Ecological Modelling 271 (2014) 103–112

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

An emergy–GIS approach to the evaluation of renewable resource flows: A case study of Campania Region, Italy

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ARTICLE INFO

Article history:
Available online 9 February 2013

Keywords:
Geographic information system
Emergy assessment
Spatial planning
Decision support system
GRASS

ABSTRACT

Natural resources are not uniformly distributed over the landscape and, as a consequence, different areas support different social and economic development challenges. In this context, geo-referred information plays a paramount role in the dynamics of economies and their interaction with the environment. Synergic use of geographic information system (GIS), spatial planning (i.e. land use, urban, regional, and environmental planning) and emergy assessment may provide a very meaningful framework toward sustainability. Measuring resources in emergy terms means to quantify their environmental worth to all species in a given area: the integration of emergy and GIS allows the description of the spatial distribution of these resources and consequently the assessment of land's intrinsic environmental value, in support of land use planning policies. Thematic maps showing the distribution and environmental quality of renewable emergy flows (solar radiation, rainfall, wind, and geothermal heat) in Campania Region (Southern Italy) are presented in this work, all converging toward the generation of an annual renewable areal empower density (seJ ha^{-1} $year^{-1}$) map. These maps are useful to identify the primary resource flows that are locally available in support of sustainable land use and production patterns. The main results show that natural areas have the highest annual renewable areal empower density (11.30E + 14 seJ ha^{-1} $year^{-1}$) among all the different regional land use patterns, much higher than the average value of Campania Region (7.22E + 14 seJ ha^{-1} $year^{-1}$). The 59.64% of the total annual renewable emergy converges to natural areas although they are only about 38.15% of the total regional land use. The proposed approach allows to classify regional areas according to their environmental value, thus providing useful policy information oriented toward supporting and conserving environmentally valuable land and natural resources.

1. Introduction

Sustainability management takes on multiple spatial and temporal scales of reference simultaneously due to the fact that economic, social, and environmental processes are inherently spatial. They can hardly be fully understood without taking into account their spatial dimensions (Bateman et al., 2002). Spatial planning can be used as an instrument to coordinate socioeconomic development preventing environmental problems and protecting the natural and the cultural environment (Eade and Moran, 1996; Troy and Wilson, 2006).

During last decades one of the undeniable priorities in the effective environmental management at regional level has been the optimization of resource use and the conservation of sites hosting endangered natural capital. In order to be in a position to make decisions about how the limited resources are used and managed within an existing area, it is preliminarily necessary to understand how effectively resource conservation is addressed at present in any given area. Considering a regional scale management, information about the local concentration and availability of natural resources need to be organized in an accessible and usable format for long-term use by local people and public administrators in order to monitor the effectiveness of policy actions and ensure that planning and decision-making processes are open to all stakeholders. To such purpose, regional spatial planning requires availability of data and tools to be integrated in complex information systems. The use of a geographic information system (GIS) framework may be considered one of the most advanced tools to enable and facilitate this policy challenge (Randolph, 2004). GIS is increasingly being used for environmental policy and ecosystem management (Rauscher, 1999), mapping the value of ecosystem services and resources accessibility (Chen et al., 2009; Huang et al., 2011).

Needless to say, proper accounting for the environmental value of resources and their use is a crucial point in order to make

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0304-3800/$ – see front matter
http://dx.doi.org/10.1016/j.ecolmodel.2012.12.023

better decisions regarding the sustainable development of a territorial system. The emergy assessment method (Odum, 1996; Brown and Ulgiati, 2004, 2010) calculates the value of resources by quantifying the work invested by the geobiosphere to develop and stabilize an ecosystem structure, growth, organization and diversity, measured in solar emergy Joule (seJ) (Huang et al., 2011; Dong et al., 2012). The combined effect of the solar energy, deep Earth processes and gravitational energy is the fuel of the "world engine". The heated ocean and atmosphere store and transform the solar energy through a living low-temperature heat engine generating winds, rain streams and ocean currents (Odum, 2007) and ultimately biodiversity and life. All the natural flows sustain the geobiosphere processes, organizing ecosystems and supporting human-dominated systems. The different types and amounts of energy received by the Earth ecosystems and organisms are not spatially uniform, due to the irregular characteristics of natural environment, generating a spatial pattern of landscape (Huang et al., 2001; Lee et al., 2009). Understanding how this pattern is organized and measuring quantitatively the environmental flows could be useful to understand the environmental support to the local economy and to locate the different resources and ecosystem services. It is of paramount importance in order to supply the information needed to policymakers for environmental planning, aimed at protecting areas where natural flows converge and accumulate.

