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Changes of human time and land use pattern in one mega city's urban metabolism: A multi-scale integrated analysis of Shanghai

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Abstract:

Human time and land use are important elements in terms of one mega city's urban metabolism, thus, it is critical to find an integrated approach to evaluate their contributions. In this paper a dual-fund analytical framework has been developed by employing the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach to analyze the metabolic pattern of one mega city from economic, social and ecological dimensions. A case study of Shanghai was undertaken to study its historical pattern changes and evaluate the possible results with the implementation of the 13th Five Year Plan. Research results show that shanghai relied on the extraneous labor force to fulfill the need of working hours and economic transition in Shanghai occurred with the booming development of tertiary sector. Shanghai's land resource is very scarce to meet its need of development, leading to a need of adopting integrated efforts to. In order to achieve the proposed targets, economic labor productivity and land use performance should be improved through the application of various measures, including industrial and energy structure optimization, energy saving, capacity building and circular economy.

Key words: urban metabolism, MuSIASEM, land use, mega city, human time

1. Introduction:

Urbanization has become a global trend and it has induced the raid development of mega cities[1]. According to UN (2014), megacities are defined as cities having at least 10 million inhabitants (UN, 2014). Given its densely-populated and short of land features, mega cities are usually described as a socio-economic phenomenon (Moghadam and Helbich, 2013) facing various issues, such as population expansion, air and water pollution, waste generation, traffic jams (Goyal et al., 2006; Moghadam and Helbich, 2013; Zhao, 2010). Urban metabolism analysis has been undertaken by many researchers to seek innovative solutions to the issues. It is a concept that applies ecological principles to analyze urban system issues. From this perspective, the urban system could be seen as a superorganism and thus urban metabolism could be defined as “the total sum of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” (Kennedy et al., 2007). Urban metabolism studies quantify the inputs, outputs and storage of the elements in the urban system by integrating process analysis, accounting, assessment, simulation and optimization of the regulating mechanisms (Zhang, 2013).

Kennedy et al.(2011) reviewed the study of urban metabolism and its application to urban planning and design. Case studies have also been undertaken in Bangkok (Færge et al., 2001), Taipei (Huang and Hsu, 2003), Paris (Barles, 2015), and Beijing (Zhang et al., 2009), etc. These studies either quantify the energy equivalents following Odum’s emergy theory or describe the city’s mass flows of water, materials and nutrients. But few studies focused on the contribution of human time and land use in urban metabolism from an integrated perspective of environment, society and economy. Discovering the allocation of human time among different sectors can provide information on human activity intensity associated with energy and economic flows. Meanwhile, land use is an important subject in urban planning as the available land is definitive and there should be enough ecological land reserved for supporting natural environment. Consequently, there is a need to conduct quantitative analysis on the contribution of human time and land use in terms of urban metabolism.

Multi-Scale Integrated analysis of Societal and Ecosystem Metabolism (MuSIASEM) is a method that allows establishing a general scheme to adequately address the nature of sustainability. It provides a methodological framework to study the metabolic pattern by addressing both human activities and land uses (Giampietro et al., 2014; Giampietro et al., 2009b). Given the complex nature of real-world systems, the MuSIASEM approach has obvious advantages over composite indicators, such as ecological footprint, which may be favorable for policy makers but represents a brutal simplification of reality by collapsing a complex information space encompassing multidimensional issues into a single numerical index when describing metabolic patterns. The application of MuSIASEM concepts derived from bio-economics and complex system theory allows the simultaneous use of social, economic, ecological variables across different levels and scales even if they are defined within distinct descriptive domains.

[1] Megacities are defined as cities having at least 10 million inhabitants (UN, 2014)

MuSIASEM has been applied to study many countries' societal and ecosystem metabolism, such as Ecuador (Falconí-Benítez, 2001) , UK (Gasparatos et al., 2009a), Romania, Bulgaria, Poland and Hungary (Iorgulescu and Polimeni, 2009), Peru (Silva-Macher, 2015). Also, there have been some applications of this method at the regional level. For instance, Ramos-Martín et al.(2009) undertook an analysis on energy metabolism of Catalonia in Spain across different scales. Siciliano et al.(2012) applied the MuSIASEM method to study the changes of two Italian regions over time. Madrid-López and Giampietro (2015) developed the scheme to study the water metabolism and applied to Punjab in India. However, studies at the city level are very rare in the international journals. With regard to the application of this method in China, the exosomatic urban metabolism was studied at national level (Ramos-martin et al., 2006) and regional level (Geng et al., 2011). At the city level, two studies were conducted for the cities of Shenyang (Liu et al., 2010) and Shanghai (Dai and Yan, 2013). Both studies were published in Chinese language journals and no papers at the Chinese city level have been published in the international journals. Since city represents the human-dominated socio-economic and ecological system at a local level, it is vital to investigate its metabolic pattern.

Most of the above applications took the human activities as the fund element (the definition of fund element would be further explicated in the next section) when applying the MuSIASEM method. Meanwhile, the MuSIASEM method has explicitly introduced land use as the fund element as well (Giampietro and Bukkens, 2015; Giampietro et al., 2014; Giampietro et al., 2009b). There have been several studies of MuSIASEM method applied from this perspective. For instance, Serrano-Tovar and Giampietro (2014) applied MuSIASEM to study the metabolic patterns of land uses across different levels and scales of rural Laos. Ariza-Montobbio et al. (2014) integrated energy and land-use planning to study the socio-metabolic profiles along the rural-urban continuum in Catalonia, Spain. Siciliano (2012) undertook a multi-level integrated assessment on land use changes in rural China. However, there have been few applications of this method to study the land use of urban system, except that Aleu and Baeza (2009) made a first attempt to extend the MuSIASEM method to a spatial dimension using GIS techniques in the Metropolitan area of Barcelona. When investigating systems operating with clearly different metabolic patterns (e.g., urban versus rural), the land evaluation depends on the set of indicators chosen to quantify performance. In a rural system, research studies on land uses focus on land productivity in terms of crop yields, while in an urban system it is evaluated by the utilization rate and the different types of construction land's proportion (Deng et al., 2008). Consequently, it is necessary to further apply this approach in the urban systems.

Under such a circumstance, this study aims to explore the applicability of the MuSIASEM method to urban systems by employing a case study approach. Shanghai is chosen as the case study area since it is the largest Chinese city and is facing various development challenges. By developing an integrated MuSIASEM scheme to characterize the performance of Shanghai's socio-economic and ecological system in a dual-fund analytical framework, this study tries to test the feasibility of MuSIASEM method to quantify and analyze the changes of land uses in urban metabolism. The whole paper is organized as below: After this introduction section, section 2 depicts the methodological framework, as well as the case study area and data sources. Section 3 presents research outcomes, including the historical changes of the metabolism pattern in Shanghai.

Section 4 discusses the policy implications for possible application results of the 13th Five-Year Plan. Finally, section 5 draws research conclusions.

