Ecological Economics 142 (2017) 56–69

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Energy Metabolism of 28 World Countries: A Multi-scale Integrated Analysis

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ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form 26 May 2017
Accepted 12 June 2017
Available online 22 June 2017

Keywords:
Exosomatic energy
Social metabolism
Multi-Scale integrated analysis
World Input-Output Database

ABSTRACT

In this paper the Multi-Scale Integrated Analysis of Social Metabolism (MuSIASEM) is used to investigate the metabolic profile of 28 world countries. The years considered are 1995 and 2007 and the socio-economic and environmental data included in the World Input-Output Database (WIOD) are used to provide consistent comparisons between countries. The analyses are performed by considering the entire society (Level N), the household and the paid sectors (Level N-1) and the different economic sectors (Level N-2). The main results show that, despite the differences existing between countries, the increasing energy throughput and per-capita consumption contributed to change the metabolic profile of the countries considered in this paper.

1. Introduction

Human societies have always been dependent on material and energy use. In recent time, however, the increasing level of per-capita consumption and the pressure generated by a rising world population have increased the worldwide energy and material demand. Based on data provided by Arto et al. (2012)and by the International Energy Agency (IEA, 2015), the quantity of material extracted increased by around 43% (between 1995 and 2007) and the world energy consumption by almost 100%, rising from 4666 Mtoe in 1973 to 9302 Mtoe in 2013. Fossil fuels have been the main source of energy supply, accounting today for around 82% of the total energy use (World Bank, 2016). The consequent impact on resource availability, pollution and unequal distribution of wealth are some of the main elements raising concerns related to possible instabilities and crisis. Over the last few decades, different models have been proposed to investigate the mutual relationships existing between the humans and the natural environment and the concept of social metabolism has been proposed to investigate the process of energy and material transformation taking place on societies (Martinez-Alier, 1987; Fischer-Kowalski, 1998). Based on the idea that the human environment is strictly dependent on the natural environment, the social metabolism analyses the energy and the material use as fundamental elements for the maintenance and development of societies. The main objective is to investigate how variation in energy, material and human time allocation can generate impact on both social and environmental elements. The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is an accounting framework specifically design to investigate the size, the allocation and the human and natural dependencies of societies (Giampietro and Mayumi, 1977, 2000). By using the MuSIASEM approach, this paper compares the metabolic profile of 28 world countries in 1995 and 2007. The main objective is to provide an overview of the variations that have taken place and to investigate the main elements responsible for changes. The paper is structured as follow: Section 2 introduces the methodology. Section 3 presents the study area and the data sources. In Section 4 the main results are reported and interpreted. Section 5 includes discussion, future development and limitations. Section 6 concludes.

2. Social Metabolism and MuSIASEM Methodology

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) has been proposed by Giampietro and Mayumi (1977, 2000) based on the integration of various concepts related to complex system theory (Prigogine, 1961, 1978; Maturana and Valera, 1980; Odum, 1971, 1983, 1996; Ulanowicz, 1986, 1995; Rosen, 1958, 2000; Zipf, 1941; Morowitz, 1979; Kauffman, 1993; Ahl and Allen, 1996; Koestler, 1969) post-normal science (Funtowicz and Ravetz, 1994) and bioeconomics (Georgescu-Roegen, 1971, 1977) (for exhaustive descriptions please see Mayumi, 1999, Ramos-Martin et al., 2007 and Giampietro et al., 2009). The main idea is to consider societies as metabolic structures that use flows and funds to sustain and expand. According to the definition reported by Velasco-Fernandez et al. (2015),

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http://dx.doi.org/10.1016/j.ecolecon.2017.06.021

