

**EV5V-CT92-0152**

**SUS.T.E.E.  
(SUSTAINABILITY THROUGH ECOLOGICAL  
ECONOMICS)**

**SUMMARY FINAL REPORT**

**MARCH 1995**

**Keywords:** Sustainable development; ecological economics; uncertainty.

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## I. OBJECTIVES

The objective of this research project was to identify the requirements for sustainable development taking into account uncertainty and irreversibility that characterise real phenomena in self-organising systems, such as economics and the biosphere and their interactions.

A critical analysis of the epistemological bases on which are founded both economics and the natural science was carried out in order to introduce new foundations, models and parameters capable of substituting the current traditional approaches (mechanistic, atomistic, static) with a dynamic, systemic and evolutionary perspective.

In particular the following objectives were pursued :

- 1) To analyse in terms of sustainability indices both the national and local scale;
- 2) To discuss the meaning of these indices for a sustainable public policy;
- 3) To compare the results of the analysis with the results obtained by the team on economics;
- 4) To suggest improvements for national and regional public policy based on new sustainability indices;
- 5) To complete a manual for understanding and use of energy analysis (that is, the analysis that covers both energy and matter)<sup>1</sup>.
- 6) To discuss in terms of uncertainty and quality of scientific information the application of the sustainability indices, with special reference to energy analysis.

All these objectives have been achieved, intensifying the collaborative effort with the team of economists, working on a parallel pathway within the project.

## II. METHODOLOGY

The background of the methodological approach was based on Prigogine's thermodynamics, namely dissipative structures, entropy and the role of irreversibility.

After an extensive survey of the main current approaches to the analysis of sustainability of development, the economic group selected the 'option approach to sustainability' as the most suitable to provide solid foundations to the theory of sustainable development taking into account the epistemological requirements discussed in the research: in particular the ubiquitous conditions of hard uncertainty, coupled with irreversibility, which haunt any plausible sustainability analysis.

This approach distinguishes long run sustainability and shorter run sustainability. Long run sustainability assures that the freedom of choice of future generations will not diminish through time as a consequence of irreversible damages to natural resources. The criterion of long run sustainability based on a measure of diversity of available options, is fully operational in principle since it avoids assumptions on the preferences of future generations, which would be liable to be considered implausible and paternalistic. This criterion of long run sustainability defines a crucial constraint for economic choices, even those characterised by a short run horizon and/or refer to local consequences. However since this criterion is a constraint consistent with a wide variety of choices, it is insufficient to guide decisions in the short run. In the second stage of the decision process it is necessary to resort to more orthodox methods of maximisation of the objective function, under the above mentioned constraint of long run sustainability, taking full account of the environmental values (not only use value, but also existence value and option value, fully internalising the related externalities). It should be emphasised that also the second stage of the decision process is affected by hard uncertainty and irreversibility. In these conditions a very important component of the value of environmental goods emerges as intertemporal option value, which is to be sharply distinguished from the plain option value of the traditional cost/benefit analysis: intertemporal option value depends on universal aversion to hard uncertainty and is independent of risk aversion and the degree of soft uncertainty. Intertemporal option values are strictly related to the option approach to sustainability. In fact the higher the option value associated with a certain choice the higher the value of the future liberty of choice. Therefore, under hard uncertainty and irreversibility, the freedom of choice becomes crucial for sustainability even in the shorter period, confirming the crucial importance of the option approach chosen in the research.

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<sup>1</sup> Emergy was defined by Odum as energy of one type required directly or indirectly to produce a product or service - expressed in Emjoules. To compare all inputs on a common basis we can express everything in solar transformity, the solar equivalent energy directly and indirectly required for a joule of product)

The methodology of emergy accounting, was adopted and compared with other, more traditional approaches in energy analysis. After data have been collected from different sources and made consistent, by means of their conversion into emergy units, emergy flows to and across the economic system have been investigated. On the basis of flow recognition, indices based on emergy have been calculated: their values in the Italian economy have been discussed, in order to extract information for policy making. Finally, some theoretical issues have been stressed, in order to contribute to the theory development: improvement of the methodology and introduction of new indices for the evaluation of economy-nature interaction have been achieved. Results have been sometimes compared with available studies in other countries.

Finally, the difference in the emergy accounting approach according to the scale and size of the system under research has been underlined and discussed.

### **III. MAIN RESULTS**

Mainstream economics assumes that historical time is substantially irrelevant from the descriptive point of view, and crucially relevant from the normative point of view. This attitude towards historical time derives from a very narrow concept of economic rationality which assumes that the environment is not affected by the decisions of economic agents and policy makers. This concept of 'substantive' rationality is an obstacle to the solution of the environmental problems of economic development.

Therefore, it is necessary to entrench the analysis of sustainable development on a different attitude towards historical time by assuming its ethical irrelevance and its crucial descriptive relevance. This will permit a thorough analysis of the prerequisites of sustainable development which fully takes into account the rights of future generations. The argument is reinforced and further developed by analysing the peculiar features of environmental uncertainty and its implications for social choice.