2. Method and data

2.1 Theoretical foundations of MuSIASEM

This study is based on the method of Multi-Scale Integrated analysis of Societal and Ecosystem Metabolism (MuSIASEM), which was introduced by Giampietro and Mayumi (Giampietro, 2000; Giampietro et al., 2009b, 2001). It is a transdisciplinary approach that integrates quantitative information belonging to non-equivalent descriptive domains across various scales and dimensions. The approach has been developed by integrating various theoretical concepts:

(i) Georgescu-Roegen's flow-fund theories in the field of bio-economics (Georgescu-Roegen, 1971) : The flow-fund theory originated from Lotka's double metabolism of human society theory, namely, the endosomatic metabolism inside the human body and the exosomatic metabolism outside the body (Lotka, 1956). Then Georgescu-Roegen (1971) introduced the flow-fund theories to study the biophysical roots of economic processes. In a system, flow elements are represented by inputs (e.g., food, energy and mineral inputs) and outputs (e.g., garbage, GHG and other pollutants), while fund elements are represented by structural elements (e.g., human beings, land, technical capital) that compose the functional compartments (e.g., economic sectors) of the system. By definition flows have to either appear (outputs) or disappear (inputs) over the duration of the analysis, and funds have to remain the same identity over the time scale of the analysis;

(ii) complex system theories (Kauffman, 1993; Morowitz, 1979; Odum, 1995) : It is related to the fact that evolving metabolic systems are operating across multiple spatial-temporal scales. Deeply rooted in complex system theory, MuSIASEM focuses on revealing the complex interrelations between structural and functional elements of society across various hierarchical levels of organization;

(iii) hyper-cyclic and dissipative compartments theories applied to ecology (Eigen, 1971; Ulanowicz, 1986, 1995) : According to the theory of ecosystem structure and self-organization, the network of matter and energy flows making up an ecosystem can be divided into two parts: one part is a hyper-cycle and the other is a purely dissipative part. The hyper-cyclic part is a net energy supplier for the rest of the system. The dissipative part is an energy degrader and is indispensable in that it provides control mechanism and thus stabilizes the whole system.

2.2 Analytical framework

MuSIASEM can be employed as both a diagnostic tool and a simulation tool (Giampietro and

Bukkens, 2015) . For the diagnostic purpose, it could be used to describe and uncover the metabolic pattern of the socio-economic system by providing integrated information on population, working force, land use, energy consumption and GDP. For the simulation purpose, MuSIASEM performs a feasibility (external constraints), viability (internal constraints), and desirability (benchmark) check on proposed scenarios.

The first step is to define what the system is in terms of fund element (Giampietro and Bukkens, 2015). In this study, two different funds are defined, including human activities and land uses. The advantage of MuSIASEM is to integrate quantitative descriptions by adopting non-equivalent accounting systems so that bridges across different analysis dimensions can be established. In particular, the two complementing but non-equivalent funds do refer to the same observed system in relation to the same set of observed flows. In this regard, the size of the society is defined by total human activities (population x 8760 hours /year [2]) from a socio-economic perspective and defined by the total managed land (in hectares/year) from an ecological view.

Figure 1 shows the analytical framework of the dual-fund system at different hierarchical levels. In terms of human activities, total human activities (THA, Level n) are allocated between paid work sector (HA_{PW}, Level n-1) and household sector (HA_{HH}, Level n-1), with the former divided into primary sector (HA_1, Level n-2), secondary sector (HA_2, Level n-2) and tertiary sector (HA_3, Level n-2). In terms of land use, total available land (TAL, Level n+1) within city boundary is divided into managed land (ML, Level n) and non-managed land (NML, Level n), and the former is further categorized into land use dedicated to productive sector (ML_{PS}, Level n-1), household sector (ML_{HH}, Level n-1) and infrastructure (ML_{INF}, Level n-1) sector, according to their distinct usage. Productive sector can be further broken into primary sector (ML_1, Level n-2) and secondary sector (ML_2, Level n-2). Primary sector mainly refers to farming, forestry, fishery, husbandry and ranching industries, secondary sector mainly refers to mining, refining, manufacturing, energy and water supply, construction industries and tertiary sector mainly refers to service, trade and government.

(insert figure 1 here)

Obviously in the human activity fund hierarchies, the primary and secondary sectors form the hyper-cyclic part (production sector) and the tertiary and household sectors form the dissipative part (consumption sector). In the land use fund hierarchies, due to the availability of land use data, it is more complicated. Land use dedicated to the tertiary sector is not specifically segregated owing to its ambiguous boundary with household sector[3]. Thus, the land used for the primary and the secondary sector can be defined as the hyper-cyclic part, the land for households and infrastructure land (which contain tertiary and household sector) as the dissipative part.

Once the fund is defined, the relevant flows chosen to analyze are energy throughputs and GDP outputs. Energy throughput shows the amount of exosomatic energy consumed at each level of

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[2] 24 hours/day x 365 days/year= 8760 hours/year

[3] The commercial and service activities usually take up some floors of a building in the center urban area while the other floors are dedicated to household sector (Ariza-Montobbio et al., 2014).

the system and GDP is considered as an output flow to check the productivity of the system. A series of intensive variables, including flow-fund ratios and fund-fund ratios, are introduced to diagnose the hierarchical structure and metabolic pattern of the society. Table 1 lists all the variables used in this paper and their meaning.

(insert Table 1 here)

2.3 Case study city

Shanghai is the largest Chinese city and also the most densely populated in China. It locates in the easternmost region of Yangtze River Delta of China. It occupies an area of around 6340 km^2 and had a population of more than 24.25 million in 2014. According to the characteristics of the continent formation, Shanghai is divided into 4 geomorphic types, i.e., the western lacustrine plain, the central Huangpu River plain, the eastern coastal plain and the estuarine delta. These terrains create the land use features, i.e., low and flat terrain, broad river, lake and fertile soil. Figure 2 shows the location of Shanghai.

(Insert Figure 2)

Shanghai has experienced robust urbanization in both scope and intensity dimensions, driven by rapid economic development. Its GDP reached 23567.7 billion RMB (currently 1USD=6.48 RMB) in 2014. Figure 3 shows the GDP composition of Shanghai from 2001 to 2015. It is obvious that the tertiary sector contributed the most GDP in Shanghai. The rapid development of Shanghai also induced a large amount of energy consumption. The total energy consumption of Shanghai reached 110.84 million tons of coal equivalents in 2014. In Shanghai's 13^{th} Five-Year Plan (2016-2020), the government of Shanghai set up distinct targets on population control and land uses, in which total resident population should not exceed 25 million and total construction land should not exceed 3185 km^2 until 2020.
(insert Figure 3)

2.4 Data source

Data on energy consumption were obtained from the Energy Balances of the Shanghai statistical yearbooks. Data concerning hours of total human activity were obtained from the population statistical data in the Shanghai statistical yearbooks and were supplemented with statistical data in the population census of Shanghai municipality. The population data were multiplied by 8760 hours/year in order to calculate the total amount of annual human activity expressed in hours (using the convention of 365 days and 24 hours per day). The hours of human activity in the Paid Work sector were obtained from statistical data of employment and per week hours of work by economic activity from the China labor statistical yearbooks. Data concerning human activity in the Paid Work category by sector of economic activity (primary, secondary and tertiary) were obtained from employment data in the Shanghai statistical yearbooks. Hours of human activity for household sector (HH) were obtained by the difference between PW and the total: HA_{HH}=THA-HA_{PW}. GDP and GDP by sector statistics were obtained from the Shanghai statistical yearbooks.

Data on land use were obtained from Bureau of Planning and Territorial Resources Management of Shanghai, in which land use is classified by farming land, development land and non-managed land. According to their functions, farming land includes agrarian land, orchard land, forestry land, pasture etc. Development land includes land used for industries, residence, infrastructure, commerce and service etc. However the detailed segregation land use data are only available from 2003 to 2007. Only data on farming land, development land and non-managed land are available for the years after 2008. In terms of applying MuSIASEM approach, farming land represents primary sector, while development land includes secondary sector, tertiary sector and household sector. In order to fill the gap of lack of available data, detailed segregation land use data of land in Shanghai for the year of 2013 was obtained from China Urban Construction Statistical Yearbook. However, in order to have a unified statistical channel, data from the two sources were not mixed together. In this regard, the data of the year 2013 obtained from the statistical yearbook were only used in the analysis of the actual metabolic pattern.

