



Research paper

Imputing missing data in non-renewable empower time series from night-time lights observations



Laura Neri^a, Luca Coscieme^{b,*}, Biagio F. Giannetti^{b,c}, Federico M. Pulselli^d

^a Department of Economics and Statistics, University of Siena, Piazza San Francesco 7, 53100 Siena, Italy

^b Post-graduation Program in Production Engineering, Paulista University, Rua Doutor Bacelar 1212, 04026002 São Paulo, Brazil

^c State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, 19 Xijiekouwai Street, Haidian District, Beijing 100875, China

^d Ecodynamics Group, Department of Earth, Environmental and Physical Sciences, University of Siena, Pian dei Mantellini 44, 53100 Siena, Italy

ARTICLE INFO

Keywords:

emergy
emergy database
time series cross section
missing data
multiple imputation
thermodynamic geography

ABSTRACT

Emergy is an environmental accounting tool, with a specific set of indicators, that proved to be highly informative for sustainability assessment of national economies. The empower, defined as emergy per unit time, is a measure of the overall flow of resources used by a system in order to support its functioning. Continuous time-series of empower are not available for most of the world countries, due to the large amount of data needed for its calculation year by year. In this paper, we aim at filling this gap by means of a model that facilitates reconstruction of continuous time series of the non-renewable component of empower for a set of 57 countries of the world from 1995 to 2012. The reconstruction is based on a 3 year global emergy dataset and on the acknowledged relationships between the use of non-renewables, satellite observed artificial lights emitted at night, and Gross Domestic Product. Results show that this method provides accurate estimations of non-renewable empower at the country scale. The estimation model can be extended onward and backward in time and replicated for more countries, also using higher-resolution satellite imageries newly available. Besides representing an important advancement in emergy theory, this information is helpful for monitoring progresses toward Sustainable Development and emergy use international goals.

1. Introduction

Energy availability, management and use are crucial aspects to consider for achieving sustainability. The United Nations Sustainable Development Goal 7 is “ensure access to affordable, reliable, sustainable and modern energy for all” (<http://www.un.org/sustainabledevelopment/>; last accessed: March 2017). Specific targets to be reached by 2030 include ensuring universal access to affordable energy, expanding and upgrading energy infrastructures and increasing the share of renewable and clean energy in the global energy mix, among others.

The current energy model is largely based on non-renewable sources being “enabling” resources necessary to support the production processes of food and other goods (Fantazzini et al., 2011). As a consequence, economic growth is largely explained by variations in oil consumption alone (Murphy and Hall, 2011).

Mounting scientific literature shows how it is crucial to move away from non-renewable based models toward development based on renewable energies (Rogelj et al., 2013; Jarvis et al., 2012). This problem has also been tackled by a number of economists involved in designing a growth theory with exhaustible resources (see for example the debate fed, among others,

by Robert , and John Hartwick, 1977, during the economic crisis in the 1970s), as well as by ecological economists (Daly, 1990) and other scientists interested in sustainable development (Bastianoni et al., 2009).

One of the main indicators used for assessing the level of sustainability of different energy use models is Emergy, a thermodynamics-based indicator, introduced by Odum (1988, 1996), that reflects the energetics of natural and human-driven systems and measures all the resource flows that feed the activity of a system, like a country or a production process. These resource flows are expressed in terms of a common unit: the equivalent solar energy that has been used, directly or indirectly, to obtain them. Emergy, in fact, represents the flow of solar energy that is “memorized” in a product or a resource, from direct solar radiation, rain, wind, wood, water, to non-renewable resources like oil, which is very old solar energy that has been stored in deep deposits, and other materials.

Emergy can be calculated as a flow per unit time (the empower) representing the environmental value of resources used to maintain a given system at a certain level of organization.

Sustainability has a global dimension and is related to global challenges. It is an extensive problem (Pulselli et al., 2008a) that needs to be solved by putting into relation the absolute consumption of resources

* Corresponding author.

E-mail address: lucaaq@gmail.com (L. Coscieme).

and energy with the absolute availability of them at the global level, which has also implications at the national/sub-national level. To assist the sustainability transition, a monitoring system of energy availability and use is thus needed at the global scale.

Remote Sensing can be of great help in achieving this task, highlighting dynamics and effects of human action at the largest scale. Monitoring systems at different scales and in different fields, including temporal and spatial energy distribution and use, can be supported by satellite observations and Geographic Information Systems (e.g. Doll and Pachauri, 2010; Min et al., 2013; Amaral et al., 2005; Kiran Chand et al., 2009).

In this vein, night-light satellite observations represent an increasingly used product. Global scale images of nocturnal lights have been used to monitor energy consumption, but also population density, urban dynamics, carbon emissions, light pollution and anthropic impacts on the environment (Proville et al., 2017; Imhoff et al., 1997; Dobson et al., 2000; Doll, 2008; Ghosh et al., 2010a, 2010b; Oda and Maksyutov, 2011; Sutton et al., 2012; Froking et al., 2013; Ceola et al., 2015; Bennie et al., 2015).

Coscieme et al. (2014) used nocturnal lights as a spatially related proxy of energy. They found that the non-renewable component of energy correlates with the sum of lights emitted within a territory, as detected by satellite imageries. This strict relationship confirms that large scale satellite-based measuring of nocturnal lights goes beyond the mere sum of bulbs turned on; on the contrary, it identifies urban, industrial and people aggregations and the consequent convergence of resource and energy flows in geographical areas. Investigating these phenomena at a systemic level allows the visualization of “an alternative geography based on environmental resource use, in which a territory is interpreted as a continuum of physical and morphological elements, infrastructures and urban settlements, rather than a combination of separated systems” or a “thermodynamic geography” (Pulselli, 2010).

