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Abstract: 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.

Key words: China, India, Energy, Multi-scale integrated analysis, Societal Metabolism, Sustainability, Socio-metabolic Transitions, Economic development.

Códigos JEL: Q43, Q48, Q56, Q57

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1. Introduction

Peak oil is one of the greatest drivers of the energy crisis we are facing currently and marks a turning point in recent economic history, the beginning of the end of cheap fossil energy. 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 disaster [4] leaves dependency on 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. 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 impossible in the short run. The relentless growth of oil demand, coupled with the stagnation of oil extraction, 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 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 and energy consumption, the standard approach is to look at changes in flow-flow ratios (GDP is a flow and Energy consumption is also a flow) 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. In this method the EEI is defined as a ratio over two flow-fund ratios: energy metabolic rate (EMR – MJ/hour average over 1 year) divided by economic labor productivity (ELP – US$/hour average over 1 year). The ratio over two flow-fund ratios makes it possible to address the issue of scales and the need of considering heterogeneity in the structural components of the economy when comparing different countries in term of energy use efficiency and labor productivity [10]. In this sense, extended studies about energy efficiency based in the study of energy intensity (see table 4 of [7]) have serious epistemological flaws, since the level of the whole country misses the specific differences of different 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. Societal metabolism studies had a boom in the 70’s 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. [11], these studies focused on the analysis of the interaction of socioeconomic systems with their environment. Many of them were widely used to study farming systems and human communities [8, 12-25].

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 [26, 10]; see also [27, 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. [28], 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 [22, 31].

MuSIASEM is an accounting scheme which allows the linking of biophysical and socioeconomic variables in an integrated manner. This makes it possible to relate the metabolism of a given society with potential environmental constraints such as availability of resources, waste generation and absorption capacity. Following this theoretical concept, biophysical variables can be combined with monetary ones to produce a ‘record’ of time use and exosomatic energy consumption in the different activities that make up the economy. This provides a biophysical overview of the economic process in the form of a quantitative representation of a metabolic pattern, showing the interrelationships between demographic, economic and environmental constraints. To do this, MuSIASEM integrates data from different levels (national, regional, local and household) and different issues such as time use, land use and energy consumption of different activities and production sectors.

In this study the chosen analytical framework —called in the MuSIASEM jargon “the grammar” [28]— distinguishes between three levels of analysis (see Figure 1): Level n, which reflects country-level variables; level n-1, which breaks down the values of level n between the paid work sector (PW, comprising all activities generating value added) and the household sector (HH); and level n-2, which breaks down the paid work sector among three lower level components: the agricultural sector (AG), the industrial and construction sector, including energy and mining (PS) and services and government (SG). The metabolic characteristics of the components defined at these different levels are defined using a combination of:

* extensive variables: (i) human time (FUND) – HAi, measured in hours of human activity in the sector over the year; and (ii) energy throughput or energy consumption (FLOW) – ETi, measured in GJ of exosomatic energy in the sector (expressed in Gross Energy Requirement thermal) over the year; and (iii) economic output (FLOW) – GDPi, measured in the conventional way;

* intensive variables: (i) Exosomatic Metabolic Rate (FLOW-FUND ratio) – EMRi, measured in Gross Energy Requirement (thermal) per hour of human activity in the sector; and (ii) Economic Labor Productivity (FLOW-FUND ratio) – ELPi, the amount of sectorial GDP per year divided by the hours of paid work in that sector;

Data for total energy consumption and by sector were obtained from the Energy Balances of the International Energy Agency dataset [32]. The energy consumption of transport has been distributed among domestic, industrial and services sectors using the following rule. The share of the household sector has been calculated on the basis of: (i) the number of private vehicles – motorcycles and cars [33, 34]; (ii) annual distance travelled [35, 36]; and (iii) average fuel consumption [37, 38]. For years in which these data are unavailable we assumed that the share of private transportation was 25% (from 1971 to 1984 China, India from 1971 to 2000), and 37% (2007-2010 India). The rest of energy consumption in transportation (total minus household) was split between the services sector (80%) and the industry sector (20%).

Data concerning hours of total human activity were obtained from the population statistics of each country —NBSC of China [33] and India from the OECD [39] — and multiplied by 8,760 to calculate the total amount of human activity per year expressed in hours (using the convention of 365 days and 24 hours per day). The hours of human activity in the Paid Work sector (HA_{PW}) have been obtained from statistics of employment and hours of work per week by economic activity from the ILO [40] and supplemented with World Bank [41] figures. For China, 47 hours/week and 50 weeks/year have been assumed, making a total of 2,350 working hours per year. For India, 46 hours/week and 49 weeks/year have been assumed making a total of 2,254 working hours per year.

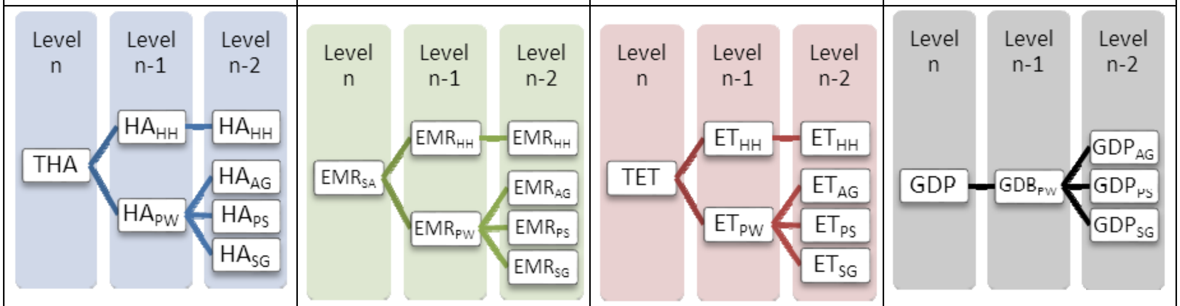
Data concerning human activity in the Paid Work category by sector of economic activity —HA_{AG}, HA_{PS} and HA_{SG}— have been obtained from employment data by sector that is available for China in the NBSC [33] and for India in the Planning Commission [42]. Hours of human activity for the household sector (HH) have been obtained by the difference between PW and the total (Total Human Activity = Population x 8,760): HA_{HH}=THA-HA_{PW}.

GDP statistics have been obtained from the World Bank [41] and GDP by sector —GDP_{AG}, GDP_{PS} and GDP_{SG}— constructed from the share of GDP by economic sectors from UN [43]. The intensive variables such as EMRi, ELPi have been obtained using the following equations:

$$EMR_i = \frac{ET_i}{HA_i} \quad (1) \qquad ELP_i = \frac{GDP_i}{HA_i} \quad (2)$$

Figure 1. Dendrograms of exosomatic energy metabolism, human activity and GDP.

Human Activity (Hours)	Exosomatic Energy Metabolic Rate (MJ/h)	Exosomatic Energy Throughput (PJ)	GDP (Constant US$ 2000)



In this way it becomes possible to establish a relation between the changes in the Economic Energy Intensity of the whole country (EEI_{AS} - Average Society = TET/GDP) and the changes in the various compartments (EEI_i – Sector *i* = EMRi/ELPi) according to the following relation:

$$EEI_{AS} = \frac{TET}{GDP} = \frac{\sum x_i\, EMR_i}{(\sum x_i\, ELP_i) * \frac{HA_{PW}}{THA}} \quad \left[where\ x_i = \frac{HA_i}{THA}\right] \quad (3)$$

This relation makes it possible to study the factors determining changes in EEI across different hierarchical levels of analysis (at the level of economic sectors and subsectors). These factors refer to: (i) the biophysical characteristics of the various sectors (including the household sector) described by their EMR and their fraction of size (measured in hours per year) over the Total Human Activity; (ii) the economic characteristics of the various sectors (only in relation to the compartments defined in the Paid Work) described by their ELPi and their fraction of size (measured in hours per year) over the Total Human Activity; and (iii) the demographic structure (dependency ratio) and other socio-economic variables (work load per year, unemployment) determining the ratio HA_{PW}/THA (the relative size of the PW sector and THA).

3. Results and discussion

3.1 At the level of the country (level n)

This level of analysis presents the main indicators aggregated at the country level such as the extensive variables TET, THA and GDP, and the intensive ones EMR_{AS} or GDP per capita.