3. Results

3.1 Human activities as the fund

By employing the MuSIASEM approach, human activities are regarded as one fund element. Figure 4 shows the characteristics of the metabolic pattern of the paid work sector and its sub-sector from 2001 to 2013. In this figure, the horizontal axis represents the ELP (Economic Labor Productivity), which equals to GDP per working hour, while the vertical axis represents the EMR (Exosomatic Metabolic Rate), which equals to energy consumption per working hour. Those bubbles represent historic changes year after year from 2001 to 2013. The size of each bubble represents the human activity time size, i.e. the whole annual working hours in each sub-sector.

(insert figure 4 here)

It is easy to identify the differences across the three sectors, due to the gradients in the technology performance. In particular, human activities input in the tertiary sector is a little bit more than the secondary industry as the sizes of the corresponding bubbles are bigger and the secondary industry is the most energy intensive among the three industries. The overall trend of labor productivity (represented by ELP variable) is on the rise. It implicates the improved quality of labor force. However, the amount of energy throughput is not reduced, indicating that energy consumption is coupling with economic development. In order to better understand temporal changes, an analysis on different variables was conducted.

Figure 5 shows the dynamic changes of ELP in Shanghai from 2001 to 2013. It is clear that the ELP of the secondary industry had the highest value among the three sectors before 2008. The turning point in 2008 could be explained by the global financial crisis occurred during 2007-2008, which had a serious impact on Shanghai's manufacturing industry. Purchasing orders from international consumers significantly decreased from the first quarter of 2007 (Shanghai Government, 2010), leading to a sharp decrease of the ELP of the secondary sector from 67.2 RMB/hour in 2007 to 58.6 RMB/hour in 2009. However, such a value increased again from the year of 2009, thanks to the recovery of the global economy and China's huge investment on infrastructure in 2008. This event eventually helped Shanghai to accelerate its industrial transition so that more service businesses have been promoted. Such an initiative resulted in that the ELP of the tertiary sector has become the highest since 2008. It also attracted more talents to move in Shanghai.

(insert figure 5 here)

Figure 6 shows the allocation of human activities (fund shares). It covers all the changes from 2001 to 2013, with a clear tendency of decreased proportions of the primary sector. This could partly be explained by the advances in agricultural technologies and successful application of these technologies. It also reflects the ongoing trends of labor force moving from primary sector to secondary and tertiary sectors. Tertiary sector experienced continuing increases in the proportion of human activities, while secondary sector experienced a decrease during global economic crisis. In general, human time allocated to tertiary sector has the highest value, which takes more than half of the paid work hours. In this regard, Shanghai has been chosen by the national government as one national innovation center, which means that high-tech businesses have been fully supported, such as the famous Zhangjiang high-tech zone in Pudong. Also, as the national financial center, Shanghai is the home of national stock market. Many international and domestic financial firms have their offices in Shanghai and hired many talents both at home and abroad. In addition, as the largest mega city in China, Shanghai has various service businesses, such as retails and wholesales, fashion design, media, information and communication technologies (ICT), etc. These sub-sectors further attracted many talents due to their agglomeration effects.

(insert figure 6 here)

As tertiary sector is playing an important role in Shanghai's economic development, a further analysis on tertiary sector is conducted by using the classical four-quadrants (see figure 7). The rightward horizontal line represents the total GDP output in the paid work sector (Level n-1). The upward vertical line represents the total labor hours (human time in the paid work sector). The leftward horizontal line represents the labor hours in the tertiary sector. The downward vertical line represents the GDP output of the tertiary sector. The whole figure illustrates human time allocation and GDP compositions for the years of 2001, 2006, 2011. For Level n-1 (the first quadrant), the economic labor productivity of the paid work sector had been almost tripled from 3.57 RMB/h in 2001 to 9.33 RMB/h in 2011. The working hours of the paid work sector are also increasing. The GDP experienced a quadruple increase from 2001 to 2011. For level n-2 (the third quadrant), both the working hours and GDP values increased significantly. The GDP experienced a quadruple increase, while the economic labor force doubled from 34.08 RMB/h to 75.42 RMB/h, verifying the prosperity of tertiary sector during this period.

(insert Figure 7 here)

In order to study the increasing trend of working hours in the paid work sector, the demographic structure of Shanghai should be investigated. Figure 8 shows the population pyramid of Shanghai for years of 2000 and 2010. Shanghai's total population experienced a significant growth from 16 million in 2000 to 23 million in 2010. The immigration populations increased from 3.8 million (24% of the whole population) in 2000 to 8.9 million (39% of the total population) in 2010 (Deng and Liao, 2014). Most immigration populations are at the age between 20 and 40 (Gao and Zhou, 2007), reflecting that they were attracted to Shanghai to meet the urgent need of local economic development. Particularly, a majority of these immigration populations are well educated or skilled since the available positions in the labor market always require special expertise or skills.

(insert Figure 8 here)

Figure 9 presents the EMR (human activity as the fund) values for the period of 2001-2013. In general, the EMR values of both Level n-1 (EMR_{pw} and EMR_{hh}) and Level n-2 (EMR_1, EMR_2, EMR_3) slightly increased, but with a clear decrease in 2007 due to the global financial crisis. Among the EMR values of three sectors, such a value for secondary sector is the highest. With the implementation of industrial relocation policies, many inefficient manufacturing businesses were phased out or relocated to neighboring provinces (such as Jiangsu or Zhejiang), leading to that only large state-owned heavy industries (such as the steel, automobile, petrochemical industries) or high-tech businesses are operating in Shanghai. These heavy industries are energy-intensive, resulting in that the EMR of secondary sector is much higher than that of the other two sectors.

(insert figure 9 here)

3.2 Land uses as the fund

When employing MuSIASEM approach to the fund of land use, the fund share of different types of land uses should be analyzed. Figure 10 depicts a clear picture of land use structure in Shanghai and its dynamic changes. It is clear that the farming land had been reduced and the development land had been increased. Since the total amount of available land is fixed, it is obvious that the farming land has been turned into the development land.

(insert figure 10 here)

In terms of the fund-fund ratio, Figure 11 shows the differences of human time per unit land use of the production sector (primary and secondary sectors) and the consumption sector. The consumption sector has the highest value as it covers both the household sector and the tertiary sector. The household sector includes people's sleep and leisure time and the tertiary sector needs intensive human time input. The increasing value of the tertiary sector implies the population increase in Shanghai and their need for more residential land. Although the modern manufacturing employs more automation technologies, the secondary sector still needs substantial human time input. The line for secondary sector is quite steady, indicating that the land needed by the secondary sector is sufficient. This is also partly due to the fact that many manufacturing firms were relocated to the surrounding provinces such as Zhejiang and Jiangsu. As for the primary sector, since Shanghai is a large mega city with very few rural populations, human time allocated to this sector is proportionally very low.

(insert figure 11 here)

In terms of flow-fund ratio, the EMR_{ML} (land use as the fund) ratios were further analyzed. The distribution of energy consumption by unit of land was calculated by multiplying the fund-fund ratios by the average values of EMR_{HA} (MJ of energy throughput per hour human time) of that sector. However, since data on the segregation of land use for tertiary and household sectors are not available, total energy consumption of tertiary and household sectors were used to divide the total land use for these sectors so that the EMR_{ML} value for the consumption sector can be obtained. As shown in Figure 12, the secondary sector is still the most energy-intensive sector in terms of land use, leading to increasing values of EMR_{ML}. It could be explained by the booming industrial development in Shanghai from 2003 to 2006. Meanwhile, due to increasing populations and improved life quality, the consumption sector consumed a lot of energy resources, mainly in various buildings and transportation areas, leading to increasing values of EMR_{ML} of the consumption sector.

