Local and Regional Resource and Landscape Management from the Point of View of the Next Larger Scale: The Emergy Synthesis Perspective

Vittoria Bandini, Lorenzo Benini, Diego Marazza, Leonardo Marotta, Luciano Vogli and Andrea Contin

ABSTRACT

Local management of environmental resources is often impaired by the lack of scientific knowledge available to policy makers, which produces environmental policies that do not take into proper account the global value of environmental components. The environmental management research group of the University of Bologna has been addressing this issue in the past few years, providing local decision makers with assessments oriented to the evaluation of system’s overall sustainability. In this context, emergy indexes and landscape metrics are used in order to introduce a proper accounting for natural resources and ecosystem services and to evaluate the overall impact of human activities on landscapes. All the applications take place in the province of Ravenna, which is located in Northern Italy, and nearby territories. Both resource and landscape management have been addressed. As for resource management, a contribution to the local energy planning process through the definition of future scenarios and their evaluation through emergy synthesis is given. As for landscape management, and the use of LDI for the study of fluvial catchments and river banks, together with other indexes of ecosystem function and human disturbance, is described.

INTRODUCTION

The study and practice of environmental assessment and management increasingly recognize the importance of scale and cross-scale dynamics in understanding and addressing global environmental issues (Cash and Moser, 2000). Moreover, decision-makers from the local scale need to understand how actions at one scale might constrain or provide opportunities at other scales. The concept of reconciling supply of scientific information with users’ demands has been explored by McNie (2007), who recognized the fact that decision makers often lack useful information, although a lot of scientific information is produced and available.

Problems arise when an environmental issue is managed at an institutional scale whose authoritative reach does not correspond with the geographical scale or spatial dynamic of the environmental problem (Cash and Moser, 2000). When this is applied to resource management, such as energy, or biodiversity or ecosystems functionality, the reference scale easily turns out to be a global one.

In opposition to the global value of the environmental components involved, local environmental management is often driven by the local system of values, short term and local-scale evaluations and in general are largely influenced by the local social and environmental issues. If this, on one hand, is good and necessary for the definition of a local-specific policy, on the other hand it can bring about the ignorance of the value of the environmental components involved. One example of this is the very low attention which is given to soil conservation in the Italian policy agenda.

In order to overcome this shortcomings of local environmental management, the Environmental Management Research Group of the University of Bologna has devoted part of its activities to the
introduction of a global dimension of evaluation into local management, by means of emergy synthesis: the use of emergy synthesis allows an evaluation of the “global value” of the environmental components, as it accounts for all the inputs of energy, materials and information which are directly or indirectly used for generating or sustaining a system. Thus, emergy synthesis is able to account for all those natural services and materials which do not have a monetary value, to evaluate the “work of nature” which supports soil formation, minerals, groundwater, air quality, etc., and to introduce a thermodynamic approach in environmental management.

In this paper, we use emergy synthesis together with other methods to evaluate the sustainability of Ravenna province, which is located in Northern Italy. These other methods mainly refer to the domain of landscape science (Farina 2006).

**Landscape Management**

Impact analysis, restoration and conservation projects concentrate only on isolated, dispersed pieces of the regional system. This approach can contribute to increase the cumulative impacts such as the fragmentation of habitats and the loss of biophysical and biogeochemical functions (Bettini et al., 2000). In the past decade or so, a new discipline known as landscape ecology and landscape science has emerged to offer us ways to look at our area on a much broader scale. We use a system approach in order to define, study, monitor and control the environmental processes and antropic impacts.

Landscape approaches consider the influences of landscape patterns on the abundance and distribution of plants and animals (Forman, 1995) and also landscape as a cultural dimension of the complexity of the system, integrating the human ecosystem (Naveh and Lieberman 1994) with its cultural and historic background (Farinelli 2003). Landscape is, at the same time, a system, a unit, a domain, a realized space, as well as a cognitive space (Farina 2006).

Emergy is integrated into this landscape approach by the use of LDI (Brown and Vivas 2005), thus using landscape analysis as the core of sustainability management and preservation of ecosystems’ health. Areas with high emergy intensity show ecosystem structures which are far away from their original equilibrium, because of the disturbance and pressure exerted by human activities such as landscape modifications, regimentation of river channels and banks, water use by agriculture. Resources flows (energy and mass and information) are organized hierarchically into spatial patterns with resources flows per area more concentrated in hierarchical centres such as cities (Odum 1996); therefore, areal empower density might serve as a measure of the level of human-induced impacts on ecological systems (Vivas and Brown, 2006).