Tables A1 and A2 (see Appendix A) list the most relevant data for level n in China and India between 1971 and 2010. Figures 2a and 3a show the evolution of the total energy consumption (TET) and the GDP in both countries between 1971 and 2010. In the case of China (figure 2a), the total energy consumption has increased more than six fold in the 39-year period studied, implying a compounded annual growth rate (CAGR) of nearly 5% for the same period. Note that since 2001 —when China joined the World Trade Organization (WTO)— the CAGR has been around 8%, which means that the energy consumption has doubled in just nine years, going from 50,330 PJ in the year 2001 to 101,200 PJ in 2010. To emphasize the importance of this change, one should note that China has increased its share of global primary energy consumption from 11.9% in 2001 to 18.9% in 2010. As regards to the GDP of China, it has shown a positive trend with a CAGR of 9%, particularly marked from China's entry into the WTO —as happened with energy— and which is around 11% for the latter period 2001-2010.

Figure 2a. Evolution of total energy consumption (TET) and GDP of China between 1971 and 2010, as constructed from data provided in Table A1.

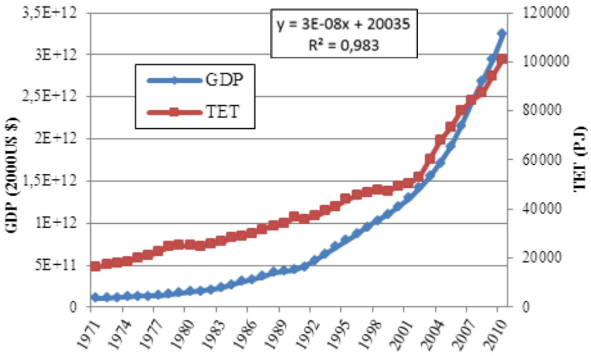
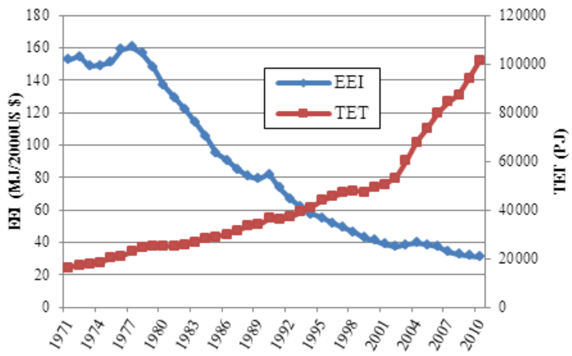


Figure 2b. Evolution of TET and economic energy intensity (EEI) of China between 1971 and 2010, as constructed from data provided in Table A1.



The correlation between TET and GDP is repeated in the case of India (figure 3a). However, India shows a more gradual evolution than China, and both variable values are considerably lower in absolute terms, a difference larger than what could be expected from the difference in population size between the two countries. This indicates that India has a level of technical capitalization —or use of machinery and infrastructure— lower than that of China. Turning to the evolution of total energy consumption, India has increased more than 4 times in the 39-year period represented and shows a CAGR of 4%. Unlike China, India has not experimented an abrupt trend change in the first decade of the XXI century and the CAGR between 2001 and 2010 stood at 4.5%, only a half point higher than the average for the whole period studied (4%). In comparison, this value is nearly half of that of China for the same period (8%). Yet, the increase in energy consumption for the latter period is not negligible, and although it did not double as in the case of China, it increased almost 40% from 19,448 PJ in the year 2001 to 29,001 PJ in the year 2010. This implied that India moved from consuming 4.6% of World energy consumption in 2001 to consuming 5.4% of World energy consumption in 2010.

It should be noted that both China's and India's increase in TET it is not only due to a growth in population (THA), but also to an increase in energy consumption per capita (see EMR in tables A1 and A2). As will be seen in the next section, this increase in energy consumption is mainly due to the greater capitalization of the Paid Work sector —EMRi of the sector within PW— and some increase in domestic consumption —the EMR_{HH} of the household sector.

With respect to the GDP of India, we can see a growing trend with a CAGR of about 5.5% between 1971 and 2010, which greatly increases during the stretch between 2001 and 2010 reaching almost 8%. Despite the difference in growth rates between China (11%) and India (8%) we are dealing with very high values when compared to the performance of other countries in the same period from 2001 to 2010: Brazil 3.9%, Russia 4.8%, Chile 3.9%, Venezuela 3.1%, Germany 0.9%, Spain 1.9%, Australia 3.2%, Canada 1.9% and the USA 1.6% [41].

Figure 3a. Evolution of total energy consumption (TET) and GDP of India between 1971 and 2010, as constructed from data provided in Table A2.

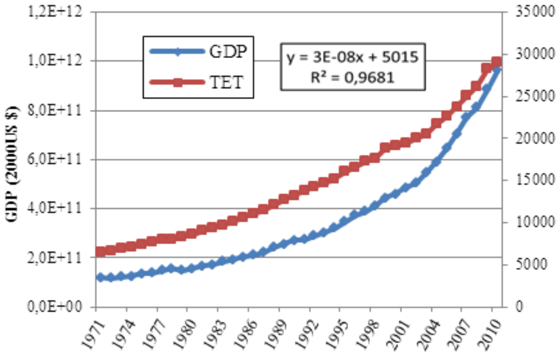
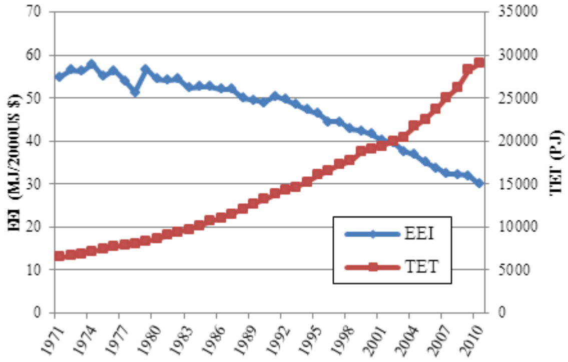


Figure 3b. Evolution of TET and economic energy intensity (EEI) of India between 1971 and 2010, as constructed from data provided in Table A2.



Figures 2b and 3b show the evolution of the total energy consumption (TET) and economic energy intensity (EEI_{AS}) for China and India between 1971 and 2010. As can be seen on these, values of EEI_{AS} —energy required to generate a unit of GDP— decreases significantly in the case of China and more tenuously in India. The tables A1 and A2 show how energy intensity for the period studied has been reduced approximately by a factor of 5 in China, while it has not even been halved in India. However, in spite of this reduction in the ratio TET/GDP, the total energy consumption has increased 6 times in China and over 4 times in India during the same period of time. Furthermore, these variables are presented together to highlight the importance of considering them simultaneously when analyzing their effects. In this regard, considering an intensive variable (FLOW/FLOW) separately, as often done with EEI, can lead to the wrong conclusion that increasing GDP will reduce environmental impact (since the energy consumption per unit of GDP is reduced). It should also be noted that if one wants to use proxy variables to assess environmental impacts, it is best to do it using extensive variables, since the use of intensive ones can lead to this kind of errors. Thus, a suitable proxy for assessing environmental impact of the economic process (both on the supply and sink side) is the TET because, apart from being an important extensive variable to be considered due to the context of energy crisis, it is strongly correlated with the consumption of materials and the generation of environmental liabilities [44]. In this sense, in figures 2b and 3b it should be noted that China and India have made impressive gains in their ability to use energy, but this does not mean that they have reduced their dependency on non-renewable energy nor their environmental impact or that they are taking steps in that direction. Their GDPs are growing at an annual rate of around 10% —which implies doubling their size every 7-8 years— and their governments make plans to continue doing so. The strong correlation between GDP and TET suggests that the social and environmental impact will continue to increase in the coming years.

3.2 At the split between production and consumption (level n-1)

The performance of China and India at national level shown in the previous section can be better understood if the energy consumption, the generation of added value and the use of human activity within the economy are analyzed at a lower scale (level n-1), which distinguishes between activities where economic production takes place generating added value —in paid work sector (PW)— and activities where consumption takes place - in the household sector (HH). Households are responsible for the maintenance and reproduction of the fund "human activity" (HA), which means that the human activity, energy and materials are required to reproduce and enhance the FUND human activity, which is essential in the definition of a socio-economic system. In addition, when analyzing the metabolic pattern at this level of analysis it becomes possible to avoid the limitations of "per capita" indicators missing important information on the demographic structure of the society, which affects the performance of the economy. This is obtained by assessing the fraction of the FUND human activity in the paid work sector (HA_{PW} = hours per year in Paid Work) in relation to the total hours of human activity per year (THA = population x 8,760). This gives an idea of demographic and socio-economic characteristics (the dependency, the employed population, the weekly hours of work and holidays). Tables A3 and A4 (see Appendix A) report the most relevant data from the level n-1 for China and India between 1971 and 2010. From tables A3 and A4, it can be seen that in 1971 the energy consumption in the production and households was relatively similar: ET_{PW}=8,097 PJ and ET_{HH}=8,250 PJ, about 50%-50% in China; ET_{PW}=2,962 PJ and ET_{HH}=3,588 PJ, about 45%-55% in India. However, in 2010 energy consumption in production became much higher than in households due to the strong capitalization processes that occurred in both countries: ET_{PW}=83,037 PJ and ET_{HH}=18,163 PJ, about 83%-17% in China; and ET_{PW}=20,930 PJ and ET_{HH}=8,071 PJ, about 72%-28% in India.

