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Emergy assessment of global renewable sources

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ABSTRACT

The empower that is derived from solar, geothermal and tidal sources drives the productive processes of the geobiosphere and is responsible for developing exergy gradients (work potential) to be transformed into secondary exergy sources (wind, and chemical potential of rain water) and tertiary sources (chemical and geopotential energy of river discharges and the available energy of breaking waves). In this paper we use the geobiosphere emergy baseline (GEB) to compute transformities for secondary and tertiary renewable exergy sources. We also refine methods used to compute secondary and tertiary sources.

In particular, we develop an emergy accounting procedure for landscape systems that prevents double counting. We suggest that when evaluating landscape systems, the geobiosphere tripartite (solar, tide, geothermal) solar equivalent inflows be summed, and compared to the largest of the secondary and tertiary flows. The driving energy for the landscape system is then the larger of these two values.

Additionally, we suggest that defining spatial and temporal boundaries is critical to emergy evaluations. Spatial boundaries should be three dimensional and include a depth below the land surface, in order to compute geothermal exergy inflows, and a height above the land surface, to include adsorption of geostrophic winds and other atmospheric phenomena. Moreover, specifying the temporal boundaries of an analysis helps to allocate driving emergy sources properly, especially related to landscape scale analyses.

1. Introduction

1.1. Geobiosphere emergy baseline (GEB)

The three main driving forces of solar, geothermal and gravitational potential exergy provide a total emergy contribution to the geobiosphere of 12.0E+24 seJ y^{-1} (Brown et al., 2016). In the past 20 years, there have been numerous baselines, which have contributed to a certain amount of uncertainty, especially when comparing evaluations by different authors. In his book Environmental Accounting, Odum (1996) computed a total emergy support to the geobiosphere of about 9.44E+24 sej y^{-1}. Later, Odum et al. (2000) calculated the global empower as 15.83E+24 sej y^{-1}. Brown and Ulgiati (2010) computed a baseline of 15.2E+24 sej y^{-1}. Campbell in several publications (Campbell et al., 2005, 2010; Campbell, 2000) had computed a baseline of 9.26E+24 sej y^{-1}. Each time there is a change in the reference baseline the unit emergy values[1] (UEVs) which directly and indirectly were derived from it must also change. When using UEVs computed with a specific GEB, their conversion to the new 12.0E+24 seJ yr^{-1} baseline is computed by multiplying the UEV by the ratio of the new baseline to the previous one.

1.2. Solar equivalent exergy of the GEB

Table 1 is a synthesis of the GEB that resulted from three studies by Brown and Ulgiati (2016), Campbell (2016) and De Vilbiss et al. (2016) using most recent estimates of global data. In order to represent tidal exergy and geothermal exergy on the same basis with solar exergy, so that they may be added to form the GEB, these studies used three different methods of equivalence to express them as solar equivalent exergy (abbreviated seJ). The methods have in common the fact that they each computed solar equivalence ratios

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[1] Unit emergy value is the generic term for the ratio of emergy per unit that includes, transformity (seJ/J), specific emergy (seJ/g) and the ratio of emergy to money (seJ/$).

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Table 1
Summary of tripartite exergy flows, solar equivalence ratios and related solar equivalent exergy (Brown et al., 2016).

Inflow	Exergy[a] ($J\,yr^{-1}$)	SER[b] ($seJ\,J^{-1}$)	Solar equivalent exergy[c] (E+24 $seJ\,yr^{-1}$)
Solar energy absorbed	3.73E+24	1	3.7
Geothermal flows	9.52E+20	4900	4.7
Tidal energy absorbed	1.14E+20	30,900	3.5
Total global empower (GEB)			12.0

[a] Average of the exergy from Brown and Ulgiati and Campbell.
[b] Average of the SERs from Brown and Ulgiati and Campbell.
[c] GEB rounded to two significant figures.

Table 2
Solar transformities of secondary global available energy flows.

Item	Global solar equivalent exergy ($seJ\,J^{-1}$)	Exergy flux (E+20 $J\,y^{-1}$)	Transformity[a] ($sej\,J^{-1}$)
Surface wind	1.20E+25	151.2	800
Land rain, chemical potential	3.74E+25	5.34	7000
Ocean rain, chemical potential	9.56E+25	19.51	4900

[a] Rounded.

