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Emergy diagnosis and reflections towards Brazilian sustainable development

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HIGHLIGHTS

- Future Brazilian development is explored from the energy perspective.
- Solution is to increase exports of raw resources and the creation of a national market.
- Brazilian development path is limited by the demand for money provided by exportation.
- The need to increase the economic performance along with a decrease in emergy requirements.
- It is essential to understand that there are limits for economic growth.

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ABSTRACT

This paper presents an environmental emergy-based diagnosis of Brazil compared with Russia, India, China, South Africa and United States. Reflections on the Brazilian sustainable development are presented and discussed based on the evaluations published since 1979. The variation of the emergy per capita for Brazil from 1979 to 2007 indicates that the country's growth is tied to the exploitation of non renewable natural resources which do not directly reflect in the welfare of the population. The total emergy exported per unit of gross domestic product increased in the period, suggesting that the country exports more emergy than that contained in the money received for the exportation. With the help of the emergy indices, the future development of Brazil is explored and discussed. The comparison among the BRICS (Brazil, Russia, India, China and South Africa) countries and United States indicates that what may be appropriate and usable within one country may not be within another and that to achieve the global sustainability two concomitant actions may occur: (i) the reduction of the total emergy use in developed economies, and (ii) the reduction of indigenous resources exportation in developing economies.

1. Introduction

In 1992, sustainability has been acclaimed in the Rio Earth Summit as a key concept for the establishment of the future policy goals of civilized nations. Since then, the academic world developed several models and indicators for quantitative evaluations of the sustainable development, among which the assessment of regions and countries had considerable projection, with several proposed indicators: Environmental Sustainability Index (Esty et al., 2005), Ecological Footprint Environmental Accounting (Wakernagel and Rees, 1995; Wackernagel et al., 2005) and Emergy Environmental Accounting (Odum, 1996). Twenty years after the Rio'92, Brazil hosted the Earth Summit and objectives of RIO+20 intended to renew the political agreement for the sustainable development, and to evaluate the progress and the hiatus of its implementation. The themes of the conference included the green economy, the poverty eradication, and the institutional framework for sustainable development. However, during the conference, it was possible to realize that the policy makers do not have yet a consensual quantitative metric for managing natural resources, which also takes into account the socio-economic issues. With the recurring number of economic crises that occur periodically, the governments need tangible diagnosis of the investments made towards sustainability. The Environmental Accounting in Emergy (Odum, 1996) was the method that had its greatest development supported by a sound scientific basis. The early efforts were published in two seminal books in the 70s: Environment, Power, and Society (Odum, 1971 with a new edition in 2007) and Energy Basis for Man and Nature (Odum and Odum, 1976).

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The theory developed by Howard T. Odum has received considerable attention and positive response from the scientist's community to evaluate nations. The theory amplifies the money-oriented approach integrating the values of free environment investment, goods, services and information in a common unit. By incorporating aspects of energy quality and ecological hierarchy to evaluate the contribution of the natural environment to the human-economic system, this methodology allows balancing the needs of both human and natural systems expressing the socio-economic-environmental effects in common terms (Campbell et al., 2005). Several researchers published emergy analyses for regions, provinces and counties (Huang and Odum, 1991; Campbell et al., 2005; Pulselli et al., 2008; Campbell and Garmestani, 2012; Dang and Liu, 2012; Zhu et al., 2012). On the national scale, emergy-based evaluations are also available, and since the 80s, several countries were assessed, including Switzerland (Pillet and Odum, 1984), France (Pasquier, 1999), Sweden (Rydberg and Jansén, 2002), Spain (Lomas et al., 2008), Japan (Gasparatos and Gadda, 2009), Italy, and China (Lan and Odum, 1994; Li et al., 2001; Jiang et al., 2008; Yang et al., 2010), among others. The National Environmental Accounting Database (Sweeney et al., 2006) that compiles detailed emergy accounting for 134 countries is available at http://cep.ees.ufl.edu/ (NEAD, 2009), and these data have been used in studies comparing the national performances of several countries (Cohen et al., 2007a, 2007b, 2009; King et al., 2007; Brown et al., 2009; Lei and Zhou, 2012; Giannetti et al., 2012).

Brazil belongs to the BRICS bloc that was established, in 2001, to reference the four countries Brazil, Russia, India and China. In 2001, the “S“ was added in reference to entry of South Africa. In their path towards the economic growth, most activities in these countries consist of exportation of raw materials and agricultural products while the developed countries converge most activities on enhancing efficiency to achieve sustainability (Brown et al., 2009). Nevertheless, interaction between increasing efficiency and economics can result in a unreasonable outcome when increasing efficiency does not result in a lower resource consumption, but increases the total consumption (Sorrell, 2009). Essentially, as the efficiency increases, the cost of a product decreases, and demand increases. The most known debate on whether or not it is possible to secure the use of natural resources through increased efficiency occurred at the beginning of the industrial development has been called the “Jevons paradox”. Accordingly to Jevons (1865): ”an increase in efficiency in using a resource leads, in the medium to long term, to an increased usage of that resource rather than to a reduction in this use”. In addition, the funds saved by using more efficient technologies may be used for activities that may be more energy intensive than the less efficient technology that was substitute for. The overall effect can be less reduction in total energy consumption than presumed. In developing economies, this rebound outcome can be considerably large because efficiency improvements can allow more consumers to satisfy a broad repressed demand.

This paper presents an environmental emergy-based diagnosis of Brazil, which is a country that joins abundance of natural resources and massive social challenges. The investigation can be used to evaluate the extent to which the development path of the Brazilian economy fulfils the conditions for the sustainable development. Using such an approach, government and decision-makers can assess both the potential and the actual environmental performance of the country. Reflections on the Brazilian sustainable development are presented and discussed based on the evaluations published since 1979. The results are compared with those of the BRICS countries and United States adopted as a reference for a developed country.

