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ANALYSIS

On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM)

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ABSTRACT

The methodology of multi-scale integrated analysis of societal metabolism (MSIASM) is applied to the analysis of the recent evolution of Chinese economy. This paper has two goals: (1) to show the MSIASM scheme is effective in handling in an integrated way different types of data, mixing extensive and intensive variables, on different levels; and (2) to provide a multi-scale integrated analysis of the trajectory of development of China. The quality of possible scenarios is checked by identifying constraints affecting their feasibility and by characterizing them in relation to different dimensions and scales of analysis.

This entails 4 tasks: (i) identifying a set of benchmarks that makes it possible to compare different characteristics and features of China to other countries and to the average values calculated for the world level; (ii) explaining the differences found over the selected set of benchmarks, by looking at the characteristics of the various sub-sectors of Chinese economy; (iii) understanding existing trends and future feasible paths of China's development by studying the existence of reciprocal constraints between the whole economy and its compartments; and (iv) examining possible future scenarios of development for China.

1. Introduction

China has achieved rapid structural changes since Deng Xiao Ping launched economic reforms in 1978. These changes can be characterized as a transition from a centrally planned economy toward a market based economy, which entails another transition from an agricultural society toward an urban industrial society. During the period of 1978–1996, real GDP grew on average by over 9% per year, contributing to a near quadrupling of the per capita income (Taejoon, 2006). Chinese leaders are determined to get another quadrupling in GDP size by 2020 (Aldhous, 2005). However, to accomplish such a goal China could face formidable problems in relation to energy, mineral resources, environment, and wealth disparity.

In relation to energy, looking at the recent history one can note that despite the huge energy demand for China's economic development, China had maintained itself as one of the largest oil exporter in Asia until early 1980s, due to China's consistent policy of promoting petroleum exports as a foreign exchange earner (Ebel, 2005). However, energy security has become an increasingly important concern for Chinese government since the mid-1990s as domestic energy production has failed to keep

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pace with demand. A rapid growth in the use of road transport has driven a considerable increase in demand for oil consumption. China became a net importer of oil in 1995 and in less than 10 years has become the second largest oil importer in the world after the United States (Andrews-Speed et al., 2002; Jian, 2005). Even though China imports only 12% of the energy it consumes, compared with 40% for the United States and 80% for Japan (Zweig and Fianbai, 2005), due to its size Chinese market is a crucial element responsible for 40% of the global increase in oil demand since 2000 (Jian, 2005). Under these circumstances, China is planning an increase in its use of natural gas and nuclear power to limit the air-quality consequences and to meet demand for electricity (Ebel, 2005). By 2020, according to official projections, gas-fired stations could meet 15% of China's electricity needs, while nuclear power may have expanded to around 5% (Aldhous, 2005). However, since power supply must be doubled over the same period, it will be absolutely necessary to secure also a sufficient supply of oil together with a massive reliance on coal consumption.

In relation to mineral resources, as Georgescu-Roegen consistently emphasized, they are essential to maintain a high level of modern economic activity (Georgescu-Roegen, 1977). Therefore, a secured supply of mineral resources is also indispensable for China's continuous economic development. China's total share of the world's consumption of aluminum, copper, nickel, and iron ore more than doubled within only ten years, from 7% in 1990 to 25% in 2000 (Zweig and Fianbai, 2005). To secure mineral resources as well as energy resources China tried to solidify its relationship with resources rich countries, in particular developing countries. For example, China has recently won access to key resources, gold in Bolivia, coal in the Philippines, oil in Ecuador, natural gas in Australia, and tar sands in Canada. It is also surprising to see that about 40% of China's outgoing foreign direct investment went to Latin America in 2004 (Zweig and Fianbai, 2005). Latin America used to be regarded as being in United States' traditional sphere of influence, so that this move could generate tension between the United States and China in a foreseeable future.

In relation to the environment, there is a serious concern linked to global warming, which is due to massive use of coal. In fact, between 75% and 80% of China's electricity is still generated by burning coal (Aldhous, 2005). The effects of acid rain are also spreading, and there are suggestions that soot is already disrupting the regional climate (Aldhous, 2005). Due to acid rain spreading linked to the increasing demand for water in China, 90% of the rivers are polluted and two-thirds of the cities are short of fresh water. Concerning the skyrocketing CO2 emissions of China, it is easy to "guesstimate" that CO2 emission of China would surpass that of the United States by the year 2020 (Mayumi, 2006 based on the similar research conducted by Li, 2003).

In relation to wealth disparity, there is the increasing tension between the rich south-east coastal areas, and the poor north east areas in the interior. If it is true that the share of poverty-stricken population has decreased from over 90% in 1980 to less than 10% in 1996, it is also true that both rural and urban incomes in China are pretty low when compared to international standards. The rural incomes in China are only 40% of urban incomes when in most countries rural incomes are 66% of urban income in 1995 (Taejoon, 2006). The income disparity is also reflected by a disparity in energy consumption. According to Smil (2003), China's per capita fossil fuel consumption was 30 GJ/capita in 2000. However, the rich in Shanghai consumed on average nearly 90 GJ/capita. On the other hand, the poor in Anhui province, Shanghai's northern neighbor consumed only about 20 GJ/capita (Smil, 2003). The growing imbalance between the rich and the poor might shake the national unity of China in the near future.

In conclusion, China will be a key actor in relation to global issues of sustainability in terms of energy, mineral resources, and environment. Obviously, the problems that China will face are so complex that it is very difficult to conduct a comprehensive theoretical and empirical analysis of them. However, in our view, the issue of sustainability of China's development is a perfect subject of analysis for Ecological Economics.

Within this large topic this paper has two goals: (1) to show the MSIASM scheme is effective in handling in an integrated way different types of data (belonging to different categories such as variables, parameters, constraints) using extensive and intensive variables, across different hierarchical levels; and (2) to provide a multi-scale integrated analysis of the trajectory of development of China. This includes the identification of possible constraints affecting the feasibility of considered scenarios and a characterization of future scenarios in relation to different dimensions and scales of analysis.

The rest of the paper is structured as follows. Section 2 presents a brief introduction of our scheme in terms of the rationale, formulation and representation of MSIASM. Section 3 presents the results of our analysis, both on the interface world level/China level, and on the interface national level/sector level of the Chinese economy. Section 4 discusses again the interface world level/national level, by considering possible future scenarios of development for China and the relative effect that the resulting characteristics of metabolism of China could have on world energy and material demand. Section 5 draws some conclusions.

2. Multi-scale integrated analysis of societal metabolism (MSIASM)

2.1. *The metabolism of human society and the biophysical analysis*

The "metabolism of human society" is a notion used to characterize the processes of energy and material transformation in a society that are necessary for its continued existence. This notion became a scientific subject starting the mid-19th century because of the work of authors such as Liebig, Boussingault, Moleschott, Jevons, Podolinski, Arrhenius, Ostwald, Lotka, White, and Cottrel (for an overview, see Martinez-Alier, 1987). However, it was in the 1970s that energy and material metabolism of human society became a fashionable scientific exercise triggered by the oil crisis having surged in that period. Starting 1970s, energy and material metabolism of human society was widely applied to farming systems, economic systems, and more in general to describe the interaction of socioeconomic systems with their environment (e.g., Georgescu-Roegen, 1971; Odum, 1971, 1983; Rappaport, 1971; Leach, 1976; Gilliland, 1978; Slesser, 1978; Pimentel and Pimentel, 1979; Morowitz, 1979; Costanza 1980; Herendeen, 1981; Hall et al., 1986; Smil, 1987; Ayres and Simonis, 1994; Fischer-Kowalski, 1998).

2.2. Rationale behind MSIASM scheme

The methodology to be presented here is called multi-scale integrated analysis of societal metabolism (MSIASM). It was introduced by Giampietro and Mayumi (1997, 2000a,b) and more systematically investigated by Giampietro (2003). Empirical analyses based on this approach have been conducted on several countries such as Ecuador (Falconi-Benitez, 2001), Spain (Ramos-Martin, 2001), Vietnam (Ramos-Martin and Giampietro, 2005), and Brazil, Chile, Venezuela, Philippines, Thailand and Vietnam (Eisenmenger et al., in press).

The rationale behind the MSIASM scheme can be summarized in the following three points: (i) energetic and material flows can be analyzed using the concept of endosomatic and exosomatic metabolism in relation to Georgescu-Roegen's flow–fund scheme; (2) the structure of the dynamic budget of the metabolism can be analyzed using the bioeconomic analogy of hypercycle and dissipative parts in ecosystems; (3) economic development entails dramatic changes in the overall size of metabolism, the pace of metabolism and the structural typology of the dynamic budget of energy, this translates into a dramatic reallocation of the profiles of human activity and land uses over the various sectors of a modern economy.

Lotka (1956) introduced the theoretical notion of human society consists of a double metabolism: (i) one related to *endosomatic* organs inside the human body; and (ii) another related to *exosomatic* organs fabricated by humans such as tools and mechanical devices. This idea was further elaborated by Georgescu-Roegen (1971) in his efforts to integrate economic and biophysical processes in view of sustainability. To effectively address the double-metabolism and to indicate the need for an integrated approach to sustainability issues, Georgescu-Roegen introduced the term *Bioeconomics* and the flow–fund scheme. Flow coordinates are elements that enter but do not exit the production process or, conversely elements that exit without having entered the process (e.g., a new product). Flow coordinates include matter and energy *in situ*, controlled matter and energy, and dissipated matter and energy. Fund coordinates (capital, labor, and Ricardian land) are agents that enter and exit the process, transforming input flows into output flows. Fund coordinates can only be used at a specified rate and must be periodically renewed. Georgescu-Roegen's scheme can account for scale and time duration and addresses the question of whether or not a given technology is *viable*. A technology is viable if and only if an economic system it represents can operate steadily as long as environmental flows of available energy and matter are forthcoming in necessary amounts in relation to the set of constraints determined by the characteristics of the fund elements.

Georgescu-Roegen's scheme is based on an explicit acknowledgment of both multi-scale integrated analysis and the existence of biophysical constraints on the process of economic development (Georgescu-Roegen, 1977).