Some authors have suggested the combined use of spatial information and environmental accounting methods, underlining how important the spatial dimension can be for environmental decision-making. Brown and Vivas (2005) proposed an index, the landscape development intensity (LDI), based on emergy assessment and GIS, computing the level of human disturbance on the biological, chemical, and physical processes of lands or waters. Huang et al. (2007) suggested an integration between GIS and energetic principles relating them to spatial hierarchy in order to simulate the evolution of an urban system due to changing energy flows. Agostinho et al. (2008) enhanced the combined use of GIS and emergy assessment in order to compare the environmental performance of family-managed farms in Brazil. Pulselli (2010) integrated emergy flows into GIS, in order to represent their spatial distribution throughout the Abruzzo Region (Italy) and to assess environmental resources use by local communities.

In this work the integration of environmental accounting methods into a GIS framework is suggested as a valuable resource management tool in support of local land use planning. Land use change impacts human environmental health, hydrological systems, ecological resources, energy and material consumption, cultural heritage and community character, and environmental justice (Randolph, 2004); thus land use must be carefully planned to protect natural capital and to preserve ecosystem services. The proposed approach uses the emergy assessment integrated in a GIS framework in order to quantify and map the regional distribution of environmental flows (solar radiation, rainfall, wind, and geothermal heat), thus offering an emergy (environmental support) perspective of the spatial distribution of natural flows within a regional boundary. The resulting maps show the annual renewable areal empower density of the region and describe the environmental value of lands, estimated on the basis of the concentration of renewable flows. Furthermore, quantifying the value of renewable flows throughout a region means understanding the spatial distribution of ecosystem services supporting all species and human society in particular (Brown and Campbell, 2007; Campbell and Brown, 2012). The added value of integrating emergy within a GIS framework relies on the possibility to go beyond the simple, though useful, description of resources as such, and characterize resource quality by means of their convergence patterns and biosphere support concentration over time and space.

2. Materials and methods

2.1. Case study area

The study area is the Campania Region, located in the southern part of Italian Peninsula. The region has a population of about 5,834,000 inhabitants and a total area of 13,595 km^2 (ISTAT, 2012) that make it the second most populous and the most densely populated Region of Italy. Campania Region urgently needs a powerful and effective environmental planning in order to preserve its natural heritage of resources and solve the huge environmental problems caused by the lack of an appropriate land use management (ARPAC, 2009; D'Alisa et al., 2012).

A digital elevation model (DEM) of the region is provided in Fig. 1a showing the orographic conformation of the Region (data from NASA, 2009). The regional landscape is prevalently hilly with an average altitude of 436 m AMSL (above mean sea level). Fig. 1b shows the different land uses (data from Corine Land Cover, 2010) within the selected area: agricultural areas (54.95%) and natural areas (38.15%) cover more than 90% of regional land. The hierarchy of partially overlapping DEM and land uses is visible in both figures, with large hilly areas that converge rainfall toward a smaller amount of plain land (Fig. 1a), and large agricultural and forested soils supporting a much smaller amount of densely populated and urbanized areas (Fig. 1b).

2.2. Emergy assessment

The emergy assessment method (Odum, 1996; Brown and Ulgiati, 2004, 2010) looks at the environmental performance of a system from the biosphere point of view, considering the resource generated by nature and its dynamics. In addition to the input flows of mineral and fossil energy resources, the emergy accounting approach takes into account all the free environmental inputs (such as sunlight, wind, rain, and geothermal heat) as well as the indirect environmental support embodied in human labor and services (i.e. the environmental support to human productive activities within the economic and societal systems), which are not usually included in the other methods such as economic or energy evaluations (Franzese et al., 2009). The accounting is extended back in time to include the environmental work needed for resource formation. In so doing, the emergy method provides a biophysical assessment of the environmental support to the generation of natural capital (resource stocks) and ecosystem services (resource flows). In the emergy method, all inputs are accounted for in terms of their solar emergy, defined as the total amount of solar available energy (exergy)[1] directly or indirectly required to make a given product, service or to support a given flow, measured in units of solar equivalent Joules (seJ) (Odum, 1996).

The amount of emergy that is required to generate one unit of each product or service is referred to as its unit emergy value (UEV) or emergy intensity. This value is used to convert matter and

[1] "Exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes, involving interaction only with the abovementioned components of nature" (Szargut, 1980). The reference environment for Szargut is seawater, dry atmospheric air and the external layer of Earth crust composition depending on the different chemical species. Since other authors use different reference environments (Gaggioli and Petit, 1976; Ahrendts, 1980; Serova and Brodianski, 2002; Valero, 2008; Exergoecology Portal, 2012), multiplicities of reference exergy values are possible. When the reference environment is the standard laboratory conditions for pressure and temperature, the term available energy is most commonly used. In this paper we use the more general term "available energy" and refer to average environmental parameters for temperature and pressure as explained in the text, unless the quoted references use the term exergy.