Sustainable development at local level and "anthropic resilience": sustainability indicators from the SPIn-ECO project

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Abstract

The socio economic context of the Province of Siena (central Italy) is peculiar because it is characterised by the same development trend of western countries but, at the same time, it is not completely affected by the negative aspects of this. The SPIn-Eco project is a triennial research program with the purpose of assessing the environmental conditions of the Province of Siena (Tuscany, central Italy) and its 36 municipalities. It is a deep analysis of the state of the territorial system by a complete set of instruments and indicators. This paper shows the aggregated results of the analysis for the northern area of the Province of Siena, called Val d'Elsa, which is composed by 6 municipalities. The area is characterised by variegated geomorphology, environmental aspects and urbanization. At the same time, each municipality is traditionally inclined to the development of some activities: agriculture, industry, craft, tourism respectively.

The paper presents an environmental assessment of the use of resources at a local level by using some methodologies and sustainability indicators: emergy evaluation (introduced by Howard Odum), greenhouse gas inventory (according to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories) and ecological footprint analysis (introduced by M. Wackernagel and W. Rees). The discussion section deals with the environmental, social and economic aspects of these under a sustainable perspective. We believe that the distribution of different peculiarities on the territory could be emphasized as a sort of "anthropic (or urban) resilience" of the system by a correct territorial planning activity towards sustainability.
Keywords: sustainable development, indicators, emergy evaluation, ecological footprint, greenhouse gases inventory, resilience.

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1 Introduction

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 within the Province of Siena is Val d'Elsa, which is located in the northern part of the Province (Fig. 1). It is composed of 6 municipalities characterised by different peculiarities at geomorphological, urban and productive level. The average population density (93.72 inhabitants/km^2) is higher than the provincial average (66 inhabitants/km^2) due to the presence of three very populated industrial centres (Poggibonsi, Monteriggioni and Colle Val d'Elsa). The other municipalities, Casole d'Elsa, Radicondoli and San Gimignano are larger, less populated and characterized by a wider environmental heritage. Manufacturing is developed in the north-western part of the area and agriculture gives very good and famous typical products such as Chianti and Vernaccia wines. Tourism is very important for local economy, with some examples of high turnout in spring and summer in particular in San Gimignano. This is feeding the development of agrotouristic activity, but it is also dangerous for the local ecosystems due to the high pressure of tourists that can be represented by the consumption of resources and the production of wastes.

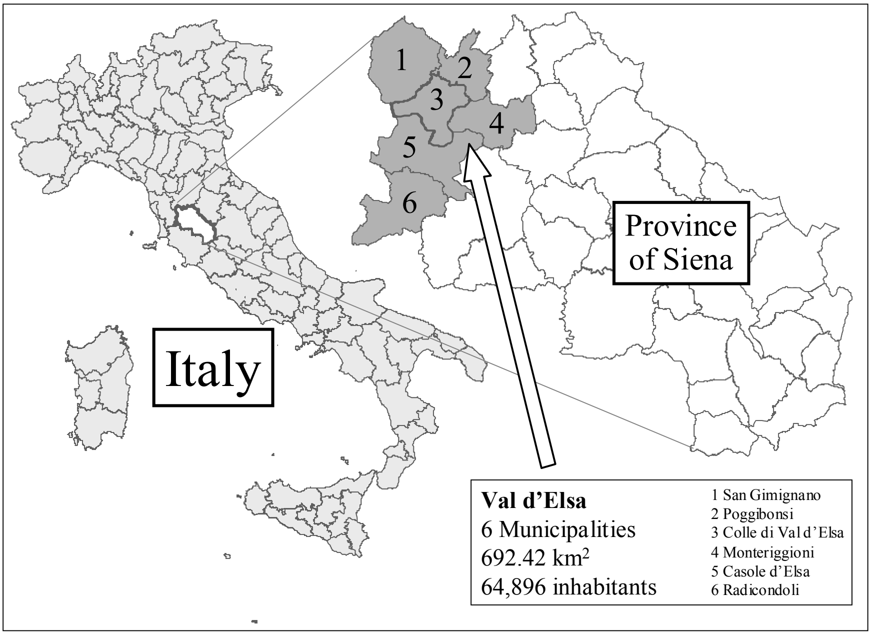

Figure 1: The area of Val d'Elsa in national and provincial contexts.

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2 Methodologies for a territorial sustainability assessment

An integrated set of instruments is needed to assess the different aspects of anthropic activity and impacts on territorial sustainability at local level. In this paper, three methods are presented and adopted for the area under study. They are Emergy evaluation, Ecological footprint and Greenhouse gas inventory.