Under the perspective of the World Resources (2000) and of the Millennium Ecosystem Assessment (2005), resource depletion and landscape and seascape modifications drain and disrupt the natural ecosystem services, as food and fiber production, water treatment, biodiversity, shoreline protection, carbon storage, etc. Normally this process is accompanied and reflected by the loss of texture complexity and of richness of the landscape. As a result, human dominated ecosystems drive extra-emergy into their system in order to offset the loss of the ecosystem functionality.

**Summary of the Research and Research Problems**

The Ravenna province was investigated through the use of multiple indexes and measures, with the aim of assessing its overall sustainability with a holistic approach. The territorial metabolism was evaluated by calculating the consumption of energy and water, the production of waste and CO₂ emissions and the overall emergy yield of the system. Ecological footprint and LDI values were also calculated (See “Methods” section for references).

This work represents a synthesis of the assessments conducted by the Environmental Management Research Group of Bologna University on the Province of Ravenna by the use of emergy indexes and other metrics derived from landscape science. Starting from the evaluation of the whole system, some components from the “next smaller scale” (recalling the “next larger scale” illustrated by Odum and Odum (2000)) were investigated:
the energetic sub-systems, which involves the supply, transformation, distribution and consumption of energy;
the landscape, particularly near the rivers and streams.

The choice of using metrics from different domains is due to the objective of a holistic assessment of the human pressure on the studied system. Through the identified metrics, we assess landscape features, biodiversity, ecosystems functionality and resilience, environmental impacts and overall environmental sustainability. We consider important to couple global measures like emergy assessment or ecological footprint with metrics deriving from landscape science, in order to be able to integrate local and global dimensions. We particularly want to test and reveal the correlation among these indices, which could highlight the relation between local and global features. In particular, with this work we try to understand if a positive or negative result in terms of emergy or ecological footprint corresponds to positive or negative local features.

Multi-Criteria Assessment

Multi-Criteria Assessment (MCA) is a tool to support environmental and social decisions in sustainability science, ecological economics and strategic assessment (Munda 2003; 2004). Our analysis can be seen as parts of a bigger process of a MCA assessment of the Ravenna province (Munda, 2004). Only the evaluation part of the whole study is presented here, without the decision-making section, although the assessment and decision-making components are strongly related, i.e. the target of sustainability requires the handling of multi-dimensional and multi-scale analyses, which generate information relevant for decision-making (Giampietro et al., 2006).

METHODS

In this section a description is given for metrics, indicators, indices and parameters used in this paper. Table 1 reports all methods and metrics used in this work. Both synthetic and simple metrics are included. Examples of synthetic indexes are emergy indexes, Ecological Footprint and Territorial Biocapacity; the other metrics are specific for the measure of biodiversity or landscape features. The choice of using metrics from different domains reflects the objective of a holistic assessment of the human pressure on the studied systems.

Landscape management

We present three different applications of the concepts of landscape management:

1) An evaluation of riparian buffers in Ravenna Province and surrounding area through the use of LDI and IVN, which allowed us to explore the relationships between the two indexes

The aim of this part of the work is the assessment of the human disturbance on the riparian areas of 32 river sub-catchments in the Province of Ravenna (Figure 1) and neighbouring areas, through the use of the landscape development intensity index (LDI) (Brown and Vivas, 2005) and through the comparison of the results to existing data of vegetation naturalness index (IVN) for the same areas (Ferrari and Dell’Aquila, 2001; Ferrari, 2008). The integrated use of LDI and IVN allows the coupling of a thermodynamic approach and a landscape ecology based approach to riparian ecosystems.

High correlation of LDI to total nitrogen, total phosphorous loads and to the Wetland Rapid Assessment Procedure score (WRAP) and the Florida Wetland Condition Index (FWCI) have been shown for Florida’s wetlands (Brown and Vivas, 2005; Reiss and Brown, 2007). The LDI index has also been proposed as one of the 4 components of the human disturbance gradient (HDG) (Fore et al, 2007), a multi-metric index developed for quantifying human disturbance on rivers.

