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Resumo This paper presents an emergy-based evaluation of the required Portugal resources inputs for the years 2000, 2005 and 2009. The main objective is to provide comprehensive emergy measures which seek to integrate the accountability values of all economic and environmental work contributions to annual national activities. Emergy (from embodied energy) was defined by Odum as being the available energy of one kind of previously used up directly or indirectly to make a service or product. The emergy m...

EMERGY-BASED EVALUATION OF RESOURCES INPUT IN PORTUGAL

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Abstract: This paper presents an emergy-based evaluation of the required Portugal resources inputs for the years 2000, 2005 and 2009. The main objective is to provide comprehensive emergy measures which seek to integrate the accountability values of all economic and environmental work contributions to annual national activities. Emergy (from ***em****bodied energy*) was defined by Odum as *being the available energy of one kind of previously used up directly or indirectly to make a service or product*. The emergy methodology employed, based on existing statistical data, deals with energy systems and amplifies the perspective of analysis by extending it to the wider level of biosphere, by including all the processes that are involved in the formation of system inputs, either being devices of material, energy or money flows. Attention is given to emergy assigned to flows of local renewable resources (R), local nonrenewable resources (N), imported resources (IMP) and exported resources (EXP). Results show a decline in the total amount of annual emergy required to support the country's activities (U) in 2009 relative to 2000 and as emergy per capita also decreased, it might indicates that the population wellbeing in 2009 might be inferior to the level attained in 2000, as less resources from the geobiosphere were invested in each person. Emergy from local nonrenewable flows was the major contribution to total emergy, and in period, more emergy was exported than imported. The contribution of the renewable emergy flow (R) is almost unchanged over time, contributing with approximately 4.5% of the total emergy, what questions the Portuguese government's efforts to reinforce the use of renewable energies.

1. INTRODUCTION

Emergy Synthesis - This paper presents the emergy-based evaluation of resources inflows to Portuguese economy for the years 2000, 2005 and 2009. The main objective is to provide comprehensive emergy measures which seek to integrate the accountability values of all economic and environmental work contributions to national economic production. In this period, the Portuguese economy was characterized by a low rate of economic growth, a significant increase of the services sector share of Gross Domestic Product (GDP), and persistent deficits in the balance of goods and services. The emergy synthesis method employed, based on existing statistical data, reports emergy assigned to annual system inflows and outflows of matter, energy and money.

Homeland - Portugal is located in the southeastern corner of Europe, in the Iberian Peninsula, and has two Autonomous Regions in the Atlantic Ocean: the Azores and the Madeira archipelagos. The Atlantic front location of the Iberian Peninsula has a great influence on the features of the Portuguese mainland due to the natural conditions it transmits and to the privilege of having a large coastline.

Population distribution – In the year 2000 the population density was 111 inhabitant/km^2, a value very close to that of the EU27 (27 member states of the European Union) average, slightly increasing in 2009 to 115 inhabitant/km^2; the higher population density along the sea-coast increased over time and the population concentration movement near the big metropolitan areas of Lisbon and Oporto was reinforced.

Portuguese Economy - The most evident changes in the productive structure since the 1990s, were: reduction in primary sector activities, mostly concerning agriculture, forests and fishing (in the year 2000 the contribution to total Gross Value Added, GVA, was 3.6% decreasing to 2.3% in 2009); decreased importance of industry and construction sectors in relation to total GVA (respectively, 17.7% and 8.2% in 2000 and 13% and 6.6% in 2009); and a slight increase in the energy sector, water and drainage (2.7% in 2000 to 3.8% in 2009). Furthermore, the tertiary sector has been stimulated by the media sector, banks, services supplied to companies and tradable services, from which tourism stands out as the main generator of external incomes (the services sector registered an increase in the share of total GVA from 67.9% in 2000 to 74.2% in 2009).