2. Methododolgy

Seven fundamental beneficial features of emergy accounting can be highlighted (Giannetti et al., 2010):

1. Emergy accounts for all the solar energy required (directly or indirectly) to obtain a product by a given activity or to support a regional system (Odum, 1996) and it avoids the step of selecting and classifying variables.
2. Emergy avoids the difficulty one would experience in normalizing and aggregating variables having different units (Giannetti et al., 2009).
3. Emergy gives transparency in evaluating systems, as weighting factors, which are value judgments and can be susceptible to errors, are not employed. Expert weighting for environmental indicators quite often includes factors of a prejudiced nature, unreliable knowledge, sometimes even vague information, which may lead to inaccurate opinions that ultimately threaten the clarity and integrity of the analysis (Almeida et al., 2007).
4. Emergy can also account directly or indirectly for the free ecological services, their contribution to human economy and the effect on it if their functioning is compromised (Odum, 1996).
5. The emergy ternary diagram permits to compare the sustainability of different systems (such as countries), to evaluate the outcome of the composition of different systems (such as the Mercosur in Giannetti et al., 2010; or the world in Giannetti et al., 2012) and, at the same time, provides information related to the use of renewable, non-renewable resources and economic resources (Giannetti et al., 2006; and Almeida et al., 2007).
6. Emergy indices have a positive correlation with sustainability dimensions (environmental, social and economic) (Giannetti et al., 2010), and can be used in the Pressure-State-Response framework providing a mechanism to monitor the status of the environmental and economics (Zhang et al., 2012).
7. Emergy has a rigorous scientific basis (Odum, 1996) that explains the biosphere functioning.

2.1. Emergy accounting for nations

The emergy accounting was performed based on the tables from National Environmental Accounting Database (Sweeney et al., 2007). Results are compared with those published by Odum et al. (1986), Coelho et al. (1998) and Demétrio (2011), and those published in the National Environmental Accounting Database for 2000. Fig. 1 shows the energy system diagram summarizing the main flows accounted for 2007. The diagram helps in visualizing the flows of emergy, materials and money used to describe emergy measures of the Brazilian economy. Sources of emergy that cross the system boundary from outside include: renewables (R), fuels and minerals (F), goods (G), and the services embodied in these imports (P2I). Sources of emergy obtained from storages within the country include resources that are used faster than they are renewed (such as soils, N0), and non-renewable resources (such as fossil fuels and minerals, N1). Exports from the country include services and labor (P1E) embodied in finished products, and non-renewable resources (N2) that are exported without the use in the internal economy. The gross domestic product (GDP) represents circulation of money within the economy as a monetary measure of the output.

Table 1 shows the indices of Brazil from 1979 to 2007 recalculated using the biosphere emergy base relative to the 15.83×10^{24} sej/year baseline (Odum et al., 2000). The total emergy use (U) is defined as the emergy value of all goods and services produced within a country in a given period. U is emergy use per unit of time (empower, Odum, 1996), which is the emergy of the output of any process per unit time that can be used in another process. When this useful empower is

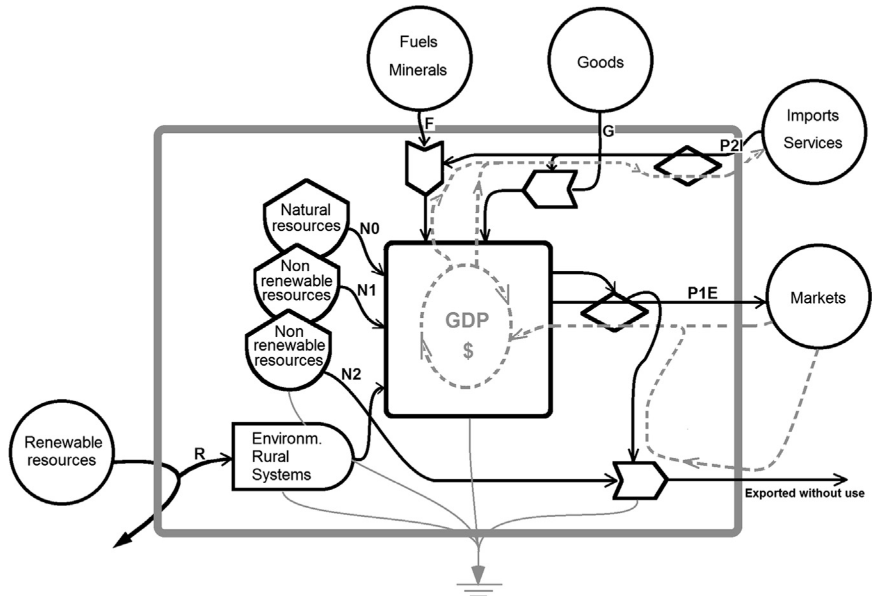


Fig. 1. Summary of national resources basis for Brazil. Symbols were identified according to the National Environmental Accounting Database and are used for the calculation of the indices shown in Table 1. The total emergy use (U) in the economy is the sum of all the inputs (U==R+F+G+P2I+N0+N1). Currency counter flows are represented by the dashed lines.

Table 1
Emergy indices calculated for the Brazilian economy for the period of 1979 to 2007.

Index Name/Units	Calculation ([a])	Value[b]					
		1979	1981	1989	1996	2000	2007
Total emergy used/10^{24} (sej/year)	U=R+N0+N1+F+G+P2I	2.99	4.40	4.72	4.65	7.07	7.74
Total imported emergy/10^{23} (sej/year)	F+G+P2I	2.49	3.95	6.22	7.02	7.38	11.31
Total exported emergy/10^{23} (sej/year)	F+G+P1E	1.68	3.06	4.65	8.18	23.80	23.44
Imports–exports/10^{22} (sej/year)	[F+G+P2I]−[F+G+P1E]	−0.62	8.87	15.6	−11.5	−164	−121
Export to imports	[F+G+P1E]/[F+G+P2I]	1.03	0.78	0.75	1.16	3.29	2.07
Empower density/10^{11} (sej/year m^2)	Total emergy used/area	3.49	5.16	5.53	5.44	8.36	9.08
Use per capita/10^{16} (sej/year capita)	Total emergy used/population	2.57	3.63	3.32	2.96	4.18	4.22
Renewable flow per capita × 10^{16}/(sej/year capita)	R/Population	2.19	2.69	2.20	2.13	2.05	1.63
Fuel use per capita/10^{15} (sej/year capita)	Total fuel use/population	2.60	3.36	2.18	2.27	2.95	2.85
Emergy Investment Ratio (EIR)	[F+G+P2I]/(R+N0+N1)	0.09	0.10	0.15	0.18	0.12	0.17
Emergy Yield Ratio (EYR)	Total emergy used/[N0+N1+F+G+P2I]	11.11	11.17	7.60	6.63	9.58	6.67
Environmental Loading Ratio (ELR)	[F+G+P2I+N0+N1] / R	0.21	0.36	0.46	0.44	1.00	1.49
Emergy Sustainability Index (ESI)	EYR/ELR	52.90	31.03	16.52	15.07	9.58	4.48
Indigenous fraction/%	(N0+N1+R)/total use	91.00	91.05	86.84	84.92	89.56	85.00
Renewable fraction/%	R/total use	83.00	73.60	68.63	69.65	49.88	40.20
Purchased fraction/%	[F+G+P2I]/total use	9.00	8.95	13.16	15.08	10.44	15.00
Electricity fraction/%	Electricity/total use	4.12	12.01	11.19	11.36	5.26	8.00
Electricity consumption/10^8 (MW h/year)		1.04	1.18	1.97	2.58	3.08	4.12
Population/10^6 persons		116	121	142	157	169	183
Renewable carrying capacity at same living standard/10^6 persons	(R/U)(population)	100	89	101	106	85	115
Developed carrying capacity at same living standard/10^6 persons	8(R/U)(population)	797	712	807	848	680	920
Gross domestic product/10^9 (US$/year)		213	243	467	575	601	1,478
National emergy money ratio/10^{13} (sej/US$)		1.40	1.13	0.60	0.48	1.17	0.52

