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Thermodynamic approach for territorial planning: different aspects of the sustainable use of resources and land. A case study from the SPIn-Eco project

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Abstract

Managing the resources, both natural and manufactured, is a key problem for every modern society. Any environmental program, both at a local and a global level, has to pay attention to the correct use of them in time. According to the statements of Herman Daly, there are some resources-use criteria to follow in order to reach a sustainable society which is founded on a sustainable economic basis as well.

The paper presents an environmental assessment of the use of resources at a local level by a thermodynamic based methodology: emergy evaluation, introduced by Howard Odum. The results of the analysis indicate some critical points and then different path of a feasible future development. The conclusions are then supported by greenhouse gas inventory and ecological footprint results.

SPIn-Eco project is an ambitious triennial research program with the purpose of assessing the environmental conditions of the Province of Siena (Tuscany, central Italy) and its 36 municipalities. This paper presents the analysis of one of them, Colle Val d'Elsa, which is located in the most industrialised and dynamic area of the whole Province of Siena. On the basis of the over mentioned considerations about the use of resources, the issues that mainly characterise Colle Val d'Elsa are agriculture, industry and urban planning.

The discussion section deals with the environmental, social and economic aspects of them under a sustainable perspective. It points out the necessity of emphasizing the qualitative aspects of resources use rather than the quantitative ones and, at the same time, the preference for development rather than growth.

1 Introduction

Territorial planning could be considered as the expression of human settlement in the space. Dealing with territorial planning on the basis of the theories of sustainable development could help us to identify also its temporal dimension. The evaluation of the correspondence of human behaviour to the rules of sustainability is a complex challenge which needs to pay attention to several aspects. For this reason we are going to take into consideration not only urban aspects of planning but also the management of the use of resources and the assessment of the environmental contribution to human activities. Hence, different methodologies are used to give the policy makers useful information for planning the activities in the long run.

SPIn-Eco project is an ambitious triennial research program whose purpose is to assess the sustainability of human activities in the Province of Siena (Italy) and in all its 36 municipalities by means of several analytical approaches. Any approach offers different information about sustainability both at local and global level.

One of the most dynamic subsystems (municipality) inside the Province of Siena is Colle Val d'Elsa, which is located in the northern part of the Province (Fig. 1). It is characterised by a population density (205.14 inhabitants/km^2) higher than the provincial average (66 inhabitants/km^2) due to the presence of industrial settlements (high quality production of crystal).

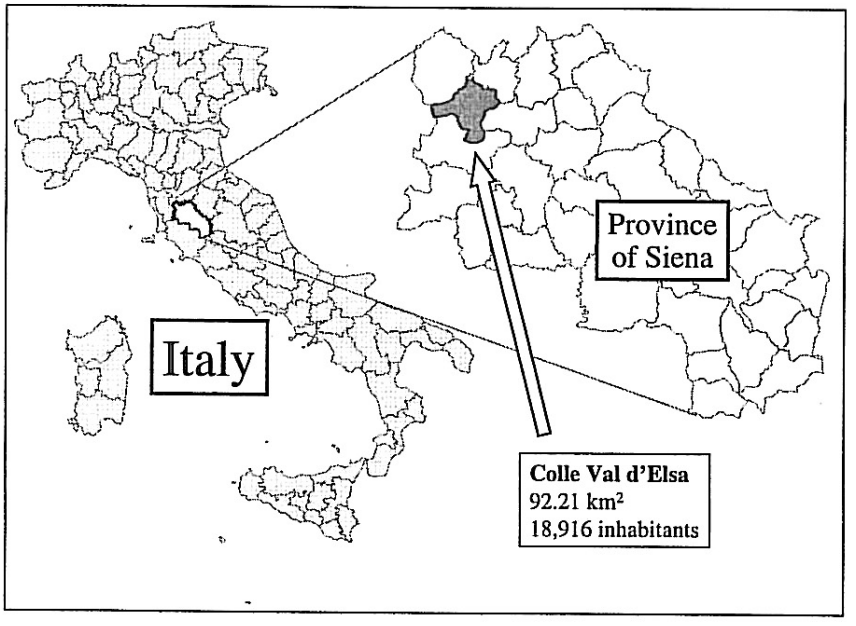

Figure 1: Colle Val d'Elsa in National and Provincial contexts.

It could cause higher environmental impacts, higher energy and matter consumption and higher levels of greenhouse gas emission than the provincial average. At the same time, agriculture does not play a fundamental role, even if there is a wide portion of land which should be used for cultivations.