The study area consists of the upper catchments of the “Fiumi Romagnoli”, a system composed by 6 main rivers and several streams that are located in the Ravenna Province and in the nearby territories, in northern Italy. LDI and IVN values have been calculated for a 100 m buffer on each side of the stream, for each sub-catchment area. Geo-referenced data provided by the Geology and soil Department of the Emilia-Romagna Region have been used, together with areal empower intensities.
**Table 1. Methods and Indices used in this work.**

<table>
<thead>
<tr>
<th>METRIC</th>
<th>SHORT DESCRIPTION</th>
<th>UNIT</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario building</td>
<td>IPCC (1994) defines a scenario as a coherent internally consistent and plausible description of a possible future state of the world. The communicative role of a scenario is very important: it needs to be stimulating and to provide a narrative able to help decision makers think at big scales, both temporal and spatial. The role of scenarios is also that of a tool for communicating to a wide audience, providing information in a clear and easy to grasp form.</td>
<td>/</td>
<td>IPCC, 1994; Alcamo, 2001; Nakicenovic et al., 2000</td>
</tr>
<tr>
<td>Emergy synthesis and emergy indexes</td>
<td>Energy is a unit of measure introduced by Odum (1996), to take into account all the resources (natural and manufactured) sustaining a system. It is the quantity of equivalent solar energy needed to obtain a product or an energy flow in a given process. Emergy flows are grouped into renewable (R), local non-renewable (N) and imported emergy (F). Several indexes: ED Empower density; ELR Environmental Loading Ratio; EYR Energy Yield Ratio; %Ren renewable fraction.</td>
<td>Sej</td>
<td>Odum, 1996</td>
</tr>
<tr>
<td>Landscape Development Intensity – LDI</td>
<td>Landscape development intensity (LDI) is an index calculated from the Areal empower density. LDI is used as an index of the human disturbance gradient. LDI is a suitable metric for the disturbance gradient that results from increasing human use of landscapes. The LDI scale encompasses a gradient which goes from undeveloped to highly developed landscapes.</td>
<td>ha</td>
<td>Brown and Vivas 2005; Vivas and Brown, 2006</td>
</tr>
<tr>
<td>Carbon dioxide equivalent emissions</td>
<td>Carbon dioxide equivalent production is used to identify and quantify anthropogenic sources and sinks of greenhouse gases.</td>
<td>Tons of CO₂eq/(person yr)</td>
<td>Eggleston et al., 2006</td>
</tr>
<tr>
<td>Ecological Footprint (EF) and Biocapacity</td>
<td>Ecological footprint (EF) is a measure of the consumption of renewable natural resources by the human population of a territory. Biocapacity, or available biological capacity (ABC), refers to the capacity of a given biologically productive area to generate a continuous supply of renewable resources and to absorb wastes deriving from their consumption. Unsustainability occurs if the area’s ecological footprint exceeds its biocapacity.</td>
<td>ha</td>
<td>Wackernagel and Rees, 1996; Wackernagel et al. 1999; 2004; 2006</td>
</tr>
<tr>
<td>Biological Territorial Capacity Index - BTC</td>
<td>Biological capacity potential or biological territorial capacity (BTC) is a measure of ecosystem function based on stability, vegetation type and metabolic data of vegetation. BTC provides an assessment of the state of ecosystems and their resilience. The unit is MJ/m² * yr.</td>
<td>ha</td>
<td>Ingegnoli, 1993; Ingegnoli and Pignatti 2007</td>
</tr>
<tr>
<td>Percolation Index</td>
<td>Percolation index is defined building on the study of the behaviour of fluids spreading randomly through a medium, and it can be considered a connectivity measure of landscapes.</td>
<td>/</td>
<td>Farina, 2006</td>
</tr>
<tr>
<td>Index of vegetation naturalness - IVN</td>
<td>The IVN is based on the so-called ‘analysis of vegetation naturalness’, based mainly on species composition and vegetation structure, whose core is represented by the assessment of the condition of a site’s native vegetation, which in turn requires a benchmark against which the existing vegetation can be assessed. The index is an extension of the Index of Landscape Conservation (ILC) and it is used in the quantitative analysis of vegetation naturalness maps, with the aim of assessing the naturality of landscape, taking into account species composition and plant communities as a basis for further comparisons with other naturalness parameters. IVN ranges from 1 (DE = ‘natural’) to 0 (DA = ‘urbanized’).</td>
<td>/</td>
<td>Ferrari et al., 2008; Pizzolotto &amp; Brandmayr, 1996</td>
</tr>
<tr>
<td>IFM index</td>
<td>Mean Animal Cenote index, or IFM (Indice Faunistico cenotico Medio) provides an estimate of biodiversity.</td>
<td>/</td>
<td>Santolini and Pasini, 2007</td>
</tr>
<tr>
<td>Sprawl Index</td>
<td>Sprawl index assesses territorial artificialization.</td>
<td>/</td>
<td>Marotta et al., 2008</td>
</tr>
<tr>
<td>Fractal Dimension</td>
<td>Fractal dimension is applied in order to assess the complexity of the landscape texture.</td>
<td>/</td>
<td>Ingegnoli, 2002</td>
</tr>
<tr>
<td>Shannon Diversity Index - SI</td>
<td>Shannon Diversity Index (SI) is used in order to assess the diversity of the patches.</td>
<td>/</td>
<td>Ingegnoli, 2002</td>
</tr>
</tbody>
</table>
Figure 1. Italy (white), Emilia Romagna Region (green) and Ravenna Province (red).

