Journal of Environmental Management 88 (2008) 326–347

Journal of Environmental Management

www.elsevier.com/locate/jenvman

# Environmental accounting as a management tool in the Mediterranean context: The Spanish economy during the last 20 years

Pedro L. Lomas*, Sergio Álvarez[1], Marta Rodríguez, Carlos Montes

*Laboratorio de Socio-ecosistemas, Dpto. Ecología, c/Darwin, 2 Despacho C-201, Edificio Biología, Facultad de Ciencias, Universidad Autónoma de Madrid, 28049 Madrid, Spain*

Received 2 March 2006; received in revised form 6 February 2007; accepted 10 March 2007
Available online 10 May 2007

**Abstract**

Although human presence is one of the main characteristics of the Mediterranean identity since ancient times, a false dialectic between conservation and social–economic development has emerged in recent decades. On the one hand, an economic growth policy is taken as the paradigm of social–economic development; on the other hand, there is a multi-scale conservation policy, in which natural protected areas, as patches of preserved nature, are used as one of the main tools to deal with the challenge of sustainability. The Mediterranean Basin is the habitat of many unique species and one of the 25 main biodiversity hotspots in the world, and as a consequence a strong conservation policy has been used to protect environmental values. At the same time, Mediterranean countries are deeply involved in promoting strong economic growth policies, which are not always compatible with environmental ones. In this paper, Spain has been studied as one model of this situation. Due to political reasons, Spanish economic growth and conservationist policies were pursued together during the last 20 years. As a result, Spain owns one of the largest networks of natural protected areas in Western Europe, and at the same time it has experienced one of the strongest periods of economic growths in the European and Mediterranean context during the 1980s and 1990s. An historical series of resource use in five annual periods in the last 20 years of conservation policy, and the effects on the preservation of natural capital have been investigated by means of the eMergy (spelled with an 'm') synthesis approach, which was used to characterize the flow of environmental services supplied by ecosystems, but not in monetary terms. This study shows that Spain is becoming less self-sufficient and more inefficient in resource use, comprehensively measured in eMergy terms. A large part of Spain's economy depends on imported goods and services, and most economic activities are based on tourist services and associated construction, which promotes intensification in the urban use of the territory and more intense environmental impacts and resource use intensification of those countries supplying the raw materials. The consequence is a decoupling of the Spanish economy from local environmental services and the increase of Ecological footprint of Spain, measured by means of eMergy-based indicators. In spite of the increase in number, area and associated budget of the natural protected areas and other conservation measures, the general sustainability of the nation is decreasing.


*Keywords:* eMergy synthesis; Spain; Sustainability indicators; Conservation policy

## 1. Introduction

### 1.1. Background

The recent millennium ecosystem assessment (MEA) Synthesis Report (MA (Milleninum Ecosystem Assessment), 2005) estimates that one third of the planet that has been altered for production purposes. This report shows that 50% of freshwater from rivers and lakes is eventually used by society, and that human activities produce more biologically available nitrogen than all natural cycles combined. Furthermore, this study estimates that 60% of the 24 great global ecosystems are experiencing degradation, and that extinction rates are increasing from 100 to 1000 times over the average estimated for geological time. In addition, they found that up to 20% of known species in many groups are disappearing. These figures are much

*Corresponding author. Tel.: +34 914978008; fax: +34 914978001.
*E-mail address:* pedro.lomas@uam.es (P.L. Lomas).
[1]Present address: Subdirección General de Relaciones Internacionales, Secretaría General Técnica, Ministerio de Medio Ambiente, Plaza de San Juan de la Cruz, s/n. 28071 Madrid, Spain.

0301-4797/$ - see front matter 
doi:10.1016/j.jenvman.2007.03.009

worse than those calculated before MEA (Postel et al., 1996; Vitousek et al., 1986, 1997; Rojstaczer et al., 2001), and turn the ideas of ''natural environment'' or ''wild nature'' as isolated areas without human participation into a fantasy. In this context, the concepts of Noosphere (Verdnasky, 1945), a biogeochemical cycling entity dominated by human influences, and Anthropocene (Crutzen and Stoermer, 2000), a new geological era in which main biophysical processes that control global dynamics (ecosphere) are driven by humankind, emerge.

From this perspective, one paradigmatic case is the Mediterranean Basin, where relationships between humans and other (living and non-living) components of ecosystems can be traced to before Neolithic times (Grove and Rackham, 2003), and where many of the original forests had already been used 7000 years Before the Common Era (BCE) (Makhzoumi and Pungetti, 1999). Naveh and Liberman (1993) suggest that we should only speak about cultural landscapes in the Mediterranean context.

In the Mediterranean Basin, 52% of plants, 30.5% of vertebrates, 25% of mammals, 13% of birds, 61% of reptiles and 52% of amphibians are endemic species. Consequently, it is considered as one of the 25 most significant hotspots of biodiversity, paradoxically located in one of the most densely populated areas of the world (Myers et al., 2000; Cincotta et al., 2000). It is generally accepted that this ancient relationship between humanity and nature, which is based on combined exploitation systems (mainly agriculture, forestry and livestock) that adapt human cycles to natural ones reinforcing ecological processes, has promoted biodiversity and long-term sustainability (González Bernáldez, 1991; Pineda and Montalvo, 1995; Schmitz et al., 2001; de Miguel and Gómez-Sal, 2002; García and Montes, 2003).

However, since the 1950s, increases in mechanized farming, population growth and economic globalization have radically changed ancient agricultural, forestry and pastoral practices. Many socio-economic constraints, like agricultural subsidies (mainly European Union Common Agriculture Policy, CAP), rural–urban migration and abandonment of traditional practices and land have affected the historic agro-ecosystems (Grove and Rackham, 2003; Mulligan et al., 2004). These changes are being accelerated by the growth of commercial relations among countries and their socio-economic consequences.

### 1.2. A case study Spain as a social–ecological system

Spain could be considered a typical case presenting the characteristic pattern described in the previous Section. Because of its location and its geological history, Spain is a land of natural contrasts, especially lithologic (lime, siliceous and clayey soils) and climatic ones (Mediterranean and continental in the central-southern area, oceanic in the north, areas of dry subtropical climate in the south-eastern Spain, and specific climatic conditions on mountainous areas all over the country), which create a great variety of ecosystems, from deserts to Atlantic forests. Because of its history and location as a bridge between Europe and Africa, in the Mediterranean framework, Spain is also a land of social contrasts. With four different official languages (Catalonian, Galician, Castilian/Spanish and Basque, the latter being a non-Romance language) and many dialects, Spain is organised into 17 regions and two autonomous cities, each of them with its own government and institutional framework. Although it is the fifth most populous country in the European Union (EU), and its population density has grown considerably in the last century (from 36.79 inhabitants/km$^2$ in 1900 to 81.26 inhabitants/km$^2$ in 2000), Spain has the fourth lowest population density in the EU, so it may validly be considered a relatively rural country in the European context.

Similar to other European countries, many changes have affected traditional exploitation systems in the last decades in Spain. If we use the historical series of official statistics, there has been a loss of cultivated areas (percentage of total area has changed from 40.15% in 1980 to 35.43% in 2002), and a relative increase of irrigated lands (from 13.76% of total cultivated areas in 1980 to 19.35% in 2000). In contrast, Spain has suffered an increase of 2.07% in the item ''other types'', which includes infrastructures and cities (Ministerio de Agricultura, Pesca y Alimentación (MAPA (Ministerio de Agricultura and Pesca y Alimentación), 1991, 1998, On-line). In fact, road density reached 0.32 km/km$^2$ in 2001 (Ministerio de Fomento (MFOM (Ministerio de Fomento On-line-a), and road surface will be doubled by 2020 according to the new Infrastructures Plan 2005–2020 (MFOM (Ministerio de Fomento On-line-b). There has also been an increase of 1.65% in forest area, probably because of replacement of croplands by forests, which has been favoured under the CAP to reduce the so-called European Community's agricultural surplus. In addition, energy use is growing (Ministerio de Economía (MINECO), On-line; IEA (International Energy Agency), 2003; 1997), and as a result greenhouse gas emissions have grown 45% from 1990 to 2004, and Spain's emissions are 25.6% above the Kyoto Protocol agreements for the country (European Environment Agency (EEA (European Environment Agency), 2005; Observatorio de la Sostenibilidad en España (OSE (Observatorio de la Sostenibilidad en España), 2005). Furthermore, Spain has been transformed into a country devoted to the services sector (Tamames and Rueda, 2000), especially tourism and commerce. This sector was responsible for 61.2% of Spanish employment and 64% of the gross added value in 1999 (INE (Instituto Nacional de Estadística)), On-line; MINECO, On-line), although it only involved 31% of the working population and accounted for 45% of the Gross Domestic Product (GDP) in 1960 (Cuadrado, 1999). In contrast, during this time industry and agriculture have declined in importance for the Spanish economy (Cuadrado, 1999; Tamames and Rueda, 2000).

In addition, the Spanish economy has created an enormous pressure on aquatic ecosystems to satisfy demand for water in a country where water is relatively scarce. This pressure is the result of a policy based on satisfying demand instead of controlling it (Arrojo, 2001). Therefore, with a consumption of 530 $m^3$ of water/inhabitant/year (Ministerio de Medio Ambiente (MIMAM (Ministerio de Medio Ambiente), 2000), Spain is one of the highest *per capita* water-consuming in 15 countries of the EU (EU-15). It has the greatest number of dams per inhabitant and per unit area in the world, with more than 1150 large dams (World Commission on Dams (WCD (World Commission on Dams), 2000). Water use has become more intensified, with more than 3 400 000 ha of land under irrigation in recent years (Llamas, 2000). Furthermore, it is estimated that there are more than 75 aquifers that are overexploited or have serious salinization problems, 13 of which have been declared "provisionally overexploited" and two "overexploited" under the Spanish Water Act (MIMAM (Ministerio de Medio Ambiente), 2000). It is estimated that 60% of Spain's wetlands were already lost at the beginning of the 1990s (Casado and Montes, 1991), and 40% of rivers are polluted or seriously polluted (Prats et al., 2000).

Despite the changes and pressures of the last decades, 80–90% of EU-15 vascular plants can be found in Spain, 1500 of which are endemic in a worldwide context, and more than 500 are exclusively shared with Northern Africa. Spain is also the habitat to approximately 50% of the fauna species in EU-15, with more than 7.5% endemic (MIMAM (Ministerio de Medio Ambiente), 1999). Within the EU context, Spain, among other Mediterranean countries, is probably the region with the highest biological diversity.

Due to political and historical reasons, Spain has dealt with most of the processes of intensive industrialization and transformation into a country dedicated to services sector, common to Western European economies, in the last 20 years. In fact, Spain has received considerable EU funding for territorial cohesion, because a great part of its territory has been considered as a priority area to be supported economically within the EU. For these reasons, Spain probably constitutes one of the best laboratories in the Mediterranean world for assessing the effect of the acceleration of societal growth promoted by globalization, its effects on sustainability and the success of different strategies of environmental management adopted by governments.

### *1.3. Objectives*

The main objectives of this paper are (1) to study patterns in the use of environmental goods and services flowing to the Spanish economy, and changes in these patterns over a historical series of 20 years in Spain, (2) to show the changes in patterns of consumption and trade that have promoted economic globalization in Spain in the past two decades, and (3) to study the success of Spanish natural conservation policies and management during the last 20 years, in relation to the preservation of the natural capital that maintains the Spanish economy.

## 2. Methods

To deal with trends of resource use in the context of these objectives, within the general framework of Ecological Economics (Daly, 1991; Goodland and Daly, 1996; Costanza, 1997; Costanza et al., 1997; Martínez-Alier, 1999), a biophysical valuation of Spain by means of eMergy synthesis (Odum, 1996; Hau and Bakshi, 2004; Brown and Ulgiati, 2004) has been performed for five annual periods (1984, 1989, 1994, 2000 and 2002).

For the purposes of this study, Spain has been considered as a social–ecological system, SES (Berkes and Folke, 1998), comprised of its territories in the Iberian Peninsula and the Balearic Islands, in the Mediterranean Basin (Fig. 1), with a land area of 498 476 $km^2$ (IGN (Instituto Geográfico Nacional), 1996), which constitutes the second biggest country in terms of area in the EU, after France. Neither the Canary Islands nor the other African territories of Spain have been studied, because of their peculiar characteristics with respect to the rest of the country (distance, singular eMergy flows, different eMergy sources, etc.). To delimit borders, the continental shelf was defined by the area between 300 m of depth, and was estimated by the Spanish Oceanographic Institute (IEO) staff as 74 037 $km^2$ (Fig. 1).

From the brief description of Spain in the previous section, a flow diagram (Fig. 2) has been drawn to characterize the Spanish SES as a kind of system picture or macroscopic view (Rosnay, 1979; Brown, 2004), allowing us to model interactions between economic and ecological systems in terms of eMergy flows, using energy symbols from Odum (1994). Symbols have been used in accordance with criteria from Odum (1996) to represent the Spanish environmental window or SES. Under these criteria, symbols are placed on the diagram in order of increasing transformity (a measure of quality in eMergy terms, as defined below), and consequently renewable sources and ecological systems are placed on the left and economic flows and components are placed on the right. An aggregated diagram and three-arm diagrams for each year of the study period are respectively presented in Figs. 3 and 4. These diagrams show explicitly the main input-output flows described in the following sections, linking flows from biogeochemical sources (sun, rain, earth cycle, tides, etc.) to those of social–economic processes (industry, commerce, imports, immigration, etc.) in order to provide environmental and social services to Spanish society.

From the flow diagram of Spain presented in Fig. 2 and the summary of this, presented in Fig. 3, most important flows and overview indexes have been calculated for each year studied with the same methodology given by the example shown in Tables 1(a–c), in order to obtain a view of the Spanish social–ecological system dynamics over 20 years (Table 2). According to the usual eMergy evaluation

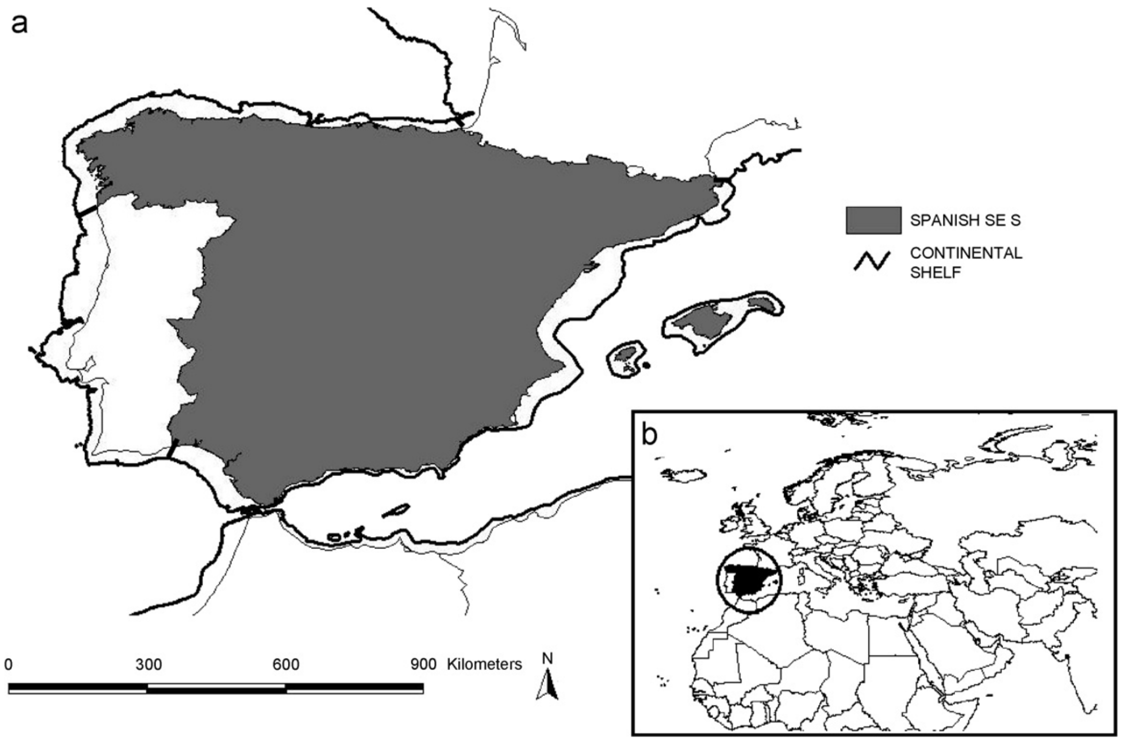


Fig. 1. Spanish social–ecological system in its context: (a) continental Spain and the continental shelf and (b) geographical context within Europe and the Mediterranean Basin.

