gleick, 1987). The research group on complex system at the Santa Fe Institute uses the terms "complex systems" to indicate whatever phenomenon, from physics to society, composed by a large number of parts strongly interacting one another. In this sense an usual example given is that of nervous systems: one thing it is to understand how a single neuron works in the mammalian central nervous system (CNS), but another is that to understand the interaction of the hundreds of millions of neurons, of hundreds of types, in that CNS. The operation of an individual neuron is unquestionably complex, but the CNS aggregate identity is much more complex than the sum of its individual neurons. So it is for people (or any individual organism) behaviour as single and when see within the society (or population and species), the human immune system, which is such a coherent system that it can distinguish you from the rest of the world and reject cells from any other human, ecosystems with their overwhelming diversity and complex cycles of matter, energy, and information, or even cities etc., (Lewin, 1993; Waldrop, 1994; Holland, 1995).

John Holland, one of the most important contributors to the field of Complexity and Artificial Intelligence (Santa Fe Institute), who invented "*genetic algorithms*", a class of optimization techniques that applies a survival-of-the-fittest heuristic to a broad range of otherwise intractable problems (Lewin, 1993; Waldrop, 1994; see also Holland, 1995 for details), states that: "*Even though these complex systems differ in detail, the question of coherence under change is a central enigma for each. This common factor is so important that at the Santa Fe Institute we collected these systems under a common heading, referring to them as complex adaptive systems (cas). This is more then terminology. It is signal that intuition that general principles rules cas behaviour, principles that point to ways of solving the attendant problems. Our quest is to extract these general principles.*" (Holland, 1995, p. 4). The challenge of the complexity programme at the Santa Fe Institute is that of extracting those general principles under the assumption that they will provide useful guidelines for dealing with CAS problems that at the moment defy easy solutions (Waldrop, 1994; Holland, 1995).

According to Holland (1995), in order to study complex adaptive systems, scientists should work to break them down into components, or building blocks. The properties of particular building blocks determine what we are going to see or think about. However, he warns that before we can recognize the building blocks of a particular complex system, we must first be able to recognize or envision that system as a whole. Holland (1995) uses the example of the internal combustion engine. The building blocks of the engine were almost all known a century before: Volta's sparking device, the spark plugs, Venturi's perfume sprayer, the carburettor, let alone gear wheels, which have been known for centuries. Each part was familiar, but to make the internal combustion engine, it wasn't enough to know about the individual parts. The invention came in putting them together.

However, this seems much an ex-post approach. One sees the whole made up of parts only when one already knows the function of the whole and the mechanism based on the components.

A definition of complexity, as related to the number of a system components, is often found related to the concept of information. Cohen and Steward, (1994, p. 20), for instance state that: "*We may tentatively define the complexity of a system as the quantity of information needed to describe it*.". This, however, much resembles the early definition given by Chaitin (1975). Recently, neuroscientists Edelman and Tononi offered another definition of complexity: "*Complexity is thus a function of the average mutual information between each subset and the rest of the system, and it reflects the number of states of a system, that result from interactions among its elements*.", (Tononi and Edelman, 1998, p. 1849 – see also Edelman and Tononi, 2000, for a detailed account of complexity in their theory of consciousness). Ruelle (1992), considered the father of the notion of strange attractors in chaos theory, states more simply that: "*An object (physical or intellectual) is complex if it contains information difficult to obtain.*", (Ruelle, 1992, p. 10).

But what is it truly possible to infer *a priori* about complex adaptive systems? To this regard Ulanowiz (1997), a renown ecologist, states that: "*The significant thing to notice is that complexity of the system is generated by the number of combinations of possible encounters*. (of its parts)" (Ulanowiz, 1997, p. 69). But then he warns that: "*A truly complex system will come close to behaving uniquely each time it functions*.", (Ulanowiz, 1997, p. 70). In the case of the engine nobody could have previously forecast that by putting those pieces together the typical function required nowadays of engines could have contributed, let alone that the dramatic increase of the use of those engines, also to the alteration of global climate of the planet. It should be noted that the Santa Fe group made this remark in discussing of general theory - see Waldrop, 1994 - but probably this observation was not considered relevant, later on, when developing their approach. Another leading ecologists, Holling (2001, p. 391), states that complexity: "… *emerges not from a random association of a large number of interacting factors, but rather from a smaller number of controlling processes*."

Horgan (1995), referring in particular to the complexity group at the Santa Fe Institute, comments that "*complexologists*" are not the first ones to have attempted to create a "*mathematical theory of almost everything*". Then, after recalling the rise and fall of cybernetics, catastrophe theory, chaos, information theory, he wonders if complexity theory is just the next one to follow.

What are the tools we should use to effectively deal with complex adaptive systems? Holland (1995), describes mathematics as the essential means by which we can explore complex adaptive systems. Curiously, Stephen Wolfram, another of the most influential scholar in the field of complexity, in his latest work: "*A New Kind of Science*" (2002), informs us to have discovered that the same complex images (made by computer graphics called cellular automata), could be produced by very simple sets of rules. Then he argues that chaotic dynamical systems and complex systems found throughout nature are triggered by simple programs. He claims that mathematical science can describe, and in some cases predict phenomena, but cannot truly explain why that happens. According to Wolfram, computers and software represent a much better alternative tool to understand complexity.

From this perspective it seems that solving complex problems, or problems related to complex systems, may just be matter of developing bigger computers, more complicated models and more sophisticated inferential systems able to take into account the behavior of all the particles making up the system. This idea has been criticized by many scholars (e.g. Anderson, 1972; Horgan, 1995; Allen and Starr, 1982; Rosen, 1991; 2000), but this requires addressing the complexity issue from a different perspective (as discussed later on). As Philip Anderson (three decades ago) pointed out: "*The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. … Instead at each level of complexity entirely new properties appear, and the understanding of the new behaviours requires research which I think is as fundamental in its nature as any other. … Psychology is not applied biology, nor biology is applied chemistry.*" (Anderson, 1972, p. 393).

2.2.2 Complexity as a whole that is more than the sum of the parts (emergence)

A second typology of definitions can be summarized in the words of Simon (1962, p. 468): "*Roughly, by complex system, I mean one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist*." Furthermore, Simon (1962), proposes that representing complex systems as hierarchical organized could help in describing their behavior.

The definition given by Gallagher and Appenzeller introducing one special issue on "Complex system in *Science* (vol. 284, April, 1999, p. 79) goes in the same direction: "*…we have taken a "complex system" to be one whose properties are not fully explained by an understating of its component parts*.".

This idea is has been popularised by the famous textbook by Eugene Odum "*Basic Ecology*" (1983), for the functioning of ecosystems. Anyway, even at present, many important textbooks on ecology still do not mention such an issue. Among the many authors that used this concept, H.T. Odum provided a comprehensive extension of the concept to the functioning of the society in his work *"Environment, power, and society"* (Odum, 1971).

2.2.3 Complexity as the ability of a system to become in time while maintaining an identity

A third typology of definitions focuses on the properties of open dissipative systems, which, under favourable boundary conditions, can self-organize and develop emergent behaviours. This characteristic makes them adaptive. This is a property found both in living organisms, as well as in other classes of open systems studied under the label of "*dissipative structures*" (Prigogine, 1980; Prigogine and Stengers, 1984; Nicolis and Prigogine, 1989). A brief account of the meaning of dissipative structure can be given by quoting Prigogine and Stengers, (1984, p. 12): "*We know that far from* (thermodynamic) *equilibrium, new types of structures may originate spontaneously. In far-from-equilibrium conditions we may have transformation from disorder, from thermal chaos, into order. New dynamic states of* *matter may originate, states that reflect the interaction of a given system with its surrounding. We have called these new structures "dissipative structure" to emphasize the constructive role of dissipative processes in their formation*."

Nicolis and Prigogine (1989, p. 218), then, define complexity as the ability of a system "*…to switch between different modes of behaviour as the environmental conditions are varied.*". Along with the theory of dissipative structure is the definition given by Clark *et al*., (1995, p. 36) that state: "*By complex systems we mean systems which have evolved a hierarchy of functional structures*."

Chris Langton, of the Santa Fe Institute, defined *complexity* as the line of balance, or transition point, between order and chaos, partaking of both (Waldrop, 1994). John Holland (1995 - see also Waldrop, 1994), argues that all adaptive complex systems, such as economies, minds and organisms, build models that allow them to forecast the world. This property (for living complex systems to anticipate changes) has been earlier proposed also by other authors, such as Polanyi (1968), and Burgers (1975), and, lately, discussed in detail, in analytical terms, by Rosen in his book "*Anticipatory systems*" (1985 – see also Rosen 1991 and 2000). A detailed epistemological analysis of the issue can be found also in Giampietro (2004). According to Rosen (2000), the idea was already present in the Schrödinger inquiry: "*What is life?*" (1944). In this work the great physicist argues about the need of a new kind of physics, able to account for the organization and functioning of biological phenomena. In other words, complex systems are able to adapt to their environments, by evolving new behavioural patterns.

The theory of self-organization seems to clash with the idea that it is possible to manage sustainability issues. If we accept the unavoidable process of becoming, then what are the limits to our planning and good intentions about sustainability? If all dissipative systems (species, ecosystems, households, societies) self-organize, then a given action aiming at organizing the system according to the will of a given actor, in any case will not, and could not, produce the expected results. In fact, "any system" that we want to control in reality is producing it-self following its own goals and rules. So the very logic to study general properties of self-organizing systems hoping to find eventually some principles that will help us to make them to follow our will (e.g. the Santa Fe approach) is problematic. If we accept that the very nature of complex systems is to self-organize and to generate in this way emergent behavior, then we have also to accept that self-organizing systems cannot be fully modeled. This is almost a tautology, if it were possible to fully catch and control their behavior using formal systems of inference they would not be self-organizing systems. They would be rather "mechanisms" according to the terminology proposed by Rosen (1991; 2000).

The idea that a theory of self-organization can be useful for handling human affairs implies an even deeper question. Why should we bother about sustaining the actual processes found in this world, in the first place. That is, why should we complain about environment destruction, human greed, the corruption of the political class, the fact that the rich gets richer and the poor gets poorer? Why should I complain about my state, or even worst to try to change it, if this is what has been given to me by the process of self-organization of the world? If things are as they are that it is surely because of the world has self-organized itself that way. On the other hand, we can also argue that our concern, protests and social revolutions, our attempts to change the world, are also part of the self-organization process… In this way, eventually, nothing can be explained or proved.

Explanations are just provided after the facts: only after the King reaches the power, he can state that this can be explained by God blessing him. Had his head been cut off before, he could not have invoked God's will (in the latter case the rival would). Whatever is the mechanism something will happen eventually as the process of becoming moves on. In retrospect any chain of stochastic events will be interpreted as the cause of the present situation (this is also part of human psychology). It seems like human beings are trying to explain to themselves things that cannot be explained but in a tautological way meeting paradoxes (see next sections for details on the issue). In the case of social science, Myrdal (1969), noted how science often confuses "*how the things are with how the things must be*".

2.2.4 Complexity à la Rosen: complexity as a "dialectic process" determined by the characteristics of the interaction between observer and the observed system

A fourth type of complexity definitions embraces a completely different approach. An approach that focuses on the relation between the observer and the observed, addressing the relative existence of a sort of dialectic process. This approach has been developed by the bio-mathematician Robert Rosen (1969; 1977; 1985; 1991; 2000). A few quotes from Rosen will show the fundamental differences between the previous definitions and the one provided by Rosen.

Rosen (1977, p. 229) "*We are going to define a complex system as one with which we can interact effectively in many different kinds of ways, each requiring a different mode of system description. That is, a complex system is one for which we have at our disposal a large number of subsets of measuring instruments, each of which gives rise to a different mode of description of the system. Another way of saying this is that 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 or properties) depending entirely on how we choose to interact with the system. … Thus complexity is indeed a function of the number of ways available to interact with a system.*", (see also Rosen, 1969).

I think that there is an interesting parallelism between Rosen's theory of complex systems and Chaitin's theory of algoritmic complexity. The definition of complexity given by Rosen, in fact, may resemble somehow that approach to algoritmic complexity of Gregory Chaitin. See for instance the following quote from Chaitin, (1975): "*The new definition of randomness has its heritage in information theory, the science, developed mainly since World War II, that studies the transmission of messages. Suppose you have a friend who is visiting a planet in another galaxy, and that sending him telegrams is very expensive. He forgot to take along his tables of trigonometric functions, and he has asked you to supply them. You could simply translate the numbers into an appropriate code (such as the binary numbers) and transmit them directly, but even the most modest tables of the six functions have a few thousand digits, so that the cost would be high. A much cheaper way to convey the same information would be to transmit instructions for calculating the tables from the underlying trigonometric formulas, such as Euler's equation* $e^{ix} = \cos x + i \sin x$*. Such a message could be relatively brief, yet inherent in it is all the information contained in even the largest tables. Suppose, on the other hand, your friend is interested not in trigonometry but in baseball. He would like to know the scores of all the major-league games played since he left the earth some thousands of years before. In this case it is* *most unlikely that a formula could be found for compressing the information into a short message; in such a series of numbers each digit is essentially an independent item of information, and it cannot be predicted from its neighbours or from some underlying rule. There is no alternative to transmitting the entire list of scores. In this pair of whimsical messages is the germ of a new definition of randomness. It is based on the observation that the information embodied in a random series of numbers cannot be "compressed,"' or reduced to a more compact form.*".

Euler' equation is a model of the system defined as the "tables of trigonometric functions", and this is a simple system according to Rosen's definition, as it has just one representation. And it is also simple, "low algorithmic complexity", according to Chaitin's definition. On the other way the system "scores of all the major-league games played since he left the earth some thousands of years before", cannot be mapped in a simple way trough an algorithmic mechanism (equation). In this sense the latter is a complex system both algorithmically and sensus Rosen.

See also the following quote: Chaitin, (2002, p. 171): "*If there are **n** bits of axioms, you can never determine the program-size complexity of anything that has more than **n** bits of complexity, which means almost everything. Let me explain why I claim that. The sets of axioms that mathematicians normally use are fairly concise, otherwise no one would believe in them. In practice, there's this vast world of mathematical truth out there—an infinite amount of information—but any given set of axioms only captures a tiny, finite amount of this information. That, in a nutshell, is why Gödel incompleteness is natural and inevitable rather than mysterious and complicated.".* In this sentence there is much of Rosen thought. A complex system can be mapped in a infinite ways, and our mapping systems "*only captures a tiny, finite amount of this information*". It has to be pointed out, however, that in the Rosen's theory the issue of scale has major relevance, while it is not addressed by Chaitin.

Wolf and Allen, (1995, p. 6), put it simply: "*Complexity is the product of interactions between levels of organization that is invoked by the question or framing of the problem.*" Simple and complex are then so defined by Rosen: "*I define a system to be "simple" if all of its models are simulable. A system that is not simple and that accordingly must have a nonsimulable model, is complex.*", (Rosen, 2000, p. 292). To further clarify: "*Another name for simple system is mechanisms.*", (Rosen, 2000, p. 303); it is to say a system that has a close, discrete, and finite set of properties and relations. A complex system on the other hand has a open, continuous, and infinite set of properties and relations.

From the previous definitions it follows that complex systems: "*In formal terms, they manifest impredicative loops.*", (Rosen, 2000, p. 24). Impredicative loops being (Rosen, 2000, p. 294): "*In particular, something was impredicative if it could be defined only in terms of a totality to which it itself had to belong. This, it was held, created a circularity: what is to be defined could be defined only in terms of totality, which itself could not be defined until that element was specified*". The definition given by Rosen implies a continuous contextualization, because of anything is defined by something else in a circular, egg-chicken loop.

2.2.5 The roots of the bifurcation in complexity thinking

The idea that the observer actively takes part in the process of complexification of reality has been recognized also by early authors. For instance it is a famous metaphor that of the Simon's ant (Simon, 1969). An ant is walking on the beach and we happen to note its complex walk. But that complexity it is only in our particular perception of the system, as for the ant the complex path it is just the simplest way to get home within the characteristics of that particular environment. "*An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself.*" (Simon, 1969, p. 24). The Santa Fe group also recognizes the unique and unexpected behaviour (novelty) of complex adaptive systems and their capacity to self-organize. On the other hand, they are just concerned with finding the general principles (Lewin, 1993, Waldrop, 1994; Holland, 1995). In the work of Rosen the concept of self-organization is also of central importance. To the best of my knowledge the only bold attempt of integrating these various typologies of complexity for developing an useful analytical tool has been made by Giampietro (2004). In this case, the concepts introduced by Rosen ("mosaic effects across scales", "impredicative loop analysis" and "surfing in complex time") are used to develop analytical tools in which numbers are used to check the quality of the narratives, rather than the reverse (as usually done in conventional mathematical models).

In the previous overview we can see a sort of line along which the concept of complexity flows: (1) it departs from a slightly different idea of complicatedness, then (2) it recognises emergence, then (3) it addresses the process of self-organization leading to novel behaviours and emergence, to end (4) by addressing more fundamental epistemological considerations, that of the relation observed-observer.

The different typologies of definition of complexity lay on different epistemological bases. They differ on what should be intended when using the term "system". True differences start from the root not on the top. A sort of neotenic process of scientific ideas, as it calls it Koestler, (1967, p. 169): "*True novelties are not derived directly from a previous adult theory, but from a new seminal idea – not from the sedentary sea urchin but from its mobile larva*". In this case the seminal idea of Rosen is that of focusing on the meaning of the process of mapping the reality. Rosen suggested a clear distinction between "simple systems" and "complex systems". A simple system is intended as the object of an observation, which is understood as an entity exiting independently from the observer. Such an entity has a set of given characteristics which is substantive and invariant to the process of observation. Non-equivalent observers operating at different scales and adopting different observation space will find in any case the same set of characteristics when observing the same entity. On the contrary the identity of complex system cannot be defined in substantive terms. The same system will be seen in different way in different observation spaces (when observed by non-equivalent observers using different criteria of observation or operating at different scales). The dialectic relation between the observed object and the observer implies that a given entity can be perceived and represented according to an open - virtually infinite – set of different ways. Any individual observer/agent with finite goals and limited means of perception will adopt only a bound and finite subset of them.

2.3 Back to basic: what is a "system"?

It is time now to try to answer the trivial question: "but what is a system then?" I left this answer for last on purpose, because this is the fundamental question/answer, on which all the rest is constructed.

A quick look at the literature immediately confirm that to define "what a *system* is" is not less complex that to define *complexity*!

The concept of *system* began to be elaborated in the 1940s by von Bertalanffy (Bertalanffy, 1968; Checkland and Scholes, 1990). According to the early "standard" definition, such as in von Bertalanffy, (1968, p. 55), we can say that: "*A system can be defined as a set of elements standing in interrelation*." Allen and Starr, (1982) on this conform to standards, as also for them a system is: "*Any interacting, interdependent, or associated group of entities*." (Allen and Starr, 1982, p. 278).

Checkland in the 1970s introduced the concept of "*soft system thinking*" in management science (operational research). Checkland and Scholes (1990), argue that many definitions of system are found in literature. Jordan, as early as 1965, listed fifteen different definitions (Jordan, 1965, in Checkland and Scholes, 1990). The authors state that all these definitions: "*… take as given the notion of a set of elements mutually related such that the set constitutes a whole having properties as an entity.*", (Checkland and Scholes, 1990, p. 4). Checkland and Scholes, (1990), reserve much attention to the term "system". In fact, "*system thinking*" on which they focus: "*… is simply consciously organized thought which makes use of that concept*.", (Checkland and Scholes, 1990, p. 18). They focus on the system adjective: "s*ystemic*", because it means: "*of or concerning a system as a whole*.", (Checkland and Scholes, 1990, p. 18). Atkinson and Chekland, 1988 (in Checkland and Scholes, 1990), examining basic systems ideas, underline that they can be expressed in the two typologies: (1) those addressing the issues of *emergence* and *hierarchy*, and (2) those addressing the issues of *communication* and *control*. According to Checkland and Scholes (1990), the very same essence of system is that it can be recognized as a whole having specific "emergent" properties in itself. The concept of emergence, on the other way, implies a view of reality as existing in hierarchical layers: "*In fact it is the ability to name emergent properties which defines the existence of a layer in hierarchical theory*." (Checkland and Scholes, 1990, p. 19). We could then say a system is what emerges (a structural definition concerning how systems are made). But systems have somehow to last in time. Their identity has to survive in a changing environment. So they have to develop processes of communication and control. Eventually the authors define system as: "*… a whole with emergent properties, a layered structure and processes which enable it to adapt in response to environmental pressures*." (Checkland and Scholes, 1990, p. 21).

In this sense Checkland and Scholes, (1990) challenge the early definition. As it confuses, or at least does not clearly distinguish, between reality (what is out there) and abstraction (the model we use to interpret nature). Referring to von Bertalanffy, they state that: "*… he made a bad mistake in using the word "system" for the name of the abstract notion of a whole he was developing*.", (Checkland and Scholes, 1990, p. 22).

An operative definition is proposed by Gallopin, (1996), who defines a system twofold: (1) "*An abstraction defined by the observer/investigator upon a portion of the world.*", (Gallopin, 1996, p. 103), and (2) "*In its most basic level, a system is defined as a set of attributes, a set of distinguishing properties, and a set of appearances for each attribute* *and distinguishing properties. The term "system", even at this most primitive level, is thus always viewed as an abstraction -or an image- of some aspects of the object and not as a real thing.*", (Gallopin, 1996, p. 103).

Simply and effectively, Kampis (1991), defines a system as: "*…the domain of reality delimited by interactions of interest.*", (Kampis, 1991, p. 70). Kampis definition makes it clear that the objectives and interests of the observer have a key role in shaping what we see interesting to see (a point underlined also by others authors, e.g. Myrdal, 1969; Simon, 1969).

I much agree on this latter definition. A system is in itself an emergent property that takes life through the process of the observer posing a question (his/her goal) within a portion of reality that is perceive being pertinent to his/her interests. Discussing the notion of "hard" and "soft" science, Röling, (1994, p. 388) states that: "*I consider the systems themselves as constructs. Hard science assumes an objective reality and looks for causes. Soft science assumes that there are many realities as people, and looks for reasons. Instead of explanation, soft science looks at interpretation. With one objective and true world, disagreement means negotiation and accommodation (Maturana undated).".* But if we agree with the definition of complexity given by Rosen it cannot be otherwise.

Robert Rosen (1974) poses further questions: "*The two crucial concepts in our analysis are those of system structure and system function. The terms, structure and function, mark polarity which goes very deeply into our apprehension of things in the world around us. Speaking very broadly, we shall say that* ***a structural question about a system concerns what the system is made of, while a functional question concerns what the system is made for.*** *As we shall see, the structural properties of a system on the one hand, and its functional or behavioral properties on the other, provide us with two quite different modes of system analysis*.", (Rosen, 1974, p. 61, bold is mine). I will not treat further this issue, since the relevant point is related to the crucial issue of modeling. To end this section let's have a look at the drawing "Three worlds" by Mautits Cornelius Escher in **Figure 2.1**: which is "the system"?

Figure 2.1 *(see p. 32a) How many systems?*
(The picture is the drawing: "Three worlds" - 1955 - by M.C. Escher, 1898-1972).

2.4 The "dialectic of complexity" made easy: two examples from Quino

Humans seem to invoke complexity when the unexpected arises, any time they are forced by their experience, to create new meanings to explain the world. In fact humans tend to adopt specific representations and meanings to simplify their perception and representation of the world. This is also necessary to save computational power, otherwise the brain would be overwhelmed by a huge amount of information and possibilities to be considered at each decision to be made.

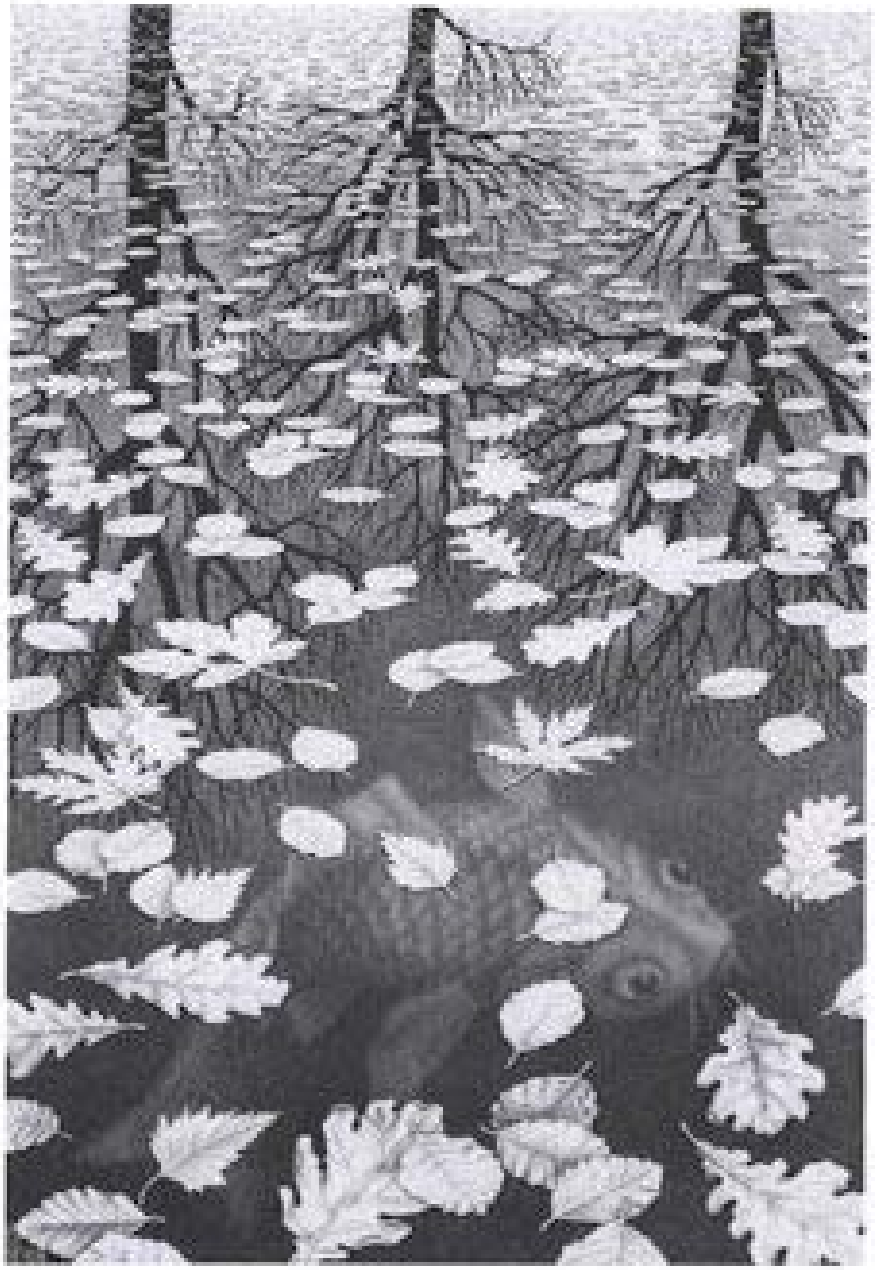

Figure 2.1 *How many systems? (The picture is the drawing: "Three worlds" - 1955 - by M.C. Escher, 1898-1972).*

2.4.1 The "human factor": perception it is not just matter of physiology or biology but also of culture, past experiences, social processes and much more

It is generally claimed by those scientists working in "hard" scientific fields, that science is an objective way to know the world. It is to say that what we know through science it is true in substantive terms. Edelman and Tononi (2000), note that science has always tried to eliminate the subjective from its own description of the world.

Giampietro, (2004) in relation to this point, when commenting a paper written by Home and Robinson (1995): "*Einstein and Tagore: Man, Nature and Mysticism*", about a conversation between Einstein (the famous German physics and Nobel laureate) and Tagore (the great Indian poet and Nobel laureate too) indicates three main epistemological positions:

(1) Einstein position – science must study (and it can) what nature does. Entities do have well defined objective properties even in the absences of any measurement and humans know what these objective properties are, even when they cannot measure them.

(2) Bohr's position – science can study starting from what we know about nature. Objective existence of nature has no meaning independent of the measurement process.

(3) Tagore position – science is about learning how to organize our shared perception of our interaction with nature. Objective existence of nature has no meaning independent of the human pre-analytical knowledge of typologies of objects to which a particular object must belong in order to be recognized as distinct from the background.

Let's now look at **Figure 2.2**, the duck-rabbit ambiguous figure, a well known drawing in gestalt psychology.

Figure 2.2 *(see p. 33a) Duck-rabbit ambiguous figure (by the Gestalt psychologist J. Jastrow, published in his book Fact and Fable in Psychology, (1900)*

This figure is ambiguous because we can see, time to time, either a duck or a rabbit. However, we cannot see both at the same time. Physiologically this depend on the fact that the brain cannot hold two contrasting patterns at the same time. What we perceive (the specific pattern-figure), is generated by the fact that we already know - before looking at the drawing - what a duck and a rabbit look like. For someone who have never seen a duck but knows rabbits the figure would not be ambiguous. He/she would never perceive the existence of a duck in it. In this case, we could even say that it is the identity of the observer that makes the figure ambiguous (the presence or absence of ambiguity, in fact, depends on our previous encounters with ducks and rabbits and/or representation of them). It is very possible that somebody can perceive in the figure even other patterns, as far as the figure could resemble things very familiar to him/her.

2.4.2 An example taken from everyday life: emergent properties and unpredictability of self-organizing systems

So far we defined complex systems as systems having the ability to adapt and self-organize (self-modify) in time. Therefore, in an observation process their structure and properties will reflect choices associated to the perception of the observer. An example of a

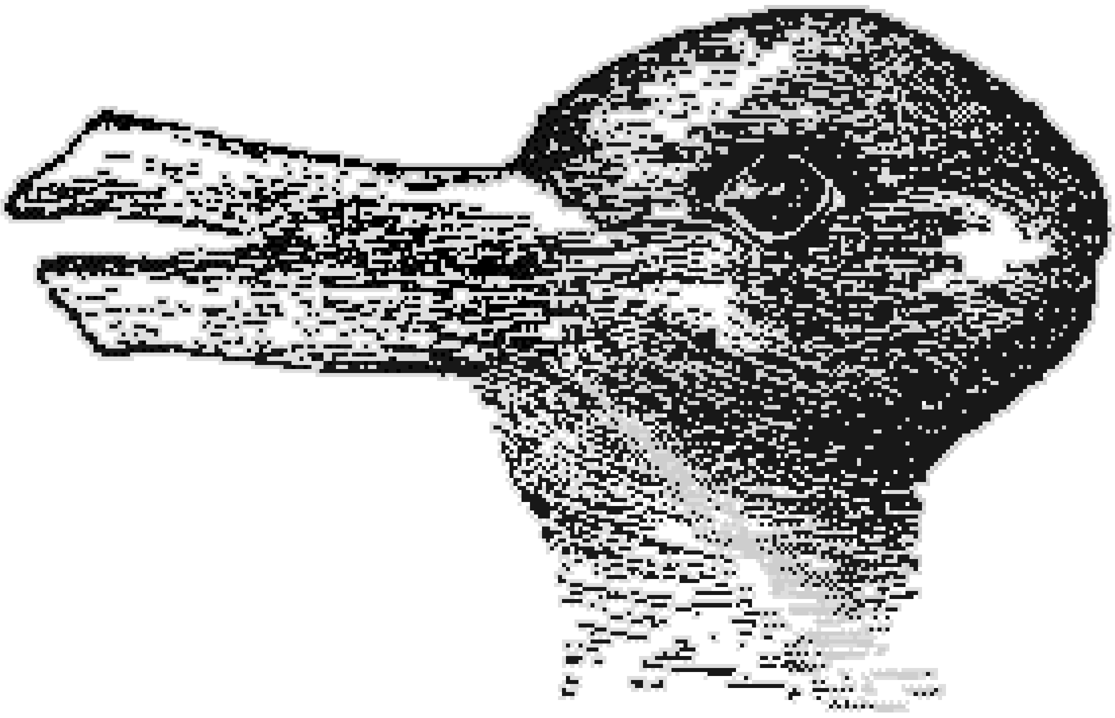

Figure 2.2 *Duck-rabbit ambiguous figure (by the Gestalt psychologist J. Jastrow, published in his book Fact and Fable in Psychology, 1900).*

complex system that fits these characteristics is shown in the strip by Quino (the famous Argentinean author of the cartoon "Mafalda") shown in **Figure 2.3**.

Figure 2.3 *(see p. 34a) Complexity in action (after Quino).*

The strip can be read as an attempt by the husband (the observer/agent) to control and direct the behaviors of his wife (the observed/self-organizing system). The husband takes action, following a plan, in order to solve the problem "messy kitchen", as it is perceived from the husband point of view.

Sequence (A): Here there is a state of affairs that the husband does not like and wish to change. If we move out from our cultural lock-in (house must be in order – or better in a certain kind of setting we label as order), it should be clear that this is just a problem of the husband. A problem due to the fact that he does not accept the world as he sees it, for he has a different idea of what the world should look like to him (there are not absolute-objective-true reasons why a kitchen should be "in order").

It has also to be stressed the profound relativity of the problem itself depending on the specificity of the context. In the case of the strip, let's imagine that in the place of the ugly woman Quino would have put a beautiful girl, or a very rich and very old wife (going to leave lots of money to the husband in her will). Probably, in these different scenarios the messy kitchen would not have been perceived as a problem by the man. In the same way, the experienced problem would have not occurred in the case the couple were rich enough to be able to afford to pay someone cleaning the kitchen. Therefore, the perceived problem "messy kitchen" depends on the perception and attitude of the observer-husband within a given context. The wife does not perceive the messy kitchen as a problem. She is living happily in spite of the pile of dirty dishes.

Sequence (B): The husband has an objective in mind. He decides that things must change. With this goal he starts interacting actively with the observed system to modify its trajectory according to his will. An alternative solution could be that the husband decides to change his attitude (the observer, rather than the observed) by, for instance, leaving the family or joining the party of the people happy to live in messy kitchen.

Sequence (C): The husband forces the system (his wife) to change in order to achieve his objective. To do that he brings home technical inputs for cleaning dishes. However his has ineluctability to deal with the limited knowledge he has of his wife (he does not know his wife's aspirations, sense of identity etc.). It has also to be noted that no "participatory" process has been previously undertaken by the husband to reach an agreement with the observed system to be managed. He did not ask the wife her opinion about the state of the kitchen and on what to do about that. After the implementation of the selected policy, the managed system (wife and wife-kitchen) seems behaving, at the beginning, as expected.

Sequence (D): An unexpected event happens. At a certain point the wife sees her image reflected on the bottom of the pot now finally clean as a mirror. This image made her aware of her poor look. This awareness however is associated with feelings the woman herself was unaware of, before the accidental discovery. At that point, she felt in need of some personal care. The activity of cleaning up and making more beautiful should have as goal herself rather than the kitchen. The observed system changed itself (emergent property) while

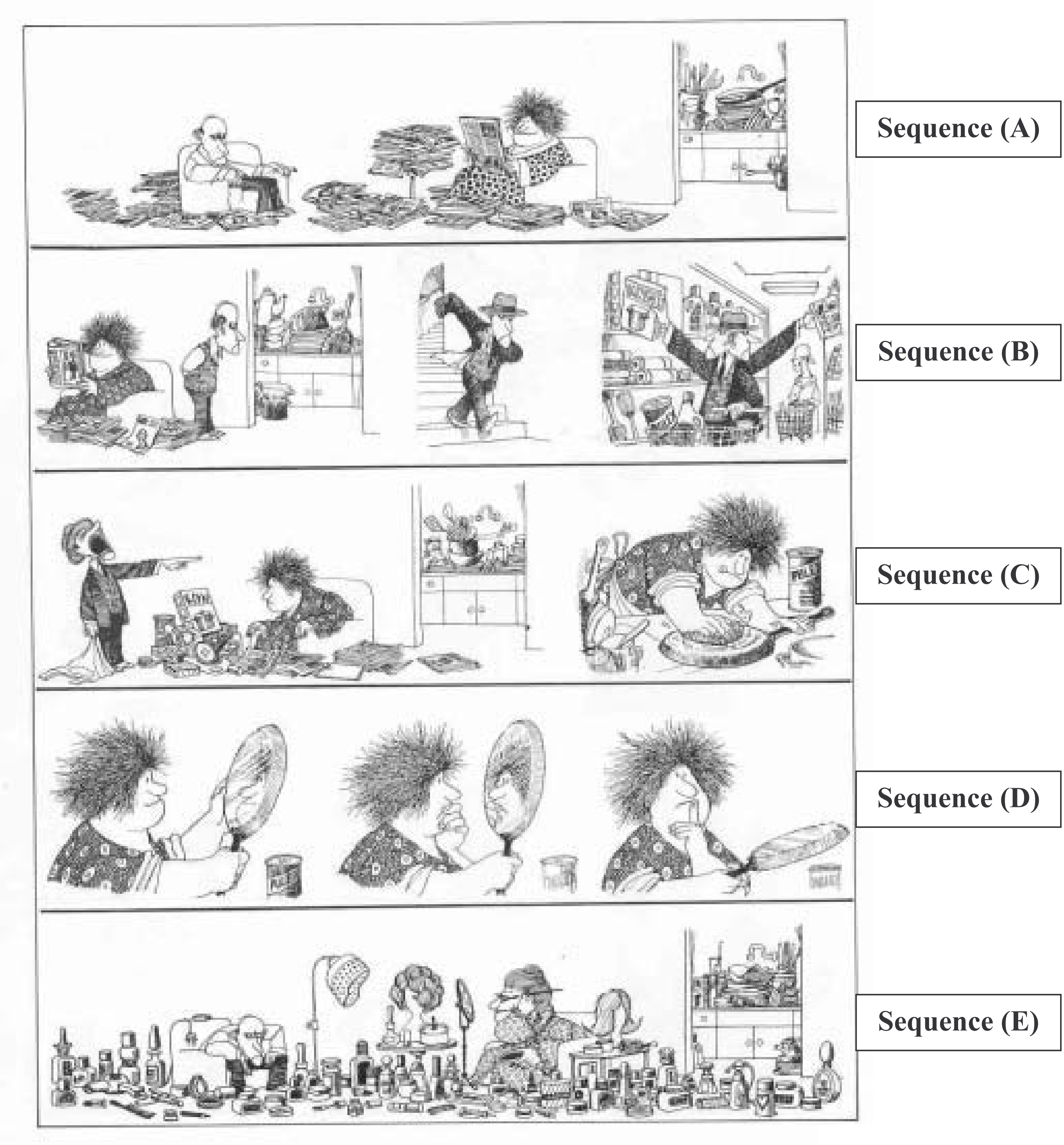

Figure 2.3 *Complexity in action (after Quino, 1993, p. 11).*

changing its relations with the surrounding environment. This event could not have been previously forecasted by the husband. In fact, this is just one of the possible infinite unexpected events that could have led the same managed system (wife and kitchen) to another trajectory. Since nobody can fully predict the future trajectories of complex adaptive systems that we want to change, any attempt to change complex adaptive system implies always the unavoidable facing of risk, uncertainty and ignorance.