(AEIs) obtained by literature review (Brown and Vivas, 2005 and Marotta and Marazza, 2006). The LDI index value was calculated for each sub-catchment as proposed by Vivas and Brown (2006). In the equation, AEI coefficients play the role of weights. Land uses have been described as percentage for the following LU classes: natural (N), agricultural (A), residential/ productive (R) areas and artificial areas (A+R). The sum of residential and agricultural land uses (R+A) represent the total human dominated percentage within a study area. The correlation between metrics has been investigated through the use of two different correlation coefficients: the Pearson’s product moment correlation and the Spearman’s rank correlation coefficient, using the algorithm proposed by Myers et al (2003).

2) An analysis of the mouth and final stretch of river courses in the Ravenna Province and surrounding areas calculated through time at different spatial scales by using LDI, BTC, Percolation, Sprawl index and IFM

In this application, a range of indexes (Jørgensen et al., 2005) have been calculated for the final parts of the rivers in Ravenna Province and surroundings, with the aim of assessing the ecosystems’ health (Costanza, 1992). Geo-referenced data have been used for the a part of the northern Adriatic sea cost, including the provinces of Ravenna, Forlì-Cesena and Rimini, and for the mouth of the rivers Reno, Bevano and Conca.

We evaluated the human pressure on landscape and on the quality and functionality of river mouth ecosystems in an area which is heavily impacted by human activities. The evaluations were performed for a time-range running from 1976 to 2008, thanks to the use of land use maps realized by the Emilia Romagna region for the years 1976, 1994 and 2003. For each index, mean values associated with land use categories of Corine Land Cover (CLC) available in literature (Marotta and Mulazzani, 2006; Marotta et al., 2007) were used.

3) An analysis of landscapes from Ravenna Province and Nearby territories, which allowed us to explore the correlation between emergy indexes (imported emergy) and landscape indicators such as fractal dimension, Shannon diversity index, BTC

Starting from the results of others (Patil and Myers, 1999; Brown, 2003; Brown and Vivas, 2005, references in Vivas and Brown, 2006) 6 sites in the Ravenna Province and other locations in Northern Italy have been investigated by image processing in order to couple landscape ecology indicators and imported emergy (normally indicated as the F term in the emergy equations).

The following landscape indicators have been used:
- fractal dimension (Df1, Df2), in order to assess the complexity of the landscape texture;
- Shannon Diversity Index (SI), in order to assess the diversity of the patches;
- Biological Territorial Capacity Index (BTC), in order to assess the biomass production and respiration rate.

References to all these methods are contained in Ingegnoli (2002).
The environmental loading ratio (ELR) and imported emergy have been evaluated in order to highlight the relationship between the landscape structure and the required emergy input.

**RESULTS**

**Multi-Criteria Assessment of the Ravenna Province**

The evaluation of the sustainability of a territory implies the ability to express a comprehensive judgement on the situation, in order to provide the decision maker with a reference scale for the distance from “optimal condition” and help him or her define appropriate policies for improvement in conformity with his own objectives. It is very important to have complete knowledge of the condition of the territory prior to the application of policies, for this indicates movement from/toward the optimal condition. The metrics with which to measure these shifts have to be defined from the beginning of the decision making process. When more than one criteria is used, we call the process a Multi-Criteria Assessment – MCA (Munda, 2008). MCA is a comparison procedure among multiple criteria, whose aim is to contribute to the knowledge of the system, which then feeds a decision making or assessment process. In this work, a group of evaluation criteria has been used to characterize the province of Ravenna, while the decision making phase is not addressed here. The metrics described in the “Methods” chapter, a clear picture is given of the studied territory, and next to some of its components.