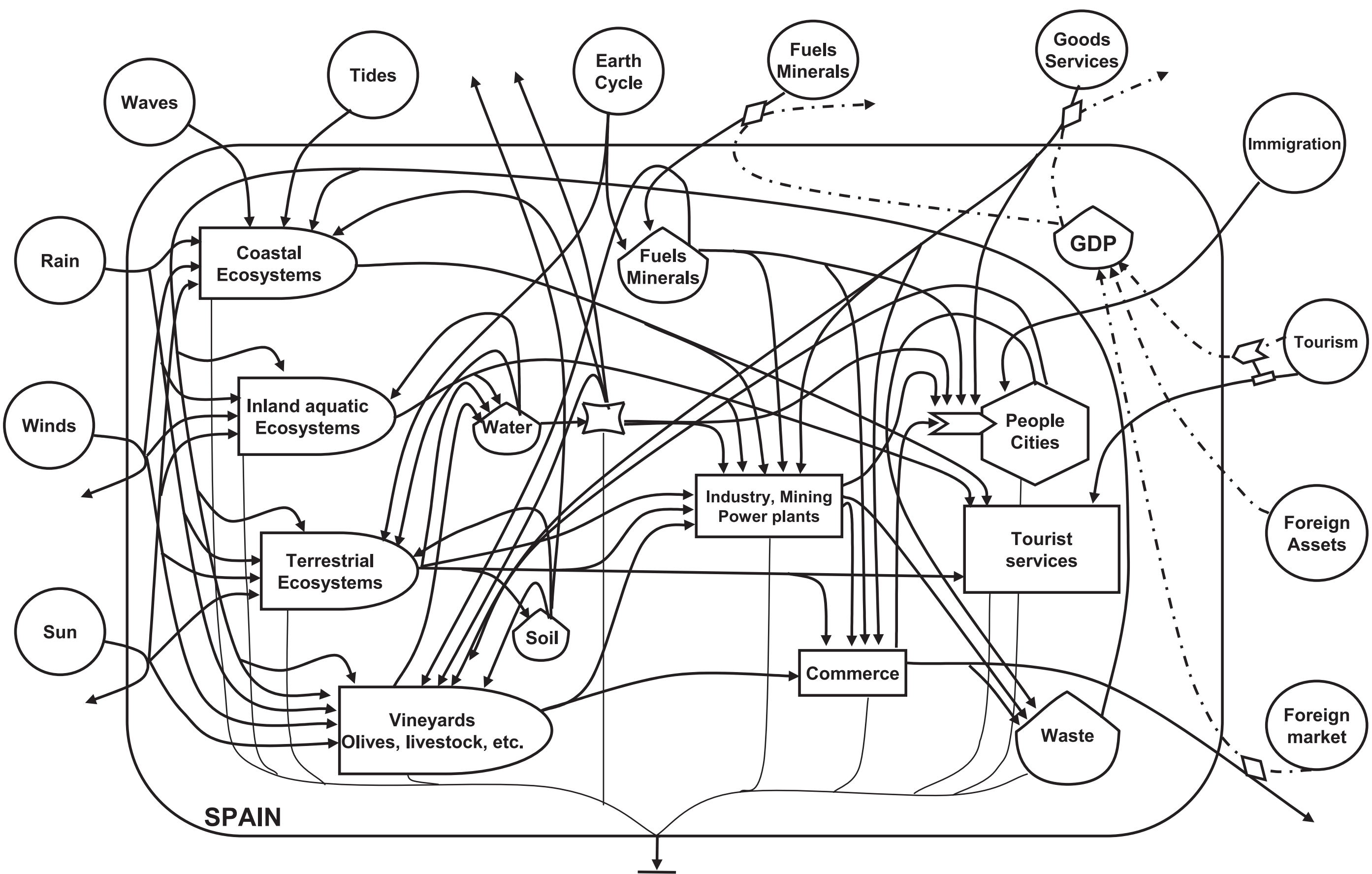


Fig. 2. Emergy flow diagram for Spain.

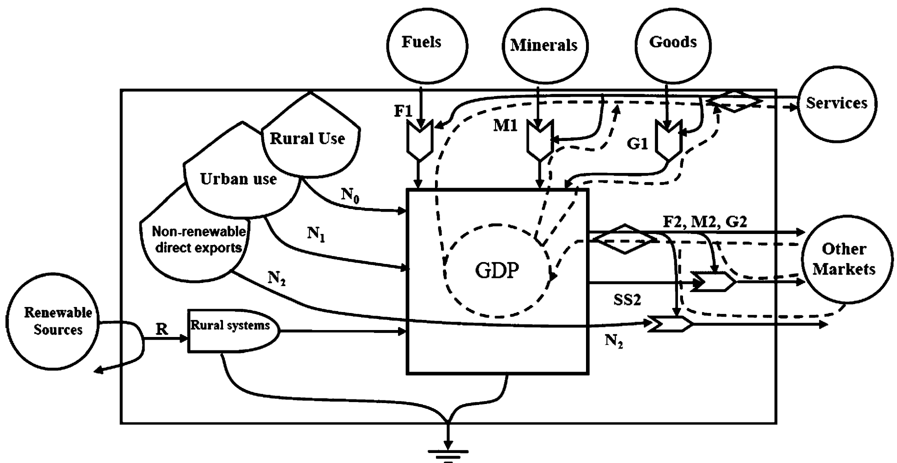


Fig. 3. Summary flow diagram for the main emergy flows in Spain.

procedure (Odum, 1996), the eMergy synthesis of Spain proceeds as follows:

(1) Drawing a flow diagram of Spain as a system (following the method established by Odum, 1996; Tilley and Swank, 2003).
(2) Preparation of an eMergy evaluation table.
(3) Calculation of main flows, storages and unit eMergy values or transformities.
(4) Discussion of the performance of main evaluation indicators.

All the transformities used in this work are updated to the new baseline (total contribution of eMergy to global processes = 15.83E + 24 sej/year) recalculated in the year 2000 (Odum et al., 2000) by multiplying unit eMergy values by 1.68 (the ratio of the new baseline between the past one: 15.83/9.44), as it is suggested by Brown and Ulgiati (2004).

In the new baseline framework, under the most accepted criteria in order to avoid double-counting (Odum et al., 2000), the renewable sources flow (*R*) for Spanish social–ecological system has been calculated as the largest inflowing eMergy of renewable ones. To complete our data for average wave height in 1984 and mean tidal range in 1984 and 1989, which were not available, an average among other years has been used. To calculate Real Evapotranspiration (ETa) and runoff rate, an average ETa (67.84% of average annual rainfall) and runoff (32.16% of average annual rainfall) rate calculated for Spain (peninsular and Balearic Islands) for 55 years by MIMAM (Ministerio de Medio Ambiente) (2000) have been used. Taking the Mediterranean nature of Spain into account, mature vegetation forests are assumed to have little net gain or loss of topsoil and it has been considered that harvested lands are net soil-losers. Thus, only the erosion rate in cultivated areas has been used to calculate topsoil energy contributions.

GDP at market prices has been used to calculate the eMergy-money ratios; although the use of Gross National Product (GNP) is very widespread. GDP instead of GNP is used to measure the economic activity within Spain regardless of the producer's nationality, following criteria used by Cialani et al. (2005) in order to avoid problems of measuring economic activity in eMergy terms.

In addition, previous eMergy synthesis data for Italy (Cialani et al., 2005) and a worldwide investigation of national economies (Brown, 2003) are used for comparison with other national economies and, especially, with the Mediterranean and European context of Spain (Appendix A and B).

## 3. Results

### 3.1. Main sources of the Spanish SES

In accordance with the system picture of Spain (Figs. 2 and 3) and the consequent calculations shown in Tables 1(a–c), main flows introduced to the Spanish social–ecological system (SES) for the studied years are represented by Fig. 5a and summarized in Table 2.

Total eMergy actually used (*U*), as potential investment in eMergy yield of the country, increases with an average of 3.77% annually with a peak in the first period (7.00% annually), except in the period of 1989–1994, in which it decreases 0.65% (Table 2).

Renewable eMergy flow (*R*) introduced to Spain is approximately unchanged at this temporal scale (Fig. 5a), although the Mediterranean nature of Spain is clear in the strong interannual variability of rain, especially in 1994, which was the last drought period of the 20th century in Spain. eMergy from waves, tides and rain (chemical potential) are the largest individual flows among renewable sources for Spain, representing 6.09E + 22, 5.66E + 22, and 4.62E + 22 sej/year, respectively. After these flows, the rank of the natural renewable drivers of the Spanish economy, according to solar emergy flow, was: the earth cycle, solar radiation absorbed, and kinetic energy of wind.

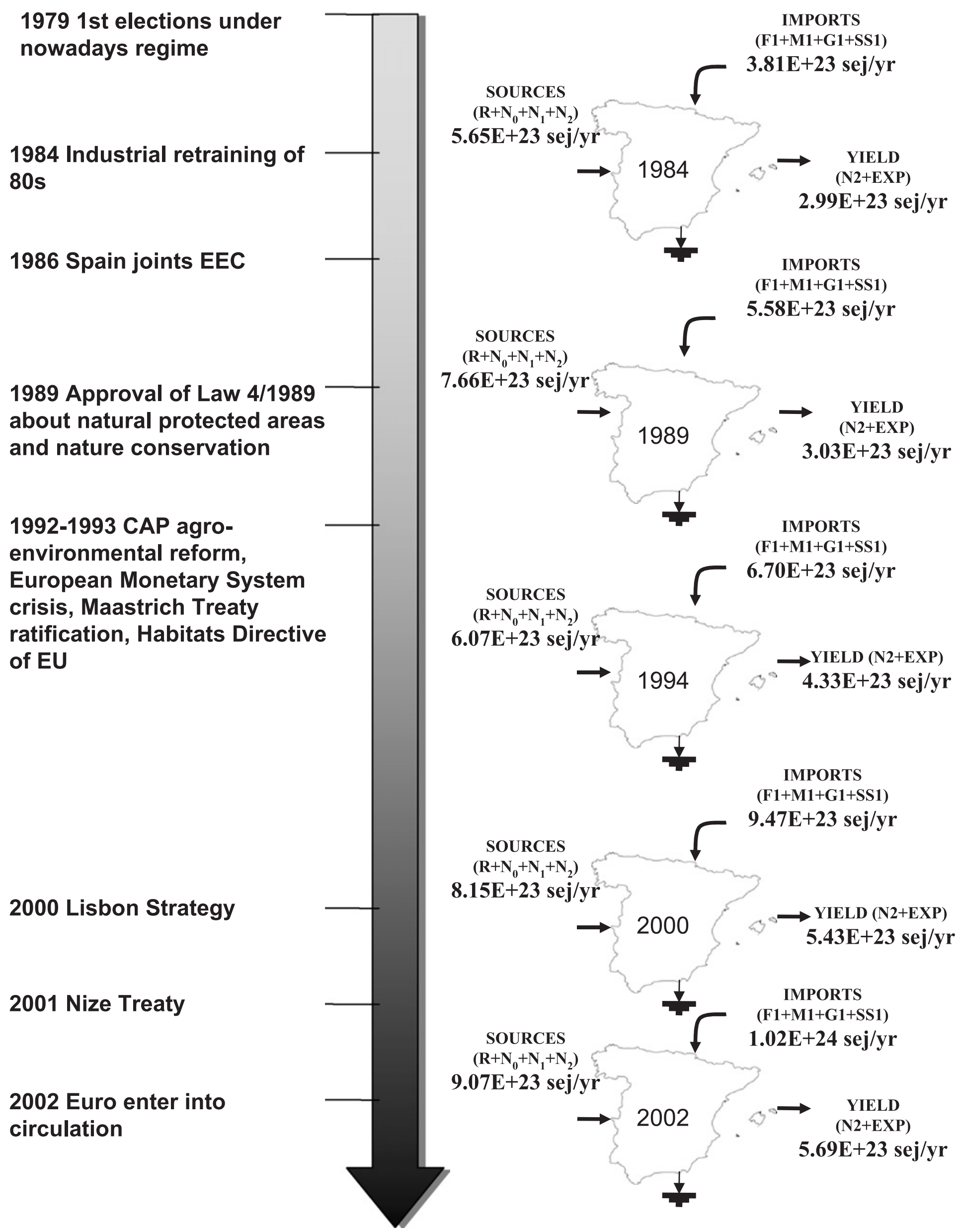


Fig. 4. Summary three arm flow diagram for the main flows in Spain contrasted with some of the main socio-economic events of the decades studied.

Participation of non-renewable eMergy flows from local Spanish sources ($N$) has increased from 5.09E + 23 sej/year in 1984 to 8.47E + 23 sej/year in 2002, although the annual increase rates have been reduced from 7.72% annually in the period 1984–1989 to 6.02% annually in the period 2000–2002 (Fig. 5a). Construction raw materials, like clay, calcium carbonate, sand and gravel are the largest individual $N$ flows.

Table 1b lists main imported inputs in terms of eMergy flows (IMP) for 2000 in Spain. IMP eMergy flow has increased from 3.81E + 23 sej/year in 1984 to 1.02E + 24 sej/year in 2002. Oil could be highlighted among the most important imported goods and services eMergy flows, as it involves from 21% to 16% of total eMergy used in 1984 and 2002; worth mentioning are also leather and leather products, textiles, mechanical, transport equipment, and the increasing importance of natural gas and coal. In emergy to money terms, imported goods have become the most important item in this category. Among the export eMergy flows (EXP) could be highlighted petroleum-derived products, minerals and mechanical and transport equipment. In emergy to money terms, eMergy flows related to services exported, in general, and particularly tourism, are increasing as a result of the tourism model introduced in Spain beginning the 1960s. As Table 2 shows, eMergy flow of exports has decreased in relation to IMP in the studied period (IMP/EXP index increases from 1.42 in 1984 to 1.87 in 2002).

The percentage of $R$ involved in $U$ decreases 50% (from 7% to 3%) during the 20 years examined (Fig. 5b), so $U$ is increasingly supported by IMP and $N$, with a growing role of concentrated eMergy sources ($N_1$) (concentrated against rural eMergy index grows from 13.64 in 1984 to 29.67 in 2002), and the increase of the relative weight of IMP, exceeding $N$ in 1989–1994 period (Fig. 5a). This increase in IMP results in decreased self-sufficiency (fraction of eMergy actually used derived from home sources decreased from 59% to 46%; Fig. 5b) for Spain, except in the last period, where there is a relative increase of $N_1$ in $U$, so self-sufficiency is maintained. In this regard, Spanish dependence on imported energy sources is still increasing strongly, and more than 21% of $U$ is imported oil in 1984 and 16% in 2002, so the purchased (non-free) component of the total economy is becoming more important, supporting the growth of the economy (Fig. 5a).

### 3.2. Some factors of scale to understand eMergy indicators

Taking into account the population factor of scale, the evolution of the potential standard of living in eMergy terms or eMergy use *per capita* shows an increase (Fig. 6a), although the growth rate of this indicator has continuously decreased from 6.69% annually in the 1984–1989 period to 2.68% in the last one, with the exception of the 1994–2000 period, in which it decreases 0.80%.

Taking into account the economic size factor of scale in terms of GDP, the average eMergy which is mobilized per monetary unit or the buying power in the Spanish SES (eMergy to money ratio; EMR) has decreased an average of 2.37% annually throughout the studied period (Fig. 6b), although this indicator experienced an increase of 3.48% annually in the period between 1994 and 2000.

Taking into account the territorial size factor of scale in terms of the Spanish SES area, territorial intensity of the eMergy actually used or Empower Density (flow of eMergy per unit area and time) has increased (except in the recession period in 1989–1994) in absolute terms, at an average annual rate of 3.77% over the whole period, but the annual growth rate within periods has decreased from the 7% annually in 1984–1989 period to 3.23% in 2000–2002 (Fig. 7c). If we consider that the Spanish economy is increasingly dependent on imports and non-renewable sources, territorial intensity of eMergy use depends mainly on the non-renewable fraction of Empower Density (96–97% of total Empower Density is non-renewable; Table 2), especially the imported fraction.