Another crucial idea associated with MSIASM scheme is Zipf's characterization of socioeconomic development as biosocial forms of organization (Zipf, 1941). Zipf proposed a basic principle of socioeconomic development: in order to be able to consume more, a socioeconomic system has to invest more in the consumption sectors both in terms of capital formation and human time. In his analysis of ecosystem structure, Ulanowicz (1986) introduced a similar idea based on Eigen's pioneering work (Eigen, 1971). According to Ulanowicz, the network of matter and energy flows making up an ecosystem can be divided into two parts: one part is a hypercycle and the other is a purely dissipative part. The hypercycle part is a net energy supplier for the rest of the ecosystem. Since dissipation is always "necessary to build and maintain structures at sub-compartment level" (Ulanowicz 1986: 119), the part producing a net supply of energy for the rest must comprise activities that generate a positive feedback by taking advantage of gradient of free energy outside the system (e.g. solar energy). The role of the hypercyclic part is to drive and keep the whole ecosystem away from thermodynamic equilibrium. The dissipative part comprises activities that are net energy degraders. However, this part is not useless for the whole system. The dissipative part provides control mechanism over the entire process of energy transformations, explore innovations (guaranteeing adaptability) and stabilizes the whole system. In fact, an ecosystem made of a hypercyclic part alone cannot be stable over time. Without the stabilizing effect of the dissipative part, a positive feedback "will be reflected upon itself without attenuation, and eventually the upward spiral will exceed any conceivable bounds" (Ulanowicz, 1986: 57). In the analogy with human societies the purely dissipative part of an ecosystems would be the final consumption sector.

One of the theoretical pillars of MSIASM is that the technological development of a society can be described in terms of *an acceleration of energy and material consumption together with the dramatic reallocation of distribution of age classes, human time profile of activities and land use patterns in various sectors of modern economy, resulting in time and land saving in the energy and agricultural sectors* (Mayumi, 1991). Within MSIASM scheme qualitative differences in energy forms are not addressed using thermodynamic concepts such as exergy or enthalpy. Rather, the time dimension of energy transformation in energy sector and its relation to other economic sectors is used to focus on crucial qualitative factors which the traditional biophysical and thermodynamic analysis has not dealt with sufficient attention. MSIASM is an attempt to incorporate these qualitative differences in the intensity of flows into a simple scheme that can be used to analyze societal metabolism for sustainability issues.

2.3. A flow–fund representation of MSIASM on three levels

The MSIASM scheme is a possible operationalization of Georgescu-Roegen's bioeconomic approach to the economic process which explicitly addresses biophysical feasibility and constraints. Biophysical feasibility and constraints are analyzed in relation to: (i) socioeconomic factors within production and consumption; (ii) energy and material transformation processes; (iii) demographic changes; (iv) the profiles of human time allocation and land uses in various economic sectors; (v) the impact on ecosystem health resulting from the compatibility of the flows of energy and matter metabolized by society and the supply and sink capacity of the ecosystems embedding the society. It is also possible to introduce GDP (or food production in the case of agroecosystem analysis) as additional flows to be considered and land as another fund to be used in the MSIASM scheme. However, since our primary concern in this paper is the biophysical aspects of China's economic development, the application of MSIASM presented here looks only at the structure of the human economy in terms of two primary factors: (i) human time as a fund in terms of hours; and (2) exosomatic energy as a flow in terms of Joules. No attempt is made in this paper to deal with the interference generated on the metabolism of terrestrial ecosystems in China.

A flow–fund representation of MSIASM on three levels (the whole national level, the paid work sectors level, and the agricultural sector level) is illustrated in Fig. 1 using extensive and intensive variables. Here variables that are additive like volume are called *extensive variables*. They depend on the size or the extent of the system. Variables that cannot be added, but represent a ratio such as pressure or potential are called *intensive variables*. They are intrinsic to the system and can vary from point to point.

There are four extensive variables and four intensive variables referring to level n and level $n-1$ on the left in Fig. 1.

The four extensive variables are:

*THA is a fund element — the total human time available for the whole economy for one year, i.e., 24 h × 365 days × population. THA consists of two parts, the total labor hours (HA_{PW}) and the rest allocated in household sector (HA_{HH}) where $THA = HA_{PW} + HA_{HH}$.

*HA_{PW} is a fund element — the total labor hours in paid work sectors for one year.

*TET is a flow element — the total exosomatic energy consumption in terms of Joule for the whole economy for one year.

*ET_{PW} is a flow element — the exosomatic energy consumption for the paid work sectors for one year. $TET = ET_{PW} + ET_{HH}$ where ET_{HH} is the exosomatic energy consumption for the household sector.

The four intensive variables are:

*EMR_{SA} (tan α) is a flow–fund ratio — the biophysical energy intensity for the whole economy where $EMR_{SA} = TET/THA$. EMR_{SA} indicates how much exosomatic energy is consumed per hour of human time at the level of the whole economy.

*Fund Share $n-1/n$ (tan β) is the fund ratio between HA_{PW} at level $n-1$ and THA at level n. This ratio indicates how much human labor is used in the paid work sectors compared with the total human activity. The combined effect of demographic structure over age class, social rules and habits, level of education, and work load for paid workers all determines the Fund Share $n-1/n$.

*EMR_{PW} (tan γ) is a flow–fund ratio and the biophysical energy intensity in the paid work sectors where $EMR_{PW} = ET_{PW}/HA_{PW}$. EMR_{PW} indicates how much exosomatic energy is used per hour of labor in the paid work sectors as a whole.

*Flow Share $n-1/n$ (tan δ) is the flow ratio between ET_{PW} at level $n-1$ and TET at level n. This ratio indicates how much energy is used in the paid work sectors compared with the total exosomatic energy consumption for the whole economy.

The paid work sector is divided into three sectors: (i) agricultural sector (AG for short) ; (ii) energy and mining sector together with other productive sectors (PS for short); (iii) service and government sector (SG for short).

There are two additional extensive variables and three intensive variables referring to level $n-1$ and level $n-2$ as illustrated on the right of Fig. 1.

On the right in Fig. 1 we illustrate only one of the three subsectors considered at the level $n-1$ — the agricultural

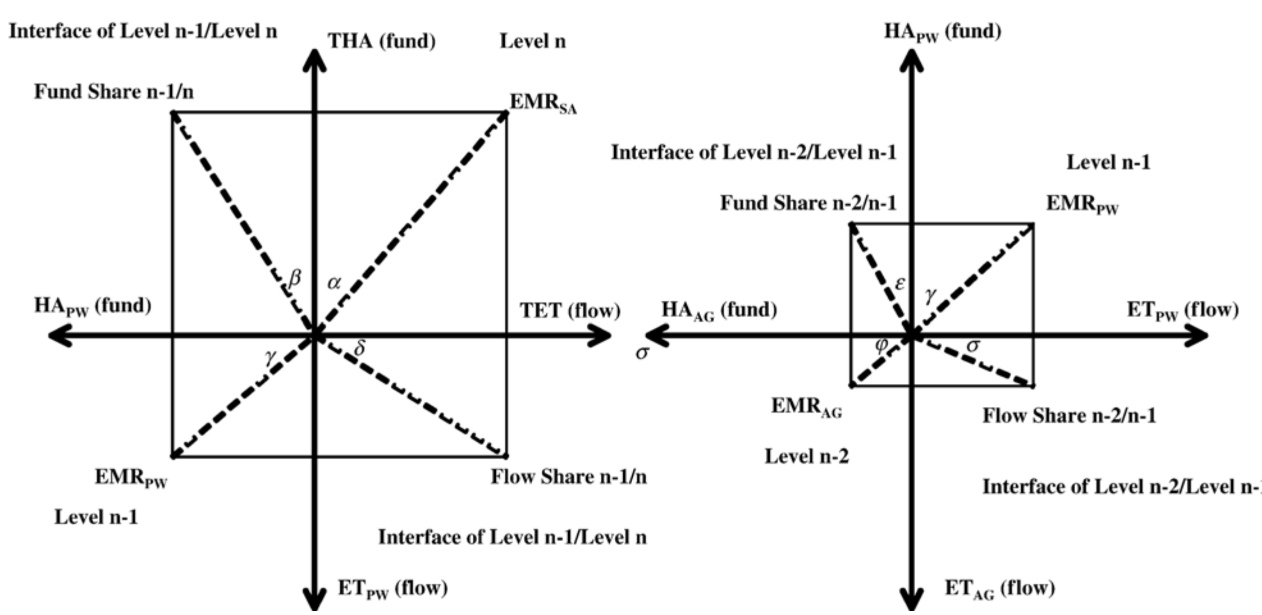

Fig. 1 – A flow–fund representation of MSIASM scheme on three levels.

sector just for illustrating the approach across different levels. The two extensive variables referring to the agricultural sector are HA_{AG} and ET_{AG}:

*HA_{AG} is the total labor hours in the agricultural sector for one year.

*ET_{AG} is the exosomatic energy consumption in the agricultural sector for one year.

Three intensive variables:

*Fund Share $n-2/n-1$ (tan ε) is the fund ratio between HA_{AG} at level $n-2$ and HA_{PW} at level $n-1$. This ratio indicates how much human labor is used in the agricultural sector compared with that in the paid work sectors as a whole.

*EMR_{AG} (tan φ) is a flow–fund ratio and the biophysical energy intensity for the agricultural sector where $EMR_{AG}=ET_{AG}/HA_{AG}$. EMR_{AG} indicates how much exosomatic energy is used per hour of labor in the agricultural sector as a whole.

*Flow Share $n-2/n-1$ (tan σ) is the flow ratio between ET_{AG} at level $n-2$ and ET_{PW} at level $n-1$. This ratio indicates how much exosomatice energy is used in the agricultural sector compared with the exosomatic energy in the paid work sectors as a whole.

Obviously, a similar system of accounting can be applied to the PS sector and the SG sector.

2.4. *Key conceptual tools of MSIASM scheme: mosaic effects and impredicative loop*

Since the MSIASM approach explicitly deals with population structure in terms of a profile of distribution of hours of human activity across compartments, it is possible to analyze the relation between human time allocation and exosomatic energy flows in parallel on different hierarchical levels. Therefore, the combination of extensive variables and intensive variables gives us redundant but useful information to increase the robustness of the analysis of hierarchically organized metabolic systems. Such 'a free ride phenomena' can be termed as *mosaic effects across levels*. A good metaphor for the mosaic effect is the process of solving a crossword puzzle. Due to the particular organizational structure of the puzzle, we can guess a lot of missing information about individual words or double check a given information by taking advantage of the internal rules of coherence of the system at different places. The right word can be easily identified if some other crucial words are already identified in the puzzle. There are situations in which one can retrieve a horizontal word totally unknown, just by solving all the vertical words crossing with it. In the case of hierarchically organized metabolic systems, individual elements express a predictable behavior due to the intrinsic organizational structure. They define for themselves what is metabolized and at what pace in parallel on different levels. This peculiar characteristic makes it possible to obtain a mosaic effect when looking simultaneously at their metabolism on various levels. For example, in Fig. 1, Flow Share $n-2/n$ can be inferred when Flow Share $n-1/n$ and Flow Share $n-2/n-1$ are already identified. In the same way, Fund Share $n-2/n$ can be inferred when Fund Share $n-2/n-1$ and Fund Share $n-1/n$ are already known. In fact, any one of the three Flow Share (or Fund Share) is identified/determined by the other two Flow Shares (or Fund Shares). The metabolic characteristics at a focal level are derived from a set of characteristics coming from a set of characteristics referring to the higher and lower levels and vice versa. That is, the generation of redundant information makes it possible to reasonably infer plausible values for certain variables from the information coming from different hierarchical levels. The generation of redundant information is also useful to see whether or not the data set coming from various sources are compatible with each other, or whether or not the assumptions about future scenarios are plausible, enhancing in this way the robustness of MSIASM scheme.