The values of BTC and LDI have been evaluated for each municipality of the province, and for relevant groups of them. In Figure 4 the values of LDI and BTC are shown for the municipalities located in the hills, coast and plains area of the province of Ravenna. The municipalities located in the hills present very low LDI values, corresponding to the relevant presence of forests and rocky areas. They also have the highest BTC values, indicating a good condition of the ecosystems. The municipalities in the coastal area show opposite results, with high LDI values and low BTC. The
municipalities located in the plain show a very low BTC, due to the presence of intensive agriculture (Figure 5).

These data suggest that the MCA should be conducted at different spatial scales, or better with geo-referenced data covering all the provinces, in order to highlight the existing variability.

**District Resource Management**

At a district level, local authorities in Italy are required to produce an energy plan which must include actions for energy saving, for the reduction of CO₂ emissions and for an increased use of renewable sources of energy (Emilia Romagna Region, 2004). In order to support the energy planning process in the Ravenna Province (Provincia di Ravenna and CIRSA, 2009), three quantitative scenarios have been defined with the support of the software LEAP (Long Term Energy Alternatives Planning System), developed by Stockholm Environment Institute, which has been made freely available for study and research purposes. Scenarios have been built starting from the baseyear 2006 and up to 2020.

Once the scenarios were defined, an emergy diagram has been drawn for the baseyear system, and an emergy synthesis has been carried out for the actual situation and for the 3 “possible” futures.

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**Figure 3. Territorial metabolism of the Province of Ravenna. 2006 values.**

**Figure 4. LDI and BTC values for the whole province and the municipalities located in the mountain, coast and plain areas. 2006 values.**
This has to be properly underlined: not all the flows in the province of Ravenna have been included, but only those related to the supply, distribution, transformation and consumption of energy.

The three scenarios have been defined as follows:

1) a Business as Usual scenario (BAU), which envisages the prosecution in the future of the actual trends;
2) a “Plan application” scenario (PEP), which is an anticipative scenario, in the sense that it is defined as a scenario which is able to reach the targets defined in the “20 20 by 2020” document by the European Commission (EC, 2008) on energy saving, green energy production, greenhouse emissions reduction, together with other targets defined at the international, national and regional level.
3) a “Self-sufficiency” scenario which foresees the production of electricity only for internal consumption.

The defined scenarios gave annual results in terms of energy transformation, energy consumption and greenhouse gases emissions, divided for economic sector and kind of fuel. All scenarios build on the situation of the year 2006, which is represented in Figure 6; some of the main features of this energy system are listed below:

- Methane is extracted both on and off-shore in the Province, with an annual extraction equal to about 6E+9 m$^3$/year.
- Two big methane-fired plants are present in the harbour area, which produce an amount of electricity which for 1/3 is consumed in the province and for 2/3 is entered in the national grid.
- Petroleum fuels reach the province mainly through the harbour; the majority of them is not consumed internally but transits to neighbouring territories.
- There is a production of electricity from renewable sources which is negligible if compared to the total production, but significant if compared to the internal consumption.

From the emergy evaluation, some emergy indexes were calculated and are shown in Table 2. The emergy signature of the system in the baseyear 2006 is shown in Figure 7. The baseyear results have been evaluated in three different ways, depending on the attribution of the methane flows to the N or F categories, and to the inclusion or exclusion of transit flows. If methane is considered as an F flow, then the EYR of the energy system is equal to 1.1, which pictures a complete detachment between the energy system and the territory which hosts it. The exclusion of transit flows reduces EYR by 40%, indicating a “passageway” use of the territory. The presence of a commercial harbour makes the Ravenna province a passageway not only for energy carriers, but also for goods. In this case, EYR is between 3 and 4, indicating an important local contribution to the process (methane is included in the...
Provincia di Ravenna 2006

Figure 6. Baseyear flows of energy carriers in the Province of Ravenna. The upper arrow represents methane flows, the central one represents electricity and the lower one petroleum fuels.

N flows here). ELR indicates a severe stress on the natural environment, whose structure is far away from its natural shape. The exclusion of the transit flows, anyway, does not take into account the increased environmental risk they generate.

