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Assessing the global environmental sources driving the geobiosphere: A revised emergy baseline

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ABSTRACT

The empower that is derived from solar radiation, tidal momentum and geothermal sources drives the productive processes of the geobiosphere and is responsible for developing gradients of potential energy transformed into secondary energy and tertiary sources. In this paper we establish the geobiosphere emergy baseline (GEB) based on earlier methods proposed by Odum (2000) and refinements by Brown and Ulgiati (2010). After revising the solar exergy input and our previous interpretation of the sources and magnitudes of geothermal exergy, we compute a revised solar equivalent exergy and solar equivalence ratios (SERs) of geothermal and tidal inputs to the geobiosphere dynamic.

A Monte Carlo simulation that includes the revised solar exergy flow of geothermal inputs and uncertainty in the flows yields SERs of 26,300 seJ J^{-1} and 5500 seJ J^{-1} for tidal and geothermal sources respectively. The solar exergy remains 3.6 E+24 sej y^{-1}, while the solar equivalent exergy of tidal and geothermal sources were 3.1 E+24 seJ y^{-1}, and 5.4 E+24 seJ y^{-1} respectively, resulting in a GEB of 12.1 E+24 seJ y^{-1}.

1. Introduction

For several years more than one geobiosphere emergy baseline (GEB) has been promoted by various researchers (Odum, 2000; Campbell et al., 2005; Brown and Ulgiati, 2010) based on different quantification or inclusion of emergy sources driving the biosphere. The different GEB thus calculated were used by emergy practitioners resulting in different values of emergy indicators of products and processes, partially generating confusion and concern. After the Eighth Biennial Emergy Conference (January, 2014), the need for revisiting the procedures and assumptions used to compute the geobiosphere emergy baseline emerged very clearly as an urgent target to strengthen the emergy accounting method and remove sources of potential misunderstanding. The goal was to develop a synthesis document to clarify the baseline issue, potentially resulting in adoption of a single baseline (or baseline range). Several different approaches to the computations, carried out by a number of emergy practitioners, are likely to allow for accommodation of different perspectives and postulations related to integration of the three driving energies (solar, geothermal, and tidal momentum) into a single emergy baseline. Of course, given the significant uncertainty that exists in our understanding of the geobiosphere system as well as in the available data about global processes, we should not expect that each approach would yield the same baseline, but rather that results achieved through different procedures and assumptions may fall within an acceptable range of values showing the same order of magnitude. In so doing, a single agreed upon baseline could be selected to reflect a reconciliation of different perspectives within a scientifically sound uncertainty estimate.

When developing the emergy approach, H.T. Odum, at first, focused on solar radiation as the ultimate driving source of planetary dynamics and life on Earth (Odum, 1976). All calculations of resource convergence through planetary metabolism to yield "embodiment" factors (previously named transformities) were based on an estimate of the total solar radiation on Earth, after albedo was subtracted (Brown and Ulgiati, 2004). With the publication of Environmental Accounting (Odum, 1996) two more global sources were included as co-responsible of Earth phenomena, namely the gravitational potential energy of the Earth–Moon–Sun system (responsible for sea and earth tides and a portion of oceanic currents as well) and the heat flow from crustal weathering and erosion, radioactive decay in the mantle, and residual heat from the Earth's formation (primordial heat) in the Earth core (called deep heat). This solar budget was referred to as the solar emergy baseline and quantified as 9.44E+24 sej y^{-1}. Modeling the simultaneous

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support of these three energy sources yielded a new estimate of the biosphere baseline as 15.8E+24 sej y^{-1} (Odum, 2000) as the starting point for calculation of the transformities of solar radiation, heat crustal flow, and tide momentum. Finally, Brown and Ulgiati (2010) performed new calculations using the same driving energies, but based on updated estimates of Earth sources and their expression as available energy (exergy), according to Odum's definition of emergy (Odum, 1996), yielding a baseline of 15.2E+24 sej y^{-1}.

In earlier work, Campbell et al. (2005) suggested that more than one baseline is justified and proposed 9.26E+24 sej y^{-1} as an alternative to the baseline computed by Odum (2000). Also Campbell (2000) in another analysis suggested two baselines 9.26E+24 sej y^{-1} and 10.58 E24 sej y^{-1} for short and long period processes respectively. More recently Campbell et al. (2010) have argue that the 9.26E+24 sej y^{-1} baseline is the most appropriate because it assumes that only the sun and deep heat are responsible for generating geologic processes. Raugei (2013) proposed a scalar baseline where the three fundamental inputs of exergy to the geobiosphere (sunlight, tidal momentum, and geothermal) are kept separate at all times, not unlike the three independent axes of Cartesian space.