Sequence (E). The system switched in another "unexpected" and "unwanted" steady state for the husband. The initial problem ends up just exacerbated. Still the final situation may be considered an acceptable one. Worse case scenarios could have been possible. For example, the wife, realizing her miserable state, could have killed the husband or herself, or could have left him. Feedbacks can be really unpredictable when dealing with complex adaptive systems. Moreover, women are genuine members of this class.

In the previous sections of comments I used loosely the word "system" in several occasions. But of what system I was talking about? In fact, in the strip shown in **Figure 2.3** it is possible to detect different systems, when considering different hierarchical levels. A system can be the "mirror-pan" made up by the metal and the mirror effect. A higher one can be the woman and the pan. The woman in the kitchen is also a system. The couple husband-wife is a system too. The couple in the house is still another system. The couple and the outside environment is again another system. And so on. Each of these systems exhibit emergent properties. The pan becomes a mirror only in a certain context. A woman, or a man, by her/himself can be a very complex system indeed, let alone if we consider them in relation to their personal history and the cultural context in which they are operating.

So when assessing the meaning of this story we can end up by asking: which is the problem to be addressed? Which is the system to be considered? Which model could be used or be useful? Which sort of scientists should be involved to work on this problem?

Let's start from the latter. A psychologist should be certainly helpful both to the husband and to the wife. But in which sense a psychologist would address the problem with a given system? What is the system that "the expert called in" should consider? Is the wife exploiting the husband (living in the house without providing an adequate flow of housekeeping), who rightly got angry? Or vice versa is the husband exploiting the wife, who in retaliation entered into a washing strike? Is this situation just an example of a typical matter of family conflict? Would not be useful to start by trying to understand why that family ended up like that? Is this crisis the result of any long hidden grudge exploding now? Would not be better for the couple just to split rather then carry on a life like that? If this is the case, then there would be no need to solve any messy kitchen problem, let alone the intervention of a psychologist helping them to agree on how to clean the kitchen. The messy kitchen is just a symptom of a more serious problem much bigger and important. A psychiatrist and a chemist would be helpful in case the behavior of the wife be due to a period of deep depression associated to hormonal imbalance. To see a physician could be also the case if the depression depends on problems of the nervous system.

Changing completely narrative, what about asking the help of a "family system analyst" to carry out in that household an integrated time-money-energy flow assessment? Maybe the wife has not enough time to do what she would like to do and because of that she decided to stop dish-washing. Had she more leisure time, she would carry out both activities. The unexpected event that moved the wife into another, equally (if not worst for the husband) behavior attractor, was the "mirror effect" of the back of a pan. Then a specialist in science of material (pans and pots in particular) could have avoided such a problem, by providing a surface not reflecting images. But this expert could have been called in, only if the "mirror effect" and its consequences could have been predicted ahead. How much this unexpected event could have been predicted? Someone could have calculated the risk (in terms of probability of insurgence) of the "mirror effect" leading to the falling into the second attractor "messy house"? If this event could have been predicted and the relative risk assessed, a competent risk analyst would have been of great help.

Quino strip is about the evolution in time of a self-organizing, adaptive complex system. Any discussion of such evolution must necessarily end up in the telling of a story about it, a story that has necessarily many interpretations. In the previous paragraphs I constructed many reasonable "*narratives*" about the existence of potential problems. Each of these narratives could have been addressed by scientific experts. This means that each of these scientific problem structuring, very rigorous when in place, in reality is based on an arbitrary choice of choosing one of the possible narratives.

What is the problem depends on the narrative we use (Checkland and Scholes, 1990; Allen and Hoekstra, 1992; Allen *at al*., 2001; Giampietro, 2004), and according to the framing we adopt, the problem has already in itself its model of interpretation and the relative implicit answer (Simon, 1969; Newell and Simon, 1972). The process of constructing and selecting narratives, in reality, is the crucial point. Depending on the narrative we selected, we will embrace a specific perception of the events occurring in the reality and the relative records of facts. Therefore, any process of framing a problem is goal dependent (Myrdal, 1969; Simon, 1969; Newell and Simon, 1972), up to the point that we can construct a narrative based on an "*interested credence*" (Myrdal, 1969), upon the state of the reality. This fact is well known in psychology (Festinger, 1962; Arker and Ayton, 1999; Aronson, 1999; Aronson *et al*., 2002).

2.4.3 Complex systems and circularities: lock-in syndrome and Jevons' paradox

The definition of impredicative loops has been defined earlier as an chicken-eggs process. As steted by Rosen (2000) an Impredicative Loop is a loop that: "*…created a circularity: what is to be defined could be defined only in terms of totality, which itself could not be defined until that element was specified.*" (Rosen, 2000, p. 294). The definition given by Rosen implies a continuous contextualization, because of anything is defined by something else in a circular, egg-chicken loop. Within an impredicative loop the identities of parts and whole self-entail them-selves across levels and scales (Rosen, 2000; Giampietro, 2004).

Paradoxes, apart from being funny intellectual exsercies, tell us something very important concerning our way to perceive and construct the reality. Etymology the word come from the Greek *paradoxon*, meaning an argument that apparently derives self-contradictory conclusions by valid deduction from acceptable premises, or more simply a statement that initially appears contradictory but actually makes sense (Merriam-Webster Dictionary). Famous paradoxes are for instance the Zeno's paradox (one can never reach the end of a racecourse, for in order to do so one would first have to reach the halfway mark, then the halfway mark of the remaining half, then the halfway mark of the final fourth, then of the final eighth, and so on *ad infinitum*), the Prisoner's Dilemma (a condition in which the rational action of each individual is to not cooperate, yet, if both parties act rationally, each party's reward is less that it would have been if both acted irrationally and cooperated), Voter's Paradox (in a national election, one vote will not make any difference in the result, yet the accumulation of all the individual votes does, in fact, decide the election), Bureaucrat's Dilemma (a family of four is poor in the USA if they make only $15,569. If they make $15,570 they are not poor) (see for a brief but clear review of paradoxes and their meaning see Quine, 1962; Burge, 1979), for a wide review in many fields of science see the following websites <http://perspicuity.net/ratlife.html>, the Internet Encyclopedia of Philosophy at URL <http://www.utm.edu/research/iep/>, Wikipedia Free Enciplopedia at URL <http://en.wikipedia.org/wiki/Paradox>. Thee seems still be a paradox in risk prevention, we call call it *risk paradox.* The issue at the core of the *Risk-tradeoff analysis* (a brach of the risk analysis), which "*... is a method for evaluating enviromental decisions that attempts to highlight the risks that may be created by an activity intended to reduce risk.*" (Hammit, 1997, p.155).

Concerning the concept of complexity hereby presented it is worth to mention the famous Bertrand Russell's paradox which states that the set of all sets that are not members of themselves is a member of itself if and only if it is not a member of itself (Russell, 1903, see also the website of the Stanford Encyclopedia of Philosophy at URL <http://plato.stanford.edu/entries/russell-paradox/>. Russell's paradox has its root in the "*vicious circle principle*", a principle which states that no propositional function can be defined prior to specifying the function's range (Rosen, 2002; Stanford Encyclopedia of Philosophy) . It is to say that before a function can be defined, one first has to specify exactly those objects to which the function will apply. From this it follows that no function's range will ever be able to include any object defined in terms of the function itself. About Russell's paradox, Rosen (2002) states that self-reference lies at the heart of the paradox: "*Such impredicativities create semantic referents within them, in this case self-referents depend entirely on the context created by the circle itself.*" (Rosen, 2002, p. 135). To overcome the logical impasse Russell developed the *theory of types*, a hierarchy which consists of sentences about individuals where the lowest level will consist of sentences about sets of individuals, the next lowest level consists of sentences about sets of sets of individuals, and so on - Russell, 1908; Rosen, 2002).

It is interesting to note that resolving paradoxes concentrate on restricting the principles and assumptions so to avoid dealing with the subjectivity aspect of science that is concerned with the structuring of the context of reference, it is to say by increased syntactic-formal abstraction escaping semantic-complex issues (Korzybski, 1933; Rosen, 1977; 1985; 1991; 2002; Checkland and Scholes, 1990; Allen and Hoekstra, 1992; Giampietro, 2004).

As far back as 1933, Alford Korzybski, the father of modern semantics, referring to the relation between paradoxes and linguistics noted that: "*At present, all the humanly important and interesting terms are multiordinal ...* ***The main characteristics of these multiordinal terms is found in that they have different meaning in general depending on the order of abstraction****. Without the level of abstraction being specify, a m.o. term is only ambiguous; its use involve shifting meanings, variables, and therefore generates not propositions but propositional functions. It may both be an exaggeration to say that the large number of human tragedies, private, social, racial, are intimately connected with the non-realization of this multiordinarity of the most important terms we use.*" (Korzybski, 1933, p. 74 , the bold is mine). Korzybski (1933, p. 80), made the example of the term temperature; temperature is by definition the measure of the vibration of the molecule but it cannot be apply to electrons. So although the term represents a good symbol in a context it is meaningless in another.

Hereafter I will provide the reader with a couple of well-known examples characterized by the phenomenon of circularity leading to paradoxes.

(1) Jevons' paradox

Jevons' paradox is named after the English economist Stanley Jevons who, in his book: "*The coal question*" (1865), came to the conclusion that, contrary to what expected by contemporaries, the higher the efficiency in using coal, the higher would have been the overall coal consumption. More efficient steam engines would have expanded the possible uses of coal for powering human activities and therefore they would have boosted rather than reduced the rate of consumption of existing coal reserves. In summary: increasing the "efficiency" in using a resource (improved output/input ratio) leads, in the medium/long term, to an increased use of that resource rather than to the expected reduction (Giampietro, 1994b; 2004; Tenner, 1996; Herring, 1998; Sanne, 2000). Jevons' paradox has different names and different applications, for example it is also called "*take-back*", or "*rebound effect*" in energy literature, and "*paradox of prevention*" in relation to public health (Herring, 1998; 2000; Sanne, 2000; Giampietro, 2004). Tenner in his extensive list of case studies referring to the counterintuitive side effects of new technologies (Tenner, 1996), calls it "*revenge effect*".

Many other cases are known (see Giampietro, 1994b; 2004; Tenner, 1996; Herring, 1998; 2000; Sanne, 2000, for more examples): doubling the area of roads did not solve the problem of traffic, it made it worse since it encouraged the use of personal vehicles; as more energy efficient automobiles were developed as a consequence of rising oil prices, American car owners increased their leisure driving (and time spent bottled in the traffic jams) leading to an overall increasing consumption; a promotion of energy efficiency at the micro level of economic agents tends to increase energy consumption at the macro level of whole society; doubling the efficiency of food production per hectare over the last 50 years (the Green Revolution) did not solve the problem of hunger, it actually made it worse, since it increased the number of people requiring food and the absolute number of malnourished.

Jevons' paradox has to do with the fact that improved efficiency at a certain point in time (intensive variable) meet with the further evolution in time of the system that is open and adaptive to changes. This system then, tends to self-organize and rapidly transferring the gain of efficiency to all the possible sectors as well as creating new ones, eventually leading to the overall consumption (the reader is referred to Giampietro, 2004 for a detailed analysis of the phenomenon).

(2) Lock-in spiral (treadmill syndrome)

Looking at the strip in **Figure 2.4**: could we say that the solution of the "problem breath" lays in producing more pills?

Figure 2.4 *(see p. 38a) A funny version of the Jevons paradox in a locked-in system (after Quino)*

Even though the strip says it all and in a wonderful way, I will analyze the main points of this story, since they are very useful to clarify the concept presented so far.

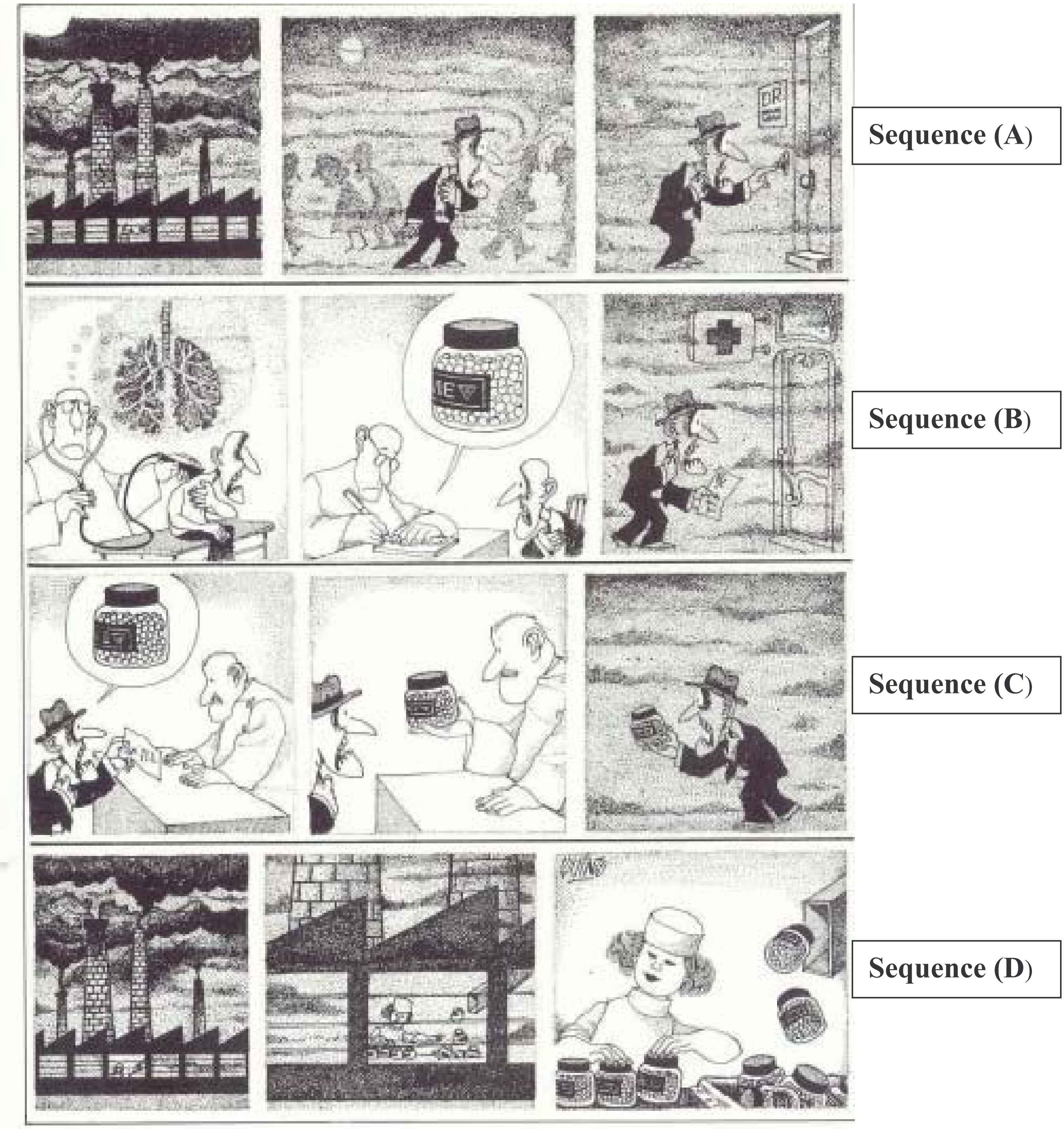

Figure 2.4 *A funny version of the Jevons' paradox in a locked-in system (after Quino, 1993, p. 25)*

(A) At this level of analysis (large scale) we have a general situation of air pollution that is useful to characterize the higher system "environment-air quality". The characteristic of the environment is affecting the health of the people causing severe respiratory problems. The problems depend on highly polluting factories, as shown in the first picture. At the lower level, an individual citizen needs a doctor to find a remedy for his problem.

The patient representation of the problem is that he cannot breathe and feels sick.

(B) The doctor, checking the general conditions of the patient, discovers a lung problem that deserves a cure. The doctor, at this point, does not care about the possible cause of the affection and focus on a check of physiology of his patient (local scale analysis). The solution proposed consists in a box of pills that will help the lungs to function better.

The doctor representation of the problem is that the lungs of his patient have problems and require intervention. In the specific: taking the proper pills would help the mechanisms associated with breathing. This can be the role of the expert called to fix a specific problem.

(C) The pharmacist provides the patient with the box of pills prescribed by the doctor. His role is just that of an executer and possibly an adviser on how to get the best effect out of the pills.

The pharmacist representation of the problem is that of supplying the technical means to cope with the lungs problem. This can be the role of the expert called to implement the selected technical fix.

(D) Eventually, there is the factory where the pills are produced, in which people work hard to produce more pills more efficiently since the demand is skyrocketing.

The industry representation of the problem is simple. Given existing regulation the task is that of increasing (maximizing) efficiency and economic gain.

From outside, when looking at the entire set of pictures (by adopting a large scale of analysis) we can have a more holistic vision of the various perspectives. We can establish a higher level relation among these different perspectives and generate yet another representation of the problem. We recognize that the doctor did a good job, the pharmacist did a good job and the people of the factory also. But this is not enough to do a good job on the system as a whole. When considering the whole system and its interactions across levels, when considering a more holistic view of the problem pills are not the solution. Actually, at the large scale, pills are part of the problem. We see that the system is in a dangerous lock-in, and that more pills will result in more air pollution and then more health problems. But to realize this we have to take a much larger view then that offered by a single frame at the time. We have to move through hierarchical levels: from the pills to the lungs condition, from the person feeling sick to the quality of the environment, considering in parallel the effects of the industry. The factory, on one side provides useful pills, whereas, on the other, contaminates the environment.

It is important to observe that in each of the different frames there are no explicit relations, which would make possible to establish cross-checking effects among the different components of the whole system: the patient, doctor, the pharmacist, the industry. In the overall process none of the agents operating at different hierarchical levels perceives its relation with the others. None of the agents perceive to be in a lock-in situation in which more and more pills will be soon needed to cure more and more sick people.

Although the strip is very funny and a bit cynic, the story is not just a bizarre fantasy. Rather we can recognize his value as metaphor representing a possible attractor in which our paradigm of technical development is trapped in (see for instance Tenner, 1996). This metaphor, for instance, fits perfectly the situation experienced in the recent technical progress of agriculture in the EU and USA, whose results are not funny at all (see the early warning of Carlson, 1962; Leopold, 1966). Increasing efficiency requires increasing the control over natural environment with the use of more and more energy, harmful chemicals, a huge amount of water and, lately, even with the artificial construction of living organisms (GMOs). Notwithstanding the fact that many seem to be aware that we are experiencing a perverse effects of lock-in in the spiral of technical progress of agriculture, still public money (subsides, see for instance the structure of the Common Agricultural Policy in EU-Grant, 1997), are poured in the agricultural sector with the goal of increasing its efficiency and profit. In spite of the fact, that it is more and more clear that this is resulting in the destruction of the environment, putting at risk human health, transforming farmers in public dependants in the hands of large corporations, and not sustaining their income in relation to the changes occurring in other economic sectors (Carlson, 1962; Colborn *et al*., 1997; Grant, 1997; Pretty *et al*., 2000; Myers and Kent, 2001; Pye-Smith, 2002) .

2.5 Hierarchy theory: dealing with the multiplicity of perceptions and representations implied by complexity

The idea of "hierarchy" entered officially into the scientific discourse, early in the 1960s, in different scientific disciplines (see Polanyi, 1968; Whyte, 1969; Wilson, 1969; O'Neill *et al*., 1986) as an attempt to deal with the complexity of the natural world.

In his seminal paper Simon (1962, found also as a chapter in Simon, 1969), gives an account of the hierarchy theory as a way to explain organization and evolution of complex systems: "*For lack of a better term, I shall use hierarchy…, to refer to all complex systems analyzable into successive sets of subsystems, and speak of "formal hierarchy" when I want to refer to more specialized concepts*.", (Simon, 1962, p. 468). More in detail: "*By a hierarchic system, or hierarchy, I mean a system that is composed of interrelated subsystems each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystems. In most systems in nature, it is somewhat arbitrary as to where we can leave off the partitioning, and what subsystems we take as elementary*.", (Simon, 1962, p. 468).

Another useful definition of hierarchy theory has been provided by Ahl and Allen, (1996, p. 29): "*Hierarchy Theory is a theory of the observer's role in any formal study of complex systems."* This definition matches precisely with the approach to complexity proposed by Robert Rosen.

It has to be pointed out that providing a hierarchical description of a system is far from a trivial matter. At least two key issues have to be take in consideration: (1) choice of boundaries; and (2) scale of analysis. In fact as stated by Koestler (1967, p. 48) :*"…"wholes" and "parts" in this absolute sense just do not exist anywhere*.".

The first point concerns the fact that in order to perform any kind of analysis we must choose or agree upon a set of boundaries because, as clearly pointed out by Georgescu-Roegen: "*no boundary, no process*", (quoted in Mayumi, 1991, p. 50).

The second point has to do with the fact that moving upwards or downwards in the hierarchy we need different means of observation and description of the system. That is, we are forced to adopt different criteria of observation (Allen and Hoekstra, 1992; Rosen, 2000). If one can use the same mean of observation at any level, it means that levels cannot be recognized as different from one another, this would make impossible to perceive and represent a structure as hierarchical. Eventually, a choice about what should be considered as the system and what should be considered as its background must be done if not we face an impasse. We can recall here that scaling can be conveniently defined as: "*the act to define the spatio-temporal level or levels of interest when attempting problem solving.*" (Wolf and Allen, 1995, p. 6). Scaling becomes a crucial point in describing the system behavior, but eventually it is the very same act of "*framing the problem*" that set the terms of what we can see (Rosen, 1977; 1991; 2000; Allen and Starr, 1982; O'Neill *et al*., 1986; 1988; Checkland and Scholes, 1990; Allen and Hoekstra, 1992; Giampietro, 1994b; 2004; Wolf and Allen, 1995; Chambers, 1997).

In a seminal paper Mandelbrot (1967; 1983) posed a famous question: "*How long is the coast of Britain*?". The amazing answer was that a single, true measure does not exist. Any measurement of length of coastline depends on the scale of measurement. A higher resolution results in a longer length of the same tract of coastline (the coast measured with a unit of measure based on km will result much shorter then the same coast measured with a unit of measure based on centimeters). Stocking (1987, p. 53) asks: "*Can we make measurements of land degradation at one scale and from them infer rates of degradation at other scale? …The short answer is "no".*" The complex heterogeneity of the processes of soil deposition and erosion on different scales prevents such an operation.

2.6 Implications of complexity in science for policy and governance

Complex systems can be seen as characterized by (Rosen, 1985; 1991; 2000; Checkland and Scholes, 1990; Allen and Hoekstra, 1992; Giampietro, 2004):

(1) the existence of impredicative loops: chicken-eggs processes (A=>B & B=>A in circular way) which are used to define an operational identity for becoming systems. This requires considering self-entailing processes across levels and scales.

(2) the co-existence of multiple identities: different boundaries for the same system when looking at different relevant aspects of its behavior. Considering different relevant dynamics on different scales requires the adoption of a set of non-reducible assumptions about the identity of the same system.

(3) the existence of complex time: complex time implies acknowledging that: (a) the observed system changes its identity in time; (b) the observed system has multiple identities on different scales that are changing in time but at different pace; (c) the observed system is not the only element of the process of observation that is changing its identity in time. Also the observer does changes in time. This entails, that depending on the selection of a time

horizon for the analysis we not only can observe multiple distinct causal relations among actors (e.g. the number of predators affecting the number of preys or vice versa), but also find out that our original problem structuring and consequent models may no longer be useful in relation to a changing context or changing goals for the analysis.

It is clear that the typical reductionistic approach developed within single specific disciplines makes it impossible such a reading. Therefore to face the new challenge to agriculture and environmental management we need: (i) transdisciplinarity, defined as the integrated use of models and variables belonging to non-equivalent systems of description, and (ii) multilevel analysis, it is to say: the description of events occurring at different hierarchical levels in the different elements operating on different time horizon (Checkland and Scholes, 1990; Allen and Hoekstra, 1992; Rosen, 2000; Giampietro, 2004).

Giampietro (2004), attempts an analysis of the implications of this fact in terms of *science for governance*, (in relation to the work of Funtowicz and Ravetz, 1990; 1991; 1994a), and states that they are at least twofold: (1) on the scientific capability of providing useful representations and structuring of these new sustainability problems, and (2) on the political capability of providing adequate mechanisms of governance. Here is manifest the importance of the complexity (*sensus* Rosen) and hierarchy theory to provide a frame to account for the inherently importance of qualitative interpretations on the system construction, it is to say for the development of "*useful narratives*" (Checkland and Scholes, 1990; Röling, 1994; 1997; Giampietro, 2004). A first attempt in this direction was made since the 1970s by Peter Checkland, an engineer working tin the field of Operational Research, who introduced the concept of "*Soft System Thinking*" to account for the inherently importance of qualitative interpretations on the system construction. It seems however, that still much has to be done in this direction in particular for what concerns the application of complex theory to the process of decision making.

Chapter 3

Introducing innovative concepts derived from complex systems thinking “*à la Rosen*”: identity, attributes and indicators

> *All models are wrong. We make tentative assumptions about the real world which we know are false but which we believe can be useful.*
> George Box[8]

René Magritte[9]

> *Before examining the problem of the true and the false, we need to examine the problem of the attitude and the method.*
> Thich - Nhat Hanh[10]

Summary

This chapter again addresses complexity, but framing it from the perspective of complex system theory developed by Robert Rosen (the only one addressing the issue of complexity in terms of the characteristics of the observer/observed complex). This chapter introduces a few concepts required to understand the philosophy of the approach presented in part 3: modelling relation, essence, identity, attributes and indicators.

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[8] George Box (1976).

[9] Belgian painter (1898-1967). The statement says: “This is not a pipe”.

[10] In: Thich Nhat Hanh, (1973, p. 19). The author is a reknown Vietnamese Buddhist monk.

3.1 Modelling as a way to inquiry about the world

We model because we want to infer future changes of a relevant situation in relation to a given set of objectives and goals. Therefore the use of a model can be associated with the following expression of belief: (a) IF now things are like this; (b) THEN taking this action will make things like that in the future. More in general, models are needed to: (a) choose a course of action; (b) assess the risk of it, by building possible future scenarios; as well as (c) explain past events in the light of present knowledge to better cope with future events.

Models play a key role in the development of science and technologies and in the understanding of the world in which we are living. Therefore, the fabrication of models is a very delicate issue as through them we interpret the world and its functioning. In fact, once we have a model, we have also an interpretation of the world, and once we have an interpretation of the world we behave accordingly, as if it were the reality. As stated by the great American sociologist W.I. Thomas: "*If men define situations as real, they are real in their consequences*.", (quoted in Merton, 1948, p. 193). From this reason is of extreme importance to be fully aware of what we are doing when performing the art of modelling.

Models are useful tools to solve problems. Although, very often, solving a given problem implies generating another problem, within the continuous process of autopoiesis of self-organizing systems. This fact points at another crucial question: what is "a problem" in the first place? According to Newell and Simon (1972): "*A person is confronted with a problem when he wants something and does not know immediately what series of action he can perform to get it*.", (Newell and Simon, 1972, p. 72). Put like that we can say that a problem is generated by a mismatch between the present state of affairs and a wished one, the one we search and hope to get in the future. Within this frame, the goals we have in mind already provide a context for the search of relevant attributes within which we will construct our models of the world. As Newell and Simon, (1972, p. 73) put it: "*To have a problem implies (at least) that certain information are given to the problem solver: information about what is desired, under what conditions, by means of what tools and operations, starting with what initial information, and with access to what resources. The problem solver has an interpretation of this information – exactly that interpretation which lets us label some part of it as "goals", another as "side conditions", and so on*". This is a very telling statement. Unfortunately it seems that very often modellers are unaware of (or unwilling to acknowledge) all that comes before the selection of useful equations. That is they seem to be unaware of the implications of the powerful act of compression that has been performed in the pre-analytical step when the problem has been defined as such. Smil (1993) goes further arguing that: "*Most of the problems in science are selected by the scientists themselves and the question formulated in ways making scientific solutions feasible. The same is true about the research requested by the governments... the problems offering little promise of solution will go largely unresearched*.", (Smil, 1993, p. 34).

Often modellers while pretending that their models represent the reality, tend rather to make the reality fit the models. An example can be the popular logistic equation, one of the oldest constructs of ecology (Hall, 1988; Peters, 1991; Smith, 1994; Kingsland, 1995). The logistic equation performs an useful function as a simple linearizing transformation when population data follow a sigmoid growth pattern. However, it rather represents an ideal of simplicity when the true growth pattern for populations is in the wild. Some authors (e.g. Hall, 1988; Peters, 1991; Kingsland, 1995), underlines how the high heterogeneity that characterize wild populations (where individuals differ in their reproductive potential and their environments, r and K vary with time and space, and among individuals, and where population growth involves time lags, stochastic events, and higher-order interactions which are not represented in the equation), does not allow the equation to effectively represent biological processes. Notwithstanding these bias the logistic finds a large use in ecology (in its standard form in all the popular textbooks) and resource management (e.g. Pearce and Turner, 1990; Tisdell, 1993; two popular textbooks of environmental economics). In the worlds of Peters (1991, p. 55): "*The success of the logistic reflects a double standard that allows ecologists to count successful applications of the model. When the data follow a roughly sigmoid growth, the logistic can be used, by definition, and its application is supported by the successful fit. However, when the data do not follow such a pattern, they are irrelevant to the logistic, and cannot be used to judge it. Thus the two results of comparing the logistic curve to data are either that the data are not appropriate or that the data fit the curve. Adherence to the logistic models of growth therefore involves an implicit tautology because all possibilities are permitted. This indulgence freed the logistic from critical scrutiny and ensured it a long life in ecology*". But "double standards" is not the only puzzling issue that affect the logistic model. Smith (1994), studied the evolution of population modelling for fisheries from 1855 to 1955. His work helps to greatly appreciate how socio-economic and political forces played a major role in determining "what" had to be taken into account (and "how") by the logistic model in assessing fish stock in view of determining catch policy. Of course, with Thomas (quoted before), one can say that a false model anyway determines true actions.

This is not to say that models are useless. Although methods are imperfects and theories time to time demonstrated false in the light of new findings, still they are un-substitutable instrument of inquiry (Smil, 1993; Sarewitz, 1996). Peters (1991) ends his strong argumentation against the present day usage of the logistic curve, stating that it may well "*... serves as "positive heuristic" by directing empirical studies of additional factors and by encouraging revision that make the basic model more adequate*.", (Peters, 1991, p. 55). They just need to be handled with care.

In the next section I will show that a narrative definition (and approach) of modelling, allows us to be much more flexible and effective when approaching problems, managing conflicting perspectives and values, and coping with the real word.

3.2 Modelling: "Substantive" versus "Narrative dependent"

We have seen that the step of modelling requires a preliminary input from the context in which the modeller is operating. In particular two factors are important: (a) the goals of the analysis; and (b) the cultural environment within which the analysis is performed. It should be noted, however, that very few analysts seems to be concerned with a clear identification of these pre-analytical factors and the relative implications. In relation to this fact, I believe that scientific models should be broadly arranged in two groups: (1) those assuming a ***substantive definition of the reality***; and (2) those acknowledging their dependency on an arbitrary ***narrative dependent construction***. Using the words of eminent scholars:

(1) Substantive definition of the reality

In the words of John von Neumann - one of the main scholars in the field of decision theory (quoted in Gleick, 1987, p. 273): "*The sciences do not try to explain, they hardly try to interpret, they mainly make models. By a model is meant a mathematical construct which, with the addition of certain verbal interpretation, describe observed phenomena. The justification of such a mathematical construct is solely and precisely that it is expected to work*.". As a *mathematical construct*, a model is supposed to be free from subjectivity and then well reflect the true properties of the real word. But because of this a pure mathematical construct is void of meaning.

Other definitions in this sense (not addressing the narrative issue) are: "*It means a simplified picture of reality, as a tool to solve problems. The model will of course never contain all the features of the real system, because, then it would be the real system itself. But it is of importance that the model contains the characteristics features, that are essential in the context of the problem to be solved or described.*" (Jørgensen, 1988, p. 9).

"A set of indicators (variables) and a set of assumed relations among them constitute a model of the original system. This model may be only a blurry mental image about how indicators are interconnected casually, or it may be a highly formalized (analytical or simulation) mathematical model." (Gallopin, 1996, p. 109).

(2) Narrative dependent construction

In the words of Allen and Starr - ecologists and leading scientists in the field of hierarchy theory - models have been defined as: "*An intellectual construction for organizing experiences. We generally do not extend our use of the word to include models as approximation of ontological reality. We prefer to acknowledge that we do not know what is the relationship of models to ontological reality*.", (Allen and Starr, 1982, p. 273). As an intellectual construction the process of modelling implies a certain degree of subjectivity. For instance: who decides what are the relevant issues to be taken into consideration? How should scales representing different indicators be arranged?

Some modellers back the idea that by adopting the scientific approach (whatever this world may mean), models can achieve a sound and useful representation of the real-world (*substantive definition*). Others scholars, on the other hand, contend that the very same "scientific" process of making up a model is implicitly and intrinsically affected by preconceived ideas, ideologies, hidden agendas, often up to the point to make them so biased not to be defendable but by pure act of blind faith (*narrative definition*). Allen and Hoekstra, (1992) – backing up a position taken by von Neumann before them - argue that: "*Science is not about truth and reality, it is about organizing experience and predictive power*.", (Allen and Hoekstra, 1992, p. 13), and that: "*Science is about organizing experience in a manageable way, the more manageable the better, and it may or may not relate to the ultimate truth*.", (Allen and Hoekstra, 1992, p. 25).

Intuitively, modelling can be perceived as a way of mapping "the territory out there" to help represent and solve a specific problem. But as Alford Korzybski warned: "*Two important characteristics of maps should be noticed. A map is not the territory it represents, but if correct, it has a similar structure to the territory, which accounts for its usefulness. If the map could be ideally correct, it would include at different scale, the map of the map, the* *map of the map, of the map; and so on, endlessly, a fact first noticed by Royce.*" (Korzybski, 1933, p. 58). What this means is that our perception of reality is not reality itself but our own version of it, or our map. The linguistic generalizing ability of humans (learn from experiences and readily transmit these experiences as symbols to succeeding generations), was for Korzybski the reason of our amazing progress over animals, but he was also concerned of how the misuse of this mechanism accounted for many of our problems as well: **"***This self-reflexiveness of language introduces serious complexity... . The disregards of these complexities is tragically disastrous in daily life and science*.", (Korzybski, 1933, p. 58).

This issue much resemble the contrasting view in statistical science between Fisher, and Neyman and Pearson (Vineis, 1990). For Fisher, the objective of statistic was not that to take decisions based on a test, but rather to make a better estimate on the bases of available information. On the other hand, Neyman and Pearson supported the idea that statistic should serve to take decisions in condition of uncertainty (Vineis, 1990). The latter view, then, took over and is still governing our present interpretation of statistics. Also in the case of statistics then, we may distinguish a *procedural approach*, that of Fisher, and a *substantive approach*, that of Neyman and Pearson. Presently statistical tests tend to used as "objective tools" required to take rational choices and even to handle uncertainty in the form of risk analysis.

It is interesting to note that a substantive approach to models is usually backed by hard scientists, experimenting in laboratory and dealing with abstract particles or theoretical economists dealing with ideal human being and societies**.** A narrative approach to models, on the other hand, is backed by scientists working in the field of complex, practical issues such as those met in ecology and social sciences, see for instance the comments by Myrdal, (1969); Simon, (1976; 1978) Allen and Starr, (1982); Altieri (1987; 2002); Checkland and Scholes, (1990); Norgaard, (1990); Hall, (1991; 1988); Funtowicz and Ravetz, (1990); Peters, (1991); Allen and Hoekstra, (1992); Munda, (1993; 1995); Smil, (1993); Giampietro, (1994b; 2004); Röling, (1994; 1997); Smith, (1994); Sarewitz, (1996); Chambers, (1997).

3.3 A review of some key terms: objective, goal, attribute, indicator, index

In this section the reader will be provided with a brief review of some key terms widely used when approaching modelling. It should be noted how the definition of the same terms may differ in meaning according to the authors and/or their field of expertise.

3.3.1 Objective

It is useful here to provide the reader with some definitions about the previously mentioned terms: objective and goal, by quoting some definitions.

"An objective is a statement of something that one desires to achieve" (Keeney, 1992 in Beinat, 1997, p. 23). "*Objectives are closely related to the values system of individuals and this definition implies that preferences can be expressed on all aspects of the decision problem"* (Beinat, 1997, p. 23). "*The degree to which objectives are achieved is measured through a set of attributes"* (Beinat, 1997, p. 24). Beinat, (1997, p. 24) referring to Zeleny

(1986), and Belton (1990), summarizes a number of other terms used in place of objectives: goals, targets, aims, ends, purposes, missions, ambitions. The different terms however may imply particular interpretation, approaches and even fundamental theoretical differences.

Munda and Giampietro, (2001, p. 331) state that: "*An objective is related to a previous definition of a relevant dimension of performance to be pursued to a maximum extent, according to: (1) expectations/wants of relevant agents; (2) previous knowledge of the problem; (3) perceptions of existing boundary conditions. (…) Each objective indicates the direction of change desired over the criteria used to characterize the performance within the dimension (e.g. economic, ecological, technical)*.".

3.3.2 Goal

Goal has been defined by Munda and Giampietro (2001, p. 331) as: *"a goal (synonymous with target) is the specification of the various objectives, in relation to a given: (1) problem structuring; and (2) context. That is, objectives are "translated" into a set of wanted states measured over the selected set of criteria. A goal is something that can be either achieved or not (e.g. increasing sales of a product by at least 10%). In this context, an indicator is a measurement that indicates the degree of achievement of a goal. The degree of achievement is referring to the distance between the actual score on the criterion and the desired state (goal) on the same criterion. The fact that a goal cannot be or is unlikely to be achieved does not imply a lack of validity of the related objective. An objective is an aspiration for change (e.g. humans would like to live as long as possible). Whereas the definition of a goal (e.g. increase the life expectancy to 85 years) is a practical reference point that can be used to "translate" aspirations and wants into action (given a problems structuring and context). When using the concept of goal in the decision theory literature, criteria are called attributes".*

Galloping states that a goal is: "*A special sort of indicator. Usually rather qualitative terms indicating a general direction rather then a specific state, the end towards which effort is directed (e.g. improving environmental quality)."* (Gallopin, 1996, p. 104).

3.3.3 Attribute

As it has been mentioned I wish to provide also a brief list of definition of the term "attribute":

An attribute is a measure that indicates the degree of achievement of goals. In practical terms it is referring to the distance between the actual score on the criterion and the desired state (target value) on the same criterion. (Munda and Giampietro, 2001, p. 331).

*A measure of the degree to which an objective is achieved. It is possible to distinguish: **i)** natural attribute, that follow directly from the definition of the objective (e.g. hectares of land impacted is a natural attribute for the objective minimize the extension of the area impacted); **ii)** constructed attributes (subjective scale), specify a finite number of degrees to which objective are met, (e.g. five-point scale from negligible to strong when assessing the outdoor impact of a waste disposal site; **iii)** proxy attributes are those only indirectly linked to an objective (e.g. air pollution concentration is a proxy being the objective that to* *minimize the respiratory disease, while a natural attribute can be the percentage of the population affected by respiratory diseases*) (Beinat, 1997, p. 24).