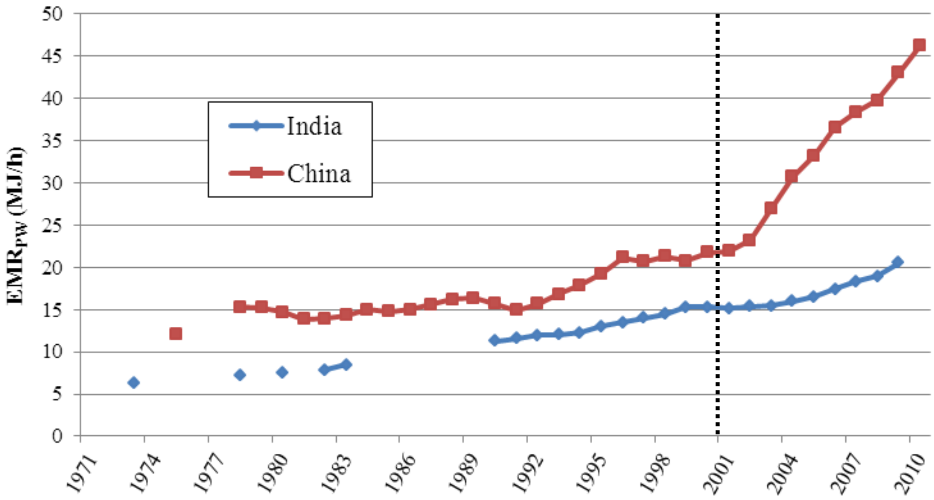
When considering the share of human activity allocated to paid work (HA_{PW}) out of total (THA), we get a much lower value for India (10%) than for China (15%) between 1990 and 2010. It should be noted that fraction of HA_{PW}/THA for China is very high when compared to other countries like Spain with 7.2% in 2006 [45], Bulgaria and Hungary with 7-8%, Poland with 8-9% and 9-10% for Romania between 1995 and 2004 [46], Brazil with 9.3% and 11.3%, Chile with 7.8% and 9.9%, and Venezuela with 7.3% and 9.9% in 1980 and 2000 respectively [47], or Australia with 9-10%, Canada with 8-9.5% and the U.S. around 10% between 1990 and 2008 [48].

The main reason for the high value in China is the low dependency ratio that characterizes the demographic structure of this country. This peculiarity is due to China's one-child policy, which has made the child dependency ratio very low in this country (24.4% in 2010), almost half as much as in India for the same year (46.6%) [49]. However, in the coming years it is expected that due to the aging of China's population the dependency ratio will increase (on the elderly side) reducing the effect of the low child dependency ratio. According to Wolf et al. [49] it is expected that by 2030 China's dependency ratio will overtake that of India.

Following Cleveland et al. [50], Hall et al, [22], and Pastore et al. [51] Giampietro et al. [28] suggest that in the MuSIASEM approach the amount of energy consumed per hour of labor (EMR_{PW}) can be used as a proxy for the level of technical capitalization of the economy, and the amount of energy consumed per hour in households sector (EMR_{HH}) can be used as a proxy for the material standard of living. The first proxy is highly relevant in a context of cheap energy where the capitalization of the industry goes in the direction of investing in machinery to replace manual labor and thus increase the power of work. This results in greater mechanization and automation of production that will generate a direct increase in exosomatic energy consumption per hour of work (EMR_{PW}). In the second case, higher energy consumption in households (EMR_{HH}) is a clear indication that the households are enjoying more energy services (home appliances, mobility with private vehicles, heating and air conditioning, etc.), which make household chores easier, improve mobility and increase the overall comfort at home.

Figure 4 shows the pace of growth of EMR_{PW} of India and China in the period 1973-2010. In a first period (1980-2001) India went from a value of EMR_{PW} of 7.46 MJ/h in 1980 to a value of 15.17 MJ/h in 2001, while China went from a value of EMR_{PW} of 14.72 MJ/h to a value of 21.91 MJ/h, which reflect a similar growth pattern in the two countries. Things dramatically changed after the year 2001 (when China joined the WTO); in the second period (2001-2009) China had an annual growth rate of 8.8% whereas India has been growing at an annual growth rate of 3.9%. As a result, China managed to achieve a higher level of technical capitalization of its Paid Work sector throughout the period and the gap between the two countries increased abruptly after China's conversion into the world's factory.

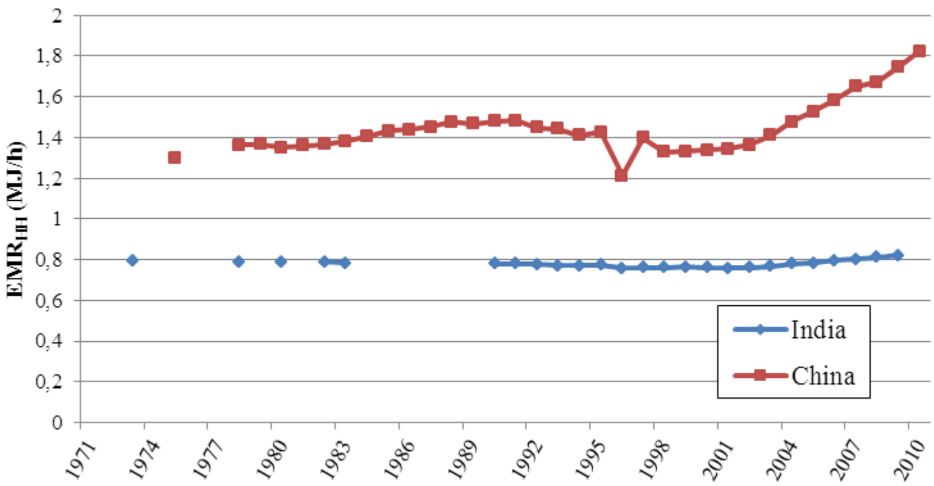
Figure 4. Level of capitalization per worker in China and India between 1973 and 2010, as constructed from data provided in Table A3 and Table A4



We can now study changes on the consumption side of the metabolic pattern, by focusing on the value of EMR_{HH} (Figure 5). When doing this comparison it can be clearly seen that India has been stagnating around 0.8 MJ/h from the beginning of the study period. This means that the duplication of energy consumption in the household sector —measured when using the extensive variable ET_{HH}— was due exclusively to the increase in population, and not to an increase in the material standard of living of the population. Considering the critical importance of energy consumption to cover basic needs [52] and the several dramatic impacts of that —specially on women and children— pointed by Reddy and Nathan [53], the stagnation on low values of EMR_{HH} during the last 40 years should be considered as a serious problem in India. These challenges can be effectively addressed through an appropriate spreading of local renewable energies —independent from centralized power systems needed for industrial development— capable of providing basic services, putting as a priority the poorest households and with an empowerment approach (see for example the suggestion of Reddy and Nathan [53] to integrate SHG networks in the energy strategy of India). Nonetheless, these strategies will not be enough to reduce the huge increase of fossil fuel dependency of Indian economy in the short-term, which come from the massive mechanization of all economic sectors as will be apparent below. When coming to the characteristics of metabolic pattern of the household sector, China shows an upward progression in the values of EMR_{HH} that are higher than those for

India. They started around 1.4 MJ/h between 1978 and 2003, and soared to 1.8 MJ/h in 2010. The different CAGR of EMR_{HH} values are quite different: (i) between 1980 and 1990 it grew at 0.82% per year for China and 0.07% for India; (ii) between 2001 and 2009 the rate was 2.9% for China and 0.8% for India. It should be stressed that between 1998 and 2001 the EMR_{HH} of China was stagnant (figure 5) in spite of the robust increase in the values of EMR_{PW} (figure 4). The difference in the pace of growth of the two EMR shows clearly how China sacrificed household consumption to achieve a greater capitalization of paid work sector (EMR_{PW}) designed to enhance their international competitiveness in the light of its entry into the WTO in 2001.