### 3.3. Interaction of Spanish SES with other systems

If the eMergy flow associated with imports and its significance was taken into proper account, the issue of trade would become crucial for Spain from an eMergy point of view. The most important component in the flow of purchased goods and services is the one for fuels and electricity.

An important aspect of trade is highlighted by the EMergy Exchange Ratio (EER, i.e. the ratio of EMR of Spain to EMRs of trade partner countries or the global economy), which shows the relative advantages and disadvantages for Spain in its international trade of products and resources. The EER for Spain with respect to the global economy has increased from 0.33 to 0.64 in the studied period, with a decline between 1994 and 2000 (Appendix B).

Furthermore, we can use macroeconomic value or eMergy price (emprice) to study the amount of eMergy received per monetary unit invested. As we can see in Tables 1(a–c), the highest values in renewable sources are related to waves and tides, with 1.97E+10 em$/year and 1.83 em$/year in the 2000, respectively; in non-renewable indigenous sources, those of calcium carbonate and sand and gravel, with 1.06E+11 em$/year and 4.43E+10 em$/year in 2000, respectively; oil and petroleum-derived products in imports, with 9.71E+10 em$/year; and textiles and mechanical and transport equipment in exports, with 2.36E+10 and 2.62E+10 em$/year, respectively.

### 3.4. The appropriation of eMergy by the Spanish SES

To get information about the appropriation of resources by the Spanish system (Raugei et al., 2004), a comparison of $U$ with emergy purchased by the national economy or eMergy yield ratio (EYR; Fig. 7a) has been used. The EYR decreases an average of 0.90% annually (except in the last period 2000–2002, in which it increases 0.52% annually) because Spain shows a growing pattern of energy and matter consumption, which is imported to produce goods and services, and this increase is higher than the growth experienced in the use of $N$ and $R$.

Regarding the non-renewable and purchased resources used to produce the yield in relation to these renewable sources, the environmental loading ratio (ELR; Fig. 7a) is used to obtain information about economic pressure on ecosystems and their functions as suppliers of environmental services to society. The ELR increases during the whole period of the study (except in the recession period of 1989–1994), especially in the first part of 1984–1989 (with a growth rate of more than 6% annually) and 1994–2000 (with a growth rate of 5.14% annually).

Both indexes can be combined to evaluate the competence of transformation processes (the ability of foreign and national economic investments to exploit local resources or the return on eMergy investment) in relation to the pressure produced on the environment (relative weight of non-renewable and purchased sources in $U$), which is called the eMergy sustainability index or ESI (Brown and Ulgiati, 1997; Ulgiati and Brown, 1998). Under a local social–ecological perspective, ESI decreases continuously (Fig. 7b), 5.15% annually in the period 1984–1989 and 3.99% in the 1994–2000 period, because the

Table 1a
Emergy flows supporting Spanish social–ecological system in 2000

| | | Unit | Amount 2000 (unit/year) | Trans. (sej/unit) | Ref. trans.* | Emergy 2000 (sej/year) | Macroeconomic value 2000 (em$/year) |
|---|---|---|---|---|---|---|---|
| *Renewable inputs* | | | | | | | |
| 1 | Sunlight[a] | J/year | 2.55E+21 | 1.00E+00 | 0 | 2.55E+21 | 8.24E+08 |
| 2 | Rain (chemical potential)[b] | J/year | 1.11E+18 | 3.06E+04 | A | 3.40E+22 | 1.10E+10 |
| 3 | Rain (geopotential)[c] | J/year | 6.91E+17 | 1.76E+04 | A | 1.22E+22 | 3.93E+09 |
| 4 | Wind kinetic energy[d] | J/year | 3.10E+17 | 2.52E+03 | A | 7.80E+20 | 2.52E+08 |
| 5 | Waves[e] | J/year | 1.18E+18 | 5.14E+04 | A | 6.09E+22 | 1.97E+10 |
| 6 | Tides[f] | J/year | 7.66E+17 | 7.39E+04 | A | 5.66E+22 | 1.83E+10 |
| 7 | Earth cycle[g] | J/year | 4.98E+17 | 1.20E+04 | A | 5.98E+21 | 1.93E+09 |
| *Indigenous non-renewable inputs* | | | | | | | |
| 8 | Oil[h] | J/year | 9.63E+15 | 9.06E+04 | A | 8.72E+20 | 2.82E+08 |
| 9 | Coal[i] | J/year | 3.21E+17 | 6.71E+04 | A | 2.15E+22 | 6.95E+09 |
| 10 | Natural gas[j] | J/year | 6.20E+15 | 8.05E+04 | A | 4.99E+20 | 1.61E+08 |
| 11 | Iron[k] | g/year | 7.51E+10 | 1.68E+09 | A | 1.26E+20 | 4.08E+07 |
| 12 | Gold[k] | g/year | 4.32E+06 | 7.39E+14 | D | 3.19E+21 | 1.03E+09 |
| 13 | Silver[k] | g/year | 1.15E+08 | 5.04E+14 | D | 5.77E+22 | 1.87E+10 |
| 14 | Copper[k] | g/year | 2.44E+10 | 3.36E+09 | E | 8.18E+19 | 2.65E+07 |
| 15 | Feldspar[k] | g/year | 4.78E+11 | 1.68E+09 | A | 8.03E+20 | 2.60E+08 |
| 16 | Zinc[k] | g/year | 2.02E+11 | 1.68E+09 | A | 3.40E+20 | 1.10E+08 |
| 17 | Lead[k] | g/year | 5.17E+10 | 1.68E+09 | A | 8.68E+19 | 2.81E+07 |
| 18 | Salt rock[k] | g/year | 3.87E+12 | 1.68E+09 | A | 6.50E+21 | 2.10E+09 |
| 19 | Sulphur[k] | g/year | 7.70E+11 | 1.68E+09 | A | 1.29E+21 | 4.18E+08 |
| 20 | Glauberite y Thernardite[k] | g/year | 8.34E+11 | 1.68E+09 | A | 1.40E+21 | 4.53E+08 |
| 21 | Fluorite[k] | g/year | 1.35E+11 | 1.68E+09 | A | 2.27E+20 | 7.33E+07 |
| 22 | Magnesite[k] | g/year | 2.21E+11 | 1.68E+09 | A | 3.71E+20 | 1.20E+08 |
| 23 | Pumice[k] | g/year | 7.62E+11 | 7.56E+09 | A | 5.76E+21 | 1.86E+09 |
| 24 | Talc[k] | g/year | 1.15E+11 | 1.68E+09 | A | 1.93E+20 | 6.22E+07 |
| 25 | Quartz and silica sand[k] | g/year | 6.59E+12 | 1.68E+09 | A | 1.11E+22 | 3.58E+09 |
| 26 | Calcium carbonate[k] | g/year | 1.95E+14 | 1.68E+09 | A | 3.28E+23 | 1.06E+11 |
| 27 | Potash[k] | g/year | 8.70E+11 | 1.68E+09 | A | 1.46E+21 | 4.72E+08 |
| 28 | Barite[k] | g/year | 3.27E+10 | 1.68E+09 | A | 5.49E+19 | 1.77E+07 |
| 29 | Sand and gravel[k] | g/year | 8.17E+13 | 1.68E+09 | A | 1.37E+23 | 4.43E+10 |
| 30 | Clay[k] | g/year | 4.33E+13 | 1.68E+09 | A | 7.27E+22 | 2.35E+10 |
| 31 | Gypsum[k] | g/year | 9.93E+12 | 1.68E+09 | A | 1.67E+22 | 5.39E+09 |
| 32 | Quartzite[k] | g/year | 2.13E+12 | 1.68E+09 | A | 3.58E+21 | 1.16E+09 |
| 33 | Dolomite[k] | g/year | 8.75E+12 | 1.68E+09 | A | 1.47E+22 | 4.75E+09 |
| 34 | Ophite and porphyry[k] | g/year | 4.74E+12 | 2.44E+09 | A | 1.15E+22 | 3.73E+09 |
| 35 | Serpentine[k] | g/year | 7.39E+11 | 1.68E+09 | A | 1.24E+21 | 4.01E+08 |
| 36 | Marble[k] | g/year | 3.66E+12 | 2.44E+09 | A | 8.92E+21 | 2.88E+09 |
| 37 | Granite[k] | g/year | 1.96E+13 | 8.40E+08 | A | 1.65E+22 | 5.32E+09 |

Table 1a (*continued*)

| | | Unit | Amount 2000 (unit/year) | Trans. (sej/unit) | Ref. trans.* | Emergy 2000 (sej/year) | Macroeconomic value 2000 (em$/year) |
|---|---|---|---|---|---|---|---|
| 38 | Slate[k] | g/year | 2.27E+12 | 1.68E+09 | A | 3.82E+21 | 1.23E+09 |
| 39 | Net topsoil loss[l] | J/year | 1.25E+16 | 1.05E+05 | A | 1.31E+21 | 4.22E+08 |

*References for transformities (Tables 1(a–c)):

0. Solar transformity is 1 sej J−1 by definition.

A. Odum, H.T., Brown, M.T., Brandt-Williams, S.B. (Eds.). 2000. Handbook of Emergy Evaluation. A Compendium of Data for Emergy Computation [Consulted: 1/6/2005]. Center for Environmental Policy, University of Florida, FL, USA. http://www.emergysystems.org/folios.php.

B. Bargigli, S., Ulgiati, S., 2003. Emergy and life-cycle assessment of steel production in Europe. In: Brown, M.T. (Ed.), Emergy Synthesis, 2: Theory and Application of the Emergy Methodology. Proceedings of the Second Biennial Emergy Conference. Center for Environmental Policy, University of Florida, Gainesville, FL, USA.

C. Brown, M.T. 2003. Resource imperialism: emergy perspectives on sustainability, international trade, and balancing the welfare of nations. In: Ulgiati, S., Brown, M.T., Giampietro, M., Herendeen, R., Mayumi, K. (Eds.), Proceedings of Third Biennial International Workshop. Advances in Energy Studies: Reconsidering the Importance of Energy, Porto Venere, Italy, pp. 135–149.

D. Brown, M.T., Arding, J., 1991. Transformities Working Paper. Center for Wetlands, University of Florida, Gainesville, FL, USA.

E. Brown, M. T., Ulgiati, S., 2004. EMergy analysis and environmental accounting. Encyclopedia of Energy 2, 329–354.

F. This study.

*Calculations*:

[a] *Sunlight*: Continental area = 498 476 km$^2$ (IGN, 1996), continental shelf area = 74 037 km$^2$ (IEO staff), average insolation = 5 704 091.20 kJ/m$^2$/año (INM (Instituto Nacional de Meteorología), 2001, 2002, continental albedo = 0.35, shelf continental albedo = 0.2 (Henning, 1989), Energy = (Area)(Average insolation)(1−Albedo) = (498 476 km$^2$)(10E+6 m$^2$/km$^2$)(5 704 091.20 kJ/m$^2$/year)(10E+3 kJ/J)(1−0.35) + (74 037 km$^2$)(10E+6 m$^2$/km$^2$)(5 704 091.20 kJ/m$^2$/año)(103 kJ/J)(1−0.2) = 2.55E+21 J/year.

[b] *Rain* (*chemical potential*): Continental area = 498 476 km$^2$ (IGN, 1996), average rain = 0.67 m (INM, 2001, 2002), ETa (67.84% of rainfall; MIMAM, 2000) = 0.45 m, Gibb's free energy of rainfall ($G$) = 4.94 J/g (Odum, 1996), rain water density = 1.00E+3 kg/m$^3$, Energy = (Area)(ETa)($G$)(Rain water density) = (498 476 km$^2$)(10E+6 m$^2$/km$^2$)(0.45 m)(4.94 J/g)(1.00E+3 kg/m$^3$)(1.00E+3 g/kg) = 1.11E+18 J/year.

[c] *Rain* (*geopotential*): Continental area = 498 476 km$^2$ (IGN, 1996), average rain = 0.67 m (INM, 2001, 2002), runoff (32.16% of rainfall; MIMAM, 2000) = 0.21 m, average elevation = 660 m, rain water density = 1.00E+3 kg/m$^3$, $g$ = 9.8 m/s$^2$, Energy = (Area)(Runoff)(Rain water density)(Average elevation)($g$) = (498 476 km$^2$)(10E+6 m$^2$/km$^2$)(0.21 m)(1.00E+3 kg/m$^3$) (660 m)(9.8 m/s$^2$) = 6.91E+17 J/year.

[d] *Wind* (*kinetic energy*): Wind (kinetic energy) estimated from EU/EWEA (European Commission-DG TREN/European Wind Energy Association), 2003 as an annual technical onshore potential of wind energy.

[e] *Waves*: component of length parallel to front wave = 2340 (our estimate from IGN, 1996), sea water density = 1027 kg/m$^3$, $g$ = 9.8 m/s$^2$, wave height ($H_s$) = 1.29 m (OAPEstado, On-line), average water depth in the breaker zone ($h$) = 6 m (Odum and Odum, 1983), Energy = (component parallel to front wave)(1/8)(sea water density)$(H_s)^2(g \times h)$1/2 = (2340 km)(1.00E+3 m/km)(1/8)(1027 kg/m$^3$)(1.29)2(9.8 m/s$^2$ × 6 m)1/2(3.15E+7 s/year) = 1.18E+18 J/year.

[f] *Tides*: Continental shelf area = 74 037 km$^2$ (IEO staff), Tides/year = 730 (2/day), mean tidal range = 167.80 cm (OAPEstado, On-line), sea water density = 1027 kg/m$^3$, $g$ = 9.8 m/s$^2$, Energy = (Area)(1/2)(Annual tides)(Mean tidal range)2(Sea water density)($g$) = (74 037 km$^2$) (10E+6 m$^2$/km$^2$)(1/2)(730)(1.68 m)$^2$(1027 kg/m$^3$)(9.8 m/s$^2$) = 7.66E+17 J/year.

[g] *Earth cycle*: Continental area = 498 476 km$^2$ (IGN, 1996), heat flow estimated from Odum (1996) = 1.00E+6 J/m$^2$/year, Energy = (Area)(Heat flow) = (498 476 km$^2$)(10E+6 m$^2$/km$^2$)(1.00E+6 J/m$^2$/year) = 4.98E+17 J/year.

[h] *Oil*: 2.30E+5 toe (IEA, 2003), Energy = (toe)(1E+7 kcal/toe)(4186 J/kcal) = 9.63E+15 J/year.

[i] *Coal*: 7.66E+6 toe (IEA, 2003), Energy = (toe)(1E+7 kcal/toe)(4186 J/kcal) = 3.21E+17 J/year.

[j] *Natural gas*: 1.48E+5 toe (EUROSTAT, On-line), Energy = (toe)(1E+7 kcal/toe)(4186 J/kcal) = 6.20E+15 J/year.

[k] Iron, gold, silver, copper, feldspar, zinc, lead, salt rock, sulphur, glauberite and thernardite, fluorite, magnesite, pumice, talc, quartz and silica sand, calcium carbonate, potash, barite, sand and gravel, clay, gypsum, quartzite, dolomite, ophite and porphyry, serpentine, marble, granite and slate extraction from IGME (Instituto Geológico y Minero de España).

[l] *Net topsoil loss*: Farmed area = 1.83E+5 km$^2$ (MAPA, On-line), erosion rate = 150.5 Tm/km$^2$ (Soto, 1990; Cerdá, 2001), % organic matter in soil = 0.02 (Porta et al., 1994), energy = (Farmed area)(Erosion rate)(% Organic matter in soil)(Energy from organic matter)(4186 J/kcal) = (1.83E+5 km$^2$)(150.5 Tm/km$^2$)(1E+6 g/Tm)(0.02)(5 kcal/g)(4186 J/kcal) = 1.25E+16 J/year.