2.1 Emergy evaluation

To take into account all the resources (natural and manufactured) sustaining a system, we adopt the concept of *Emergy* introduced by H.T. 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. It is the memory of all the solar energy necessary during the process to make a resource available. It is measured in Joules, but not indistinct Joules, solar emergy Joules (*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]. It is the solar energy directly or indirectly necessary to obtain one unit of another type of energy. All the inputs are classified in renewable (R) and non-renewable (N) resources and local (L) (natural) and imported (F), then some indicators of environmental stress can be calculated. The *Environmental loading ratio* (ELR) is the ratio of non-renewable (local and imported) emergy to renewable environmental emergy. The *Emergy per person* (EpP) is the ratio of total emergy to the inhabitants of the system. The *Empower Density* (ED) is the ratio of total emergy to the area (expressed in m^2). The *Emergy yield ratio* (EYR) is the ratio of total to purchased emergy.

2.2 Ecological footprint analysis

The Ecological Footprint (E.F.), introduced by William Rees and Mathis Wackernagel in the 1990’s, is defined as the total area of ecologically productive land (forests, arable land, pasture, built-up area, marine land, etc.) and 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 each unit of energy and matter supporting the system 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 defines also 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.

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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 and discussion

3.1 Emergy evaluation

The emergy methodology enables to account for all the resources that support a territorial system. Table 1 shows the amount of local renewable, local non renewable and imported inputs to the system, respectively. Total emergy of Val d'Elsa is 1.44×10^{21} sej/yr, the 15% of the emergy of Siena. Local emergy, both renewable (R) and non renewable (N) in Val d'Elsa is the 42.38% of total emergy, while the 57.62% is the emergy of imported energy and goods and services (F). Renewable resources are fundamental in the municipality of Radicondoli (more than 76% of total emergy) which is characterized by a large territory mostly covered by forests. Anyway, the portion of renewable emergy in all the area is not negligible (12.16% with respect to the provincial level equal to 8.57%) due to the presence of large natural ecosystems and green areas. Even a fraction of consumed electricity can be considered renewable because it is produced inside the Province of Siena from geothermal sources and it is imputed to all the 36 municipalities. Important roles are played by extractive activity (N) especially in the municipalities of Colle Val d'Elsa, Monteriggioni and Poggibonsi (due to the high transformity of mined materials) and by industrial activities (due to the quantity of input - F - involved), especially in Poggibonsi.

Table 1: Emergy flows for the municipalities of the area of Val d'Elsa and the Province of Siena.

	R sej/yr	N sej/yr	F sej/yr	Total sej/yr
Siena	8.30E+20	5.98E+21	2.87E+21	9.68E+21
Val d'Elsa	1.75E+20	4.34E+20	8.27E+20	1.44E+21
Casole d'Elsa	2.79E+19	1.29E+19	5.98E+19	1.01E+20
Colle Val d'Elsa	3.56E+19	1.25E+20	1.83E+20	3.44E+20
Monteriggioni	2.26E+19	1.87E+20	1.52E+20	3.62E+20
Poggibonsi	2.76E+19	1.04E+20	2.97E+20	4.29E+20
Radicondoli	3.24E+19	1.78E+18	8.22E+18	4.24E+19
San Gimignano	2,85E+19	3,11E+18	1,27E+20	1,59E+20

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Once all the inputs are classified into categories, some indicators for the area are calculated. Each municipality has been detected and the results of the analysis are shown in Table 2. The territory of Val d'Elsa presents a level of Environmental Loading Ratio (ELR) lower than the provincial level. However, the conditions at municipal level are very different. ELR varies from 14.98 and 14.51 of Monteriggioni and Poggibonsi (industrial areas) respectively, to 2.61 of Casole d'Elsa (rural area) and 0.31 of Radicondoli, that is one of the lowest value of ELR ever calculated in Italy. The Emergy Density (ED) analysis also reflects this situation. In particular, the high concentration of the flows of energy and matter inside the territory of Poggibonsi can indicate how the low availability of land is a limiting factor for future development. Anyway, this measure of spatial stress is lower in Val d'Elsa than the average value of the Province of Siena. The Emergy per Person (EpP) represents the responsibility of each inhabitant for the use of resources. However, it is important to consider the nature of resources which are used. For example, the values of Monteriggioni and Radicondoli are similar but while the 76% of the 4.37×10^{16} sej/yr of Radicondoli is renewable, the 94% of the 4.67×10^{16} sej/yr of Monteriggioni is not. The lowest values are 1.81 in Colle Val d'Elsa and 1.56 in Poggibonsi, meaning that a high level of population density is supported by a not so high amount of resources per capita. The Emergy Yield Ratio (EYR) measures the relevance of local inputs with respect to the total emergy supporting the system. The higher values indicate where a larger environmental value is added to the emergy imported from outside the system. The Province of Siena, in general, is characterized by a good use of environmental inputs. Those areas mainly covered by natural ecosystems, such as Radicondoli, present the highest values of EYR, while the most industrialized and urbanized territories, such as Poggibonsi, are more dependent on imported inputs. The degree of dependence form other ecosystems is a factor of weakness for the sustainability of a territorial system because the future availability of resources necessary for the development of the system is out of control.