(insert figure 12 here)

3.3 Metabolic pattern based on a dual-fund

Figure 13 presents the analysis results of the urban metabolic pattern in Shanghai for the year of 2013. The funds are represented by the circles with human figures. The size of each circle represents the amount of managed land allocated to this sector. The number of human figures represents the proportion of human time allocated to this sector. The described flows represent energy throughput and GDP output. The breadth of the flows represents the associated quantity. This figure depicts different flows' compositions and the funds' allocations. The primary sector occupied most land, but with the least human time allocation. It consumed the least energy resource and produced the least GDP. The secondary sector occupied the second most land, but with the penultimate human time. It consumed the most energy resource and produced the second highest GDP. The tertiary sector occupied nearly the same land as the household sector, but with much less human time. It consumed penultimate energy resource, but produced the most GDP. The household sector consumed the most human time with the second largest energy consumption.

(insert figure 13 here)

4 Policy implications for the 13th Five Year Plan of Shanghai

In order to provide more valuable policy implications, the MuSIASEM approach is applied as a simulate tool to perform a viability (internal constraints) and desirability (benchmarks) check on the proposed scenarios (Giampietro and Bukkens, 2015). The scenario designed in this paper is the prediction of policy implementations of Shanghai's 13th Five-Year Plan (for the period of 2016-2020). The Five-Year Plan is the comprehensive plan in China, covering economic development initiatives, mapping strategies for economic development, growth targets and reform policies in the relative time frame (Shiu and Lam, 2004). It started in 1953 and then had a break for the period of 1963-1965. It then recovered in 1966 until now. Shanghai government has set up the goal to control the total resident population within 25 million and the total construction land within 3185 km^2 until 2020. Under such a circumstance, policy implications can be achieved by considering the local realities.

First of all, in terms of population control the population of Shanghai reached 24.2 million in 2014, leading to only 0.8 million's population increase till 2020. Table 2 lists some ELP values of the paid work sector in several countries or regions from previous studies. The ELP of the paid work sector in Shanghai had increased from 3.54 dollars/h in 2001 to 11.03 dollars/h in 2013. Compared to these benchmarks, the ELP of Shanghai is much lower than that of the EU and higher than the average level of China. Such a phenomenon can be explained by China's abundant labor forces. It is relatively easier to attract cheap labor forces to mega cities in China where more opportunities are available.

(insert Table 2 here)

However, China's "one-child" policy has threatened its demographic dividend (Cai, 2010) and the increasing aging populations have brought heavy burdens to local governments, such as medical care, lack of skilled labor forces, specific housing requests by aging peoples, and spiritual needs, etc (Flaherty et al., 2007). Although some policies have been released in order to respond these challenges, such as the second child policy, improved pension policies and increasing concerns on retired persons, mega cities (such as Shanghai) are still facing a lack of younger labor forces. Therefore, it will become a dilemma to call for more young labor forces while controlling the total population in due time. With regard to Shanghai, it may be more rational to set up higher criteria for the new immigration populations while at the same time providing more attractive policies to those aging persons so that they can find other places for their retired life.

Second, the Chinese government announced that the annual GDP increasing target would be 6.5% per year in the 13th Five Year period. Based on 2356.8 billion RMB's GDP in 2014, Shanghai will have to achieve the GDP of 3438.9 billion RMB in 2020. If working force will not substantively change from 2016 to 2020, the labor productivity should be at least 16.36 USD/hour in 2020 in order to reach the economic target. Compared to the ELP value of Shanghai in 2013 (11.03 USD/hour) and the ELP values of the developed economies, it is still feasible to achieve such a target without substantial work force changes.

However, such a GDP increase target cannot be achieved without significant industrial structure changes. Although many inefficient manufacturing businesses were shut down or relocated outside Shanghai, there are still many state-owned heavy industries. Many of them are energy intensive and generate a lot of pollutants. Consequently, there is a need to further consider how to relocate these industries so that more land can be recovered for new development. During such a process, it will be more important for Shanghai government to pay more attention on cleaning up such brownfields since many of them have been contaminated by various pollutants, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyl (PCBs). Similar experiences have already been gained in Shenyang and their expertise and experiences should be transferred to Shanghai (Sun et al., 2013; Ren et al., 2014). Also, new industrial sectors, such as ICT, bio-pharmaceutical, smart manufacturing, new energies, new materials and new energy, should be supported with more preferable policies. In this regard, Shanghai has been chosen as the national scientific innovation center, which means that high-tech industries will be the mainstay for its future development. It implies that more high quality labor forces will be recruited from both at home and abroad. Thus, the Shanghai government should create better working and leisure conditions so that such new immigration persons can adapt to their new homes. As such, appropriate policies should also be prepared so that those emigration populations (from those state-owned heavy industries) can find their new homes in the neighboring provinces. With such a robust industrial structure change and low-end labor forces' moving-out and high-end talents moving-in, corporate leaders should seek business opportunities from low-end and labor-intensive industries to high-tech and innovative industries.

Third, with regard to land use in Shanghai, there are several aspects that deserve more discussions. With the unprecedented housing price increase in late 2015 and early 2016, now the real estate price in Shanghai is extremely high, leading to that it is difficult for young employees to purchase their own apartments (Gu et al. 2015). Shanghai is a mega city, with limited land supply. In 2013, only 30.47 km^2 land was available for new development, while this number became 30.67 km^2 in 2014. Unfortunately, the construction land reached more than 46% of the total land area in 2014. This percentage is higher than that of Greater London, Grand Paris and Tokyo metropolitan (China Development Research Foundation, 2010). According to Shanghai's 13^{th} five year plan, the potential new development land should be less than 60 km^2 till 2020. Such a fact impelled the local government to enforce more stringent regulations on urban development and leading to the auction of high land prices by the real estate companies, which result in the increasing housing price.

In order to solve such a problem, various efforts should be initiated. For instance, it will be rational to reclaim some new land from sediment. Shanghai locates at the estuary of Yangtze River, in which this river annually transports 4.68×10^8 t of sediment into the East China Sea (GSCI, 1996). Half of the sediment settles in the area of the river mouth (Chen et al., 1985), leading to that the intertidal marsh on the southeast side of Chongming island (the third largest Chinese island under Shanghai's control) expands at an annual rate of 100–150 m and creates about 5 km^2 new marsh flats every year (Wu et al., 2005). At least over 500 km^2 of intertidal marsh flats had been reclaimed by constructing dikes since 1956 (Wu et al., 2002). These tidal lands are important land reserve for Shanghai. Some local large state-owned industries, such as the Baosteel group, Shanghai Petrochemical group, and Pudong International Airport, were established partly on the reclaiming tidal lands. Another key project, namely, Lingang new town, a project initiated in 2003, includes 133km^2's reclamation land (Sha et al., 2014). However, land reclamation takes longer time and a big amount of financial investment. In addition, previous studies showed that the reclaiming land may degrade the coastal environment and result in the loss of biodiversity (Goss-Custard and Yates, 1992; Wu et al., 2002). Therefore, it is not feasible to solely rely on such a solution.

Another feasible solution is to consider how to better manage the existing urban land. With the increasing investment on tertiary sector, it is suitable to reconsider the use of the original industrial land. With the relocation of more manufacturing industries, the reclaimed brownfields should be first regarded as the key land for service sector although special care should be taken to ensure that the soil in such brownfields is safe for new development. This will create new business opportunities, such as soil remediation and field reconstruction. Also, many old residential buildings are old with only several stories. Thus, it makes sense to first demolish them and then allow the new skyscrapers to be built up so that more residents can move in and more land can be saved. Moreover, even the need to suit the new immigration populations is critical, more ecological land (such as green land or wetland) should be reserved so that ecosystem can function well.