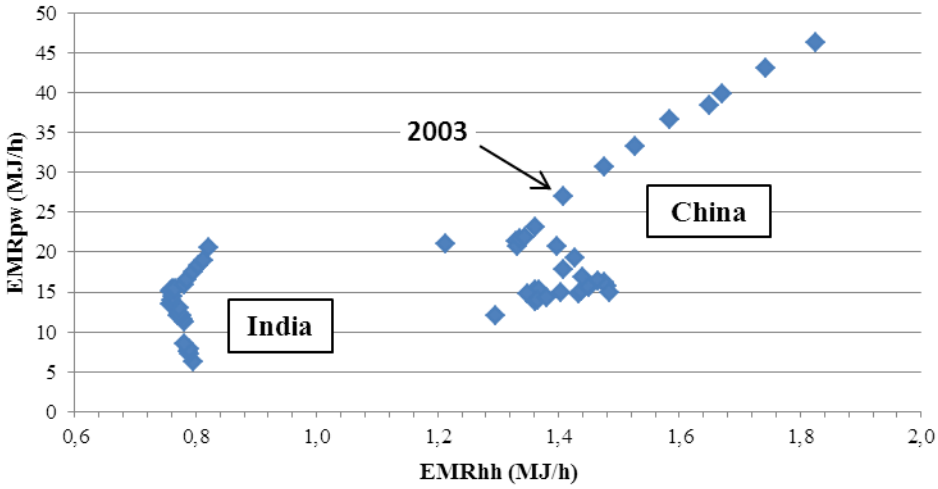
Figure 5. Capitalization of the household sector in China and India between 1971 and 2010, as constructed from data provided in Table A3 and Table A4.



The combination of two intensive variables for both countries is shown in Figure 6. This graph clearly shows progression and scale differences between China and India. Specifically, the EMR_{HH} for India remained stagnant whereas in the case of China the EMR_{HH} as well as the EMR_{PW} soared in the last decade. An assessment of the material standard of living based on the proxy variable EMR_{HH} —the value of India is 0.8 MJ/h and the value of China is between 1.3 and 1.8 MJ/h in the period 1980-2009— can be compared with the corresponding value of other countries: Brazil 1.46-1.41 MJ/h; Chile 1.54-2.64 MJ/h; Venezuela 2.36-2.07 MJ/h in 1980 and 2000 [47]; Spain 1.67-3.27 MJ/h in 1976 and 1996 [45]; Australia 5.56-6.77 MJ/h, Canada 9.00-8.84 MJ/h and USA 9.47-10.2 MJ/h in 1990 and 2008 [48]. From this comparison, we can see that the value of EMR_{HH} is particularly low for India, but also for China: we are dealing with values low also for the standards of developing countries. This suggests that if in China and India industrialization levels will continue to rise with further economic growth (EMR_{PW}), the material living standards will have to raise as well —increasing the value of EMR_{HH}— toward the benchmarks typical of the so-called developed countries, a combination of change that will further increase the total energy consumption (TET). Otherwise, an increase in social unrest is expected in these countries, resulting from a growing inequalities and socio-environmental injustices[2]. Notwithstanding, the increase of TET will also entail an increase of social unrest, but this time, in the commodity frontiers[3].

[2] https://chinastrikes.crowdmap.com/ [accessed 17.07.13].
[3] http://www.utne.com/environment/environmental-activists-zm0z13jfzwil.aspx#axzz2WCmuAkrk, http://www.guardian.co.uk/environment/2012/jun/19/environment-activist-deaths [accessed 17.07.13].

Figure 6. EMR_{PW} vs. EMR_{HH} of China and India between 1973 y 2010, as constructed from data provided in Table A3 and Table A4.



The relationship between the energy consumption per hour of work (EMR_{PW}) and the economic labor productivity (ELP_{PW}) has been found in several studies of biophysical economics for countries like Spain [45], Ecuador [54] or Australia [48]. This correlation is also given in the case of China and India as seen in figures 7 and 8. This relationship is logical if it is assumed that higher energy consumption per hour of work indicates greater capitalization of production, implying larger costs that will not be covered unless this change allows for greater economic labor productivity (ELP_{PW}). However, at level n-2 it will be seen that there are certain productive sectors more sensitive to this relationship than others.

Figures 7a and 8a show the evolution of EMR_{PW} and ELP_{PW} between 1973 and 2009 for both countries. It can be seen that China has higher labor productivity (ELP_{PW}) and has grown significantly since 1990, but especially after 2003 (after settling into the WTO) this value has skyrocketed. For India the growth is lower, but still at a considerable rhythm.

Figure 7a. Evolution of EMR_{PW} and ELP_{PW} of China between 1975 and 2009, as constructed from data provided in Table A3.

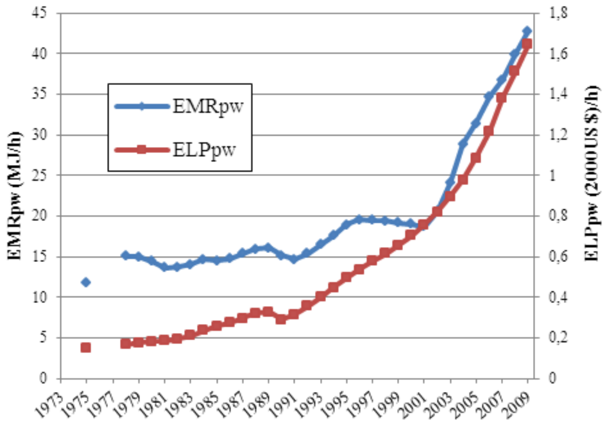


Figure 7b. EMR_{PW} vs. ELP_{PW} of China between 1975 and 2009, as constructed from data provided in Table A3.

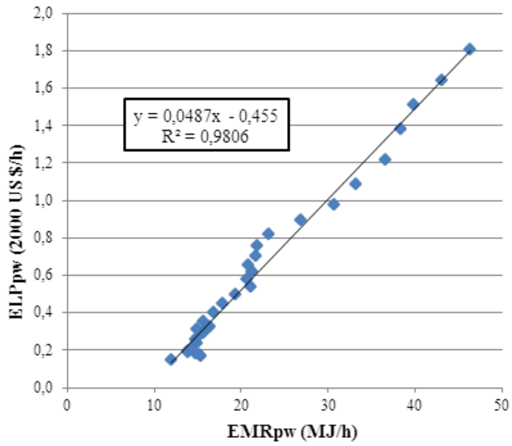


Figure 8a. Evolution of EMR_{PW} and ELP_{PW} of India between 1973 and 2009, as constructed from data provided in Table A4.

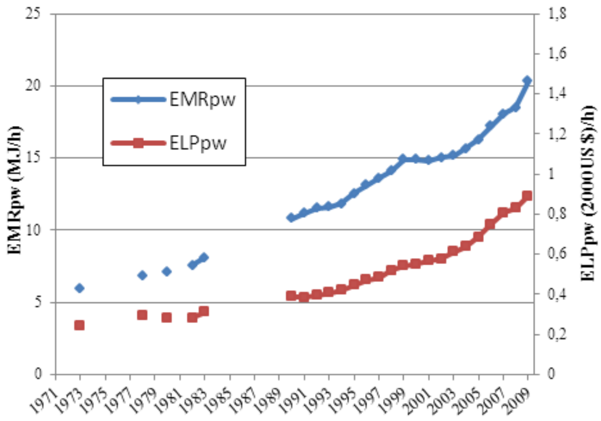
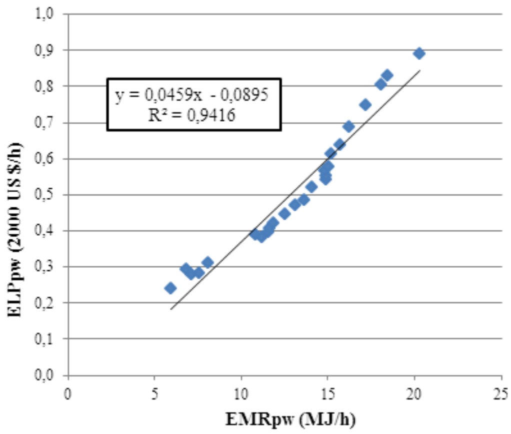


Figure 8b. Evolution of EMR_{PW} and ELP_{PW} of India between 1973 and 2009, as constructed from data provided in Table A4.



3.3 At the sector level (level n-2)

Once having seen that energy consumption and economic growth of a country do not necessarily lead to improvements in material standards of living for the population (it depends on where the surplus generated in this way is invested: either in more capitalization or in more final consumption), it is necessary to understand what happens within the productive sector (PW sector). In fact, macro-level changes (at the level n) are generated by changes in the internal components of the economy: (i) qualitative changes in the relevant characteristics of the various sectors (ELP_i and EMR_i); and (ii) quantitative changes in the size of the various sectors (the profile of distribution of HA_i and ET_i). This is done by analyzing changes in the metabolic pattern at the level n-2 which characterizes the productive sectors of the economy.
Tables A5 and A6 (see Appendix A) list the most relevant data —referring to the level n-2— for the economic sectors of China and India, between 1971 and 2010. In the case of India, only employment data by sector for the years 1994, 2000 and 2005 could be obtained. Therefore, it was not possible to build a full representation based on all the extensive variables such as HA_{AG}, HA_{PS} and HA_{SG}; nor intensive ones arising from these: EMR_{AG}, EMR_{PS}, EMR_{SG}, ELP_{AG}, ELP_{PS} and ELP_{SG}.