Macroeconomic Performance - In 2009, the nominal Gross Domestic Product (GDP) amounted to 168.5 billion of euros. This value corresponds to a nominal decrease of 2.0% and to a real decrease of 2.9% when compared to 2008, which can be seen as a consequence of the recessionary effects of the international financial crisis. The performance of the Portuguese economy during the period 2000-2009 illustrates how difficult it has been for Portugal to adapt to the changes in the economic environment brought about by increased economic globalization, enlargement of the European Union and the introduction of the Euro. The increasing gap over the last decade between Portugal's per capita

GDP and that of the European (EU 27) average is the main indicator of the poor macroeconomic performance of the Portuguese economy (GDP per capita in Purchasing Power Standard was around 78.0% of the EU27 average in 2000, but only 76.6% in 2009). Other indicators include: increase in the unemployment rate (from 3.9% in 2000 to 9.5% in 2009); low labor productivity (68.8% of the EU27 average in 2000 and 71.8% in 2009); and an excessive weight of private consumption and, mostly, of public expenses on national expenditure. Both have increased faster than production (82.5% of GDP in 2000 and 87.6% in 2009) and were supported by increasing private and public debt. Furthermore, there was an important and long lasting investment crisis (Gross fixed capital formation was of 27.1% of GDP in 2000 and only 20.9% in 2009) and a slowdown of the exports of goods and services (real growth of 8% in 2000, 8.7% in 2006, -0.5% in 2008 and -11% in 2009) which, combined with increased imports of goods and services until 2008, produced a persistent deficit in the balance of goods and services (-11% from GDP in 2000 and -7.5% in 2009) and in the current account, leading to the accumulation of a very large stock of external debt (data sources: GEPEARI 2010, Banco de Portugal 2001, Banco de Portugal 2010 and Instituto Nacional de Estatística).

2. METHODOLOGY

The procedures to evaluate the emergy assigned to resources supporting the Portuguese Economic System, for the years 2000, 2005 and 2009, followed the general Emergy Synthesis Methodology of states and nations presented in several previous studies (e.g., Odum 1996, Brown 2003, Brown *et al*. 2009, Sweeney *et al*. 2006, Campbell 2009, Cialani *et al* 2004, Gasparatos 2009, Lomas *et al* 2010, Siche 2006, Yang *et al* 2010). Employed emergy methodology consisted of the main following steps. 1) Energy systems diagramming. The diagramming defines the system boundary, as well as inputs and outputs that cross the boundary. The principal components within the boundary (materials, energy sources, stocks) and processes (flows, relationships, interactions, production and consumption processes, and so on) were described. Flows and transactions of money believed to be important were included. 2) Emergy evaluation table. Raw data on inflows that actual cross the boundary (of materials, energy and money) were converted into emergy units, according to the respective Unit Emergy Values, UEV, and then summed to obtain total emergy supporting the system. In this paper, the new emergy reference baseline of 15.2E25 seJ/yr was used (Brown and Ulgiati 2010), UEV (seJ/J, seJ/kg or seJ/$), were obtained from several previous studies and converted to new updated values by multiplying them by the ratio between the new baseline and the previous one. 3) Aggregated system diagram. The numerous resource flows were aggregated into: local renewable resources (R); local nonrenewable resources (N), which

are categorized into dispersed rural sources (N_0), concentrated resources (N_1) and non transformed minerals and metals that are exported (N_2); imports (IMP), whose major items are grouped into three categories including fuels, minerals and electricity (F), other goods (G), and services in imports (P2I); exports (EXP) divided also into three parts, one consisting of transformed products (B), a second one of services in exports (P1E) and a third part, already mentioned, of non transformed metals and minerals (N_2). Total emergy required (U), was calculated for each year by adding emergy flows from local renewable resources, from local nonrenewable dispersed and concentrated resources, and from imports ($U = R+N_0+N_1+F+G+P2I$).

This study includes Portugal's mainland and its two autonomous regions (Madeira and Azores). For renewable emergy accounting, the overall area of the country was divided into two different areas (Campbell 2009) – the country's coastal area and the land area. Only the largest renewable flow for each area was accounted for in order to avoid double counting, and the two major flows were added to get the total input renewable emergy flow of the entire area of the country.

3. RESULTS AND DISCUSSION

Emergy National Account

The emergy evaluation of the Portugal resources inputs for the years 2000, 2005 and 2009 is presented in Table 1. Table 2 contains, for those years, a summary of the main inflows and outflows.

Table 1. Emergy evaluation of resource basis for Portugal (2000, 2005 and 2009).