Furthermore, the epistemological basis of the research has been related to the new achievements of evolutive physics. Namely, on one hand the first law of thermodynamics is concerned with conservative quantities (energy and matter), whereas the second law of thermodynamics is concerned with non conservative quantities, e.g. entropy, which flows in networks associated with energy and matter and is always produced in every compartment of every ecological or economic system.

From a thermodynamic point of view ecosystems are far from equilibrium states or dissipative structures, according to Prigogine's definition.

Keeping in mind the conceptual difference between natural capital and man-made, namely, two complementary and non interchangeable quantities, it seems to the team that man-made capital can be considered in ecological modelling and calculations in terms of the First Law, whereas for natural capital, having evolutionary properties, the Second Law is required and entropy has to be taken into account.

This viewpoint helps the integration of different approaches that for many years have been proposed looking at only one side of a very complex problem: the one involving environmental protection and economic development, quality of life and jobs. What is needed is a set of integrated economic and environmental indicators, able (as a whole) to give a deeper insight to the problems of the various economic/environmental sectors and policy fields at various levels.

The methodology of emergy accounting seems to be closer to its possible use on a large national scale for policy planning. A set of reliable indices are available to investigate the performance of large economic systems as well as production sectors or even individual processes. Their use to assess efficiency and eco-compatibility has been widely investigated and the team believed that they could be usefully applied to compare different use of the available resources, to plan incentives, to apply taxation schemes, to choose between policy options. Of course, the research has been focused to selected systems, while a larger set of case studies would be needed: this larger investigation can be made, starting from the results of the present project.

A new index has been introduced, adding an entropy term to modelling based on Odum's emergy, whenever natural capital and its evolutionary properties are concerned: otherwise the irreversible and evolutionary character of natural capital is neglected. For example, all energy processes related to the greenhouse effect strongly influence the co-evolutionary behaviour of the atmosphere and of biomass production: in all these cases the entropy term may become dominant with respect to the energy-mass conservative terms.

The project introduced a new parameter very similar to the Gibbs' function in thermodynamics, partially modifying Odum's emergy.

This parameter the free emergy  $\Delta F_m$  can be defined as:

$$\Delta F_m = \Delta E_m - T \Delta S_m$$

where  $\Delta E_m$  is Odum's emergy and  $T \Delta S_m$  is the entropy term.

The main results obtained in the economic section are the following:

- identification of a two-stage option approach, in principle operational and applicable also at the local level, fully consistent with the epistemological and ethical requirements of sustainability analysis;
- definition of long run sustainability of economic development in terms of degree of diversity of the set of options available to future generations. This assures that the freedom of choice of future generations will not be jeopardised by economic development;
- clarification of a concept of intertemporal option value fully consistent with irreversibility and hard uncertainty. This value must play a crucial role in the short-medium run analysis of sustainability;
- integration of emergy analysis in the above framework as a fundamental link with the ultimate biophysical source of the economic options;
- first exploration of a scheme of ecological taxation based on indices suggested by emergy analysis.

#### **IV. SCIENTIFIC INTEREST AND POLICY RELEVANCE**

##### **i) Scientific interest and novelty**

The main implication of the epistemological approach is related to the use of Prigogine's thermodynamics in Ecological Economics. The main results are connected to the role of irreversibility and dissipative structures in modelling sustainable processes.

The emergy theory has been introduced very recently, and its development is still in progress. Its novelty and scientific interest basically are in its ability to evaluate all inputs of a system on a unified basis. It does not consider the economy as something apart from nature, but tries to unify nature and the economy within the same framework, where the same laws and behaviours apply. Therefore, it provides a tool to bridge humanity and nature and understand the existing interactions: this is the basis for a sustainable design of the economy within the equilibrium of the biosphere.

##### **ii) Policy relevance**

The main implications of the analysis developed in the economic section are the following:

- the arduous problems raised by the conditions of hard uncertainty and irreversibility which haunt the environmental problems raised by the economic development may be analysed through the "option approach" here suggested;
- the above approach clarifies that a serious analysis of hard uncertainty and irreversibility greatly reinforces the urgency for a conservationist environmental policy able to preserve and extend the liberty of choice into the future;
- environmental policy should be based on biophysics indices which go to the root of the process of generation and maintenance of economic options;
- from the above point of view, existing emergy indices appear superior to most alternative indices;
- emergetic indices could provide, e.g., solid foundations for a comprehensive scheme of green taxation able to improve the sustainability of economic development.

The set of indices provided by the emergy theory can be applied in policy making, by means of laws and regulation. The long run perspectives of emergy analysis can be of some interest for individuals, whose short-time perspectives may seem more consistent with maximisation of monetary values and fast exploitation of natural resources irrespective of their environmental quality. Emergy analysis results should be taken into account by public policy makers in programming sustainable pathways for their country as well as in careful managing with natural resources. Favourable emergy balance of trade and agro-industrial production, sustainable exploitation of indigenous storages of resources, foreign resources import, competitive resources investments on a local scale, efficiency in non renewable emergy use when environmental resources are exploited, attraction of foreign emergy (tourism, information, trained immigrants, etc.) are all long-term purposes which are the basis of any sustainable development and increase in wealth.