Figure 9a shows the evolution of the energy metabolism rate of productive sectors of China between 1975 and 2009. The industrial sector is undoubtedly the sector with the large rate of energy consumption per hour of labor (EMR_{PS}). This is due to the increasing use of machinery and the growth of infrastructures. The EMR_{PS} of China shows more or less stable behavior between 60 and 80 MJ/h between 1975 and 1999. Nevertheless, from 2000 the EMR_{PS} shoots up at a high rate and leads this indicator up to 147.7 MJ/h in 2010. Once again, it is China's entry into the WTO in 2001 which explains this sudden change. This moment of change also coincided with a growth of EMR_{AG}, which goes from 0.9 MJ/h in 2000 to 2.04 MJ/h in 2010 reflecting an increase in the use of inputs in the agriculture during this period (see table A5). This is moving huge amounts of workers from farming to go to the cities to work in industry [11]. Furthermore, the service sector shows a similar trend: rising from an EMR_{SG} of 7 MJ/h in 2000 to 9.42 MJ/h in 2010 (see table A5), indicating an increased use of motorized vehicles in transport and more computerization of administrative tasks.

Figure 9a. Evolution of EMR_{AG}, EMR_{PS} & EMR_{SG} of China between 1975 and 2010, as constructed from data provided in Table A5.

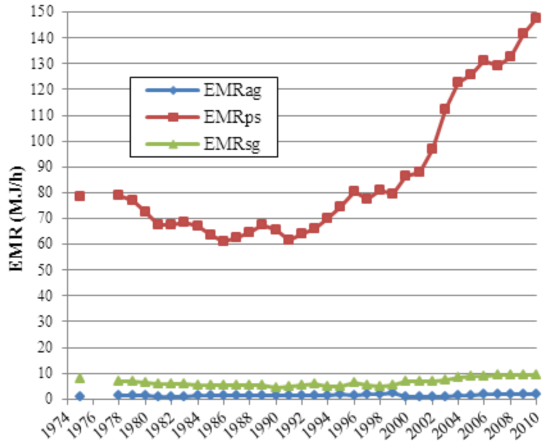
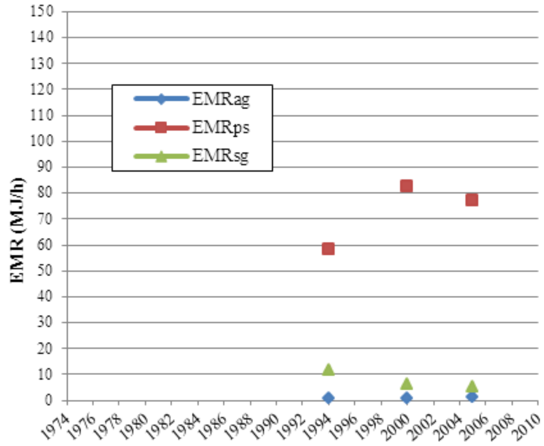


Figure 9b. Evolution of EMR_{AG}, EMR_{PS} & EMR_{SG} of India for years 1994, 2000 & 2005, as constructed from data provided in Table A6.



In the case of India very little EMR_i data is available due to the lack of information on the number of workers employed in each sector of the economy. However, energy consumption per hour follows the same hierarchy than in China: EMR_{PS}> EMR_{SG}> EMR_{AG} (figure 9b). Moreover, India's industrial sector shows a rise in the EMR_{PS} since 1994 that seems stuck around 80 MJ/h between 2000 and 2005. These values are similar to those of China before the year 2000 —the EMR_{PS} of India is 82.66 MJ/h while it is 86.28 for China. Nonetheless, the decline of Indian EMR_{PS} to 76.95 MJ/h in 2005 and the evolution of its GDP and other indicators suggest that since then India's industrial sector has not had the same pattern of strong capitalization of China. As seen in the level n-1, the increase in energy consumption in India has not been enough to increase levels of technical capitalization (technical capital per worker, or EMR_i) in industry or in households. It has only been able to offset the increase in population.

Figures 10a and 10b show how the economic labor productivity of the agricultural sector (ELP_{AG}) was more or less the same in China than in India in 1994 (0.18 $/h), but in 2005 China's value was 26% higher (0.29 $/h versus 0.23 $/h). Likewise, economic labor productivity of the industrial sector (ELP_{PS}) is much higher in China than in India: in 1994 it was 55% higher, 0.81 $/h versus 0.53 $/h; whereas it was 74% higher in 2000, 1.26 $/h compared to 0.72 $/h; and finally it was 165% higher in 2005: 1.92 $/h versus 0.73 $/h. This growing differential largely explains why China's GDP is greater than the Indian one. Finally, the economic labor productivity of the service sector was higher in India than in China —up 49% in 1994: 1.49 $/h vs. 0.75 $/h—, a fact that can be explained by the increase in service outsourcing, software companies and R&D in India (taking advantage of the more diffuse use of the English language). However, in recent years China has invested significantly in these areas and is reducing this difference: in 2005 Indian ELP_{SG} was only 4% above that of China: 1.65 $/h compared to 1.58 $/h. In 2010 the ELP_{SG} of China increased to 2.55 $/h which is likely to be greater than in India.

Figure 10a. Evolution of ELP_{AG}, ELP_{PS} and ELP_{SG} of China between 1975 and 2010, as constructed from data provided in Table A5.

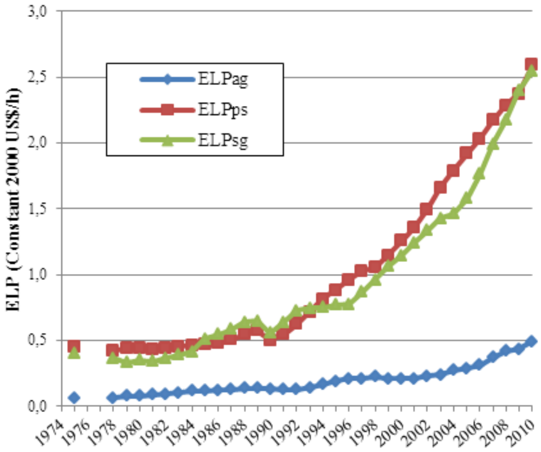
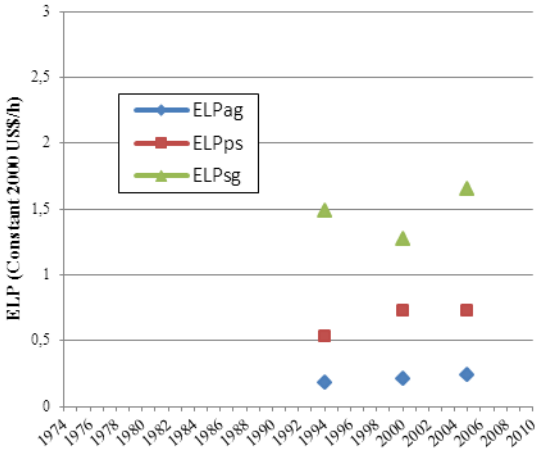


Figure 10b. Evolution of ELP_{AG}, ELP_{PS} & ELP_{SG} of India for years 1994, 2000 & 2005, as constructed from data provided in Table A6.



As illustrated in Figure 10a when considering China the values of ELP_{SG} and the ELP_{PS} are almost similar and following the same trend. This, fact shows clearly the labor intensive nature of the industrial sector of the Chinese economy that get a comparative advantage on the international market, thanks to the possibility of using cheap labor. The situation is even worse for the PS sector in India where, as explained before, the SG sector does better than the PS sector in terms of added value generated per hours of labor. Having seen this last level of analysis, one can say that the fact the ET_{PW} has grown much more in China than in India stems from both the larger weight of GDP_{PS} in the Chinese economy (where $EMR_{PS} > EMR_{SG} > EMR_{AG}$) with a EMR_{PS} continuously increasing, meaning that the difference between Chinese and Indian EMR_{PS} is still rising.