(SERs: solar equivalent exergy per unit of exergy; $seJ\,J^{-1}$) that when multiplied by the exergy of the tripartite flows, yielded solar equivalent exergy (the last column in Table 1).

The inflowing exergy from the tripartite is available to drive geobiosphere processes and its availability is "destroyed" as it is used up and assigned to secondary and tertiary renewable flows as well as to all the downstream chain of products. By definition, one solar equivalent joule (1 seJ) of inflowing exergy that drives the secondary, tertiary, etc. processes of the geobiosphere, when destroyed, translates into one solar emjoule (1 sej). The conversion of units from seJ (equivalent exergy of inflows) to sej (availability used up, emergy) is as follows:

$$X\,\text{seJ} \times \frac{1\ \text{sej}}{1\ \text{seJ}} = X\,\text{sej} \quad (1)$$

while the quantitative amounts of flows (X) are derived from calculations.

2. Secondary and tertiary global renewable emergy

The global empower derived from the tripartite of solar, geothermal, and tidal exergy drives the productive processes of the geobiosphere and is responsible for developing the potential energy gradients that are transformed into secondary and tertiary renewable exergy sources. Based on the hierarchical organization of geobiosphere processes, we categorize the renewable flows of available energy into *secondary sources* (wind, and chemical potential of rain water) and *tertiary sources* (chemical and geopotential energy of river discharges and the available energy in breaking waves).

2.1. Transformities of secondary global available energy flows

The geobiosphere's tripartite of solar, tidal and geothermal exergy is linked in a hierarchical web which generates secondary global flows that include wind and rainfall. The hierarchical web of energy flows of the geobiosphere illustrated in Fig. 1 shows the main driving energies and the pathways of available energy flows linking the continents, oceans and atmosphere. The diagram makes visible the interconnected nature of the geobiosphere which results in the transformation of driving energies into secondary energy flows, with the products of all three driving energies acting collectively to build structure and increase power flows. Table 2 summarizes these secondary flows, their available energy, and their transformities. Transformities are computed by dividing the driving emergy by the flow of available energy for each secondary source.

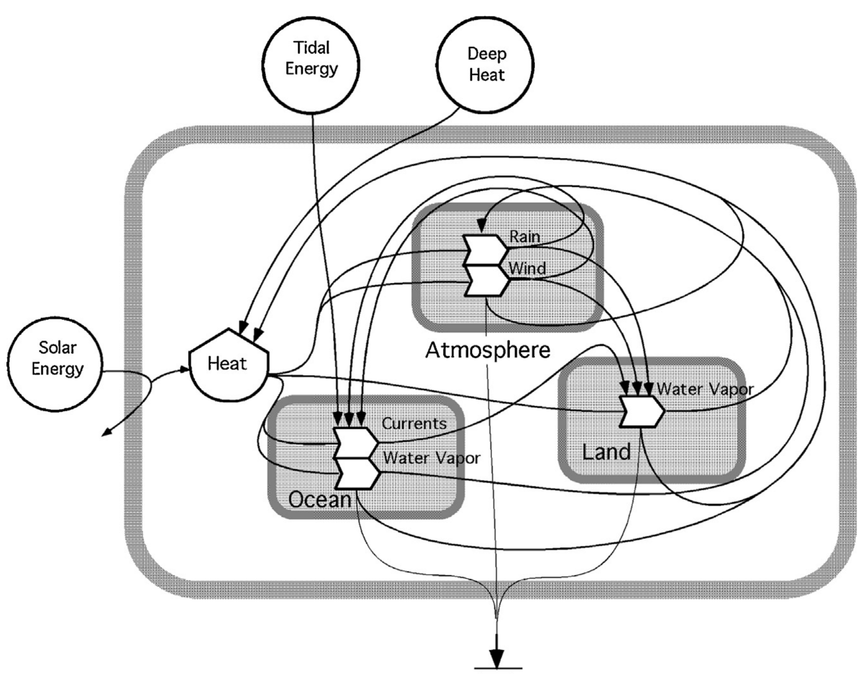

Fig. 1. Secondary emergy flows of the geobiosphere (rain, wind, and ocean currents driven by tripartite of solar, tidal and geothermal exergy. Cumulative stored heat in the geobiosphere is heat that has a gradient with the average environmental temperature and the heat sink represents energy that is dispersed and has no gradient with the environment and therefore is not capable of doing work.

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