All the over mentioned conditions make necessary an assessment of the sustainability of the system Colle Val d'Elsa to enable the design of future scenarios of development, paying attention to the environmental impacts as well as the correct use of resources.

2 Methods

Three methodologies are presented to evaluate different aspects of human activity impacts on the territorial sustainability. They are Emergy evaluation, Ecological Footprint analysis and Greenhouse gas inventory.

2.1 Emergy evaluation

To take into account all the resources (natural and manufactured) sustaining a system and to evaluate the environmental work to make them available, we adopt the concept of *Emergy* introduced by Howard Odum. He defined emergy as the quantity of solar energy necessary (directly or indirectly) to obtain a product or an energy flow in a given process. Emergy is the common basis on which a system of environmental accounting can be built. Hence emergy is the memory of all the solar energy consumed during the process. It is measured in Joules, but not indistinct Joules, solar emergy Joules, that Odum called *sej* [1]. To convert all the inputs in sej, the concept of *Transformity* is introduced. Solar Transformity is defined as the emergy required per unit of product or service [2] or as the solar energy directly or indirectly necessary to obtain one unit (Joule) of another type of energy. Once all the inputs are classified in renewable (R) and non-renewable (N) resources and local (L) (natural) and imported (F) inputs, some indicators of the environmental stress can be calculated. The *Environmental loading ratio* is the ratio of non-renewable (local and imported) emergy to renewable environmental emergy. The *Emergy per person* is the ratio of total emergy to the inhabitants of the system. The *Empower Density* is the ratio of total emergy to the area (expressed in m^2).

2.2 Ecological Footprint analysis

The Ecological Footprint (E.F.), introduced by W. Rees and M. Wackernagel in the 1990's, is defined as the total area of ecologically productive land (forests, arable land, pasture, built-up area, etc.) and water ecosystem required to produce the resources and services consumed by a given population as well as to assimilate wastes generated by that population [3]. The classic ecological footprint formulation considers the average consumption of the population and it is based on the hypothesis that every consumption of energy and matter derives, directly or indirectly, from a certain extension of land, hosting the ecosystems

that support the resource drawing and/or guarantee the absorption of the emission. The analysis also defines a bio-productive capacity of a certain region (local, national or global) and compares its E.F. with this capacity, to determine the so-called ecological deficit or surplus. The ecological deficit provides an evaluation of the local overload, revealing how much a region depends on extra-territorial productive capacity.

2.3 Greenhouse gas inventory

The anthropic emissions of greenhouse gases have global implications in terms of sustainability. According to the IPCC guidelines [4], energy, agriculture, land-use change and forestry and waste are monitored. The main result is the comparison between the emission of equivalent CO_2 and the absorption capacity of the ecosystems inside the territory. The inventory includes emissions of CO_2, CH_4, N_2O, NO_x, CO, NMVOC (non-methane volatile organic compounds), SO_2, HFC, PFC, SF_6 and the absorption of CO_2.

3 Results

3.1 Emergy evaluation

The collection of data shows which inputs support all the activities inside the municipality of Colle Val d'Elsa. The inputs (expressed in energy or mass) are converted in sej and then aggregated in renewable (R), non renewable (N) and imported (F) ones. Finally, some synthetic indicators are calculated (Table 1).

Table 1: Emergy flows and indices for the Municipality of Colle Val d'Elsa and the Province of Siena.

Flows and Indices	Unit	Municipality of Colle V.E.	Province of Siena
Emergy flows			
Local renewable (R)	sej/yr	$3.56 \cdot 10^{19}$	$8.30 \cdot 10^{20}$
Local non renewable (N)	sej/yr	$1.25 \cdot 10^{20}$	$5.98 \cdot 10^{21}$
Imported energy (F1)	sej/yr	$1.03 \cdot 10^{20}$	$1.69 \cdot 10^{21}$
Imported goods & services (F2)	sej/yr	$7.93 \cdot 10^{19}$	$1.18 \cdot 10^{21}$
Total import (F=F1+F2)	sej/yr	$1.83 \cdot 10^{20}$	$2.87 \cdot 10^{21}$
Total Emergy (U=R+N+F)	sej/yr	$3.43 \cdot 10^{20}$	$9.68 \cdot 10^{21}$
Indices			
Environmental Loading Ratio	-	8.65	10.65
Empower Density	10^{12} sej/m^2/yr	3.72	2.53
Emergy per person	10^{16} sej/man/yr	1.81	3.83

In terms of flows, the 47% of the total emergy supporting the system is local (both renewable and non renewable), while the 53% is imported from outside as energy sources (30%) and other goods and services (23%). An important role is played by extraction activity (due to the high transformity of mined materials) and by industrial activities (due to the quantity of input involved), but the system is also supported by a relevant level of renewable resources (more than 10%), in particular, a percentage of consumed electricity is produced inside the Province of Siena from geothermal sources and it is imputed to all the 36 municipalities.