"Variables that represent characteristics of the environment are defined as attributes, and changes in environmental attributes provide indicators of changes in the environment". (Jain, *et al*., p, 85).

Beinat, (1997, p. 24) referring to Zeleny (1986), and Belton (1990), summarizes a number of other terms used in place of attributes: criteria, performance indicators, yardsticks, standards, gauges, principles, norms, and rulers. The different terms however may imply particular interpretation, approaches and even fundamental theoretical differences.

3.3.4 Indicator

Because of the central importance of the term indicator in modelling, and in science in general, it will be treated more extensively then the previous.

The recent call for a science of sustainability (e.g. WCED, 1987) led scientists to a massive search for more indicators. The hope is that by increasing the number of indicators it will become more probable to find good indicators of sustainability, as if "sustainability" is just a matter of getting the right indicator. Obviously, this is not the case, because: (1) an indicator is a human construct and does not carry any meaning outside the original context in which has been developed, (2) complex systems require a virtually infinite number and types of indicators depending on the relevant space-time scales and relevant observers/agents.

For decades, now, the number of sustainability indicators has been growing exponentially. Lists of indicators (nowadays often labelled as "*indicators of sustainability*") are spreading in publications and books. In the fields of agriculture and environmental sustainability a few well known examples are: ***Human Appropriation of Net Primary Productivity*** (HANPP): The fraction of total plant growth or net primary production (NPP) appropriated by humans. Estimates very widely ranging from 10 to 55% of terrestrial photosynthesis products, reflecting the uncertainty in the measure of key parameters (Vitousek *et al*., 1986; 1997; Haberl, 1997; Rojstaczer *et al*., 2001); ***Emergy***: It evaluates the work previously done to make a product or service. Emergy is a measure of energy used in the past and thus is different from a measure of energy now. The unit of emergy (past available energy use) is the emjoule to distinguish it from joules used for available energy remaining now. The concept of "transformity" is also proposed as the ratio of emergy (work put into a product) and energy (value received from the product) (Odum, 1988; 1996; Brown and Ulgiati, 1999); ***Index of Sustainable Economic Welfare*** (ISEW): It is an attempt to measure the portion of economic activity which delivers genuine increases in our quality of life, it accounts for the "quality" of the economic activity distinguishing defensive expenditures (e.g. defense from pollution) and natural capital depletion from real wealth; ISEW includes 19 adjustment indicators of wealth performance (Daly and Cobb, 1989; Neumayer, 2000); ***Ecological Foot Print***: It calculates human demands for natural resource and ecosystem services by estimating the ecosystem area - the ecological footprint - functionally required to support human activities (Wackernagel and Rees, 1996; Rees, 2000); ***Material Flow Accounting*** (MFA): A monitoring system for national economies based on methodically organised accounts and denoting the total amounts of material used in the economy. Material flow accounting enables monitoring of total consumption of natural resources and the associated indirect flows, as well as calculation of indicators (Moll *et al*., 1999; Eurostat, 2001). Because it would take quite some writing to properly present each of these indicators (or better indexes), for more information I refer the reader to the specific references.

Additional lists of indicators (as well as discussion of related theoretical issues) can be found in many publications in the field of environment, ecology and agriculture: Kuik and Verbruggen, (1992); McKenzie et al., (1992); SEAMEO, (1995); Prescot-Allen, (1996; 2001); Bockstaller et al., (1997); FAO, (1997; 1999a); Moldan et al., (1997) ; Rennings and Wiggering, (1997); Vereijken, (1997; 1999); Bell and Morse, (1999); Bossel, (1999); Brouwer and Crabtree, (1999); Giampietro and Pastore, (1999; 2001); Girardin *et al*., (1999); Halberg, (1999); Paoletti, (1999); Bockstaler and Girardin, (2000); Masera and López-Ridaura, (2000); Pré Consultants, (2000); Dixon and Gulliver, (2001); Dixon *et al*., (2001); Rigby *et al*., (2001); Hayo *et al*., (2002); López-Ridaura *et al*., (2002); Rydin, (2002); van der Werf and Petit, (2002), UNEP (2004). A wide review of indicators used in energy analysis, ecology and biophysical analysis of the economic process can also be found in Ulgiati *et al*. (1999; 2001; 2003). Furthermore there is a large number of indicators already in use by international organizations [e.g. European Environmental Agency (EEA); Unite Nations (UN) – for an overview of documents on the issue see in particular the website http://earthwatch.unep.net/about/docs/indicat.htm, Organisation for Economic Co-operation and Development (OECD), Food and Agriculture Organization (FAO), World Bank (WB), World Health Organization (WHO), World Resources Institute (WRI), Worldwatch Institute, International Institute for Sustainable Development (IISD); the European Joint Research Centres (JRC)], which can be found both on their web-sites and in publications.

Reflecting this abundance of indicators, there is an analogous abundance of technical and scientific definitions of the term “indicator”. The number of these definitions can be considered close to infinity, as anything can be considered as an indicator of something else. See for instance Gallopin, (1996), Beinat, (1997) for general reviews; McKenzie *et al*., (1992), for a review on ecological indicators; Kuik and Verbruggen, (1991), Bossel (1999) for general indicators of sustainable development, SAMEO (1995) for sustainable agriculture indicators, and also sets of indicator used by the World Bank, the World Resource Institute, and others international institutions.

Many definitions deal with what an indicator is and what it does (or better with what they deal with what an indicator is supposed to be and is supposed to do). Below I provide a list of a few, both general and technical definitions, that sound effective (many other definitions are available but I decided to list only a few more relevant for this discussion). An indicator is:

- *1 : one that indicates : as a : an index hand (as on a dial) : POINTER b (1) : GAUGE 2b, DIAL 4a (2) : an instrument for automatically making a diagram that indicates the pressure in and volume of the working fluid of an engine throughout the cycle; 2 a : a substance (as litmus) used to show visually (as by change of color) the condition of a solution with respect to the presence of a particular material (as a free acid or alkali) b : TRACER 4b, 3 : an organism or ecological community so strictly associated with particular environmental conditions that its presence is indicative of the existence of* *these conditions, 4 : any of a group of statistical values (as level of employment) that taken together give an indication of the health of the economy*. (Merriam Webster Dictionary)

- *A variable, a pointer, an index related to a criterion. Its fluctuations reveal the variation in those key attributes of sustainability in the ecosystem, the fishery resource to the sector and social and economic well-being. The position and trend of the indicator in relation to the reference points or values indicate the present state and dynamic of the system*. (Garcia and Staples, 2000, p. 385-386)
- *A variable, pointer, or index. Its fluctuation reveals the variations in key elements of a system. The position and trend of the indicator in relation to reference points or values indicate the present state and dynamics of the system. Indicators provide a bridge between objectives and action.* FAO (1999a)
- *A numerical representations of variables that indicate (or approximate) the presence and/or state phenomena that cannot be directly measured*. (Hermanides and Nijkamp, 1998, p. 63).
- *An indicator is used to gauge significant trends in some state of affairs. It may be a single selected index, or it may be compounded from several indices; it does not exist in isolation from its policy functions. The index is a pointer (as the index-finger or forefinger), whereas the indicator is the thing that point to some other thing.* (Funtowicz and Ravetz, 1990, p. 170).
- *Signals - of processes, inputs, outputs, effects, results, outcomes, impacts, etc. - that enable such phenomena to be judged or measured. Both qualitative and quantitative indicators are needed for management learning, policy review, monitoring and evaluation*. (Choudhury and Jansen, 1999, p. 37).

A more detailed and complex explanation is provided by Gallopin (1996). Indicators can be defined as having the nature of variables (therefore they are not “values” taken by such a variable). The variable must convey information on the condition and/or trend of a relevant attribute (or attributes) of the system considered – Gallopin (1996). That is, an indicator conveys information that is relevant for the process of decision-making at some level. It is to say that indicators are chosen to describe the evolution of the system of interest and/or to assess performance in relation to some targets or goals (Gallopin, 1996). At a given level of aggregation, or perception (such as local, regional etc.) indicators can be defined as individual variables or as variable that are a *function* of other variables. The function may be as simple as a *ratio* (including the concept of index number relative to some base values), an *index* (a single number which is a simple function of two or more variables, usually summation of individual variables, a multiplication etc.), or as complex as the outcome of a large simulation *model*. According to Gallopin (1996) indicators are operational representation of attributes. However he warns that any variable “indicates” an attribute, but it is not the real attribute of the real object. The sets of attributes and indicators are chosen to describe the evolution of the system of interest and/or to assess performances in relation to some targets or goals. An indicator is then a mean, a tool. As such it has no meaning on its own. Its meaning is given by the nature of the context and the purpose for which it has been chosen. Such an issue should always be kept in mind when dealing with selection of indicators (Gallopin, 1996). This means that writing a list of "indicators of sustainability" – out of a given context – is not particularly meaningful.

All the definitions quoted so far, although perfectly sound, did not address an important issue: what is the process that is required to generate an indicator? An indicator, in fact, after all has been said, should be more associated with a process than to a given variable or epistemic category. Indicators refer to system qualities, that within those observables, are representative of the system behavior of interest and useful to map it within descriptive domains relevant in relation to criteria of interest.

3.3.5 Index

I think it useful to report also some notes on the term Index. The term has been defined as:

- *An aggregate of indicators*. (Bailey *et al*., 1996, p. 12).
- *An index is a scalar, it is to say a single number generated by aggregation from two or more values.* (Gallopin, 1996, p. 106). ... *A scalar is a quantity defined only by its magnitude (i.e. its state or value is not compound).* (Gallopin, 1996, p. 106).
- *An index is an aggregate of indicators. This implies that what really defines an index is the set of formal, descriptive and normative properties underlying its aggregation convention. One should note that the issue of aggregation of multiple indicators is exactly the mathematical problem addressed by multicriteria decision theory*. (Munda and Giampietro, 2001, p. 331).
- *A statistical index is, in its broader sense, a measure of the magnitude of a variable at one point relative to its values at a base point. It is a statistic that may be gathered as a matter of routine, though it inevitably reflects the dominant conceptions of reality and of its representations*. (Funtowicz and Ravetz, 1990, p. 170).

Lately the term "composite indicator" has entered into use to indicate synthetic indices of individual indicators [e.g. Human Development Index (United Nations), Health System Achievement Index (WHO) Environment Index (World Travel and Tourism Council), Living Planet Index (UNEP & WCMC), Economic Sentiment Indicator (EC)]. Composite indicators are increasingly being used to rank countries in various performance and policy areas (Saisana and Tarantola, 2002; Freudenberg, 2003; Munda and Nardo, 2003).

Composite indicators are mathematical combinations (or aggregations) of a set of indicators or sub-indicators that have no common meaningful unit of measurement (are then incommensurable because of they belongs to completely different domains). This implies that there is no obvious way of weighting these sub-indicators. So if from one side they can be useful in their ability to integrate large amounts of information into easily understood formats (numerical figures), and are valued as a communication and political tool, on the other the construction of composites suffers from many methodological difficulties, with the result that they can be misleading and easily manipulated (Cox *et al*., 1992; Saisana and Tarantola, 2002; Freudenberg, 2003; Munda and Nardo, 2003). The huge compression eventually makes it difficult to grasp what we are really talking about when presented with a figure which summaries a wide number of indicators belonging to very different domains (and often also to very different spatio-temporal scales).

In the next section, when presenting the Rosen approach on modelling, I will illustrate from an epistemological perspective the main problems deriving from such a compression of meanings. Time to time I will be back on this issue also in the next chapters.

3.4 Adopting Rosen approach on modelling

Some authors are well aware that an indicator is more a process then a figure or formula, and the questions of scale, time and context are then addressed (e.g. Gallopin, 1996; Bossel, 1999; Brouwer and Crabtree, 1999; Rydin, 2002). Brouwer and Crabtree (1999), for instance, acknowledged that: "All indicators require a context for their interpretation and this will depend on the appropriate scale." (Brouwer and Crabtree, 1999, p. 280). Anyway, as in the definitions given earlier, generally in literature such issues are rarely, clearly addressed. Few are the authors who focused on the epistemological process of indicator construction (e.g. Gallopin, 1996; Giampietro, 2004). In the next section a more detailed epistemological analysis on the indicator construction is attempted, focusing on the indicator-context relation.

3.4.1 Constructing System Identity

The very same act of perception/representation of "the reality" in the form of a natural system requires a "previously assigned **identity**" to it. It is to say the natural system perceived in the reality is associated with a set of observable qualities (Rosen, 1985; 2002). The definition of an identity for such a system, therefore, coincides with the selection of a set of relevant qualities that makes it possible for the observer to perceive the investigated system as an entity (or individuality) distinct from its background and from other systems with which it is interacting. Therefore, in order to be able to do that, the observer must be equipped with a preliminary definition of an expected identity for the observed systems, which is associated to an expected pattern to be recognized in the information flux coming from the environment, and which makes possible the perception of the system in the first place (Rosen, 2002; Giampietro, 2004). This is required, either when detecting the existence of the system or when measuring some of its characteristics.

This means that any observation must rely on a specified pattern recognition known a-priori. An observer that does not know about the identity of a given system would never be able to make a distinction between that system (an expected pattern or behavior) and its "back-ground noise". The reader can recall here the comments about the example given in **Figure 2.2 (**the duck-rabbit shape) in Chapter 2. In the same way, the table mentioned by Einstein in his discussion with Tagore (again in Chapter 2) may be in the room, but if the epistemic category associated to the equivalence class "table" were not present in the mind of the observer, it would not possible to talk about tables in the first place, let alone checking whether or not a table, or that table, is in the room (Giampietro, 2004). It is important to note that a previously assigned identity coincide with a sort of gestaltic perception from the observer on the environment. A gestaltic perception which developed through a co-evolutionary process by which mutual mapping (encoded set of qualities and expected behaviors) has been established in languages and knowledge (Giampietro, 2004).

"Identity" defines what something (a natural system) is "expected to be" according to a set of known attributes associated with that system. The identity of the natural system then can be used in the construction of a formal model. To save computation capability, as well time, to run anticipatory models in real case situations, the set of attributes used to define an identity for a observed natural system must finite and discrete (Rosen, 1985; 2000; Giampietro, 2004). This set of qualities is then translated into a set of observable qualities. Such observable qualities can be called proxies, and they represent the encoding variables used in the model to describe and simulate changes in relevant system qualities. In order to be considered proxy variables it should be possible to operate on them a measurement scheme (Rosen, 1985; 2000; Giampietro, 2004).

The definition of an identity for a system, then, entails (Giampietro, 2004):

(1) the existence of some mechanisms generating the coherence of the expected patterns across levels, found when observing that natural system.

(2) the possibility of making prediction about expected associations among epistemological categories (e.g. if it has 4 legs, it has also 2 eyes, if it has a fur, it is a mammal, if it is a mammal it has warm blood; if it lives in the water it has fins, scales, cold blood, and drops eggs...) which are associated with the label used to refer to that identity (e.g. a dog, a fish); Obviously, the expected patterns associated to the identity of the observed system in this way, must result useful for the observer.

(3) the assignment of a weak identity to the environment. The environment has to be admissible in relation to the identity given to the system;

(4) the information associated with the identity of a given natural system has to be shared among interacting non-equivalent observers/agents (e.g. all humans using the words/labels "dog" and "fish" must know what a dog, or a fish is).

This discussion about the required characteristics to define an identity can be clarified by a simple example. Let's try to answer an innocent question like: "what is a fish?" Although this may seem a rather trivial question, the example given in **Figure 3.1** makes it extremely clear that is not at all so. The figure clearly shows that it is not possible to reach a simple, a univocal answer to such a question. Rather it is very easy to get soon lost in the open semantic information space that can be associated with the label – "fish" (that actually is what the word "fish" is).

Figure 3.1 *(see p. 54a) What is a fish? The importance of the goal*

Each single individual of the specie *Cyprinus carpio* (Common carp) is a specific, unique entity. But when we see a specimen of Common carp we recognize it as belonging to this species (as well as of being a fish). In doing this we are assessing the differences of the individuals of this species with all other living organisms called fish, against a number of criteria (e.g. shape, ecology, physiology/anatomy, utility for human), and for each criteria using multiple sets of different indicators (e.g. pattern of colors, length/high, for the first criteria; feeding habits, behavior for the second; metabolic functioning, presence-absence of some organs for the third; edibility, taste, economic value, for the latter).

Figure 3.1 *What is a fish? The importance of the goal.*

It may be noted at this point that often children (and many adults too) would confuse dolphins and whales with the category "fish". To prevent this error we should explain them why it is not so. This would require to make them aware of other sets of characteristics (expected qualities) concerning the natural history of the species, that are much more relevant (for zoologists) then that of "swimming in the sea" and being of "color bleu" when defining that animal as belonging to the category of "fish". For a primitive fisherman, however, the relevant qualities for making categories could be "easy to catch" or "good for the diet" or "very valuable to sell". At this point, it can be noted that what is relevant for the observer, is also the guiding principle for learning about names and useful categories. Such a process, in fact, has to be related to the problems experienced by the observer (e.g. a child is concerned with where the animal lives, a biologist on its physiology, an ecologist on its ecology, a fisherman on its characteristics as a prey). The different definition of identity can in turn affect the scale of analysis. For instance specialists in aquatic ecology can go much further, and differentiate a species in different sub-species, e.g. in British Columbia more then 3,000 genetically distinct populations of salmon, belonging to six species, have been identified. In this case, experts/scientists are using additional sets of indicators (useful categories) able to take into account other characteristics that go unnoticed at the first view of a specimen. Because of the large scale of operations and the relative knowledge accumulated in time, these experts can adopt a more detailed description of categories, that can be used, later on as indicators already standardized. In this way, they are tackling different questions (e.g. the form of a fin, pattern of colors, specific body structures, or even variation on DNA), to do that they need to introduce other categories and indicators in order to investigate these specific domains.

When asking what a fish is to lay person, we can easily get the usual answer, something like: a fish is an animal that lives in the water, with very few additional categories.

It should be clear from **Figure 3.1** that the word fish has many meanings for different people (e.g. a trophy for a person doing sport fishing, subsistence food for poor populations, a product to sell, something to carry), and that the many meanings taken by the word fish can be associated to different contexts (e.g. genetic material, animal anatomy, a possible danger for humans). This reflects the existence of a universe of possible dimensions of analysis reflecting the universe of reasons for being relevant to different observers (e.g. a pet, a source of enjoyment, art, an element of complex ecosystems). The detail of our answer to the question will depend on the kind of problem we are interested in (see **Figure 3.2** in the next section).

3.4.2 Constructing indicators

Indicators (*sensus* Rosen) can be defined then as a selection of encoding variables reflecting the existence of observable qualities (proxies) referring to a system which has a given identity (Rosen, 1985; 2000; Giampietro, 2004). These observable qualities must be relevant to study and predict changes which are known to be affecting an outcome of interest, that is to say they are driven by goals.

It is important at this point to make a distinction between:

* a ***semantic identity*** as the open and expanding set of potentially useful shared perceptions about the relevant characteristics of an equivalence class (the many expanding definition of

a fish in **Figure 3.2** as resulting from the different combinations of observers and contexts illustrated in **Figure 3.1**); and

* a ***formal identity*** as a closed and finite set of observable qualities used to represent the expected characteristics of a natural system belonging to a type (a set of definitions in **Figure 3.2**), adopted by a particular observer in a particular point in space and time.

Figure 3.2 *(see p. 56a) What is a fish? The relation between the natural system and the interests of the observer*

A semantic identity includes all a fish can be (most of which I do not know) for interested observers in all possible contexts. Because of this, the semantic identity of a fish (that is to say the set of qualities which can be used to define a fish) is open and virtually infinite (Giampietro, 2004). It is evident then that when we ask "what is a fish?" there are many different legitimate formal identities for it, according to the goals and experience of the various observers. The relative formal identities can be very different from each other. It can be just food for an angry observer, or a sacred thing, for another observer more concerned with spiritual meditation. This is where we face the problem of being able to share the meaning about labels when dealing with a population of interacting non-equivalent observers. This is the problem of sharing the meaning about variables used as indicators when dealing with a population of interacting stakeholders carrying legitimate but contrasting interests, values and goals.

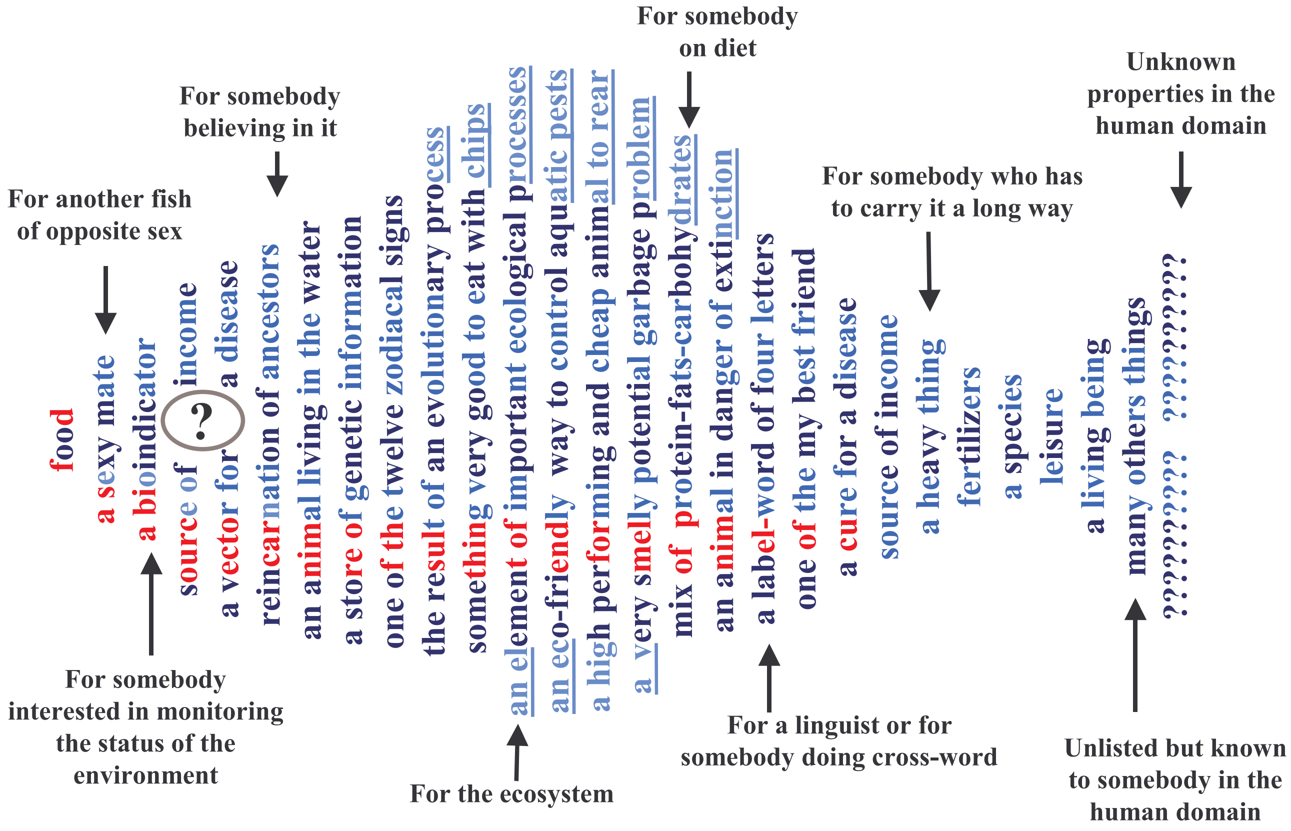
To get an indicator we have to compress a large amount of semantic information into a given finite and discrete syntactic formal model. This process has to be validated according to a previous knowledge, and requires the following steps:

(1) The population of interacting stakeholders have to agree on the definition of a semantic identity for the system under analysis (the expected patterns among relevant qualities associated to the system) – selection of relevant attributes of performance.

(2) The population of interacting stakeholders have to agree on the definition of a formal identity for the representation of the system under analysis (the expected patterns over the values taken by a set of variables used as proxies of relevant observable qualities) – selection of reliable set of observable qualities that can be associated with changes in relevant attributes.

(3) The population of interacting stakeholders have to agree on the choice of a set of detectors and relative measurement schemes, able to provide reliable data in relation to the set of variables chosen in the second step.

At this point we can say that an indicator finally came into existence. However, one should always be aware that the previous threes steps (especially step #1) cannot be performed in a substantive way (the right way). It remains a process that implies negotiating among contrasting goals, opinions, fears in relation to existing power relations and boundary conditions. It is to say that in order to have an indicator a social group must agree on what the system is, what should be changed in the system and how to control the trajectory toward the envisioned change. Reaching these agreements implies much more than hard science.



Warning: this fish is not a fish!

Figure 3.2 *What is a fish? The relation between the natural system and the interests of the observer*

3.4.3 Key characteristics of epistemic categories

The problem of communication among disciplinary sciences is often generated by pre-analytical differences about basic assumptions on how to organize perceptions. As noted earlier the same natural system is observable on different scales, and therefore it entails the co-existence of multiple identities (Giampietro, 2004) (**Figure 3.3**).

Figure 3.3 *(see p.57a) A fish is: a label for a number of shared epistemic categories*

An example of a fish seen by different observes, belonging to two different cultures, is presented in **Figure 3.3**. On the left we have a consumers and fisherman and a scientist who belong to the cultural background "A", and on the right inhabitants of the Fish island who belong to a cultural background "B". For an observer belonging to the culture A, there are of course different perceptions about what a fish is. Then, there will be a number of shared epistemic categories (a, b, c, d), and a number of different, but anyway comparable, epistemic categories (different numbers but numbers that belong to the same system of perception of the culture A). When we compare culture A with culture B, then, it can turn out that there is not much overlapping. We can have of course a set of partially comparable epistemic categories ("à" and **"ç").** in culture B can resemble somehow "a" and "c" in culture A, also "32#" in culture B could be partially understood by an observer belonging to the culture A. But what it is more important we have also a set of incomparable epistemic categories. "@" and "&" in culture B do not resemble anything of the culture A, they are completely new epistemic categories for an observer belonging to culture A. "d" is the only epistemic category that is found in both cultures, which can be perceived as the same by observers belonging to both cultures. Those categories having no relation across cultures, can be understood by a foreigner only after entering in the specific system of thought of the other culture.

What has this long story about "what a fish is" to do with science and modelling? For answering this question I refer to Giampietro (2004, p. 19): "*Whenever we are in a situation in which we can expect the existence of multiple identities for the investigated system (complex systems organized on nested hierarchies) we must be very careful when using indications derived from scientific models. That is, we cannot attach to the conclusions derived from models some substantive value of absolute truth. Any formal model is based on a single couplet of "organized perception" and "agreed representation" at the time. Therefore, before using the resulting scientific input, it is important to understand the epistemological implications of having selected just one of the possible couplets (one of the possible identities) useful for defining the system. The quality check about "how useful is the model" has to be related to the "meaning" of the analysis in relation to the goal and not to the technical or formal aspects of the experimental settings (let alone the significance of statistical analysis checked through p= 0.01 tests)*.". Then to illustrate this concept he provides a very simple as well as effective example: "*The idea that the pre-analytical selection of a set of encoding variables (deciding the formal identity which will be used as a model of the natural system) does affect what the observer will measure has huge theoretical implications. When using the equation of perfect gas (PV = nRT) we are adopting a model (a formal identity for the gas) that perceives/describes a gas only in terms of changes in temperature, pressure, volume and number of molecules. Characteristics such as smell or colour are not considered by this equation as relevant qualities of a gas to be mapped in such a formal identity. Therefore, this particular selection of relevant*

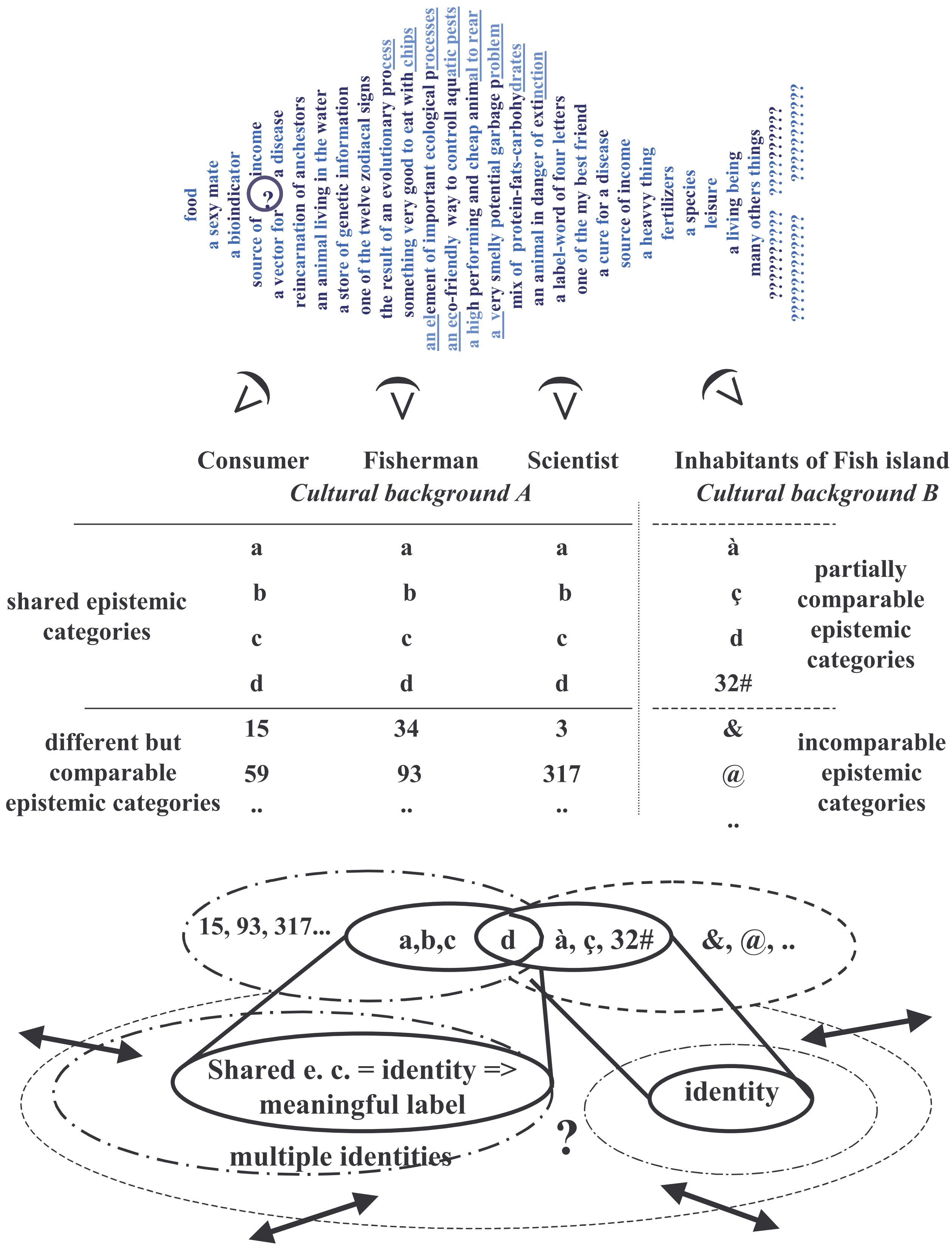


Figure 3.3 *A fish is: a label for a number of shared epistemic categories*

qualities of a gas has nothing to do with the intrinsic "real" characteristics of the system under investigation (a given gas in a given container). This does not mean, however, that a modelling relation based on this equation is not reflecting intrinsic characteristics of that particular gas kept in the container, and therefore that our model is wrong or not useful. It means only that what we are describing and measuring with that model, after having selected one of the possible formal identities for the investigated system (a perfect gas), is a simplified version of the real system (a real amount of molecules in a gaseous state)." (Giampietro, 2004, p. 23).

To close this section we can quote the warning of McCullagh and Nelder, 1989, quoted by Laloë *et al*., 2001): *"... all models are wrong; some though are more useful then others and we should seek those ... not to fall in love with one model to the exclusion of alternatives ... "*.

3.4.4 Back to models (à la Rosen)

According to Munda and Giampietro, (2001) a descriptive model is a given set of *formal representations of attributes/qualities* associated to a label (e.g. a set of indicators connected to various dimensions, e.g. economic, social and environmental, used to describe the performance of a system).

One should note that the construction of a descriptive model depends on very strong assumptions about:

(1) the *purpose* of this construction, e.g. to evaluate the sustainability of a given city,

(2) the *scale* of analysis, e.g. a block inside a city, the administrative unit constituting a Commune or the whole metropolitan area, and

(3) the *set of dimensions, objectives and criteria used for the evaluation process*. A reductionist approach for the building of a descriptive model can be defined as the use of just *one measurable indicator* (e.g. the monetary city product per person), *one dimension* (e.g. economic), *one scale of analysis* (e.g. the Commune), *one objective* (e.g. the maximization of economic efficiency) and *one time horizon*. A ***formal descriptive domain*** is the representation of reality resulting from the arbitrary assumptions needed for the definition of a descriptive model.

By using an indicator or sets of indicators, we are able to make ***typologies***. A "type" then is a model (or a metaphor), that can be used and to which to refer to when representing, describing, assessing a real system (Rosen, 1985; 1991; 2000, Giampietro, 2004). When we talk about "fish" we all know, if we share the same system of values and experiences associated with this word, what we are talking about. We are referring to a typology of animal, or living being, that is made up by a number of specific characteristics that have previously been show useful to perceive and represent such an animal.

Being able to draw typologies out of real systems and organize them in categories about which it possible to establish expected relation is the major achievement of the scientific endeavor. A carp is a fish, because any member of the equivalence class of carps has some characteristics, most of which are common to the animals we include in the epistemic category "fish". Moreover, a fish is an animal (and not a plant) because it has a number of characteristics that indicate its belonging to the higher level type of biological systems we include in the epistemic category “animals”.

Once we adopt a thinking procedure based on type and categorizations, then we can make science. Science makes it possible to deal with the reality in terms of classes of things rather then getting lost within the specificity of single, unique, individuals.

3.5 Moving from “*substantive assessments*” to “*participatory procedures for assessing*”

In this section the idea of procedural rationality, porposed by Herbert Siomon, is introduced, along with the concept of Post-Normal Science as a science for governance and policy making.

3.5.1 From a “substantive rationality” to a “procedural rationality”

Herbert Simon, considered a pioneer in fields of artificial intelligence, complexity theory, cognitive psychology, firm behavior, and Nobel Laureate in economics, in his autobiography (Simon, 1991), states that he gave up the myth of “exact sciences” (in case he had it), as soon as he had to face real problems (e.g. air pollution, acid rains, global warming, diets), where uncertainties regarding facts were as much as those in the social sciences. He argues that we should not draw a line between “exact” natural science and “inexact” social science, but between exact sciences limited to extremely abstract and simplified phenomena, studied in laboratory, and the approximate science and technology that have to do with the real world phenomena

A couple of papers published by Herbert Simon in the 1950s (Simon, 1955; 1956) became the basis of a new research field on human rationality. In these seminal works Simon challenged the neo-classical economic view of the rational economic man' and argued that objects (real or symbolic) in the environment of the decision making influence choice as much as the intrinsic information-processing capabilities of the decision-maker. The environment, in this case, should be intended as “*…those aspects of the totality that have relevance as the “life space” of the organism considered. Hence, what we call the “environment” will depend upon the “needs”, “drives”, or “goals” of the organism, and upon its perceptual apparatus*.”, (Simon, 1956, p. 130).

In the late 1940s, Simon, in alternative to the neo-classical paradigm, introduced the concept of “*limited-approximate rationality*” (Simon, 1947; 1955; 1956), later redefined “*bounded rationality*” (Simon, 1976; 1983). This lead to propose a paradigm shift in economics (and social sciences dealing with decision making). It implies moving from a concept of “*substantive rationality*”, the extent to which appropriate courses of action are chosen, to that of “*procedural rationality*”, the effectiveness, in the light of human cognitive power and limitation, of the procedure used to chose actions (Simon, 1976; 1983; 1988a). According to Simon (1988a, p. 67), “*As economics moves out toward situation of increasing cognitive complexity, it becomes increasingly concerned with the ability of actors to cope with the complexity, and hence with the procedural aspect, of rationality*”. Simon argues that the procedural rationality theory is consistent with the vision of the world as a dynamic entity, in which humans are creative beings, a theory of substantive rationality instead embrace a much more static, and far unrealistic, vision of the world (Simon, 1976). Furthermore procedural rationality is based on the acknowledgement of ignorance and uncertainty that characterize human action in dealing with the real world, as well as it acknowledges the existence of legitimate non-equivalent views of different stakeholders (Simon, 1976; 1983; 1988a). "*When problems became interrelated, as energy and pollution problems have become, there is the constant danger that attention directed to a single facet of the web will spawn solution that disregard vital consequences for the other facets. ... It is futile to talk of substantive rationality in public affairs without considering what procedural means are available to order issues on the public agenda in a rational way, and to ensure attention to the indirect consequences of actions taken to reach specific goals or solve specific problems.*", (Simon, 1988a, p. 73).

3.5.2 The challenge of Post-Normal Science as a Science for Governance

The challenge associated with Post-Normal Science and Science for Governance (Funtowicz and Ravetz, 1990), suggest that when dealing with scientific analyses of sustainability it is not the formal output that is relevant, but rather the quality of procedure that generated it (Munda, 2004).

There are many discussions on how to organize such a procedure based on a number of ideas and models developed by different authors from different fields. Some key reviews and original works can be found in: Nijkamp, (1979); Chambers, (1983, 1997); Munda, (1997; 2004); Checkland and Scholes, (1990); Funtowicz *et al*., (1999); Funtowicz and Ravetz, (1990); Giampietro, (2004); Giampietro and Pastore, (2001); Munda and Giampietro, (2001).

As stated by Munda (1997), when approaching management strategies and decision making about the environment and sustainability we basically deal with *conflict analysis* characterized by technical, socio-economic, environmental and political value judgments. Key questions are: What do we want to sustain? Whose goals count? Eventually an answer to these questions leading to a decision about what to do should come out from a social debate concerning trade-offs, negotiations and compromises.

Within this framework the analytical tool presented in this thesis – Multi-Objective Integrated Representation – has the goal to help scientists to provide a useful input to such a social process. The role that MOIR should play in a participatory procedure of Social Multicriteria Evaluation is illustrated in **Figure 3.4**.

Figure 3.4 *(see p. 60a) Integrating MOIR in a procedure of social multicriteria evaluation (after Nijkamp, 1979; Munda and Giampietro, 2001; Munda, 2003)*

The overview of the procedure illustrated in **Figure 3.4** clearly indicates the importance of indicators of sustainability as key (fundamental) means to support informed decisions. On the other hand, the same overview also indicates the crucial importance of adopting participative approaches and addressing explicitly the unavoidable existence of conflicts within the process.