Note	Item	2000	2005	2009	% Diff. 00-09
Renewable resources (seJ/yr)					
1	Sunlight	4.11E+20	4.11E+20	4.11E+20	0.0
2	Rain, chemical	1.02E+22	4.69E+21	7.72E+21	-24.2
2a	Land	8.76E+21	4.03E+21	6.63E+21	-24.2
2b	Continental Platform	1.43E+21	6.61E+20	1.09E+21	-24.2
3	Rain, geopotential	6.07E+21	2.79E+21	4.60E+21	-24.2
4	Wind, kinetic energy	8.39E+21	8.39E+21	8.39E+21	0.0
5	Waves	5.23E+22	5.23E+22	5.23E+22	0.0
6	Tide	1.67E+22	1.67E+22	1.67E+22	0.0
7	Earth Cycle	4.43E+21	4.43E+21	4.43E+21	0.0

Indigenous Renewable Energy (seJ/yr)					
8	Renewable Energy	8.59E+21	4.50E+21	9.26E+21	7.9
8a	Hidroelectricity	8.11E+21	3.39E+21	5.87E+21	-27.6
8b	Geothermal	6.48E+19	5.80E+19	1.48E+20	127.6
8c	Wind	5.76E+19	6.06E+20	2.59E+21	4396.3
8d	Others (solar, tides and waves)	7.27E+17	2.18E+18	1.11E+20	15100.0
8e	Biomass and waste	3.50E+20	4.49E+20	5.46E+20	55.7
9	Agriculture Production	1.07E+23	1.05E+23	1.04E+23	-3.5
10	Livestock Production	4.43E+22	4.34E+22	4.41E+22	-0.4
11	Fisheries Production	2.71E+21	2.96E+21	2.80E+21	3.5
12	Fuelwood Production	7.69E+19	7.69E+19	7.69E+19	0.0
13	Forest Extraction	1.31E+21	1.30E+21	1.15E+21	-12.4
14	Total electricity used	4.48E+22	5.37E+22	5.62E+22	25.5
Nonrenewable sources from within system (seJ/yr)					
15	Minerals	7.72E+23	8.23E+23	6.64E+23	-14.0
16	Metals	3.81E+22	3.96E+22	4.03E+22	5.7
17	Soil losses	1.34E+22	1.11E+22	1.11E+22	-16.8
Imports (seJ/yr)					
18	Fuels	1.47E+23	1.67E+23	1.45E+23	-1.0
19	Metals	7.91E+21	6.49E+20	5.83E+20	-92.6
20	Minerals	1.34E+22	1.28E+22	8.41E+21	-37.0
21	Transformed metals	7.18E+22	9.09E+22	7.41E+22	3.3
22	Transformed minerals	5.90E+22	5.42E+22	1.26E+23	112.8
23	Food and agricultural products	2.93E+22	3.50E+22	3.69E+22	25.8
24	Livestock, meat and fish	1.50E+22	1.75E+22	2.56E+22	70.3
25	Plastics and rubber	6.43E+21	7.96E+21	9.38E+21	45.9
26	Chemicals	5.93E+22	6.51E+22	7.13E+22	20.2
27	Finished materials	7.39E+22	6.09E+22	6.67E+22	-9.8
28	Machinery and transportation equipment	1.21E+22	1.14E+22	1.53E+22	26.4
29	Electricity	5.47E+21	1.12E+22	8.84E+21	61.7

30	Imported services (tourism included)	1.50E+22	1.22E+22	1.65E+21	-89.0
31	Services on imported goods	9.23E+22	8.15E+22	8.10E+22	-12.3
Exports (seJ/yr)					
32	Food and agricultural products	4.22E+21	6.58E+21	1.02E+22	141.0
33	Livestock, meat and fish	7.37E+21	8.81E+21	1.23E+21	67.1
34	Finished materials	5.06E+22	5.21E+22	6.02E+22	18.9
35	Fuels	1.22E+22	2.07E+22	2.05E+22	67.8
36	Metals	4.15E+22	4.05E+22	3.95E+22	-4.8
37	Minerals	5.27E+21	6.38E+21	8.06E+21	53.1
38	Transformed metals	9.67E+21	3.72E+22	3.85E+22	298.2
39	Transformed minerals	2.63E+22	3.40E+22	3.12E+22	18.6
40	Chemicals	3.62E+22	4.37E+22	3.41E+22	-5.6
41	Machinery and transportation equipment	6.99E+21	7.16E+21	1.09E+22	55.3
42	Plastics and rubber	3.66E+21	6.46E+21	7.18E+21	96.0
43	Exported services (tourism included)	1.00E+23	6.16E+22	1.13E+23	12.3
44	Service on exported goods	3.36E+23	3.79E+23	3.05E+23	-9.3
45	Electricity	4.38E+21	3.26E+21	3.28E+21	-25.1