BAU scenario does not vary significantly from baseyear values. Self-sufficiency scenario has empower densities and emergy/person which are 50% lower than the 2006 values. As methane is considered a local resource, its missed use influences the EYR value, which is 2.1, significantly lower than in the other scenarios. ELR and %Ren, instead, show the best results among the baseyear and other scenarios values.

PEP scenario shows an increase in the total yield of the energy system, which scores 4.48 thanks to the increased use of local renewable resources. This allows also for a lower value of the ELR index, which in this case is 32.54 versus 62.72 for the BAU scenario.

%Ren is very low in all considered scenarios, ranging from 1 to 5.2%. As for the compliance with international or national targets (which concern energy saving, renewable energy production and greenhouse emissions reduction), BAU scenario does not comply with any of the three. PEP scenario does manage to comply with all the three targets, but only if the surplus electricity generated in the province is not accounted for, both in terms of energy production and emissions.

Self-sufficiency scenario does achieve the targets on renewable energy production and greenhouse emissions reduction, but does not comply with the energy saving target.
Table 2. Main emergy indexes for the actual situation and the three scenarios.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>2006 - methane considered as a local resource</th>
<th>2006 - methane considered as an imported resource</th>
<th>2006 - methane considered as a local resource and transit flows of fossil fuels excluded</th>
<th>2020 - PEP scenario</th>
<th>2020 - BAU scenario</th>
<th>2020 - self-sufficiency scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y/P</td>
<td>Emergy/person</td>
<td>4.41E+16</td>
<td>4.41E+16</td>
<td>2.72E+16</td>
<td>2.48E+16</td>
<td>2.90E+16</td>
<td>1.61E+16</td>
</tr>
<tr>
<td>Y/A</td>
<td>Empower density</td>
<td>sej/m²*yr</td>
<td>9.15E+12</td>
<td>9.15E+12</td>
<td>5.64E+12</td>
<td>5.15E+12</td>
<td>6.01E+12</td>
</tr>
<tr>
<td>EYR</td>
<td>Emergy yield ratio (Y/F)</td>
<td>3.73</td>
<td>1.01</td>
<td>3.88</td>
<td>4.48</td>
<td>3.65</td>
<td>2.10</td>
</tr>
<tr>
<td>ELR</td>
<td>Environmental loading ratio (N+F)/R</td>
<td>97.05</td>
<td>97.05</td>
<td>59.14</td>
<td>32.54</td>
<td>62.72</td>
<td>18.02</td>
</tr>
<tr>
<td>ESI</td>
<td>Emergy index of sustainability (EYR/ELR)</td>
<td>0.038</td>
<td>0.010</td>
<td>0.066</td>
<td>0.138</td>
<td>0.058</td>
<td>0.117</td>
</tr>
<tr>
<td>% Ren</td>
<td>% renewables</td>
<td>%</td>
<td>1.02%</td>
<td>1.02%</td>
<td>1.65%</td>
<td>2.98%</td>
<td>1.57%</td>
</tr>
<tr>
<td>% Local</td>
<td>eMergy investment ratio F/(N+R)</td>
<td>0.367</td>
<td>97.053</td>
<td>0.350</td>
<td>0.288</td>
<td>0.378</td>
<td>0.906</td>
</tr>
</tbody>
</table>

Figure 7. Emergy signature of the energy system of the Ravenna Province – year 2006.

These results show how both PEP and self-sufficiency scenarios present overall better scores than the BAU one. In particular, Self-sufficiency scenario has by far the best ELR value, but presents a much lower EYR then PEP scenario, and it doesn’t comply with international targets on energy saving.

Surely, the definition of another scenario, building on the Self-sufficiency one but including actions for energy saving may be an interesting evolution of this research.

In order to estimate the emergy magnitude of the energy system in comparison to the whole province of Ravenna (estimated yield of 3E+22 sej/year, our estimate on 2000 data), the energy system accounts for about 30% of the total yield.

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Exploring the relationships between LDI and IVN: an approach on riparian buffers

The sum of the percentage of residential and agricultural land uses (R+A) is highly positively correlated to the IVN values (Pearson’s r = -0.88), as was well expected. This makes the physical effect of the substitution of natural ecotypes with human dominated land uses explicit.