Results for 1979 were published by Odum et al. (1986), data of 1981, 1989 and 1996 were taken from Coelho et al. (1998). Data for 2007 were taken from Demétrio (2011) and those published for 2000 can be found in the National Environmental Accounting Database.

[a] Symbols are shown in Fig. 1.

[b] Values (recalculated using biosphere emergy base relative to the 15.83 × 10^{24} sej/year baseline.

derived for an entire country it is considered equivalent to the economic concept of Gross Domestic Product (Brown et al., 2009), which is defined as the market value of all final goods and services produced within a country in a given period.

Several indices are used to assess the emergy intensities of the Brazilian economy (Table 1). For a national economy, the EYR is the ratio of the total annual emergy use (U) in the economy to the non-renewable emergy use from indigenous sources (N0 and N1 in Fig. 1). It is a measure of total emergy use (U) derived from the investment of local resources. The environmental loading ratio (ELR) is calculated as the total non-renewable emergy use (indigenous plus imports) divided by the renewable emergy use. It is an indicator of the pressure on the environment and can be considered a measure of ecosystem stress due to overall economic activity. Emergy intensities (EMR) of the country's economy are the result of summing all emergy use to obtain U and then dividing by population or GDP.

2.2. Emergy ternary diagrams

An alternative examination is carried out based on the emergy ternary diagram (Table 2). The graphic tool produces a triangular plot of three variables with constant sum. Most commonly, three percents add to 100 or three fractions add to 1. The constant sum constraint means that there are just two independent pieces of information. Hence, it is possible to organize observations in two dimensions within an equilateral triangle. The emergy ternary diagram has three components, which are represented the diagram axis. Each side corresponds to a binary system and ternary combinations are represented by points within the triangle. The relative proportions of the elements are given by the lengths of the perpendiculars from a given axis to the opposite side of the triangle. Hence, the “composition” of any point plotted on a ternary diagram can be determined by reading from zero along the basal line (axis) at the bottom of the diagram to 100% at the vertex of the triangle. The analytical properties of ternary diagrams used in this work are presented in Table 2. More details on theoretical aspects and the use of the emergy ternary diagram can be found in the literature (Almeida et al., 2007, 2010; Giannetti et al., 2006, 2007, 2011a).

2.3. Brief description of the Brazilian political and economic development from 1979–2007

The end on the dependence on coffee production led Brazil to a long period industrialization aiming the substitution of imports, which went through the World War II and continued until the mid-60s. In an effort to transform the economy from its inflationary and indebted roots to a diversified capitalist market economy, military leadership has implemented a broad economic reform in 1964. The economic reform simplified the exchange rules, introduced incentives for investment and promoted exportation. The result was a period of rapid growth, with an average increase of 11% per year for the Brazilian economy between 1968 and 1973. During the oil crisis, the Brazilian government continued to support the growth policies, and the domestic debt increased from $ 1.7 billion in 1973 to $ 12.8 billion in 1980. The external debt increased from $ 6.4 billion to $ 54 billion over the same period. This debt that propelled the growth of the 1980s and early 1990s resulted in inflation, which remained around 100% during the early 1980s, rose to 1000% in mid-1980 and reached 5000% in 1993. Nevertheless, the Brazilian development policies have also undergone erratic changes. Like other Latin American countries, Brazil passed by both populist democracies and dictatorships. The “Real Plan”, promulgated in 1994, was a landmark in the political and economic history of Brazil. The plan was the first successful policy to prevent persistent economic challenges in the management of external debt and inflation. The fundamental principle of the Real Plan was the introduction of a new currency (the Real) tied to a US dollar relatively high, increasing interest rates, encouraging investment and savings, and restraining of government expenditures. Brazil was approved by the international investment community, stabilized inflation and entered a period of economic growth with a GDP growth of 5% per year since the turn of the 21st century.

3. Results and discussion

3.1. Emergy used per capita: the Brazilian case

The emergy per person is a macro indicator that is found by dividing the nation annual emergy budget (U) by the country's population. It includes the real wealth that people derive directly from the environment without spending money. In the Brazilian case, the emergy per person mostly represents the urban population that accounted for approximately 80% of the total population in 2007 (IBGE, 2010). During the period 1979–2007, the GDP increased approximately 7 times, but the total emergy per capita increased only 1.6 times (Table 3).

In Brazil, the demographic distribution and the concentration of economic resources are remarkably irregular. The Census 2010 shows that the income inequality is still strong, despite the declining trend observed in recent years. Although the national average of the per capita household income was US$ 334 in 2010, 25% of the population received less than US$ 94 and half of

Table 2
Properties of emergy ternary diagrams functioning as auxiliary tools for emergy analysis.