Table 2 - Summary of emergy flows of the Portuguese economy (2000, 2005 and 2009)

	Item	Expression	2000	2005	2009	% Diff. 00-09
1	Country area (m^2)	-	9.22E+10	9.22E+10	9.22E+10	0.0
2	Population (inhabitants)	-	1.02E+07	1.05E+07	1.06E+07	4.1
3	Renewable sources (seJ/yr)	R	6.71E+22	5.91E+22	6.35E+22	-5.3
4	Nonrenewable resources (seJ/yr)	N	8.70E+23	9.20E+23	7.63E+23	- 12.4
5	Local nonrenewable resource (seJ/yr)	N0+N1	8.24E+23	8.73E+23	7.15E+23	- 13.2
6	Dispersed rural source (seJ/yr)	N0	1.34E+22	1.11E+22	1.11E+22	-16.8

7	Concentrated used (seJ/yr)	N1	8.10E+23	8.62E+23	7.04E+23	-13.1
8	Exported without use (seJ/yr)	N2	4.68E+22	4.69E+22	4.76E+22	1.8
9	Imported fuels and minerals (seJ/yr)	F	1.74E+23	1.91E+23	1.63E+23	-6.0
10	Imported goods (seJ/yr)	G	3.27E+23	3.43E+23	4.25E+23	30.0
11	Dollars paid for imports (USD)	I	4.73E+10	4.57E+10	4.42E+10	-6.5
12	World emergy/USD ratio, used in imports (seJ/USD)	P2	2.27E+12	2.05E+12	1.87E+12	-17.6
13	Emergy of services in imported goods and fuels (seJ/yr)	P2I	1.07E+23	9.37E+23	8.26E+23	-23.0
14	Dollars received for exports (USD)	E	3.41E+10	3.44E+10	3.55E+10	4.2
15	Emergy exported of processed products (seJ/yr)	B	1.62E+23	2.20E+23	2.28E+23	41.3
16	Flow of imported emergy (seJ/yr), IMP	F+G+P2I	6.08E+23	6.28E+23	6.71E+23	10.4
17	Total emergy inflows (seJ/yr)	R+N+F+G+P2I	1.55E+24	1.61E+24	1.50E+24	-3.1
18	Total emergy (seJ/yr), U	N0+N1+R+F+G+P2I	1.50E+24	1.56E+24	1.45E+24	-3.3
19	Flow of exported emergy (seJ/yr), EXP	B+N2+P1E	6.45E+23	7.07E+23	6.94E+23	7.6

From Tables 1 and 2, and for better comprehension, several graphics were made and are presented in Figures 1 to 5. Regarding emergy national account, the total emergy required (U) was 1.50E24 seJ in 2000 and 1.45E24 seJ in 2009 (-3.3%), while 2005 presents the highest value of the three (Table 1). As population increased slightly, from 1.02E7 inhabitants in 2000 to 1.06E7 in 2009, and total emergy reported slightly decreased, emergy per capita decreased 7.9% over this period, from 1.47E17 seJ/capita in 2000 to 1.36E17 seJ/capita in 2009 (Figure 1).

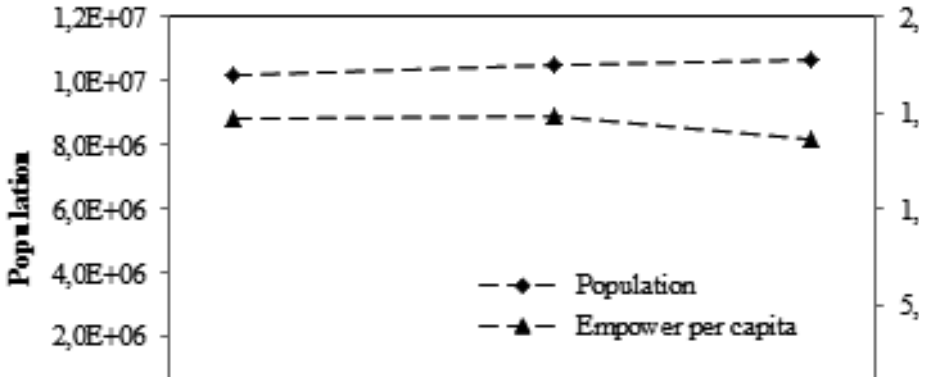

Figure 1: Portuguese population and empower per capita for the years 2000, 2005 and 2009.