4. Conclusions

There are several conclusions which can be drawn from this comparison of the changes of the energetic metabolic pattern of China and India. Firstly, the large differences in levels of development between China and India are due to the greater size, capitalization level and growth of China's industrial sector, especially since its entry into the WTO in 2001. In this regard, China has capitalized all sectors to a greater extent, boosting economic labor productivity and GDP, but also its total energy consumption. Therefore, in this phase of industrialization China has at the moment an advantaged position over India, with a more developed infrastructure and a larger level of technical capitalization of economic sectors determining a higher economic labor productivity. However, these achievements have been only possible thanks to an increased dependency on fossil energy. This increased dependency has taken place at the very some moment in which it is becoming clear that a cheap supply of imported energy is no longer an option. All these questions introduce uncertainty about the future metabolic pattern of China and India, but also elsewhere due to their huge weight in the world economy.

At the same time, both China and India have still low levels of household energy consumption and an excessive importance of the agricultural sector —both in terms of workers and the relative sectorial share of GDP— compared to other developed countries. This situation suggests that both India and China will continue to require strong injections of technical capitalization and will have to increase their total energy consumption in order to absorb surplus labor from rural areas, remain competitive internationally with their economies, increase domestic consumption, and boost their internal production of food for their food security. Failure to meet any of these points, especially the last two: a quick increase in household energy consumption —providing a badly needed increase in the energy services of the poorest fraction of the population— and the possibility of guarantee cheap food to the poor may trigger social unrest, given that inequalities and socioeconomic injustices are already serious in these countries.

From this analysis some peculiarities of these countries can also be noted. For example, China shows a very high fraction of human activity allocated to paid work which makes its economy very competitive at the moment. This positive peculiarity is largely due to its demographic structure: a low dependency ratio because of the past one-child policy. However, this plus of the Chinese economy can become a major liability in the future with a sudden aging of the population, that is composed now of a vast majority of adults. A second peculiarity is represented by the fact that even though the economic energy intensity is decreasing significantly for both countries, the effect the strong pace of growth moving-up the value of the metabolic characteristics of their various sectors toward the benchmarks typical of developed countries (EMR_{PW} and EMR_{HH}) implies that such a decrease has no appreciable effect on the total energy consumption (TET) of the economy of both countries.

Considering the size of these two giants-countries and when considering the trends of change in the energetic metabolic pattern of China and India we can only conclude that it is extremely important to pay more attention to the biophysical roots of the economic process and to the existing link between the availability of resources and the ability of the economic process to guarantee an adequate production and consumption of goods and services for a changing population.

Acknowledgements
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Appendix A

Table A1. Main indicators of China at level n from 1971 to 2010.

China Level n

Year	TET (PJ)	THA (h)	GDP (Billions of Constant 2000 US$)	EMR_{SA} (MJ/h)	EEI (MJ/Constant 2000US $)	MJ per capita	GDP per capita (Constant 2000 US$)
1971	16,348	7.47E+12	107	2.19	152.7	19,181	126
1972	17,184	7.64E+12	111	2.25	154.6	19,711	127
1973	17,817	7.81E+12	120	2.28	148.6	19,972	134
1974	18,276	7.96E+12	123	2.30	149.0	20,114	135
1975	20,168	8.10E+12	133	2.49	151.2	21,822	144
1976	20,845	8.21E+12	131	2.54	158.9	22,243	140
1977	22,692	8.32E+12	141	2.73	160.7	23,893	149
1978	24,721	8.43E+12	158	2.93	156.7	25,682	164
1979	25,131	8.54E+12	170	2.94	148.1	25,765	174
1980	25,051	8.65E+12	183	2.90	136.9	25,380	185
1981	24,864	8.77E+12	192	2.84	129.2	24,846	192
1982	25,639	8.90E+12	210	2.88	122.1	25,222	207
1983	26,660	9.02E+12	233	2.95	114.5	25,881	226
1984	28,275	9.14E+12	268	3.09	105.4	27,095	257
1985	28,990	9.27E+12	304	3.13	95.2	27,387	288
1986	29,998	9.42E+12	331	3.19	90.6	27,903	308
1987	31,533	9.57E+12	370	3.29	85.3	28,850	338
1988	33,260	9.73E+12	411	3.42	80.8	29,957	371
1989	33,947	9.87E+12	428	3.44	79.3	30,120	380
1990	36,514	1.00E+13	445	3.65	82.1	31,936	389
1991	35,850	1.01E+13	486	3.53	73.8	30,952	419
1992	37,054	1.03E+13	554	3.61	66.8	31,624	473
1993	39,201	1.04E+13	632	3.78	62.0	33,076	533
1994	40,988	1.05E+13	715	3.90	57.3	34,200	596
1995	43,802	1.06E+13	793	4.13	55.3	36,164	655
1996	45,368	1.07E+13	872	4.23	52.0	37,069	713
1997	46,911	1.08E+13	953	4.33	49.2	37,946	771
1998	47,803	1.09E+13	1028	4.37	46.5	38,315	824
1999	47,414	1.10E+13	1106	4.30	42.9	37,694	879
2000	49,517	1.11E+13	1198	4.46	41.3	39,069	946
2001	50,330	1.12E+13	1298	4.50	38.8	39,435	1,017
2002	53,008	1.13E+13	1416	4.71	37.4	41,267	1,102
2003	60,303	1.13E+13	1558	5.33	38.7	46,664	1,205
2004	67,956	1.14E+13	1715	5.97	39.6	52,279	1,319
2005	73,276	1.15E+13	1909	6.40	38.4	56,041	1,460
2006	80,053	1.15E+13	2151	6.95	37.2	60,901	1,637
2007	84,357	1.16E+13	2457	7.29	34.3	63,844	1,859
2008	87,341	1.16E+13	2693	7.51	32.4	65,768	2,027
2009	94,175	1.17E+13	2940	8.06	32.0	70,569	2,203
2010	101,200	1.17E+13	3246	8.62	31.2	75,471	2,421

Sources: IEA (2010) [32], NBSC (2011) [33] & World Bank (2012) [41].

Table A2. Main indicators of India at level n from 1971 to 2010.

India Level n

Year	TET (PJ)	THA (h)	GDP (Billions of Constant 2000 US$)	EMR_{SA} (MJ/h)	EEI (MJ/Constant 2000US $)	MJ per capita	GDP per capita (Constant 2000 US$)
1971	6,551	4.96E+12	119		55.0	11,561	210
1972	6,704	5.08E+12	118		56.6	11,562	204
1973	6,886	5.20E+12	122	1.32	56.3	11,602	206
1974	7,175	5.32E+12	124		57.9	11,809	204
1975	7,441	5.45E+12	135		55.1	11,962	217
1976	7,748	5.58E+12	137		56.4	12,164	216
1977	7,964	5.71E+12	147		54.0	12,209	226
1978	7,995	5.85E+12	156	1.37	51.3	11,970	233
1979	8,370	5.99E+12	148		56.7	12,240	216
1980	8,589	6.13E+12	158	1.40	54.5	12,270	225
1981	9,044	6.28E+12	167		54.1	12,623	233
1982	9,405	6.42E+12	173	1.46	54.4	12,829	236
1983	9,718	6.57E+12	185	1.48	52.4	12,956	247
1984	10,141	6.72E+12	193	1.51	52.7	13,219	251
1985	10,668	6.87E+12	203	1.55	52.7	13,598	258
1986	11,066	7.03E+12	212	1.58	52.1	13,797	265
1987	11,497	7.18E+12	221	1.60	52.1	14,025	269
1988	12,117	7.34E+12	242	1.65	50.1	14,465	289
1989	12,708	7.50E+12	256	1.70	49.6	14,851	300
1990	13,261	7.65E+12	270	1.73	49.0	15,177	310
1991	13,795	7.81E+12	273	1.77	50.5	15,467	307
1992	14,345	7.97E+12	288	1.80	49.7	15,763	317
1993	14,673	8.13E+12	302	1.80	48.6	15,808	325
1994	15,242	8.29E+12	322	1.84	47.3	16,106	340
1995	16,089	8.45E+12	347	1.90	46.4	16,682	359
1996	16,608	8.61E+12	373	1.93	44.6	16,903	379
1997	17,258	8.76E+12	388	1.97	44.5	17,249	388
1998	17,679	8.92E+12	412	1.98	42.9	17,358	404
1999	18,771	9.08E+12	442	2.07	42.4	18,114	427
2000	19,143	9.23E+12	460	2.07	41.6	18,164	437
2001	19,448	9.39E+12	484	2.07	40.2	18,152	452
2002	19,992	9.54E+12	502	2.10	39.8	18,363	462
2003	20,494	9.69E+12	544	2.12	37.6	18,532	492
2004	21,733	9.84E+12	590	2.21	36.9	19,353	525
2005	22,578	9.99E+12	644	2.26	35.0	19,805	565
2006	23,729	1.01E+13	704	2.34	33.7	20,508	609
2007	25,071	1.03E+13	773	2.44	32.4	21,355	659
2008	26,213	1.04E+13	812	2.51	32.3	22,012	681
2009	28,269	1.06E+13	885	2.67	31.9	23,407	733
2010	29,002	1.07E+13	963	2.70	30.1	23,682	787

Sources: IEA (2010) [32], OECD (2012) [39] & World Bank (2012) [41].