Finally, it will be appropriate to optimize local energy structure and promote circular economy. As the largest mega city in China, Shanghai's energy consumption is huge. However, it mainly relies on coal-burning power plants for its power supply and fossil fuels for its heat supply and transportation system. Therefore, it will be crucial to increase the share of renewable or clean energy sources, such as wind power, solar power or geothermal power. In this regard, geothermal power is more feasible since it provides low cost and reliable energy supply with much less carbon dioxide emissions and other air pollutants emissions (Geng et al., 2013). Some demonstration projects were demonstrated in Shanghai's 2010 world exposition, but wide applications should be further provided. As such, energy saving efforts should be made by local industries. Although the city is going to phase out all the energy intensive or polluting industries, such a progress may take longer time and their operation will continue. Under such a circumstance, it is necessary for these industries to take all the necessary energy saving measures, such as energy cascading, the application of energy efficiency technologies and equipment, energy saving education, and collaboration with local communities. Furthermore, circular economy has been proved as one effective method on reducing the overall consumption of virginal materials and increasing resource efficiency (Geng et al., 2012). Useful strategies, such as eco-design, process integration, cleaner production, green governmental procurement, eco-industrial parks and urban symbiosis, should be implemented both at the individual company level and the whole city level (Geng et al., 2016; Zhu et al., 2013).

5. Conclusions

Due to rapid economic development and increasing population, mega cities are facing more challenges, such as solid wastes, water supply and wastewater treatment, energy supply and very recently climate change. In order to make sure that these mega cities are moving toward sustainable development, it is critical to study urban metabolism in mega cities so that the detailed metabolic patterns can be identified and appropriate development policies can be prepared. Under such a circumstance, this paper employs the MuSIASEM approach to study urban metabolism in Shanghai (the largest Chinese city) for the period of 2001-2013,. Land use was investigated as the fund in urban metabolism and an analytical framework based on dual-fund was established.

The key research finding is that MuSIASEM approach is a useful diagnostic tool to study the historical dynamic changes of the human time and land use pattern in mega cities. The results show that Shanghai's economic development experienced rapid development with increasing working hours and more immigrated labor forces. Also, labor productivity significantly improved, demonstrating the advancement of technology and improved labor force quality. Although the 2007-2008 financial crises brought some negative impacts on Shanghai, it accelerated Shanghai's economic transition by supporting more tertiary businesses and phasing out/relocating many inefficient manufacturing businesses. Since then more working hours had been allocated to the tertiary sector, leading to the change of population structure. However, with limited land available for further development, the city of Shanghai is facing serious challenges on continuing its efforts for enlarging its total land. Therefore, rational consideration on land use should be taken so that feasible solutions can be recognized. In order to further improve this city's sustainability, integrated efforts should be made, such as industrial and energy structure optimization, energy saving, circular economy and related capacity building actions. Although these policy implications are prepared for Shanghai, many other mega cites may refer to this case study and raise its own strategies so that mega cities can move toward sustainable development.

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Figure

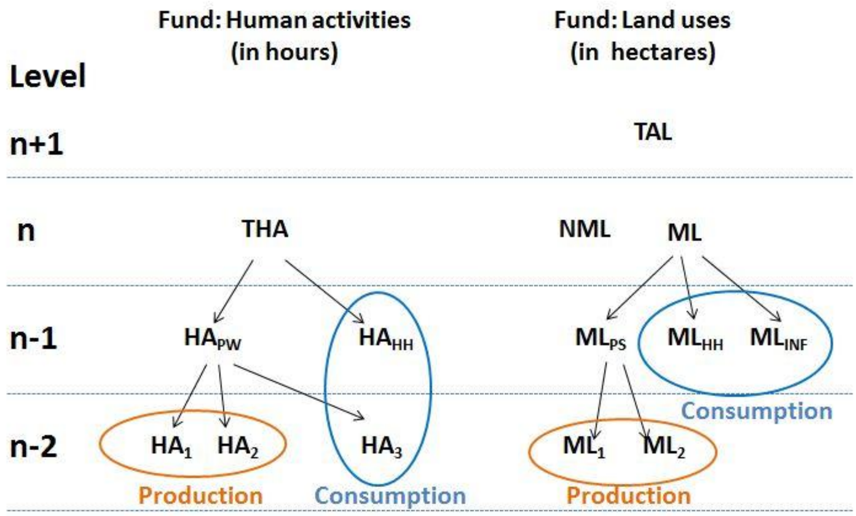

Figure 1 Dendrogram of the dual-fund elements at different hierarchical levels

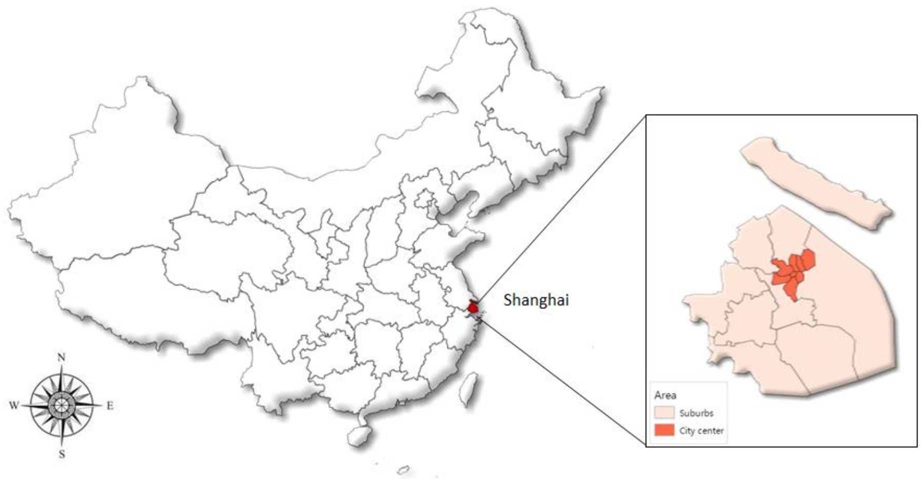

Figure 2 Location of Shanghai

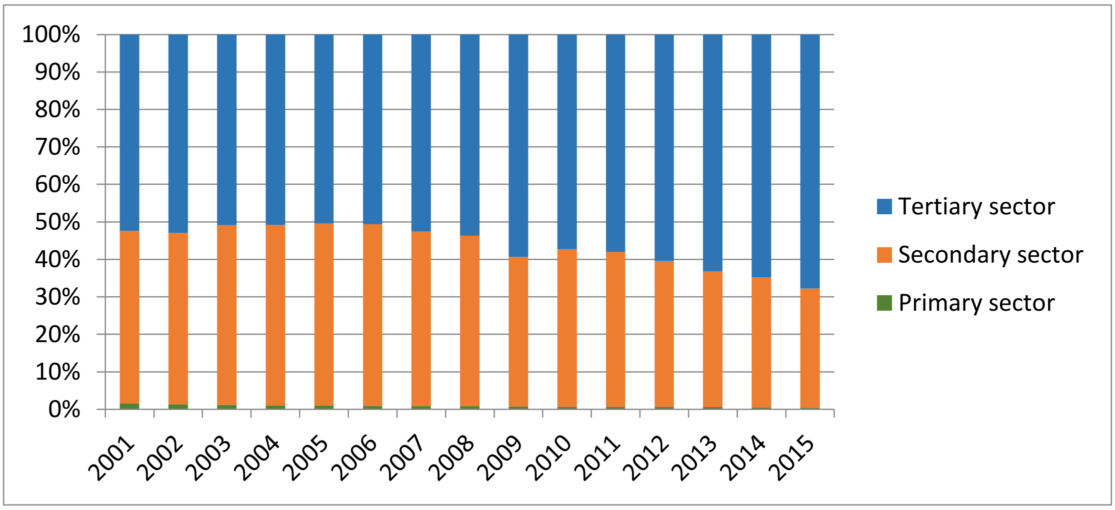

Figure 3 GDP compositions (Flow shares)