The term, 'impredicative', might sound strange to many readers in Ecological Economics. However, without grasping the meaning of this term, any scientific activity in the field of sustainability issues could be muddled. So, let us begin with the definition introduced in mathematical logic:

"When a set *M* and a particular object *m* are so defined that on the one hand *m* is a member of *M*, and on the other hand the definition of *m* depends on *M*, we say that the procedure (or the definition of *m*, or the definition of *M*) is impredicative. Similarly when a property *P* is possessed by an object m whose definition depends on *P* (here *M* is the set of objects which possess the property *P*). An impredicative definition is circular, at least on its face, as what is defined participates in its own definition" (Kleene, 1952, p. 42).

In fact, impredicativity is considered as a nuisance in scientific reductionism, since it makes it impossible to establish a linear causation, which is a typical goal of any traditional scientific activity. Thus, in order to avoid impredicativity, the usual procedure adopted by scientific analysis is to choose a particular linear causation (a narrative explaining the facts of interest, resulting from a choice of a single scale) and resort to empirical validation to see whether or not this particular causation is acceptable, whenever controlled and repeated experiments are possible. However, when dealing with a metabolic system operating on different hierarchical levels it becomes difficult to obtain a robust identification of just a linear causal relation. This is especially true when considering a set of 'attributes' referring to different processes occurring simultaneously at different levels. In this case, what can we do most?

Impredicative loop analysis (Giampietro, 2003) is an attempt to deal with this problem within MSIASM scheme. It works by: (i) deriving a set of ex-post (or accounting) impredicative relations among a selected set of categories (the definition of flows, funds and compartments) to which the division between variables and parameters are assigned later; (ii) trying to identify a set of plausible causal relations among these categories based on available data; (iii) identifying crucial constraints on variables belonging to different hierarchical levels in response to changes in some of the selected parameters. Fig. 2 shows such a set of impredicative relations among categories (variables or parameters) on three levels introduced in Fig. 1. Numbers indicated in parenthesis (n, $n-1$, and $n-2$), show the hierarchical level to which the respective category (variable or parameter) belongs. Any change in any

$$TET(n) = ET_{PW}(n-1) + ET_{HH}(n-1) = ET_{AG}(n-2) + ET_{PS}(n-2) + ET_{SG}(n-2) + ET_{HH}(n-1)$$

$$THA(n) = HA_{PW}(n-1) + HA_{HH}(n-1) = HA_{AG}(n-2) + HA_{PS}(n-2) + HA_{SG}(n-2) + HA_{HH}(n-1)$$

$$Flow-Share(n-1/n) = \frac{ET_{PW}(n-1)}{TET(n)} \qquad Fund-Share(n-1/n) = \frac{HA_{PW}(n-1)}{THA(n)}$$

$$Flow-Share(n-2/n-1) = \frac{ET_{AG}(n-2)}{ET_{PW}(n-1)} \qquad Fund-Share(n-2/n-1) = \frac{HA_{AG}(n-2)}{HA_{PW}(n-1)}$$

$$EMR_{SA}(n) = \frac{TET(n)}{THA(n)} = \frac{ET_{PW}(n-1) + ET_{HH}(n-1)}{HA_{PW}(n-1) + HA_{HH}(n-1)} = \frac{ET_{AG}(n-2) + ET_{PS}(n-2) + ET_{SG}(n-2) + ET_{HH}(n-1)}{HA_{AG}(n-2) + HA_{PS}(n-2) + HA_{SG}(n-2) + HA_{HH}(n-1)}$$

$$EMR_{AG}(n-2) = \frac{ET_{AG}(n-2)}{HA_{AG}(n-2)} = \frac{TET(n) - ET_{HH}(n-1) - ET_{PS}(n-2) - ET_{SG}(n-2)}{THA(n) - HA_{HH}(n-1) - HA_{PS}(n-2) - HA_{SG}(n-2)}$$

Fig. 2 – Impredicative loop relationships among various categories (variables or parameters) belonging to three levels.

variable (or parameter) belonging to a particular level can/must be associated with (is affecting/is affected by) changes in other variables (or parameters) belonging to other levels. So, any change in any variable (or parameter) will result in an overall change in configuration among various variables (or parameters). It should be noticed that any a priori choice of division between variables and parameters cannot be made by default, contrary to the case of linear causation typical in optimization procedures in neoclassical economics. This distinction depends on the task of the analysis (what could happen if this parameter is changed, or what should be changed to get this result, or what would represent the bottleneck if we try to change the overall result of these integrated set of relations). On the contrary, the usual procedure in neoclassical economics is conducted to look for an optimal set of values of a set of objective functions subject to a set of constraints. This requires, however, that the set of causal relations, based on a clear division between variables and parameters, must be already chosen in the pre-analytical stage. Due to this particular nature of linear causation, dynamic systems in conventional economics cannot deal with real structural changes that are intrinsic to evolving systems (Giampietro, 2003; Mayumi, 2005; Giampietro et al., 2006). In fact, dynamical systems within themselves cannot deal with identification of both structural causality and functional causality for evolving systems *endogenously*. By structural causality we mean which part of a system affects other parts of the system. By functional causality we mean how a part of a system affects other parts of the system. Impredicative loop analysis allows us to visualize the existence of a set of reciprocal constraints affecting the forced equilibrium of the dynamic budget in societal metabolism. A plausible configuration of human time allocation and exosomatic energy distribution among various variables (or parameters) using two four angle representations can be

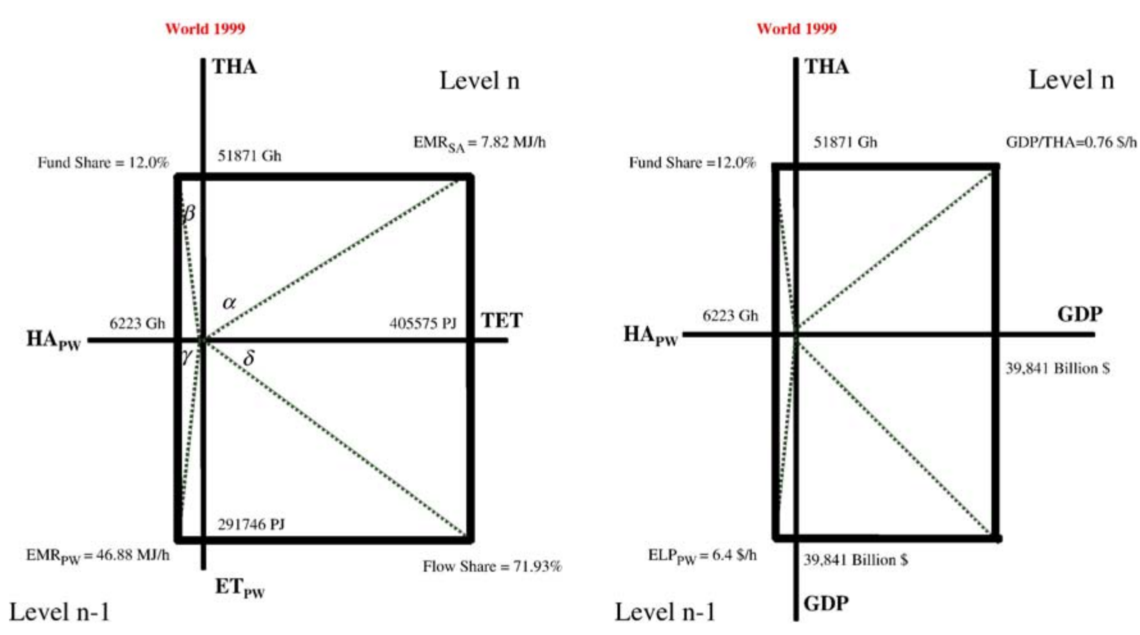

Fig. 3 – Flow–fund representation of two dynamic budgets for the world economy, 1999.

obtained by coordinated changes of the characteristics of parts in relation to the characteristics of the whole, and changes in the characteristics of the whole in relation to the characteristics of the parts. In this way MISASM approach is used to make comparisons between the values of variables referring to different hierarchical levels or the same hierarchical level but belonging to different places. MSIASM has the explicit goal of addressing the existence of chicken-egg patterns in the perception and representation of hierarchically organized systems operating on multiple levels. Whenever we deal with any metabolic system, the identity of the whole defines the identity of the parts and vice versa. MSIASM is an attempt to deal with this fact, rather than pretending that this is not a crucial issue.

3. Results

3.1. Country groups and benchmarks to characterize and contextualize China's exosomatic energy metabolism

Before getting into an analysis of China's exosomatic energy metabolism, we propose first a comparison of the characterization of the world economy against a set of 6 representative country groups, one of which is China.

We start with two representations of the world economy based on the MSIASM scheme in 1999. In this case, we are using a single definition of Fund (human activity) THA and two definitions of Flows (exosomatic energy) TET and (added value) GDP. Because of this double definition of flows, on the right of Fig. 3, there is a new category: ELP_{PW}, which is the economic labor productivity (GDP divided by the amount of human labor hours in the paid work sectors). Therefore, Fig. 3 shows two representations of two kinds of dynamic budgets for the world economy: (i) THA (the total human time available for the world) is producing and consuming the flow of TET (the total exosomatic energy consumption for one year); and (ii) THA is producing and consuming GDP.

We selected 6 country groups listed in Table 1: (#1) China; (#2) India; (#3) former-USSR; (#4) AUSCAN (Australia, USA and Canada); (#5) Rest of OECD countries; and (#6) Rest of the World to have a first comparison of the relative shape of the dynamic budget of these two flows against the fund.