The aggregated emergy inflows supporting Portuguese activities, in the period, are shown in Figure 2. It is noticeable that emergy from local

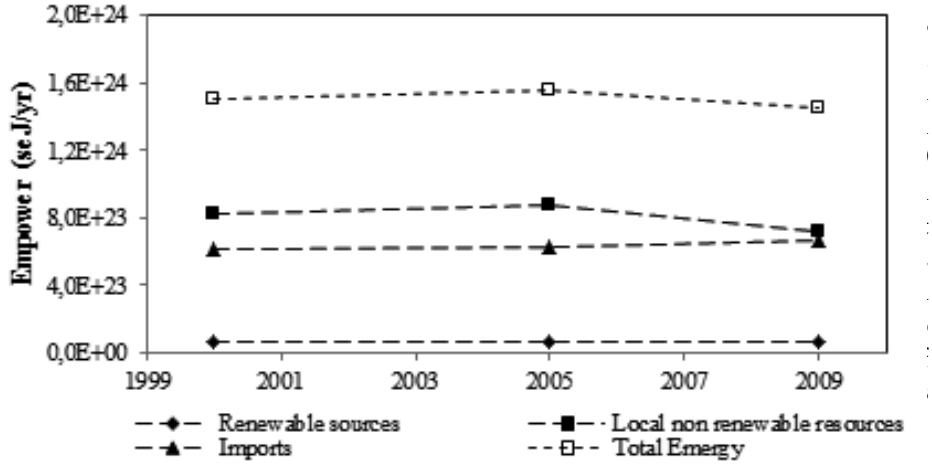

Figure 2: Emergy inflows and total emergy supporting the Portuguese economy for the years 2000, 2005 and 2009.

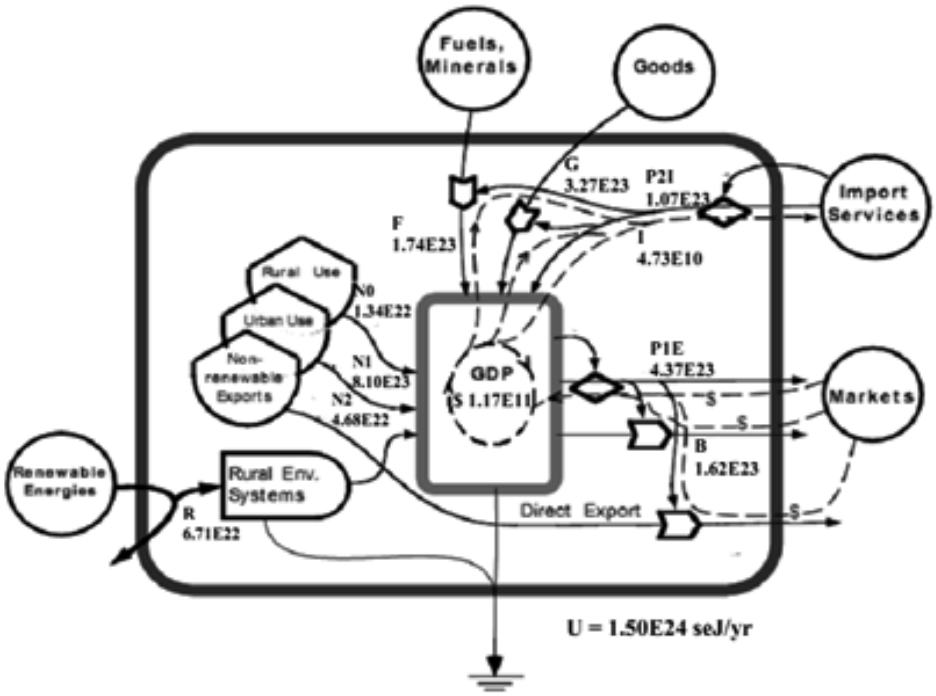

Figure 3: Emergy flows aggregate diagram for the Portuguese economic system for the year 2000 (adapted from Brown 2003).