1.1. Conflicting baselines

Currently, the geobiosphere emergy baseline used in the emergy methodology is composed of the solar exergy received by Earth, geothermal exergy, and the exergy from dissipation of tidal momentum that results from the interaction of the earth, sun, moon system. From these three exergy sources the qualities of all other forms of exergy are computed. The conflicting baselines that have been proposed over the years have increased the difficulty of comparing results from one evaluation to another.

2. The geobiosphere emergy baseline (GEB)

The three main driving forces of sunlight, geothermal exergy and the dissipation of gravitational potential provide the total exergy (available energy, work potential) contribution to the geobiosphere.[1] These three driving sources are referred to as the *global tripartite* and are the primary sources of renewable exergy that support geobiosphere processes. By definition, the total exergy used up by a system process, expressed in common units, is the emergy of the final product or service (Odum, 1996). In order to represent tidal exergy and geothermal exergy on the same basis with solar exergy, we use a method of equivalence that expresses these two sources as solar equivalent exergy by means of appropriate *solar equivalence ratios* (SER). In so doing the three flows can be added to yield the geobiosphere emergy baseline (GEB).

When represented on the same solar basis, tidal and geothermal exergy are no longer actual exergy, but instead are *solar equivalent exergy*. The units of solar equivalent exergy are solar equivalent joules abbreviated seJ (note the capital J). Instead, all other emergy flows computed from the GEB (rain, wind, down to human made products) are expressed in solar emjoules, abbreviated sej (note the small j). The difference arises for consistency with the international energy and exergy nomenclature: according to International System of Units (S.I.: NIST, 2015) the word joule is never capitalized, but the abbreviation for the unit is capitalized (J); therefore, units of equivalent joules are abbreviated using a capital "J". On the other hand, emergy is no longer actual energy or exergy carried by a flow or item and cannot do further work or be degraded like exergy, for it is not measured using joule, but emjoule. The emjoule is the record of joules used in the past, thus the 'j' in the abbreviation for emjoule is not capitalized (sej).

In conclusion, we are suggesting the following convention. The exergy inflows of the tripartite are expressed in units called solar equivalent joules, abbreviated as seJ. This inflowing exergy is available to drive geobiosphere processes and its availability is "destroyed" as it is used up and assigned as emergy to secondary and tertiary renewable flows as well as to all the downstream chain of products. By definition, 1 seJ (solar equivalent exergy), when destroyed translates into 1 sej (solar emjoule); that is to say, one solar equivalent joule of inflowing exergy that drives the secondary, tertiary, etc. processes of the geobiosphere, when destroyed, becomes one solar emjoule, i.e. a record of the exergy destroyed. Mathematically, the conversion of units from seJ (solar equivalent exergy) to sej (emergy) is as follows:

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

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

2.1. The geobiosphere: a frame of reference

Interestingly, there is no standard definition of *geobiosphere* in the scientific literature. The *biosphere* is generally defined as the part of the earth's crust, waters, and atmosphere that supports life. *Geosphere* is the collective name for the lithosphere, the hydrosphere, the cryosphere, and the atmosphere. We therefore define the geobiosphere as "the ecological system that is the sum total of the living (biotic; including humans) components and non living (abiotic; including geologic, hydrologic and atmospheric processes) components of the Earth". The geobiosphere is the system where emergy gradients are generated and degraded, ultimately supporting a multiplicity of matter and energy transformations and storages on Earth.

2.2. Spatial boundary

We define the system boundaries of the geobiosphere to include Earth processes of the crust (to a depth of approximately 100 km) and the atmosphere (to a height of approximately 80 km) (see Brown and Ulgiati, 2010). In this way flows of available energy that cross this boundary are inputs to the geobiosphere.

When evaluating smaller areas of the Earth system, for example regional systems, or terrestrial ecosystems, it is appropriate to adjust the spatial boundaries to coincide with the temporal and spatial scales of system processes under study. For instance the input of available geothermal energy that affects surface processes within a region probably does not extend deeper than the deepest mines or oil wells. And the atmospheric input of available energy of wind generally does not need to extend higher than the atmospheric boundary layer taken as an average of approximately 1500 m (Garratt, 1992). If the study area is a single ecosystem (or agro-ecosystem) the lower boundary may only be the rooting depth. In all cases, when doing an emergy evaluation, it is absolutely necessary to specify the three-dimensional spatial boundaries of the investigated system.

[1] While a concept put forth by Odum (1996), others have suggested that "all activity on Earth derives from four primary reservoirs of exergy that have existed since the formation of the solar system: fusible atoms in the Sun, fissionable atoms on Earth, the thermal energy of the Earth's interior, and the gravitational potential energy and relative kinetic energy of celestial bodies." (Hermann, 2006). Szargut (2007) describes the driving exergy as follows: Besides exergy losses derived from human activity, huge losses within the biosphere result from the irreversibility of natural phenomena "the absorption of solar radiation, the emission of thermal radiation, the irreversible heat transfer from inside the Earth to its surface and the braking of the planetary motion."