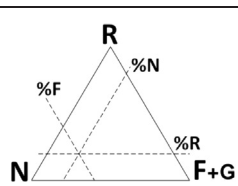
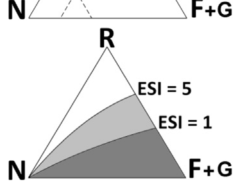
Properties		Description
Resource flow lines		Ternary combinations are represented by points within the triangle, the relative proportions of the elements being given by the lengths of the perpendiculars from the given point to the side of the triangle opposite the appropriate element. These lines are parallel to the triangle sides and are very useful to compare the use of resources by products or processes.
Sustainability lines		The graphic tool permits to draw lines indicating constant values of the sustainability index. The sustainability lines depart from the N apex in direction to the RF side allowing the division of the triangle in sustainability areas, which are very useful to identify and compare the sustainability of products and processes. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for the long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for the medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable.

Table 3
Evolution of the total emergy used, population and annual emergy used per capita in Brazil.

Index name/units	Value ([a])					
	1979	**1981**	**1989**	**1996**	**2000**	**2007**
Total emergy used/10^{24} (sej/year)	2.99	4.40	4.72	4.65	7.07	7.74
Gross national product/10^{9} (US$/year)	213	243	467	575	601	1.478
Population/10^{8} (persons)	1.16	1.21	1.42	1.57	1.69	1.83
Urban/10^{8} (persons)	0.78	0.81	1.01	1.17	1.29	1.45
Rural/10^{8} (persons)	0.38	0.41	0.41	0.40	0.40	0.38
Use per capita/10^{16} (sej/year capita)	2.50	3.60	3.30	2.90	4.10	4.20
Gross national product/10^{3} (US$/capita)	1.84	2.01	3.29	3.66	3.56	8.08
GINI index	0.593	0.582	0.634	0.6	0.592	0.552

[a] Values (recalculated using biosphere emergy base relative to the 15.83×10^{24} sej/year baseline.

Brazilians earned up to US$ 186, less than the minimum wage in that year (US$ 255). Historically, the country has presented a constant social inequality, which initially was based on uneven distribution of wealth (mainly related to land ownership) and later based on unequal division of economic and social property. The relative economic stability achieved in the 90s, positively influenced the expansion of private investment, impacting the generation of formal jobs and leading to the reduction of inequalities. However, the reduction of the GINI index for the period (Table 3) may be understood as negligible, despite progress in better planning and public policies (IBGE, 2010). The resources required per person depend on the standard of living and the economic activity, and with the GDP increase, the later has been significantly improved. For example, the percentage of households with refrigerators in 1981 was 56.61% and increased to 90.69% in 2007; and at the same period, the percentage of households with electricity increased from 66.38% to 81.93% (IBGE, 2010). However, the money flow only measures the human services of inputs and gives no indication of how much total wealth is derived from the free environmental contribution.

Fig. 2 shows the variation of the total emergy per capita and the emergy of electricity and fuels use for Brazil from 1979 to 2007. The total emergy use derives primarily from renewable sources or from non-renewable sources, and electricity and fuel use are traditional measures of effectiveness at the scale of national economies. The more energetically intense is the economy, the most effective it will be. Despite the relative increase in the percentage of households with electricity (IBGE, 2010), the emergy of the electricity use per capita did not increase, which indicates that the welfare of the Brazilian population is only partially tied to a fair distribution of electricity (Fig. 2). The use of fossil fuels per capita in 2007 decreased by 26%, with respect to 1979, as a result of the different technological developments and of the lower population growth. However, the index that relates the total emergy use to the fraction of indigenous non-renewable resources provides insight into the provision of resources, goods and services to the population. The use of the indigenous fraction (N0+N1+R) per person increased by about 53% in the period (Fig. 2) while the use of renewable resources decreased from 83% to 40%. This result indicates that the country's growth is tied to the exploitation of non renewable natural resources which do not directly reflect in the welfare of the population.

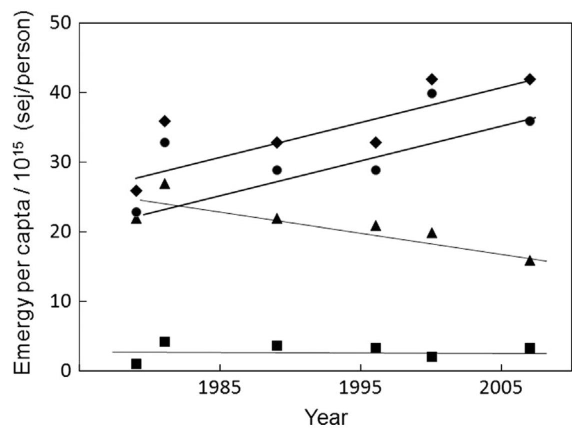


Fig. 2. Emergy intensity of Brazil measured as total empower per capita from 1979 to 2007. The total empower is the sum of annual renewable and non-renewable emergy use. (◆) total emergy use per person, (■) emergy of electricity use per person. (▲) emergy of total fuel use per person and (●) indigenous emergy fraction per person.

3.1.1. *Emergy used per capita: BRICS and US*

The comparison of the Brazilian results and the other BRICS countries is shown in Table 4 (NEAD, 2009). The indices of the United States were included as a reference of a developed country. By comparing a country's emergy consumption with its available emergy support, one can determine whether the country's socioeconomic activity is sustainable. The value of the human emergy support on Earth, if equally divided, would be the one that considers that all humans should receive the same amount of available emergy. China and India populations use less emergy than one hypothetical average human while in Brazil, Russia and South Africa the population relies on 50–80% more emergy. The population of the developed country consumes twelve times more emergy than that available to an Indian citizen and 1.6 times more than Brazilians. Thus, in some part of the Earth, there are people prevented from using the resources that the planet theoretically provides for their welfare and prosperity so that these countries can compete according to the existing rules of economic development.

The use of indigenous resources suggests that all the BRICS countries have their development based on the exploitation of natural indigenous resources. This result shows that the development of these countries goes against one of the Daly's principles (Daly, 1991), where “non renewable resources should be exploited, but at a rate equal to the creation of renewable substitutes.” Despite the use of emergy per person in Brazil and Russia being approximately 30% lower than that of US, none of the BRICS countries presents an electricity fraction comparable to that of US, and Brazil has the lowest value. This result confirms that the country's development path depends on the exploitation of non renewable natural resources, which does not translate into well-being of the local population. In fact, the development model adopted by Brazil is characteristic of economies in growth phase (Brown and Ulgiati, 1997) and is based on models already known and used in the past by the developed countries. According to this

Table 4
Comparison of the BRICS countries human emergy support of the BRICS countries in 2000. The indices of the United States were included as a reference of a developed country.