The relative representations with the benchmarks determining the impredicative loop for these 6 country groups together with the distribution of types of these country groups are given in Fig. 4. For the purpose of simplicity, only one flow–fund representation of each country group on two levels is shown in Fig. 4 (the one dealing with energy TET). It should be noted that the definition of the eight benchmarks (four

Table 1 – World and country groups 1999

	THA [a] Gh	HA_{PW} [b] Gh	TET [c] PJ	ET_{PW} [d] PJ	EMR_{PW} [e] MJ/h	EMR_{SA} [f] MJ/h	Fund Share $(n-1/n)$ [g]	Flow Share $(n-1/n)$ [h]
World	51,871	6223	405,576	291,746	46.88	7.82	12.00%	71.93%ac
AUSCAN [i]	2825	295 [j]	109,503	83,005	281.25	38.77	10.45%	75.80%
Rest OECD	6955	546 [k]	109,088	82,038	150.15	15.68	7.86%	75.20%
India	8738	945 [l]	20,081	10,759	11.38	2.30	10.82%	53.58%
China	10,982	2020 [m]	45,493	31,947	15.81	4.14	18.40%	70.22%
Ex-USSR	2545	216 [n]	38,272	28,093	130.00	15.04	8.49%	73.40%
RoW [o]	19,827	2200 [p]	83,139	55,903	25.41	4.19	11.10%	67.24%

Sources: OECD (2002, 2004), ILO Statistics (2006), Ramos-Martin (2001), Giampietro and Mayumi (2000b).

[a] Total Human Activity, in Giga hours. 1 Gh = 10^9 or 1 billion hours. Population × 8760 h. Data on population from OECD (2002).

[b] Human Activity in the Paid Work sectors in Giga hours. PW sectors are those generating economic added value. PW = PS + SG + AG, where PS stands for Industry, Mining and Energy; SG for Services and Government; and AG for agriculture, as in Giampietro and Mayumi (2000b). HA_{PW} is generated from combining employment data with working hours. Data from Laborsta data base, ILO website (www.ilo.org). Otherwise, see specific notes for calculations.

[c] Total exosomatic Energy Throughput, in Peta Joules. 1 PJ = 10^15 Joules. We use Total Primary Energy Supply (TPES) for our calculations. Data on energy from OECD (2002).

[d] Exosomatic Energy Throughput in the paid work sectors, in Peta Joules. That is, TET minus the energy consumed at the Household Sector (HH). For HH energy we use Residential Energy plus 50% of energy use at Transportation sector (our assumption, see Giampietro (2003) for the rationale). Disaggregated data on energy use by sectors from OECD (2002).

[e] Exosomatic Metabolic Rate of the paid work sectors, in Mega Joules per hour of activity. $EMR_{PW} = ET_{PW}/HA_{PW}$. 1 MJ = 10^6 or 1 million Joules.

[f] Exosomatic Metabolic Rate, societal average, in Mega Joules per hour. EMR_{SA} = TET/THA.

[g] This is the fund ratio between HA_{PW} at level $n-1$ and THA at level n. This ratio indicates how much human labor is used in the paid work sectors compared with the total human activity.

[h] This is the flow ratio between ETPW at level $n-1$ and TET at level n. This ratio indicates how much energy is used in the paid work sectors compared with the total exosomatic energy consumption for the whole economy.

[i] Australia, USA, and Canada.

[j] Employment data from OECD Employment Outlook 2004. working hours based on ILO statistics: 1600 h for Australia, 1927 for USA, 1645 for Canada.

[k] Employment data from OECD Employment Outlook 2004. 1700 h for Total OECD, then deduction of AUSCAN.

[l] Employment data interpolated from ILO data for 1998, and 2000. 1800 h per year.

[m] Employment from ILO. 8 h a day × 7 days × 50 weeks.

[n] 1800 h per year.

[o] Rest of the World.

[p] Our assumption, based on ILO statistics. 45% of Economically Active Population, and 10% unemployment. 2400 h per year.

extensive and four intensive categories) associated with the flow–fund representation can be used to determine another benchmark category EMR_{HH} (ET_{HH}/HA_{HH}) referring to the compartment of consumption. This is due to impredicative loop over the set of relations introduced in Figs. 1 and 2. EMR_{HH} indicates the level of capitalization of the Household Sector, that is, it indicates the ability of a society to consume more exosomatic energy per hour of human activity invested in that sector.

By utilizing these eight categories in terms of extensive and intensive variables it is possible to: (i) characterize each one of the 6 representative country groups; and (ii) define a profile of distribution of human activity in the world over these groups. In this way, it becomes possible to establish a relation between the overall characteristics of the world economy – e.g. total emission of GHG – and the specific characteristics of each one of the 6 groups. It is also possible to compare the exosomatic metabolic characteristics of one country group with those of other country groups. For example, useful benchmarks for studying China's exosomatic energy metabolism are compared with other country groups in Figs. 5–10.

For example, Fig. 5 shows the values of EMR_{SA} and THA (a proxy for population size) for 6 country groups in 1999. EMR_{SA} for China and India is 53% and 29% of the world average (7.82 MJ/h). Looking at the relative size it is easy to see that even a slight change in EMR_{SA} for these two countries will trigger a dramatic increase in energy consumption due to the huge population size of them. In Fig. 6 a new set of country groups are introduced: (i) USA, Canada, and Australia; (ii) OECD; (iii) Italy, Spain and Japan; (iv) Ecuador, Egypt and China. This new classification focuses more on population density, capital intensity and resource abundance.

Three biophysical energy intensities, EMR_{SA} (TET/THA), EMR_{PW} (ET_{PW}/HA_{PW}), and EMR_{HH} (ET_{HH}/HA_{HH}) for 1990 and 1999 are compared among these new types of country groups in Figs. 6–8. Obviously, China's biophysical energy intensities are still much lower levels compared with those of USA, Canada and Australia. Fig. 9 shows EMR_{PW} and Fund Share ($n-1/n$) in 1999 for the same country groups. Fig. 10 shows EMR_{PW} and EMR_{HH} in 1999 for these groups. Now we can see an important characteristic of China's exosomatic energy metabolism which will be a severe constraint for China's further economic development. The value of EMR_{PW} for China is lower than the values found for Ecuador and Egypt. However, Fund Share ($n-1/n$) for China is 18.3%, much higher than those of

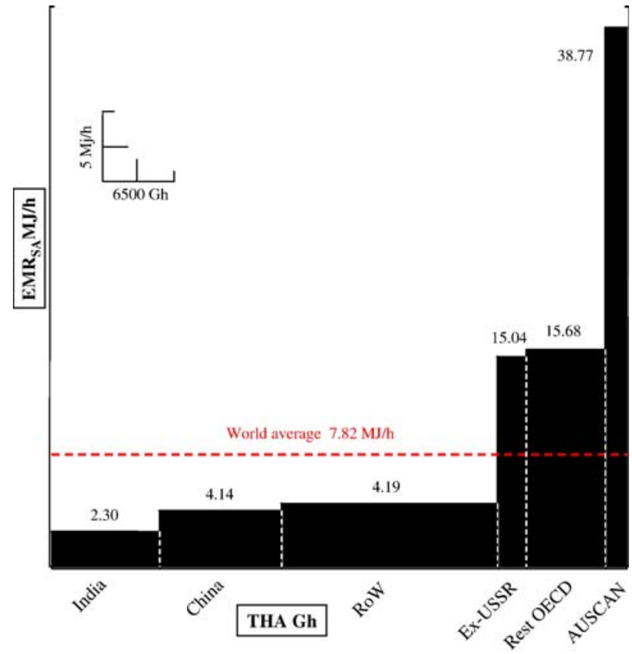

Fig. 5 – EMR_{SA} and THA for various country groups 1999.

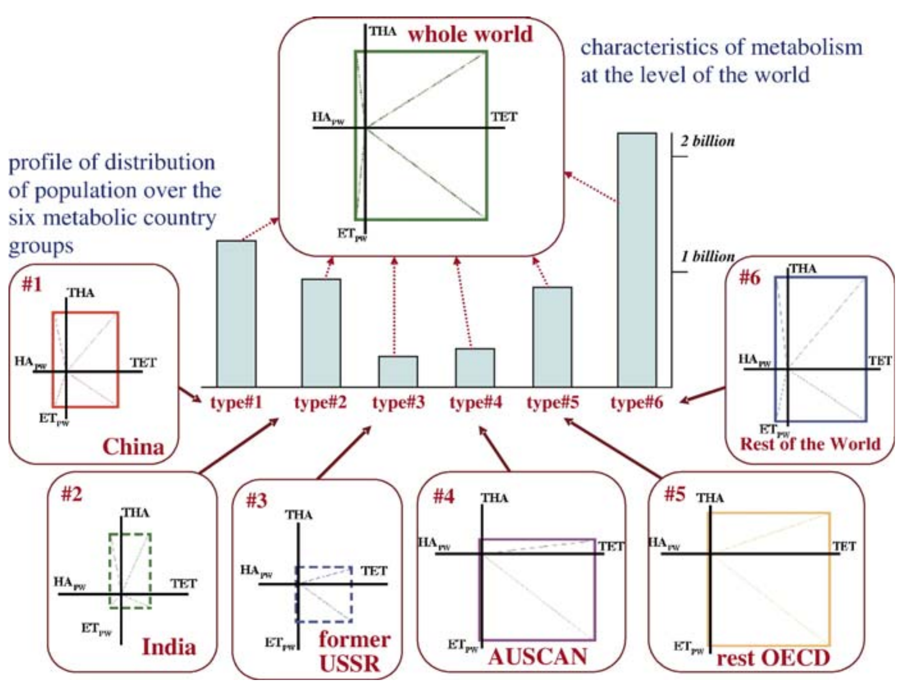

Fig. 4 – flow–fund representation of country groups using MSIASM, 1999.

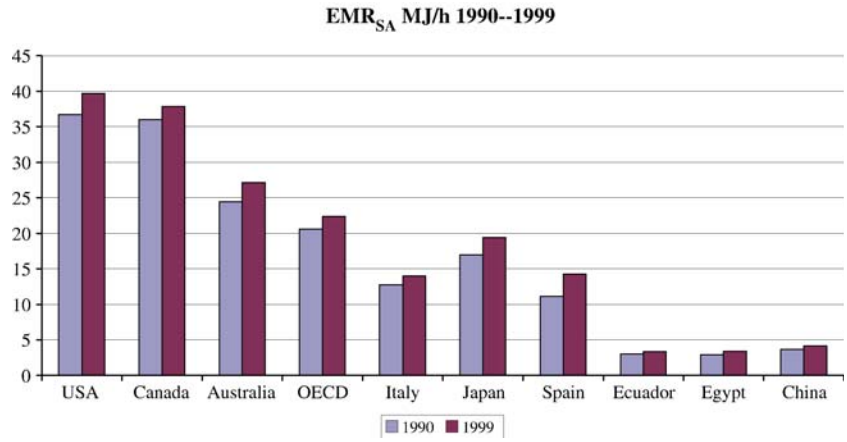

Fig. 6 – EMR$_{SA}$ for a selected group of countries, 1990 and 1999.

