Quantifying possible pathways of sustainable development of a territorial system

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Abstract

The assessment of the environmental sustainability of a territorial system requires a holistic approach, based on thermodynamic functions and able to consider all the complex mechanisms that are involved in a system.

Many of the most used indicators focus their attention on single aspects, and they are not able to consider the system as a whole. Some authors have developed the use of different indicators such as emergy analysis and greenhouse gas inventory. The first methodologies point out their attention on the resource use. In particular, the Emergy Analysis measures the quantity and type of resources necessary to sustain the system. Greenhouse gas inventory is directly focused on the indirect impact of the system, i.e. the CO\textsubscript{2} equivalent emissions produced.

These methodologies have already been used in order to assess the sustainability of a territorial system while the suggested strategies and pathways for sustainability still need investigation. It is in fact very important to test if and how these methodologies are able to assess these possible paths of sustainability and to measure quantitatively the choices made.

The case study is the Province of Grosseto. The different indicators (emergy analysis and greenhouse inventory) define the Province of Grosseto as a system that makes a low impact on the territory. In this paper we formulate possible scenarios of sustainable development and we quantify how these developments affect indicators.

\textit{Keywords: sustainable pathways, emergy analysis, greenhouse gas inventory, territorial system, hydrogen production.}
1 Introduction

A territorial system is a complex system in a steady state. Its structure is based on many levels of organizations; its openings to the outside, its irreversible dynamics are peculiar features of a complex system. This system requires resources and energy to enhance internal order and to self-organize, while increasing the entropy of the surroundings. The increase in entropy exceeds the internal entropy decrease of the system, so that the second principle of thermodynamics is observed. Hence a territory behaves like a dissipative structure [1]. When dealing with complex territorial systems, common indicators (i.e. analytical pollution measures) are not sufficient to address all the environmental aspects involved.

“Macro” indicators capable of evaluating the global environmental performance of a system are needed. A growing need has been felt to create instruments capable of monitoring more sensitive phenomena and elaborating more complex and meaningful information with greater portent than the usual stress, state and response data. In this paper, we present how it is possible to define sustainable pathways of development. The analysis is made on the province of Grosseto and uses two environmental approaches: emergy analysis and greenhouse gas inventory. The aim of this paper is to test if these environmental approaches are able to address quantitatively sustainability pathways and to describe which steps we have to use in order to analyse the sustainability options.

Our approach is focused either on the global scale, i.e. the system as whole in order to test the changes produced following different sustainable strategies or on the local scale in order to test the sustainability of the single option chosen.

The province of Grosseto is located in the southern part of Tuscany (Italy); its territory extends along the Tirrenic coast and it is delimited by the province of Livorno, Siena, Pisa and Viterbo. This territorial system produces a low impact on the environment [2]; its main activities are connected to agriculture and tourism. There is a production of electricity from geothermal heat that is very interesting from the point of view of sustainability. Another important characteristic of the system is, as we have said before, the presence of important agricultural activity, and then a great production of biomass residues.

The idea of using these environmental techniques to assess the sustainability pathways of a territorial system, comes form the fact that province of Grosseto has been characterized by a geothermal production and from the fact that there is a rising interest in hydrogen production for transport and energy production.

We test, with the two methodologies, the effect of considering electricity made by geothermal resources in spite of the Italian average resources used (mainly fossil fuel). Results from emergy analysis have tested using a graphical approach presented at 3rd Biennal Emergy Analysis Research Conference [3].

As our aim is to indicate sustainable pathways, in relation to the characteristics of the territory. We have checked the possibility of exploiting residues from agricultural activities in order to produce hydrogen. This study was a part of a national project entitled “Innovative Catalytic technologies for the
Production of Hydrogen and Syngas from Natural Gas, Biomass and CDR” a project financed by Italian Ministry of Instruction, University and Research (PRIN 2003).

As our aim is to construct a method able to identify sustainability pathways, we have performed the analysis of the territorial system considering two scenarios, one with electricity produced from average Italian fuel composition and another one considering the geothermal resources. Moreover we have tested, using emergy analysis, if it is sustainable the gasification of biomass for the production of hydrogen in comparison with fossil fuel. What we present is only the first part of an important project we are developing about technologies of hydrogen production.

2 Methodology

In this article we want to show how it is possible by the combination of different methodologies to follow the sustainable development of a system and therefore we do not spend much in the description of the methodologies but we indicate references for a better understanding.

Emergy analysis is an environmental methodology based on the laws of thermodynamics. Emergy is defined as the quantity of solar emergy necessary (directly or indirectly) to obtain a product in a given process. It can be used to assess complex relationships between the economy and its supporting environment since the work of both is expressed in equivalent terms. By calculating the emergy indicators we are able to understand how far from the sustainability the territorial system is [4,5]. Transformity is an intensive quantity measured in “solar energy joules/Joules” (sej/J). It is an indicator of (in)efficiency since, for equivalent processes, giving the same product, the lower the transformity, the higher the efficiency of production.

In this paper we used one of the emergy indicators, i.e. the Environmental Loading Ratio (ELR) that is the ratio between non renewable and renewable resources used in a territory. The lower the indicator, the higher is the use of renewable resources with respect to non renewable ones.

