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The energy metabolism of China and India between 1971 and 2010: Studying the bifurcation

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A B S T R A C T

This paper presents a comparison of the changes in the energetic metabolic pattern of China and India, the two most populated countries in the world, with two economies undergoing an important economic transition. The comparison of the changes in the energetic metabolic pattern has the scope to characterize and explain a bifurcation in their evolutionary path in the recent years, using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach. The analysis shows an impressive transformation of China's energy metabolism determined by the joining of the WTO in 2001. Since then, China became the largest factory of the world with a generalized capitalization of all sectors, especially the industrial sector, boosting economic labor productivity as well as total energy consumption. India, on the contrary, lags behind when considering these factors. Looking at changes in the household sector (energy metabolism associated with final consumption) in the case of China, the energetic metabolic rate (EMR) soared in the last decade, also thanks to a reduced growth of population, whereas in India it remained stagnant for the last 40 years. This analysis indicates a big challenge for India for the next decade. In the light of the data analyzed both countries will continue to require strong injections of technical capital requiring a continuous increase in their total energy consumption. When considering the size of these economies it is easy to guess that this may induce a dramatic increase in the price of energy, an event that at the moment will penalize much more the chance of a quick economic development of India.

Contents

1. Introduction

"Peak oil" defined as the peak of conventional oil extraction is determining the beginning of the end of cheap fossil energy and therefore it should be considered as a turning point in recent

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economic history. Associations such as ASPO have been warning about the problem for a long time, and recently even the International Energy Agency (IEA) admitted in its *World Energy Outlook 2011* that the peak of 70 million barrels of daily crude oil production was reached in 2008 and has not been regained again [1]. The current optimism shown by IEA [2] with new shale oil and gas discoveries is contested in the academia and investment worlds for not being so financially attractive as claimed by speculators [3]. This, along with the tar sands troubles [4] leaves the importance of conventional oil untouched. The overwhelming dependence on cheap fossil fuels of the current economic model will certainly generate stress on the pattern of economic growth in coming decades when these fossil fuels will be no longer cheap. The transition to a global economy free of fossil fuels is certainly desirable to reduce socio-environmental impact – especially in extraction areas – but the complexity of the global economy is locked-in on existing technical and political institutions that make such a transition very difficult in the short run. The relentless growth of oil demand, coupled with the stagnation of conventional oil extraction, it is expected to trigger important increases in oil prices, which in turn may deepen the economic crisis in the U.S., Japan and Europe. Although the economic stagnation in these countries has slowed its energy consumption, global demand has continued to increase due to the strong growth in emerging countries like China, India, Brazil and Russia [5]. This is the reason why, the study of these fast transition countries and, in particular, of those with a very significant population size, is extremely important.

This paper presents a biophysical analysis of changes in the energy metabolic pattern of China and India for the period 1970–2010 by using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) accounting method. These two countries are extremely interesting since they are the most populated countries in the world – together around 2.6 billion inhabitants in 2011, 37% of the world's population – and they are undergoing an important metabolic transition [6]. As result of this fact, China was the largest world energy consumer and India the fourth in 2011 (BP Statistical Review of World Energy [5]). This paper studies the biophysical roots of economic growth analyzing changes in the energetic metabolic pattern associated with the analogous changes in the characteristics of the structures of consumption and production within the economy. In this way it becomes possible to individuate and explain those relevant characteristics determining differences in the energetic metabolic pattern of China and India, possible future trends and potential environmental consequences. There are several studies about China and India energy economy – e.g. literature review of China's one in [7]. Nonetheless, the quantitative analysis found in available literature does not take into account the crucial difference between flows, funds and stocks [8]. For example, if we want to study changes in the relation between GDP (a monetary flow) and energy consumption (an energy flow), the standard approach is to look at changes in a flow–flow ratio (GDP/total energy throughput) as it happens with Economic Energy Intensity (EEI). This procedure can lead to serious troubles as shown by Fiorito [9]. This problem is solved by adopting the MuSIASEM method of accounting based on the integration of flow-fund ratios [10]. In this method the EEI is defined as a ratio over two flow-fund ratios – energy metabolic rate (total energy throughput/total human activity = energy metabolic rate – MJ/h of human activity, average over 1 year) divided by economic labor productivity (GDP/total human activity = ELP – US$/h of human activity, average over 1 year). By generating a ratio over two flow-fund ratios we can address the issue of scale, considering heterogeneity in the structural components of the economy when comparing different countries in term of energy use efficiency and labor productivity [11]. In this sense, studies of energy efficiency based on energy intensity (see Table 4 of [7]) carried put at the level of the whole country misses the existence of important differences at the level of specific economic compartments. On the contrary, a multi-scale analysis based on flow-fund ratios can identify the role of each economic sector in determining both the economic labor productivity and the energy consumption of the country, when considered as a whole. Therefore, this method makes it possible to identify and compare the characteristics of “apples” and “oranges” and generate more robust forecasts of possible future scenarios.

The rest of the paper is organized as follows: Section 2 briefly introduces the methodology; Section 3 presents the results and interprets them; and finally Section 4 lists the most important conclusions that have been reached. Appendix A presents the tables with the main data analyzed.

2. Methodology

The concept of societal metabolism refers to the set of transformation processes of energy and materials taking place in a given society which are necessary for reproducing the society over time. This study must be organized bridging two non-equivalent narratives: (i) in relation to internal constraints – focusing on the set of transformations under human control (the interaction of the parts inside the black-box); (ii) in relation to external constraints – focusing on the existence of favorable conditions determined by processes outside human control (the interaction of the black-box with its context). Societal metabolism studies had a boom in the 70s due to the oil crisis, which highlighted the need to better understand human dependence on natural resources, especially energy-related ones. As indicated by Ramos-Martin et al. [12], these studies focused on the analysis of the interaction of socio-economic systems with their environment. Many of them were widely used to study farming systems and human communities [8,13–26].

The research methodology used here is based on the approach of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This analysis framework was introduced by Giampietro and Mayumi [11,27]; see also [10,28]. This approach is an application of Georgescu-Roegen's flow-fund scheme [8,29] and seeks to provide a socioeconomic and biophysical analysis from complex autopoietic system theory inspired by Maturana and Varela [30,31].

As pointed out by Giampietro et al. [10], when studying metabolic systems the distinction between fund and flow becomes fundamental to understand not only the way systems work, but also their sustainability over time. Flow categories are those elements that enter but do not exit the system representation or exit without having entered – e.g. fossil energy or a new product. Instead, fund categories are those agents that preserve their identity over the duration of the representations and transform input flows into output flows – e.g. capital, people, or Ricardian land. Funds are the elements to be sustained when speaking of sustainability: they have to be reproduced in the process. Another useful distinction is that of endosomatic and exosomatic metabolism. Endosomatic metabolism is one that refers to food energy and which is transformed inside the human body in order to maintain its activity and development. Exosomatic metabolism is one that refers to energy converted outside the human body, but still converted into applied power under human control, in order to facilitate the work associated with human activity, which gained special importance since the industrial revolution [24,32].

MuSIASEM is an accounting scheme which allows the linking of biophysical and socioeconomic variables in an integrated manner. This makes it possible to bridge two non-equivalent views of the