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Evaluating dynamics of national economies through cluster analysis within the input-state-output sustainability framework

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ABSTRACT

In this paper a cluster analysis is applied to an input-state-output indicator framework that represents the interconnection of the three aspects of sustainability, namely environmental, social and economic. This framework is a useful and comprehensive tool for assessing country performances over time and improving guidelines for the classification of countries under a sustainability perspective. The method enables identification of trends and traps that characterize the evolution of countries over time. The analysis is performed for 83 countries in 2000 and 2008 in order to observe system behaviour and development patterns.

1. Introduction

In order to monitor and promote sustainability, policy makers need the scientific community to develop new metrics that go beyond the measure of material wealth, also considering other aspects related to the status of the environment and the well-being of society (Kubiszewski et al., 2013; Costanza et al., 2014; Hasselmann et al., 2015).

As Rinne et al. (2013) stressed "*...the core motivation behind indicator initiatives lies in the alleged ability of indicators to give a comprehensive, reliable, and easy-to-understand picture of the ecological, social, and economic trends in a concise form*". In this perspective, many indices providing an insight into sustainability exist, such as the Human Development Index (HDI), the Happy Planet Index (HPI), the Environmental Performance Index (EPI), the Index of Sustainable Economic Welfare (ISEW), or its evolution, the Genuine Progress Indicator (GPI), the Sustainable Society Index (SSI) (Bolcárová and Kološta, 2015; Singh et al., 2012; Giannetti et al., 2015), the FEEM Sustainability Index (FEEM SI) (Pinar et al., 2014) among others. These aggregated indices are often computed as a composition, integration or algebraic sum of sets of variables concerning economic, social and environmental aspects. At the international level, an agreement on the so-called Sustainable Development Goals (SDGs) has been recently reached, pointing out 17 goals that will drive the future United Nations political agenda. However, the identification of a set of significant indicators to monitor progress towards these goals is still under debate (Hák et al., 2016; Costanza et al., 2016).

Indicators are a crucial issue for monitoring sustainability and related problems; they mainly rely on parameters that can be measured to show trends or sudden changes in a particular condition (Reed et al., 2009). The number of indicators tends to increase because every single aspect of a system under observation is considered, thus multiplying the number of quantitative measures. On the other hand, the idea of aggregating the scores of many variables, computing a single-number index could be meaningless, or hard to interpret, often implying loss of information and a certain degree of substitutability among different aspects. For example, if the economy is doing well but the environment or society is suffering in some way, is the aggregate index able to detect it? Or is that truly

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sustainable? How can these phenomena be detected by relying on a single aggregate? On this argument, Böhringer and Jochem (2007) and Ravallion (2012) presented interesting discussions on aggregate sustainability indices, questioning on their explanatory power and correctness of their design. In sum, using one measure for every single aspect of sustainability may result in a totally reductionist approach that is not able to provide a view of a system as a whole; on the other hand, the need to aggregate more measures/aspects into one multi-dimensional number may result in an excessive loss of information due to the over-simplification of the reality (on this trade-off, see also Pulselli et al., 2016).

Nevertheless, a better and easy understanding of the changes in economic, social and environmental conditions is needed especially when the aim is a cross-country comparison. Pulselli et al. (2015) stressed that sustainability is an issue of relationships among compartments, therefore a sustainability analysis can be based upon an information framework able to identify and describe human activity and the physical, social and economic context in which it develops. Following this perspective, and trying to privilege a systemic view in which components interact, they defined an input-state-output (I-S-O) framework to depict the life of a system that survives and develops by virtue of essential (physical) inputs from the environment, has organizational properties that characterize its state and capacity to process those inputs, and ultimately generates an useful output (Pulselli et al., 2011; Coscieme et al., 2013; Coscieme et al., 2014a; Pulselli et al., 2015). For a socio-economic system, the I-S-O framework is thus able to represent the interconnection of the three aspects of sustainability, namely the environment, the societal organization and the economy. Each compartment of the I-S-O framework independently represents one of these three aspects with appropriate measures. These measures have independent identity, because each aspect of sustainability must be taken into account, therefore these are considered separately from each other without further integration into a super-index (e.g. an aggregate or composite indicator that concentrates information), so that "*...the information gained by different indicators is not lost in final aggregations; instead it is maintained by keeping non-redundant indicators separated*" (Pulselli et al., 2015). At the same time, the composition and representation of framework entirety is needed as well, and can be obtained through a statistical/graphical composition of the three measures in order to detect the behaviour of the whole system and potentially visualize comparisons and trends. One option, proposed by Pulselli et al. (2015), is to identify a country with a point in a three axis diagram, whose position being determined by the value assumed by each one of the three indicators; in this way, a graphical synthesis preserves from aggregating variegated information into only one number.