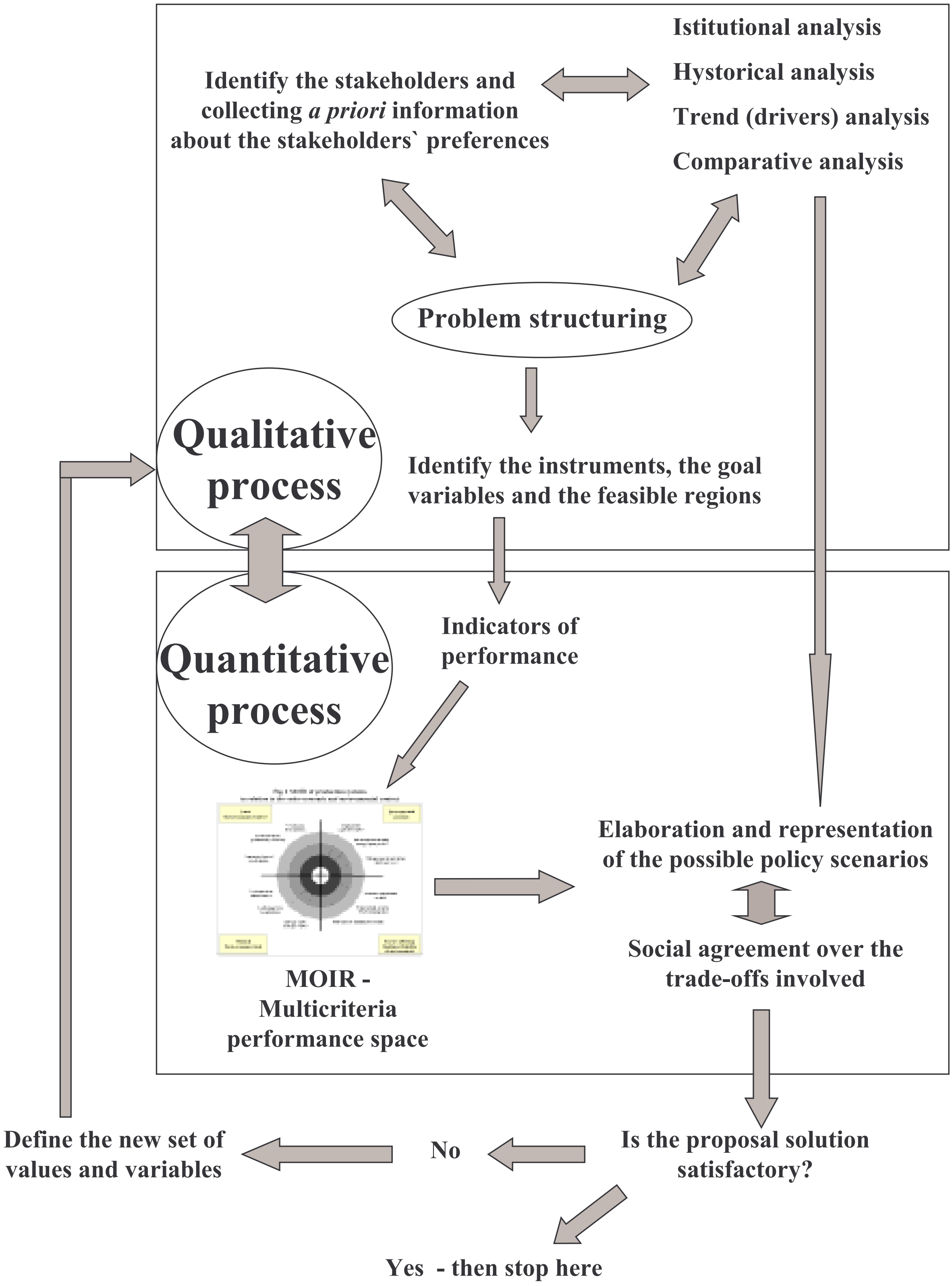


Figure 3.4 *Integrating MOIR in a procedure of social multicriteria evaulation (after Nijkamp, 1979; Munda and Giampietro, 2001; Munda, 2004)*

Coming back to the main topic of this chapter I would like to conclude by saying that modelling should be considered rather a sort of “art” rather then a rigorous scientific activity (Funtowicz and Ravetz, 1990; 1994; Smil, 1993; Giampietro, 2004; Munda *et al*., 1994; Kingsland, 1995; Munda, 2000; Rosen, 2000). An art in which it is the “*... ability and the ethical behavior of the researcher constructing the model...*”, (Munda *et al*., 1994, p. 111), that determines its form, meaning, usefulness and effectiveness to solve, or to better understand, a given problem. Such an art, however, requires a clear and honest statement of the premises on which the artist’ point of view is based.

Part 2

An overview of existing graphic tools and the procedure for Multi-Objective Integrated Representation of farming systems

This part is made of 2 chapters. It has the goal of presenting innovative procedures for structuring the representation of scientific information used in a process of decision making about sustainability. In particular it deals with the integrated use of indicators belonging to non-reducible descriptive domains (= using in parallel variables referring to observable systems qualities, which are defined at different scales, or referring to system attributes associated to incompatible definitions of identity for the same system). In particular:

Chapter 4: A critical appraisal of the state-of-the-art of graphic tools for data representation in Integrated Analysis

It provides an overview of graphic tools that are currently used for integrated analysis (in general coupled to Multi-Criteria Analysis). The overview includes also an appraisal of the various methods in terms of pros and cons.

Chapter 5 : Introducing the Multi-Objective Integrated Representation (MOIR) applied to farming system analysis

It presents a procedure that can be used to perform Multi-Scale integrated analysis (multi-objective representation based on package of indicators and covering different perceptions of relevant aspects of the reality referring to different space-time scales and to a diversity of social actors). The various tools illustrated in this chapter are referring to farming system analysis.

Chapter 4

A critical appraisal of the state-of-the-art of graphic tools for data representation in Integrated Analysis

A picture is worth thousand worlds
Chinese saying

It illuminates how the availability of representations and the invention of new ones has influenced my efforts to construct explanations.
Herbert Simon[11]

What is to be sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult – that is, the revelation of the complex.
Edward R. Tufte[12]

Summary

This chapter provides an overview of graphic tools that are currently used for integrated analysis. The overview includes also an appraisal of the various methods in terms of pros and cons.

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[11] Simon (1988b, p. 395).

[12] Tufte (1984, p.191).

4.1 The usefulness of graphic representation for Multicriteria analysis

Graphs and graphical representations provide a powerful tool for analyzing scientific data as well as they are useful to quickly and easily convey data and information to the reader (Tufte, 1983; 1990; Cleveland, 1985; Cleveland and McGill, 1985; Larkin and Simon, 1987; Kosslyn, 1989). Herbert Simon (1969, p. 77), stated: "*That representation makes a difference is a long-familiar point. We all believe that arithmetic has become easier since Arabic numerals and place notation replaced Roman numerals, although I know of not theoretical treatment that explains why. That representation makes a difference is evident for different a reason. All mathematics exhibits in its conclusions only what is already implicit in its premise, as I mentioned in a previous chapter. Hence all mathematical derivation can be viewed by simply changes in representation, making evident what was previously true but obscure. This view can be extended to all of problem solving – solving a problem simply means representing it so as to make the solution transparent. If the problem solving could actually be organized in these terms, the issue of representation would indeed become central. But even if it cannot – if this is too exaggerated a view – a deeper understanding of how representations are created and how they contributed to the solution of problems will become essential component in the future theory of design*."

When dealing with various sets of data, one of the major advantage provided by graphical representation is that they can show the presence of patterns that would be difficult to perceive in a matrix of alfa-numerical data (if the same selection of sets of data were presented in the form of conventional tables). As Cleveland and McGill, (1985, p. 832) argue: "*Graphing means and standard sample deviations, the most commonly used graphical method for conveying the distribution of group measurements, is frequently a poor method. We cannot expect to reduce distributions of two numbers and succeed in capturing the widely varied behaviour that data sets in science can have. For example using, using just the mean and standard deviation does not reveal outliers. Box plots give us more information about distributions and allow us to appreciate the behaviour of outliers.*" As stated by Cleveland (1985, p.10). "*Graphical methods tend to show data sets as a whole, allowing us to summarize the general behavior and to study detail.*" Graphical representations have the ability to suggest an overall "meaning", a sort of *gestalt* emerging from of the data set.

On the other hand, this very same special ability can generate problems. Living in a world dominated by the influence of media we are all very aware of how the maker of a picture can affect the perception of a given situation that it is conveyed to the observer by that picture. That is, pictures not only can make easier the comprehension of a situation, but can also be used to hide on purpose some relevant aspects of it, and therefore induce a biased perception of the reality (Tufte, 1983). This is why a discussion on procedures to be followed to generate sound and effective graphical representations deserves the maximum attention (Tufte; 1983; 1990; Zar, 1984; Cleveland, 1985; Cleveland and McGill, 1985). When organizing various sets of data within a graph, whatever we do, we are performing a manipulation. A manipulation that will increase the degree of arbitrariness implied by the chain of decisions required to select a particular realization of how to perceive and represent a complex problem. This unavoidable presence of arbitrariness is amplified by the fact that any graphical representation of a given problem or situation - when considering different dimensions and multiple criteria - does require a lot of work on the original set of data to guarantee an overall coherence and clarity in the final image (Cleveland, 1985; Cleveland and McGill, 1985; Tufte, 1983; 1990). Even the representation of simple "numbers" is not immune from such a problem. A number says very little if it is not accompanied by a detailed explanation of the assumptions and process through which it has been generated (Tufte, 1983; Cleveland, 1985; Tversky and Kahenman, 1981; Zar, 1984; Funtowicz and Ravetz, 1990).

The writing of a set of data to be used as indicators is, in fact, just the last act of a long process (as discussed in chapter 3) that started with:

(a) the definition of the goals of the study;

(b) the definition of the identities of (= the set of relevant attributes and observable qualities associated with) the elements to be included in a model. This definition determines the scale adopted in the model;

(c) the selection of proxies (= variables) that can be used to encode changes in relevant characteristics of the relevant identities considered in the problem structuring;

(d) the setting of a measurement scheme making possible to gather data;

(e) the actual processes of measuring.

In alternative, the steps (d) and (e) can be replaced by the use of second hand data, which introduces a new problem of comparability of the quality of these second hand data.

Each one of these steps entails possible sources of confusion among those using the final model about the shared meaning which should be assigned to perceptions and representations of the reality over different descriptive domains. Organizing data in a graphical representation, therefore, implies adding another step to this chain:

(f) organizing the data in a graphical representation. This step, being the last of a long chain, cannot be performed without an explicit knowledge and linkage to the previous ones. The overall process, when performed carefully, forces awareness in the analyst. According to Simon, (1988b, p. 383): "*The basic ideas, which I will not elaborate upon here, are (a) that in the course of transforming verbal proposition into images, many things are made explicit that were previously implicit and hidden, and (b) that (learned) inference operators facilitate making additional inferences from the images in computationally efficient way*.".

This is why one should be aware that during the process of building a graphical representation of a Multi-Criteria Analysis the scientists must always have two goals clear in mind:

(1) *making aware as much as possible the reader of potential misunderstandings in the transmission of information.* This can be obtained by making as explicit as possible, where, when and why the various external referents (direct data, indirect data, basic assumptions) have been used to build the structured information space carrying the integrated representation;

(2) *enhancing the robustness of the characterization of various alternatives (or compared situations*). This can be obtained by looking always for a "mosaic effect" in the set of indicators used, that is to say to create a cross contextualization among different scales and

criteria (e.g. by covering the same criteria using indicators referring to different scales or representing the same element, at one given scale, but in relation to different dimensions). In this way an indicator aquires a strong identity as it maps on many different domains (see chapter 5 for).

4.2 From the single number to multicriteria "pattern" representation

As stated by Jacquard, (1985, quoted in Smil, 1993, p. 32): "*When we are comparing one number to another, non-equality implies that one is greater than the other; when we are comparing sets, it implies that they are different. This is not a plea motivated by moralistic considerations; it is a statement of logical fact*." When using different sets of data referring to non-equivalent criteria (when accounting for the relevant characteristics of a given system-typology), we can no longer expect to obtain a simple and unique ordinal ranking (1, 2, 3,…) of the various alternatives or different realizations of that system-typology. To do that we should be able to reduce the heterogeneous information carried out by different indicators referring to non-equivalent criteria (e.g. economic, aesthetic, moral, ecological, technical) into a single definition of quality. This would require defining an ultimate "absolute" index of performance for the typology of system. This would require being able to give a profile of different weights – the relative importance they have in a given analysis – to the set of considered indicators. The problem is that such a reduction and comparison can only be done in a give point in space and time (in a special situation) by a given group of social actors. It is impossible to even think that it would be possible to do that in general terms. Put in another way, when considering: (i) all possible social agents (of different age, sex, social status, culture, religion) operating in different places and in different moments of their life trajectory; and (ii) all possible situations in which the considered analysis can be relevant for action; we cannot expect to use the same standard algorithmic protocol to weight incommensurable criteria. This is why a multicriteria evaluation requires addressing explicitly "values" which are reflected in preferences, cultural identity and personal aspirations. A process of multicriteria analysis, therefore, implies to chose among different combinations of incommensurable typologies of "pros" and "cons" when defining objectives, criteria and indicators. A system-typology is required to have reference against which it becomes possible to evaluate alternatives or to compare different systems.

The issue of sustainability implies handling indicators and data referring to different scales and dimensions of analysis. This heterogeneous information space can be processed using different rationales. To put better in perspective the discussion about the role of graphical representation in a process of Multi-Criteria Evaluation, we would like to make an important distinction about possible ways in which multiple data can be handled either for a process of decision making or for a simple comparison. In particular three approaches are relevant for our discussion:

(1) Aggregation of indicators referring to different dimensions into a single numerical index.

In this approach, the analysts assume that it is possible to deal in substantive terms (in general terms and with no possible contestations) with: (1) technical incommensurability (it is to say that it is impossible to reduce to a single model analyses referring to non-equivalent descriptive domains); and (2) social incommensurability (it is to say that it is normal to find legitimate but contrasting views in social actors about what should be considered as an improvement). The two terms, technical incommensurability and social incommensurability have been proposed by Giuseppe Munda (Munda, 2004, on this point see also Giampietro, 2004, chapter 5). Those following this approach propose protocols, which are used to aggregate a set of indicators referring to different criteria into a single numerical index. Such an index then is assumed to provide a reliable measure for the overall system performance. An example of such an approach is the "Total Economic Value" in environmental economics, TEV expressed in US$ of a given year, per year (Pearce and Turner, 1990; Tisdell, 1993). In this approach the GNP is corrected to account for the effect – expressed in monetary value – of changes in the environment. Others examples of the same idea are the "*Sustainability Barometer*" (Prescott-Allen, 1996; 2001), and the ISEW developed by Daly and Cobb (1989). Also in these two examples, different indicators referring to different dimensions of sustainability are collapsed into a single numerical index. In the first example, the Sustainability Barometer, it is qualitative index, in the second example, ISEW, again it is a number based on monetary value (e.g. US$ of 1987).

(2) Algorithmic multicriteria evaluation (ranking of different alternatives using: a given impact matrix, a given profile of weighting factors and a given algorithm).

In this approach, the various options (or the various systems to be compared) are characterized in a Multi-Criteria framework. This approach requires the following inputs: (a) a set of relevant criteria used to evaluate the performance in relation to the relevant objectives associated to the analysis; (b) a set of attributes and indicators for each criteria to characterize the performance; (c) a set of possible options (or the given set of systems to be compared); (d) a profile of weighting factors associated to the attributes of performance determined in the previous steps. The basic rationale associated to this approach is that, by having available these 4 inputs, it becomes possible to deal with the challenge implied by technical and social incommensurability. On the descriptive side, technical incommensurability is avoided by not aggregating different indicators into a single number, and on the normative side social incommensurability is dealt with by a determination of an agreed upon profile of weighting factors. When accepting as valid these assumptions, it becomes possible to use algorithms to process the information space organized in this way and to generate a ranking among the set of alternatives (or systems to be compared). A description of tools and procedures adopted in multicriteria analysis is available in several books (Bana e Costa, 1990; Munda *et al*., 1994, Beinat and Nijkamp, 1998; Goitouni and Martel, 1998; Janssen, 2001).

(3) Social Multicriteria Evaluation process (generation of a representation of the issues to a participatory process of integrated assessment of alternatives).

The term Social Multicriteria Evaluation has been proposed by Giuseppe Munda (2004) to explicitly acknowledge a systemic impasse found when attempting to apply multicriteria analysis to problems of sustainability characterized by high levels of technical and social incommensurability. When operating within this rationale, the graphical organization of data (e.g. in the form of radars, triangles, Cartesian axes) has the only goal to improve the exchange of information among those participating in the process. Actually, the very choice of how to organize the representation of relevant issues is itself a step which is object of scrutiny. In this situation, rather than attempting to collapse the descriptive and the normative side into a single process of aggregation, it could result more useful to keep separated the two processes. Within this approach Social Multicriteria Evaluation has to be based on two processes having two distinct goals: (1) on the descriptive side: guaranteeing quality in the activities aimed at handling the heterogeneous information space required for perceiving and representing a problem on different scales and dimensions; and (2) on the normative side: guaranteeing quality in the activities aimed at handling the heterogeneous universe of values, goals, fears, aspirations found in the universe of different social actors relevant for sustainability.

4.3 A survey on multicriteria graphical representations

In this section we present a few examples of graphical representations found in literature especially in relation to integrated representation of farming and environmental systems. Listing early examples of graphical integrated representations linked to sustainability Gallopin (1996) describes the work of: (a) Dansereau, (1971; 1977) - a star diagram (spider web), divided into a number of sectors corresponding each to an environment component. In this case, the goal of the analysis is a qualitative assessment of environmental health. and (b) Bugnicourt (1979) adopt a similar approach. The goal of the analysis is that of providing an integrated assessment of the most pressing needs of African population. Graphical integrated representations range from the use of Cartesian plain (e.g. Prescott-Allen, 1996-2001; Masera *et al*., 2000; Vreeker *et al*., 2001) to simple radar diagrams (called also spider web in market research) to represent multiple indicators of sustainability (e.g. Bossel, 1999; Masera *et al*., 2000; López-Ridaura *et al.,* 2002), to quite complex figures based on radar (or other shape) diagram (e.g. Clayton and Redclife, 1996; Spash and Clayton, 1997)

The examples of graphical representation discussed in this paper are:

(1) AMOEBA - which is a Dutch acronym used for a special form of radar diagram;

(2) Sustainability Barometer (SB);

(3) Sustainability Reference System (SRS) - Kite diagram;

(4) Sustainability Assessment Map (SAM);

(5) Prototyping Integrated and Ecological Arable Farming System (I/EAFS);

(6) Intervention Impact Assessment (IIA);

(7) Mixing triangle;

(8) Kite diagram for NUSAP applications;

(9) Pie for Policy Performance Index (PPI)

(10) The Flag Model

(11) Multi-Objective Integrated Representation (MOIR) (this method will be presented in detail in the next chapter 5)

Additional details for some of these approaches are available in internet, for these I make reference to the relative web site.

4.3.1 The AMOEBA approach

The AMOEBA approach is becoming a popular graphical representation in the field of integrated analysis of sustainability (e.g. ten Brink *et al*., 1981; ten Brink, 1992; Sucur, 1993; de Zwart and Trivedi, 1995; Bockstaler *et al*., 1997; Bell and Morse, 1999; Verhagen, 1999; Bockstaler and Girardin, 2000; LEEC, 2000; Masera and López-Ridaura, 2000; Masera *et al*., 2000; Wefering *et al*., 2000; Tonon *et al*., 2001; López-Ridaura *et al*., 2002; Heyer *et al*., 2003). This graphical presentation technique has been developed by ten Brink *et al*., (1981) for providing an integrated description and assessment of aquatic ecosystems (**Figure 4.1a**), in the Netherlands, by the Ministry of Transport, Public Works and Water Management in the framework of the 3rd National Water Management Policy Plan.

Figure 4.1a *(see p. 69a) AMOEBA representation (Coastal Monitoring: Amoeba of the Aegean Sea, after Verhagen, 1999)*

The acronym AMOEBA stands for: A general Method Of Ecological and Biological Assessment (but it is based on a corresponding set of Dutch words). The goal of this method is that of providing an integrated view of the ecological situation of a given environmental system. Main relevant features are: (a) different indicators (e.g. abundance of organisms belonging to key species) do monitor the state of the ecosystem at different scales - indicators are clustered for typologies of species operating in different spatial domains and on different scales; (b) the actual state is put in relation to a reference situation. The ability to handle different sets of indicators, referring to characteristics and events occurring in different places and scales, linked to the ability to put in perspective the information given by the indicators in relation to expected values makes this graphical method suitable for structuring the information used in the process of decision making.

The AMOEBA is based on a radar graph. The values taken by the various indicators are represented over axes moving away from the centre. The numerical values assumed to be the target for each of the various indicators are normalized. They all lay at the same distance from the origin and therefore represents a circumference of a circle used as benchmark. In this way, it is immediately clear which values of the various indicators [characterizing the actual state of the monitored ecosystem] fall short or exceed the target. That is, they will respectively lay inside or outside the reference circumference.

This graphical representation makes possible to compare the existing situation characterized on a set of indicators in relation to a target situation. In the application illustrated in Fig. 1 the radar diagram represents the comparison between the current ecosystem state (reflecting a given selection of indicators) and the “natural state” of the same typology of ecosystem used as a reference benchmark. In this practical example, then, reference numbers and actual numbers are given for a number of key species. In this way it is easy to convey the information. “*Since water authorities and policy-makers require a clear and simple presentation a “radar diagram” has been used.*” (ten Brink, 1992, p. 79). In this way, one can also represent the potential effects of alternative policies in relation to the changes that they could induce.

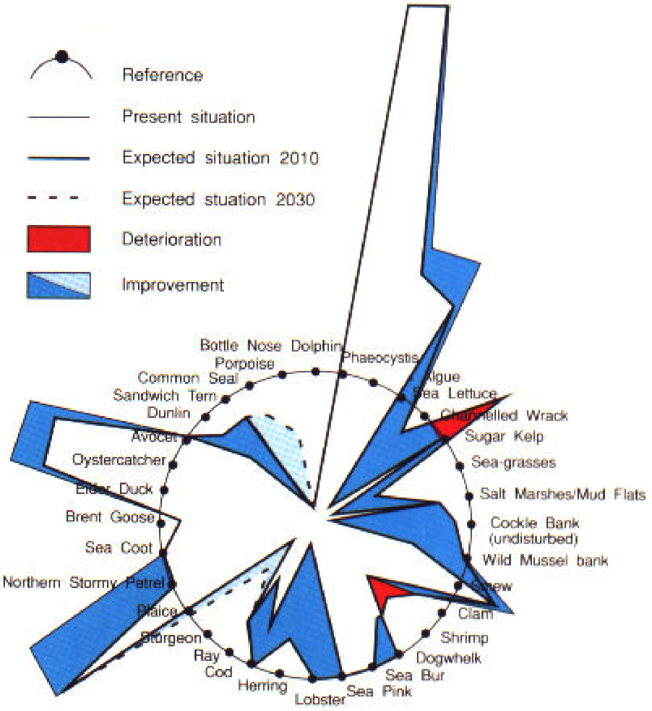


Figure 4.1a *AMOEBA representation (Coastal Monitoring: Amoeba of the Aegean Sea, after Verhagen, 1999)*

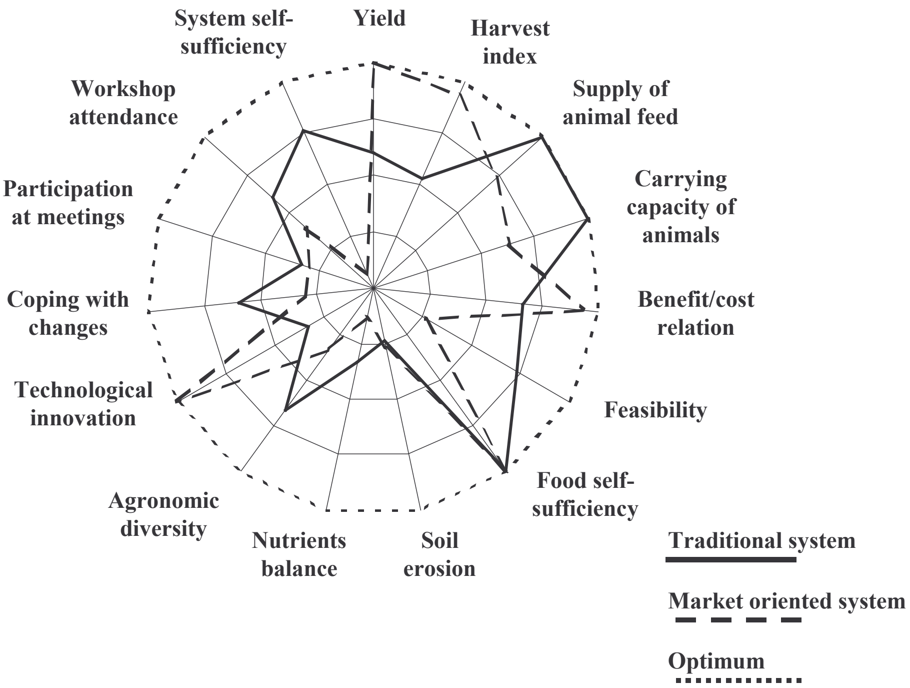


Figure 4.1b *Amiba representation for an Integrated assessment of farming system (from Masera and López-Ridaura, 2000, p. 310, modified)*

An alternative representation using the same rationale is given in **Figure 4.1b**.

Figure 4.1b *(see p. 69a) Amiba representation for an Integrated assessment of farming system (from Masera and López-Ridaura, 2000, p. 310, modified)*

In this example, various indicators can be represented on the axes moving out from the origin on a standard scale from 0 to 100, where 0 refers to the worst imaginable situation and 100 stands for a ideal situation of a pristine ecosystem completely undisturbed by humans. For ecological applications see for instance Sucur, 1993. For farming system analysis see Amiba representation by Masera and López-Ridaura, 2000; Masera *et al.*, 2000; López-Ridaura *et al.*, 2002. Note that in this case, Amiba is used instead of AMOEBA probably for a misinterpretation of the original acronym.

Comments

Although ten Brink, (1992, p. 82) stated that "*AMOEBA can serve as an adequate indicator for sustainable development by definition ...*" this claim is not so obvious. In fact, this would require the knowledge of: (a) what is the right set of indicators to be used for such an integrated evaluation; (b) what is the right set of values to be used as a reference benchmark; (c) how to interpret the distance between the actual state and the target state in terms of performance. These three conditions would imply the ability to deal successfully with uncertainty, genuine ignorance, non-linear behaviour, threshold values associated with possible catastrophic events. Moreover, the set of indicators used in this graph include only ecological indicators. Humans are not included in such an analysis.

The handling of different sets of data using the AMOEBA approach does not avoid the "aggregation syndrome" (a point that has been recognized by the author himself). Put in another way, whenever hundreds of data gathered in non-equivalent descriptive domains have to be handled in a single graph there is always the risk of: (a) loosing valuable information; (b) reducing the transparency and reliability of data. In the first case, it is the quality of the problem structuring which affect the first type of loss. In the second case, it is the procedure adopted for the making of the graph (e.g. how to normalize the values), which can imply the second type of loss.

4.3.2 Sustainability Barometer

According to the author (Prescott-Allen, 1996; 2001), the Barometer of Sustainability is a tool for measuring and communicating the degree of well being and progress towards sustainability of a given society. The Barometer of Sustainability provides a systematic way of organizing and combining indicators (**Figure 4.2**). Its goal is that of helping users to clarify their understanding of the conditions of the people living in that socioeconomic system, the conditions of the ecosystem and the expected effects of the interaction of the economic process with the ecological process. In this approach a number of indicators of human and ecosystem well being are aggregated into two indices and than represented in a Cartesian axes, divided in a number of quality zones.

Figure 4.2 *(see p. 71a) Barometer of Sustainability (source Prescott-Allen, 1996)*

The Cartesian plan is built by putting on: (a) the axis of ordinate the value taken by an aggregate index (based on the values taken by a set of adequate indicators) indicating the degree of ecological well being of the ecosystem in which the society is operating. and (b) the axis of abscissa the value taken by an aggregate index (based on the value taken by a set of adequate indicators) indicating the degree of human well being of the society. The axes are divided in qualitative equal segments representing bad, poor, medium, OK, and good performances, according to the two indices of exploitation pressure and well being. These two indices are scaled in a way to make the differences on the axes in relation to the qualitative segments comparable. It should be noted that due to the existence of non-linearity in the mechanisms determining the "health" of ecosystems and the well being of people living in socio-economic systems such an operation of scaling and linearization is particularly delicate and dangerous. This is especially relevant when considering that the aggregate indices on the two axes, in reality are derived by using the information coming from different indicators, which can exhibit different forms of non-linearity. As a consequence of this fact, also the clear definition of targets and thresholds on the quality zone (referring to indices) carry very limited information on what is going on in relation to the characteristics of the systems described by each indicator.

Recently Prescott-Allen (2001) combines in the Barometer: (a) 36 indicators for the Human Well-being Index (e.g. health, population, wealth, education, communication, freedom, peace, crime, and equity); and (b) 51 indicators for the Ecosystem Well-being Index (e.g. land health, fraction of protected areas, water quality, water supply, global atmosphere, air quality, species diversity, energy use, and resource pressures). The two indices are then combined into a Well-being/Stress Index that measures the degree of human well-being each country (or human-environmental system) obtains for the amount of stress it places on the environment.

Comments

Such an approach provides a very effective communicative tool, but presents also a few relevant problems. When aggregating a multitude of indicators into only two indices we completely loose track of the information that each one of them was carrying into the representation. By looking at the final diagram we cannot have a clue about what is going on both in the human and environmental systems in terms of relevant characteristics, variables and mechanisms that are considered important for the analysis. Moreover, a lot of indicators can be redundant (since very often indicators of development are strongly correlated). Again, any aggregation process requires value judgments when assigning the relative weights to different indicators included in the two sets (36 and 51 indicators). As noted earlier, value judgment (and therefore a certain degree of arbitrariness) is involved also in the very act of choosing this set of indicators. Another interesting issue is how to know whether or not the same set of indicators can be used to compare different typologies of societal systems (whether, for instance, well-being in Islamic countries is perceived in a different form that in Western countries) and different typologies of ecosystems (stress in semi-desert ecosystems versus stress in tropical ecosystems). This is especially important

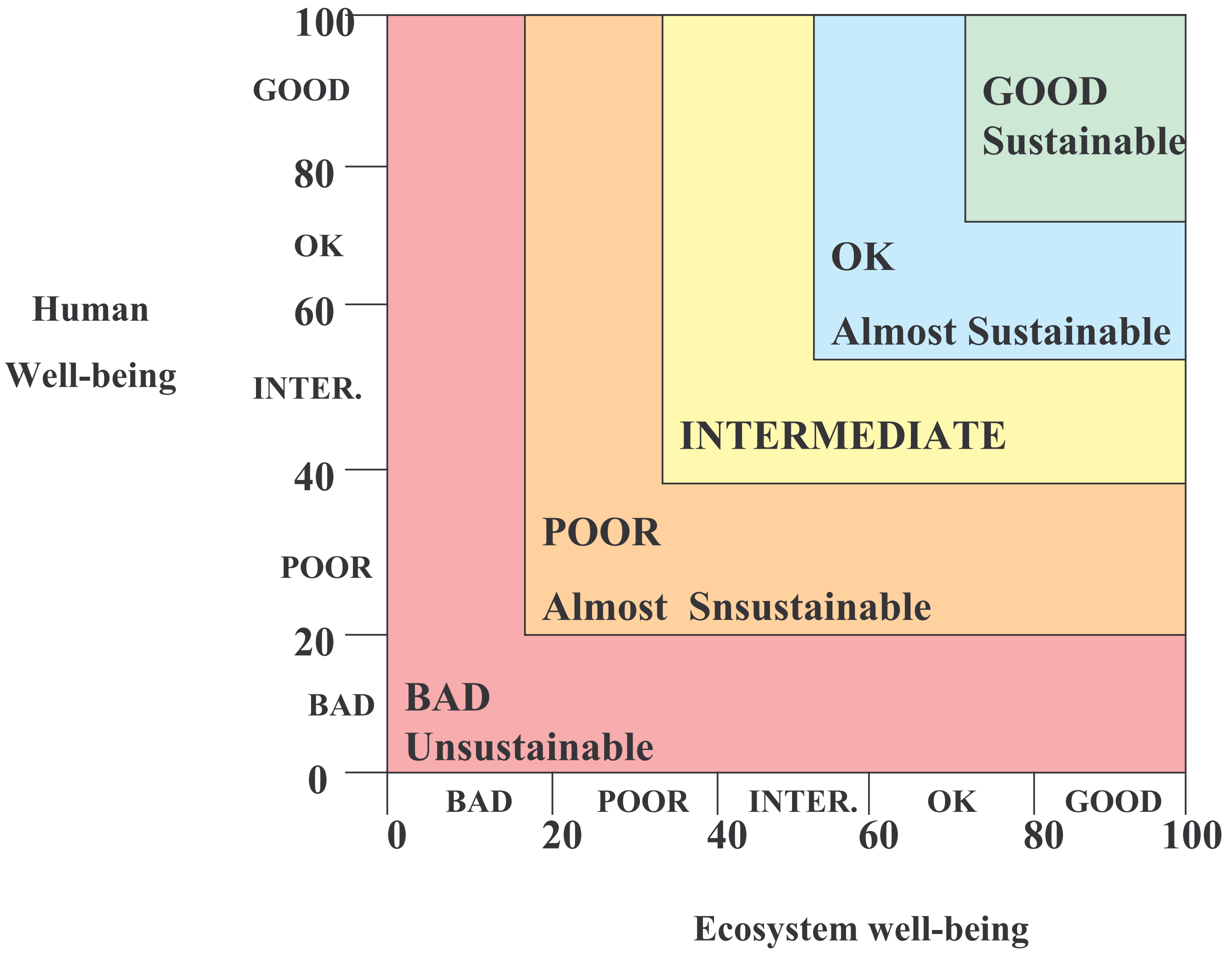


Figure 4.2 *Barometer of Sustainability (source Prescott-Allen, 1996)*

when the approach is used to compare societies and ecosystems quite different in their typologies. Put in another way, the incredible ability of this method to organize the information in a pattern very easy to communicate (throughout an enormous simplification in the final image) is at the same time its weakest point.

4.3.3 Sustainability Reference Systems (SRSs) – Kite diagram

Starting from the rationale of the Sustainable Barometer developed by Prescott-Allen (1996), Garcia (1997), has developed a Sustainable Reference System to be applied to the sustainable management of fishery. For this task he proposes a kite diagram illustrated in **Figure 4.3** (see also FAO, 1999; Garcia and Staple, 2000; Garcia *et al*., 2001).

Figure 4.3 *(see p. 72a) Example of SRSs-Kite Diagram (Isometric Kite), indicating the position of a fishery (black polygon) in relation to four criteria (after FAO, 1999 and Garcia and Staple, 1997, modified)*

Two domains are considered in this graphical representation: (a) human well-being, and (b) ecological well-being. Four parameters are represented over the four axes of the kite diagram:

(1) Revenues; and (2) Jobs for the human well-being, and (3) Spawning biomass, and (4) Nurseries for the ecological well-being. The values on each axis are normalized from 0 to 1 (in the case of isometric representation). The grey scale refers to the assessment based on categories used in the representation: (a) "good" (clearer belts) and (b) "bad" (darker belts). SRS is thought as a device that helps to "represent" sustainability, more than "measure" it. It can be used to develop a method for representing the pressure of system exploitation. As Garcia (1997, p. 146) states, the representation: "*…can be used to compare the profile of different* (fishery) *systems including the "ideal" one with optimal values for all parameters.*".

Comments

The definition of the terms "***Isometric***" and "***Anisometric***" proposed by the authors are confusing. As they stand, in fact, they refer at the same time to both a quantitative and qualitative issue. That is, how figures are scaled along the axes, and how they are qualitatively evaluated (by some given observers).

In this approach the problem of aggregation remains unsolved, or better untreated in clear terms. Although Prescott-Allen is clearly concerned with the value judgment that the qualitative assessment implies (even though less attention is given to the value judgment involved in the aggregation procedure and choice of indicators), the authors of the SRS seem not consider such an issue. This can be explained by the fact that they are concerned only with fishery (a more defined field for structuring the sustainability assessment) and therefore they are considering experts' opinions as sufficient for dealing with resources management in a "value-free" way.

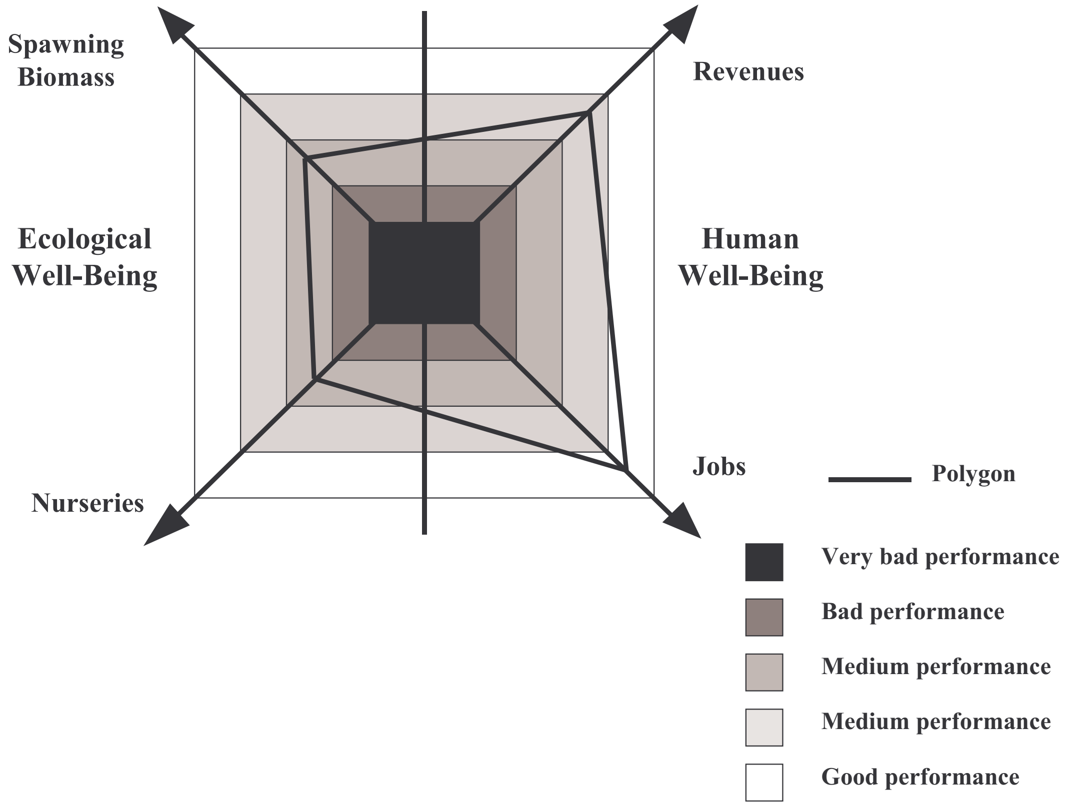


Figure 4.3 *Example of SRSs-Kite Diagram (Isometric Kite), indicating the position of a fishery (black polygon) in relation to four criteria (after FAO, 1999 and Garcia and Staple, 1997, modified)*

4.3.4 Sustainability Assessment Map (SAM)

Clayton and Redcliffe (1996), and Spash and Clayton, (1997) adopting insights from system theory propose Sustainability Assessment Maps (SAMs) (**Figure 4.4**) as a tool to understand behavioral patterns of system performance.