Ecuador and Egypt. This Fund Share ($n-1/n$) is the ratio between HA_{PW} (human labor in paid work sectors) and THA (the total human time available). This anomaly can be explained by the adoption in China of one child policy for a long time period. The result is that now China is facing an extraordinary fraction of adults in its population. For the moment, this provides a comparative advantage in terms of cheap labor supply. However, how to secure a sufficient labor power supply to an economy specialized in labor intensive activities in the future is a critical issue, which will be touched upon later in this paper.

3.2. *Interface national level/sector level: characterizing the metabolism of China*

In the period between 1980 and 2002 illustrated in Fig. 11, defenders of the so-called "dematerialization hypothesis" or "the environmental Kuznets curve (EKC) hypothesis" would argue that China is a clear example of a country that is dematerializing in energy terms. The hypothesis underlying the EKC is that resource depletion and pollution tend to fall as incomes rise, producing an inverted U-shape function (for a summary on the EKC see, e.g. Stern, 2004). In fact, EI (the economic energy intensity), i.e., the amount of energy per dollar of GDP generated, has been decreasing over time, from 33.3 MJ/$ in 1980, to 8.7 MJ/$ in 2002 (about 6% per year on average). However, in the same period the value of TET (the extensive variable) has increased from 24,767 PJ (Peta Joules is 10^{15} Joules) in 1980 to 50,696 PJ in 2002 (about 3% per year on average). So, China is steadily heading for continuous expansion in terms of exosomatic energy consumption. However, it should be emphasized that many economic activities generating welfare for China were not counted as those contributing to added value before. After China started shifting toward a more market oriented economy, those economic activities performed in biophysical terms were finally recorded in monetary terms in the economic statistics. Obviously, this relative increase in GDP is not necessarily associated with a relative increase in energy consumption. Since China's per capita GDP is still very low level, at this moment we cannot make any conclusion on whether or not China is in the process of dematerialization.

Since the MSIASM scheme explicitly addresses the effects of demographic variables, we first check the evolution of

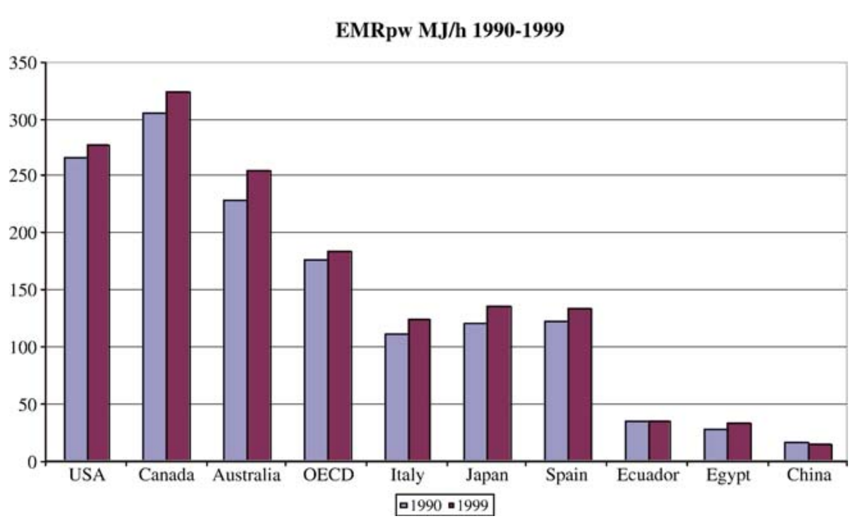

Fig. 7 – EMR$_{PW}$ for a selected group of countries, 1990 and 1999.

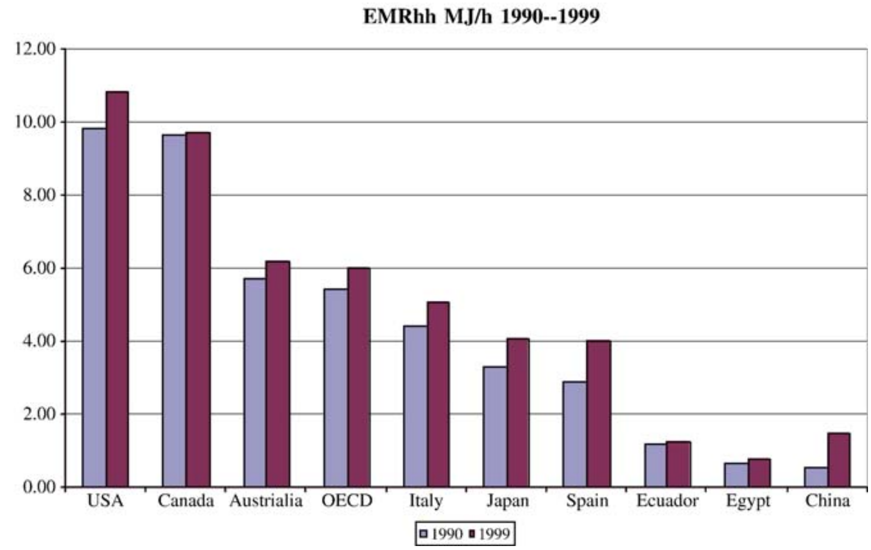

Fig. 8 – EMR_{HH} for a selected group of countries, 1990 and 1999.

population in the period analyzed. The analysis of relevant changes in extensive and intensive variables referring to the various benchmarks of the exosomatic energy metabolism of China is given in Fig. 12 in the form of dendograms for 1980 and 1999. A flow–fund representation of MSIASM scheme for China in 1999 is shown in Fig. 13.

Chinese population increased from 841 million people in 1980 to 1253 million in 1999. The population growth rate is about 2% per year on average, but due to the already very large size of the population this translated into the addition of almost 410 million people (much more than the actual population of the USA). This is a major challenge for the economy of China. During the same period, TET increased from 24,767 PJ in 1980 to 45,493 PJ in 1999 (about 3% per year on average). The combined effect of increases of both TET and population (THA) resulted in a slight increase in EMR_{SA}: from 2.8 MJ/h in 1980 to 4.1 MJ/h in 1999. Still, EMR_{SA} for China in 1999 is much lower than world average (7.8 MJ/h) and OECD levels (22.3 MJ/h), as already mentioned. As studied in the case of Ecuador (Falconi-Benitez, 2001) changes in demographic structure can entail a slow down in the level of capitalization of an economy and therefore changes in average level of energy consumption EMR_{SA}. This can pose a real challenge to accomplish a rapid economic development.

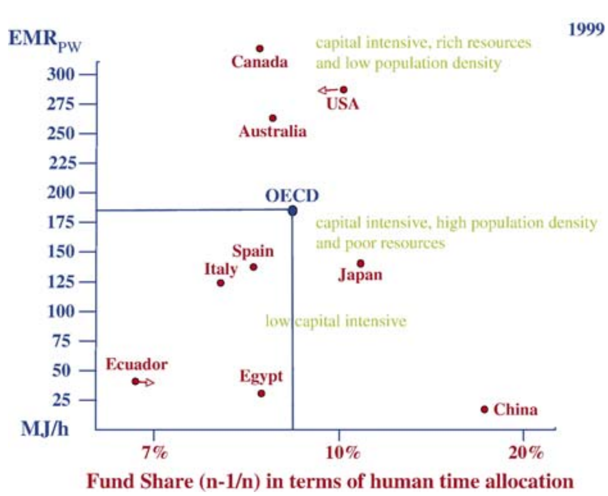

Fig. 9 – Fund Share ($n-1/n$) in terms of human time allocation 1999.

Let's start by checking the evolution in time of how total human activity was distributed between paid work activities (HA_{PW}) and non-paid work activities (HA_{HH}). HA_{PW} is used to guarantee the functioning and growth of the metabolic input (in the introduction we indicated this role as the role performed by the hypercycle part). HA_{HH} on the contrary is related to the dissipative part to enhance the consumption activities. Fund Share ($n-1/n$), i.e, HA_{PW}/THA (the fraction of human activity invested in paid labor out of total amount of hours of human activity) for China increased from 14% of total available time in 1980 to 18.3% in 1999. Therefore, not only did China see a huge increase in population in absolute terms, but also a *growing fraction* of its THA which was allocated to HA_{PW}, paid work activities. This implied an additional challenge, in terms of the need of capital accumulation for the economy. To boost the dissipative part (final consumption) and to enjoy higher consumption in the longer time horizon, the level of capital accumulation of the Chinese economy per worker (or better per hour of work) has to keep growing. But this implies matching the pace of capital accumulation with the pace of growing of HA_{PW}. As noted earlier, the degree of increase of the extensive variable HA_{PW} was driven by the combined effect of the increase in the extensive variable THA and by the increase in the fraction of paid working time, Fund Share ($n-1/n$) indicated in Fig. 13. That is, more capital was required by China not only to deliver more goods, services and infrastructures to the growing population, but also to maintain the original level of EMR_{PW} for an increasing working population. The problem of changes in the demographic structure of China's population will remain in the future, getting worse, when this wave of adults will move to the category of retired elderly.

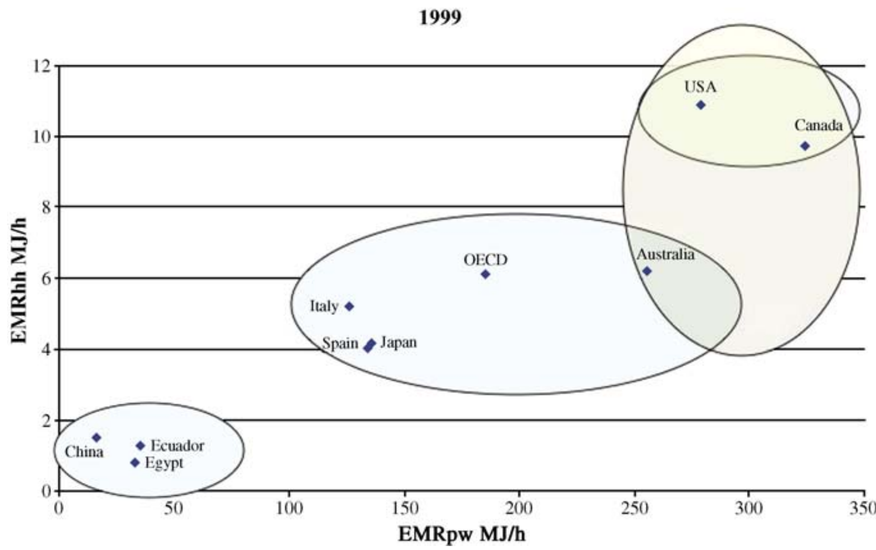

Fig. 10 – EMR_{HH} and EMR_{PW} for a selected group of countries, 1990 and 1998.