Table 1b
Emergy imports for Spanish social–ecological system in 2000

| | | Unit | Amount 2000 (unit/year) | Trans. (sej/unit) | Ref. trans* | Emergy 2000 (sej/year) | Macroeconomic value 2000 (em$/year) |
|---|---|---|---|---|---|---|---|
| 40 | Oil and petroleum-derived products[a] | J/year | 3.32E+18 | 9.06E+04 | A | 3.00E+23 | 9.43E+10 |
| 41 | Coal[b] | J/year | 5.56E+17 | 6.71E+04 | A | 3.73E+22 | 1.17E+10 |
| 42 | Natural gas[c] | J/year | 6.47E+17 | 8.05E+04 | A | 5.21E+22 | 1.64E+10 |
| 43 | Electricity[d] | J/year | 4.44E+16 | 3.36E+05 | A | 1.49E+22 | 4.68E+09 |
| 44 | Agriculture and forest products[e] | J/year | 4.51E+16 | 1.75E+05 | A | 7.88E+21 | 2.48E+09 |
| 45 | Livestock and products[f] | J/year | 4.85E+15 | 5.33E+06 | A | 2.58E+22 | 8.11E+09 |
| 46 | Food industry products[g] | g/year | 7.64E+12 | 3.36E+05 | A | 2.57E+18 | 8.06E+05 |
| 47 | Fishery products[h] | J/year | 5.44E+15 | 3.36E+06 | A | 1.83E+22 | 5.74E+09 |
| 48 | Metallic minerals[g] | g/year | 1.14E+13 | 1.68E+09 | A | 1.92E+22 | 6.01E+09 |
| 49 | Non-metallic minerals[g] | g/year | 1.20E+13 | 1.68E+09 | A | 2.02E+22 | 6.34E+09 |
| 50 | Steel and pig iron[g] | g/year | 1.79E+13 | 3.69E+09 | B | 6.61E+22 | 2.08E+10 |
| 51 | Metallic minerals (products/alloys)[g] | g/year | 1.27E+12 | 1.68E+09 | A | 2.13E+21 | 6.69E+08 |
| 52 | Mechanical and transport equipment[g] | g/year | 7.03E+12 | 1.13E+10 | A | 7.91E+22 | 2.49E+10 |
| 53 | Industrial minerals[g] | g/year | 1.75E+12 | 1.68E+09 | A | 2.94E+21 | 9.23E+08 |
| 54 | Leather and products[i] | J/year | 4.47E+15 | 1.44E+07 | A | 6.46E+22 | 2.03E+10 |
| 55 | Textiles[j] | J/year | 1.91E+16 | 6.38E+06 | A | 1.22E+23 | 3.83E+10 |
| 56 | Wood and products[k] | J/year | 9.19E+16 | 5.86E+04 | A | 5.39E+21 | 1.69E+09 |
| 57 | Paper[g] | g/year | 5.33E+12 | 6.55E+09 | A | 3.49E+22 | 1.10E+10 |
| 58 | Chemicals[g] | g/year | 1.39E+13 | 6.38E+08 | A | 8.89E+21 | 2.79E+09 |
| 59 | Rubber[g] | g/year | 8.85E+11 | 7.22E+09 | A | 6.39E+21 | 2.01E+09 |
| 60 | Total goods associated to imports[l] | $ | 1.51E+11 | 1.85E+12 | C | 2.80E+23 | 8.80E+10 |
| 61 | Total services associated to imports (without tourism)[l] | $ | 2.60E+10 | 1.85E+12 | C | 4.81E+22 | 1.51E+10 |
| 62 | Total money associated to tourism services imports[l] | $ | 5.51E+09 | 1.85E+12 | C | 1.02E+22 | 3.20E+09 |

*See footnotes in Table 1a.

[a] *Oil and petroleum-derived products*: 7.92E+7 toe (IEA, 2003), energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (7.92E+7 toe)(1.00E+7 kcal/toe)(4186 J/kcal) = 3.32E+18 J/year.

[b] *Coal*: 1.33E+7 toe (IEA, 2003), Energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (1.33E+7 toe) (1.00E+7 kcal/toe)(4186 J/kcal) = 5.56E+17 J/year.

[c] *Natural gas*: 1.55E+7 toe (IEA, 2003), energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (1.55E+7 toe) (1.00E+7 kcal/toe)(4186 J/kcal) = 6.47E+17 J/year.

[d] *Electricity*: 1.06E+6 toe (IEA, 2003), energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (1.06E+6 toe) (1.00E+7 kcal/toe)(4186 J/kcal) = 4.44E+16 J/year.

[e] *Agriculture and forest products*: 1.54E+13 g (AEAT, On-line), energy = (1.54E+13 g)(0.20)(3.5 kcal/g)(4186 J/kcal) = 4.51E+16 J/year.

[f] *Livestock and products*: 1.05E+12 g (AEAT, On-line), energy = (1.05E+12 g)(0.22)(5.0 kcal/g)(4186 J/kcal) = 4.85E+15 J/year.

[h] *Fishery products*: 1.18E+12 g (AEAT, On-line), energy = (1.18E+12 g)(0.22)(5.0 kcal/g)(0.22)(5.0 kcal/g)(4186 J/kcal) = 5.44E+15 J/year.

[i] *Leather and products*: 2.83E+11 g (AEAT, On-line), energy = (matter)(15 800 J/g) = (2.83E+11 g) (15 800 J/g) = 4.47E+15 J/year.

[j] *Textiles*: 1.21E+12 g (AEAT, On-line), Energy = (matter)(15 800 J/g) = (1.21E+12 g) (15 800 J/g) = 1.91E+16 J/year.

[k] *Woods and products*: 6.10E+12 g (AEAT, On-line), Energy = (matter)(15 800 J/g) = (6.10E+12 g) (15 800 J/g) = 9.19E+16 J/year.

[g] Food industry products, metallic minerals, non-metallic minerals, steel and pig iron, metallic minerals (products and alloys), mechanical and transport equipment, industrial minerals, paper, chemicals and rubber (AEAT, On-line).

[l] Total goods associated to imports, total services associated to imports (without tourism), total money associated to tourism from BDE (On-line-a).

relative importance of the flow of renewable eMergy sources is reduced.

### 3.5. Carrying capacity of the Spanish SES

In eMergy terms, carrying capacity may have two main approaches (Fig. 8): a people-based one (more similar to the classical concept of carrying capacity), linked to number of people supported by eMergy used (Odum, 1996; Campbell, 1998), and an area-based one (similar to ecological footprint), associated to support area needed to maintain the standard of living of people (in terms of eMergy use *per capita*) (Brown and Ulgiati, 2001). These two approaches could be applied to both "only renewable" and "developed" scenarios. The renewable scenario would be a lower limit, based only on renewable flows, and the

Table 1c
Emergy exports and selected products for Spanish social–ecological system in 2000

| | | Unit | Amount 2000 (unit/year) | Trans. (sej/unit) | Ref. Trans.* | Emergy 2000 (sej/year) | Macroeconomic value 2000 (em$/year) |
|---|---|---|---|---|---|---|---|
| *Exports* | | | | | | | |
| 63 | Petroleum-derived products[a] | J/year | 3.17E+17 | 9.06E+04 | A | 2.87E+22 | 9.02E+09 |
| 64 | Coal[b] | J/year | 2.26E+16 | 6.71E+04 | A | 1.52E+21 | 4.76E+08 |
| 65 | Electricity[c] | J/year | 2.58E+16 | 3.36E+05 | A | 8.68E+21 | 2.73E+09 |
| 66 | Agriculture and forest products[d] | J/year | 3.42E+16 | 1.75E+05 | A | 5.98E+21 | 1.88E+09 |
| 67 | Livestock and products[e] | J/year | 2.97E+15 | 5.33E+06 | A | 1.58E+22 | 4.97E+09 |
| 68 | Food industry products[f] | g/year | 5.35E+12 | 3.36E+05 | A | 1.80E+18 | 5.65E+05 |
| 69 | Fishery products[g] | J/year | 3.07E+15 | 3.36E+06 | A | 1.03E+22 | 3.24E+09 |
| 70 | Metallic minerals[f] | g/year | 9.93E+11 | 1.68E+09 | A | 1.67E+21 | 5.24E+08 |
| 71 | Non-metallic minerals[f] | g/year | 1.27E+13 | 1.68E+09 | A | 2.14E+22 | 6.71E+09 |
| 72 | Steel and pig iron[f] | g/year | 7.50E+12 | 3.69E+09 | B | 2.77E+22 | 8.69E+09 |
| 73 | Metallic minerals (products/alloys)[f] | g/year | 8.80E+11 | 1.68E+09 | A | 1.48E+21 | 4.64E+08 |
| 74 | Mechanical and transport equipment[f] | g/year | 7.21E+12 | 1.13E+10 | A | 8.12E+22 | 2.55E+10 |
| 75 | Industrial minerals[f] | g/year | 8.00E+12 | 1.68E+09 | A | 1.34E+22 | 4.22E+09 |
| 76 | Leather and products[h] | J/year | 2.12E+15 | 1.44E+07 | A | 3.06E+22 | 9.61E+09 |
| 77 | Textiles[i] | J/year | 1.14E+16 | 6.38E+06 | A | 7.30E+22 | 2.29E+10 |
| 78 | Wood and products[j] | J/year | 1.96E+16 | 5.86E+04 | A | 1.15E+21 | 3.61E+08 |
| 79 | Paper[f] | g/year | 2.79E+12 | 6.55E+09 | A | 1.83E+22 | 5.74E+09 |
| 80 | Chemicals[f] | g/year | 9.11E+12 | 6.38E+08 | A | 5.82E+21 | 1.83E+09 |
| 81 | Rubber[f] | g/year | 6.65E+11 | 7.22E+09 | A | 4.80E+21 | 1.51E+09 |
| 82 | Total goods associated to exports[k] | $ | 1.17E+11 | 3.09E+12 | F | 3.61E+23 | — |
| 83 | Total services associated to exports (without tourism)[k] | $ | 2.28E+10 | 3.09E+12 | F | 7.06E+22 | — |
| 84 | Total money associated to tourism services exports[k] | $ | 3.12E+10 | 3.09E+12 | F | 9.66E+22 | — |
| *Selected products* | | | | | | | |
| 85 | Population 2000[l] | Inhabitants | 3.99E+7 | 4.35E+16 | F | 1.73E+24 | — |
| 86 | GDP 2000[m] | $ | 5.62E+11 | 3.09E+12 | F | 1.73E+24 | — |

*See footnotes in Table 1a.
[a]*Petroleum-derived products*: 7.57E+6 toe (IEA, 2003), Energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (7.57E+6 toe)(1.00E+7 kcal/toe)(4186 J/kcal) = 3.17E+17 J/year.
[b]*Coal*: 5.40E+5 toe (IEA, 2003), Energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (5.40E+7 toe) (1.00E+7 kcal/toe)(4186 J/kcal) = 2.26E+16 J/year.
[c]*Electricity*: 6.73E+5 toe (IEA, 2003), Energy = (toe)(1.00E+7 kcal/toe)(4186 J/kcal) = (6.73E+5 toe) (1.00E+7 kcal/toe)(4186 J/kcal) = 2.82E+16 J/year.
[d]*Agriculture and forest products*: 1.17E+13 g (AEAT, On-line), Energy = (1.17E+13 g)(0.20)(3.5 kcal/g)(4186 J/kcal) = 3.42E+16 J/year.
[e]*Livestock and products*: 6.46E+11 g (AEAT, On-line), Energy = (6.46E+11 g)(0.22)(5.0 kcal/g)(4186 J/kcal) = 2.97E+15 J/year.
[g]*Fishery products*: 6.67E+11 g (AEAT, On-line), Energy = (6.67E+11 g)(0.22)(5.0 kcal/g)(0.22)(5.0 kcal/g)(4186 J/kcal) = 3.07E+15 J/year.
[h]*Leather and products*: 1.34E+11 g (AEAT, On-line), Energy = (matter)(15 800 J/g) = (1.34E+11 g)(15 800 J/g) = 2.12E+15 J/year.
[i]*Textiles*: 7.24E+11 g (AEAT, On-line), Energy = (matter)(15 800 J/g) = (7.24E+11 g)(15 800 J/g) = 1.14E+16 J/year.
[j]*Woods and products*: 1.30E+12 g (AEAT, On-line), Energy = (matter)(15 800 J/g) = (1.30E+12 g) (15 800 J/g) = 1.96E+16 J/year.
[f]Food industry products, metallic minerals, non-metallic minerals, steel and pig iron, metallic minerals (products and alloys), mechanical and transport equipment, industrial minerals, paper, chemicals and rubber (AEAT, On-line).
[k]Total goods associated to exports, Total services associated to exports (without tourism), Total money associated to tourism from BDE (Banco de España), 2006.
[l]Population from INE (On-line).
[m]GDP from UNSD (On-line).

developed scenario would be an upper limit, based on actual conditions.

If a people-based approach to renewable carrying capacity for Spain is employed, the population that could be supported only with renewable sources shows a decline of 50%, shifting from values of 6% to 3% of the actual population, caused by the relative decrease in the use of renewable eMergy flows in relation to local non-renewable or imported flows.

When using the people-based approach for developed carrying capacity, Spain is considered embedded in the European or the Mediterranean contexts. The Mediterranean context implies the use of the traditional ecological knowledge accumulated during centuries of adaptive

Table 2
Comparison of main emergy indexes and flows for time series emergy synthesis of Spain