In Table 1 some indices are presented. The Environmental Loading Ratio (ELR) is a measure of environmental stress for the use of non renewable resources compared with renewable. In spite the presence of industry, ELR is lower than the provincial level. This could mean a correct use of energy and matter inputs which is consistent with the good quality of the typical product of the district: the precious crystal from Colle Val d'Elsa. The Empower Density represents how the availability of land could be a limiting factor for future development. It is similar to the concept of carrying capacity (even if it does not give a measure of the upper bound). In general the higher the ED, the higher the anthropic pressure on the system. The case of Colle Val d'Elsa confirms that, in general, an industrial district has a low margin of action in terms of designing future scenarios of qualitative development. The Emergy per person expresses the individual responsibility in terms of consumption of resources. Its value for Colle Val d'Elsa is lower than the provincial average due to the high population density. It is important to emphasize that an industrial district with a relevant population (more than 18,000 inhabitants) is not supported by huge quantities of energy and matter. However, it could not be neglect that, as in every economic model of the occidental society, the 90% of the inputs per capita are non renewable, which means that the future is as uncertain as the sustainability in the long run. The Province of Siena and its subsystems presents good results because of the availability of some renewable sources of input such as geothermal heat.

3.2 Ecological Footprint analysis

The analysis starts with the conversion of all consumed inputs to calculate the extension of land which is necessary to produce the resources and to absorb the emissions. The result is the Ecological Footprint. In Colle Val d'Elsa it is 4.99 equivalent hectares per capita, given as follows in Table 2.

The principal factor which needs land is the energy demand: in all industrialized regions of the world more than 60% of E.F. is necessary to produce energy and to absorb the emission of CO_2 due to the use of fossil fuels. The E.F. derives from high levels of consumption. The main categories for Colle Val d'Elsa are food and transport.

The E.F. has to be compared with the bio-productive capacity of the same region, that is 2.12 equivalent hectares per capita for Colle Val d'Elsa. Hence there is an ecological deficit of 2.87 equivalent hectares per capita. This means that the bio-productive capacity can meet only the 42% of the demand of ecological services by the inhabitants of Colle Val d'Elsa.

Table 2: Ecological Footprint calculation. The matrix of consumption categories (first line) and land categories (first column).

Eq. ha. per capita	Energy	Agricult.	Pastures	Forests	Degraded surface	Sea	Total
Food	0.69	0.68	0.49	0.00	0.00	0.04	1.89
Residence	0.60	0.00	0.00	0.02	0.04	0.00	0.66
Transport	1.17	0.00	0.00	0.00	0.07	0.00	1.23
Other goods	0.29	0.03	0.02	0.13	0.01	0.00	0.48
Services	0.27	0.00	0.00	0.01	0.02	0.00	0.30
Wastes	0.21	0.00	0.00	0.18	0.04	0.00	0.43
Total	3.22	0.71	0.51	0.34	0.17	0.04	4.99

3.3 Greenhouse gas inventory

The difference between the emission of greenhouse gases (which are converted in terms of equivalent CO_2 by their Global Warming Potential coefficients) and the absorption by natural ecosystems is rather high (Table 3) because of the high population density and the industrial settlement.
The emissions of 119.1 Gg of equivalent CO_2 mainly depend on the energy demand of both electricity and fossil fuels, while agriculture (in particular cattle-breeding) is not so relevant. Total absorption is only the 14.8% of total emissions.

Table 3: Equivalent CO_2 emission and absorption for the Municipality of Colle Val d'Elsa and the Province of Siena.

Greenhouse gas emission	Equivalent CO_2 Colle V.d'E. (Gg)	Equivalent CO_2 Province (Gg)
Electricity: emission of CO_2	+77.4	+782.02
Fossil fuels: emission of CO_2	+61.30	+1050.08
Livestock: emission of methane	+1.11	+58.6
Forests: absorption of CO_2	–20.7	–1119
Wastes: emission of methane	+0.00761	+0.119
Net Balance	+ 119.1	+ 772

4 Discussion

The territory of Colle Val d'Elsa and its population are supported by a continuing and relevant flow of non renewable resources and a low quantity of renewable ones. This is a fragile and unsteady equilibrium for the future of the system, even if the results are better if compared with other industrial districts in Italy.