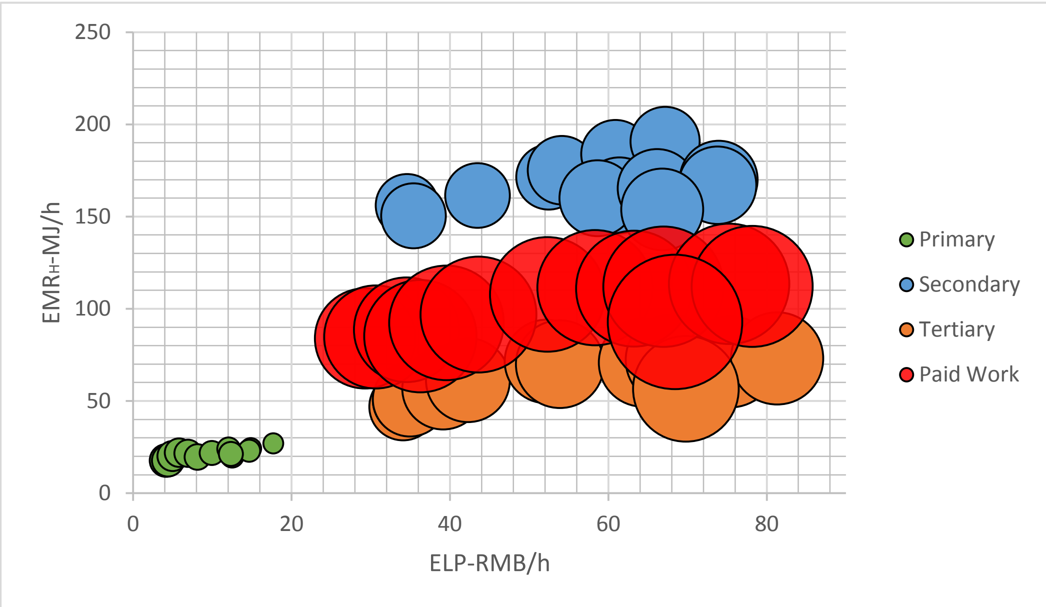

Figure 4 Characteristics of the metabolic pattern of sub-sectors of the economy of Shanghai from 2001 to 2013

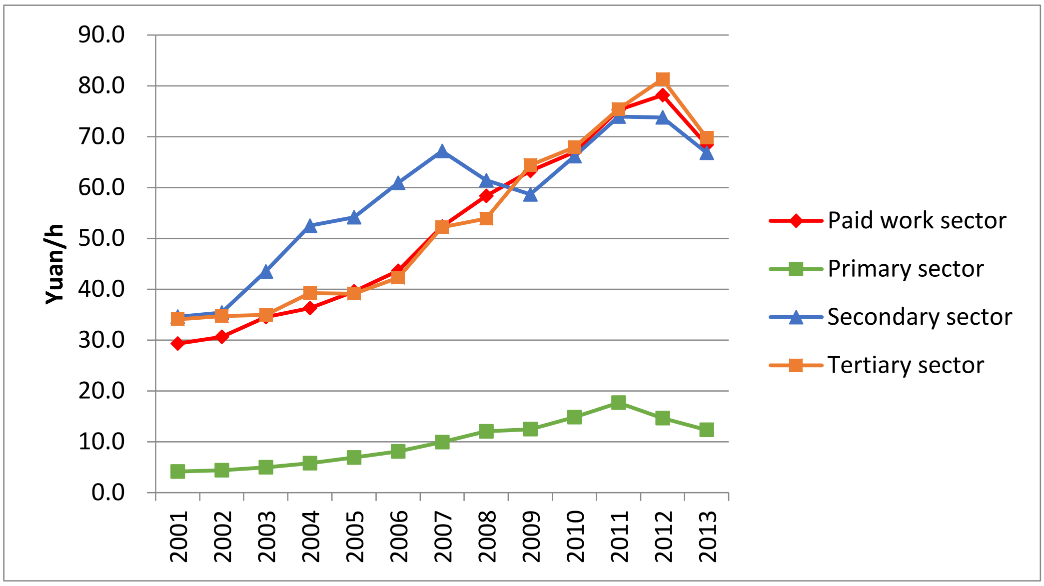

Figure 5 ELP values in Shanghai from 2001 to 2013 (Flow-Fund ratio)

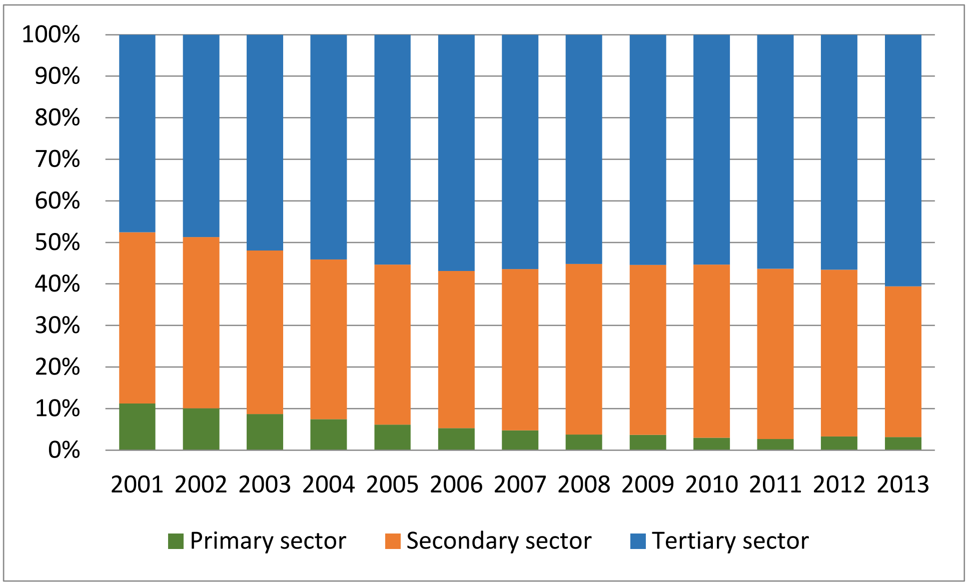

Figure 6 Human activities allocations (Fund shares)

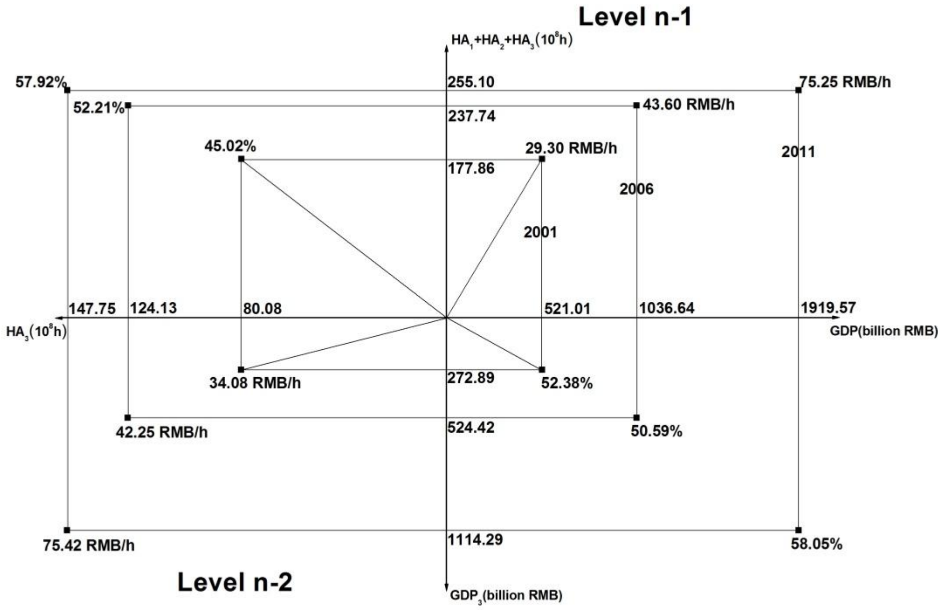

Figure 7 Flow-fund representation scheme of Shanghai's tertiary sector for the years of 2001, 2006 and 2011