Local Renewable and Nonrenewable Emergy Flows

Sea waves provide the largest renewable emergy flow for the coastal area, while rain is the main provider for the land area. The former is on average about five times the latter, 5.23E22 seJ and 1.10E22 seJ, respectively (Table 1). The small variability in the renewable emergy flows calculated depends exclusively on annual rainfall, due to lack of data concerning the variability of other flows in the time period of this study. Dispersal rural sources, N_0, consist exclusively of soil loss (mineral and organic), because for the time period considered in this study, the data indicated no losses concerning forest extraction, and no data were available regarding losses associated with other resources like fishery production or water extraction. Concentrated resources, N_1, consist of reserves of metals and minerals, since fuels are not included because Portugal is not a producer of this type of resources. The largest component of nonrenewable emergy flows consists of minerals, which was 7.72E23 seJ in 2000 with a decrease to 6.64E23

seJ in 2009 (-14%) representing, respectively, 94% and 93% of the total flow. The second largest component is metals, which was 3.81E22 seJ in 2000 with an increase to 4.03E22 seJ in 2009 (+5.7%), representing 5% and 6% of the total local nonrenewable emergy flows, respectively. Soil loss is a minor component, and was 1.34E22 seJ in the year 2000, decreasing to 1.11E22 seJ in 2009 (-16.8%) representing nearly 1% of the total nonrenewable emergy flows in each year. Thus, the decrease in the nonrenewable contribution in 2009, compared to 2000, is due to a decrease in mineral consumption. This is related with the decrease in construction materials consumption, such as sand, gravel, gypsum and clay, which reflects the evolution of the construction sector in Portugal over the last decade. National accounts data also indicate that the construction sector is losing weight in relation to total GVA (8.2% in 2000 and 6.6% in 2009).

Imported and Exported Emergy Flows

The composition of imported emergy flows and exported emergy flows in 2000 and in 2009 is presented in Figure 4.

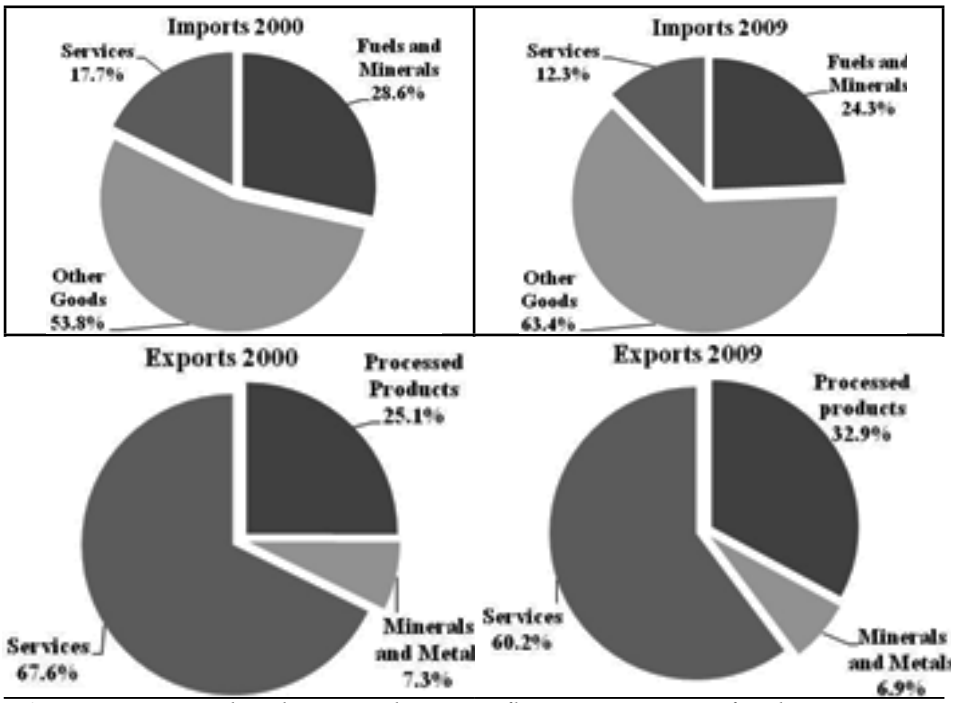

Figure 4: Imported and exported emergy flows composition for the years 2000 and 2009.