As explained with the idea of impredicativity, the effect of changes in demographic variables that determine a change in HA_{PW} at the level (n–1) can be only studied by looking at the structural change of the economy happening at lower levels (n–2). That is in the three sectors: AG (agricultural sector), PS (energy and mining sector together with other productive sectors) and SG (service and government sector). This implies looking at how energy is used within this sector to boost the productivity of workers. Two extensive and one intensive categories for level $n-2$ can be introduced for this task: (i) the distribution of the working time HA_{PW} over the three sub-sector sectors at level $n-2$ — HA_{AG}, HA_{PS} and HA_{SG}; (ii) the distribution of exsosomatic energy ET_{PW} over the three sub-sectors at level $n-2$ — ET_{AG}, ET_{PS} and ET_{SG}; and (iii) the resulting biophysical energy intensities for these three sub-sectors at level $n-2$ — EMR_{AG}, EMR_{PS} and EMR_{SG}. It is only when we look at these different types of information coming from lower levels of the metabolic system, then we can understand the overall trend of exosomatic metabolism of the Chinese economy (EMR_{PW} at level $n-1$ as well as EMR_{SA} at level n) over time.

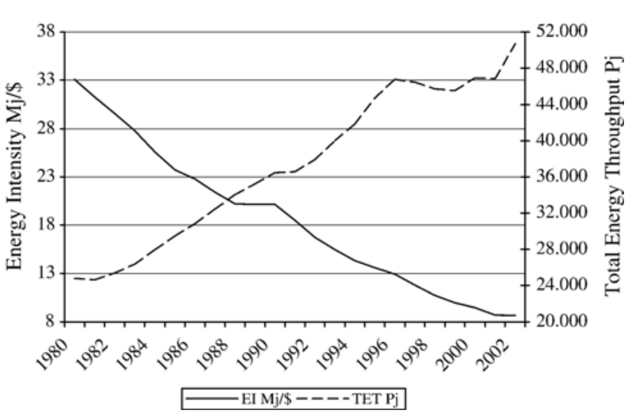

Fig. 11 – Evolution of energy intensity and total energy throughput in China, 1980–2002.

The trends of EMR_{PW}, EMR_{AG}, EMR_{PS} and EMR_{SG} in the period between 1980 and 1999 are shown in Fig. 14. Nine extensive and intensive variables belonging to sub-economic sectors for 1980 and 1999 together with EMR_{PW} are shown in Fig. 15. Looking at Fig. 15 (and Fig. 12) we can make the following observation. Fund Share ($n-2/n$) in agricultural sector, HA_{AG}/THA, dramatically decreased from 68% in 1980 to 47% in 1999. In spite of this negative trend, HA_{AG} itself increased from 821 Gh in 1980 to 944 Gh in 1999, an increase of 15% due to the effect of the increase in population (THA).

EMR_{PS} and EMR_{SG} decreased by 13% and 34%, respectively, during the same period. EMR_{AG}, which is the only category that increased by 41% from 0.96 MJ/h in 1980 to 1.35 MJ/h in 1999. This increase in EMR_{AG} can be easily explained by the fact that the use of agricultural inputs has increased with the demographic pressure (Giampietro et al. 1999; Li et al., 1999). For example, according to US Department Agriculture (2006) sown area of China in 1991 and 1999 remained the same (112.3 million hectares and 113.2 million hectares). On the other hand, for example, nitrogen use increased from 12.5 million tons in 1980 to 23. 8 million tons in 1996, which is much more than the total amount of nitrogen consumed jointly by EU and the United States (more on these issue, see Giampietro et al., 1997, 1999; Paoletti et al., 1999).

Between 1980 and 1999 China's GDP almost quadrupled, but it is well known that the exosomatic energy consumption, TET, increased less than twice in the same period, from 24,767 PJ in 1980 to 45,493 PJ (only 84% increase).

Four main reasons can be used to explain how China achieved the tremendous economic growth without an analogous increase in energy consumption. These reasons are also relevant for discussing the *future challenges that China would face*.

First of all, Chinese government strongly took initiatives to promote energy efficiency policy, as reported by Sinton et al. (2005). However, the steady increase in energy consumption with rapid economic growth has rendered Chinese government's decentralized regulatory and policy-making apparatus ineffective, as state-owned supply company incentives have

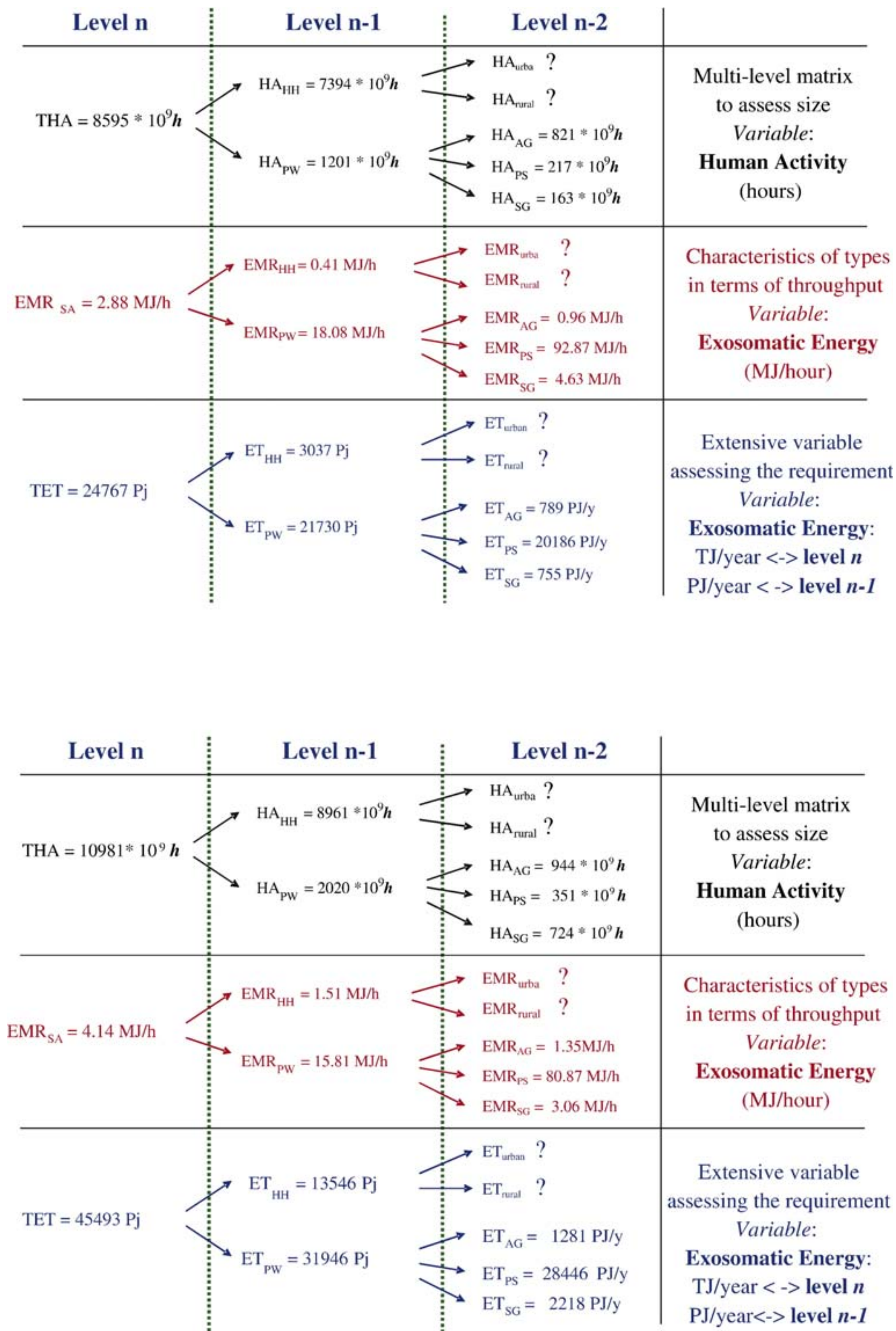

Fig. 12 – Dendograms of exosomatic energy metabolism of China in 1980 and 1999.

diverged from private demand and public well-being. The relative weakness of the central government in the face of vested interests has led to energy sector inconsistencies, energy inefficiency, and policy paralysis (Sinton et al., 2005). So, it is very difficult to predict whether or not China's energy efficiency policy can be maintained, while aiming at continued economic growth. Moreover, because of Jevons' paradox (Giampietro and Mayumi, 2006) we can expect that any improvement in efficiency will result, in the long term, in an expansion of both final consumption or in a faster rate of capitalization of the economy (leading to higher energy consumption).