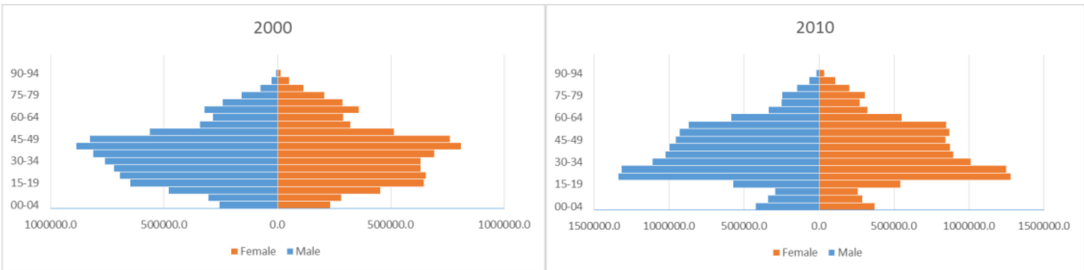

Figure 8 Population pyramid for Shanghai in years of 2000 and 2010

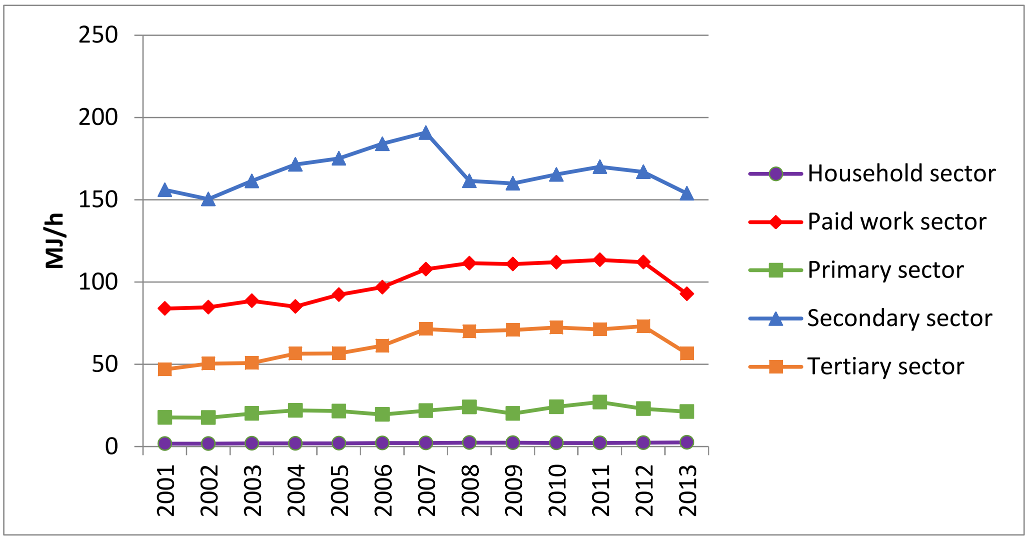

Figure 9 EMR_{HA} values in Shanghai from 2001 to 2013 (Flow-Fund ratio)

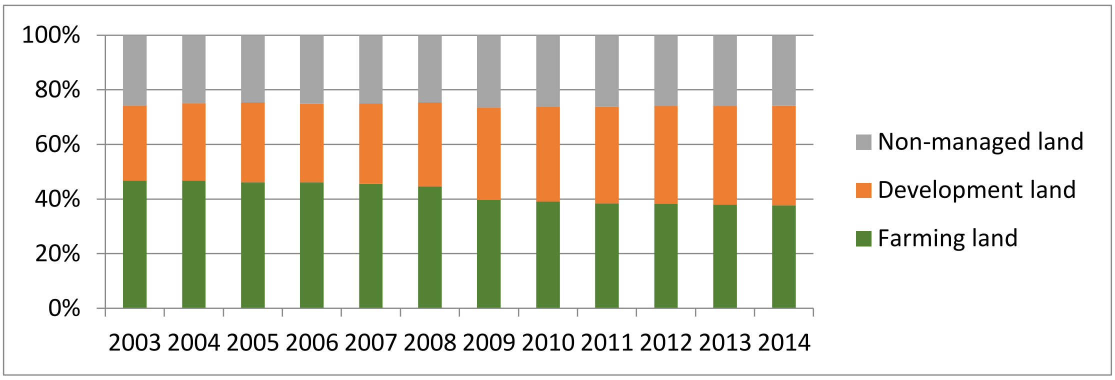

Figure 10 Land use changes from 2003 to 2014 (Fund share)

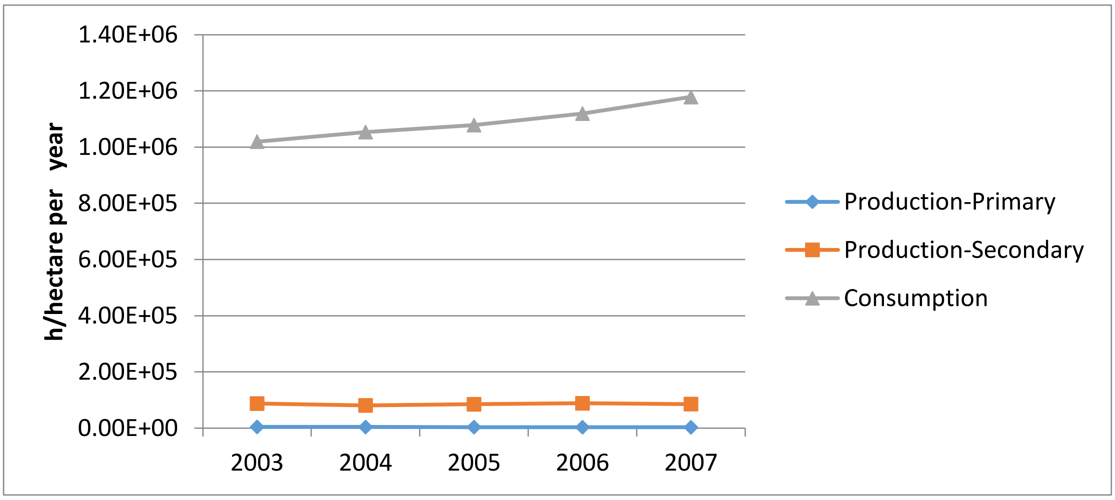

Figure 11 Human activity/Land use changes from 2003 to 2007 (Fund-fund ratio)