Table 2: Emergy indices in the area of Val d'Elsa and in the Province of Siena.

	ELR	ED *sej x10^12*	EpP *sej x10^16*	EYR
Siena	10.65	2.53	3.83	3.37
Val d'Elsa	7.22	2.10	2.21	1.74
Casole d'Elsa	2.61	0.68	3.60	1.68
Colle Val d'Elsa	8.65	3.72	1.81	1.88
Monteriggioni	14.98	3.63	4.67	2.38
Poggibonsi	14.51	6.06	1.56	1.44
Radicondoli	0.31	0.32	4.37	5.16
San Gimignano	4.56	1.14	2.26	1.25

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3.2 Ecological footprint analysis

The results of the Ecological Footprint analysis (expressed in equivalent hectares per capita) for the Area of Val d'Elsa are shown in Table 3 together with the results for the Province of Siena and Italy. EF value (second column) reflects the level of consumption. In Italy (as well as in all the western countries) it is homogeneous, so that the EF in Val d'Elsa is not so different from the average national value. What is really different is the gap (fourth column) between EF and the biocapacity, i.e. the natural potentialities of the environment to provide resources (third column). The fact that the Province of Siena does not present an ecological deficit (only –0.06 eq.ha per capita) is very positive in terms of sustainability. This is due to the presence of hugely bio-productive lands for example in Radicondoli and Casole d'Elsa, that present an Ecological Surplus of 35.16 and 11.82 eq.ha per capita, respectively. At the same time, low levels of biocapacity characterize two of the municipalities of Val d'Elsa, Poggibonsi and Colle Val d'Elsa, that present a high Ecological Deficit (4.32 and 2.87 eq.ha per capita, respectively). This result is negative because the two areas are limited and mostly occupied by urban infrastructures and human settlements. This means that the bio-productive capacity of the territories of Poggibonsi and Colle Val d'Elsa can meet only the 21.6% and the 42.5% of the demand of ecological services by their inhabitants. In general, Val d'Elsa is a mix of natural ecosystems and urbanized and industrial areas and it is not in a condition of high environmental stress.

Table 3: The Ecological Footprint analysis in the Area of Val d'Elsa.

	Ecological Footprint	Biocapacity	Ecological Deficit
Italia	5.51	1.92	-3.59
Siena	5.80	5.74	-0.06
Val d'Elsa	5.46	3.89	-1.56
Casole d'Elsa	5.69	17.51	11.82
Colle Val d'Elsa	4.99	2.12	-2.87
Monteriggioni	5.94	4.83	-1.11
Poggibonsi	5.51	1.19	-4.32
Radicondoli	5.52	40.68	35.16
San Gimignano	5.94	7.71	1.77

3.3 Greenhouse gas inventory

For each territorial system under study, the difference between the emissions 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 represented in Table 4. The emissions are rather high in Colle Val d'Elsa and

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Poggibonsi (145.61 and 130.30 Gg of equivalent CO_2, respectively: the 65% of total emissions in Val d'Elsa and the 15% of total emissions in the Province of Siena), mainly depending on the energy demand of both electricity and fossil fuels necessary to feed the productive and urban systems. In general, agriculture (in particular cattle-breeding) is not so relevant as well as waste production and management. In those municipalities with large green areas and forests the absorption of greenhouse gas is relevant. In Val d'Elsa, total absorption is the 45.2% of total emissions (less than in the Province of Siena, 59.2%), but some areas can be defined as real sink of CO_2. For example, Casole d'Elsa and Radicondoli present a net absorption of equivalent CO_2 even if the levels of emission per capita are the highest of the whole area (but this is due to the very low level of population density).

Table 4: The Greenhouse Gas Inventory in the Area of Val d'Elsa and in the Province of Siena.