| No. | Flow/index | Expression | 1984 | 1989 | 1994 | 2000 | 2002 | Units |
|---|---|---|---|---|---|---|---|---|
| 1 | Renewable sources used | $R$ | 6.09E+22 | 6.28E+22 | 5.90E+22 | 6.09E+23 | 6.09E+23 | Sej/year |
| 2 | Non-renewable indigenous sources | $N$ | 5.09E+23 | 7.05E+23 | 5.49E+23 | 7.55E+23 | 8.47E+23 | Sej/year |
| | Dispersed rural sources | $N_0$ | 1.47E+21 | 1.45E+21 | 1.31E+21 | 1.31E+21 | 1.28E+21 | Sej/year |
| | Concentrated used | $N_1$ | 4.76E+23 | 6.84E+23 | 5.25E+23 | 7.30E+23 | 8.22E+23 | Sej/year |
| | Exported without use | $N_2$ | 3.11E+22 | 2.00E+22 | 2.26E+22 | 2.46E+22 | 2.27E+22 | Sej/year |
| 3 | Imported emergy | IMP | 3.81E+23 | 5.58E+23 | 6.70E+23 | 9.47E+23 | 1.02E+24 | Sej/year |
| | Fuels and electricity | F1 | 2.19E+23 | 2.63E+23 | 3.00E+23 | 4.05E+23 | 4.28E+23 | Sej/year |
| | Minerals | M1 | 4.21E+22 | 5.48E+22 | 6.48E+22 | 1.08E+23 | 1.16E+23 | Sej/year |
| | Goods (without fuels and electricity) | G1 | 9.85E+22 | 2.00E+23 | 2.68E+23 | 3.76E+23 | 4.10E+23 | Sej/year |
| | Services (without tourism) | SS1 | 2.03E+22 | 3.52E+22 | 2.90E+22 | 4.81E+22 | 5.68E+22 | Sej/year |
| | Touristic services | P1E3 | 1.54E+21 | 5.70E+21 | 7.63E+21 | 1.02E+22 | 1.23E+22 | Sej/year |
| 4 | Exported emergy | EXP | 2.68E+23 | 2.83E+23 | 4.10E+23 | 5.19E+23 | 5.46E+23 | Sej/year |
| | Fuels and electricity | F2 | 5.17E+22 | 4.79E+22 | 5.03E+22 | 3.89E+22 | 3.34E+22 | Sej/year |
| | Minerals | M2 | 5.80E+22 | 3.32E+22 | 4.85E+22 | 5.22E+22 | 5.07E+22 | Sej/year |
| | Goods (without fuels and electricity) | G2 | 6.40E+22 | 1.11E+23 | 1.74E+23 | 2.60E+23 | 2.80E+23 | Sej/year |
| | Services (without tourism) | SS2 | 5.11E+22 | 3.76E+22 | 8.45E+22 | 7.06E+22 | 8.40E+22 | Sej/year |
| | Touristic services | P1E2 | 4.34E+22 | 5.39E+22 | 5.30E+22 | 9.66E+22 | 9.78E+22 | Sej/year |
| 5 | Total emergy available | $R+N+\text{IMP}$ | 9.50E+24 | 1.33E+24 | 1.28E+24 | 1.76E+24 | 1.93E+24 | Sej/year |
| | Total emergy actually used | $U=R+N+\text{IMP}-N_2$ | 9.19E+23 | 1.31E+24 | 1.25E+24 | 1.74E+24 | 1.91E+24 | Sej/year |
| 6 | Economic component of emergy used | $U-R$ | 8.58E+23 | 1.24E+24 | 1.20E+24 | 1.68E+24 | 1.85E+24 | Sej/year |
| 7 | Fraction of use derived from indigenous sources | $(R+N_0+N_1)/U$ | 0.59 | 0.57 | 0.47 | 0.46 | 0.46 | — |
| 8 | Fraction of use that is renewable | $R/U$ | 0.07 | 0.05 | 0.05 | 0.04 | 0.03 | — |
| 9 | Fraction of use that is free | $(R+N_0)/U$ | 0.07 | 0.05 | 0.05 | 0.04 | 0.03 | — |
| 10 | Fraction of use that is imported | $\text{IMP}/U$ | 0.41 | 0.43 | 0.53 | 0.54 | 0.54 | — |
| 11 | Imports minus exports | IMP−EXP | 1.13E+23 | 2.75E+23 | 2.59E+23 | 4.28E+23 | 4.76E+23 | Sej/year |
| 12 | Imports/exports | IMP/EXP | 1.42 | 1.97 | 1.63 | 1.83 | 1.87 | — |
| 13 | Ration of concentrated to rural | $(U-R-N_0)/(R+N_0)$ | 13.74 | 19.32 | 19.79 | 26.95 | 29.67 | — |
| 14 | Emergy use *per capita* | $U$/population | 2.40E+16 | 3.37E+16 | 3.20E+16 | 4.35E+16 | 4.70E+16 | Sej/people/year |
| 15 | Fraction of use that is electrical | Electrical emergy/$U$ | 0.20 | 0.22 | 0.23 | 0.20 | 0.18 | — |
| 16 | Fuels *per capita* | Fuels/population | 6.77E+15 | 7.65E+15 | 8.12E+15 | 9.58E+15 | 1.05E+16 | Sej/people/year |
| 17 | Population | — | 3.83E+07 | 3.88E+07 | 3.92E+07 | 3.99E+07 | 4.05E+07 | people |
| 18a | Empower density | $U$/Area | 1.84E+12 | 2.62E+12 | 2.52E+12 | 3.49E+12 | 3.83E+12 | Sej/m$^2$/year |
| 18b | Non-renewable empower density | $(\text{IMP}+N)$/Area | 1.78E+12 | 2.53E+12 | 2.44E+12 | 3.41E+12 | 3.75E+12 | Sej/m$^2$/year |
| 19 | Emergy investment ratio (EIR) | $\text{IMP}/(R+N_0+N_1)$ | 0.71 | 0.75 | 1.14 | 1.20 | 1.16 | — |
| 20 | Emergy yield ratio (EYR) | 1+1/EIR | 2.41 | 2.34 | 1.87 | 1.84 | 1.87 | — |
| 21 | Environmental loading ratio (ELR) | $(U-R)/R$ | 14.10 | 19.79 | 20.26 | 27.55 | 30.32 | — |
| 22 | Emergy sustainability index (ESI) | EYR/ELR | 0.17 | 0.12 | 0.09 | 0.07 | 0.06 | — |
| 23 | Emergy exchange ratio (EER) | EMRg/EMR | 0.33 | 0.56 | 0.74 | 0.60 | 0.64 | — |
| 24 | Gross DOMESTIC product at market prices (GDP) | GDP | 1.64E+11 | 3.94E+11 | 5.04E+11 | 5.62E+11 | 6.55E+11 | $ |
| 25 | Emergy to money ratio (EMR) | $P_1=U/\text{GDP}$ | 5.62E+12 | 3.31E+12 | 2.49E+12 | 3.09E+12 | 2.91E+12 | Sej/$ |
| 26 | Global emergy to money ratio | $P_2$ | 1.85E+12 | 1.85E+12 | 1.85E+12 | 1.85E+12 | 1.85E+12 | Sej/$ |
| 27 | Renewable carrying capacity | $(R/U)\times$ population | 2.45E+06 | 1.87E+06 | 1.84E+06 | 1.40E+06 | 1.29E+06 | People |
| 28 | Developed carrying capacity at European standard of living | ESL $(R/U)\times$ population | 6.09E+07 | 4.48E+07 | 4.43E+07 | 3.36E+07 | 3.11E+07 | People |
| 29 | Developed carrying capacity at Mediterranean standard of living | MSL $(R/U)\times$ population | 3.41E+07 | 2.51E+07 | 2.48E+07 | 1.88E+07 | 1.74E+07 | People |
| 30 | Renewable support area ($\text{SA}_{(r)}$) | $(\text{IMP}+N)/\text{REmpD}_{(r)}$ | 7.28E+12 | 1.00E+13 | 1.03E+13 | 1.39E+13 | 1.53E+13 | m$^2$ |
| 31 | Synchronal support area at European standard of living ($\text{SSA}_\text{E}$) | $R^*/\text{E\_REmpD}_{(r)}$ | 1.87E+11 | 2.66E+11 | 2.56E+11 | 3.58E+11 | 3.93E+11 | m$^2$ |
| 32 | Synchronal support area at Mediterranean standard of living ($\text{SSA}_\text{M}$) | $R^*/\text{M\_REmpD}_{(r)}$ | 4.42E+11 | 6.27E+11 | 6.05E+11 | 8.45E+11 | 9.28E+11 | m$^2$ |

Details about ESL (European Standard of Living) and MSL (Mediterranean Standard of Living) are contained in Appendix C.
$R^*$ is the required amount of renewable emergy necessary to lower the ELR of the country to that of the region. ($R^*=(\text{IMP}+N)/\text{ELR}(r)$, where ELR($r$) is the environmental loading ratio of the region, calculated in Appendix C).
EMRg is the global Emergy to money ratio from Brown (2003) and EMR is the Emergy to money ratio calculated in this paper for Spain.
E_REmpD($r$) and M_R EmpD($r$) are the renewable empower density for European and Mediterranean context, respectively, and are calculated as renewable emergy used of the region (Europe or Mediterranean Basin)/total area of the region (data in Appendix C).

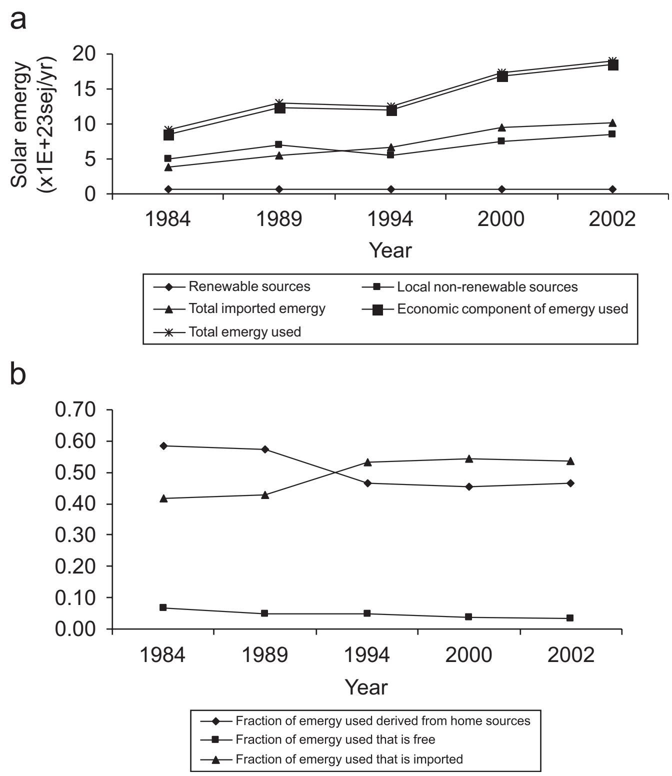


Fig. 5. Main emergy flows in the Spanish social–ecological system: (a) total emergy actually used and its components and (b) main relations among components.

learning to couple the Mediterranean natural perturbation regime with the human activities, although possibilities of economic growth are limited by the connections between the economy and the flow of environmental services that Mediterranean ecosystems supply to Spain. The European context implies the increasing use of international trade to supply goods and services for the national economy, so there is a growing disconnection between local flow of environmental services and the national economy. Potential possibilities for growth are higher for the European context but it means a disconnection between the use of energy and materials and the supply of local environmental services and a loss of resilience as a result. To estimate a benchmark standard of living (ratio of the total eMergy actually used to the renewable one) for those two regions, we have used data contained in Brown (2003) and Cialani et al. (2005) for 14 European and five Mediterranean countries in the 1990s, which are summarized in Appendix C.

If we assume that the Western European standard of living is the correct one, we use the developed carrying capacity with the European Standard of Living (ESL) as the upper limit. The developed carrying capacity at the European standard of living is above present Spanish population in the periods from 1984 to 1994. This means that there was a margin for growth that has been exceeded in the period 1994–2000, in which the

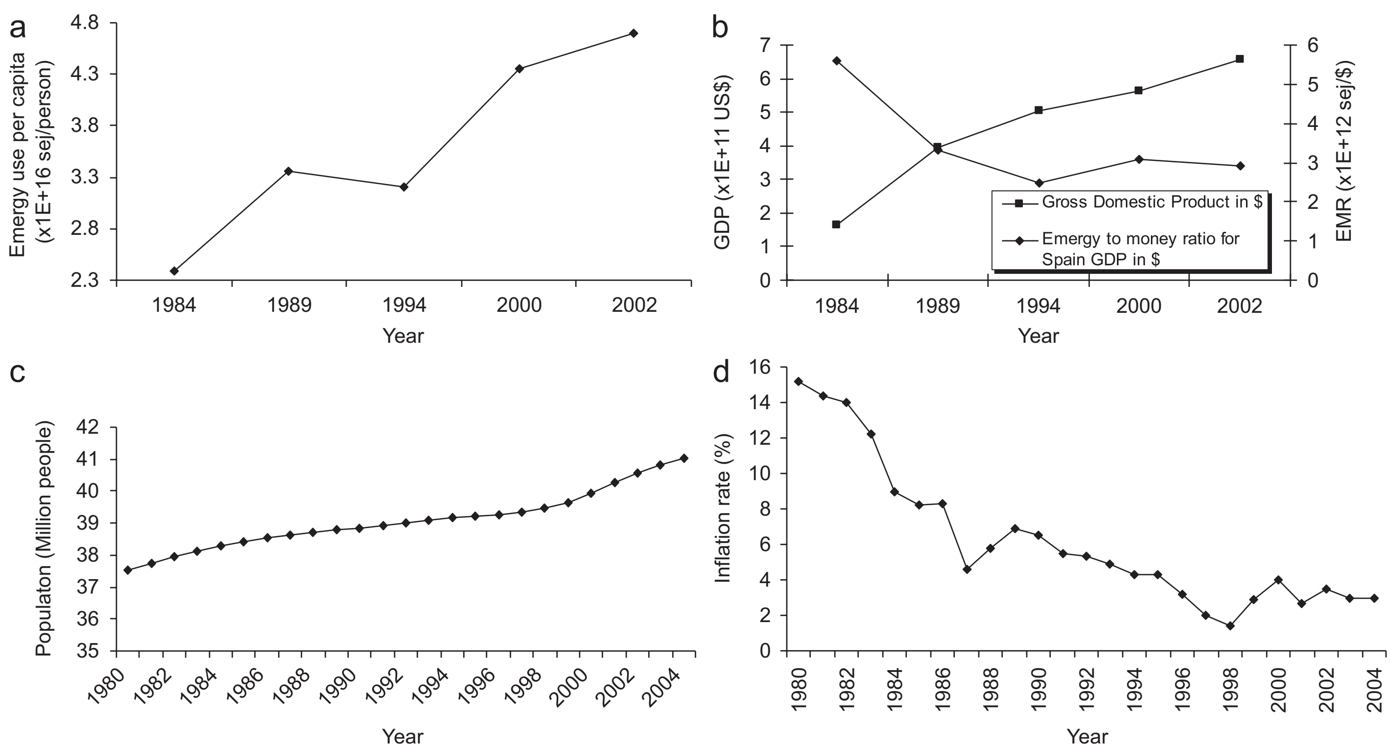


Fig. 6. Some of the standard of living emergy indicators compared with traditional social–economic indicators: (a) emergy use per capita, (b) emergy to money ratio compared with GDP, (c) population patterns in Spain (1980–2004) and (d) inflation rate patterns in Spain (1980–2004).

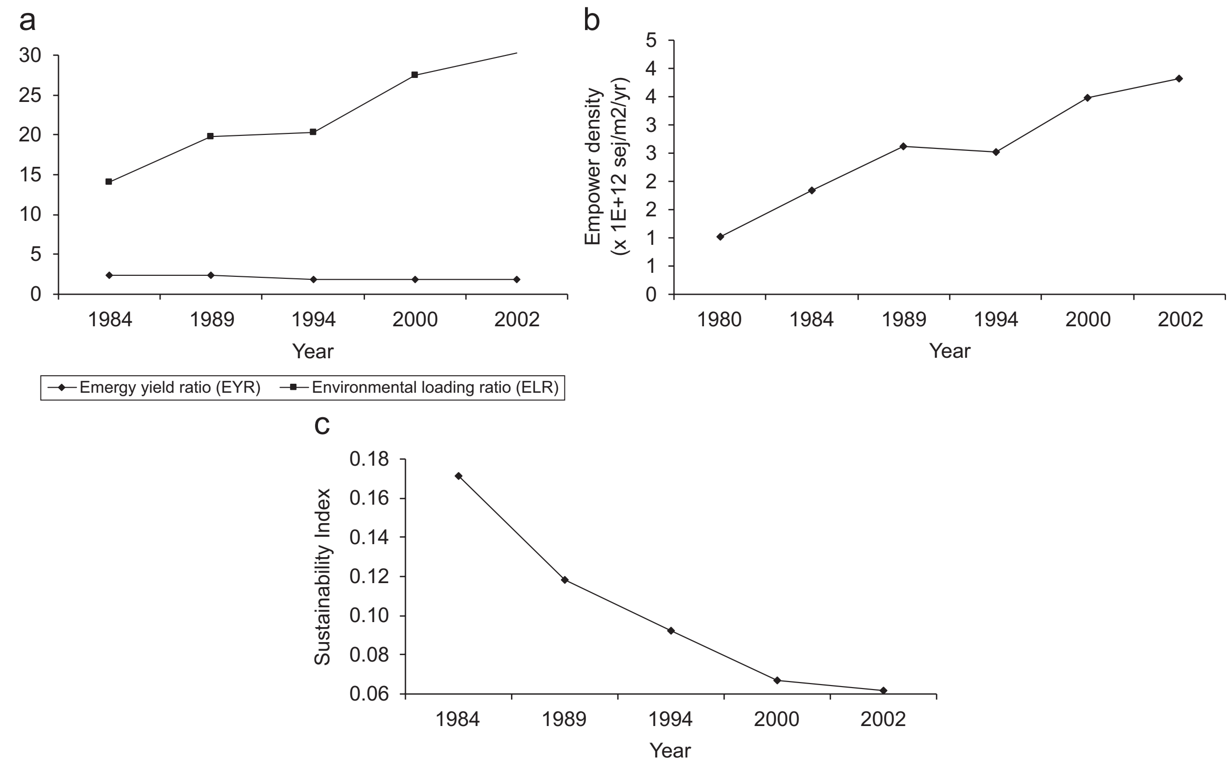


Fig. 7. Emergy indicators for Spain 1984–2002: (a) emergy yield ratio and environmental loading ratio, (b) sustainability index and (c) empower density.