SAM consists of a diagram in which each critical dimension of a complex problem is represented by an axis on a radar diagram. Measurement of changes or indications of priorities are then mapped onto these axes.

Figure 4.4 *(see p. 73a) Sustainability Assessment Map representing indicators referring to different energy policies (from Spash and Clayton, 1997)*

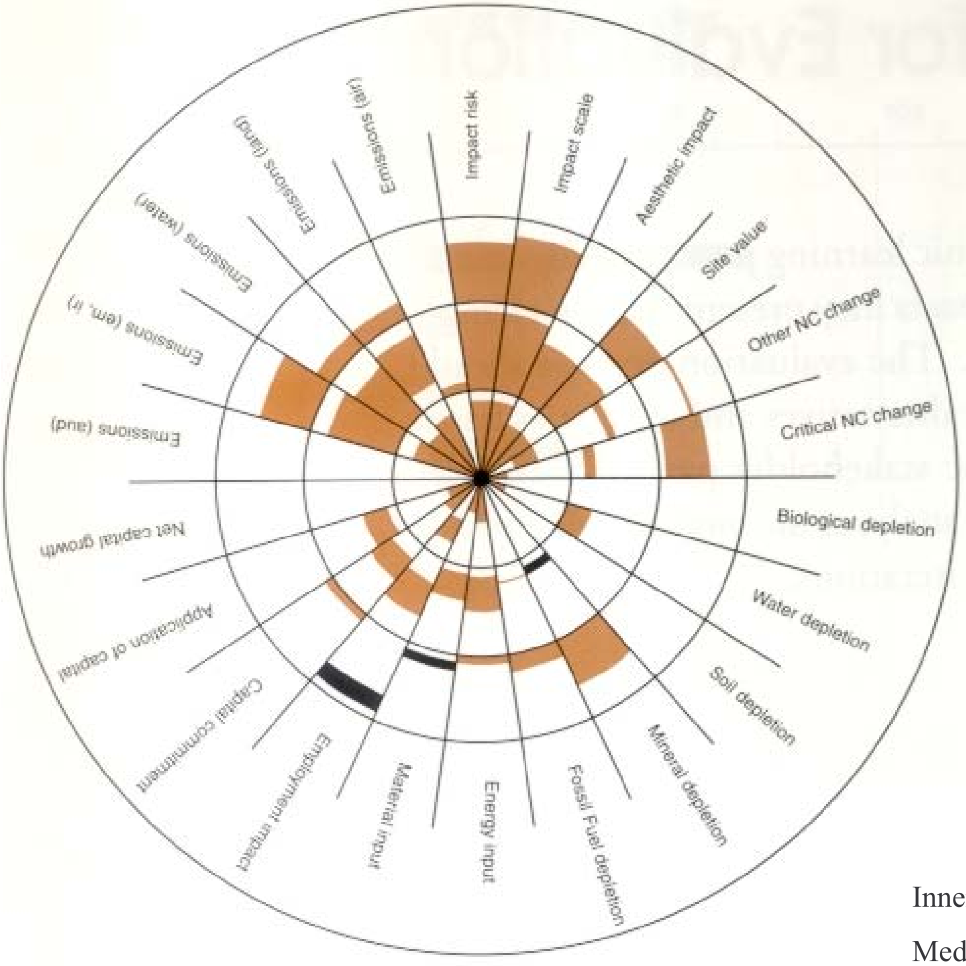
According to the authors (Clayton and Redcliffe, 1996; Spash and Clayton, 1997), this approach offers a framework in which information from different descriptive domains can be integrated without being forced into a single, one-dimensional mapping. Here different policy options are analysed according to different criteria belonging to different dimensions (e.g. ecological, social, economic). A comparison of different system performances can be obtained by the analysis of their different graphical representations. By this approach the effects of "sustainability dialectics" (facing incommensurable trade-offs when trying to pull a too short blanket in different directions), can be made more explicit and it can be easier for the decision-makers to understand complex problems (Spash and Clayton, 1997; Clayton and Redcliffe, 1996).

Comments

The graphical representation is intended to represent multiple indicators over local, regional as well as global scale. However the figure is not easy to understand because of too much visual complexity. Moreover, it can induce visual illusions, of the sort described for pie charts based on the use of sectors. In fact, this is a procedure for graphical representation of data that is not recommended (Tufte, 1983; Zar, 1984; Cleveland, 1985). Tufte states that pie chart representation "*… pie charts should never be used*" (Tufte, 1983, p.178), since the representation of the values taken by the indicators is affected by the compression effort, so that their visual assessment is compromised. Even more straight is a statement by Bertin (1981, p. 111, as quoted in Tufte, 1983 p. 178), who claims that pie charts are: "*… completely useless...*" for this purpose. Representing together different sort of indicators, belonging to different domains, without a clear distinction of these domains, is another additional reason of potential confusion for the reader.

4.3.5 A methodical way of prototyping Integrated and Ecological Arable Farming System (IEAFS)

Vereijken, (1992; 1997; 1999) proposes a system of reference based on a radar diagram as a tool helping the process of defining prototypes in integrated farming system analysis. After establishing a hierarchy of objectives (Food supply, Nature/landscape, Basic income/profit), these objective are transformed into a given set of multi-objective



Inner circle refers to the Local level

Medium circle refers to the Regional level

External cycle refers to the Global level

Figure 4.4 *Sustainability Assessment Map representing indicators referring todifferent energy policies (from Spash and Clayton, 1997)* parameters. Such a selection aims at characterizing the performance of the system in terms of cost-effectiveness.

The actual performance of the farming system under analysis is compared against the set of values reflecting desirable results. Such a comparison is graphically represented by a radar diagram as in **Figure 4.5**.

Figure 4.5 *(see p. 74a) Radar diagram for a prototype of Integrated Ecological Arable Farming System (I/EAFS) (from Vereijken, 1997)*

The external circumference of the diagram is determined by the union of reference points, it is to say the previously established target of desirable values to be achieved by the defined variables. The diagram then conveys information about: (a) the relative shortfall of achieved results; in relation to (b) desirable results (where the difference between the value expected and achieved = relative shortfall). Let have a few examples to explain better the diagram. Let's consider the desirable value of the parameter "Exposure of the Environment to Pesticides" (EEP), setting the target value at 0 (no exposure). In the same way in relation to Plant Species Diversity (PSD) the diagram shows a great improvement in time (from only a few species in 1992 to 42 species in 1996). This is described by the parameter getting closer to the reference point. On the contrary, the potassium available reserve in the soil (KAR) got worse from 1992 to 1996 resulting in a movement on the graph away from the reference point.

Comments

This is an interesting approach to monitor farming system changes as it is quite simple to understand and effective to communicate the trends in the farming system. The selection of indicators, however, focuses specifically on agriculture technical performance missing many other important aspects that concur to shape the structure of the farming system (e.g. economic criteria).

4.3.6 Intervention Impact Assessment (Sustainability assessment)

A graphical representation based on a matrix of boxes of different colours is proposed by Efdé (1996) for a multicriteria assessment of seven typologies of livestock management interventions (e.g. Efdé, 1996; Udo *et al*., 1999 ; Masera *et al*., 2000). Each intervention is assessed according to four different indicators: 1) total production; 2) productivity of labour; 3) productivity of capital, and 4) environmental impact on soil (**Figure 4.6a**). Seven quality-classes are defined by the authors and the quadrants of the matrix (the boxes of different colours) are coloured according to the categories given in the legend.

Figure 4.6a *(see p. 74b) Example of quality matrix - Intervention Impact Assessment (after Efdé, 1996, modified)*

This approach may be useful to provide rapid and easily comprehensible data to farmers. As acknowledged by some authors (Udo *et al*., 1999) the Intervention Impact

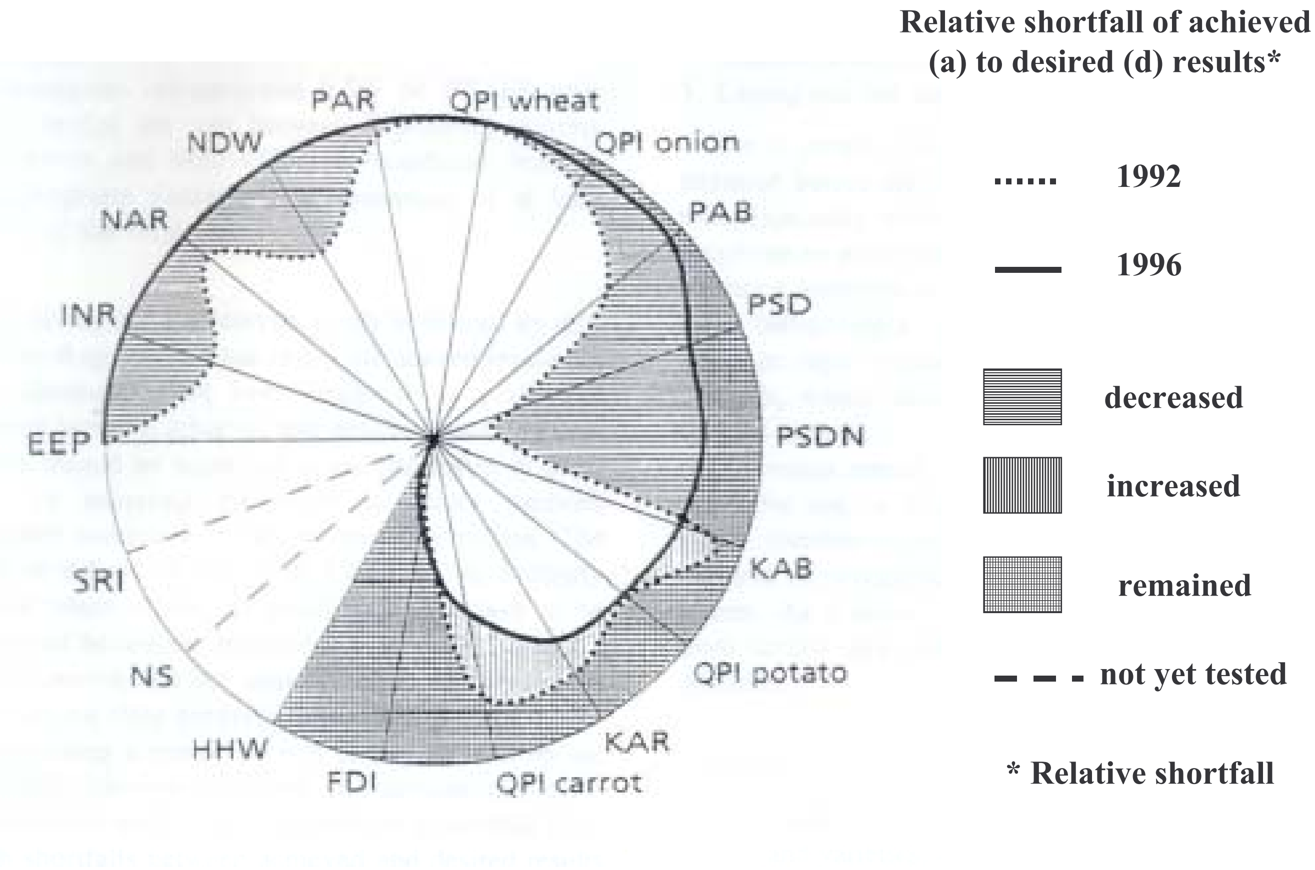


Figure 4.5 *Radar diagram for a prototype of Integrated Ecological Arable Farming System (I/EAFS) (from Vereijken, 1997)*

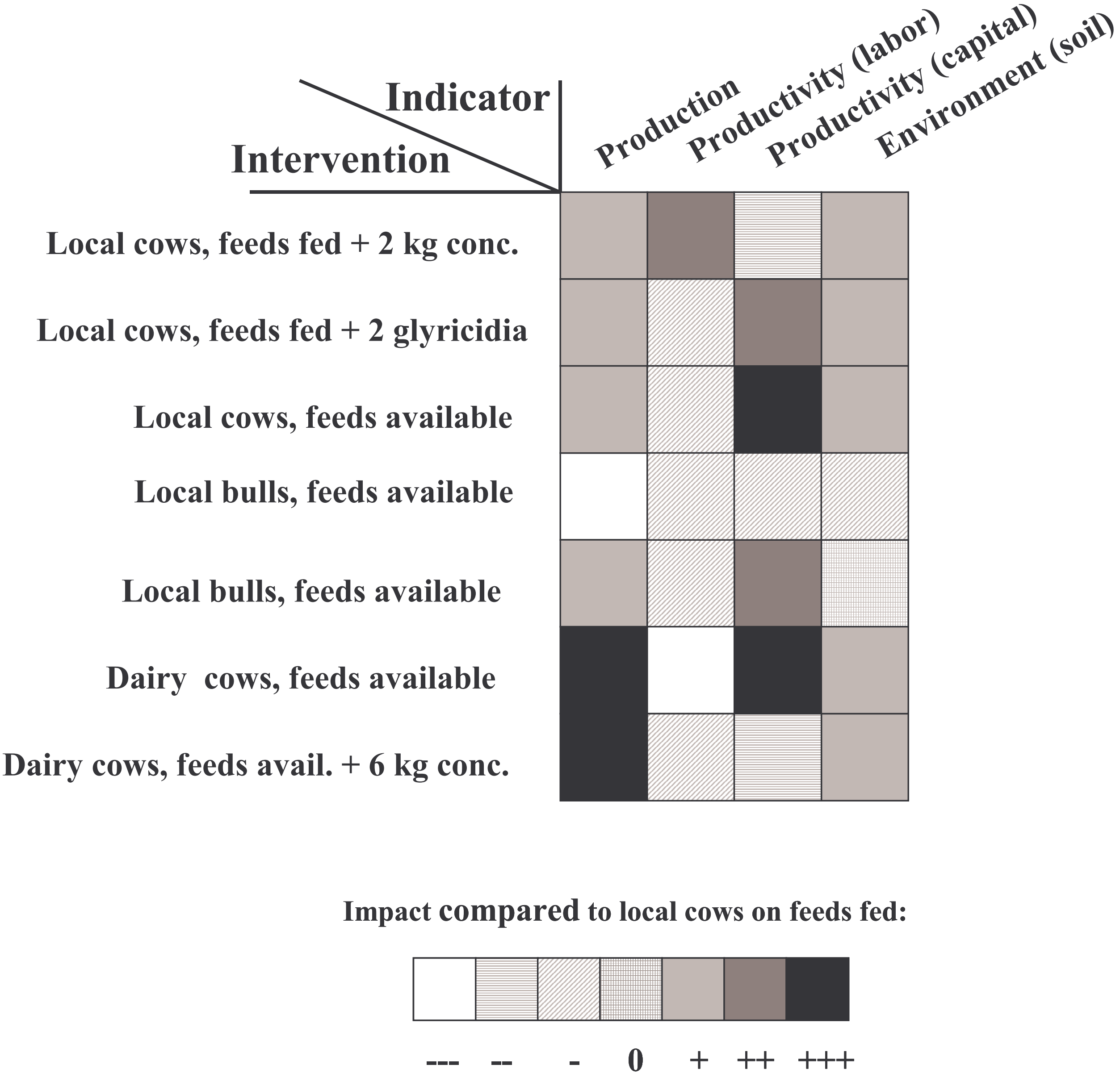


Figure 4.6a Example of quality matrix – Intervention Impact Assessment (after Efdé, 1996, modified)

Assessment approach has to be considered as a rather approximate qualitative tool. Nevertheless it can represent a useful tool to structure a participatory discussion on the sustainability of a farming system.

Masera *et al*. (2000) use a mix technique for the presenting integrated results (**Figure 4.6b**).

Figure 4.6b *(see p. 75a) Diagram for the presentation and integration of results of a sustainability evaluation (from Masera et al., 2000)*

Their Sustainability assessment diagram is a way to combine graphic representation and numerical data. On the left of the matrix diagram a number of typologies of farming systems are listed (e.g. cereal production, integrating corn and beans, integrating cereals with orchards and vegetable production). On the top, a number of relevant indicators are listed to characterize the farming system typology. Four types of quadrants are then used to represent the achievements of the farming systems according to a previous established range of values.

Comments

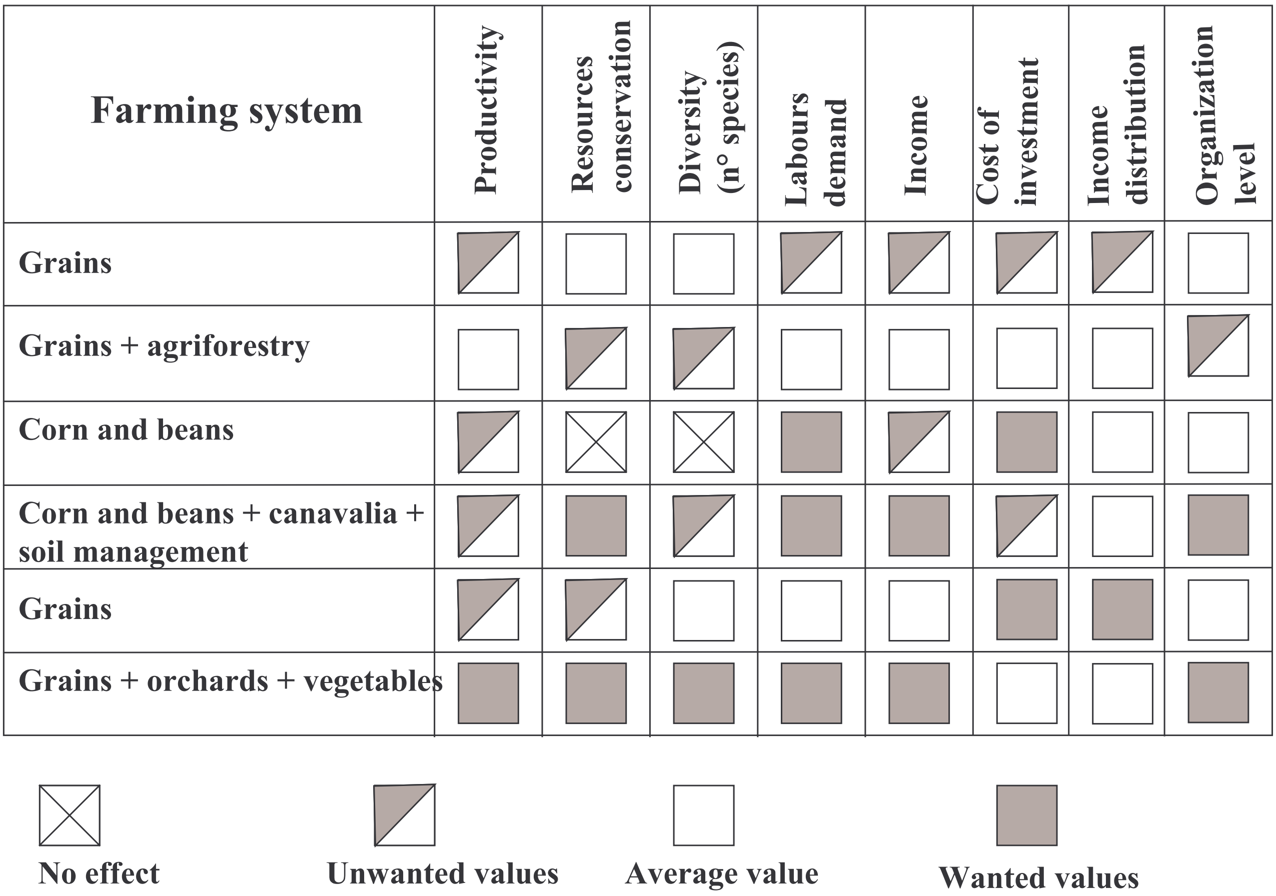
Graphical representation based on a matrix of boxes results easy to comprehend, anyway when the number of levels considered increases (e.g. **Figure 4.6b**), comprehension can be somehow compromised. The representation also is quite rough and does not consent to represent actual values of system performance. It can be anyway useful to easily manage qualitative information or rough quantitative figures, in particular in contexts where stakeholders can have problems in the comprehension of more complicated graphical representations.

4.3.7 Mixing triangle.

The use of Mixing Triangle graphical representation has been proposed by Hofstetter (1997, 1999) for Life Cycle Assessment (LCA) analysis (**Figure 4.7a** and **4.7b**). However triangular graphics of this sort have been in use for many decades in other disciplines (e.g. geology, mineralogy, soil science, material science). The triangle can be used to graphically depict the outcome of product comparisons for all possible weighting sets. Each point within the triangle represents a combination of weights that add up to a 100%.

Figure 4.7a and 4.7b *(see p. 75b) Mixing Triangle (from Hofstetter, 1999)*

In the example of **Figure 7a**., the point is positioned where Human Health is weighted 50%, Ecosystem Quality 40% and Energy Resources 10%. The position of such a point is defined by following each side until the dotted flashes leave towards the point in the triangle (Pré Consultants, 2000 - based on Hofstetter, 1998). A key feature is the possibility to draw lines of indifference. These are lines representing weighting factors for which



Farming system	Productivity	Resources conservation	Diversity (n° species)	Labours demand	Income	Cost of investment	Income distribution	Organization level
Grains	◩	☐	☐	◩	◩	◩	◩	☐
Grains + agriforestry	☐	◩	◩	☐	☐	☐	☐	◩
Corn and beans	◩	☒	☒	■	◩	■	☐	☐
Corn and beans + canavalia + soil management	◩	■	◩	■	■	◩	☐	■
Grains	◩	◩	☐	☐	☐	■	■	☐
Grains + orchards + vegetables	■	■	■	■	■	☐	☐	■

☒ No effect

◩ Unwanted values

☐ Average value

■ Wanted values

Figure 4.6b *Diagram for the presentation and integration of results of a sustainability evaluation (from Masera et al., 2000)*

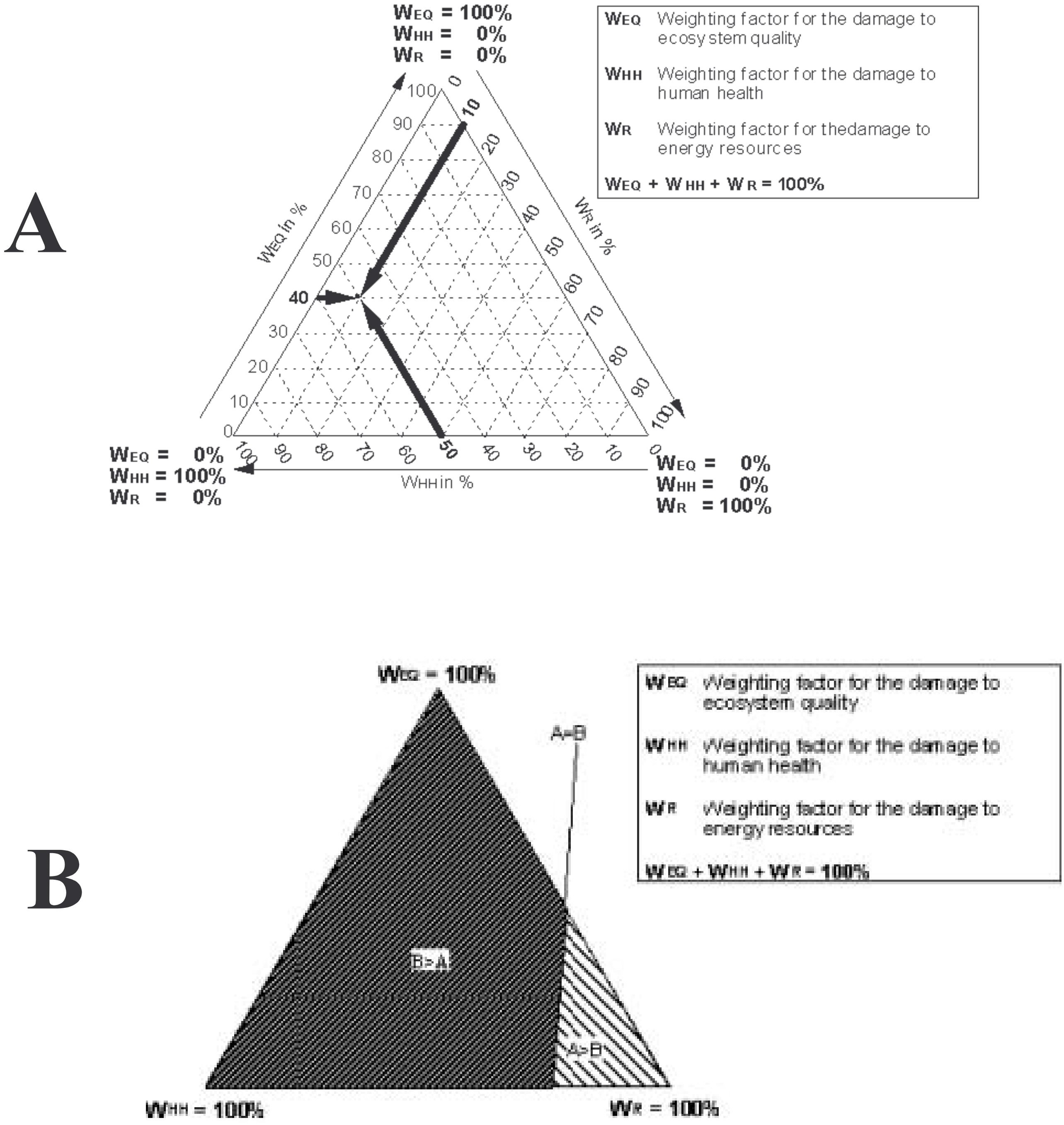


Figure 4.7a and 4.7b. *(see p.87a) Mixing Triangle (from Hofstetter, 1999)*

product A and B have the same environmental loads. The lines of indifference divides the triangle into areas of weighting sets for which product A is favourable to product B and vice versa.

According to Hofstetter (1998; 1999) this representation is very useful, since it enhances the transparency of the weighting process. In fact, it shows under which conditions (which weighting factors) product A is better than product B. The stakeholders do not have to set discrete weights, but they have to agree whether it is plausible that the weights would fulfil the conditions under which A is better than B or not. Such an approach therefore turns LCA into a consensus building process, instead of a tool that produces simple single statements. This methodology can facilitate an open discussion with the stakeholders. More information on this subject can be found in Hofstetter (1999). The line of indifference in the weighting triangle and the sub-areas with their specific ranking orders (B>A means that alternative B is environmentally superior to A and the eco-index A is higher than B).

Comments

Dewulf and van Langenhove (2001), point out that such methodology presents some important problems. The various effects related to the life cycle of a given product are measured on a particular scale, with a given set of units. Both the set of units and the scale can differ from one item to the other. In spite of this fact, in the final assessment these numerical measures have to be reduced (assuming full comparability) in order to obtain a unique final assessment as result. They argue that "*The balancing process is . . . a rather subjective and arbitrary step in LCA methodology*", (Dewulf and van Langenhove, 2001, p. 1). Also in this case we face the same problem found with the approach proposed by Prescott-Allen. That is, in the aggregation process we "get the point but loose the system".

4.3.8 Kite diagram for NUSAP applications

NUSAP is a novel approach to uncertainty assessment proposed by Funtowicz and Ravetz (1990). NUSAP is an acronym for the 5 categories: (1) Numeral, (2) Unit, (3) Spread, (4) Assessment and (5) Pedigree, in which: ***Numeral*** entry may be a number, or a set of elements and relations expressing magnitude (e.g. decimal digits, fraction, intervals, or ordinal indexes sometimes expressed in verbal locutions - small, large etc.); ***Unit*** represents the base of the underlying operations expressed in the numeral category (can be divided into standard and a multiplier (grams, or GNP per capita); ***Spread*** category conveys an indication on the inexactness of the information in the numerical and unit places (statistical notation); ***Assessment*** should express a judgment of the (un)reliability associated with the quantitative information conveyed in the previous categories**.** It may be represented through "confidence limits" and "significance level" of classical statistics; or alternatively through those of Bayesian statistics; ***Pedigree*** conveys an evaluative account of the production process of the quantitative information. This category operationalizes the epistemological sort of uncertainty, border with ignorance, mentioned previously. It maps the state-of-the-art of the field in which the quantity is produced.

Kite diagrams (**Figure 4.8**) have been used within NUSAP approach for pedigree and uncertainty assessment of data on SO_2 and CO_2 emission and scenarios (Corral Quintana, *et al.*, 2000; Risbey, *et al.*, 2001; van der Sluijs *et al.*, 2002). Pedigree conveys an evaluative account of the production process of information and indicates different aspects of the underpinning of the numbers and scientific status of knowledge used (Funtowicz and Ravetz, 1990; van der Sluijs *et al*., 2002 – see p. 92 for the kite diagram). As pedigree assessment involves qualitative expert judgment, NUSAP based approached, uses a linguistic description on a four level, discrete, numerical scale (0 = week, to 4 = strong) on the qualitative pedigree of information. In the case of van der Sluijs *et al*., (2002) the criteria used are: *Proxy*, (it refers to how good or close a measure of the quantity that we model is to the actual quantity we represent), *Empirical basis* (it refers to the degree to which observation and statistics are used to estimate the parameter), *Theoretical understanding* (it refers on how well are theory established in the scientific field), *Methodological rigor* (it refers to the degree of reliability of a specific methodology), *Validation* (it refers to the degree to which it has been possible to cross-check the data and assumption used to produce the numeral of the parameter against independent sources). However a different combination of criteria can be used, for instance Risbey *et al*., (2001) for the same assessment (CO_2 emission) use only four of these: Validation, Method, Proxy and Empirical basis. Within NUSAP approach Corral Quintana (2000) uses radar diagram to visual representing Pedigree of data (concerned with the quality of the Used Information, the role of the analyst, and the influence of the decision tools).

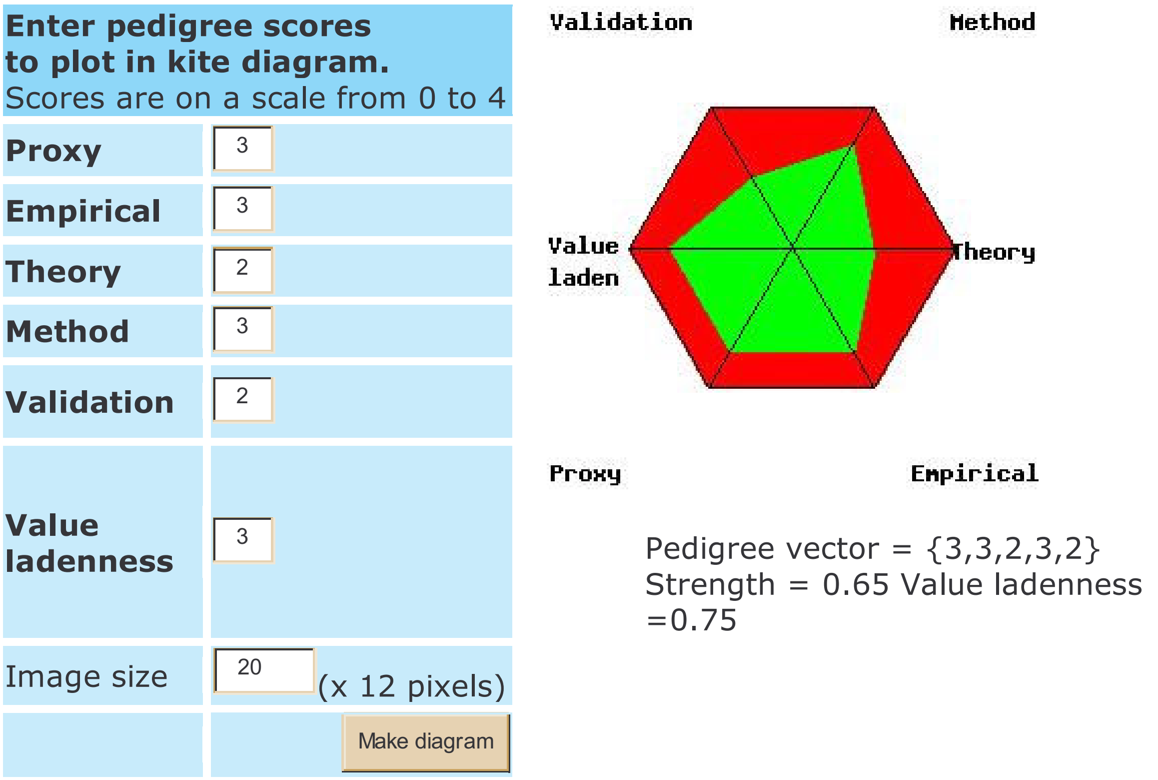
Figure 4.8 *(see p. 77a) Kite Diagram Maker for NUSAP (available on the web site nusap.net at http://www.nusap.net/sections.php?op=viewarticle&artid=3)*

Comments

This approach it is very interesting for it forces the researcher to address issues that are usually missed or overlooked and that concern the quality of the process of data construction. Using kite diagram representation in this case is well appropriated as it supplies an easy understanding of the evaluation exercise. An observation should be made concerning the creation of an overall qualitative numerical pedigree averaging out the linguistic description of the four level, discrete, numerical scale (0 = week, to 4 = strong). It should be noted, in fact, that the same comprehensive index can result from a number of value combinations, so that if used alone to represent the quality of the process, it looses significance. This is again an example of how difficult is to forced compression of different incommensurable criteria.

4.3.9 Pie for Policy Performance Index (PPI)

Anther sort of graphical representation is that used by Jesinghaus, (1999) at the EU Joint Research Centre at Ispra (Italy). The representation aims at allowing the citizens be able to judge “at glance” the government’s performance on a broad range of issues. The pie is divided in three sectors representing: (1) economy, (2) environment, and (3) social care (assuming that the relative indicators are available and widely used by the media). In the detailed representation the environmental pressure index, is sub-divided in ten “policy field indices”, each of which composed of six indicators (i.e. a total of 60 components). A similar index is also created to cover social issues, like the quality of health services, income



Enter pedigree scores to plot in kite diagram.
Scores are on a scale from 0 to 4

Proxy	3
Empirical	3
Theory	2
Method	3
Validation	2
Value ladenness	3
Image size	20 (x 12 pixels)

Pedigree vector = {3,3,2,3,2}
Strength = 0.65 Value ladenness =0.75

Figure 4.8 *Kite Diagram Maker for NUSAP (available on the web site nusap.net at http://www.nusap.net/sections.php?op=viewarticle&artid=3)*

distribution and poverty, education etc.; and another index is made for the economic performance and consists of typical indicators such as GDP, inflation and investment rates.

An example of the approach is provided in **Figure 4.9** (different types of this representation are used from the author).

***Figure 4.9** (see p. 78a) Pie representation for the Policy Performance Index (PPI) (after Jesinghaus, 1999)*

All three indices are then aggregated to a Policy Performance Index (PPI), and presented as a pie chart organised in three concentric circles as follows: (1) one overall index (PPI) in the centre of the pie, (2) three sub-indices for Economy, Social Care and Environment, and (3) an outer circle representing sub-sub-indices or "simple" indicators such as: GDP (even though technically speaking, GDP is an *index* composed of several hundred *indicators* weighted by market prices); inflation rate, poverty rate; Climate Change; Waste; and Air Pollution pressure index. In this example, it is well evident that the choice of indicators is a very delicate matter.

The construction of the pie is made trough polls asking people about the most urgent problems and how the government performance is solving them. The size of each segment, then, reflects the importance (the "weight") of the issue for politics. The colour of each segment reflects the judgment of performance using a seven colour scale, i.e. green for "good" and red for "bad". The inner two levels are aggregated valuations of the underlying segments (i.e. the "yellow" = "medium" PPI shows the average of the underlying valuations "good+bad+very bad").

Comments

Although at first sight the mechanism looks a bit complicated, it provides the government with two simple rules for their decision-making: (1) *you must eliminate the red spots:* voters do not trust governments that are unable to solve a crisis or to deal with a very bad situation; (2) *indicators with high weights have a high political priority:* in the cases of two environmental signals of "crisis", the government should focus on improving the one with a higher influence on the colour of the "Environment" segment; In this representation economic indicators (40%) count more than environmental ones (25%). Whenever, this representation is a tool used to inform citizens about government performance in solving the perceived problems it becomes a communication rather than a working tool.

The problem with this representation is that it is difficult to order the values encoded on the pie chart from smallest to largest. Relative sector dimensions are then difficult to be adequately perceived. As already discussed in the section 4.3.4 for the Sustainability Assessment Map, scholars in the field of data representation (e.g. Tufte, 1983; Zar, 1984; Cleveland, 1985) strongly advice not to use pie charts to convey complex information.

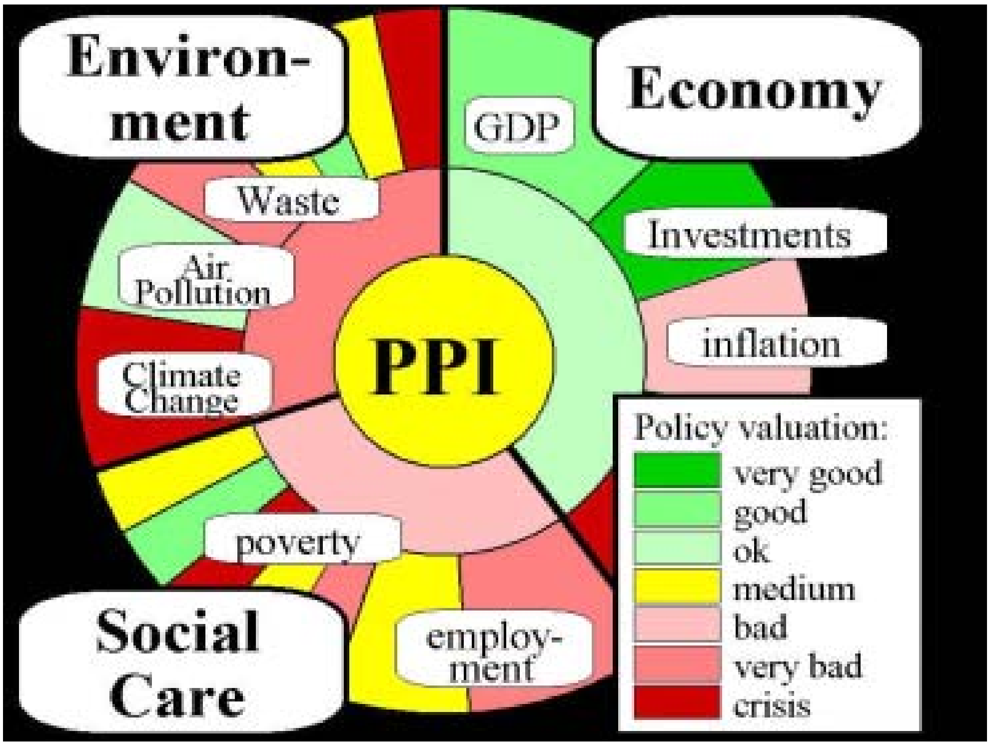


Figure 4.9 Pie representation for the Policy Performance Index (PPI) (after Jesinghaus, 1999)

4.3.10 The Flag Model

The Flag Model has been develop by Nijkamp and colleagues with the purpose to analyse whether one or more policy alternatives can be classified as acceptable or not in the light of an a-priori set of constraints (Vreeker *et al*., 2001; Nijkamp and Vreeker, 2000; Nijkamp and Ouwersloot, 1998). The Flag Model has been designed to assess the degree to which competing alternatives fulfill pre-defined standards or normative statements in an evaluation process.

