Energy and economic growth. An empirical Coupled Human and Natural Systems (CHANS) evaluation in developed and developing countries

Summary

The link between energy and economic growth is re-evaluated for approximating the actual biophysical properties and the relevant constraints of the production process, within the context of the Coupled Human and Natural Systems (CHANS) approach. The present article questions the prevalent Energy Intensity (EI) analysis, based on the Energy/Growth (E/GDP) prototype, and proposes Energy/Utility index as an alternative framework for evaluating the link between energy and production. We compare the prevalent (Energy/Growth) with the proposed (Energy/Utility) Energy Intensity prototype, through estimates of the Energy Intensity of USA; Japan; Germany; and UK, as four representative high developed countries, and China; India; Brazil; and Mexico, as four representative highly developing countries. Based on a broad range of estimates, we argue that energy is the indispensable engine of economic growth, once the EI estimates are evaluated as an integral part of CHANS approach.

Extended Abstract

Energy flows feed the economic process. Energy inputs are necessary for the production of goods and emerge as a primary production factor in innovative production functions, such as the LINEX (Ayres and Warr, 2010) and other more generalized forms (Ayres and Voudouris, 2014). Furthermore, recent forecasts of energy use trends underline the vital importance of energy inputs on further economic growth (Nel and van Zyl, 2010). The dependency of the economic process on energy inputs, and the constraints on growth that could be imposed as a result of energy scarcity, is an old and hot issue in economics. The most eloquent conflicting theoretical considerations are those founded by Solow and Georgescu-Roegen during the second half of the 20^{th} century. Solow, based on a Cobb-Douglas

production function, indicates that "*the world can, in effect, get along without natural resources*" (Solow, 1974, p. 11).This tenet reflects the premise of standard economic theory that regards capital and labor as the main production factors, neglecting the important contribution of energy in the production process (Ayres et al., 2013). On the other hand, Georgescu-Roegen, based on a prototype of flow-funds production function that disaggregates the role of the production functions, highlights the crucial role of natural resources in the production process (Georgescu-Roegen, 1971); especially energy inputs emerge as the indispensable engine of production since, unlike mass inputs, energy inputs evade any form of recycling or up-cycling potentials, as the result of the entropy law (the second law of thermodynamics), while energy inputs are necessary for the function of man-made capital.

Recently developed databases permit, for first time, an essential empirical investigation of the dependency of the economic process on energy. This empirical analysis could be seen as the empirical test of the conflicting theoretical approaches concerning the role of natural resources in the economic process. The relevant findings support a gradual but permanent delink between economic growth and energy use (Krausmann et al., 2009; Stern, 2011). The Energy Intensity (EI) trends indicate, after the WWII, that one unit of GDP has been produced with gradually decreasing energy inputs (Krausmann et al., 2009). These trends establish the so-called decoupling effect between economic growth and energy use, for the global economy (Krausmann et al., 2009) and the majority of national economies (Schandl and West, 2012).

The Energy Intensity (EI) is broadly defined as the ratio of energy use to economic growth, namely the amount of energy that is required to produce a unit of economic growth (GDP). There exist many alternative applications of the E_t/GDP_t prototype that could be briefly summarized in four categories:

- Total Energy Consumption (TEC) $_t/GDP_t$ (Kauffman, 1992)

- Total Primary Energy Supply $(TPES)_t$ /GDP_t (Krausmann et al., 2009)

- Domestic Energy Consumption $(DEC)_t$ /GDP_t (Haberl et al., 2006)

- Useful $Work_t$/GDP_t (Ayres and Warr, 2010)

Contemporary analysis is mainly directed towards criticizing the methods and the techniques concerning the appropriate energy measurement (Ayres and Warr, 2010; Serrenho et al., 2014). Towards this direction, many deal with the proper energy aggregation (Stern, 2011), while others analyse the substitution trends between qualitative different energy resources (Kaufmann, 1992). Eventually, these studies are mainly dealing with the appropriateness (or not) of the nominator of the E_t/GDP_t prototype, which represents the Natural System, while the relevant literature completely ignores the important implications and constraints raised by the use of GDP, as the dominant denominator, in the vast majority of the published studies (which represents the Economic System). GDP index has been severely and extensively criticized by many distinguished scholars, concerning its inability to reflect the actual welfare that the economic system creates (Ayres, 1996; Daly, 2013; Costanza et al., 2014). Furthermore, contemporary literature proposes new economic output measurements, beyond GDP (Costanza et al., 2014).

Our approach further questions the appropriateness of aggregate GDP to approximate, in monetary terms, the actual outcome of the production process and, therefore, to be used as the sole monetary-based index in the bio-physical analysis of the economy, within the context of CHANS (Liu et al., 2007). The analysis adopts an improved approximation of the actual outcome of the economic system, thus the produced goods. Towards this objective, GDP is disaggregated to the Utility level which is adopted as an improved indicator of the actual outcome of production. Indeed, the production process does not create a homogenous bulk of goods, as reflected by the aggregate GDP, but goods that be consumed by individuals. The average “bundle of goods” consumed by the representative individual actually reflects the Utility the average citizen obtains. In that sense, the “Utility” approach

represents a more “actual” set of goods in comparison to the aggregate GDP. This set of goods emerges as a far more tangible economic entity whose biophysical properties can be traced more accurately than those of the aggregate GDP. Furthermore, the average Utility has a genuine advantage, since it reveals the economic welfare enjoyed by citizens. Economic welfare is the actual outcome of the economic system and can only be accounted at the per capita level.

Towards these objectives, we evaluate and compare the energy intensity trends of 4 developed (USA, Japan, Germany, United Kingdom) and four developing (China, India, Mexico, Brazil) countries, within the context of the standard “Energy requirements for producing one unit of growth” index; and the proposed “Energy requirements for producing one unit of Utility” framework. Based on the empirical estimates, we argue that energy is the indispensable engine of economic growth, once the EI estimates are evaluated as an integral part of CHANS approach.

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