	Use per Capita[a]/ (sej/year)	Use relative to global	Indigenous fraction/%	Electricity fraction/%	Fuel fraction/%	Renewable fraction/%
Earth[b]	2.8×10^{16}		–	–	–	14.3
United States	6.6×10^{16}	2.4	41.4	19.7	36.85	12.1
Brazil	4.1×10^{16}	1.5	89.6	5.3	7.1	49.9
Russia	5.0×10^{16}	1.8	91.2	10.6	45.6	35.0
India	0.5×10^{16}	0.2	85.5	9.4	20.2	28.3
China	1.0×10^{16}	0.4	75.2	9.6	23.1	26.1
South Africa	4.7×10^{16}	1.7	86.2	9.1	16.3	7.9

[a] Values refer to global emergy base 15.83×10^{24} sej/year.
[b] Earth emergy: data of 2000 related to 134 countries (NEAD, 2009).

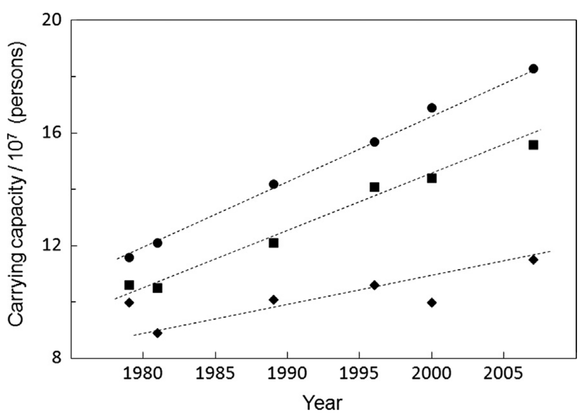


Fig. 3. Brazilian population growth (●) from 1979 to 2007 and the corresponding renewable carrying capacity (◆) and indigenous carrying capacity (■) over the period.

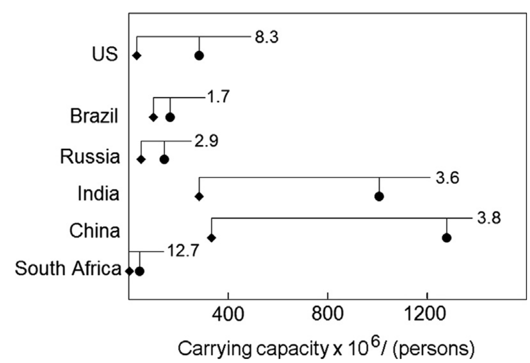


Fig. 4. Actual population of the BRICS countries and United States (●) and the corresponding renewable carrying capacity (◆) in 2000. The numbers within the graphic show how many times the actual population exceeds the countries' renewable carrying capacity.

model, developing countries rely on the consumption of non renewable resources as probably the most competitive way to achieve their goals.

Since limits to the biosphere's ability to sustain life, provide resources, and absorb and recycle wastes are becoming easier to learn and comprehend, the concept of carrying capacity for human use of the biosphere became more important. Methods, using emergy analysis techniques, for evaluating carrying capacity of economic developments were proposed by Brown and Ulgiati (2001) and evaluated by Agostinho and Pereira (2012). This method assumes that the long-term welfare of humanity can be maximized by minimizing environmental impacts and maximizing useful work and recognizes that there are limits to the environment for providing services and resources and absorbing wastes. Thus, long-term welfare may be associated to long-term carrying capacity. Fig. 3 shows the extent of the change of the Brazilian carrying capacity from 1979 to 2007 compared to the actual population growth. Living under the renewable carrying capacity implies that the population will be spread over the territory, counting exclusively on the renewable income obtained from relatively diffuse renewable sources. It is evident that renewable carrying capacity of the national environment has been exceeded before the 80s and that the country is sustained through the increase of inputs of non renewable resources. The gap between the countries renewable carrying capacity, and the actual population is also observed for the BRICS countries (Fig. 4) in a greater or lesser degree depending on the amount of resources imported and on the population size. However, none of these countries reaches the value of a developed country, 8.3 (R/U). It is interesting to note that Brazil has the lowest gap, even with the use of renewable resources decreasing from 83% (1979) to 40% (2007) and that South Africa, with a gap of 12.7 (R/U), relies almost entirely on its non renewable resources.

3.2. Brazilian emergy/dollar ratio, foreign trade and emergy exchange ratio

Emergy evaluations often show that there is no balance on international trade (Odum, 1996). Less emergy is consumed per unit of GDP in developed economies, and industrialized nations have lower emergy money ratios. Countries with the highest ratios would have smaller GDPs and are often countries which supply natural resources to world markets instead of developing a national industrial infrastructure (Brown et al., 2009). The highest total emergy money ratio (EMR) for Brazil was recorded in the 80s. In general, high EMR values indicate a smaller GDP, and the country's susceptibility to the market rules imposed by developed economies, which all have lower EMR. Since emergy and money flow counter current to each other, the EMR calculated for a national economy can determine the buying power of its currency. A high value indicates more emergy use per unit of currency circulation. While the economic development and the urban concentration increased, more money circulated for the same emergy use and the emergy money ratio decreased (Fig. 5).

The difference between the Brazilian emergy exports and imports became positive in late 90s. However, despite the increase in circulating money, the total emergy exported per unit of GDP also increased, indicating that the country exports much more emergy (from indigenous resources) than that contained in the money received for the exportation. The same pattern was observed in national subsystems, such as the agricultural system (Giannetti et al., 2011a, 2011b). Balanced international trade is accomplished when emergy of imports and exports of trading partners is equal. The increase of the total exported emergy per unit of GDP indicates that Brazil, despite its recent economic development, still exports more emergy than that enclosed in the money received for the exportation. For the benefit of the Brazilian economy and population, the indigenous resources should be kept and used to make final products for exports, which would also create jobs in the country.

3.2.1. BRICS and US emergy/dollar ratio, foreign trade and emergy exchange ratio

The ratio of emergy in imports to the emergy of exports characterizes the trade of an economy (Table 5). Since imports are purchased with income from exports, this ratio can estimate the emergy in imports that can be "bought" with the emergy sold (Brown et al., 2009). A national economy that imports raw resources and exports finished products will have the best performance. Table 5 shows the trade performance of the BRICS countries, which determines the main direction of each economy according to the values of the imported and exported emergy. BRICS countries (with ratios lower than one) export large quantities of raw resources (or resources of low UEV value) and have poor performances. At the other extreme, United States exports 2.5 times more emergy in finished products than in raw resources. Despite the difference in imports–exports of Brazil being positive since the 90s, the trade efficiency has a value of 0.3, suggesting that the country exports low quality emergy and imports high quality goods and services.