The greenhouse gas inventory is realized according to the method proposed by IPCC [6]. We consider the emissions of the three greenhouse gases that give the largest contribution to global warming, i.e. CO₂, CH₄ and N₂O. The gas emissions were transformed into carbon dioxide equivalent using the Global Warming Potential (GWP). We calculated the emissions produced by the energetic sector, the livestock sector and the wastes. The quantity of CO₂ sequestered by the annual growth of forests was also considered in the greenhouse balance while forests cut and wood burnt were subtracted from the natural absorption. In this paper we use as indicator the total CO₂ eq emitted in the province of Grosseto.

3 Results and discussion

In the analysis of the Province of Grosseto, we have calculated emergy analysis and greenhouse gases inventory considering that electricity is produced from the
Italian average fuels (1st scenario) and from geothermal resources (2nd scenario). The results are showed in table 1.

Table 1: Results of the emery and greenhouse gas inventory in the two scenarios.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>1st scenario</th>
<th>2nd scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELR (Emergy analysis)</td>
<td>8.15</td>
<td>7.46</td>
</tr>
<tr>
<td>Total CO$_2$eq (Gg)</td>
<td>844.66</td>
<td>748.02</td>
</tr>
</tbody>
</table>

As we can see in the previous table, the two indicators present better value in the 2nd scenario when we use a renewable resource (geothermal) in spite of fossil fuel. To confirm this statement, as energetic indicator (environmental loading ratio) express a relationship between two independent variables and the same indicator may be obtained using different values for the two variables in consideration (if the two parameters, renewable and non-renewable resources, are doubled or halved, the environmental loading ratio remains unchanged); we adopt an approach capable of simultaneously measuring both the value of the indicator and the variations brought about by the independent variables that give rise to it. We applied to the analysis of the Province of Grosseto the method proposed by Ridolfi et al. [3]. The graph is reported in figure 1.

![Figure 1: Graphic representation of ELR in the two scenarios.](image)

As it can be seen in Figure 1, the decrease in the value of the angular coefficient shows an improvement in the sustainability of the system. This is due to the fact that, in the 2nd scenario, the system is using a renewable resource instead of a non-renewable one. In the graph it is clear that the lower ELR of the
system is not due to an increase in the use of renewable resources but to the decrease in the use of non-renewable one. This diagram should be used to test the different pathways and to see what is really the best option chosen.

To develop sustainable strategies it is necessary to develop new productive activities in the territory, trying to choose the ones with the lowest impact. The option chosen should be adapted for the development of the system and in accordance with the characteristics of the territory. Then the alternatives should be tested with a methodological procedure in order to assess what is most advantageous from the point of view of sustainability.

We calculated the transformity of hydrogen from biomass: this indicator gives information about the emergy used to produce a J of product. Transformity is an indicator of inefficiency because for equivalent processes, giving the same product, the lower the transformity, the higher the efficiency of production. In the table 2 we present the emergy evaluation of hydrogen production from biomass; data are from Hamelinck et al. [7].

<table>
<thead>
<tr>
<th>Item</th>
<th>quantity</th>
<th>unit</th>
<th>transformity (sej/unit)</th>
<th>solar emergy (sej)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>1.24E+16</td>
<td>J</td>
<td>4.40E+04</td>
<td>5.43E+20</td>
</tr>
<tr>
<td>Plant cost</td>
<td>2.37E+07</td>
<td>$</td>
<td>1.55E+12</td>
<td>3.67E+19</td>
</tr>
<tr>
<td>H₂</td>
<td>6.13E+15</td>
<td>J</td>
<td>9.47E+04</td>
<td>5.80E+20</td>
</tr>
</tbody>
</table>

The transformity of hydrogen from biomass gasification is compared to the one of fossil fuels used for transport. The latter one has a value of 1.11x10⁵ sej/J. This means that hydrogen can be produced from biomass in a slightly more efficient way than fossil fuels from oil. Moreover ELR of fossil fuel production tends to infinite (the process is fed by non-renewable resources), while for hydrogen from biomass we can imagine a finite (and quite low) number. What we still need to calculate to get ELR is the percentage of renewable to assign to biomass residues. The next step of this analysis is to study how this process can be integrated in the territory: we have to manage the size of a plant for hydrogen production, where it can be located, etc. The last step is then to estimate how the new production alters emergy analysis of the territory, and to imagine how the substitution of fossil fuel with hydrogen (considering all the necessary investments in terms of infrastructure) can change emergy indicators and in particularly environmental loading ratio. This change will be tested in the graphic method to understand if the pathway is going towards a more sustainable development.
4 Conclusions

The approach used is mainly based on two indicators: greenhouse gas inventory and emergy evaluation. The advantage of the latter methodology is that all flows of energy and matter sustaining the territorial system are accounted for and conducted to a single common denominator. In our approach we are able to assess the pathways of sustainability studying the system at the macro and micro scale. The latter scale permits us to test if the option chosen is a real alternative. The macro scale permits us to evaluate if the changes due to the introduction of a different way of production represents really a positive aspect to pursue sustainability. The use of a graphic method makes possible to take complete advantage of the information contained in the various components of the environmental loading ratio by making use of the information contained both in the emergy indicator itself as well as in their component variables.

In particular we have analyzed the territorial system in two different scenarios with a local geothermal production and without. The ELR and the CO$_2$eq decreases in the scenario with the geothermal production. For the ELR we have also used the graphic method, that is able to consider the index variation together with variables variation and so we can identify the reason of ELR decrease.

At the local level we have assessed hydrogen production from biomass in order to verify if it is an option to be followed for a sustainable development. This solution should be then investigated at the territorial level with all the necessary infrastructure to substitute fossil fuel with hydrogen and then it will be possible verify its sustainability with respect to the actual situation.

References