flows are elements that enter into the system, as energy or material and that are transformed by the socio-economic processes. Funds are elements that are sustained by the flows and that preserve their identity, as for example capital or human time. The way in which flows and funds are combined characterise the metabolic profile of societies. The analysis of the relationships existing between energy, materials and socio-economic variables, as human time, demography and economic elements, provides information about the way in which societies evolve and self-organise. During the last decade, the MuSIASEM approach has proven to be particularly useful to analyse how technological development and acceleration of energy and material use, generates changes in the metabolic structure of societies. The increasing use of exosomatic energy, defined as the non-human body energy source, has been related to changes in demographic structure, economic activities, human time allocation, social stability and environmental impacts (Mayumi, 1991; Falconi-Benitez, 2001; Ramos-Martin, 2001; Ramos-Martin and Giampietro, 2005; Eisenmenger et al., 2007; Ramos-Martin et al., 2009; Serrano-Tovar and Giampietro, 2014; Velasco-Fernandez et al., 2015; Ginard-Bosch and Ramos-Martin, 2016). According to this approach, the accounting framework proposed by MuSIASEM is specifically designed to study biophysical and socioeconomic elements in an integrated way (Giampietro and Bukkens, 2015). The analysis of the interrelationships existing between them is useful to identify constraints that can affect the evolution of the system as well as impacts that can be generated both on the human and on the natural environment. Since the MuSIASEM approach recognises the idea that societies are complex systems operating at different levels, the proposed accounting framework includes different scales of analysis. The objective is to investigate societies as a whole or disaggregated between activities. The main levels of analysis can be summarised as:

- Level N consider the entire society;
- Level N-1 disaggregates society between consumption and production activities, respectively defined as household and paid sectors. The paid sector includes all the activities that are responsible for value added generation. The household sector includes the activities related to value added consumption.
- Level N-2 split the paid activities into different subsectors. The economic sectors considered in this paper are reported Table 1.

For every one of the three levels, the energy and the human time constraints are investigated. The mutual relationships existing between them are also taken into account by considering that changes in one level generates impacts in the other levels.

Different variables and indicators have been proposed by the MuSIASEM approach. An overview is reported in Tables 2 and 3. These variables and indicators have been specifically designed to have a multi-level and multi-dimensional structure. The main objective is to analyse both the characteristics of the different compartments of society as well as to take into account the mutual relationships existing between them. This multi-level descriptions, together with the inclusion of quantitative information related to biophysical and socio-economic elements provide an useful tool to investigate the complex relationships and constraints existing between the human and the natural environment.

The MuSIASEM approach has proven to be an effective tool to analyse the characteristics of societies based on population, socio-economic variables and environmental constraints (Velasco-Fernandez et al., 2015; Giampietro and Bukkens, 2015). By using the accounting framework described above, the present paper analyses the energy metabolism of 28 world countries in 1995 and 2007. The results provide an overview of the development path of countries and can be used to support policy in the design of sustainable strategies.

3. Study Area and Data

The study area considered in this paper includes the 28 world countries reported in Table 4. Fourteen of the countries have been classified as western European countries, six countries as eastern European countries and the remaining eighth as extra European areas. This selection of countries has been mainly driven by consistency in data availability. Since the main objective was to provide an overview of the exosomatic energy metabolism of different countries, only the areas with consistent information across all the variables have been considered in this paper. For this reason, all the countries requiring alternative data sources have been excluded.

Based on this data consistency approach, the World Input-Output Database (WIOD) has been used as the main data source for calculation. This database includes a set of socio-economic and environmental information for 40 world countries plus the Rest of the World (for a description of the database see Dietzenbacher et al., 2013). The socio-economic

Table 1
Economic sectors.

Sector	Code	Description
Agriculture	A + B + C	Agriculture, hunting, forestry, mining and quarrying
Industry	D	Manufacturing
	E	Electricity, gas and water supply
	F	Construction
Services	G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
	H	Hotel and restaurant
	I	Transport, storage and communications
	J	Financial intermediation
	L	Public administration and defence; compulsory social security
	M	Education
	N	Health and social work
	O + P + Q	Other community, social and personal service activities, private households with employed persons

Table 2
MuSIASEM variables.

Level N	Level N-1	Level N-2
Variable/description/unit	Variable/description	Variable/description
THA: Total human time available for one country for one year. It is calculated as: population * 24 h * 365 days It is measured in hours (h)	THA can be disaggregated in: – HA_{PW}: accounts for the hours allocated to the paid sector – HA_{HH}: accounts for the hours allocated to the household sector	HA_{PW} can be disaggregated between the different economic sectors - HA_{PWi}
TET: Total energy throughput quantify the total exosomatic energy consumed by one country in one year. It is measured in megajoule (MJ)	TET can be disaggregated in: – ET_{PW}: accounts for the exosomatic energy consumption of the paid sector – ET_{HH}: accounts for the exosomatic energy consumption of the household sector	ET_{PW} can be disaggregated between the different economic sectors - ET_{PWi}
GDP: Gross domestic product is the value added generated by one country in one year. It is measured in dollar ($)		GDP can be disaggregated between the different economic sectors - GDP_i