The most important activity based on a prudent use of land and resources is the "good agriculture": in Colle Val d'Elsa there is not a good quality agriculture which rationally exploits renewable resources and safeguards and improves the land. A suitable policy of stimulating some cultivations and the production of typical local products would be necessary, even from an economic point of view (markets are more and more sensitive to the products of great quality), because of the availability of arable land which is not used in the right way.

Industry is very important for this system: in particular, the production of crystal is really a cultural element which constitutes a business for more than 1000 workers. The flows of energy and matter which support the sector is wide and the only way to make it sustainable is the unceasing pursuit of quality, the increasing attention for the inputs in the productive process and for the environment as sink of wastes and emissions.

In the Province of Siena, manufacturing could gain a competitive advantage from an environmental point of view: it could be supported by renewable energy from geothermal technology.

A question to be analysed in terms of territorial planning is the urbanization which, in general, grows up to relevant values where there is a city and where a lot of resources (energy and matter) are used. It could appear obvious that a city is a system that feeds on big flows of energy. It is, in fact, a dissipative structure and many flows of energy and matter cross its boundaries: high quality energy are purchased from the external environment and, at the same time, wide quantities of degraded energy, in form of wastes and pollution, are released to the environment. However, a city makes many resources available. It is a dynamic system able to produce welfare and services, labour and capital, interaction factors and communicability, opportunities to create and diffuse information, culture and news. This kind of productions justifies the existence of cities in spite of their high values of environmental loading with reference to the other less populated parts of territory.

The model of urban areas is based on the idea of an urban development able to enhance and requalify the essential nodes of the cities and to rationalize the consumptions of energy and matter. First of all, sustainability demands to leave gradually and clearly those planning practices based on the aggrandizement of cities. The space (surface) is going to finish and it is no more sufficient to sustain the pressure of cities on their environment (as we know by examining the Empower Density and the Ecological Footprint for Colle Val d'Elsa). It means that building areas should be limited and territory should develop those biologic cycles necessary to product food and to absorb pollution and wastes. Taking into account the relationships existing between urban areas and natural areas, the new planning tools have to think about architectural shapes and territorial configurations strikingly coherent with their local context, the environment and the weather. New projects have to promote local architecture as a cultural value and to suggest the application of those technologies able to reduce energetic consumptions of buildings. The final purpose is reducing consumptions and emissions of cities.

5 Conclusions

Three different methodologies are used to provide an assessment of environmental impacts and sustainability at local level with some implications in terms of global sustainability: Emergy evaluation, Ecological Footprint analysis and Greenhouse gas inventory. Looking at the sum of the results can help policy makers to design a way of managing the resources and the environment into an organic model, together with economic, social and political/institutional issues. For an industrialised and populated system such as Colle Val d'Elsa we suggest a model of development which considers productions of increasing quality and the reduction of consumption of resources and emissions. The key points are: a) to emphasize natural capital; b) to control the availability and the renewability of resources and the state of the environment; c) to evaluate day by day the degree of exploitation of natural resources; d) to systematically collect statistical data about land, activities and environment.

Finally, it is necessary to emphasize the qualitative aspects of resources use rather than the quantitative ones and, at the same time, the preference for a society to develop rather than to grow.

References

[1] Odum, H.T. Self organisation, transformity and information. *Science*, 242, pp. 1132-1139, 1988.

[2] Ulgiati, S., Odum, H.T. & Bastianoni, S. Emergy use, environmental loading and sustainability. An emergy analysis of Italy. *Ecological Modelling*, 73, pp. 215-268, 1994.

[3] Wackernagel, M., Rees, W. The Ecological Footprint: reducing human impact on the Earth, New Society, Gabriola Island, BC, Canada, 1996.

[4] IPCC. Greenhouse Gas Inventory. Reporting Instructions, 1996 (revised). IPCC, Intergovernmental Panel on Climate Change, 1,2,3.

[5] Daly, H.E. Toward some operational principles of sustainable development. *Ecological Economics*, **2**, pp. 1-6, 1990.

[6] Tiezzi, E. The essence of time. Wit Press, 2002.

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