BRICS countries have different emergy/US$ ratios (Table 5). Russia has the highest EMR value followed by South Africa. Brazil, India and China have low and similar values. Despite of these countries do not constitute an economic bloc, Table 5 shows that a fair international trade can occur among Brazil, China and India while these countries would take advantage trading with Russia and South Africa. However, all BRICS countries sell more emergy than that contained in the money received for their exportation to United States or other developed country. In this way, BRICS countries could strengthen their political positions in the future starting with the strengthening of their commercial relationships through compromises among themselves.

The EMR value of the BRICS countries vary from five to fifteen times higher than that of United States because their economy is mainly driven by the supply of raw resources to world markets. Developed countries continually invest money to pay for the natural resources available in developing ones, and the currencies of developed economies have greater buying power in developing economies. However, the dependence of the developing countries on this capital investment creates a vicious cycle, in which developing countries overexploit their indigenous resources in the search for circulating money for their economic development. This is particularly evident when one observes that 42% of Brazil's and 32% of South Africa's exports are non-renewable resources (e.g., ores) that are sold directly without the use within the country. Fig. 6 shows the emergy signature of the BRICS countries exportation and Fig. 7 compares the UEVs of minerals and metals exported by each country. It is evident that the pattern/path adopted for the development of each country is different: Russia, India and China export a large portion of fuels, metals and minerals, but the amount of finished products is more than twice the quantity of raw materials sold to world markets. Brazil and South Africa's export more metals and minerals than finished goods. Fig. 7 shows that the metals and minerals exported by Brazil have lower UEVs values. UEV and concentration are linearly related. Ore grade cut-offs values (concentration ore body/average crustal concentration) represent minimum for economically viable current mining (Cohen et al., 2007a,

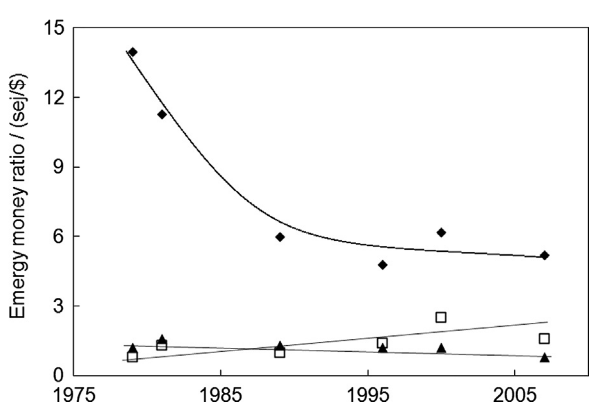


Fig. 5. Emergy intensity of Brazil measured as total empower per GDP from 1979 to 2007: (□) total emergy exported per dollar, and (▴) total emergy imported per dollar. The national emergy money ratio (◆) is the ratio of total annual empower (U) to the gross domestic product (GDP).

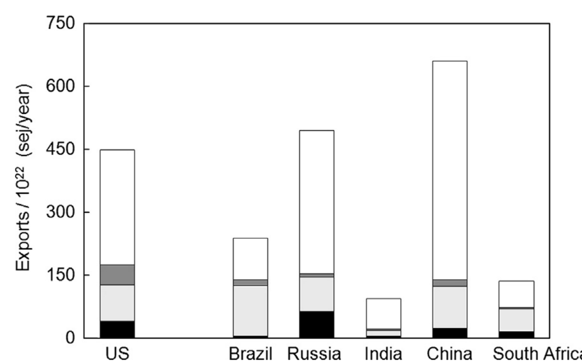


Fig. 6. Emergy exports of the BRICS countries. Fuels (black), minerals and metals (light gray), food, agriculture products, livestock, meat and fish (dark gray); chemicals, wood fiber and mineral products, machinery/transportation equipment and other refined goods (white). The ratio between exports of finished goods and raw materials is 2.2 for United States, 0.8 for Brazil, 2.4 for Russia, 4.0 for India, 4.2 for China and 0.9 for South Africa.

Table 5
Exported and imported emergy of the BRICS countries and United States. The emergy money ratio shows the emergy employed by each country to generate one dollar in 2000.

	National emergy money ratio/10^{12} (sej/$)	Total exported emergy/10^{23} (sej/year)	Non renewable flow exported without use/(%)	Total imported emergy/10^{23} (sej/year)	Imports/exports
United States	1.93	44.7	5	110.0	2.5
Brazil	11.7	23.8	42	7.4	0.3
Russia	28.5	49.4	3	6.6	0.1
India	11.3	9.4	3	7.7	0.8
China	11.8	66.1	3	31.9	0.5
South Africa	16.1	13.5	32	2.9	0.2

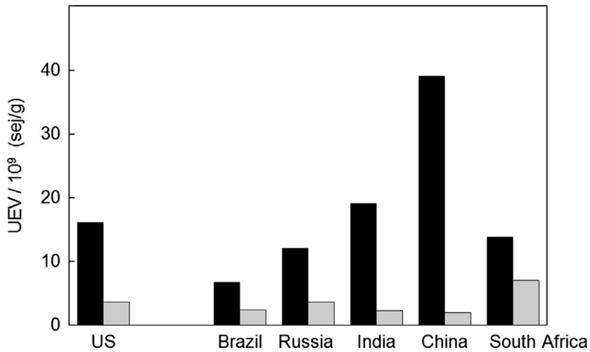


Fig. 7. UEVs of metals and minerals exported by the BRICS countries: metals (black) and minerals (gray).

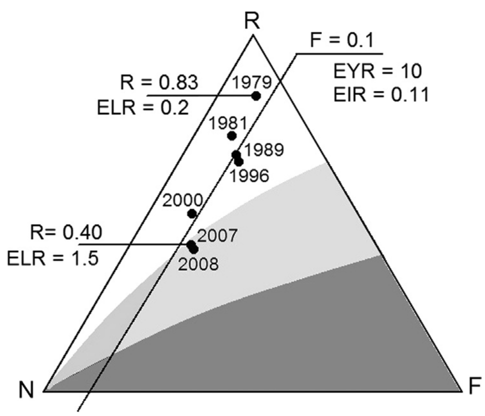


Fig. 8. Emergy ternary diagram of the Brazilian economy from 1979 to 2007. Data relative to 2008 were taken from Lei and Zhou (2012). The size of the points is proportional to the total emergy of each year. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for the long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for the medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable.