In this paper, night-time lights observations are used, together with Gross Domestic Product (GDP) per capita, to estimate the annual non-renewable empower in 57 countries of the world from 1995 to 2012 continuously. Complete time series are useful to investigate variability in resource use, expressed in energy terms, and possible trends in energy-based indicators, which are useful tools for investigating sustainability (Brown and Ulgiati, 1997). However, energy time series are only available for a limited number of countries and non-continuous years. For example, Lomas et al. (2008) provided energy values for Spain for 1984, 1989, 1994, 2000 and 2002; Lei et al. (2012) for Italy and Sweden (and Macao) for different non-continuous years; similar analyses have been performed by Yang et al. (2010) and Lou and Ulgiati (2013) for China, and Giannetti et al. (2013) for Brazil, among others. Sweeney et al. (2007) and Brown et al. (2009) calculated energy values for most of the world countries for the years 2000, 2004 and 2008. These gaps are due to the large amount of information needed for energy assessments.

Time series estimation is here proposed by means of statistical reconstruction based on a multiple imputation strategy that is usually adopted to complete data affected by missing values. Beyond the main aim of the reconstruction of 1995–2012 time series for the non-renewable component of energy for a large set of countries, the method enables calculation and visualization of the uncertainty involved in the reconstruction and further development of energy representations at a more detailed spatial resolution.

Ultimately, this analysis facilitates time-series reconstructions that can be used to refine/monitor national and international policy goals.

2. Methods

2.1. DMSP-OLS time series of night-time emitted lights

Visible light emitted at night within a territory can be detected by satellites equipped with specialized sensors. A repetition of the observations is needed to exclude areas obscured by clouds and remove other sources of noise (Elvidge et al., 2001). A system of six satellites, the Operational

Linescan System (OLS) flown by the U.S. Air Force Defense Meteorological Satellite Program (DMSP), has been providing time series of night-lights data available since 1992, archived at the NOAA National Geophysical Data Center (NGDC) (Elvidge et al., 2009). Each year, a global picture is composed by reporting the observational data on a latitude-longitude grid (Plate Carree projection) with a resolution of 30 arc seconds, or approximately 1 km² at the equator. Furthermore, a measure of the total brightness of nocturnal observed lights within each country of the world is calculated for each year as a Sum of Lights Index (SOL in digital brightness value) (Elvidge et al., 2001). The total brightness of night-time observed lights is expressed as the sum of the values of every 1 km² pixel in the nation's territory. Pixels are characterized by a digital number value that stretches from 0 (totally dark areas, e.g. wilderness settings) to 63 (maximum brightness detectable by the sensor; e.g. densely populated urban areas) (Tuttle et al., 2013). These values can be used as a proxy to describe and monitor patterns of resource consumption that are difficult to measure and map (Coscieme et al., 2014, 2017).

2.2. Emery evaluation of territorial systems

Emery is defined as the available energy of one type required in transformations to generate a flow or storage (Odum, 1988, 1996). Solar energy, being the fundamental energy for all biosphere processes, is used to express all energy flows in a common unit. Therefore, emery is expressed in solar energy joules (sej) and measures the convergence of different forms of energy flows into a final energy form, through a series of energy transformations, starting from solar radiation. Different energy forms are converted into sej by means of specific factors called Unit Emery Values (UEVs).

Emery is extensively used to study anthropic activity on a territorial basis (Pulselli et al., 2008b; Campbell and Ohrt, 2009; Campbell and Garmestani, 2012; Morandi et al., 2015; Giannetti et al., 2016; Agostinho et al., 2016; Tassinari et al., 2016). Emery evaluations of territorial systems are informative to understand the environmental costs of the use of resources by humans. Thus, these analyses investigate the sustainability of territorial systems such as cities or entire countries (Giannetti et al., 2010, 2012, 2013; Sevegnani et al., 2016; Pulselli et al., 2008b; Pulselli, 2010; Bastianoni et al., 2005; Brown and Ulgiati, 1997).

The largest available database of emery and empower data is the National Environmental Accounting Database (NEAD) hosted by the Center for Environmental Policy (University of Florida). The NEAD provides emery data for a large set of world's countries in three different years, i.e. 2000, 2004 and 2008 (Sweeney et al., 2007; Brown et al., 2009). Total empower for every nation is calculated as the sum of renewable resources, non-renewable resources, and imported resources (data are available at <http://www.cep.ees.ufl.edu/need/>; accessed March 2017). Imported resources are resources purchased from outside the national economy and include fuels, minerals, and finished goods. The services embodied in imported resources are also sometimes included. In this paper, we refer to the sum of non-renewable and imported resource flows as “non-renewable empower”.

The Emery baseline used in this paper is 15.2 E + 24 sej year⁻¹, which is also adopted within the NEAD framework.

2.3. Assumptions

Coscieme et al. (2014) showed that non-renewable empower, as calculated in the NEAD, is strongly correlated with the sum of lights emitted by countries in 2000, 2004 and 2008. On the other hand, renewable empower and sum of lights are not related. Night-time lights, in fact, help identify human settlements (both urban and industrial) that require a large convergence of resource flows, especially non-renewable, from raw material and minerals to a wide set of products coming from human-driven transformation processes (Proville et al., 2017); renewable energy flows, on the contrary, are properties of an area independently of human presence (sunlight, rainfall, geothermal heat, spring water sources, etc.).

This strong linear association of the sum of lights with non-renewable empower can be used to specify a regression model able to explain the

Download English Version:

<https://daneshyari.com/en/article/5741533>

Download Persian Version:

<https://daneshyari.com/article/5741533>

[Daneshyari.com](https://daneshyari.com)