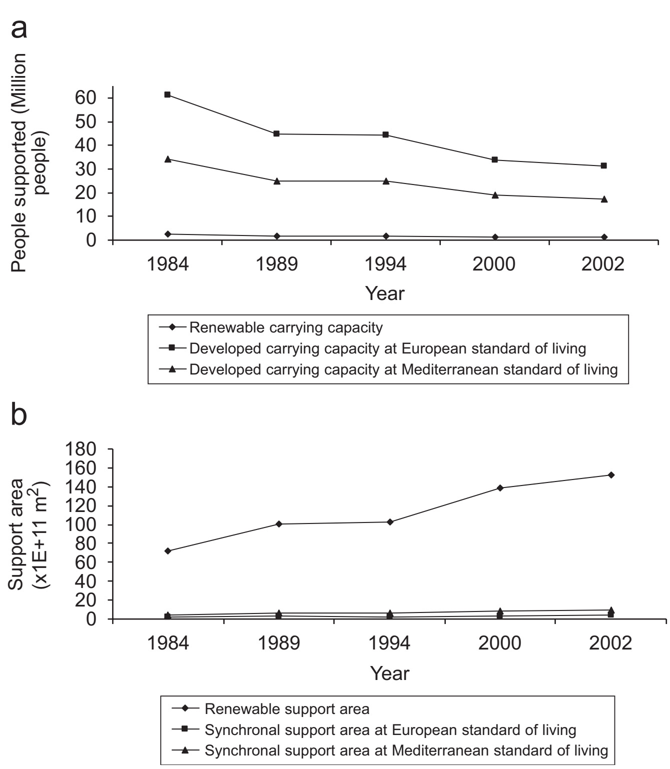


Fig. 8. Evolution of carrying capacity in emergy terms for Spain (1984–2002): (a) people supported and (b) support area.

population supported was 84% of actual population in 2000. In the case of the Mediterranean standard of living, we use the developed carrying capacity at the Mediterranean Standard of Living (MSL) as the upper limit. We have to take into account that it has been calculated with data from only five countries, which was all the available data in the literature for the Mediterranean Basin. The number of people supported decreases from 88% (1984) to 43% (2002) of the respective actual population for these years. It means that the Spanish standard of living had already exceeded the Mediterranean one in the middle 1980s, so if Spain wants to maintain the Mediterranean way of life, which it has experienced so far, Spain has to reduce its eMergy consumption *per capita*.

If the support area-based approach is used for renewable carrying capacity, the area that we would have to use in order to maintain the Spanish standard of living with only renewable sources is 15 (1984) to 30 (2002) times the actual area of the country. This illustrates a doubling of the renewable ecological footprint due to the strong growth experienced in recent decades.

To estimate the support area-based approach for developed carrying capacity (sometimes called synchronal support area), we have to calculate ELR (Appendix C the reference region (Mediterranean or European). We use the same sources that the previous people-based approach to calculate Mediterranean and European regional ELR for 14 European and five Mediterranean countries in the 1990s, summarized in Appendix C. If the standard of living of the European region is employed as a reference, our territorial margin, in terms of the area of Spain that remains after using our territory to reach European ELR, is decreasing, because synchronal support area has increased from 37% of actual area in 1984 to 78% in 2002. In contrast, if the Mediterranean Basin is employed as a reference regional ELR, the increase in support area needed to equal our actual ELR to the Mediterranean regional one was growing from the 88% of the actual area in 1984 to 185% in 2002.

## 4. Discussion

### *4.1. Patterns in the supply of environmental goods and services flows to the Spanish economy and its changes*

Spanish eMergy use, *U*, has similar values to other western countries (Appendix A). Compared with population size, *U* significantly increased over the investigated two decades. As a result, the Spanish standard of living in terms of resources use has increased (eMergy *per capita*). Spain ranks within the group of highly industrialised countries, although still below the average level of several European countries (Appendix A). The particular decrease in eMergy use *per capita* that took place in the 1989–1994 period may have been affected by the recession of the European Monetary System from 1992 to 1993, which caused the peseta (the Spanish currency at that time) to leave the Exchange Rate Mechanism of the European Monetary System in 1992. Three devaluations of the peseta took place between 1992 and 1993 (Gadea, 2000), causing strong disturbances in the energy and materials required and in economic growth levels within the nation. This indicator coincides with the increase of energy use and total material requirements emphasized in the first sustainability report for Spain (OSE (Observatorio de la Sostenibilidad en España), 2005).

This situation could be considered as a case of inflation in eMergy terms, therefore, more money circulating for the same eMergy. However, we have to take into account that the study has been done during some of the years involved in increasing monetary inflation periods for Spain (1987–1989, 1998–2000 and 2001–2002), despite the decreasing inflation rates during the last two decades (Fig. 6d). It will be necessary to study more years to avoid accounting for only inflation-peak years.

As a consequence, there has been an intensification of transformation activity on the territory (empower density) and an increase of pressure or stress on ecosystems due to production (environmental loading ratio). Spain reaches ELR values close to those of the USA or Switzerland for 1999. This process has been supplied by flows of matter and energy mainly based on imports of external energy memory, thus, Spain has become less autonomous (self-sufficient), especially with regards to fuels. As a consequence, there has been a loss in the potential contribution of local eMergy sources to the main economy (eMergy yield ratio), because growing amounts of resources have to be imported to support the growing Spanish standard of living. In the international context, the Spanish EYR is within the range of EYR for European and other western countries. The result is that the Spanish ESI decreases because of the growing pressure on ecosystems derived from the intensification of the economy related to its high dependency on external eMergy sources, added to the relative low contribution of local eMergy sources to production. The ESI change rate has to be emphasized, especially in the mid-1990s. In the international context, there are many countries which show higher ESI indexes than Spain (Appendix B), but because of different causes. There are countries which have an extremely low value of eMergy use *per capita* with a high use of locally available renewable resources, which sometimes could mean potential wealth not adequately used, and others with a low value of eMergy *use per capita*, but with a high use of non-renewable sources. This could be the case of countries like Bolivia, Kenia, India, etc. Spain shows the patterns of a western country, with a small ESI derived from its high IMP and *N* flows, but still with higher values than most of the European countries, as a result of the relatively late incorporation into the European Union (Fig. 4) economic and consumption patterns.

### *4.2. Patterns of trade in the context of economic globalization*

As we have seen, the IMP has become by far the most significant eMergy flow in the Spanish economy, and so trade is a crucial aspect to the study of Spain as a social–ecological system. In classic and environmental economic assessments of trade employed to support decision-making, the predominant approaches are monetary ones, with a user-side value approach. In these approaches, economic policy is reduced to the balance of payments, and value is measured by what is considered to be the best indicator of utility: price. In this sense, in the official statistics on foreign trade for Spain for every year studied, the countries mainly involved in trade exchanges with Spain in monetary terms are those of the European Union and the Organisation for Economic Co-operation and Development (OECD), whose economies are mainly based on manufacture exports. As a result, Spain could be considered within the group of countries reaching a kind of dematerialization, growing without an increase in matter and energy use, but with some problems in the balance of payments.

On the contrary, in a donor-side value approach, as provided by eMergy Synthesis, the concept of value is related to the work done by nature to produce environmental goods and services that support the economy. In eMergy synthesis, value is related to the energy memory of these environmental goods and services. And, in this case, buying power is not estimated by price but by the EMR or eMergy potentially bought by one monetary unit. Therefore, the origin of the main imported eMergy flows for Spain is the oil and natural gas extracting countries (Nigeria, Algeria and some Middle Eastern countries), whose economies are mainly based on raw materials exports. As a result, Spain could be considered as a net importer of raw materials, with a high increase in the use of energy and matter, promoting a kind of false dematerialization by moving the environmental loading required by its growth to countries that supply raw materials (Muradian et al., 2002; Ramos Martín, 2001, 2003; Cañellas et al., 2004; Carpintero, 2005).

A comparison of EMRs (or buying power in eMergy terms) for different countries to the global EMR (Appendix B) or EER shows that there are differences in the relative buying power of different countries, so in the commerce trade with raw materials exporting countries, Spain commerce with an eMergy advantage in these product exchanges. In these terms, there is a natural decapitalization of supplier countries, promoted by the organization of trade, international division of labour, and economies of scale related to the export of primary sources by developing countries and the import by western countries. In this context, Spain, like other industrialised countries, is promoting natural decapitalization and poverty in the supplier countries with trading disadvantages in eMergy terms (those which have an EER smaller than our EER). This is another example of what Brown (2003) calls resource imperialism. On the other hand, Spanish EER is below the value of most western countries (Appendix B), and therefore many of them have eMergy advantages in trade relations with Spain.

Thus, the greatest part of the pressure, in terms of non-renewable stocks of resource depletion or exploitation, is transferred to the exporting countries (they have to use their own resources and processes to satisfy Spanish demand). These resources are used to exploit and develop the importing country beyond the possibilities that a renewable economy would provide Spain, promoting a decoupling of the Spanish national economy from the flow of local environmental goods and services (natural capital), and the limits that this imposes on the local growth of the importing country.

### *4.3. Decoupling between national flow of environmental services and the Spanish economy*

The Mediterranean standard of living has supported an agricultural way of life for more than eight millennia. This fact might intuitively be interpreted as a measure of the sustainability of this way of life (Butzer, 2005). In the last 40 years, many economies, especially in the northern part of the Mediterranean Basin have become disconnected from this ancient way of life: that is, disconnected from the goods and services that their territories supply. In the present, the standard of living of these countries is mainly supported by imported flows of goods. As we have seen from the eMergy indicators, the strong growth of the Spanish standard of living (eMergy *per capita*) has been mainly supported by imports of primary resources (high content in eMergy and a low monetary value), promoting a disconnection between the original flow of environmental services and the requirements of the Spanish economy. How important is this decoupling? Or to what extent is Spain exploiting its system over its endogenous possibilities?

It seems clear that the Spanish endorsement of the European economic community (EEC) Treaty in 1986 entailed great social–economic changes. It is probable that previous patterns of strong growth in the 1960s were accelerated, and, as is shown by standard of living, carrying capacity and footprint eMergy indicators, Spain left the Mediterranean standard of living to adopt a Western European one. This disconnection becomes evident from the middle 1980s, but its growth rate is especially strong after the middle 1990s. In this sense, both carrying capacity measures show that in the mid-1980s Spain disconnects definitively from its Mediterranean way of life to adopt an European one.

To deal with the challenge of natural capital decapitalization (strong use of $N$, high dependency on imports, high pressure on environmental systems, low efficiency in the yield, etc.), different Spanish governments invested a great amount of money in conservationist programmes. In fact, Spain ranks as the third country in the EU in terms of the money spent on environmental protection measures, with an average of 0.8% of GDP and 108 € *per capita* (EUROSTAT On-line-a, b). The natural protected areas in Spain will be considered a good measure of conservation policies, in terms of area and money spent during the past 20 years. Creation of a natural protected areas policy has been developed since the 1980s (Morillo and Gómez-Campo, 2000), supported mainly by international and European legislation. The Conservation of Nature-Wild Flora and Fauna Act of 1989 created different types of natural protected areas to preserve some parts of the country outside of the general economic process of growth and land transformation, and it is the real starting point of the natural protected areas declaration in Spain (Fig. 9). In 2003, there were already 950 protected areas in 38 different protection categories embracing more than 9% of the country's surface (EUROPARC-España, 2004).

eMergy indicators illustrate that conservation policies are not successful enough in terms of preservation of natural capital to enhance sustainability. It has been shown that the intensity of use of the territory has grown and that carrying capacity is strongly decreasing, so the Spanish ecological footprint, in eMergy terms, is increasing too. In this Mediterranean context, natural protected areas cannot be managed as islands inside the territory in which they are embedded, since a full set of biophysical, socio-economic and historical–cultural aspects are shared by both sides of the fence (García and Montes, 2003). In fact, other indicators, like the Natural Capital index (NCI) illustrate that Spain has a great quantity of "natural

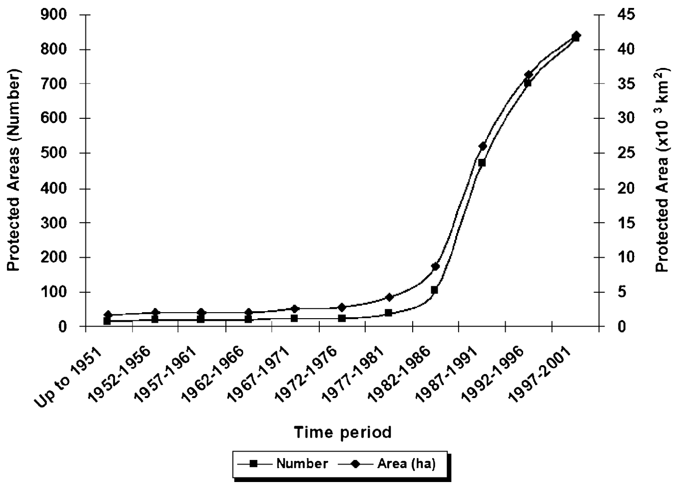


Fig. 9. Evolution of number and area of natural protected areas in Spain during the last 50 years (*Data source*: EUROPARC-España, 2003.)

areas'' but that their quality (ratio between current state of the ecosystem and the defined baseline state) is low (Ten Brink, 2000). In fact, there are countries with a low quantity of natural areas but with a high quality, so their NCI is higher than Spain. This is the case with regard to another Mediterranean country, Greece (De Groot et al., 2003).

It would be interesting to have historical series to study previous periods and compare evolution in the last 15 years with the past decades prior to the entry of Spain in the EU. However, these eMergy indicators confirm patterns suggested by other studies of ecological footprint in Spain. Carpintero (2005) has studied the economic metabolism of Spain, and estimates the ecological footprint changes from 2 ha/inhabitant (1955) to 5 ha/inhabitant (2000), which is more than three times the total area of Spain, including the marine portion. The World Wildlife Fund (WWF) (WWF/WCMC-UNEP, 2004) estimates the ecological footprint to be 4.8 ha/inhabitant, so that there would be an ecological deficit of 2.9 ha/inhabitant.

Although Spain has only been studied between 1984 and 2002, it has to be underlined that patterns obtained are confirmed by the partial indicators of the OSE (Observatorio de la Sostenibilidad en España) (2005): so far from recovering a Mediterranean way of life connected to the flow of goods and services of its own territory, sustainability indicators are getting worse and deepening in the ''growth without limits'' model.

## 5. Conclusions

Despite ancient transformations of its territory, Spain began the first part of the 1980s with one of the best-preserved natural heritages in the Mediterranean and European area. From a socio-economic point of view, the 1980s starts with a political transition and with the economy in a growth period, without strong pressure on ecosystems and with a productive system that was still extensive in many cases.

In this paper, an historical series of eMergy indicators, instead of traditional monetary ones, has been studied in Spain for five different years to determine the balance and evolution of social–ecological dynamics (trends of resource use) during the last two decades. It can be inferred from the use of these indicators that Spain has suffered a global backward movement in sustainability, with increased intensity in the second part of the 1990s. eMergy indicators stress the magnitude and speed of the changes that the Spanish economy faced in the last two decades, as well as its strong dependence on imported resources. Other eMergy indicators estimate the consequences that those changes have had on the territory, in terms of natural capital decapitalization and the increasing need to spend money to substitute for the free environmental services formerly supplied by the lost of the past Mediterranean way of life to adopt a Western European one.

The sustainable use of resources in the Mediterranean Basin has been accomplished as a consequence of human and ecological resilience (Butzer, 2005). The Mediterranean nature of most of Spain produces highly-resilient ecosystems, because their ecosystems obtain their stability by adjusting their dynamics to couple with climatic local perturbation regime (García and Montes, 2003). Mediterranean way of life has been characterized by the reproduction of these patterns (management of fire, water, etc.) in a smaller scale to avoid great perturbations (wild fires, flooding, etc.). Today, the Mediterranean standard of living is endangered, and there is an effort to preserve some of it characteristics. In this sense, although the Mediterranean nature of the Spanish social–ecological system guarantees a high level of ecological resilience *sensu* Holling (1973), management policies, distant from Mediterranean traditional management that was its identity in the past, are not succeeding in preserving the flow of environmental goods and services that supports our economy. As we have seen in the results of this eMergy synthesis figures, Spain is still in the reversible phase of its economic evolution: in other words, it is more endangered than irreversibly degraded.