Table A3. Main indicators of China at level n-1 from 1971 to 2010.

China Level n-1								
Year	ET_{PW} (PJ)	ET_{HH} (PJ)	HA_{PW} (h)	HA_{HH} (h)	EMR_{PW} (MJ/h)	EMR_{HH} (MJ/h)	ELP_{PW} (Thousands of Constant 2000 US$/h)	ELP_{PW}/EMR_{PW} (Thousands of Constant 2000 US$/MJ)
1971	8,098	8,250						
1972	8,670	8,514						
1973	9,110	8,707						
1974	9,418	8,857						
1975	10,847	9,321	9.02E+11	7.19E+12	12.02	1.30	0.15	12.3
1976	11,383	9,462						
1977	12,821	9,871						
1978	14,530	10,191	9.49E+11	7.48E+12	15.31	1.36	0.17	10.9
1979	14,772	10,359	9.69E+11	7.58E+12	15.24	1.37	0.18	11.5
1980	14,733	10,318	1.00E+12	7.65E+12	14.72	1.35	0.18	12.4
1981	14,336	10,527	1.03E+12	7.73E+12	13.88	1.36	0.19	13.4
1982	14,932	10,707	1.07E+12	7.84E+12	13.96	1.37	0.20	14.1
1983	15,713	10,947	1.10E+12	7.93E+12	14.33	1.38	0.21	14.8
1984	17,037	11,238	1.14E+12	8.00E+12	14.97	1.40	0.24	15.7
1985	17,391	11,599	1.18E+12	8.10E+12	14.77	1.43	0.26	17.5
1986	18,190	11,808	1.21E+12	8.21E+12	15.03	1.44	0.27	18.2
1987	19,446	12,087	1.25E+12	8.33E+12	15.61	1.45	0.30	19.0
1988	20,792	12,467	1.28E+12	8.44E+12	16.22	1.48	0.32	19.8
1989	21,386	12,560	1.31E+12	8.57E+12	16.38	1.47	0.33	20.0
1990	23,945	12,568	1.53E+12	8.49E+12	15.68	1.48	0.29	18.6
1991	23,084	12,766	1.54E+12	8.60E+12	14.95	1.48	0.31	21.0
1992	24,438	12,615	1.56E+12	8.70E+12	15.67	1.45	0.36	22.7
1993	26,513	12,688	1.58E+12	8.81E+12	16.83	1.44	0.40	23.8
1994	28,435	12,553	1.59E+12	8.91E+12	17.88	1.41	0.45	25.1
1995	30,946	12,855	1.60E+12	9.01E+12	19.28	1.43	0.49	25.6
1996	34,333	11,035	1.63E+12	9.10E+12	21.12	1.21	0.54	25.4
1997	34,076	12,835	1.65E+12	9.18E+12	20.70	1.40	0.58	28.0
1998	35,481	12,321	1.67E+12	9.26E+12	21.31	1.33	0.62	29.0
1999	34,971	12,443	1.68E+12	9.34E+12	20.78	1.33	0.66	31.6
2000	36,942	12,574	1.70E+12	9.40E+12	21.74	1.34	0.71	32.4
2001	37,607	12,723	1.72E+12	9.46E+12	21.91	1.34	0.76	34.5
2002	40,036	12,972	1.73E+12	9.53E+12	23.18	1.36	0.82	35.4
2003	46,799	13,503	1.74E+12	9.58E+12	26.92	1.41	0.90	33.3
2004	53,728	14,228	1.75E+12	9.64E+12	30.69	1.48	0.98	31.9
2005	58,470	14,806	1.76E+12	9.69E+12	33.23	1.53	1.08	32.6
2006	64,619	15,434	1.77E+12	9.75E+12	36.56	1.58	1.22	33.3
2007	68,184	16,173	1.78E+12	9.80E+12	38.40	1.65	1.38	36.0
2008	70,877	16,464	1.78E+12	9.85E+12	39.79	1.67	1.51	38.0
2009	76,910	17,265	1.79E+12	9.90E+12	43.03	1.74	1.65	38.2
2010	83,037	18,163	1.79E+12	9.95E+12	46.29	1.82	1.81	39.1

Sources: IEA (2010) [32], NBSC (2011) [33], ILO (2012) [40] & World Bank (2012) [41].

Table A4. Main indicators of India at level n-1 from 1971 to 2010.

India Level n-1								
Year	ET_{PW} (PJ)	ET_{HH} (PJ)	HA_{PW} (h)	HA_{HH} (h)	EMR_{PW} (MJ/h)	EMR_{HH} (MJ/h)	ELP_{PW} (Constant 2000 US$/h)	ELP_{PW}/EMR_{PW} (Thousands of Constant 2000 US$/MJ)
1971	2,963	3,588						
1972	3,041	3,664						
1973	3,154	3,732	5.06E+11	4.69E+12	6.23	0.80	0.24	38.8
1974	3,373	3,802						
1975	3,538	3,903						
1976	3,741	4,007						
1977	3,853	4,111						
1978	3,789	4,206	5.29E+11	5.32E+12	7.17	0.79	0.29	41.1
1979	4,067	4,304						
1980	4,199	4,390	5.63E+11	5.57E+12	7.46	0.79	0.28	37.5
1981	4,563	4,481						
1982	4,822	4,584	6.13E+11	5.81E+12	7.87	0.79	0.28	35.8
1983	5,046	4,672	5.98E+11	5.97E+12	8.44	0.78	0.31	36.7
1984	5,371	4,769						
1985	5,797	4,870						
1986	6,092	4,974						
1987	6,392	5,105						
1988	6,898	5,219						
1989	7,362	5,346						
1990	7,828	5,433	6.97E+11	6.96E+12	11.24	0.78	0.39	34.6
1991	8,262	5,533	7.12E+11	7.10E+12	11.60	0.78	0.38	33.1
1992	8,715	5,630	7.28E+11	7.24E+12	11.96	0.78	0.40	33.1
1993	8,972	5,701	7.44E+11	7.39E+12	12.06	0.77	0.41	33.7
1994	9,433	5,809	7.68E+11	7.52E+12	12.29	0.77	0.42	34.2
1995	10,156	5,933	7.80E+11	7.67E+12	13.03	0.77	0.44	34.1
1996	10,678	5,930	7.91E+11	7.82E+12	13.49	0.76	0.47	34.9
1997	11,198	6,060	8.00E+11	7.96E+12	13.99	0.76	0.48	34.6
1998	11,480	6,199	7.93E+11	8.13E+12	14.48	0.76	0.52	35.9
1999	12,462	6,309	8.15E+11	8.26E+12	15.30	0.76	0.54	35.5
2000	12,752	6,390	8.32E+11	8.40E+12	15.32	0.76	0.55	36.1
2001	12,978	6,470	8.56E+11	8.53E+12	15.17	0.76	0.57	37.3
2002	13,388	6,604	8.72E+11	8.67E+12	15.36	0.76	0.58	37.5
2003	13,752	6,742	8.89E+11	8.80E+12	15.47	0.77	0.61	39.6
2004	14,775	6,959	9.26E+11	8.91E+12	15.95	0.78	0.64	39.9
2005	15,478	7,101	9.38E+11	9.05E+12	16.50	0.78	0.69	41.6
2006	16,416	7,312	9.41E+11	9.19E+12	17.45	0.80	0.75	42.9
2007	17,575	7,496	9.59E+11	9.32E+12	18.33	0.80	0.81	44.0
2008	18,530	7,683	9.78E+11	9.45E+12	18.96	0.81	0.83	43.8
2009	20,395	7,874	9.93E+11	9.59E+12	20.54	0.82	0.89	43.4
2010	20,930	8,071		1.07E+13				

Sources: IEA (2010) [32], OECD (2012) [39], ILO (2012) [40] & World Bank (2012) [41].

Table A5. Main indicators of China at level n-2 from 1971 to 2010.