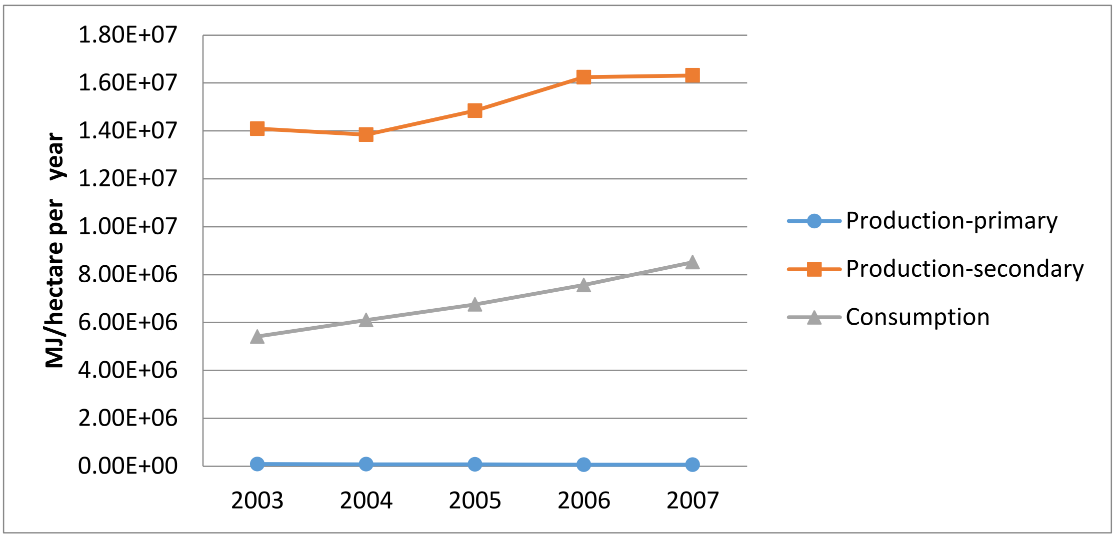

Figure 12 EMR_{ML} changes from 2003 to 2007 (Flow-fund ratio)

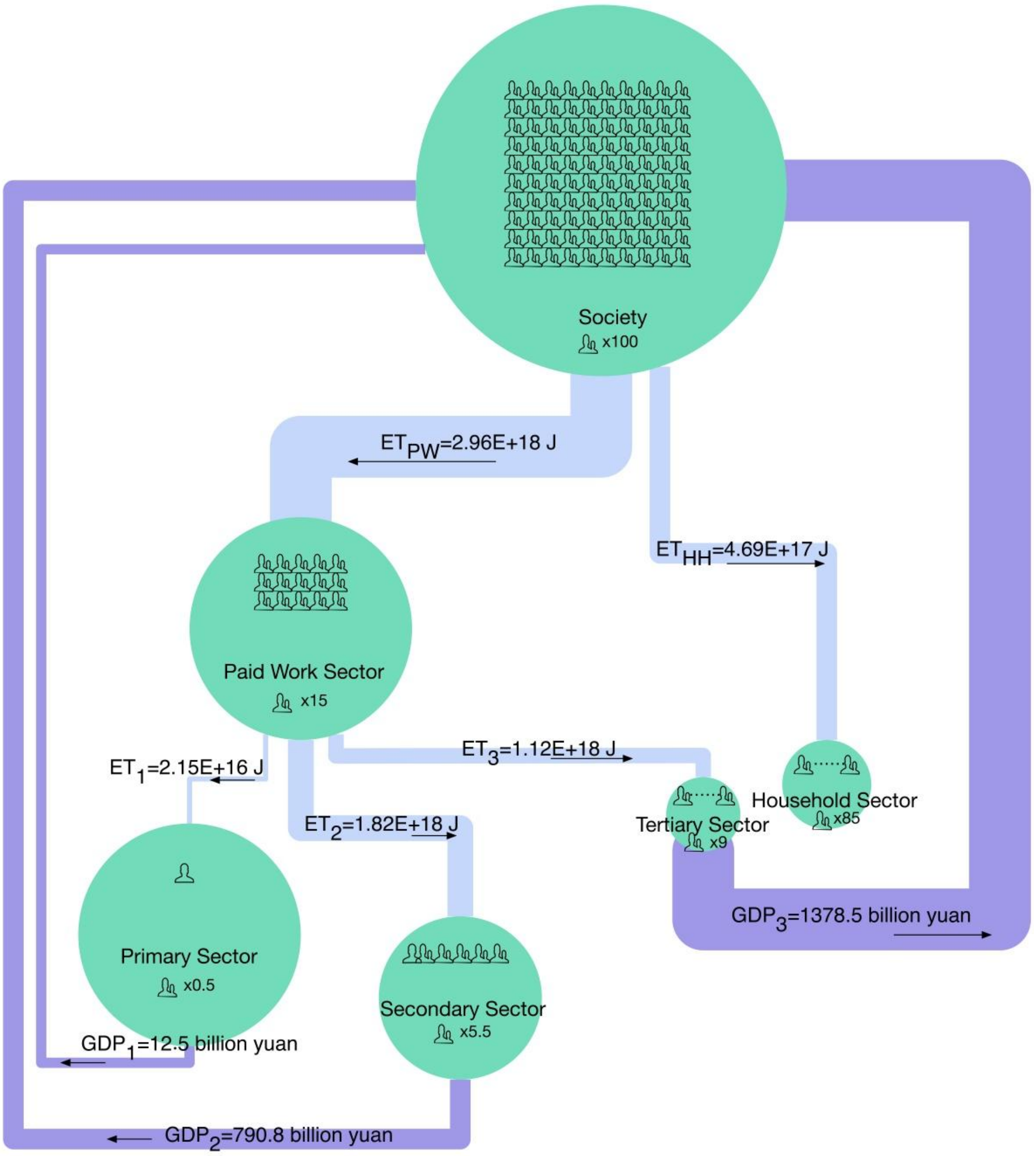

Figure2 13 Metabolic pattern in Shanghai (2013)

Table

Table 1 List of variables

Category	Variables	Nature	Calculation formula	Explanation
Extensive variables	Human Activities (HA_i)	Fund	Human activities in Sector i over the year (Measured in h)	
	Land Uses (LU_i)	Fund	Land use in Sector i (Measure in ha)	
	Energy Throughput (ET_i)	Flow	Exosomatic energy in Sector i over the year (Measured in MJ)	
	Economic output (GDP_i)	Flow	Added value generated in Sector i over the year (Measured in RMB)	
Intensive variables	Exosomatic Metabolic Rate (EMR_i)	Flow-Fund ratio	Exosomatic energy throughput per hours of human activities/hectares of land in sector i (Measured in MJ/h or MJ/ha)	It enables comparison of energy intensity between different hierarchical levels and among the same hierarchical level but with different sizes.
	Economic Labor Productivity (ELPi)	Flow-Fund ratio	The added value per year divided by the hours of human activities in the paid work Sector i (Measured in RMB/h)	It allows a performance check on the ability of human time to produce.
	Spatial Density of Human Time	Fund-fund ratio	The amount of human activity time per hectare of land (Measured in h/ha)	It represents how much human time is devoted to unit of land in one year, which reflects the temporal density from a spatial perspective. It helps to link the two dimensional funds to a unified bio-economics variable.

Table-2

Table 2 Benchmark ELP values of the paid work sector

Country/City	Shanghai	Shanghai	China[1]	Catalonia[2]	UK[3]	Germany[4]
Year	2001	2013	2010	2005	2003	2003
ELP(dollars/h)	3.54[5]	11.03[6]	1.7	31.67[7]	31.8	32.5

Source :
[1] Chen et al. (2015)
[2] Source: Ramos-Martín et al. (2009)
[3] Source: Giampietro et al. (2010)
4 Source: Giampietro et al. (2010)

[1] Source : Xiaohui et al. (2015)
[2] Source: Ramos-Martín et al. (2009)
[3] Source: Giampietro et al. (2010)
[4] Source: Giampietro et al. (2010)
[5] The currency exchange rate is taken from the World Bank Official Exchange Rate Database. The value used is 1 USD=8.28 RMB for the Year 2001.
[6] The currency exchange rate is taken from the World Bank Official Exchange Rate Database. The value used is 1 USD=6.20 RMB for the Year 2013.
[7] The currency exchange rate is taken from the EU document (http://www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT(2007)379231_EN.pdf) . The value used is 1 USD = 0.81 Euro