There are four important steps in applying the model:

- Identifying a set of measurable indicators;
- Assessing the impact of the alternatives on the above-mentioned indicators;
- Establishing a set of normative reference values (standards);
- Evaluation of the relevant alternatives.

The Flag Model uses two types of input: an impact matrix and a set of Critical Threshold Values. The impact matrix is formed by the values that the indicators (from economic, social and environmental domains)assume for each alternative considered. Besides the construction of the impact matrix, for each indicator a Critical Threshold Value has to be defined. These values represent the reference system for judging the alternatives.

For each indicator in the Flag Model, preferably a critical threshold value (CTV) has to be defined. These values represent the reference system for judging alternatives. Since in many cases experts and decision-makers may have conflicting views on the precise level of the acceptable threshold values, a bandwidth of critical threshold values is constructed. This bandwidth ranges from a maximum value (CTVmax) to a minimum value (CTVmin). This can be represented as follows:

Section **A**	**Green**	no reason for specific concern
Section **B**	**Yellow**	be very alert
Section **C**	**Red**	reverse trends
Section **D**	**Black**	stop further growth

The Flag Model can operate both as a classification procedure and as a visualization method. There are three approaches to such a representation: i) a qualitative, ii) a quantitative and iii) a hybrid approach, that are complementary one another. This allows for the method to be flexible to the requirements of its users. The qualitative approach only takes into account the colours of the flags, and merely displays in various insightful ways the results obtained from the evaluation (this approach is adopted in the MOIR approach illustrated in **Figure 4. 10)**. The quantitative approach defines the values of the standards that may be acceptable or not (see for instance Vreeker *et al*., 2001; Nijkamp and Vreeker, 2000; Nijkamp and Ouwersloot, 1998, for further details).

Comments

The Flag Model offers a very interesting potential for representing integrated assessment of environmental systems in a way that can be helpful for the stakeholders. This because it faces the challenge posed by the acknowledgement of the existence of trade-offs in decision making.

However as the number of the flags gained by a domain (economic, social, environmental), depends on the number of criteria considered for each domain, this still leave much to subjectivity of the assessment. In fact if many criteria are selected in the economic domain and few in the environmental (or vice versa) this can greatly affect the overall results. Likewise for any other methods of this kind the normalization process and the setting of critical threshold value requires as much transparency and detailed explanation.

4.3.11 Multi-Objective Integrated Representation (MOIR)

A particular organization of data in a graphical representation, called Multi-Objective Integrated Representation (MOIR), has been proposed by Giampietro and colleagues (Giampietro and Pastore, 1999; 2001; Giampietro, 2004; Gomiero and Giampietro, 2001; Pastore et al. 1999) (**Figure 4.10**). MOIR has the goal of establishing bridges across non-equivalent representations referring to patterns perceived and detected on different hierarchical levels (e.g. household, village, county or local, regional, global label). This graphic representation was developed starting from the basic idea of the AMOEBA (different indicators for different scales) but it has been developed as to include two key steps: i) the message of normalization of values for communication of information (by dividing the area of the radar graph in zones indicating bad, medium and good performance – e.g. by adopting the "flag model" proposed by Nijikamp and colleagues, e.g. Vreeker *et al*., 2001; Nijkamp and Vreeker, 2000; Nijkamp and Ouwersloot, 1998), and, even more important, ii) the benchmarking process over the set of indicators. Once defined the viability domain (or other sets of benchmark points), for a given indicator of system performance, it has to be established the sense of direction. It is to say, which of the extremes have to be regarded as preferable as representing the best performance according to some specific goals. This implies the explicit introduction of a value judgment that can be given both by the analysts (outsiders the system) and stakeholders (insiders the system).

Figure 4.10 *(see p. 80a) MOIR application: a comparison of Italian and Chinese freshwater aquaculture (after Gomiero and Giampietro, 2004)*

By the Integrated Representation it is possible to establishment of links among the value taken by different indicators, in order to be able to discuss of the trade-off associated to different scenarios. Integrated representation means: (A) establishing links among processes occurring on various contexts and levels (e.g. by using congruence over flows of money, human time, energy and matter); (B) establishing links among relevant criteria; (C) focusing on the existence of trade-offs.

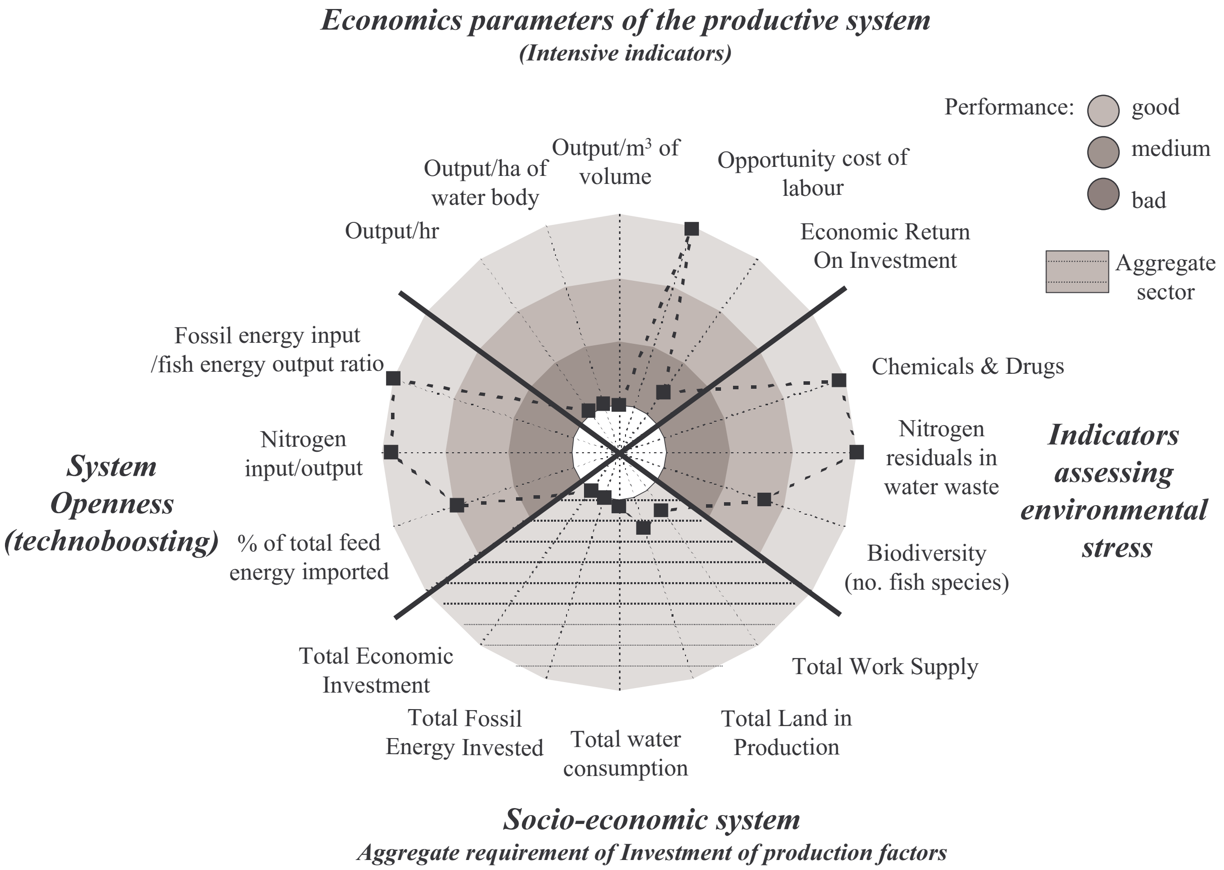


Figure 4.10 *MOIR application: a comparison of Italian and Chinese freshwater aquaculture (after Gomiero and Giampietro, 2004). See chapter 5 and 6 for details.*

Comments

MOIR can be an useful tool to: (1) force the analysts, as well as the stakeholders, to think in a systemic way, it is to say, to see the problem under multiple dimension, and (2) to recognize pattern of functioning in the system under analysis. Of course, changing the sets of indicators the patter will be modified, as well as if we choose a scale instead of another and so on. Anyway, it has to be recognized that the option space and the constraints posed to a given system from its lower and higher hierarchical levels does not allow whatever system structure to take place. Much better a system will be characterized by some given patterns, that can be more or less characteristic for a given farming system. This holds true also for other systems.

4.4 A critical appraisal of these graphical representations

Graphical representations can have problems because of: (a) the psychology of human vision and its organization and interpretation as performed by the brain. Distorted interpretation of graphical images is a field much studied in psychology, e.g. Gestalt psychology (Köhler, 1947; Asch, 1968; Kanizsa, 1980); (b) epistemological issues related to the very same process of figure and diagrams making, e.g. use of particular forms, scales, colours, etc. In fact, the very same act of selecting a scale to represent a set of data, can determine in the reader different feelings and generate different feed-backs (Zar, 1984).

4.4.1 Pros of Graphical Integrated Representations

By mean of graphical representation we can:

- ***convey relevant information in a form easily comprehensible to the stakeholders***

Graphical representations make possible to have a clear and simple presentation of technical data often required by policy-makers and stakeholders in general (ten Brink, 1992). This aspect is particularly important in participatory processes where information has to be understood by a wide range of people, also in relation to the generation of possible feedback (Nijkamp, 1979; Vereijken, 1992; 1997; Chambers, 1997; Spash and Clayton, 1997; Nijkamp and Ouwersloot, 1998, Giampietro and Pastore, 1999; 2001; Giampietro, 2004).

- ***make detectable some properties of the whole not easy to detect for non-experts (Gestalt)***

Graphical representations can provide a profile of system performance (within the chosen set of criteria and indicators), than can be thought as a sort of “map” of the system performance in relation to different set of indicators referring to criteria not-optimizable all at the same time (e.g. when dealing with sustainability dialectics). As such, it provides information not only on the values of the individual variables included but also a sort of “gestalt” view of the whole (Funtowicz and Ravetz, 1990; Gallopin, 1996). This can be used to have a look at the “winners and the losers” so to speak in the final negotiation over those sustainability trade-offs which do not have compensation. At this regards Funtowicz and Ravetz, (1990, pp. 83-98) provide several insights about the practical usefulness of maps and diagrams in delivering information for policy. The crucial role that the graphical representation can play in a process of multicriteria evaluation points at the consequent problem of individuating "quality" criteria for making them (Funtowicz and Ravetz, 1990; Gallopin, 1996).

- ***generate a dynamic graphical representation of changes in indicators when discussing scenarios***

By establishing relations between changes in biophysical variables and economic variables it can be possible to describe with models the possible effects – or better the feasibility domains – in terms of values taken by a given indicator in relation to another (Giampietro, 1997a; 1997b; 2004; Giampietro *et al*., 1997). By using the same rationale it is possible to establish a link between changes described in a multicriteria graphical representation and changes in land use. Software for a dynamic graphical representation of land use change does exist and can be used to discuss of scenarios (e.g. Clark *et al*., 1995; Hall *et al*., 1995; de Koning, et al., 1998; Hall *et al*., 2000; Verburg, 2000). Obviously, due to the inherent complexity of the interaction between socio-economic systems and ecological systems extreme caution has to be adopted when using these innovative tools. However, in spite of the caution due to the short history of this field, a dynamic integrated assessment of scenarios seems to represent a very promising direction of development.

- ***facilitate the discussion on incommensurable trade-offs (effects of sustainability dialectics)***

Graphical representations help the stakeholders in visualizing the implications of sustainability dialectics. Put in another way, they make explicit the consequences (both in positive and negative) implied by an alternative (or differences found in systems compared in the analysis). These consequences are expressed according to the set of indicators that better reflect the concern of the various social groups involved in the process (admitting that a participatory process was employed to select the identity of the multicriteria space). In this way, a "tailored" representation of the profile of distribution of "costs" and "benefits" over the social groups (represented considering both the perceptions provided by the scientists and those provided by the stakeholders) can represent a valid tool to facilitate an open discussion over contrasting views about the set of alternatives (ten Brink, 1992; Spash and Clayton, 1997; Garcia *et al*., 2001; Giampietro and Pastore, 2001; Giampietro, 2004).

Obviously, this applies only to those representations that keep the set of various indicators (which are relevant and significant to a different degree for different social groups) in the final graph (rather than collapsing them into a single overall index). In this way it is possible to keep separated: (a) the phase of the understanding of the implications of different options (according to both the perceptions provided by the scientists and those provided by the stakeholders): and (b) the phase of decision making in which the indications given by various indicators have to be mediated in relation to the effects expected on each social group (direct relevance) and to the effects that they will imply on other social groups (indirect relevance). Those aggregation procedures aiming at getting a final index of performance in the step of representation do not have the ability of keeping these two steps separated.

It should be noted that this graphic representation is very flexible for handling any type of analysis requiring the simultaneous consideration of different criteria. The example of Multi-Objective Integrated Representation given in Fig. 11 shows a characterization of the quality of a process of evaluation (in this case, it is the scientific process it-self which is characterized) in relation to an agreed upon set of non-equivalent criteria (after Corral, 2001).

4.4.2 Cons of Graphical Integrated Representations

Graphical representations are not to be expected, in general, to be "intuitive" or "self-explanatory". On the contrary, they present a wide array of problems both in the making and in the comprehension of the different graphs. Especially problematic is the case of integrated graphical representations having the goal of handling indicators referring to different scales and incommensurable criteria. In all those cases in which the graphic representation is used to aggregate the various indicators into a single index (this requires that weighting factors have to be applied to the various indicators) there is the obvious risk of loosing track of the information carried by the original indicators. The problem is already observed for graphical representations in the field of Life Cycle Assessment (Hofstetter, 1998; 1999; Pré Consultants, 2000). As already noted commenting individual methods, the aggregation of indicators on one side helps a holistic vision in the characterization of the problem structuring, on the other hand, implies the loss of a lot of useful information in the final graphical output. In this case, it is crucial to know how relevant for decision making was the information lost in the process.

- ***can lead to an oversimplification of the reality***

This problem is certainly true, but it is common to all types of representation (and all types of models). Simplification and compression in the demand of information used in a process of decision making is a necessary step which implies a necessary cost. In order to be able to make a decision in a finite time, the information space used for the problem structuring has to be reduced as much as possible. The goals is to try to avoid loosing too much relevant information.

Therefore, the criticism to methods of graphical representations has to be based on the consideration of the trade-off between "loss of relevant information" and "gain of usefulness in the organization of the information space used for problem structuring" that the various procedures entail. Obviously, we are discussing here graphical representations acknowledging from the beginning the Multi-Criterial nature of the analysis (e.g. acknowledging the necessity of structuring the representation on multi-objectives and multiple scales). This goal should call for an attempt to preserve as much as possible the original information available from the various set of data used as input. In this view, another basic goal of graphical representations is that of involving stakeholders in a "quality check" of themselves (to check the discrepancy between the representation provided by the scientists and that agreed-upon by the social actors). This ability to involve the stakeholders is crucial, since in a dynamic reality the perception and representation of both: (a) problems;

and (b) expected consequences of solutions; are continuously changing in time with strong non-linearity and unpredictable twists. In relation to this challenge, in spite of all their problems graphical integrated representations supporting multicriterial participatory processes of evaluation should be preferred to more conventional approaches such as chrematistic Cost-Benefit Analysis. In fact, it is our opinion that these conventional systems leads to an even more simplified results (since all relevant variables are collapsed in a single index with dubious procedures of aggregation), which moreover are not open to a quality check from local actors.

- ***can be used to mislead the perception of a given situation***

Also in this case, the problem is certainly a serious one. The choice of a given set of relevant criteria, of a given set of indicators, and on them of targets and admissible ranges, can imply a structuring of the problem that does not necessarily reflect the perceptions of the various stakeholders. As discussed in the first two chapters different choices of identities for the elements to be adopted in a model, different choices of observable qualities and then of encoding variables lead to different representations of system's profile.

Also in response to this objection we can only observe that this type of problem is common to any form of representation and problem structuring of a real situation. This is the reason why we envision the use of graphical integrated representation in a process of decision making, only within a participative procedure.

4.5 Concluding remarks

I wish to end this overview by presenting a sound procedure for generating Multicriterial graphical representation and by warning the reader that these graphical representations cannot be used as an overall assessments of the system performance.

4.5.1 The steps to be followed for a sound integrated representation

In conclusion, the procedure for generating a sound Multicriteria (or Multi-Objective) Integrated Representation is based on:

(1) *Definition of the relevant objectives that should be considered in the integrated analysis, according to relevant stakeholders.* This requires first of all: (a) an institutional analysis to study the set of relevant actors affected and affecting the decision to be taken; (b) the definition of the objectives related to the process of decision making; (c) the definition of the dimensions of the sustainability predicament which have to be considered in parallel to have a meaningful analysis; (d) the individuation of different levels of analysis required to cover relevant information; (e) the various criteria that should be considered within the various dimensions.

(2) *Definition of a set of indicators that can represent the performance of the investigated system in relation to the set of objectives, dimensions, criteria and levels considered as relevant in step 1.*

(3) *Assessment of the values taken by those indicators in relation to the alternatives considered in the analysis*. This step obviously must reflect the peculiarity of the local context and the availability of data gathered in the study.

(4) *Establishment of links among different indicators*, in order to be able to: (a) generate mosaic effects to increase the robustness and reliability of the information space; and (b) make explicit the implications of "*sustainability dialectics*" associated to different scenarios.

The definition of such a procedure and related steps is, more or less, present in the work of different authors proposing the adoption of multicriteria integrated representation in different fields (Nijkamp, 1979: ten Brink *et al*., 1991; ten Brink, 1992; Munda *et al*., 1994; Munda, 1997; 2004; Garcia, 1997; FAO, 1999; Giampietro and Pastore, 1999; 2001; López-Ridaura *et al*., 2002; Giampietro, 2004).

4.5.2 Multicriterial graphical representation cannot be used as an overall assessments

This is an objection that deserves the maximum attention. In fact, a multicriterial graphical representation is providing a quality profile in relation to a specific set of indicators and criteria considered by the analysts as relevant for determining the performance of the system. For example, when adopting a radar diagram, and looking at the consequent graph, one could be led to believe that given the normalization over the values taken by the indicators over the various axis and given a common direction of performance on the various axis (e.g. the more distant from the center the better), the total area included inside the profile of performance should be considered as an index of overall quality for the system. This is not correct for several reasons:

(a) the various indicators refer to non-commensurable criteria and therefore the process of normalization does not imply that they have been weighted in relation to their relative importance in determining the overall performance of the system. In order to compare the indication given by a set of non-equivalent indicators (that can be both quantitative and qualitative) referring to different criteria we must apply to the various indicators weighting factors in relation to the specific situation considered reflecting the preferences, aspirations, fears of the stakeholders. This profile of weighting factors can only be obtained after a discussion with stakeholders based on a first tentative integrated representation (a tentative input to start the iterative process). That is, we can start the process by adopting as a first input an "etic" perspective (from the system outsiders) and only after having achieved an "emic" perspective of the problem structuring - agreed among the stakeholders (the system insiders) - it is possible to get into the step of negotiating weighting factors ("etic" and "emic" are terms taken from anthropology that well address the issue of world representation asking "from which point of view?" - Harris, 1987; Headland *et al*., 1990). At this point, since different social groups (or different systems of knowledge) can express different profiles of weighting factors for the same set of criteria, the final profile of weighting factors that will be adopted in the decision is the result of a negotiation (power relation) among the different perspectives, and therefore has nothing to do with an objective assessment of the overall quality for the system!

(b) the profile of weighting factors used to compare the indications provided by the set of indicators used for the integrated representation is location and time specific. For example, in a general discussion about how to characterize and assess on a multicriteria problem structuring the environment in which one wants to operate, one can assign a crucial importance (very high weight) to a healthy air quality. However, the very same person can then decide (a few minutes after having expressed such a preference) to enter into a building in fire filled with dangerous fumes to save children trapped inside.

(c) the profile of performance resulting from the integrated representation on a multicriteria space is referring to just one of the possible integrated representations of the system. This means that any graph providing an integrated representation of a situation should be considered as just one of the possible inputs to be adopted for a multicriterial problem structuring. Put in another way, the particular identity of any particular graph has very little chance to remain the same when going through a participatory process of integrated evaluation.

It has to be pointed out, as mentioned above, that aggregation procedures aiming at getting a final index of performance make the reader to loose track of the heterogeneous characteristics of the systems.

Chapter 5

Introducing the Multi-Objective Integrated Representation (MOIR) applied to farming system analysis

> *Nothing exists by itself or in itself. Everything exists through reciprocity.*
> Bodin[13]
>
> *Every human tool relies upon, and reifies, some underlying conception of the activity it is designed to support.*
> Lucy A. Suchman[14]

Summary

This chapter presents a procedure that can be used to perform Multi-Objective Integrated Representation (a multi-objective representation which is based on integrated package of indicators which is able to cover perceptions of the reality referring to different space-time scales and reflecting the legitimate contrasting interests of social actors). The various tools illustrated are referring to farming system analysis.

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[13] Bodin (1943 - quoted in Allen and Starr, 1982, p. 25).

[14] Suchman (1987, p. 3).

5.1 Introduction - MOIR: farming system analysis across scales

A particular organization of data in a graphical representation, called Multi-Objective Integrated Representation (MOIR) [a longer and better acronym would be Multi-Objective Multiple-Scale Integrated Representation -MOMSIR- but it results more difficult to use], makes it possible to establish bridges across non-equivalent representations referring to patterns perceived and detected on different hierarchical levels (in the examples given in Part 3 these levels are the household, village, county or local, regional, global level). Three crucial characteristics of this method require (Giampietro and Mayumi, 1997; 2000a; 2000b; Giampietro and Pastore, 1999; 2001; Giampietro, 2004):

(A) *acknowledging the existence of different dimensions* (social, economic, and ecological) within the issue of development and management;

(B) *acknowledging the fact that socio-economic and environmental systems are organized in elements belonging to a nested hierarchy* (e.g. crop-fields, household, village, province, country). Therefore, a MOIR requires first to individuate a nested hierarchical structure that will be used as a skeleton for the integrated representation;

(C) *representing the integrated performance of the various elements in different ways on different hierarchical levels*. Each of these representations is based on a set of indicators (specific for the particular element and hierarchical level chosen) which are reflecting the selection of relevant criteria of performance associated with a given descriptive domain. These indices can be combined in “radar diagrams” typical of multicriteria analyses (see chapter 3 for a review of graphical methods for multicriteria representation). In the examples given below each indicator (e.g. the income of a household belonging to a village) is benchmarked against reference values provided by its context (e.g. the average income found in the society in which the household is operating). This operation can be re-iterated in the nested hierarchy (by benchmarking the income per capita of the household, to that of the village, the income of the village to that of country, the income of the country to world averages);

5.2 Three key-concepts in MOIR: (1) Multi-Objective, (2) Multiple-Scale, and (3) Integrated Representation

MOIR requires using in parallel and across scales, non-equivalent descriptive domains. The peculiarity of this approach is related to 3 key-concepts: Multi-Objective, Multiple-Scale, and Integrated Representation.

5.2.1 Multi-Objective

An example of multi-objective representation of a farming system is provided in **Figure 5.1.** Here we have criteria and indicators belonging to different domains. Each domain is represented by a set of indicators of performance (a detailed explanation of this figure will be given in section 5.2.2).

Figure 5.1 *(see p. 89a) Multi-Objective representation of a farming system type (e.g. high intensity of input farming system)*

The representation of the performance for a given rural system as in **Figure 5.1**, is based on a family of indicators (social, economic, and environmental), which are able to:

(A) Consider legitimate contrasting goals of relevant stakeholders (those affecting and affected by events and having recognized rights) over different dimensions of analysis (economic, ecological, social) and different scales (levels of analysis). The relevant attributes of performance considered in the analysis have to fulfill such a goal.

For instance, "paying less taxes" can be considered as a positive change for "households" and as a negative change for the "local government". The value taken by this indicator can be crucial for the stability of these two agents (households and local governments), which have legitimate contrasting goals about changes of this indicator. Whenever this dilemma is important for the analysis, these two views have to be represented using two different indicators (e.g. disposable cash for household, and characteristics of the economic budget for the local government) in the integrated representation of performance. In the same way, two indicators such as: "economic return per hour of work" and "economic return per hectare of land" can be given different priorities by different typologies of household depending on the relative shortage of work and land. That is we can expect that two typologies of household operating with different budgets of working time and arable land, even if living in the same ecological and socio-economic context, will adopt different weighting factors in a trade-off analysis involving the balancing of performance in relation to these two indicators. Different weights given to changes in the value taken by these indicators will be reflected into different decisions of the households about how to allocate their working time or their land, among the set of available options of management of their farm.

(B) Handle different sets of relevant criteria and attributes referring to non-equivalent descriptive domains.

Attributes would be considered individually all along the work, eventually they also would be represented graphically as single entities (i.e. the value taken by individual indicator). By using this approach it is possible to characterize the performance of a given rural system in relation to a selected family of indicators (social, economic, and environmental), which are defined in different descriptive domains associated with different forms of disciplinary knowledge. For instance when considering the economic return per hour of work and per hectare of land, we are dealing with two different aspects of the household economy. Understanding the possible combinations of investments of these two production factors in relation to their relative perceived performance can be useful to explain the time use strategy of the household. When considering the ecological criterion, Net Primary Productivity, Gross Primary Productivity and Standing Biomass, would represent non-equivalent indicators giving different information about the performance of agro-ecosystems. This is a well known problem represented by the separate use of disciplinary knowledge. When using each one of these informations separately we can loose a lot of valuable, if not essential, information about the whole. What is crucial in an integrated analysis is the understanding of relations among changes in these different attributes, existing links and constraints in relation to possible changes of functions and structure.

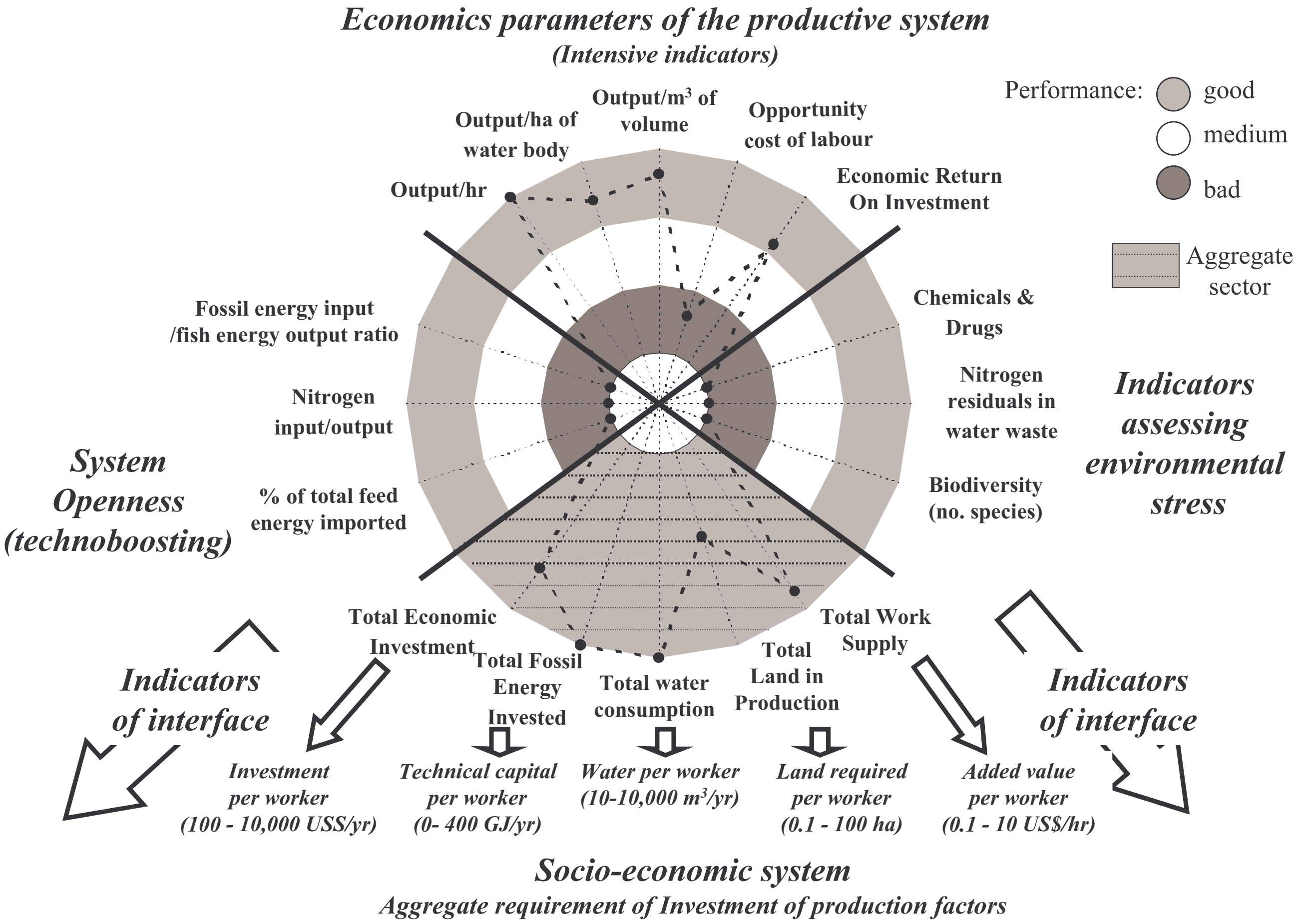

***Figure 5.**1 Multi-Objective representation of fresh water aquaculture systems (e.g. high intensity of input freshwater aquaculture system in Italy, see chapter 6*). The graphic presents three sets of indicators referring to: Economic parameters (top), Environmental stress (right), System openness (left). On the bottom there is a set of indicators of interface that links the systems to its socio-economic context, these represent the aggregate indicators of investment of production factors. The min. and max. values provide the range of viability within which the indicators lay.

5.2.2 Multiple-Scale

The family of indicators used to describe the performance on a multicriteria space almost always implies considering "qualities" of the farming systems that can be defined only using different hierarchical levels. For example, indicators should reflect: the health of the soil, the health of the rural community, the material standard of living of individual households, the health of the economy of a province, the preservation of biodiversity at a regional level. In turn, different levels imply the existence of patterns linked to events recognizable only at different space-time scales, **Figure 5.2**. For this reason, when considering an assessment referring to a particular level (e.g. the household) it is important to put in relation its relative "system description" with that obtained, on different levels, when assessing other indicators (Giampietro and Mayumi, 2000a; 2000b).

Figure 5.2 *(see p. 90a) Different levels imply the existence of patterns linked to events recognizable only at different space-time scales (pictures by the author referring to a village in the Centre Vietman).*

For example, the assessment of "income per capita" of a country does not say anything about the situation of marginal social groups living in it. To address such an issue you have to describe the system at the household level. On the other hand the environmental impact, generated by the land use of a particular household, is too "location specific" to become relevant for ecological processes. That is, it cannot be directly related to the degree of environmental impact at the watershed level, without first "scaling-up". To do that we have to address how the various "typologies" of land-use found in the farming system considered can be aggregate to detect effects at a larger scale.

The approach of MOIR makes it possible to establishing bridges across levels by following the approach of Multi-Scale Integrated Analysis presented by Giampietro (2004) and in particular, for farming system analysis, in Giampietro and Gomiero (2003). This requires:

(A) representing the performance of a particular socio-economic element as belonging to a given hierarchical level (e.g. field, household, rural community, local-regional ecosystem etc.) defining for it a type according to its spatio-temporal dimension (e.g cropping period, household planning time-frame, national economic trends, ecosystem seasonal fluctuation, ecosystem trends etc.).

The representation is then based on a set of indicators – relative to the selected type, which are applied to a given level (e.g. the income of a household belonging to a Vietnamese village) and also to its context (e.g. the average income found in Vietnam). This operation can be re-iterated in a cascade (by comparing the average value of income per capita of the household, to the village, to Vietnam, to world averages);

(B) scaling across level. The characteristics of lower level elements are defined over a discrete set of typologies (e.g. a set of household types) and then the characteristics of the higher level (e.g. the village) can be obtained by combining the knowledge of: (1) characteristics of each of the household types belonging to the set; (2) the curve of distribution of the population of households over the set; (3) residual information related to characteristics of the higher level not retrievable from the knowledge of lower level elements

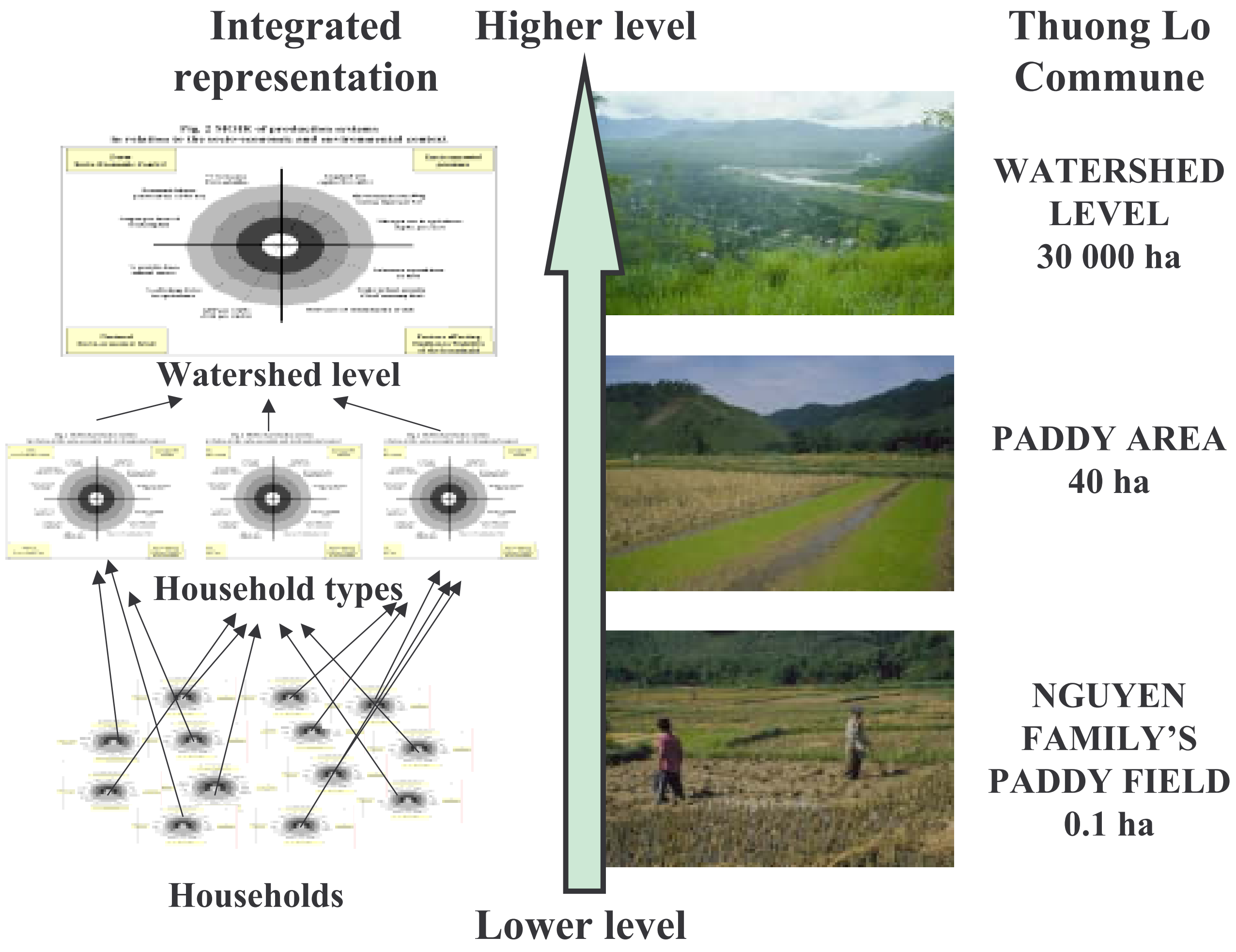

Figure 5.2 *Example of multiple scale representation using MOIR*

(e.g. communal land use – such as roads, schools and facilities) which are not affected by choices performed at the household level.

5.2.3 Integrated Representation across scales

Different indicators of performance (reflecting a set of given goals) require the use of descriptive domains utilizing different space-time scales. That is, a real integrated analysis requires the ability of scaling within the non-equivalent descriptions of the farming system.

This can be obtained by adopting a characterization of household types (e.g. as characterised in **Figure 5.1**) which makes it possible to associate at each "household type" a selected set of characteristics referring to: (1) a unit of human activity belonging to the household type, when dealing with indicators of socio-economic performance, and (2) a unit of managed land, when dealing with indicators linked to ecological impact (e.g. **Figure 5.2**).

By adopting the same approach we can move across scales and characterize, using the same selection of variables, a village (made of households which must belong to the set of types. This movement across levels is possible by extrapolating the characteristics of the types defined at the **level *n+1*** from the knowledge of characteristics of types defined at the **level *n*** (Giampietro and Pastore, 1999; 2001; Gomiero and Giampietro, 2001; Giampietro, 2004). That is: (1) characteristics of the various household types found in it; (2) curve of distribution of the population of households over the set of types; (3) additional information referring to relevant socio-economic processes and land-uses whose agency is at the level of the village, and therefore out of the control of the household considered in step (1) and (2) (**Figure 5.3**). This additional information is required to obtain closure in the representation across levels (Giampietro, 2004).

Figure 5.3 *(see p. 91a) Linking different hierarchical levels with indicators of "farm-context" interface (numerical figures refer to Chapter 8: the case of aquaculture)*

In this way, information referring to the village level, can be inferred (to a certain extent) from the knowledge of lower level elements (households) even when not gathered directly at the village level. In this way, it is possible to establish a link between our knowledge/description of the farming system at the household level with the knowledge/description obtained at the village level. The parallel use of this information can be useful to fill data gap or to generate new insights on the existence of reciprocal constraints on characteristics of the farming system when using typologies at different levels.

An Integrated Representation establishes links among the value taken by different indicators defined on different descriptive domains (different scales and different dimensions of analysis). Therefore, it enables a discussion of "*sustainability trade-offs*" associated to different scenarios.