IVN and LDI show a high correlation coefficient (Spearman’s r = -0.82, α<0.0001, which is a nonparametric correlation statistic), meaning that they give very similar results for the classification of sub-catchments in terms of ‘impairment’ or ‘affection by human disturbance’ (Table 3).

Biases in the LDI index evaluation are due to two main causes: the use of generic AEI coefficients that are not specifically evaluated for the study area, and the gap in time between the land use map that has been used for evaluating LDI values (updated in 2003) and the vegetation maps used for calculating IVN values (updated in 2000). These biases can significantly affect the LDI values and the correlation between the two metrics.

The relationship between the IVN/LDI ratio and the dimension of the sub-basin has been investigated in order to verify if there are scale effects on the IVN/LDI ratio. Catchments located in the upper hills are characterized by smaller dimension than the ones located in the medium hills and the lower hills. The highest values of the IVN/LDI ratio are observed for the upper hill basins; this is probably due to the pristine condition of the upper catchments compared to the others, suggesting that the relationship between LDI and IVN for catchments that are located in the mountain is not linear (Figure 8).

In general, the observed difference between IVN and LDI values is due to the fact that LDI accounts for integrated pressure on ecosystems, both direct and indirect. Then, it is relevant to note that the LDI index is able to include all the emery inputs that flow in a given system, embedding the concept of human disturbance on a planetary scale and thus overcoming the local scale of the assessment. For instance, the use of electricity in a house that stands within the 100 meters buffer of a river, has surely an indirect effect on ecosystems at global scale due to the consumption of fossil fuels for generating electricity and the consequent production of CO₂, but it has an irrelevant direct effect on the riparian system, that is more directly impacted by land use modifications.

Analysis of the mouth and final stretch of river courses through various indexes calculated through time at different spatial scales

At the regional scale (coastal areas) we can observe all the values of the human pressure indexes (Sprawl, LDI) increase over time, while the values of ecosystem functionality indexes (BTC, IFM, percolation) decrease (Table 4). The northern coast, corresponding to the Province of Ravenna, while presenting a worsening of the values of the human pressure indexes, remains constant or even improves in the values of the ecosystem function indexes. The southern coast (Provinces of Forlì-Cesena and Rimini) results to be the area subject to major human pressure. At the local scale of river mouths, the Conca river appears to be in a worse condition than the coast to which it belongs, unlike the rivers Reno and Bevano which appear in a better condition than the coast to which they belong.

Table 3. Spearman’s correlation coefficients among the considered metrics.

<table>
<thead>
<tr>
<th>Spearman’s rank correlation (rs)</th>
<th>IVN</th>
<th>LDI</th>
<th>Residential</th>
<th>Agricultural</th>
<th>Natural</th>
<th>R+A</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVN</td>
<td>1</td>
<td>-0.84</td>
<td>-0.43</td>
<td>-0.84</td>
<td>0.90</td>
<td>-0.92</td>
</tr>
<tr>
<td>LDI_1</td>
<td></td>
<td>1</td>
<td>0.72</td>
<td>0.68</td>
<td>-0.84</td>
<td>0.84</td>
</tr>
<tr>
<td>LDI_2</td>
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<td>0.93</td>
<td>0.34</td>
<td>-0.57</td>
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<tr>
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<td>0.22</td>
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Table 4. Main results from the analysis of the mouth and final stretch of river courses.

<table>
<thead>
<tr>
<th>STUDY AREA</th>
<th>LDI</th>
<th>BTC</th>
<th>PERCOLATION</th>
<th>IFM</th>
<th>SPRAWN INDEX</th>
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<tbody>
<tr>
<td></td>
<td>year</td>
<td>mean</td>
<td>mean value</td>
<td>value</td>
<td>temporal frame</td>
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<td></td>
<td></td>
<td>value</td>
<td>MJ m⁻² yr⁻¹</td>
<td></td>
<td>value</td>
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<td>1976</td>
<td>2.54</td>
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<td>4.61</td>
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<tr>
<td></td>
<td>1994</td>
<td>4.16</td>
<td>4.83</td>
<td>0.46</td>
<td>4.48</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>5.34</td>
<td>4.56</td>
<td>0.44</td>
<td>4.16</td>
</tr>
<tr>
<td>NORTHERN COAST</td>
<td>1976</td>
<td>2.56</td>
<td>4.59</td>
<td>0.47</td>
<td>4.56</td>
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<td></td>
<td>1994</td>
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<td>5.07</td>
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<td></td>
<td>2003</td>
<td>4.88</td>
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<td>0.46</td>
<td>4.58</td>
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<td>SOUTHERN COAST</td>
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<td>0.52</td>
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<td>2003</td>
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<td>7.40</td>
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<td>5.97</td>
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<tr>
<td>BEVANO CREEK MOUTH</td>
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<td>1.85</td>
<td>8.39</td>
<td>0.62</td>
<td>5.43</td>
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<tr>
<td></td>
<td>1994</td>
<td>2.08</td>
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<td></td>
<td>2003</td>
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<td>10.83</td>
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<td>CONCA RIVER MOUTH</td>
<td>1976</td>
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<td>0.59</td>
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<td></td>
<td>2003</td>
<td>6.22</td>
<td>3.66</td>
<td>0.36</td>
<td>3.07</td>
</tr>
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</table>