Secondly, growth in the service sector has been phenomenal since 1990, as the income level in terms of per capita GDP in service sector soared from around US$ 300 per year in 1990 to above US$ 1200 in 2004, maintaining an average annual

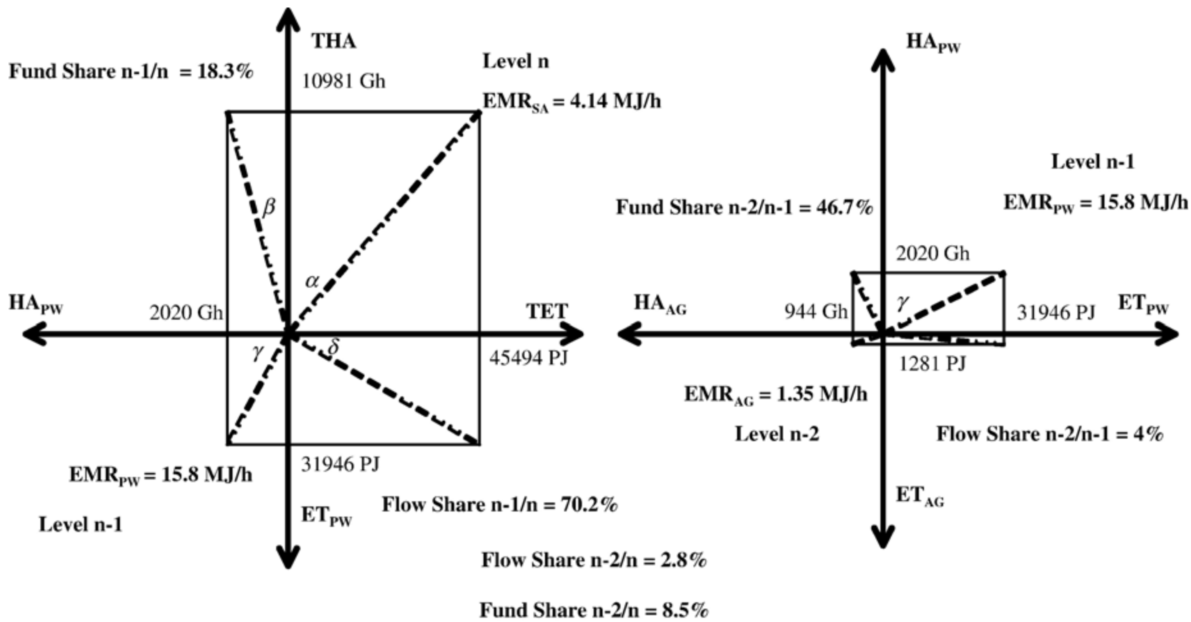

Fig. 13 – A flow–fund representation of MSIASM scheme on three levels: China in 1999.

growth rate of 8.7% in real terms (Qin, 2006). The higher economic income in service sector is the real reason why there is a massive labor shift from the agricultural sector to the service sector. This trend has been favored by the very low EMR_{SG} – implying a lower requirement of capital per worker – compared with the relative high EMR_{PS}. The government promotion of the service sector is mainly targeted to alleviate the acute labor supply pressure at relatively low expenses of material and capital resources. Moreover, it is felt that a growing service sector would help strengthening the non-state-owned business sector, increasing the overall economic efficiency, and accelerating trade and technological progress (Qin, 2006).

Thirdly, capital investment is a key to rapid economic development. China's fixed investment divided by GDP between 1991 and 2003 is amazingly high and increasing in the last years. The average value was 39.6% between 1991 and 1995; 37.6% between 1996 and 2000; and 40.5% between 2001 and 2003 (National Bureau of Statistics of China, 2004). These values can be compared with Japan's fixed investment during

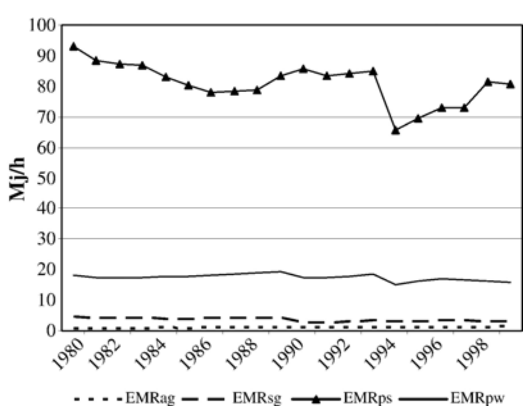

Fig. 14 – Evolution of EMR_i at the levels ($n-1$) and ($n-2$).

its most rapid economic development (between 1961 and 1970). Japan's fixed investment during that period was 32.6% (Heston et al., 2002). China's fixed investment in 2003 was about 2600 billion US dollars (in terms of the year 2000). This value can be compared with Japan's fixed investment in 1970 that was about 390 billion US dollars (in terms of the year 2000). That is, in the last ten years, China's fixed investment far surpassed that of Japan in its most rapid period of economic development.

Finally, there is another key to China's rapid economic development to which our MSIASM can shed considerable light. It is related to the issue of labor supply.

HA_{PW} increased from 1200 Gh in 1980 to 2020 Gh in 1999 (a 68% increase). However, ET_{PW} increased only 47% from 21,730 PJ in 1980 to 31,946 PJ in 1999. This lower rate of increase of ET_{PW} compared with HA_{PW}, can be explained only partly by increases in energy efficiency. As result of this two trends the value of EMR_{PW} decreased by 17% during the same period. China's exosomatic characteristics can be seen more clearly if we make the comparison of flow–fund representation of MSIASM between 1990 and 1999 shown in Fig. 16. Even though EMR_{SA} increased from 3.67 MJ/h in 1990 to 4.14 MJ/h, EMR_{PW} decreased from 17.51 MJ/h in 1990 to 15.81 MJ/h in 1999. On the other hand, due to the relatively higher proportion of small children and young people at this stage of China's socioeconomic phase, EMR_{HH} increased from 0.59 MJ/h in 1990 to 1.51 MJ/h in 1999. This illustrates that what is really happening in China is a dramatic increase in the fund share over human activity, which results in a surge in labor hours entering into the economy. During the same period (1990 and 1999), Fund Share ($n-1/n$) increased from 18.2% in 1990 to 18.4% in 1999, while Flow Share decreased from 86.7% in 1990 to 70.2% in 1999. Since China's effort to increase energy efficiency is stagnating and China had not had enough foreign currency to secure energy resources, in particular oil, in early 1990s, moving this huge mass of available working hours to

	1980	1999	Percent change
EMR_{PW}	18 MJ/h	15 MJ/h	-17%
ET_{AG}	789 PJ/year	1281 PJ/year	62%
ET_{PS}	20186 PJ/year	28446 PJ/year	41%
ET_{SG}	755 PJ/year	2218 PJ/year	193%
HA_{AG}	821 x 10^9 hours	944 x 10^9hours	15%
HA_{PS}	217 x 10^9 hours	351 x 10^9 hours	62%
HA_{SG}	163 x 10^9hours	724 x 10^9 hours	344%
EMR_{AG}	0.96 MJ/h	1.35 MJ/h	41%
EMR_{PS}	92.87 MJ/h	80.87 MJ/h	-13%
EMR_{SG}	4.63 MJ/h	3.06 MJ/h	-34%

Fig. 15 – Values for relevant MSIASM variables for China, 1980 and 1999.

labor intensive economic activities was an inevitable strategy for China during the phase of rapid economic development. Despite serious concern with the adoption of long working days in Chinese economy, this strategy worked well for the economy so far. Georgescu-Roegen remarked on this point: "in view of our loudly proclaimed aims, to help the underdeveloped economies not only to make progress but also make *rapid* progress, the legal regimen of the eight-hour day in such economies (even in those where overpopulation brings about unwanted leisure) is a patent incongruity, if not a planned anachronism as well" (Georgescu-Roegen, 1971, p. 248). However, the solution of using comparative advantages associated with the very high fund share on human time (a very large fraction of the population in the work force) can pay

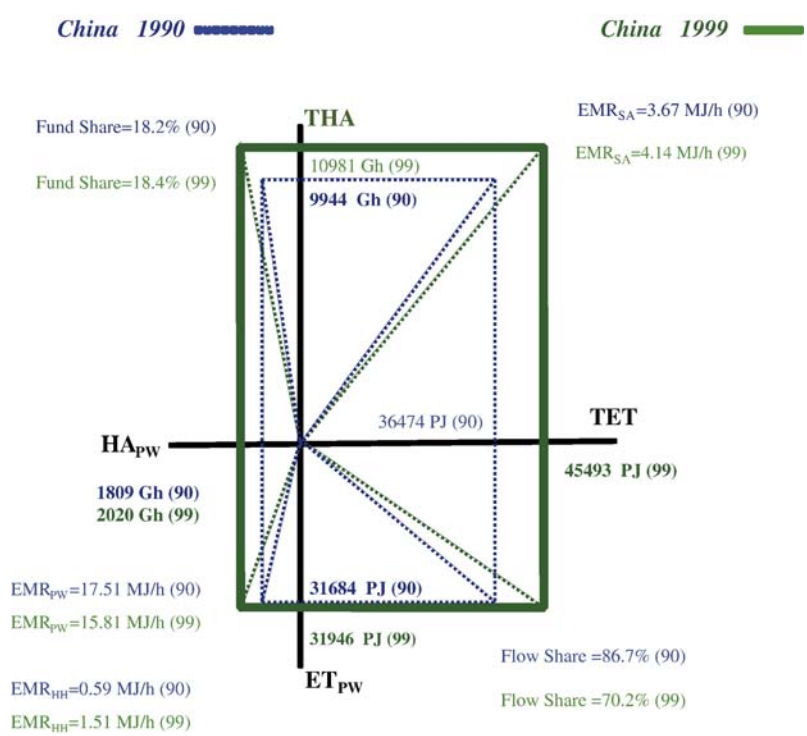

Fig. 16 – Flow–fund representation of MSIASM for China, 1990 and 1999.

only in the short/medium term. Due to China's adoption of one child policy, China will have to face in 20 years shortage of labor supply unless China will succeed in transforming itself into more energy intensive economy (increase dramatically the level of capitalization per worker – EMR_{PW} – of its economic sectors). Naturally, more energy intensive economy for China will create additional problems for global energy and environmental issues.

Concerning the labor supply issue, it should be noted that the following plausible estimates are based on World Population Prospects (2004). The number of senior people (65 years or older) in China would increase by 244 million between 2000 and 2050. On the other hand, the number of people whose age is between 20 and 65 would increase only by 150 *thousand* between 2000 and 2050!

4. Back to the interface world level/national level: future scenarios of development for China

The following quote clearly indicates the predicament associated with China's demographic trend: "During the next 50 years China will experience a dramatic population aging. According to this most recent UN population projection (the 1998 Revision) China will have about 630 million people age 50 and above in 2050 — while there will be only some 78 million children below the age of 5 and just 324 million children and teenagers below the age of 20. In other words: by 2050 China will have almost twice as many people above age 50 than below age 20" — Heilig (1999). This means that a strategy of economic development based on cheap labor with intensive work load may no longer be feasible in this time horizon. The intensive work load per year of Chinese workers (2800 h per year) may be totally untenable in the future of China's economy. As mentioned in the introduction the MSIASM scheme addresses the ability of a society not only to produce, but to produce and consume goods and services. As stated there, in order to be able to produce more, any economy must allocate more of the available human time and energy in consumption sectors (Zipf, 1941). A reduction in the work load for the working population, not only is an ethical imperative, but also an essential requirement for achieving this shift toward a larger level of internal consumption within China to guarantee an internal demand. When looking at both aspects (fraction of population economically active and very high work load) it looks very improbable, that China will maintain the existing peculiarity in relation to the values of these two benchmarks. Hence it should be expected that, sooner or later, China will try to move toward the benchmark values found in developed countries. When comparing the biophysical intensity (capitalization per worker) in the paid work sectors, EMR_{PW}, China (15.8 MJ/h) has a value that is almost twelve times smaller than that of OECD (185.4 MJ/h) in 1999. Due to a low value of EMR_{PW}, China's strategy was to export manufacturing products with labor intensive characteristic. However, this strategy cannot achieve its aim if the import of capital intensive goods due to increase in internal demand is not replaced by China's domestic production of capital intensive goods in the medium/long term. An expansion of the exosomatic energy consumption of ET_{PS} to be accompanied by decreased HA_{PS} will surely result in a dramatic increase in EMR_{PS} that will trigger a huge increase in energy demand. Just to have an idea of the implication of this fact, we provide, in Fig. 17, a comparison of exosomatic metabolism between China and OECD in 1999 based on the MSIASM representation (note that the two systems have a similar size in terms of population!).