	Popul.	Emissions *Gg eq. CO_2*	Em/popul. *t/ab*	Absor. *Gg eq. CO_2*	Net Emiss. *Gg eq. CO_2*
Siena	252972	1891	7.48	1119	772
Val d'Elsa	64896	427.15	6.58	193.09	234.05
Casole d'Elsa	2796	32.18	11.51	54.15	-21.97
Colle Val d'Elsa	18916	130.30	6.89	18.27	112.04
Monteriggioni	7744	54.80	7.08	26.56	28.24
Poggibonsi	27442	145.61	5.31	10.32	135.29
Radicondoli	971	7.96	8.19	50.10	-42.15
San Gimignano	7027	56.29	8.01	33.70	22.59

4 Anthropic resilience and public policy

People are a part of nature and humans can transform ecosystems into more or less favourable systems, and policy-makers need information from many sources for their decision-making processes. Managing environmental assets and resources in such a way that secures their capacity to support societal development far into the future is a difficult venture. A large number of case studies have revealed the link between resilience, diversity and sustainability of human-environmental systems.

The concept of resilience is not completely new. It has been used by ecologists for at least thirty years. In fact, in 1973, Holling introduced the concept of ecosystem resilience as the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures [7].

The role of resilience to achieve the goal of sustainable development is essential. To sustain development in a changing world, policy must enhance resilience in social-ecological systems and strengthen the perception of humanity

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and nature as interdependent and interacting. As Common stated "A system is sustainable in the ecological sense if it is resilient. In this sense, sustainability is a system property the presence or absence of which can only be determined with hindsight by observation of its behaviour in the face of disturbance" [8].

Resilience is the foundation of change in social-ecological systems. Loss of resilience foreshadows change, and building resilience can lead to sustainable paths. Resilience is important because resilient systems persist, prosper, innovate and give rise to the systems of the future. Vulnerability is the counterpart of resilience: when a social or ecological system loses resilience it becomes vulnerable to change that previously could be absorbed. In a resilient system, change has the potential to create opportunity for development, novelty and innovation. In a vulnerable system even small changes may be devastating [9].

Resilience is often associated with diversity of species, of human opportunity and of economic options. For this reason, there are some different definitions of resilience. "Ecological resilience" describes the capacity of an ecosystem to cope with disturbances, such as storms, fire and pollution, without shifting into a qualitatively different state. A resilient ecosystem has the capacity to withstand shocks and surprises and, if damaged, to rebuilt itself. "Social resilience" is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, economic and environmental change [10]. This introduces a human element into a classic ecological definition of resilience, which is the ability of a system to maintain its characteristics when disturbed [11].

Ecosystems rich in biodiversity have the capacity to generate ecosystem goods and services, which form the basic foundation for social and economic development. Social and ecological resilience, providing humans and nature the inter-connected capacity to absorb shocks while maintaining function, is a crucial quality of our resource base.

Anthropic resilience can be defined as a synonym of sustainability as an anthropocentric concept, i.e. describing those conditions for a mutual harmonic coexistence of society with environment and resources. Anthropic resilience may be a useful approach to address the mechanisms to guarantee sustainability with the advantage of assuming a relationship with ecological resilience. In this sense, the role of public policy is crucial. In particular, it has to:

– implement an active and adaptive management of natural resources preventing the risks of exhaustion and uncertainty.
– safeguard or support the diversity of ecosystems and human behaviours for enhancing resilience in both ecological and social systems.
– provide incentives for participation by stakeholders and stimulate ecological knowledge into institutional structures in a multi-level governance system.
– develop indicators of gradual change and early warning signals for loss of ecosystem resilience and imminent shifts to less desirable ecological states.

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5 Conclusions

This paper has detected the environmental properties and loading factors of the territory of Val d'Elsa, a portion of the Province of Siena (central Italy). The main result of the analysis by three methodologies (Emergy evaluation, Ecological footprint and Greenhouse gas inventory) is the representation of an area characterized by very different but complementary urban and anthropic subsystems. Each one is peculiar for different reasons and the most suitable territorial policy should be the preservation of this anthropic diversity. High environmental loading somewhere are compensated by environmental richness elsewhere, while the presence of urban centers provide services for the population of rural areas. The city offers employment opportunities and capital circulation; natural systems provide resources and absorb wastes and emissions. The analytical measure of the sustainability level for each territorial system can be the starting point of a policy which is based on "anthropic resilience" even at local level. Resilience has been introduced as a synonym of sustainability, i.e. the capacity of a system to maintain its characteristics when disturbed, in order to determine those factors of unsustainability (depending on human activities) and, at the same time, to enhance diversities and indicate feasible paths for the territorial government.

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