2007b). In this way, UEV values are scaled to ore grade so that ore bodies with higher ore grade cut offs values have lower UEVs. The lowest UEVs values of the Brazilian metals and minerals indicate that the country is exporting a high proportion of metals and minerals that are abundant (mostly, iron ore and iron), with consequent low economic value. In fact, according to the Brazilian Mining Association (IBRAM, 2012) a total of US$ 54 billion on investments for the period 2010 e 2014 was provided, and iron is the principal ore in which investments were made, accounting for about 67% of the total.

3.3. *Emergy ternary diagram and emergy indices: trends for Brazil*

The ternary diagram shows the path taken the Brazilian economy during the period 1979–2007 (Fig. 8). The parallel line to the segment NR shows that the emergy of the purchased fraction remained around 10% till 2000 as the relative amount of materials and services brought from abroad did not change significantly. The emergy investment ratio (EIR=0.11) is a measure of the extent to which the economic system invests emergy from sources outside the country and shows that Brazil had its economic development at low emergy investment. From 2000 to 2007, the relative use of non renewable resources and purchased inputs increased in nearly 5% each while the relative use of renewable resources decreased, indicating that the country was not able to maintain the less intensive development and compete in the international market. As a consequence, the emergy sustainability index (ESI) decreased from 9.6 to 4.5 leading the country to the region of medium term sustainability (Fig. 8). The size of each point is proportional to the total emergy of each year. From 1979 to 1981, the total emergy use doubled, and the same was observed for the period of 1996–2000. During these years, the Brazilian economy relied on the use of non renewable resources to boost the economic growth.

The EYR measures the potential contributions to society of the energy/materials sources. This indice is also an indicator of the changes needed in the future if lower net yielding energy sources or lesser amount of raw materials are to be relied upon (Odum, 1996; Brown and Ulgiati, 1997). The concept can complement energy return on investment (Hall et al., 1986), being more robust as it includes quality correction (UEVs) and inputs such as labor and environmental contributions. Countries that count with a high proportion of non-renewable resources and have relatively small economies tend to have the highest EYRs. Most industrialized nations, with less non-renewable resources and relatively large economies, present EYR values below 2 (Brown et al., 2009; Giannetti et al., 2012). Fig. 8 shows that the change in the EYR from 1979 to 2000 of the Brazilian economy was not significant. The development path suggests that Brazil relied on the use/exportation of its non-renewable storages instead of purchasing resources from other countries.

For the environmental load ratio (ELR), the change from 1979 to 2000 of the Brazilian economy had an overall increase of 600% (Fig. 8). This result indicates that the indigenous capacity to promote economic processes of the country's is being used or consumed much faster than 30 years ago. This observation is consistent with the idea that the country is exploiting large amounts of non-renewable resources, loading the national environment in order to maintain the economic development. Since the processes that support the Brazilian economy within its territory consume their indigenous support, other processes cannot be added to the support base at the same time. This pattern of growth can proceed only until the environment becomes overloaded and the increasing ELR may indicate that there may be a slowing of the economic growth or a revision of the economic development policy.

Another measure of national efficiency is the percent of total emergy use that comes from renewable sources, %R (Brown et al., 2009). From 1979 to 2007, there was an overall reduction of 43% in the contribution from renewable sources to the Brazilian economy. Economies that use relatively small non renewable empower dominate the top of the ternary diagram (Giannetti et al., 2012), such as Brazil in the 80s. Generally, these countries have difficulties for providing to their populations while countries that have lower percent renewable (which dominates the bottom of the diagram) are considered as the economically wealthiest nations on Earth. Brazil in 2007 is at the midway between the two extremes, with 40% of its total empower provided by renewable sources.

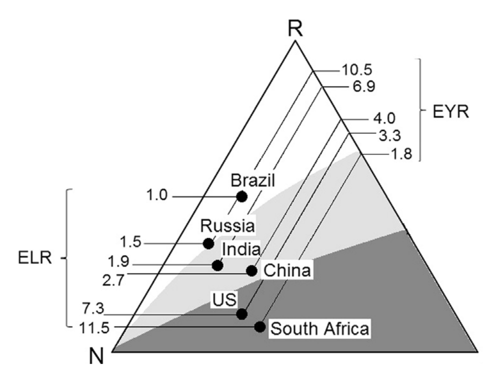


Fig. 9. Emergy ternary diagram of the BRICS economies in 2000 and United States (EYR==3.4, ELR==7.3, %R==12.1). The %R of the countries in 2000 were: Brasil 49.9%; Russia 34.9%; India 28.1%; China 26.1%; and South Africa 7.9%. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for the long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for the medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable.

3.3.1. Comparison with BRICS countries and US

Fig. 9 compares the BRICS countries in 2000. The American economy in 2000 is placed in the ternary diagram as reference developed country. Brazil, Russia, India and China, with large territories count with the contribution of relatively great amounts of renewable and non renewable resources and are placed in the region of medium-term sustainability in the ternary diagram (light gray). South Africa relying almost entirely on its non renewable resources is placed in the region of short-term sustainability (dark gray). This country, even with the lowest population of all BRICS countries has also the smaller territory (approximately 1/14 of the Russian area), but exports 1.3 times more metals and minerals than Russia. In regard to the environmental load, it is clear that, among the BRICS countries, South Africa is the country that has put at risk its sustainability more intensely.

4. Perspectives for the future

The future holds infinite possibilities, and each can be obtained through different paths. The question now is to choose which endpoint is eventually the right one and which pathway is the most appropriate to achieve there. For the future development of Brazil, there are numerous options (represented by the dashed lines in Fig. 10) that may be explored:

1) to increase the relative proportion of purchased inputs (materials and services) maintaining its indigenous resources;
2) to maintain/increase the exploitation of the indigenous resources, before starting to use materials and services from outside the country (business-as-usual scenario);
3) to increase the use of renewable resources while maintaining the relationship between N and F; or using the non renewable resources at a rate equal to the creation of renewable substitutes;
4) to increase the use of renewable maintaining reserves of non-renewable resources along a reduction of purchased resources.