Therefore Integrated Representation means:

(A) establishing links among processes occurring on various contexts and levels (e.g. by using congruence over flows of money, human time, energy and matter across types defined on different levels);

(B) establishing links among relevant changes referring to different criteria;

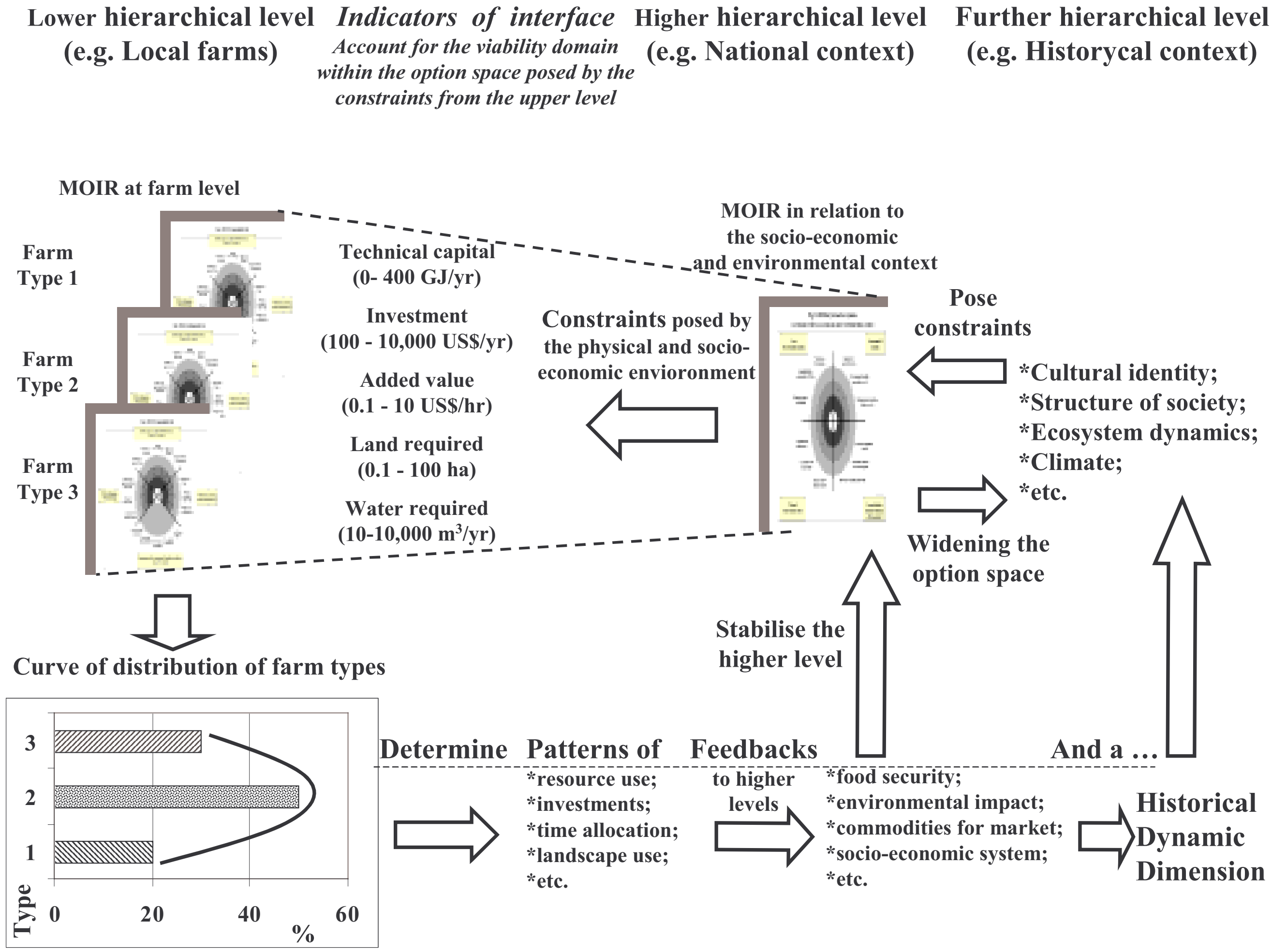

***Figure 5.3** Linking different hierarchical levels with indicators of "farm-context" interface (numerical figures refer to Chapter 6: the case of aquaculture)*

(C) focusing on mechanisms generating incommensurable trade-offs, that is to say trade-offs occurring at different space-time scale (e.g. farmers introducing a new technology at farm level to increase production, such as irrigation wells, resulting in a complete alteration of the bio-physical and climatic characteristics of a vast region, such as salinization), and/or among different domains (e.g. converting "sacred land" of native inhabitants into a waste disposal area for a nearby city, or forest clearing for fast economic profit resulting in habitat disruption and the extinction of wild species).

The MOIR approach is therefore one of the many tools required for a procedure of *conflict analysis.* This procedure is characterized by technical, socio-economic, environmental and political value judgments. This means that one of the goal of the MOIR approach should be that of resulting useful for the involvement of the stakeholders in the process. MOIR should help the discussion over relevant criteria, validity of the models used in the analysis, and the characterization of scenarios in terms of relevant pros and cons.

5.3 Technical aspects of Multi-Objective Integrated Representation

5.3.1 Building a graphical representation for MOIR

In order to obtain an integrated representation based on the adoption of a set of indicators it is necessary to go through 4 basic steps:

(1) *Choosing the type of graph*. This requires selecting an adequate overall pattern of visualization of the set of indicators. In practical terms, this implies deciding to organize the information in the form of a radar diagram rather than an alternative solution (e.g. a bar diagram).

(2) *Benchmarking over the set of indicators*. This implies assuming, whenever possible, that the characteristics described by the various indicators can be framed within a given range of values. This range of values refers to the expected characteristics of a typology to which the analyzed system is supposed to belong. This requires assuming that the system can be imagined as a member of a class (a rural household of Vietnam, a medium city of Midwest USA, a developed country). In this way, **we are adding to our representation information which is no longer coming from the experimental operation of a measurement scheme**. This information is rather coming from previous knowledge of the typology of systems we want to represent. Therefore, this approach requires assuming that the investigated system (the population of households that will be included in the study) belongs to such a typology. Benchmarks can also be associated to the existence of "feasibility domain" or "viability domains" related to a set of admissible values which can be taken by the various indicators in relation to different definitions of constraints. Put in another way, for well known typologies and when dealing with systems that can easily be associated to these typologies, we can reasonably guess, from experience, that individual members of the known equivalence class cannot operate outside a certain range of values taken by these indicators. For example the quality of life of individuals for rural households of a given area can be associated with a range of admissible values for the set of indicators used to characterize the quality of life in that context. The set of indicators could be: food

intake (e.g. no less than 2,000 kcal/day as average), net disposable cash (e.g. no less than a given of US$ per month), work load (e.g. no more than 3,500 hours/year for adults), and life expectancy (e.g. no less than 40 years). For each of these indicators then we can predict a range of values that can be associated to the viability of the relative type. In conclusion, when benchmarking, we can utilize information which is available from previous knowledge of the identity of the types to which the investigated system is supposed to belong.

(3) *Translating the semantic message carried out by an "objective" into a formal representation in the graph*. This requires generating a graph that makes it possible to represent the implications of "movements" (different values) taken by the corresponding indicator. That is, if the criterion of economic performance supports the use of the variable "personal income" as indicator, then the objective of "maximizing personal income" has to be represented over the graph. Then, increases in "personal income" should be considered as an "improvement" when considering that particular indicator. In practical terms, this means determining a direction on the axis used for representing the value taken by the indicator. In all cases of maximization of an objective the convention is that the higher is the value on the axis representing the indicator the better is the performance.

It should be noted, however, that this step entails a clear "value judgment" which is dependent on both the selection of the dimension of analysis and the selection of the indicator considered. That is, it is always possible to find legitimate contrasting views on whether or not an increase of "personal income" should be considered as an improvement (especially when several dimensions of analysis are considered in parallel). Many proponents of alternative life styles, in fact, could object about the opportunity of maintaining such an optimization above a given threshold.

(4) *Providing a harmonized representation of the original data set over the selected set of indicators.* This requires determining a protocol of representation that makes it possible to compare the various indications provided by the selected set of indicators. In practical terms this implies that: (a) the values of the various indicators have to be normalized over segments of the same length; (b) all the indicators of performance have to follow a common direction of performance. In the remaining examples of this thesis, I adopt the convention that points more distant from the center are indicating a state which is "better" in relation to individual indicators and objectives.

5.3.2 Possible types of graphical representation for MOIR

An overview of options for a graphical representation of performance in relation to multiple criteria has been given in Chapter 4. As discussed there, there are several options that can be used for this task. The choice of one option versus another is often just a matter of personal taste. Depending on the specific application, a type of graphical representation can result more effective than others.

For the following discussion about MOIR of farming system to be used in a participatory integrated assessment of sustainability I suggest to use a radar representation, which can employ either a Christian and/or a St Andrew's Cross. Because of its intrinsic symmetry, radar diagrams allow for a representation of different indicators in the form of identical radius departing from the same center. This makes easy for the reader to perceive the considered system as a complex whole, which is described using different indicators referring to multiple identities. A radar diagram makes it easy to convey the perception that the various qualities represented by the various indicators should be considered as belonging to an overall pattern and that, therefore, they should be considered as linked to each other (due to the existing links among the multiple natural identities of the system).

There are, of course, different types of radar diagram that can be employed within the frame proposed in section 5.3.1 Below I present 7 types of possible "Radar diagrams" based on the adoption of either: (a) a Christian cross (5 types); and (b) a St Andrew's Cross (2 types):

*** Examples of Christian cross** are given in **Figure 5.4**; **Figure 5.5**; **Figure 5.6**; **Figure 5.7**; **Figure 5.8**;

A discussion and explanation of these examples will be provided below.

Figure 5.4 *(see p. 94a) Radar representation (iso-metric and etic), with quintiles statistical benchmarks (see next sections for details)*

Figure 5.5 *(see p. 94b) Radar representation (iso-metric and etic representation) (see next sections for details)*

Figure 5.6 *(see p. 94c) Radar representation (iso-metric and emic representation) (see next sections for details)*

Figure 5.7 *(see p. 94d) Radar representation focusing on joint-sectors (iso-metric and etic representation) (see next sections for details)*

Figure 5.8 *(see p. 94e) Radar representation focusing on distinct sectors*

*** Examples of St Andrew's Cross** are given in **Figure 5.9**; and **Figure 5.10**;

Figure 5.9 *(see p. 94f) Simple radar diagram*

Figure 5.10 *(see p. 94g) Radar diagram with benchmarks*

Of course "bar diagrams" can also be employed to generate profiles of performance (such as those used in marketing – when representing the profile of consumer satisfaction). In marketing a profile of consumer satisfaction is basically a multicriteria assessment reflecting the appeal of products in relation to a set of relevant criteria for a specified consumer target. Bar diagrams can be also useful, when a more detailed account of individual assessments (e.g. the value taken by each indicator) is important. Bar diagrams in fact allow for a better

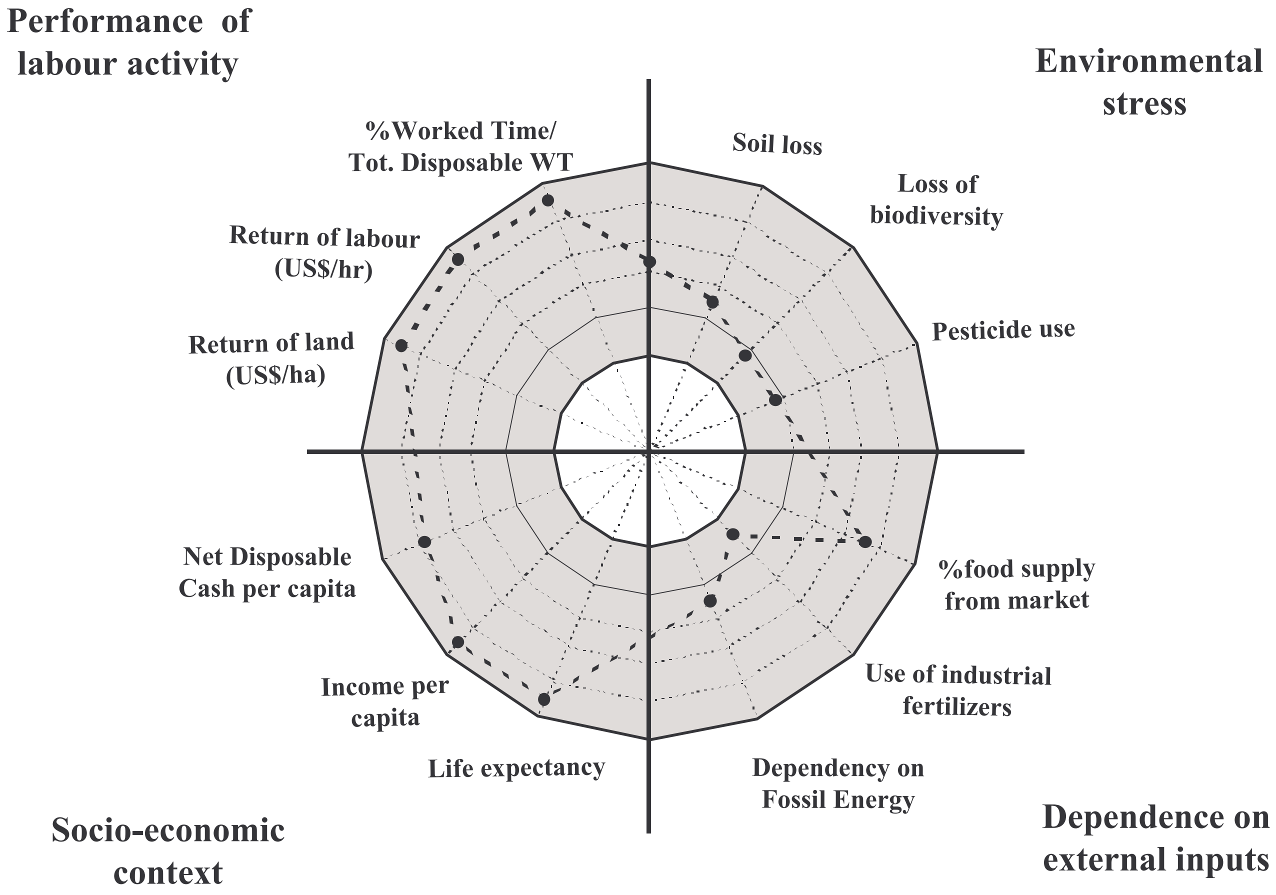

Figure 5.4 *Radar representation (iso-metric and etic), with quintiles statistical benchmarks (see next sections for details)*

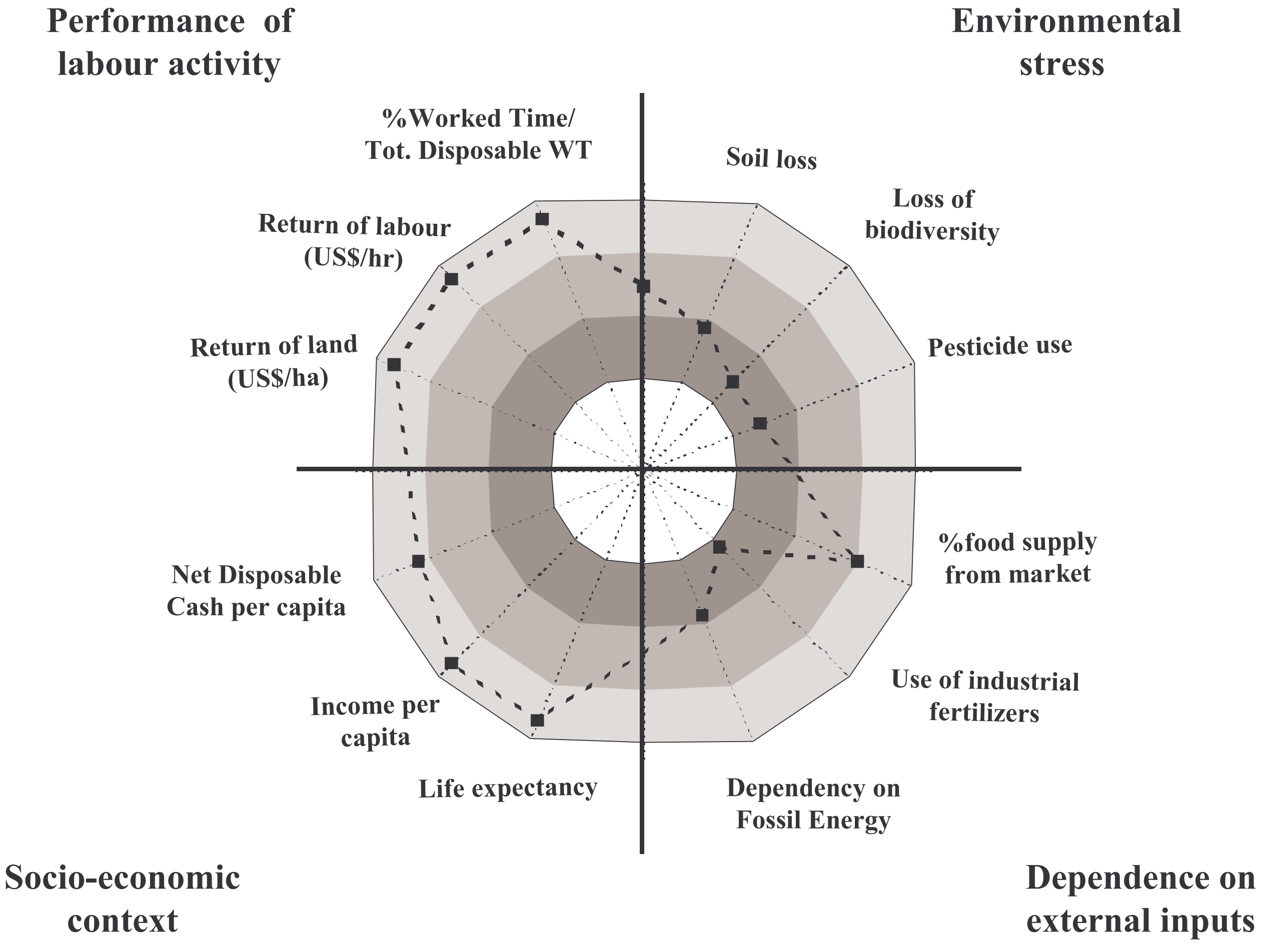

Figure 5.5 *Radar representation (iso-metric and etic representation) (see next sections for details)*

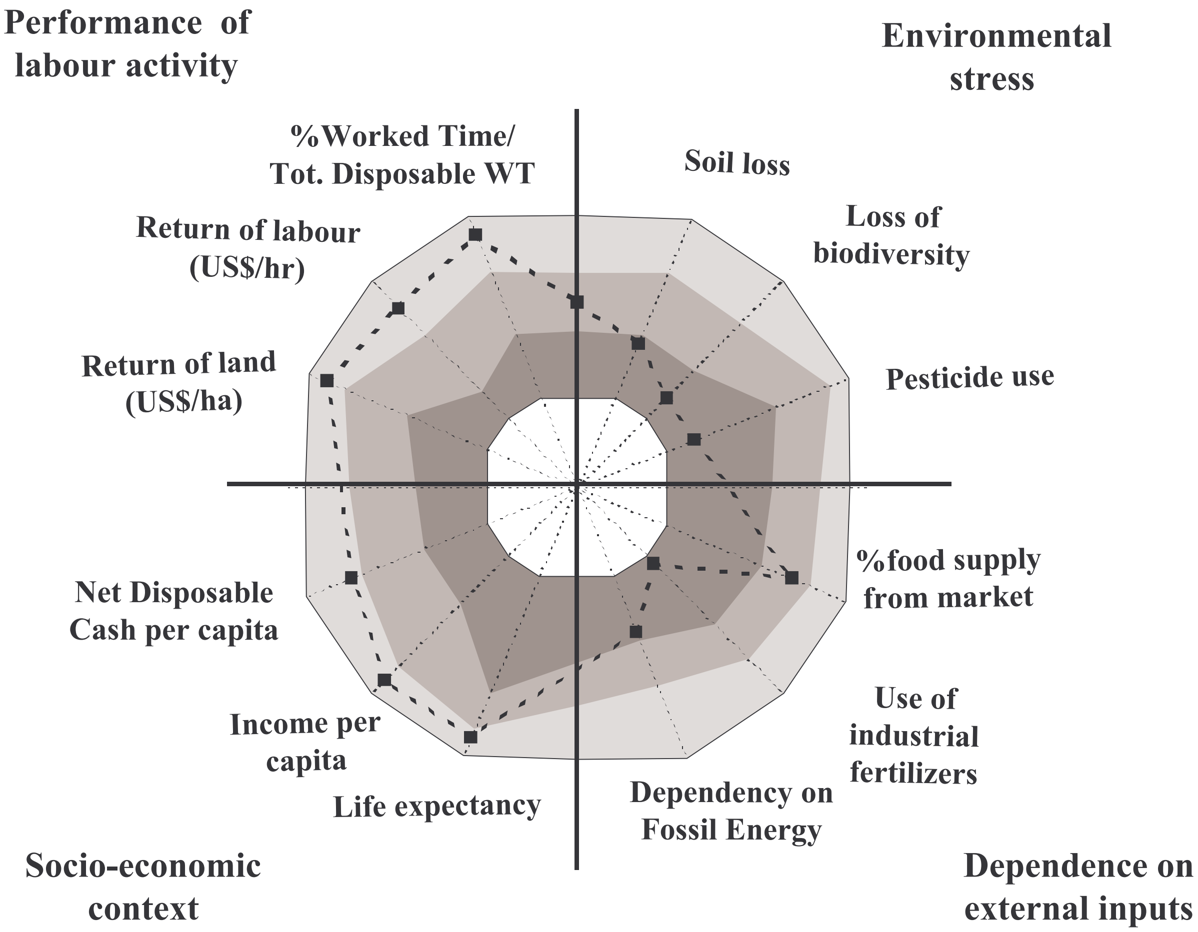

Figure 5.6 *Radar representation (iso-metric and emic representation) (see next section for details)*

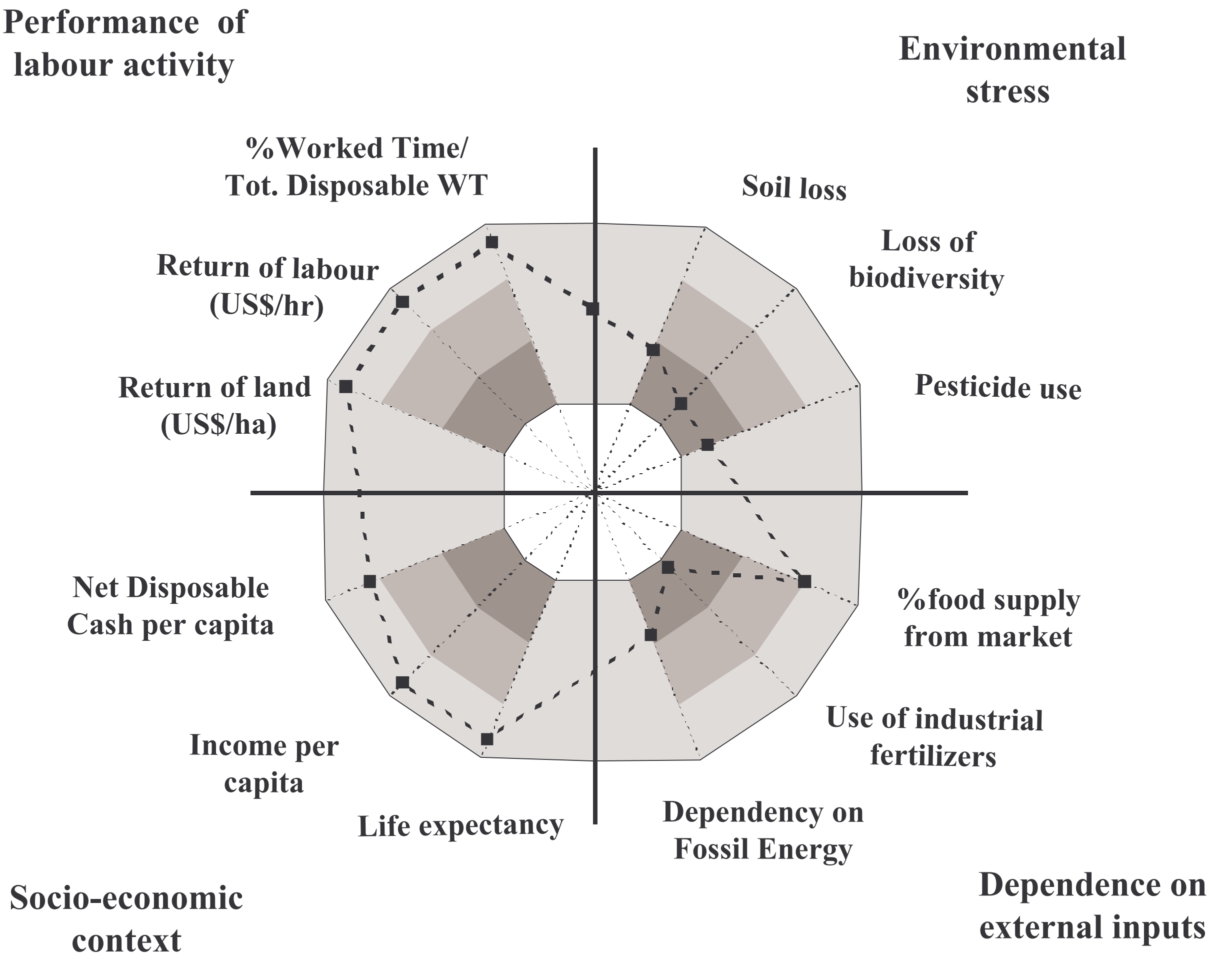

Figure 5.7 *Radar representation focusing on joint-sectors (iso-metric and etic representation) (see next sections for details)*

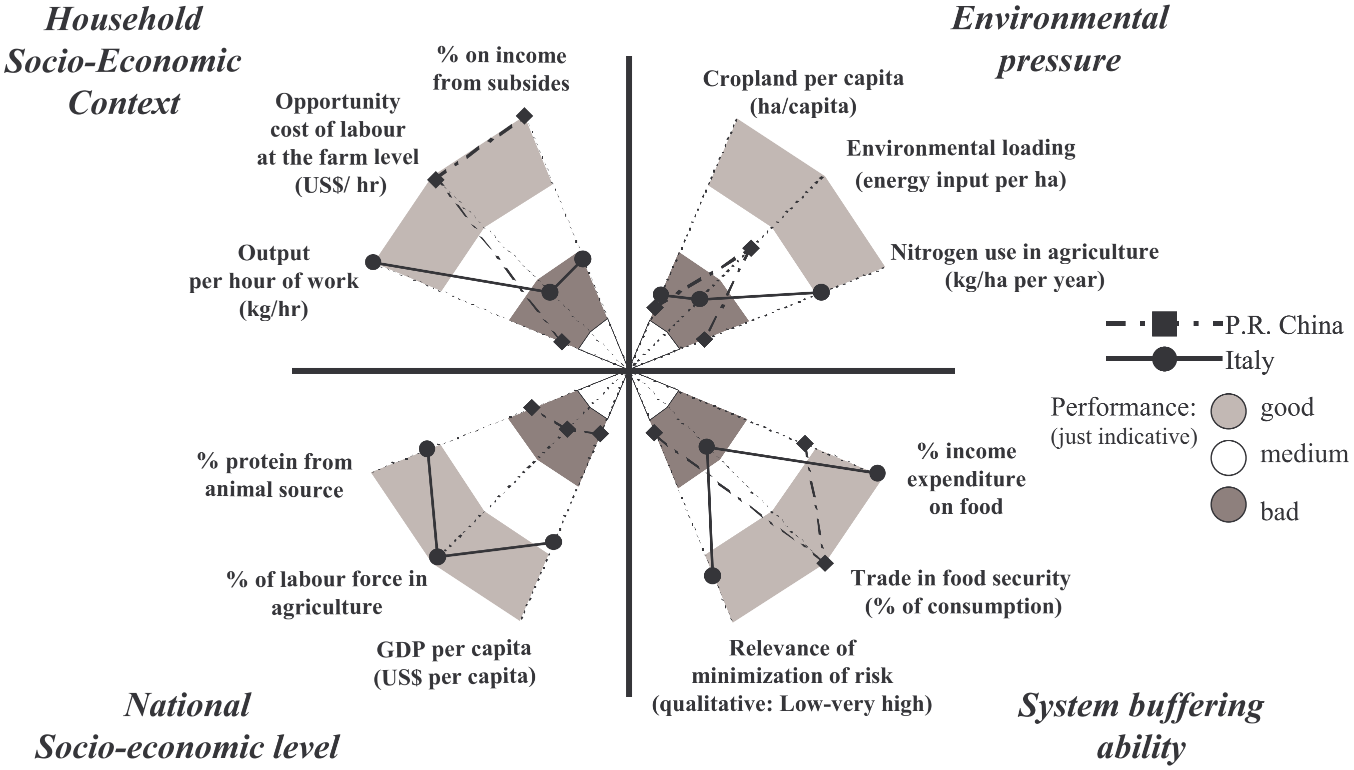

Figure 5.8 ***Radar representation focusing on distinct sectors***

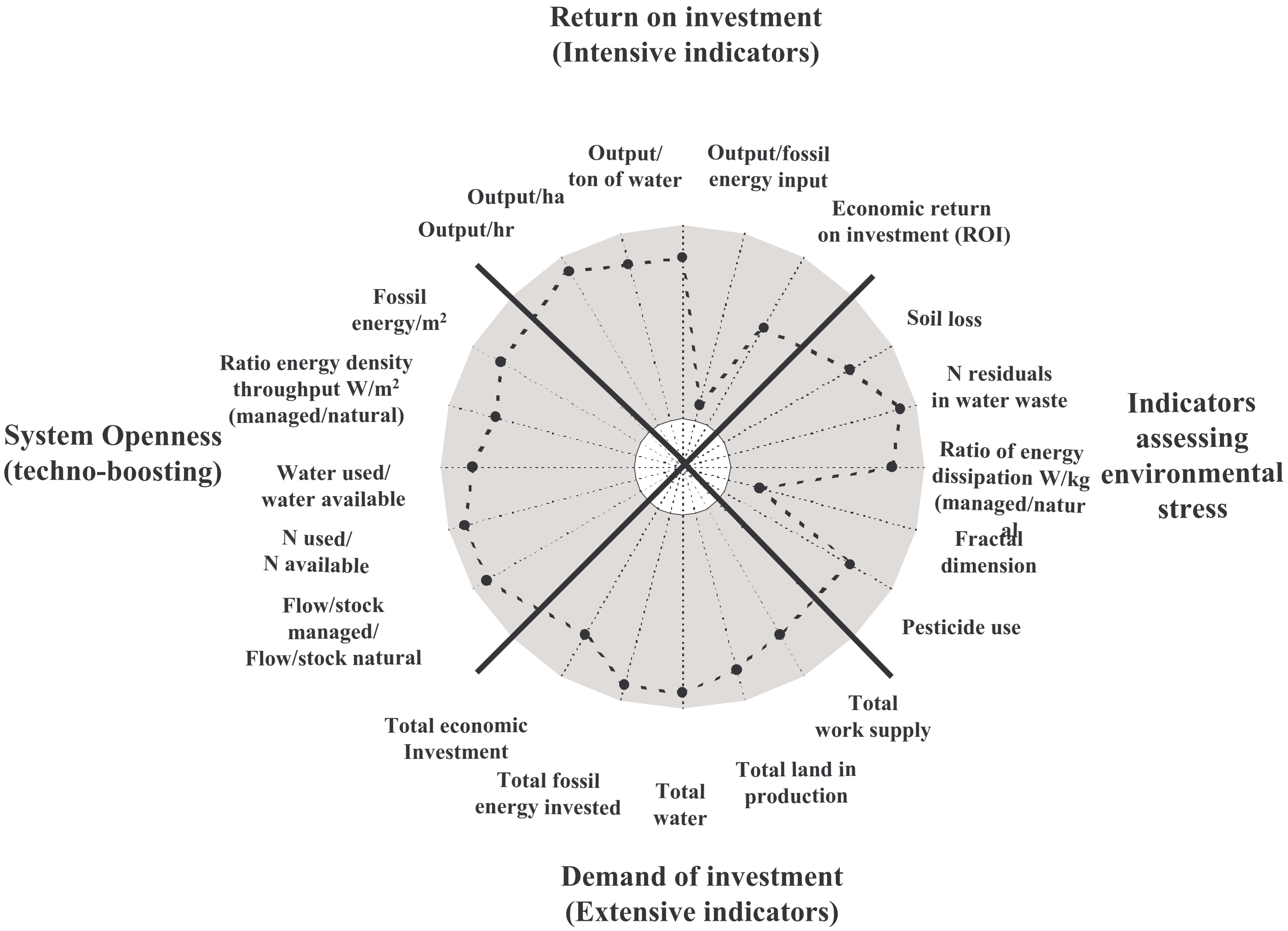

Figure 5.9 *Simple radar diagram* ***(St.Andrew's cross)***

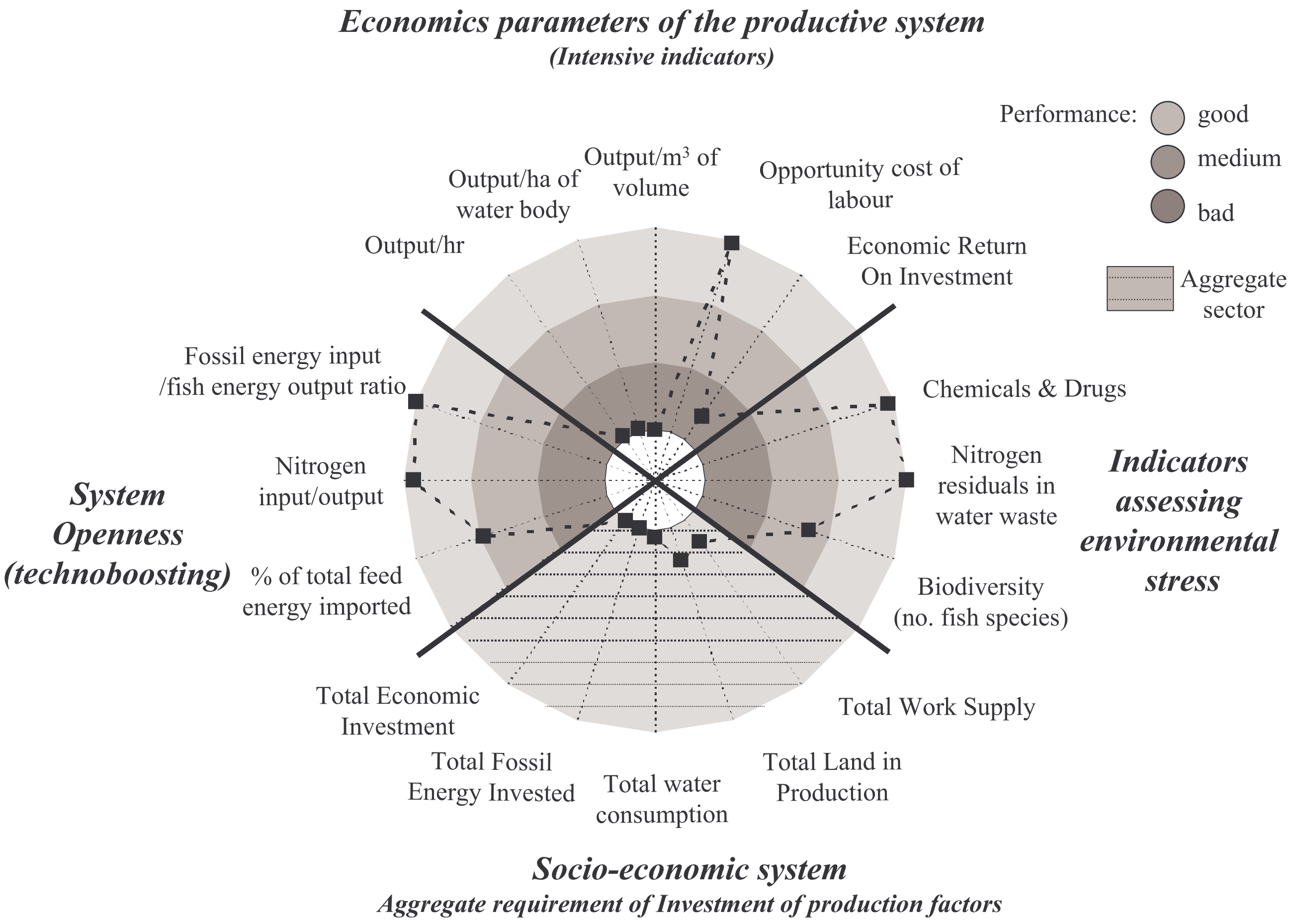

Figure 5.10 *Radar diagram with benchmarks (St. Andres's cross)*

perception of small gradients in data. In fact, when the grid of percentiles becomes too crowded in radar graphs there is the risk of creating too much visual "noise" in the representation of data.

* **Examples of bar diagrams** are given in **Figure 5.11; Figure 5.12; Figure 5.13**.

Figure 5.11 *(see p. 95a) Opposed bars diagram (iso-metric and etic representation statistical benchmarks)*

Figure 5.12 *(see p. 95b) Linear bars diagram (iso-metric and etic representation, statistical benchmarks - quintiles) (see next sections for details)*

Figure 5.13 *(see p. 95c) Linear bars diagram (iso-metric and etic representation, statistical benchmarks - quintiles) (see next sections for details)*

5.3.3 Benchmarking over the set of indicators (adding targets and quality zones)

Different typologies of qualitative benchmarking can be adopted according to the goal of the graphic representation. Some concepts related to benchmarking can be described as follows:

**** Feasibility domain***:

It is associated with the definition of *the range of values that might be taken (or achieved) somehow* by a given system, when characterizing its performance with the selected set of indicators. Feasibility however does not imply that the resulting system is viable. Some values can be feasible and achievable for a system, but only for a limited time. The term feasible does not include the dimension of long term sustainability – i.e. the respect of reciprocal constraints implied by the parallel consideration of different dimensions – which is implied by the term viable. A human being can remain without food for a day or two, during a war a society can accept censorship on newspapers and TV programs. However, values that can be accepted in the short run, when perceived as a momentary perturbation, could result in a collapse of the system if they would become perceived as average expected values. In the rest of this work feasibility domains are never used in graphical representations.