Here, we identify anthropic systems (e.g. a number of nations) by a triad of indicators representing economic, social and environmental aspects of the system, and classify them into different clusters based on the value of these indicators.

Namely, the clustering algorithm (Everitt et al., 2011) generates a partition of the countries in such a way that countries included in the same cluster shares common values of the chosen indicators whereas countries belonging to different clusters are very dissimilar. Unlike many other statistical procedures, cluster analysis is a multivariate statistical technique mostly used in the exploratory phase of a study when no assumptions on the existing data structure are made. It aims at uncovering a structure that is already present in the observed data, and grouping objects (e.g., respondents, countries, or other entities) based on their characteristics. This can lead to very useful taxonomy and therefore is a suitable method to be applied in this framework.

Moreover, this paper evaluates not only the composition of the clusters at a given year but also the transition of nations from one cluster to another (change in composition) over time with the aim of monitoring two aspects: a) the identification and comparison of socio-economic systems in a given instant; b) the path and the characteristics of "transient" socio-economic systems. This will help highlight the relationships among indicators and the patterns followed by nations over time.

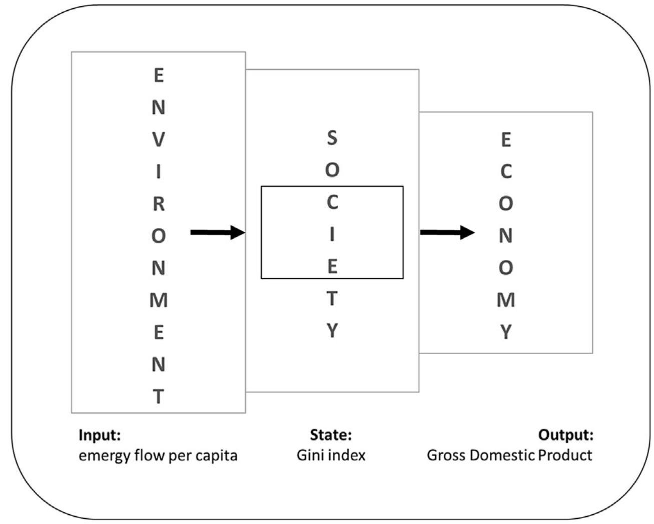

Fig. 1. The input-state-output diagram to investigate socio-economic systems.

In sum, Pulselli et al. (2015) presented an I-S-O framework application for categorizing national economies in a static picture referred to 2008. Here we propose a numerical experiment to evaluate the ability of the I-S-O framework to give information on dynamic trends of socio-economic systems, on the basis of a triad of indicators and cluster analysis. Though not relevant from the point of view of the period under study (2000–2008), it might be useful for facilitating the adoption of this method for the use and interpretation of indicators in a dynamic way.

2. Indicators and data

The I-S-O framework can be adopted to investigate economic systems (e.g. national economies) and make considerations on their level of sustainability. We consider three distinct indicators concerning economic, social and environmental aspects which cannot be considered as interchangeable (see Ostrom, 2009). In particular, the approach makes use of the following three indicators: the emergy flow per capita (for a complete overview on emergy, see Odum, 1988, 1996), the Gini index of income distribution, and the Gross Domestic Product per capita (GDP), to represent the input, the organization of the state of the system and total economic output, respectively (Fig. 1). The Emergy flow per capita accounts for the value of natural and economic resource inputs, expressed in physical unit, and it is thus chosen as environmental indicator; the Gini index of income distribution is representative of societal organization because the level of inequality is related to many social aspects such as employment, inclusion, emancipation, etc.; the GDP per capita is used to measure the level of economic output.

It is worth noting that cross-country classification analysis based on conventional economic data like the Gini index of income distribution and the GDP per capita is well known in literature. Nevertheless, the introduction of the emergy flow per capita provides additional points of view, highlighting unaccounted aspects and facilitating the identification of existing relationships. For instance, the use of GDP per capita together with the Gini index as a state indicator helps visualize the generation and distribution of income among a country's population. At the same time, the emergy flow