The paths represented by dashed lines 2 and 3 display the most extreme options, where there is a risk of exhausting all the country's natural resources (path 2) or of economic stagnation (path 3). Between path 2 and path 3 there are infinite combinations. The Brazilian Mining Association analysis (IBRAM, 2012) show that Brazil is taking a path between paths 1 and 2 in the coming years. Therefore, in the future, it will be necessary to increase the UEVs of the metals/minerals exported, investing to add value to these metals and minerals, and transforming them into final products. In less than ten years (2000–2007), the relative use of non renewable resources and purchased inputs increased more than in the previous 20 years while the relative use of renewable resources decreased. As a consequence, the emergy sustainability index (ESI) and the environmental yield ratio (EYR) decreased, along with a substantial increase in the environmental load ratio (ELR).

The relationships shown by the ternary diagram provide a look at the limits that encompass the future. Generally higher %R means low to moderate environmental degradation. As economic development progresses, the environmental impacts associated to the use of non renewables and imported goods and services also increase. In practice, paths 3 and 4 are not realistic. The percent of total resource use that is derived from renewable sources is calculated based on the total renewable input to the country's territory. It cannot be increased since it represents the total input, thus to increase the %R and thereby the sustainability of an economy requires either confiscating land elsewhere or reducing non-renewable emergy use. At the same time, increasing the use of renewable sources within the territory is not an easy task, especially when the country is trying to compete with economies based on the model practiced by developed countries. The net contributions of the proposed renewable sources must be evaluated with all costs included, and keeping in mind that many of the alleged renewable energy sources are actually of lower quality (lower UEVs). For example, the renewable energy options (solar, tide, biomass) appear at intensities sufficient to provide net energy in very limited areas, and thus their overall contribution will not replace even the current global energy needs (Cleveland, 2007). In addition, the use and transformation of indigenous sources is system dependent. The appropriateness of an energy or material in a particular country is dictated by its area, storages and geographic location. To utilize these indigenous sources for the complex demands of the present economy requires that they be upgraded to a quality corresponding to the economy's current and future demands that are driven by population and consumption growth.

The measures of emergy intensity of national economies show that, as expected, developed economies have highest emergy per capita and the lowest emergy money ratio. The higher the EMR, the more susceptible an economy is to the developed economies demands for resources (Brown, 2003). Currencies from developed economies have greater buying power in undeveloped economies; thus the constant movement of capital investment from developed to undeveloped economies forces the perpetual exportation of indigenous resources in the same direction. In this way, the choice for the path to development does not depend solely on the choice

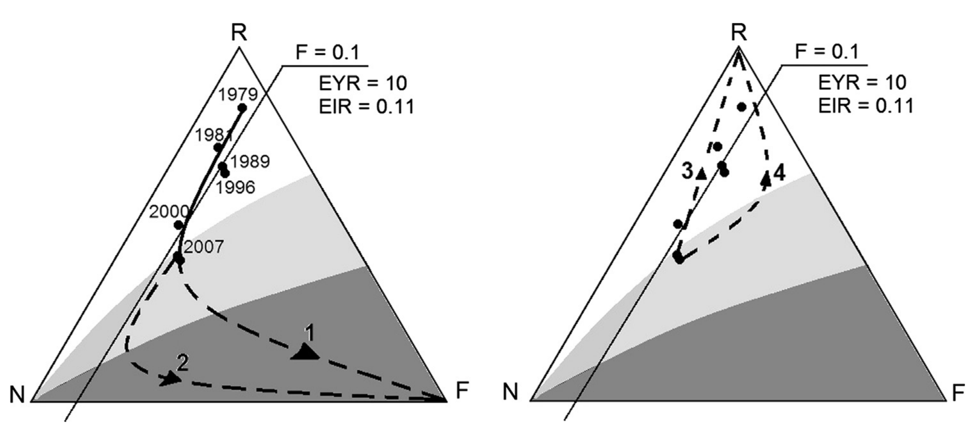


Fig. 10. Emergy ternary diagram of Brazil from 1979 to 2007 with possible paths for future development. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for the long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for the medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable.

or political will of a given country. It also depends on its natural environment, on the nature and the storages of its non renewable resources and the global market demand for these resources. What may be appropriate and usable within one country may not be within another, and a global solution is required, in which two parallel actions may occur:

(i) the reduction of the total emergy use in developed economies, reducing empower per capita and the demand for energy and raw materials.
(ii) the reduction of indigenous resources exportation in developing economies, increasing the quantity and the quality of final products for export and especially for domestic use, creating jobs and an internal market.

5. Conclusions

The options for the future imposed by economic and environmental realities on Brazil, compared to the other BRICS countries, were explored from the perspective of energy and resources driving economies. The results show that the flexibility of different options of future development depends on the national territory. Developed nations with the highest emergy use require extremely large flows of emergy per year to carry on with large GDPs. The maintenance and expansion of these economies result in high demand of materials and energy provided by the developing economies and creating a vicious cycle that blocks developing countries' full development. This scenario becomes worse if the rebound effect (Jevons Paradox) is taken into account: an increase in the developed nations performance may reduce costs and increase energy use.

For the BRICS countries that are nations with high EMR, the solution appears to be increasing efficiency by exporting less raw resources and the creation of a national market for finished products. However, this path is limited by the demand for circulating money that is provided by the raw resources exportation, and the increase in efficiency will not come easily. To support the development strategy already traveled by developed countries and to ensure competitiveness in the current market, considerable amounts of energy and resources in higher education, research, technology and information must be invested. The increase of final products exportation may provide a temporary solution, which can in long-term be limited by lack of foreign buyers.

The challenge is to increase the economic performance of developing countries (with an imports/exports ratio less than 1, Table 5) along with a concomitant decrease in emergy requirements of developed countries that have efficiencies greater than 1. The solution will require a global agreement involving developed, developing and underdeveloped nations. To achieve a global sustainable development framework, Odum and Odum (2001) suggest that the only solution is to restrict the economies, reduce the overall emergy use and reduce consumption. Looking for sustainability, where economy, environment and society are interconnected, it is essential to understand that there are limits for economic growth and that there should be a more equitable distribution of resources and opportunities around the planet for the present and future generations.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2013.08.085.

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