**** Viability domain:***

It is associated with the definition of *minimum and maximum values within which a given system performance can range when represented using the selected set of indicators*. This represents the range of admissible values taken by a given indicator in relation to the type considered in the analysis. The definition of what is a viable performance space is quite a complex issue as it depends on the agreed perception and representation of the

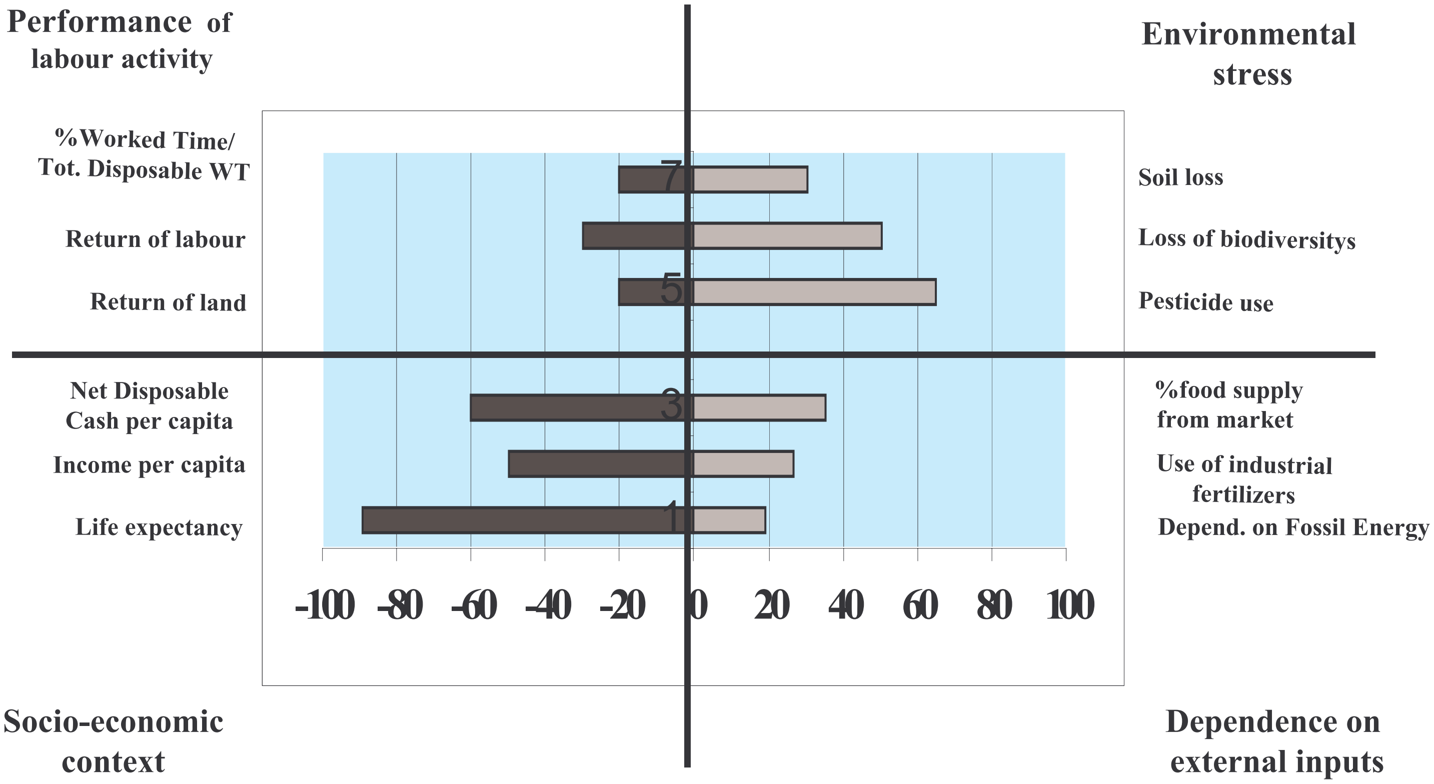

Figure 5.11 *Opposed bars diagram (iso-metric and etic representation statistical benchmarks)*

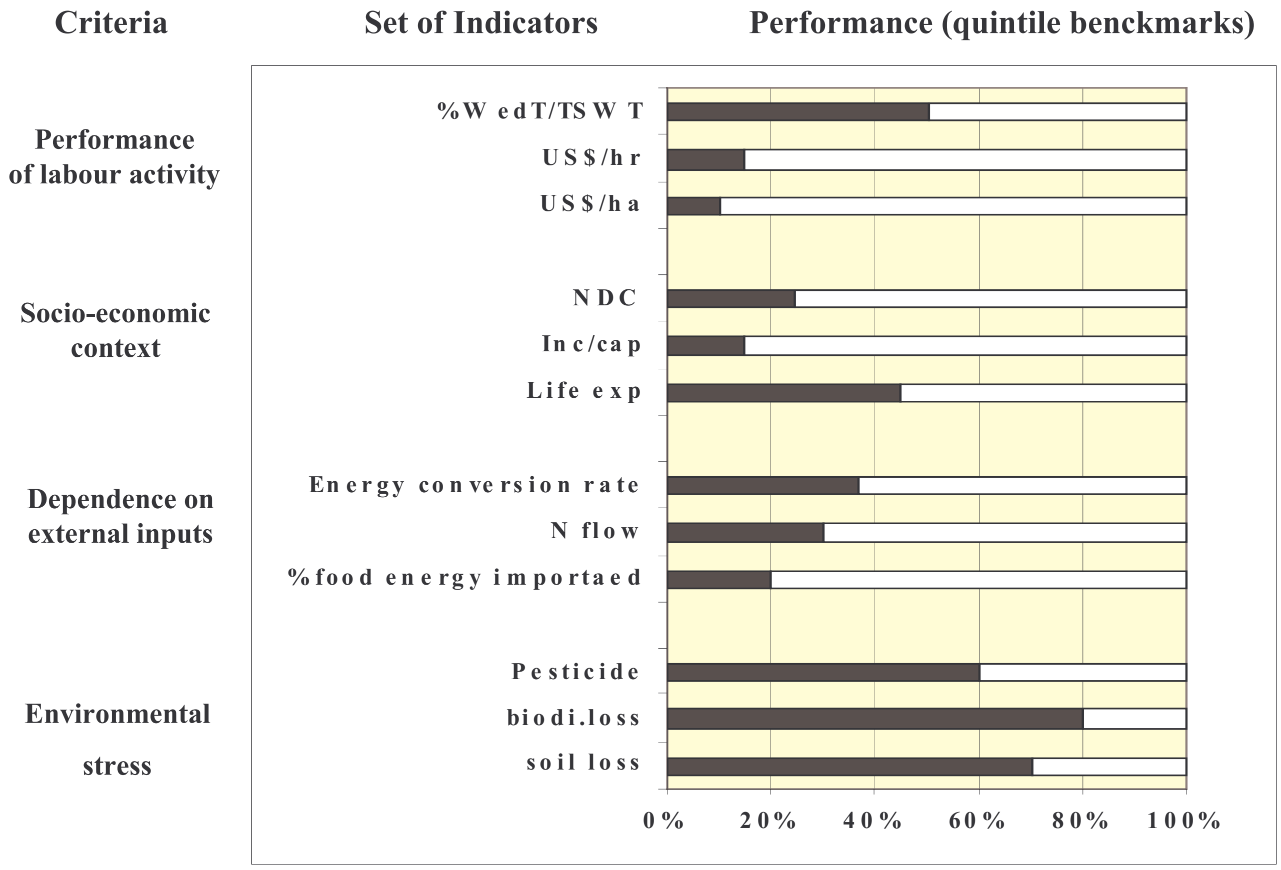

Figure 5.12 *Linear bars diagram (iso-metric and etic representation, statistical benchmarks - quintiles) (see next sections for details)*

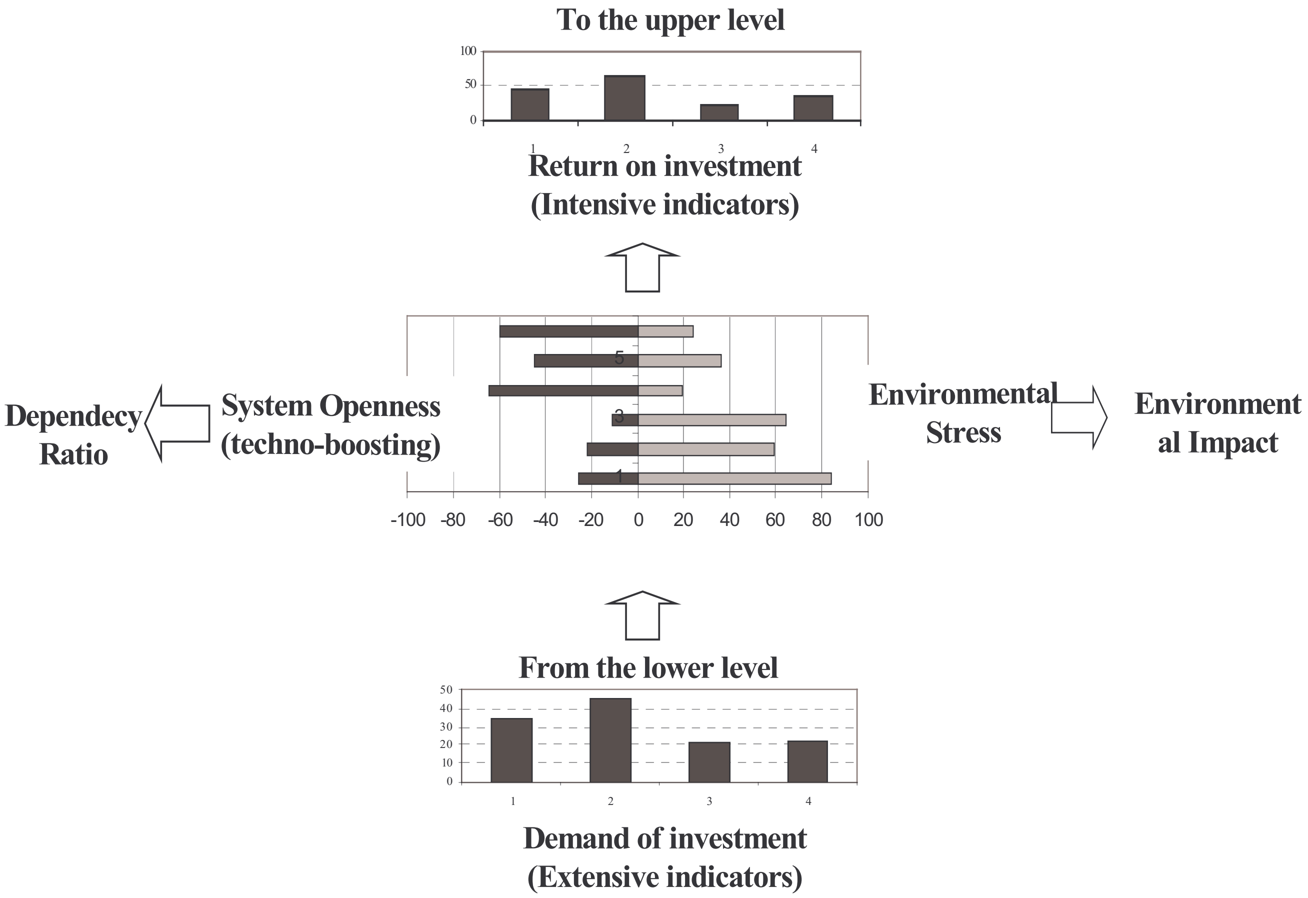

Figure 5.13 *Linear bars diagram (iso-metric and etic representation, statistical benchmarks - quintiles) (see next sections for details)*

performance of a given system. As noted earlier, one can accept very harsh conditions in temporary situation. Put it in another way, the validity of any representation of a feasibility or viability domain on a graph depends on a previous sharing of the perception and representation of the problem structuring with the stakeholders. Since we are dealing in this chapter only with technical aspects of graphic representation, we assume here that such information is available in the form of an input to the analyst from a participatory process. A legitimized definition of the range of values that defines what is viable in the given situation and in relation to the selected set of indicators is supposed to be available.

** Target values*

It is related to the *value that an indicator is expected to take as result of the implementation of a selected policy*. This expectation can be related to: (a) previous knowledge of the existence of a natural identity for the type that has to be preserved (e.g. the temperature of human body is expected to be around 37 degrees Celsius); (b) aspirations found among the stakeholders about future changes to present situation (e.g. the wish that the personal income of last quartile of income classes be no less than half of the personal income of the second quartile of income class); (c) policy targets proposed by decision makers (or other actors).

** Performance benchmarks*

They are related to *the interpretation of the position of values within the range of viability over the selected set of indicators*. Some simple and possibly useful representations of this sort are the median or quintile (or tercile) marks (e.g. **Figures 5.4; 5.5; 5.10**) dividing the axes in segment of equal lengths. In such a representation there are no "value judgments" expressed (about what threshold values should be considered as good or bad), but just contextualization of data. In this way, the reader can only know in which segment, among those we decided to divide the domain, the value of the selected indicator belongs.

** Quality zones*

In this way it is possible to add to the graphical representation a qualitative assessment referring to a given method for evaluating the performances. Specific ranges of values - or ring belt – can be defined as being representative of "good", "medium", or "bad" system performance (e.g. **Figures 5.5, 5.8; 5.10**). The flag model described in Section 4.3.10 is an example of these methods.

Again this sort of "quality assessments" can be made starting from very different perspectives. A return of labor of 1 US$ per hour can be considered a great achievement in China, but would be considered unthinkable in a developed country. In this example, it is important to be aware that the adoption of a benchmark from a scientist operating in developed world (using the maximum and minimum economic return of labor in farming activities found in the world) may result in a domain so large to would hide differences between different types of labor return found in a farming system operating in China.

In any diagram it should be possible to tailor the range of qualitative assessment on the particular requirements and goal of the analysis. Examples different tailoring of the same representations are given in **Figures 5.4; 5.8; 5.10** and in **Figure. 5.6**.

5.3.4 Defining a common representation of gradients of performance on the graph

Once defined the viability domain (and other benchmark points) for each indicator included in the graph, it has to be established a common direction for representing gradients of performance. It is to say, on the various axes coming out from the origin, used to represent the selected set of integrated indicators, one has to define a common direction which has to be regarded as an improvement, when representing changes, in relation to each of the objectives.

5.3.5 Pattern representation in a multicriteria space

MOIR can be an useful tool to: (1) force the analysts, as well as the stakeholders, to think in a systemic way, that is to say, to see an overview of the various aspects of a system considering simultaneously its multiple relevant dimensions, and (2) to recognize the existence of patterns of functional relations in the system under analysis.

Of course, whenever the set of indicators is changed the resulting observed pattern will be modified. The same result will be obtained by shifting the focus of the analysis on events occurring at a given scale instead of another. Anyway, it is important to observe that when dealing with farming system analysis there is series of interlocking constraints determining the identity of a given farming systems. That is, the typologies of elements operating at the lower level (e.g. types of households), the typologies of elements operating at the higher hierarchical levels (e.g. type of economy) and the typologies of elements operating at the focal level (e.g. type of village) cannot be totally independent from each other. This implies that experienced analysts can recognize patterns of expected relations taken by the values of a set of indicators defined over different levels and dimensions.

To discuss this topic (the possibility of detect systemic patterns of different typologies of observed systems over a MOIR), let's give an example of this phenomenon using a MOIR of the performance of a system totally unrelated to faming system. Let's now consider different patterns over MOIR of cars. In order to do that, we have to choose a set of indicators useful to characterize the performance of a car. A standard choice could be based on 4 criteria: (1) power, (2) consumption, (3) safety/reliability, and (4) cost. The resulting MOIR (assuming that the various steps describing the process were properly followed) is given **Figure 5.14**. This example provides a comparison of two models of car that looking at the differences determined by the dashed line connecting all the numerical values taken by the indicators can be recognized as belonging to two very different typologies: (A) "Luxury sport" vs. (B) "Economy class".

Figure 5.14 *(see p. 97a) Comparison of two patterns of performance (using 4 indicators) for two car types: "Luxury sport" vs. "Economy class"*

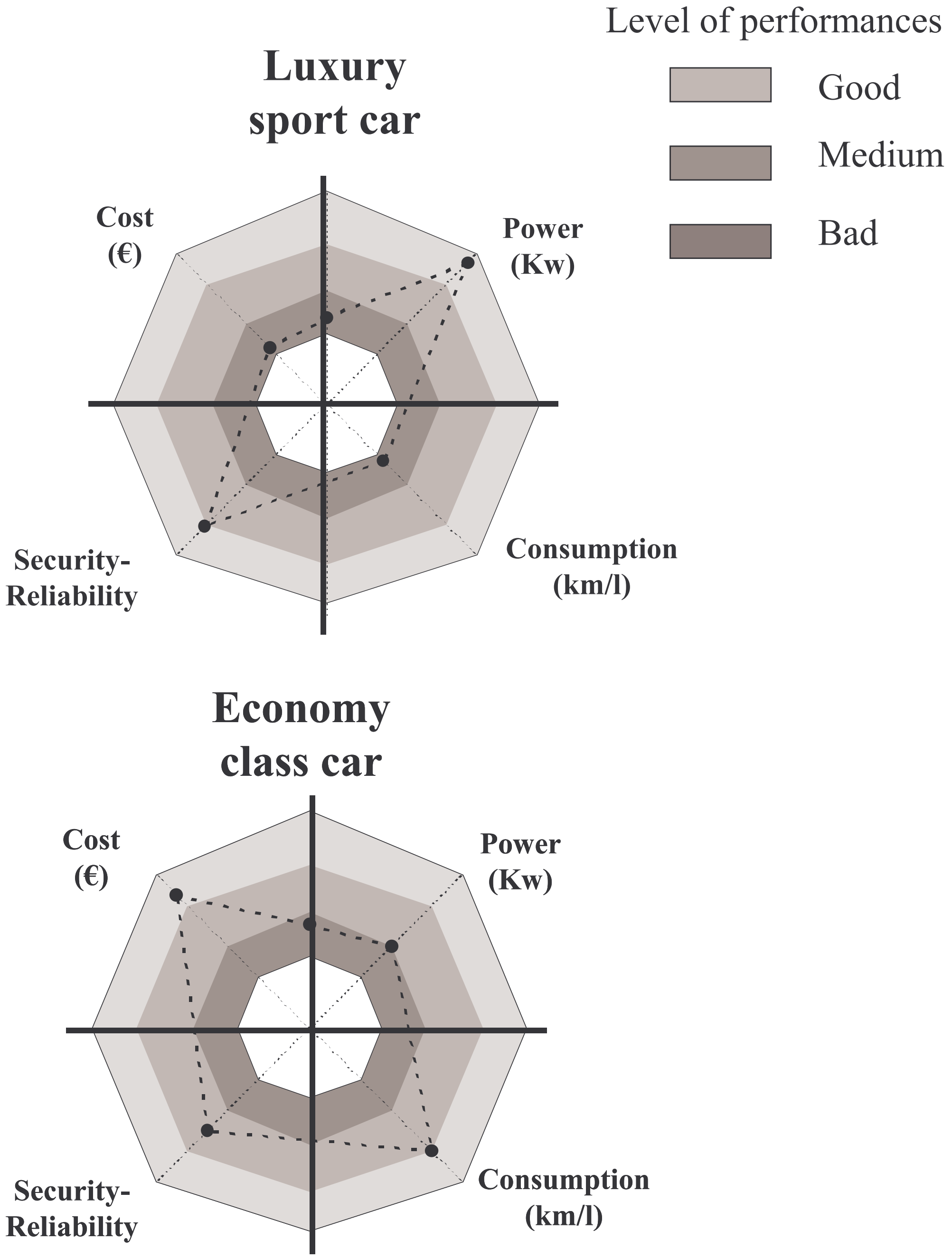

Figure 5.14 *Comparison of two patterns of performance (using 4 indicators) for two car types: "Luxury sport" vs. "Economy class"*

It is pretty clear, from **Figure 5.14**, that the values taken by the various indicators generate two clearly distinct patterns in the radar diagram. The points represented by the values taken by the indicators, when connected, generate two totally different shapes. These different shapes will remain different also if the method of normalization of the various indicators on the graph would be changed. Actually, even the set of indicators for characterizing these two models of cars would be changed, we can expect that it is very likely that the new MOIR will still point at the fact that we are dealing with two different typologies of cars. Several examples of this fact will be provided, using MOIR based on real data, when comparing in this way Freshwater aquaculture in China and Italy (Chapter 6).

In this regard it is important to point out that the internal area limited by the dashed line used to link the values taken on the different axes on the radar by the various indicators, has not any mathematical, statistic, or technical meaning. The only meaning of the dasced line is that of attracting the attention of the reader on the existence of a multidimensional pattern which can be associated to a given typology of performance. However, this pattern makes sense only when comparing typologies of performance, expressed within the same performance space.

5.3.6 Representing available data on axes

The act of normalizing the value taken by numerical indicators on axes requires special attention (Funtowicz and Ravetz, 1990; Prescott-Allen, 1996; Garcia and Staples, 2000). In fact, it requires the previous setting of the minimum and maximum point of the viability segments of the axes and the minimum grain determining differences on the axes. In technical jargon this has to do with selecting the scale and the modality of representation. This is a very delicate issue especially when these choices are made within such a structured graphical context. The definition of the distances of individual values from the minimum and maximum value on the axis, and their relation to targets and other benchmark values can have important implications on the meaning given by such a representation.

Garcia, (1997); FAO (1999); Garcia and Staple, (2000) for their Kite Diagram distinguish between two methods of manipulation of data in the representation:

Isometric: When the axes of the graphical representation are identical both quantitatively (e.g. both are from 0 to 1) and qualitatively (e.g. on both scales the values judgments correspond to the same range) such representation could be called "isometric"

Anisometric: "When different scales and particularly different values judgments are used in the representation, we can say that such a representation is "anisometric".

These two definitions address both quantitative and qualitative aspects of the graph: how numerical values are normalized along the axes, and how they are qualitatively evaluated by an observer. This is extremely relevant when we want to adopt quality zone across different indicators in the radar diagram. For the sake of clarity, the two aspects should be maintained separated.

In fact, the terms isometric and anisometric refer to the "metric" of the scale of representation. In these terms, therefore, there is no indication about qualitative values attached to the corresponding graphical representation. In the case of anisometric representation as defined by Garcia and Staples (2000), we cannot generate the effect of an "overall pattern" as done in **Figure 5.14** when comparing the two models of cars. In fact, if different normalizations are adopted over the various axes of the graph, we can no longer draw profiles using dashed lines by joining values-points laying on the different axes. There is no meaning in doing so. It should be recalled here that the various indicators are in fact incommensurable in their nature, as they represent different properties of the system (e.g. food intake per day, income per capita, pesticides use, soil loss, working time on total time available).

With the isometric representation we can at least compare the degree of lack of balance in the satisfaction of different objectives. However, there is no reason why the various objectives should be given equal priority. On the other hand, a particularly uneven distribution of the level of performance over different relevant criteria could be interpreted as a signal of a particular stress of extreme specialization or the facing of a critical situation. That is, the acceptance of a particularly bad situation in relation to an individual criterion (or a few criteria) can be interpreted as a forced choice for the system (or a weak power relation within the socio-economic systems for those actors giving a higher priority to that criterion.

There are also formalised multicriteria methods dealing with such an issue. For instance NAIADE (Novel Approach to Imprecise Assessment and Decision Environments), a multicriteria software developed by Munda (1995; 2004), based on the fuzzy set theory which deals with incommensurability of values and conflict analysis, supplying also a graphical representation of the latter (according to the data inputs from institutional analysis and stakeholder interviews the software produces a graphic representation of the distance among different stakeholders, the distance then indicate the possibility to generate coalitions and agreemets). Other famous qualitative multicriteria methods are REGIME and ELECTRE (for a review of methodologies see Bana e Costa, 1990; Munda *et al*., 1994; Beinat and Nijkamp, 1998; Janssen and Munda, 1999; Janssen, 2001; NERA, 2002).

Anisometric representation instead, does not offer coherence of scale over the set of indicators and therefore does not allow the linking of the values taken by different indicators on different axes to generate some overall pattern of performance. In this case, we can use a representation as in **Figure 5.8**, with the values taken by the indicators on the various axes kept disconnected. Such a graph, however, may result a bit hard for the reader.

5.3.7 Problems with the normalization of data on axes

The process of normalization of the values taken by the various indicators on the various axes, which is required to make indicators qualitatively comparable, presents some difficulties, which can become, at times, quite serious:

- *the functions to be normalized are often non-linear*
- *the indicators selected in an integrated set are often correlated (so that the presence of non-linearity tend to spread across axes)*
- *the arbitrary choice of different benchmarks can generate different perceptions for identical numerical values*

These are deep theoretical problems that cannot be dealt with in terms of a standard protocol to be adopted for the MOIR. Dealing with these issues has to do with the unavoidable predicament of handling uncertainty and ignorance in any scientific analysis of sustainability.

As discussed in Part 1, it is unavoidable to face a series of epistemological predicaments in any analysis of sustainability. This in turn requires the ability of performing a series of semantic quality checks in the process associated to a multicriteria evaluation. Because of this reason, one should not be too much concerned with the fact that it is impossible to find a standard protocol that guarantees that a given MOIR is done in "the right way". No matter how many rules and algorithms we will add to such a protocol, we will never be able to avoid the necessity of deciding together with the relevant social actors how to deal with arbitrary choices, using value calls. This implies that, the particular MOIR that is considered to be more effective in relation to a particular problem and system to be analyzed has to be decided each time in each different case together with the stakeholders and cannot be decided once and for all in theoretical terms.

5.3.8 Problems with the definition of quality zones (application of the Flag Model)

In more general terms we can say that each time we develop a MOIR of the performance of a given farming system using different indicators in relation to different quality zones we cannot escape the dilemma, well known in anthropology, related to the metaphorical distinction associated to the two terms *etic* and *emic*. Such a distinction was developed in linguistics by Pike in early 1940s and then introduced in anthropology by himself in 1954 with the book "*Language in relation to a unified theory of the structure of human behavior"* (Harris, 1968). In anthropological science the linguistic metaphorical terms *emic* and *etic* are used to indicate two different approaches to the study of human behaviour (Harris, 1968; 1987; Headland *et al*., 1990; Pike, 2003).

* The *emic description* reflects how the reality is perceived and represented from the perspective of the actor living **within** the given cultural system, it is to say **what facts, words, sounds mean to the members of a society**. It reflects the classification system or cognitive structure of living people. This has to do with a **subjective** perception of a fact.

* The *etic description* reflects a set of observable events about which **there is an agreement of objective classification** (for instance by using an agreed upon measurement scheme). It is to say **what facts, words and sounds mean in relation to a "formalized" scientific perspective**. It reflects the classification system and the analytical goals of the scientists. This has to do with a **formalized** perception of a fact.

We can now try to use this scheme to discuss the basic problem faced when trying to apply quality zones (e.g. the Flag Model discussed in section 4.3.10) to the axes representing indicators within the viability domain. In this case we can adopt a formalized representation:

(i) An "etic" representation - a view from outside (e.g. **Figure 5.8** and **Figure 5.10**)

The axes (representing the viability domain of the indicators) are divided, in this case, in three "quality zones" representing the statistical terciles (or quintiles or other divisions), in relation to a previously defined reference viability domain. This means that on the basis of the opinion of experts [= previously validated knowledge of the system] we assign to the various areas of the graph a qualitative connotation. For example: (1) An inner dark-gray zone within which system performance (in relation to the considered indicator) is considered as "bad"; (2) a light-gray median zone within which the system performance (in relation to the considered indicator) is considered as "medium", and (3) a very light gray external zone within which system performance (in relation to the considered indicator) is considered as "good". We are adopting a selection of zone compatible with the Flag Model [when adopting color dark-gray = red; light-gray = yellow; and very light-gray = green].

It is obvious that by adopting such a representation the various decisions about how to build the graph and enter the data used to characterize the overall performance of the system will be very value loaded and important in determining an information, which will result very relevant for normative purposes.

An important problem with this way of representing quality zones is related to the fact, discussed in the previous section, that the analytical functions to which the value taken by the indicator refers to are often (if not always) non linear. Non linearity implies that qualitative assessments of the effects associated to a given change in value cannot be expected to be linearly related to changes in numerical values taken by the indicator. We can have cases where more than 50% of the segment within the viability domain should considered bad whereas only 10 % can be considered acceptable in terms of performance. The example of food intake can represent a good example of this problem. When considering a possible viability domain for food intake (average per person over population) we can expect an overall range included between 1,500-3,000 kcal per day per capita (approximately). That is a range of variability of about 1500 kcal per day per capita. Such a viability domain however, refers to different roles of food (meanings in the definition of what is food). On the lower side of the range, the food has the only meaning to allow the surviving without considering the overall quality of life. On the other side, the process guaranteeing an adequate intake of nutrients is aimed at guaranteeing optimal expression of physiological potentialities of consumers. In this example we have a case in which a small increase in food intake (e.g. 300 kcal/day) on the lower side of the range – summed to the value of 1,800 kcal/day - can bring large benefits for an undernourished population. Whereas the same changes in the amount of caloric intake (e.g. 300 kcal/day) for an already well nourished population – summed to the value of 3,000 kcal/day - can result totally negligible (if not harmful!). These issues are well discussed in formalised multicriteria methods (e.f. the concepts of "fuzziness" and "distance" (Keeney and Raiffa, 1976; Bana e Costa, 1990; Munda *et al.*, 1994; Beinat and Nijkamp, 1998; Janssen and Munda, 1999; Janssen, 2001; NERA, 2002; Munda, 2004).

(ii) An "emic" representation – a view from the inside (e.g. **Figure 5.6**)

In this case the qualitative assessment (the determination of quality zones) is based on the relative perception of what should be considered as "good" or "bad" as expressed by the actors themselves. The representation given in **Figure 5.6** is a visualization of a qualitative assessment of the effects of movements of the value taken by the various indicators within the viability domain as perceived by the stakeholders themselves. Therefore, this can be interpreted as a personalized version of the graphical representation given in **Figure 5.8**. Obviously, we can imagine multiple "emic" representations of the same situation depending on the particular selection of stakeholders considered each time. Whenever, multiple "emic" representations are found, it is virtually impossible to collapse them into a single representation without entering in a process of discussion and negotiation. Such a process is in fact needed to combine the various "emic" representations (subjective views) into a single "etic" representation (a formalized view agreed upon by the various actors). At this point, however, whatever agreed upon representation ("etic") will reflect not only the original set of "emic" perspectives, but also the effects associated with the process of negotiation and compression. That is, the formal representation of a problem perceived in different ways by different social actors will reflect not only a set of experienced facts, but also the existing power relation among these interacting actors.

Coming to the possible options for a MOIR, **Figure 5.6** can also be restructured to make it to look like **Figure 5.5** or **Figure 5.10** by deciding to assign equal room to each qualitative zone. This is made by: (i) dividing the axes in a number of equal segments, and (ii) rescaling the qualitative assessment within the new segment, as proposed for instance by Prescott-Allen (1996). In this case however we are affecting (changing) the scales of the indicators and moving from the iso-metric to an aniso-metric representation.

5.4 How to do a MOIR of the performance of a farming system

In this section I describe step by step the making of a MOIR applicable to farming system analysis. The procedure indicated below refers to the making of a MOIR of the type indicated in **Figure 5.8**.

5.4.1 Choice of the graphical representation

For reason of clarity, it is better not to start with the representation of the indicators from the centre of the radar. Therefore, a part of the internal area of the radar, that may account for let say 25% of the total length of the radius, is excluded from data representation. This means that a new "points zero" circumference is created. We can call this the internal reference circumference (IRC). The representation of the system performance profile will concern than, just a radial belt limited on the IRC and external reference circumference (ERC), which is traced on the external part of the radius.

5.4.2 Dividing the radar area into sectors: selection of relevant criteria

The radar diagram is divided in a number of sectors-quadrants (four in this example), according to the number of selected criteria useful for the representation of the system under study. Each criterion describes a distinct perspective of the system. Each sector then has to include a number of axes, according to the number of indicators selected for each given criterion (three in each sector for the figures considered in this example). Each axis is therefore used to represent the values referring to a single specific indicator.

5.4.3 Representing the values taken by the indicators on axes

This example is based on a iso-metric representation. This is to say, the same normalization procedure is adopted for all axes. This allows for drawing dashed segments linking the various values on the different axes.

Data transferring from an impact matrix to the graph is not a trivial process. Data in the impact matrix, which reflect the values taken by the relative sets of indicators, can be “transported” in the axes of the radar diagram using the following steps:

a. Normalization

Let’s assume that the extreme of the possible range of values taken by an indicator (max and min) are x_{max} and x_{min}. Any value included in this range can be expressed as a fraction of this overall difference $[\boldsymbol{x} - x_{min}] / [x_{max} - x_{min}]$. Getting at the radius of the graph on which we want to represent the viability domain, we can express is total length in terms of arbitrary graphical units ***n***. This implies that the length of the graphical representation of the viability domain will result $\boldsymbol{N} = \boldsymbol{k}\ \boldsymbol{n}$ – where k is the number of times sub-segments of length n (those adopted as graphical unit) are represented in that segment. Assuming as N_0 the extreme of the segment on the side of the center of the radius, the position of the representation of a value ***x*** will be determined by the following relation:

$N_{data} = N_0 + \{[(\boldsymbol{x} - x_{min}) / (x_{max} - x_{min})] * (\boldsymbol{k}\ \boldsymbol{n})\}$

For an overview of methods for normalizing the values on the axes, see Torgerson (1958).

b. Defining proper gradients of performance along the axes

Once the viability domain for an indicator has been established on each axis, we have to define a direction towards which the increasing or decreasing values taken by the indicator are perceived as an improvement or worsening. Depending on the direction of the gradients of performance decided for the indicator in relation to the objective, it is necessary to decide whether using $(x_{max} - \boldsymbol{x})$ or $(\boldsymbol{x} - x_{min})$ to determine the position of the value ***x*** within the viability domain. As indicated in the examples given in **Figure 5.8** and **Figure 5.10** the use of quality zones, characterized by different colors (the reader can recall the Flag Model presented in section 4.3.10) can make such a direction quite clear to the observer.

c. Setting internal benchmark points and qualitative zones

At this point, it is possible to add to the radar graph both benchmark points and qualitative zones to include further information.

Statistical benchmarks (e.g. **Figure 5.4** quintiles rings) may be useful to put the values taken by a given indicator in context. These benchmarks, in fact, refer to the characteristics of the class – typology - to which the represented system is supposed to belong.

Qualitative zones (e.g. **Figure 5.6, Figure 5.8** and **Figure 5.10**). In these examples three qualitative zones are used. Obviously, a different number of qualitative zones could be employed according to the needs.

5.4.4 Practical aspects of MOIR representations

All the graphical representations presented in this chapter have been made by using excel and power point software. In this section, I present technical details related to how to make graphical integrated representation. The example is about a multi-criteria representation of aquaculture.

The original impact matrix with data is represented in a radar diagram of the type illustrated in **Figure 5.8** and **Figure 5.10**. These diagrams are realized with the software "Power Point". In this example the axes of the diagram (originating in the center) are divided in 150 units. Out of these 150 graphical units, the internal 30 units are not used for the sake of visual clarity (this is what generate the inner circle of the graph with no values for the indicators). Therefore, point 30 of the axis (starting the counting from the center) becomes point 0 of the viability domain, which uses only 120 units of the axes (within the range 30-150).

Data from tables, are then organized (normalized) for the making of the graph according to the procedure presented earlier. Then they are transferred into an excel spread-sheet.

At this point, it is possible to import the spread-sheet of excel into the software power point to generated a graphical representation in the form of a radar diagram.

In this way, different discussions or hypotheses or alternative models can be used to generate different inputs of data. Changing data set will generate relative changes in the spread-sheet, which will then be reflected into a different configuration of the graphical representation given in the radar diagrams.

5.5 Final remarks

Differently from standard formalised multi-criteria analysis, MOIR approach does not use indicators to develop a matrix analysis, rather it compares the indicator sets by a spider web diagram. In this way, it aims at focusing on an across scales reading and to establishing links among processes occurring on various contexts and levels.

Differently from formalised multi-criteria analysis (e.g. ELECTRE, REGIME, NAIADE), MOIR is intended to help the discussion over relevant criteria, validity of the models used in the analysis, and the characterization of scenarios in terms of relevant pros and cons.

For formal multi-criteria analysis instead, the main aim is to elicit clear subjective preferences from a decision-maker and then try to solve a well-structured mathematical decision problem thanks to a more or less sophisticated algorithm. In this way a multi-criterion problem can be still presented in the form of a classical optimisation problem (Keeney and Raiffa, 1976; NERA, 2002; Munda, 2004). It has to be pointed out, however, that some authors (e.g. Roy in Munda 2004), argue that it is impossible it is impossible to say that a decision is a good one or a bad one by referring only to a mathematical model. Roy states that the principal aim of multicriteria analysis is not to discover a solution, but to construct or create something which is viewed as liable to help "*...an actor taking part in a decision process either to shape, and/or to argue, and/or to transform his preferences, or to make a decision in conformity with his goals*" (a sort of constructive or creative approach) (Roy, 1990, quoted in Munda, 2004).

A key feature of multi-criteria analysis is its emphasis on the judgment of the decision making team, in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion.

A standard feature of multi-criteria analysis is a *performance matrix*, or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The individual performance assessments are often numerical, but may also be expressed as "bullet point" scores, or colour coding (Keeney and Raiffa, 1976; Bana e Costa, 1990; Munda *et al*., 1994; Beinat and Nijkamp, 1998; NERA, 2002).

Data sets for MOIR can also be used as a performance matrix in formal multicriterial analysis but the point of MOIR is not that to find the best options among some possible, rather that to represent-understand the system performances across scales, that is to say within its supra and sub-systems/contexts. In this sense MOIR and formal multicriteria analysis have different goals.

The building of a sound MOIR makes easier discuss of incommensurable sustainability trade-offs associated to different scenarios, that is to say to evaluate alternative policy options according to a given set of relevant criteria in a process of decision making (Giampietro and Pastore, 1999; 2001; Giampietro and Mayumi, 2000a; 2000b; Giampietro, 2004). However, this implies the necessary involvement of the stakeholders in such a process. In fact, they are needed to: (1) discuss the quality of the problem structuring (that is to say the selection of a set of relevant criteria able to reflect the existence of legitimate and contrasting objectives among the stakeholders); (2) reach an agreement on the choice of a set of explanatory models adopted in the analysis (that is to say the check on the validity and cost-effectiveness of the set of models proposed against the specific reality of the given context); (3) reach an agreement on the policy to be implemented (that is to say the evaluation of trade-offs implied by the various options and the uncertainty associated to given scenarios, reflecting different perceptions found among the stakeholders).

This means that the "quality" of MOIR has 2 dimensions:

(1) "*analytical dimension*", that depends on: (i) the capability of individuating an adequate set of relevant criteria (the indicators included in the multicriteria space), (ii) the possibility of measuring or assessing the selected indices of performance, and (iii) an adequate understanding of the existing relations among them across scales with models (the ability of forecasting how changes in the value of an indicator will be reflected into changes in the value taken by other indicators).

(2) "*participatory dimension*" that depends on the ability to involve the stakeholders in the "quality check" of the analytical input in an effective, fair and transparent way.

A useful MOIR, therefore, should be based on a genuine iterative process between scientists and the rest of stakeholders aimed at generating an evolving discussion on how to better represent and structure the problem to be tackled.

This method of problem structuring also forces the analyst to put in perspective local characteristics with the larger socio-economic and ecological context. Socio-economic characteristics of household typologies can be compared with those of the village in which they live. In the same way villages can be compared to those of the province or the country. At higher level the characteristics of the country can be compared with macroeconomic regions and world averages. The characteristics of the specific agroecosystems under analysis can be related to the characteristics of the natural biomes in which agricultural production takes place. As the new hierarchical level represent a different and specific entity, at each new level new information are added and new properties emerge.