Results show that emergy of aggregated imported goods (G), mainly from metallic products, chemicals and finished products (textiles, wood, paper and leather), makes the largest contribution to the total imported emergy. It was 3.27E23 seJ in 2000 and rose to 4.25E23 seJ in 2009 (+30.0%), accounting for 53.8% and 63.3% of the total imported emergy flows, respectively, and is responsible for its greater value in 2009 compared to the year 2000. The second major contribution was from emergy of aggregated fuels, metals, minerals and electricity flows (F), which was 1.74E23 seJ in 2000 and 1.63E23 in 2009 (-6.0%), accounting for 28.6% and 24.3% of the total imported emergy flows, respectively. Fuels represent 84.5% of the group in 2000 and 89.0% in 2009, although the absolute value is nearly the same for both years (Table 1). Emergy flows of imported services (P2I), which include imported services (including tourism) and services in imported goods, decreased its contribution to the total imported emergy flows, from 1.07E23 seJ in 2000 to 8.26E23 seJ in 2009 (-23.0%) accounting, respectively, for 17.6% and 12.3% of the total emergy imported flows.

As far as exported emergy flows are concerned, the largest contribution was from services (P1E), which includes exported services (including tourism) and services in exported goods, with 4.37E23 seJ in 2000 and 4.18E23 seJ in 2009 (-4.4%), accounting for 67.8% and 60.2% of the total exported emergy flows, respectively. The second major contribution to exported emergy flows was from transformed products (B), mainly finished products (textiles, wood products and paper), metallic products and chemicals, with 1.62E23 seJ in 2000 and 2.28E23 seJ in 2009 (+41.3%), accounting for 25.1% and 32.9% of the total exported emergy flows, respectively. Emergy of metals and minerals non-transformed flows (N_2) was 4.68E22 seJ in 2000 and 4.76E22 seJ in 2009 (+1.7%), decreasing its contribution to the total exported emergy flows from 7.3% to 6.9%, respectively. The total imported emergy flows and the total exported emergy flows for the years 2000, 2005 and 2009 are close to each other, the former being lower than the latter (Figure 5).

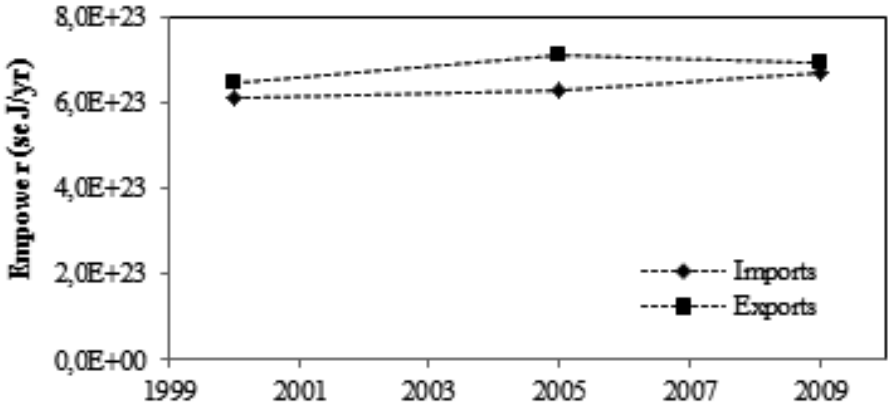

Figure 5: Imported and exported emergy flows for the years 2000, 2005 and 2009.

4. CONCLUSIONS

Total emergy of Portugal resources inputs decreased over the time period analyzed in this study. From 2000 to 2009, there was a reduction of 3.3% in the total emergy accounted for. Additionally, emergy per capita also decreased, which indicates that the population wellbeing in 2009 might be inferior to the level attained in 2000, as fewer resources from the geobiosphere were invested in each person. Emergy from local nonrenewable flows was the major contribution to total emergy (+49.3% in 2009), but its importance decreased in favor of emergy imported flows, revealing that Portugal reinforced its dependence on the latter (+46.3% in 2009). While, in the period, more emergy was exported than imported and from the emergy perspective Portugal presented a persistent deficit. The contribution of the renewable emergy flow (R) is almost unchanged over time, contributing with approximately 4.5% of the total emergy. Results obtained indicates that besides the Portuguese government's efforts to reinforce the use of renewable energies, a significant reduce in emergy assigned to flows of imported fuel, capable of shifting the economy to a growth path based on a larger weight of renewable resources, was not achieved in the period.

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