Results highlighted a severe trivialization of natural ecosystems in the coastal plain, characterized by the widespread phenomenon of "urban sprawl" which increases the hydrological and ecosystem vulnerability by fragmenting agricultural areas, besetting natural ecosystems and reducing the room for the river banks. However, there are a few remaining wetlands with excellent natural resources, which are at risk of becoming isolated due to human pressure and abandonment of some traditional agricultural activities.

Results have been used by decision makers in the context of Integrated Coastal Zone Management for the choice of priorities in the protection, rehabilitation and restoration of coastal wetlands.

An evaluation of correlations between indexes resulted in a high negative correlation between LDI and Percolation.
Coupling emergy synthesis and landscape ecology

Results showed that there is an effective correlation between landscapes indicators and imported emergy, with homogeneous or rectilineous landscapes having a higher import of external emergy (Figure 9), and suggested that it is possible to define an optimal ratio between the landscape settlement and ecosystem services.

DISCUSSION AND CONCLUSION

The data acquired on the Ravenna Province in the context of the MCA should be used as thresholds against which to measure the future states of the territory. As the identified metrics are not strictly related to environmental policies, the proposed set of metrics could be used as a set of indicators for the monitoring of all local plans and policies. The selected metrics imply that a good policy for the territory should obtain the following results: decrease the ELR of the system, the imported emergy (F), LDI and ecological footprint, reduce the amount of waste, improve the values of BTC, Shannon index and IVN.

In the context of energy management at local and regional scales, emergy synthesis enabled us to evaluate the overall environmental performance of the use of local resources: of the three scenarios which were evaluated, the one which includes the use of less local methane (N resource) resulted in a much lower value of EYR.

Emergy synthesis also highlighted the importance of a correct use of electricity and in general of energy carriers, which should be only applied when other energy carriers of lower quality cannot be exploited.

The definition of a fourth scenario, which integrates the “self-sufficiency” scenario with the actions for energy saving foreseen by the PEP scenario, may represent an interesting option to be provided to policy makers in the context of the regional energy planning process.

In the context of landscape management, the use of LDI gave a good statistical correlation with the IVN index. Still, a study which involves the calculation of spatial indices should be carefully designed, for the scale of the sample landscapes can influence the outcome of the research: in particular, the smaller the samples, the more fluctuating can be the results. The correlation between LDI and IVN shows that LDI can be useful as a first-assessment tool for predicting regions of potential ecosystem impairment, when land use maps or satellite images are available; nevertheless, even if LDI index takes into account different source of pressure, it probably overestimates the pressure on the naturalness of the riparian buffer vegetation.

![Imported Emergy versus Shannon Index in three sites](image)

*Figure 9. Plot of imported emergy versus Shannon index for the investigated sites.*
LDI provides different information from single landscape metrics, without substituting them. The best use of these metrics is the development of a multi-criteria approach, where resource intensity-based indicators, such as LDI and landscape metrics, such as IVN or BTC, are integrated.

The downscaling of the MCA to wetlands and river mouths in the Ravenna province can be a useful tool for assessing the sustainability of coastal ecosystems, in the context of the integrated management of coastal zones.

To conclude, we experimented with the coupled use of emergy and LDI indexes with other metrics: indexes derived from landscape ecology in the case of landscape management, and CO₂ emission and normative compliance in the case of local resource management. This was done in order to reveal the correlation among these indices and assess if the positive or negative value of global indices is reflected also by the value of local metrics on biodiversity and landscape.

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