According to what has been said so far, three general points can be made about the future evolution of Chinese exosomatic energy metabolism:

Point #1 — there is a crucial uncertainty associated with the ability to keep coherence in the process of governance of the major transition ahead. As illustrated by the study of Ramos-Martin (2001) the successful economic transition of Spain, can be explained by the combined effect of a limited population growth and a restrictive policy of the dictatorship in the previous decades (the so called 'Franco era'). These two characteristics of Spain compressed household consumption in favor of capital investment. Can China afford to keep the extraordinary low levels of final consumption actually experienced by the majority of its households compressed in the same way?

For sure boosting of the level of capital accumulation of the PW sector as fast as possible is and must remain a key strategy for the Chinese government. In fact, keeping as high as possible the level of investment in capital and infrastructure is the only strategy for generating a virtuous circle in Chinese economy. However, the priority given to the goal of establishing as quick as possible such a virtuous circle must be evaluated against the existing demographic trend. As already touched on several times in this paper, when the boosted cohorts of adults will move through the age-class out of the economically active population, China may face a difficult situation, with an economic sector based only on cheap labor. Then it may be no longer able to support a larger fraction of dependent population. On the other hand, the meager material standard of living experienced now by a large fraction of the population (in rural areas, in marginal social groups in urban areas) suggests an opposite priority aimed at boosting as fast as possible the level of final consumption in the household sector. If China continues to compress final consumption we may see a further increase in the level of social unrest (with even more criminality, demonstrations, strikes, and violence), which could lead to a breakdown of the social fabric of the Chinese society, as suggested in introduction.

Point #2 — a second crucial aspect will be the ability to prevent the possibility of a breakdown of the national unity due to the increasing tension between the rich south-east coastal zones, and the poor interior and former industrial area of the north east. As discussed earlier, the forces of free market that are so good at boosting the efficiency of the production and consumption of goods and services within a socioeconomic process, tend to preserve and amplify the existing wealth disparity. In relation to this issue the government has to face another daunting dilemma: (i) going for a maximisation of economic efficiency by leaving the market forces operate freely without serious constraints; or (ii) giving priority to the unity of the country, by reducing the rate of generation of the much required economic surplus. The MSIASM approach can be used to look at different density of

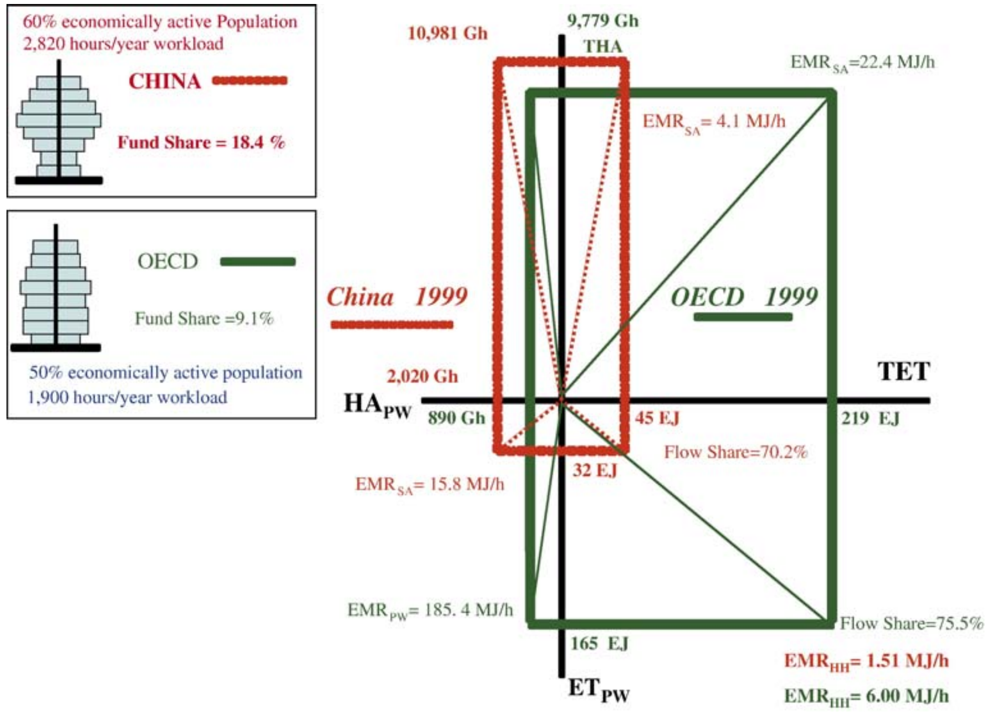

Fig. 17 – Comparison of the characteristics of the exosomatic metabolism of China and OECD countries in 1999.

added value, energy and human activity per hectare in different geographic areas, in relation to different mixes of economic activities, studying how these mixes are affected by geographic differences. However, this application has not been presented in this paper.

Point #3 — a third crucial aspect is related to what will happen in the future with demographic variables. Looking at the past changes of demographic structure of China and at future projections (from Heilig, 1999), one can notice the presence of echo-effect. There is a possibility of another baby boom following the previous one. We can use again two quotes from Heilig (1999) to summarize the main implications of this situation:

[1] "Looking at the change of the population pyramids one can see how the "baby boom" generation from the 1960s and early 1970s "moves up" the age pyramid. The animation also visualizes the *aging* of the Chinese population, which is caused by the significant fertility decline since the mid-1970s (and the further increase in life expectancy)".

[2] "The number of young adults of *reproductive age* (20–50) will reach its maximum of more than 660 million around 2010. This explains why the period between 1995 and 2025 is the most critical for the country's future population growth".

These two quotes point at another daunting dilemma faced by Chinese government: (i) keeping a strong control on population to prevent another rate increase of population growth. But this will imply having a large fraction of elderly in the long term; or (ii) increasing the number of young people entering into the Chinese economy to prevent a general ageing of the work force. But, this will imply getting back to an increase of population size, something that would be very dangerous for the environment.

5. Conclusion

Three conclusions can be driven home in relation to the goals of this paper.

5.1. *Usefulness of MSIASM scheme for integrated multi-scale analysis of exosomatic energy metabolism*

In our view this paper shows that MSIASM scheme is a useful tool for organizing and performing an integrated and multi-scale analysis of changes in the characteristics of socioeconomic systems. The MSIASM scheme makes it possible to handle simultaneously extensive and intensive variables belonging to different levels in relation to different selections of observable categories. MSIASM allows us to better understand the complexity of the sustainability problem and to provide a very useful structuring of available information concerning identification of plausible causal relations, which are often hidden when studying a given system at a single scale or using a single disciplinary narrative. By adopting the MSIASM scheme it also becomes possible to assign benchmark values that can be related to lower level characteristics of the socioeconomic system and that can be compared with other socio-economic systems. This approach makes it also possible to formulate hypothesis to explain differences from expected values of extensive and intensive variables, as well as, to combine various historic series and variables belonging to different disciplinary fields. We believe that MSIASM helps in having an informed discussion about possible scenarios of development.

5.2. Multi-scale characterization of the development process of China and possible scenarios

We have not made any conclusion whether or not China is following the hypothesis of the inverted-U curve for energy intensity, or the so called dematerialization hypothesis. However, it should be noted that the rapid development of China started when economic liberalization was introduced in the economy. This liberalization primed a sharp increase both in energy and materials consumption. This is not a surprise at all. According to the set of benchmark values that characterize Chinese exosomatic metabolism, China still belongs to the developing countries group, and given its size it will keep growing in its consumption of both materials and energy. This is not good news for people concerned with energy and materials resources in the world, because of its huge size of population and enormous disparity, China does not have any other option but boosting both its energy and materials consumption per capita. We can expect that the amount of resources (both energy and material) metabolized by China in the future will grow dramatically, following Ostwald's predictions for societies under development (Ostwald, 1909).

When analyzing population structure and actual trends, we could identify a very special characteristic of China in relation to the rest of developing countries. This is the large fraction of working force in the population at this moment. This special characteristic, in fact, on one hand, is providing a clear comparative advantage for China (at the cost of tolerating longing working hours). On the other hand, this peculiarity may represent an Achilles' heel for the future development of this society, when the large mass of adults will transform into a large mass of elderly. The combined effect of demographic growth and the distribution of the population over age classes put China, in the same situation experienced by Ecuador regarding the spiral of development (Falconi-Benitez, 2001). That is, in spite of the high rate of investments in its economy China might not be able to keep the positive spiral of economic growth.

5.3. The possible effect of China's economic growth on world energy demand

Regardless of whether or not China wins the battle to get into a positive spiral of growth, it will keep consuming more and more energy and natural resources. China has the third largest coal reserves in the world, but for the increasing cost associated with pollution and for efficiency reasons, it must develop new technologies – such as coal gasification – before being able to make a more efficient use of it. Moreover, in spite of dramatic improvements in energy efficiency, the Chinese economy is consuming more and more energy despite its effort to shift from coal to oil and natural gas. So, before developing those technologies, the international demand China poses on oil and natural gas will keep increasing. These facts explain why China is not only a key player at the international energy market as a buyer of oil and natural gas, but it explains also why China is starting to buy prospecting rights everywhere, and oil and gas facilities to satiate its long term thirst for energy carriers. It is clear that unless both extraction and refining capacity are increased at the world level, Chinese pressure will keep oil, gas, coal, and other key materials prices high in the foreseeable future. This has been finally acknowledged by the International Energy Agency (IEA, 2005) in its last World Energy Outlook, where it asks for an investment of about $480 billion up to 2030.

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