A transition to a global and coherent landscape management that overcomes the current dichotomy between territories exclusively managed for conservation and those exclusively dedicated to production is needed. In a Mediterranean context, this goal would be achieved by a landscape management proposal in which natural protected areas contributed to the preservation of a heterogeneous mosaic of traditional uses, in which different ecosystems in many states of maturity that changed with time would be combined and complemented (Burel and Baudry, 1995, 1999; Farina, 1997; González Bernáldez, 1991, 1992). Also, a real integration of conservation practices and the sustainable use of biological diversity with other sectoral or cross sectoral activities, plans and programs that have and impact upon them, is desirable.

## Acknowledgements

For discussion and ideas we would like to thank Sergio Ulgiati, from University of Naples "Parthenope", Mark T. Brown, from the Florida University, and Fernando Valladares, from Environmental Sciences Centre of the Spanish National Research Council in Madrid. We would also thank the Spanish Meteorology Institute, the Spanish Oceanographic Institute and the Spanish Port Organism staffs for their help with some geophysical variables used in the synthesis. Also, we would like to thank Phil Mason and Daniel Welsch for their English language edition. Finally, we would like to thank two anonymous reviewers for their critical comments about the earlier draft paper. Financial support for this research activity has been made available thanks to the Andalusian Regional Government Department of Environment (Project NET413308/1).

## Appendix A

Main emergy flows supporting national economies for Spain and other selected countries, arranged by EMR are given in Table A1.

Table A1
Main emergy flows supporting national economies for Spain and other selected countries, arranged by EMR[a]

| Country | *U* (E+20 sej/year) | Renewable (E+20 sej/year) | Non-renewable (E+20 sej/year) | Population (E+6 inhabitants) | GDP (E+9 US$/year) | Emergy per capita (E+15 sej/inhab) | EMR (E+12 sej/US$) |
|---|---|---|---|---|---|---|---|
| Nicaragua 1994 | 816.06 | 720.00 | 90.00 | 4.51 | 1.40 | 18.09 | 58.29 |
| Zambia 1997 | 1250.00 | 1030.00 | 220.00 | 8.96 | 2.50 | 13.94 | 50.00 |
| Morocco 1994 | 976.21 | 380.00 | 600.00 | 28.55 | 8.28 | 3.42 | 11.79 |
| Argentina 1994 | 4520.00 | 1940.00 | 2580.00 | 35.66 | 54.80 | 12.67 | 8.25 |
| Kenia 1999 | 765.60 | 370.00 | 390.00 | 29.35 | 10.24 | 2.61 | 7.48 |
| India 1999 | 26 210.60 | 6750.00 | 19 440.00 | 442.00 | 442.00 | 2.62 | 5.93 |
| **Spain 1984** | **9190.00** | **609.00** | **5090.00** | **38.28** | **164.00** | **24.00** | **5.62** |
| Syria | 790.00 | 90.00 | 700.00 | 15.02 | 17.00 | 5.25 | 4.64 |
| Italy 1984 | 16 100.00 | 2030.00 | 5040.00 | 56.64 | 390.00 | 28.40 | 4.12 |
| Canada 1999 | 23 359.05 | 7800.00 | 15 550.00 | 30.49 | 598.95 | 76.56 | 3.90 |
| **Spain 1989** | **13 100.00** | **628.00** | **7050.00** | **38.79** | **394.00** | **33.70** | **3.31** |
| Saudi Arabia 1994 | 7953.00 | 2580.00 | 5370.00 | 22.03 | 241.00 | 36.11 | 3.30 |
| Italy 2000 | 37 900.00 | 2030.00 | 7430.00 | 57.84 | 1210.86 | 65.50 | 3.13 |
| **Spain 2000** | **17 400.00** | **609.00** | **7550.00** | **39.93** | **562.00** | **43.50** | **3.09** |
| Brazil 1995 | 17 880.00 | 6870.00 | 8830.00 | 167.20 | 600.00 | 10.71 | 2.98 |
| Italy 2002 | 34 700.00 | 2030.00 | 5850.00 | 57.30 | 1176.27 | 60.50 | 2.95 |
| **Spain 2002** | **19 100.00** | **609.00** | **8470.00** | **40.55** | **655.00** | **47.00** | **2.91** |
| **Spain 1994** | **12 500.00** | **590.00** | **5490.00** | **39.17** | **504.00** | **32.00** | **2.49** |
| Italy 1989 | 21 300.00 | 2030.00 | 6000.00 | 56.70 | 866.00 | 37.50 | 2.45 |
| Bolivia 1997 | 195.20 | 180.00 | 10.00 | 8.04 | 8.00 | 2.43 | 2.44 |
| Italy 1995 | 25 900.00 | 2030.00 | 8020.00 | 57.33 | 1070.00 | 45.10 | 2.41 |
| South Africa 1999 | 9270.00 | 2400.00 | 6860.00 | 43.20 | 412.00 | 21.44 | 2.25 |
| Uruguay 1995 | 308.70 | 200.00 | 110.00 | 3.22 | 14.70 | 9.56 | 2.10 |
| Italy 1991 | 23 200.00 | 2030.00 | 8430.00 | 56.76 | 1150.00 | 40.90 | 2.02 |
| **Global economy 1999** | **510 350.00** | **158 600.00** | **343 700.00** | **5900.00** | **27 100.00** | **8.52** | **1.85** |
| Netherlands 1994 | 6789.30 | 250.00 | 6550.00 | 15.67 | 371.00 | 43.40 | 1.83 |
| USA 1999 | 90 100.00 | 8380.00 | 81 620.00 | 266.56 | 8500.00 | 33.76 | 1.75 |
| Denmark 1997 | 1786.40 | 20.00 | 1760.00 | 5.35 | 123.20 | 33.27 | 1.45 |
| Switzerland 1999 | 2538.00 | 280.00 | 2260.00 | 7.20 | 270.00 | 35.25 | 0.94 |
| Ireland 1994 | 469.56 | 70.00 | 400.00 | 3.67 | 54.60 | 12.74 | 0.86 |
| Japan 1999 | 36 000.00 | 1330.00 | 34 600.00 | 126.97 | 4500.00 | 28.30 | 0.80 |
| Germany 1995 | 15 257.77 | 220.00 | 15 100.00 | 83.03 | 2090.10 | 18.43 | 0.73 |

[a]Data source for selected countries, Brown (2003), for Italy Cialani etal., (2005), and this study for Spain.

## Appendix B

Some of the main emergy indicators for Spain and other selected countries, arranged by ESI are given in Table B1.

Table B1
Some of the main emergy indicators for Spain and other selected countries, arranged by ESI[a]

| Country | $U$ (E+20 sej/year) | EER [$EMR_{ge}/EMR_i$][b] | ELR [$(U-R)/R$] | EYR [$U/(N_0+N_1+IMP)$] | ESI [EYR/ELR] |
|---|---|---|---|---|---|
| Bolivia 1997 | 195.20 | 0.76 | 1.07 | 15.00 | 14.00 |
| Nicaragua 1994 | 816.06 | 0.03 | 1.14 | 8.33 | 7.33 |
| Zambia 1997 | 1 250.00 | 0.04 | 1.21 | 5.68 | 4.68 |
| Uruguay 1995 | 308.70 | 0.88 | 1.57 | 2.75 | 1.75 |
| Kenia 1999 | 765.60 | 0.25 | 2.05 | 1.95 | 0.95 |
| Brazil 1995 | 17 880.00 | 0.62 | 2.61 | 2.03 | 0.78 |
| Argentina 1994 | 4520.00 | 0.22 | 2.33 | 1.75 | 0.75 |
| Canada 1999 | 23 359.05 | 0.47 | 1.99 | 1.50 | 0.75 |
| **Global economy 1999** | **510 350.00** | — | **2.17** | **1.46** | **0.70** |
| Morocco 1994 | 976.21 | 0.16 | 2.56 | 1.64 | 0.64 |
| Saudi Arabia 1994 | 7953.00 | 0.56 | 3.08 | 1.48 | 0.48 |
| India 1999 | 26 210.60 | 0.31 | 3.88 | 1.35 | 0.35 |
| South Africa 1999 | 9270.00 | 0.82 | 3.85 | 1.35 | 0.35 |
| Italy 1984 | 16 100.00 | 0.45 | 6.91 | 1.78 | 0.26 |
| **Spain 1984** | **9190.00** | **0.33** | **14.10** | **2.41** | **0.17** |
| Italy 1991 | 23 200.00 | 0.92 | 10.46 | 1.76 | 0.17 |
| Italy 1989 | 21 300.00 | 0.76 | 9.47 | 1.61 | 0.17 |
| Ireland 1994 | 469.56 | 2.16 | 6.87 | 1.17 | 0.17 |
| Italy 1995 | 25 900.00 | 0.77 | 11.72 | 1.59 | 0.14 |
| **Spain 1989** | **13 100.00** | **0.56** | **19.79** | **2.34** | **0.12** |
| Syria | 790.00 | 0.40 | 9.20 | 1.12 | 0.12 |
| Switzerland 1999 | 2538.00 | 1.97 | 9.10 | 1.12 | 0.12 |
| USA 1999 | 90 100.00 | 1.28 | 10.74 | 1.01 | 0.10 |
| **Spain 1994** | **12 500.00** | **0.74** | **20.26** | **1.87** | **0.09** |
| Italy 2002 | 34 700.00 | 0.63 | 16.13 | 1.29 | 0.08 |
| Italy 2000 | 37 900.00 | 0.59 | 17.65 | 1.33 | 0.08 |
| **Spain 2000** | **17 400.00** | **0.60** | **27.55** | **1.84** | **0.07** |
| **Spain 2002** | **19 100.00** | **0.64** | **30.32** | **1.87** | **0.06** |
| Japan 1999 | 36 000.00 | 2.32 | 27.06 | 1.04 | 0.04 |
| Netherlands 1994 | 6789.30 | 1.01 | 27.20 | 1.04 | 0.04 |
| Germany 1995 | 15 257.77 | 2.53 | 69.55 | 1.01 | 0.01 |
| Denmark 1997 | 1786.40 | 1.75 | 89.00 | 1.01 | 0.01 |

[a] *Data source*: For selected countries Brown (2003), for Italy Cialani et al. (2005), and this study for Spain.
[b] EMRge = EMR of global economy; EMR$i$ = EMR of the country.

## Appendix C

Calculations of the average standard of living (ESL and MSL) and regional ELR to be used in carrying capacity and support area for selected European and Mediterranean Basin countries are given in Table C1.

Table C1
Calculations of the average standard of living (ESL and MSL) and regional ELR to be used in carrying capacity and support area for selected European and Mediterranean Basin countries

| European Countries | Total emergy actually used ($U_E$) (sej/year) | Renewable emergy used ($R_E$) (sej/year) | Area ($m^2$) | Analysis year | $R_E/U_E$ | ESL = $U_E/R_E$ | ELR |
|---|---|---|---|---|---|---|---|
| Spain | 1.25E+24 | 5.90E+22 | 4.98E+11 | 1994 | 0.05 | 20.26 | 19.67 |
| Italy | 2.26E+24 | 1.21E+23 | 3.01E+11 | 1995 | 0.08 | 12.73 | 11.72 |
| Czech Republic | 1.55E+23 | 5.60E+22 | 7.90E+10 | 1998 | 0.36 | 2.77 | 2.57 |
| Finland | 1.20E+23 | 2.70E+22 | 3.38E+11 | 1994 | 0.23 | 4.44 | 4.44 |
| Ireland | 4.70E+22 | 7.00E+21 | 8.40E+10 | 1994 | 0.15 | 6.71 | 6.87 |
| Portugal | 1.76E+23 | 1.70E+22 | 9.20E+10 | 1995 | 0.10 | 10.35 | 10.35 |

Table C1 (*continued*)

| European Countries | Total emergy actually used ($U_E$) (sej/year) | Renewable emergy used ($R_E$) (sej/year) | Area ($m^2$) | Analysis year | $R_E/U_E$ | $ESL = U_E/R_E$ | ELR |
|---|---|---|---|---|---|---|---|
| Slovakia | 6.70E+22 | 6.00E+21 | 4.90E+10 | 1994 | 0.09 | 11.17 | 11.75 |
| France | 1.32E+24 | 8.30E+22 | 5.91E+11 | 1999 | 0.06 | 15.90 | 15.92 |
| Netherlands | 6.80E+23 | 2.50E+22 | 4.10E+10 | 1994 | 0.04 | 27.20 | 27.20 |
| England | 2.82E+24 | 8.30E+22 | 1.30E+11 | 1999 | 0.03 | 33.95 | 34.05 |
| Germany | 1.53E+24 | 2.20E+22 | 3.57E+11 | 1995 | 0.01 | 69.55 | 69.55 |
| Austria | 2.59E+23 | 1.60E+22 | 8.39E+10 | 1997 | 0.06 | 16.19 | 16.19 |
| Switzerland | 2.54E+23 | 2.80E+22 | 4.13E+10 | 1999 | 0.11 | 9.07 | 9.10 |
| Denmark | 1.78E+23 | 2.00E+21 | 4.31E+10 | 1997 | 0.01 | 89.00 | 89.00 |
| | | Total $R_E$ = 5.52E+23 | Total area of European countries used = 2.73E+12 | | Average = | ESL = 24.02 | ELR($r$) = 23.50 |
| | | | | | SD = | 25.23 | 25.41 |

| Mediterranean basin countries | Total emergy actually used ($U_M$) (sej/year) | Renewable emergy used ($R_M$) (sej/year) | Area ($m^2$) | Analysis year | $R_M/U_M$ | $MSL = U_M/R_M$ | ELR |
|---|---|---|---|---|---|---|---|
| Spain | 1.25E+24 | 5.90E+22 | 4.98E+11 | 1994 | 0.05 | 20.72 | 19.67 |
| Italy | 2.26E+24 | 1.21E+23 | 3.01E+11 | 2000 | 0.05 | 18.68 | 17.65 |
| France | 1.32E+24 | 8.30E+22 | 5.91E+11 | 1999 | 0.06 | 15.90 | 15.92 |
| Morocco | 9.80E+22 | 3.80E+22 | 4.44E+11 | 1994 | 0.39 | 2.58 2 | 2.56 |
| Syria | 7.90E+22 | 9.00E+21 | 1.85E+11 | 1997 | 0.11 | 8.78 | 9.20 |
| | | Total $R_M$ = 3.10E+23 | Total area of Mediterranean countries used = 2.02E+12 | | Average = | MSL = 13.44 | ELR($r$) = 13.12 |
| | | | | | SD = | 7.65 | 7.18 |

*Data source*: Brown (2003) and Cialani et al. (2005).

## References


AEAT (Agencia Estatal de Administración Tributaria) [On-line]. Información estadística sobre el comercio exterior de España-Diciembre 2000 [Consulted: 2/2/2006], Ministerio de Hacienda. Departamento de Aduanas e II.EE., Madrid, 〈http://www.aeat.es/aduanas/descarga/est1200.pdf〉.

Arrojo, P (Co-ord), 2001. El Plan Hidrológico Nacional a debate, Colección Nueva Cultura del Agua, 8. Bakeaz/Fundación Nueva Cultura del Agua, Bilbao.

BDE (Banco de España) [On-line]. Balanza de Pagos y posición de inversión internacional frente a otros residentes en la Zona del Euro y al resto del mundo, Boletín Estadístico del Banco de España [Consulted: 2/2/2006], Banco de España, Madrid, 〈http://www.bde.es/infoest/a1603.pdf〉.

Berkes, F., Folke, C. (Eds.), 1998. Linking Social and Ecological Systems. Cambridge University Press, Cambridge.

Brown, M.T., Ulgiati, S., 1997. Emergy-based indices and ratios to evaluate sustainability monitoring economies and technology toward environmentally sound innovation. Ecological Engineering 9, 51–69.

Brown, M.T., Ulgiati, S., 2001. eMergy measures of carrying capacity to evaluate economic investments. Population and Environment 22 (5), 471–501.

Brown, M.T., Ulgiati, S., 2004. eMergy analysis and environmental accounting. Encyclopedia of Energy 2, 329–354.

Brown, M.T., 2003. Resource imperialism: eMergy perspectives on sustainability, international trade, and balancing the welfare of nations. In: Ulgiati, S., Brown, M.T., Giampietro, M., Herendeen, R., Mayumi, K. (Eds.), Proceedings of Third Biennial International Workshop, Advances in Energy Studies: Reconsidering the Importance of Energy, Porto Venere, Italy, pp. 135–149.