China Level n-2															
Year	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (Billions of Constant 2000 US$)	GDP_{AG} (Billions of Constant 2000 US$)	GDP_{AG} (Billions of Constant 2000 US$)	$EMR_{A(}$ (MJ/h)	EMR_{PS} (MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (Constant 2000 US$/h)	ELP_{PS} (Constant 2000 US$/h)	ELP_{SG} (Constant 2000 US$/h)
1971	480	7,109	509				36	41	30						
1972	530	7,589	551				37	43	31						
1973	576	7,943	591				40	47	34						
1974	602	8,181	636				42	48	33						
1975	660	9,490	696	6.92E+11	1.21E+11	8.90E+10	43	55	36	0.95	78.39	7.82	0.06	0.45	0.40
1976	679	9,998	707				43	54	34						
1977	746	11,296	778				42	61	38						
1978	825	12,855	850	6.65E+11	1.63E+11	1.20E+11	44	69	44	1.24	78.76	7.07	0.07	0.43	0.37
1979	848	13,037	887	6.73E+11	1.70E+11	1.27E+11	53	75	42	1.26	76.90	6.98	0.08	0.44	0.33
1980	789	13,096	847	6.84E+11	1.81E+11	1.35E+11	55	80	48	1.15	72.31	6.26	0.08	0.44	0.35
1981	782	12,727	828	7.00E+11	1.88E+11	1.45E+11	62	81	50	1.12	67.67	5.71	0.09	0.43	0.34
1982	801	13,246	885	7.25E+11	1.96E+11	1.48E+11	69	86	55	1.10	67.54	5.96	0.10	0.44	0.37
1983	832	13,929	953	7.32E+11	2.04E+11	1.61E+11	77	93	63	1.14	68.29	5.93	0.10	0.46	0.39
1984	895	15,133	1,010	7.25E+11	2.25E+11	1.87E+11	86	105	78	1.23	67.15	5.39	0.12	0.46	0.42
1985	890	15,459	1,041	7.32E+11	2.44E+11	2.02E+11	85	116	104	1.22	63.35	5.16	0.12	0.47	0.51
1986	944	16,144	1,103	7.34E+11	2.64E+11	2.12E+11	89	126	116	1.28	61.25	5.19	0.12	0.48	0.55
1987	982	17,291	1,173	7.44E+11	2.76E+11	2.26E+11	96	140	133	1.32	62.75	5.19	0.13	0.51	0.59
1988	1,029	18,475	1,288	7.58E+11	2.86E+11	2.39E+11	103	156	152	1.36	64.70	5.39	0.14	0.55	0.64
1989	1,018	19,021	1,347	7.81E+11	2.81E+11	2.43E+11	107	163	158	1.30	67.59	5.54	0.14	0.58	0.65
1990	1,265	21,369	1,311	9.14E+11	3.26E+11	2.87E+11	120	165	160	1.38	65.63	4.57	0.13	0.51	0.56
1991	1,314	20,340	1,430	9.19E+11	3.29E+11	2.96E+11	117	180	189	1.43	61.76	4.83	0.13	0.55	0.64
1992	1,298	21,533	1,607	9.09E+11	3.37E+11	3.13E+11	116	211	227	1.43	63.83	5.13	0.13	0.62	0.73
1993	1,320	23,231	1,962	8.85E+11	3.52E+11	3.38E+11	126	253	253	1.49	66.06	5.80	0.14	0.72	0.75
1994	1,379	25,253	1,803	8.61E+11	3.60E+11	3.70E+11	143	293	279	1.60	70.18	4.87	0.17	0.81	0.75
1995	1,525	27,457	1,964	8.35E+11	3.68E+11	4.02E+11	159	325	309	1.83	74.63	4.89	0.19	0.88	0.77
1996	1,020	30,601	2,712	8.18E+11	3.81E+11	4.27E+11	174	366	331	1.25	80.37	6.36	0.21	0.96	0.78
1997	1,594	30,156	2,325	8.19E+11	3.89E+11	4.39E+11	172	400	381	1.95	77.55	5.30	0.21	1.03	0.87
1998	1,722	31,517	2,242	8.27E+11	3.90E+11	4.49E+11	185	411	432	2.08	80.79	5.00	0.22	1.05	0.96
1999	1,824	30,610	2,538	8.41E+11	3.86E+11	4.57E+11	177	442	486	2.17	79.32	5.56	0.21	1.15	1.07
2000	761	32,884	3,297	8.47E+11	3.81E+11	4.71E+11	180	479	539	0.90	86.28	7.00	0.21	1.26	1.14
2001	792	33,471	3,344	8.55E+11	3.81E+11	4.79E+11	182	519	597	0.93	87.74	6.98	0.21	1.36	1.25
2002	847	35,732	3,457	8.61E+11	3.69E+11	4.98E+11	198	552	666	0.98	96.96	6.94	0.23	1.50	1.34
2003	965	42,050	3,785	8.51E+11	3.74E+11	5.13E+11	202	623	732	1.13	112.35	7.38	0.24	1.66	1.43
2004	1,137	48,098	4,493	8.19E+11	3.93E+11	5.39E+11	223	703	789	1.39	122.49	8.33	0.27	1.79	1.46
2005	1,252	52,427	4,791	7.86E+11	4.18E+11	5.56E+11	229	802	878	1.59	125.57	8.61	0.29	1.92	1.58
2006	1,305	58,132	5,182	7.51E+11	4.44E+11	5.73E+11	237	904	1011	1.74	130.92	9.05	0.32	2.03	1.77
2007	1,269	61,374	5,540	7.22E+11	4.74E+11	5.79E+11	270	1032	1155	1.76	129.38	9.57	0.37	2.18	1.99
2008	1,216	64,047	5,614	7.03E+11	4.83E+11	5.95E+11	296	1104	1292	1.73	132.60	9.44	0.42	2.29	2.17
2009	1,265	70,061	5,584	6.79E+11	4.95E+11	6.13E+11	294	1176	1470	1.86	141.43	9.11	0.43	2.37	2.40
2010	1,341	75,816	5,880	6.56E+11	5.13E+11	6.24E+11	325	1331	1591	2.04	147.71	9.42	0.49	2.59	2.55

Sources: IEA (2010) [32], NBSC (2011) [33], ILO (2012) [40], World Bank (2012) [41] & UN (2011) [43].

Table A6. Main indicators of India at level n-2 from 1971 to 2010.

India Level n-2															
ar	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (Billions of Constant 2000 US$)	GDP_{AG} (Billions of Constant 2000 US$)	GDP_{AG} (Billions of Constant 2000 US$)	$EMR_{A(}$ (MJ/h)	EMR_{PS} (MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (Constant 2000 US$/h)	ELP_{PS} (Constant 2000 US$/h)	ELP_{SG} (Constant 2000 US$/h)
71	58	2,273	632				50	20	49						
72	65	2,351	624				50	20	49						
73	72	2,460	622				55	20	48						
74	70	2,653	650				52	22	50						
75	65	2,801	672				53	24	58						
76	71	2,991	679				51	26	60						
77	77	3,079	697				56	27	65						
78	90	2,994	706				58	31	67						
79	92	3,206	769				52	31	65						
80	110	3,336	754				58	32	68						
81	123	3,649	791				58	35	73						
82	109	3,915	797				59	36	78						
83	111	4,097	838				65	39	82						
84	123	4,348	900				64	40	89						
85	133	4,773	891				65	45	93						
86	148	5,070	875				66	47	100						
87	173	5,310	909				66	46	108						
88	185	5,728	985				75	53	114						
89	209	6,139	1,014				77	56	123						
90	233	6,522	1,073				81	60	130						
91	269	6,858	1,135				82	57	134						
92	286	7,267	1,162				87	61	141						
93	325	7,480	1,168				88	63	151						
94	381	7,824	1,229	5.27E+11	1.34E+11	1.06E+11	93	71	158	0.72	58.17	11.56	0.18	0.53	1.49
95	388	8,439	1,329				94	80	173						
96	436	9,094	1,148				104	86	183						
97	480	9,528	1,190				101	85	202						
98	506	9,832	1,143				107	87	218						
99	517	10,731	1,214				111	88	243						
00	481	11,039	1,232	4.96E+11	1.34E+11	2.03E+11	106	97	258	0.97	82.66	6.07	0.21	0.72	1.27
01	467	11,290	1,222				111	97	276						
02	486	11,647	1,255				106	106	291						
03	560	11,936	1,257				114	109	321						
04	568	12,944	1,263				112	118	360						
05	561	13,674	1,243	5.22E+11	1.78E+11	2.39E+11	122	129	393	1.08	76.95	5.21	0.23	0.73	1.65
06	613	14,470	1,334				127	148	430						
07	647	15,487	1,440				139	162	472						
08	666	16,294	1,571				138	162	511						
09	564	18,122	1,709				159	168	558						
10	593	18,512	1,825				183	173	607						

Sources: IEA (2010) [32], OECD (2012) [39], ILO (2012) [40], World Bank (2012) [41], UN (2011) [43] & Planning Commission (2012) [42].