Brown, M.T., 2004. A picture is worth a thousand words: energy systems language and simulation. Ecological Modelling 178 (1–2), 83–100.

Burel, F., Baudry, J., 1995. Species biodiversity in changing agricultural landscapes: a case study in the Pays d'Auge, France. Agriculture Ecosystems & Environment 55, 193–200.

Burel, F., Baudry, J., 1999. Ecologie du paysage. Concepts, methods et applications. Edition Tec et Doc, París, France.

Butzer, K.W., 2005. Environmental history in the Mediterranean world: cross-disciplinary investigation of cause- and effect for degradation and soil erosion. Journal of Archaeological Science 32, 1773–1800.

Campbell, D., 1998. eMergy analysis of human carrying capacity and regional sustainability: an example using the state of Maine. Environmental Monitoring and Assessment 51, 531–569.

Cañellas, S., Citalic, A., Puig, I., Russi, D., Sendra, C., Sojo, A., 2004. Material flow accounting of Spain. Journal of Global Environmental Issues 4 (4), 229–241.

Carpintero, O., 2005. El metabolismo de la economía española. Recursos naturales y huella ecológica (1955–2000). Fundación César Manrique, Islas Canarias (España).

Casado, S., Montes, C., 1991. Estado de conservación de los humedales peninsulares españoles. Quercus 66, 18–26.

Cerdá, A., 2001. La erosión del suelo y sus tasas en España. [Consulted: 2/2/2006]. Ecosistemas, 3, Año X., Asociación Española de Ecología Terrestre, 〈http://www.aeet.org/ecosistemas/013/revisiones1.htm〉.

Cialani, C., Russi, D., Ulgiati, S., 2005. Investigating a 20-year national economic dynamics by means of eMergy-based indicators. In: Brown, M.T., Bardi, E., Tilley, D., Ulgiati, S. (Eds.), eMergy Synthesis 3: Theory and Applications of the eMergy Methodology, Proceedings of the Third Biennial eMergy Conference. Center for Environmental Policy, University of Florida, Gainesville, FL, USA, pp. 325–334.

Cincotta, R.P., Wisnewski, J., Engelman, R., 2000. Human population in the biodiversity hotspots. Nature 404, 990–992.

Costanza, R., 1997. La Economía Ecológica de la sostenibilidad Invertir en capital natural. In: Goodland, R., Daly, H., El Serafy, S., von Droste, B. (Eds.), Medio Ambiente y desarrollo sostenible. Más allá del Informe Brundtland, Editorial Trotta. Serie Medio Ambiente, Madrid, pp. 103–114.

Costanza, R., Cumberland, J., Daly, H., Goodland, R., Norgaard, R., 1997. An Introduction to Ecological Economics. St. Lucie Press, FL, USA.

Crutzen, P.J., Stoermer, E.F., 2000. The Anthropocene IGBP Newsletter, 41. Royal Swedish Academy of Sciences, Stockholm, Sweden.

Cuadrado, J.R., 1999. Sector servicios: una visión de conjunto. In: García Delgado, J.L. (Dir.), Economía ante el s, XXI, Ed. Espasa Calpe, España, Madrid.

Daly, H.E., 1991. Ecological Economics and Sustainable Development: From Concept to Policy. The World Bank, Washington, DC, USA.

De Groot, R., Van der Perk, J., Chiesura, A., van Vliet, A., 2003. Importance and threat as determining factors for criticality of natural capital. Ecological Economics 44, 187–204.

De Miguel, J.M., Gómez-Sal, A., 2002. Diversidad y funcionalidad de los paisajes agrarios tradicionales. In: Montalvo, J. (Coords.), La diversidad Biológica de España. Pearson Education S.A., Madrid, pp. 273–284.

EEA (European Environment Agency), 2005. The European Environment—State and Outlook 2005 [Consulted: 2/2/2006], Copenhagen, Denmark, 〈http://reports.eea.eu.int/state_of_environment_report_2005_1/en/tab_content_RLR〉.

EU/EWEA (European Commission-DG TREN/European Wind Energy Association), 2003. Wind Energy-the facts. An analysis of wind energy in the EU25 [Consulted: 2/2/2006], European Wind Energy Association, 〈http://www.ewea.org/index.php?id=91〉.

EUROPARC-España, 2004. Anuario EUROPARC-España del estado de los espacios naturales protegidos 2003. Fundación Fernando González Bernáldez, Madrid, 123pp.

EUROSTAT [On-line-a], Energy Yearly Statistics: Data, 2001 [Consulted: 2/2/2006], 〈http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-CN-03-001-3A/EN/KS-CN-03-001-3A-EN.PDF〉.

EUROSTAT [On-line-b], Environmental protection expenditure in Europe by public sector and specialised producers 1995–2002 [Consulted: 2/2/2006], 〈http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-NQ-05-010/EN/KS-NQ-05-010-EN.PDF〉.

Farina, A., 1997. Landscape structure and breeding bird distribution in a sub Mediterranean agro-ecosystem. Landscape Ecology 12, 365–378.

Gadea, M.D., 2000. La peseta en la cultura de la estabilidad, 1989–1999. In: García Delgado, J.L., Serrano Sanz, J.M. (Dirs.), Del real al euro. Una historia de la peseta, Colección Estudios Económicos, vol. 21. Servicio de Estudios de La Caixa, Barcelona, pp. 169–190.

García, R., Montes, C., 2003. (Eds.), Vínculos en el paisaje mediterráneo. El papel de los espacios protegidos en el contexto territorial/Linkages in the Mediterranean Landscape. The Role of Protected Areas in the Territorial Context, Junta de Andalucía, Sevilla, 216pp.

González Bernáldez, F., 1991. Diversidad biológica, gestión de ecosistemas y nuevas políticas agrarias. In: Pineda, F.D., Casado, M.A., de Miguel, J.M., Montalvo, J. (Eds.), Biological Diversity/Diversidad Biológica, Fundación Areces, WWF/ADENA. SCOPE, Madrid, pp. 23–31.

González Bernáldez, F., 1992. Ecological consequences of the abandonment of traditional land use systemes in central Spain. Options Mediteranéennes Series Seminars 15, 23–29.

Goodland, R., Daly, H., 1996. Environmental sustainability: universal and non-negotiable. Ecological Applications 6 (4), 1002–1017.

Grove, A.T., Rackham, O., 2003. The Nature of Mediterranean Europe: An Ecological History, second ed. Yale University Press, London, UK.

Hau, J.L., Bakshi, B.R., 2004. Promise and problems of eMergy analysis. Ecological Modelling 178 (1), 215–225.

Henning, D., 1989. Atlas of the Surface Heat Balance of the Continents. Gebruder Borntraeger, Berlin, Germany.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4, 1–23.

IEA (International Energy Agency), 2003. Energy Balances of OECD Countries 2000–2001, Paris, France.

IGME (Instituto Geológico y Minero de España) [On-line]. Panorama minero España 1993–2002. [Consulted: 2/2/2006], 〈http://www.igme.es/internet/RecursosMinerales/indexc.htm〉.

IGN (Instituto Geográfico Nacional), 1996. Atlas Nacional de España Tomo I, Centro Nacional de Información Cartográfica. Ministerio de Fomento, Madrid.

INE (Instituto Nacional de Estadística) [On-line], 2006. Padrón municipal Cifras oficiales de población [Consulted: 2/2/2006], 〈http://www.ine.es/inebase/cgi/um?M=%2Ft20%2Fe260&O=inebase&N=&L〉.

INM (Instituto Nacional de Meteorología), 2001. Calendario Meteorológico 2001, Serie Monografias. Secretaría General Técnica, Madrid.

INM (Instituto Nacional de Meteorología), 2002. Calendario Meteorológico 2002, Serie Monografias. Secretaría General Técnica, Madrid.

Llamas, R., 2000. Análisis de los sistemas hidráulicos. Recursos, demandas, balances, [Consulted: 2/2/2006]. In: Jornadas Colegio de Ingenieros de Caminos, Canales y Puertos, Madrid, 〈http://www.unizar.es/fnca/docu1.php〉.

MA (Milleninum Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC, USA.

Makhzoumi, J., Pungetti, G., 1999. Ecological Landscape Design and Planning: The Mediterranean Context. E and FN Spon, London, UK.

MAPA (Ministerio de Agricultura, Pesca y Alimentación), 1991. Anuario de estadísticas agrarias—1990. Secretaría General Técnica, Madrid.

MAPA (Ministerio de Agricultura, Pesca y Alimentación) [On-line]. Anuario de Estadística Agroalimentaria—2003 [Consulted: 2/2/2006], 〈http://www.mapya.es/es/estadistica/pags/anuario/Anu_03/indice.asp〉.

MAPA (Ministerio de Agricultura, Pesca y Alimentación), 1998. Anuario de Estadística Agraria—1997, Madrid.

Martínez-Alier, J., 1999. Introducción a la Economía Ecológica. Editorial, Rubes, Barcelona.

MFOM (Ministerio de Fomento) [On-line-a]. Plan Estratégico de Infraestructuras y Transporte. Horizonte 2005–2020 [Consulted: 2/2/2006], Secretaría General Técnica, Madrid, 〈http://www.fomento.es/MFOM/LANG_CASTELLANO/INFORMACION_MFOM/PEIT2/050711-1.htm〉.

MFOM (Ministerio de Fomento) [On-line-b]. Anuario Estadístico 2004, [Consulta: 2/2/2006], Secretaría General Técnica, Madrid, 〈http://www.fomento.es/MFOM/LANG_CASTELLANO/INFORMACION_MFOM/IN.FORMACION_ESTADISTICA/Anuari2004/anuario.htm〉.

MIMAM (Ministerio de Medio Ambiente), 1999. Estrategia español para la conservación y el uso sostenible de la diversidad biológica, Secretaría General de Medio Ambiente. Dirección General de Conservación de la Naturaleza, Madrid.

MIMAM (Ministerio de Medio Ambiente), 2000. Libro blanco del agua en España, Dirección General de Obras Hidráulicas. Secretaría General Técnica, Madrid.

Morillo, C., Gómez-Campo, C., 2000. Conservation in Spain, 1980–2000. Biological Conservation 95, 165–174.

Mulligan, M., Burke, S., Ramos, C., 2004. Climate change, land-use change and the ''Desertification'' of Mediterranean Europe. In: Mazzoleni, S., di Pasquale, G., Mulligan, M., di Martino, P., Rego, F. (Eds.), Recent Dynamics of the Mediterranean Vegetation and Landscape. Wiley, Chichester, pp. 259–279.

Muradian, R., O'Connor, M., Martínez-Alier, J., 2002. Embodied pollution in trade: estimating the ''environmental load displacement'' of industrialised countries. Ecological Economics 41, 51–67.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Naveh, Z., Liberman, A., 1993. Landscape Ecology. Theory and Application. Springer, New York, USA.
Odum, H.T., Odum, E.C., 1983. Energy Analysis Overview of Nations Working Paper, WP-83-82. International Institute for Applied System Analysis, Laxenburg, Austria.
Odum, H.T., 1994. Ecological and General Systems: An Introduction to Systems Ecology, revised ed. University Press of Colorado, Niwot, CO, USA.
Odum, H.T., 1996. Environmental Accounting: eMergy and Decision Making. Wiley, New York, USA.
Odum, H.T., Brown, M.T., Brandt-Williams, S., 2000. Folio #1. Introduction and Global Budget. Handbook of eMergy Evaluation. A Compendium of Data for eMergy Computation issued in a Series of Folios. Center for Environmental Policy, Gainesville, FL, USA.
OSE (Observatorio de la Sostenibilidad en España), 2005. Sostenibilidad en España 2005, Informe de primavera. Observatorio de la Sostenibilidad en España. Alcalá de Henares, España.
Pineda, F.D., Montalvo, J., 1995. Biological diversity in dehesa systems. In: Gilmour, D. (Ed.), Biological Diversity Outside Protected Areas. Overview of Traditional Agroecosystems, IUCN. Forest Conservation Programme, Gland Suiza, pp. 107–122.
Porta, J., López-Acebedo, M., Roquero, C., 1994. Edafología para la agricultura y el medio ambiente. Mundi-Prensa, Madrid.
Postel, S.L., Daily, G.C., Ehrlich, P.R., 1996. Human appropriation of renewable fresh water. Science 271, 785–788.
Prats, N., Munné, A., Rieradevall, M., Bonada, N., 2000. La determinación del estado ecológico de los sistemas acuáticos en España. In: Fabra, A., Barreira, A. (Eds.), La aplicación de la Directiva Marco del Agua en España. Instituto Internacional de Derecho y Medio Ambiente, Barcelona, pp. 47–81.
OAPEstado [On-line]. Base de datos oceanográficos [Consulted: 2/2/2006], Ministerio de Fomento, Madrid, 〈http://www.puertos.es/index2.jsp?langId = 1&catId = 1014806377970&pageId = 1037009598954〉.
Ramos Martín, J., 2001. Non-linearity in Energy Metabolism of Spain: Attractor Points for the Development of Energy Intensity. In: Ulgiati, S., Brown, M.T., Giampietro, M., Herendeen, R.A., Mayumi, K. (Eds.), Proceedings of the Second Biennial International Workshop in Advances in Energy Studies, Exploring Supplies, Constraints and Strategies, Padova, Italy, pp. 535–542.
Ramos Martín, J., 2003. Intensidad energética de la economía española: una perspectiva integrada. Economía Industrial 351, 59–72.
Raugei, M., Bargigli, S., Ulgiati, S., 2004. eMergy "Yield" Ratio: problems and misapplications. In: Brown, M.T., Bardi, E., Tilley, D., Ulgiati, S. (Eds.), eMergy Synthesis 3: Theory and Applications of the eMergy Methodology. Proceedings of the Third Biennial eMergy Conference. Center for Environmental Policy, University of Florida, Gainesville, FL, USA, pp. 105–124.
Rojstaczer, S., Sterling, S.M., Moore, N.J., 2001. Human appropriation of photosynthesis products. Science 294, 2549–2552.
Rosnay, J., 1979. The Macroscope: A New World Scientific System. Harper & Row, Publishers Inc., New York, USA.
Schmitz, M.F., de Aranzabal, I., Rescia, A., Pineda, F.D., 2001. Implications of socioeconomic changes in Mediterranean cultural landscapes. In: Mander, U., Printsmann, A., Palang, H. (Eds.), Development of European Landscapes, vol. 92. Publicaciones Instituti Geographici Universitatis, Tartuensis, pp. 788–793.
Soto, D., 1990. Aproximación a la medida de la erosión y medios para reducir ésta en la España peninsular. Ecología 1, 169–196.
Tamames, R., Rueda, A., 2000. Estructura económica de España, 24th ed. Alianza Editorial, Madrid.
Ten Brink. B., 2000. Biodiversity indicators for the OECD environmental outlook and strategy, RIVM Rapport. 402001014, Globo Report Series, 25.
Tilley, D.R., Swank, W.T., 2003. EMERGY-based environmental systems assessment of a multi-purpose temperate mixed-forest watershed of the southern Appalachian Mountains, USA. Journal of Environmental Management 69, 213–227.
Ulgiati, S., Brown, M.T., 1998. Monitoring patterns of sustainability in natural and man-made ecosystems. Ecological Modelling 108, 23–36.
UNSD (United Nations Statistical Division) [On-line]. GDPmp for Spain. National Accounts Main Aggregates Database. Basic Data Selection [Consulted: 2/2/2006], 〈http://unstats.un.org/unsd/snaama/selection-basicFast.asp〉.
Verdnasky, V.I., 1945. The biosphere and the noosphere. American Scientist 33, 1–12.
Vitousek, P., Ehrlich, P., Ehrlich, A., Matson, P., 1986. Human appropriation of the products of photosynthesis. Bioscience 36 (6), 368–373.
Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277 (5325), 494–499.
WCD (World Commission on Dams), 2000. Dams and Development. A new framework for Decision Making: The Report of the World Commission on Dams. Earthscan, London, UK.
WWF/WCMC-UNEP (World Wildlife Fund/World Conservation Monitoring Centre—United Nations Environmental Program), 2004. Informe Planeta Vivo 2004, [Consulted: 2/2/2006], Gland. Switzerland, 〈http://www.wwf.es/planeta_vivo04.php〉.