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Evaluating newly added embodied energy inventory of China and the United States: An economic input–output LCA model

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A B S T R A C T

China and the United States are the top two largest energy consumers, but they have totally different energy consumption patterns. Firstly, newly added embodied energy inventory (NAEEI) is created based on the concept of embodied energy. We combine the improved economic input-output approach with LCA for modeling. NAEEI and its proportion to national aggregate primary energy consumption for the first decade of the 21st century of the two largest energy consumers were calculated. In 2001, China's annual NAEEI is 199.98 million tons of oil equivalents (toe). The figure soared to 908.50 million toe in 2010, with an average annual growth rate of 118.31%. Correspondingly, the proportion of NAEEI to China national aggregate primary energy consumption increased from 23.87% in 2001 to 37.35% in 2010, which implies that more and more energy have been embodied in fixed assets. By contrast, the United States holds only 37.29 million toe of the NAEEI, accounting for merely 1.65% of the national aggregate primary energy consumption. In 2010, the situation has not transformed, with the NAEEI of 32.38 million toe and the proportion of 1.42%, slightly decreasing compared to that of 2001. These statistics have shown us two totally different energy consumption patterns: U.S. for heavy instant consumption, light accumulation pattern and China for heavy accumulation, light instant consumption pattern. We name the proportion of the NAEEI to national aggregate primary energy consumption embodied energy accumulation (EEA) coefficient, which would be a number ranging from zero to one. Embodied energy accumulation coefficient can be taken as a concise criterion to demonstrate a country's economic development stage and energy consumption pattern. As for the huge gap of EEA coefficient between China and the United States, discrepancy in economic and social development, as well as investment-decision regimes are mainly to blame.

Keywords

newly added embodied energy inventory (NAEEI)
improved economic input-output approach
life cycle analysis (LCA)
energy consumption pattern

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1Introduction

The issue of energy has been attached the greatest importance by the whole world. As the continual growth of energy demand and global climate change worsening goes, countries that consume huge amount of energy especially fossil fuels like China and the United States have bore tremendous social, political and public pressure from the international community.

According to the data from Organization of Economic Co-operation and Development (OECD), China and the United States are the top two largest energy consumers [1]. In 2010, China consumed 2432.2 million toe and the United States 2285.7 million toe, each accounting for approximately 20% of the total global energy consumption [2].

At first glance, the resemblance of huge amount of energy consumption classified China together with the United States into the same category of energy consumption pattern. Yet further research has displayed big differences between these two countries, especially concerning input of energy to different economic sectors. China's demand for energy has surged to fuel its rapidly expanding industrial and commercial sectors as well as households experiencing rising living standards [3]. Actually, industrial sectors in China consumed more than 70% of the national total energy, while construction consumed 20% [4]. In contrast, in the United States, industrial sectors consumed barely 33% of the national total energy consumption, with construction and transportation consuming 67% [5].

The energy consumption of industrial sectors of the United States is less than half the quantity of China, while transportation and construction energy consumption per capita is more than 5 times compared to China [5]. By the end of 2009, the car retention of the United States is 246 million, while this number of China is 76.19 million with tricycle, agricultural vehicles all included [6]. In the United States, The huge car and private plane retention brings convenience and comfort for people of the United States, meanwhile pushes up energy consumption in transportation.

In 2000, the total building area of China is 35 billion square meters, 2.2 times compared to 15.5 billion square meters in the United States [7]. During the past decade of the rapid development of urbanization, China's newly added building area had reached 2 billion square meters each year, accounting for half of the newly added construction area of the whole world. Based on a conservative estimate, the present construction area of China is triple of that of the United States, but the energy consumption of construction is only half of the United States, which means that construction energy consumption per unit area of the United States is 6 times compared to China. Take household electrical appliances for example, laundry dries and computers that been widely used in the United States raises the construction energy consumption per unit area to 28 kWh/(m^2.a). However, sunlight and wind which have been used instead of clothes dryers to dry clothes in China only consumed 6.3 kWh/(m^2.a), much less than that of the United States [7].

To sum up, during the past one decade, the national energy consumption of the United States kept constant, because as the most developed country in the world with rather or relatively good infrastructure, vast majority of energy had been consumed in transportation and construction operations. However, China has totally different situations. The national energy consumption of China increased conspicuously each year, which is about 3 times in

2010 compared to that of 2001. China, the largest developing country with the most total population, has accelerated economic development and urbanization, in turn, a huge amount of energy-intensive products like iron and steel, cement and other building materials are in great need to improve the infrastructure.

The energy consumption patterns of China and the United States are essentially different. Energy consumed in industrial sectors can form fixed assets such as equipment, road and buildings with a lifecycle of 10 to 70 years. However, energy consumed in transportation and construction operations is kind of instant consumption without forming fixed assets. This paper tries to figure out how much energy was consumed to form fixed asset with long lifecycle in China and the United States respectively. If there is a huge gap of proportion of energy consumed in fixed assets to national aggregate energy consumption of the two countries, what are implied by the huge gap?

In this paper, started from the creation of the new concept of NAEEI, based on the input-output energy analysis approach, the authors improved the calculation models and methods, and comprehensively and thoroughly study energy consumption patterns of China and the United States. According to the calculation results, the authors try to analyze and discuss the policy implications of them.

2 Literature Research

2.1Embodied energy

Any kind of product or service is produced with a variety of materials and each material consumes energy throughout its stages of production. The concept of embodied energy was first put forward in 1974 in a meeting of energy analysis group of International Federation of Institutes for Advanced Study (IFIAS). Embodied energy was taken to evaluate the sum of the direct and indirect energy consumed when producing a product or service in terms of raw materials and fuels [8]. Obviously, the amount of embodied energy is much greater than that of direct energy consumed in the final processing steps. Embodied energy helps understanding energy consumption more comprehensively and deeply. From then on, embodied energy gradually attracts the attention of academic community.

The recent representative definitions of embodied energy are as follows. S. Rahimifard et al. believe that energy consumption comprises direct and indirect energy consumption, and direct energy consists of theoretic energy consumption and accessory energy consumption [9]. S. Kara et al. defined the embodied energy from the perspective of life cycle including all steps from site selection, transportation to production [10].

In domestic academic community, Luo Siping et al. stated that embodied energy refers to the total energy consumption of every links of materials, production and transportation [11]. Chen Ying et al. defined embodied energy as the total energy consumed in the whole process of upstream processing, manufacturing and transportation [12].

To sum up, the energy consumed during the entire industrial chain to gain the products is called embodied energy. From Fig.1, it is very clear that producing a product or service needs not only direct energy consumption, but also other materials, workshops & equipments, miscellaneous services such as transportation, health care, which also consume energy during their production.

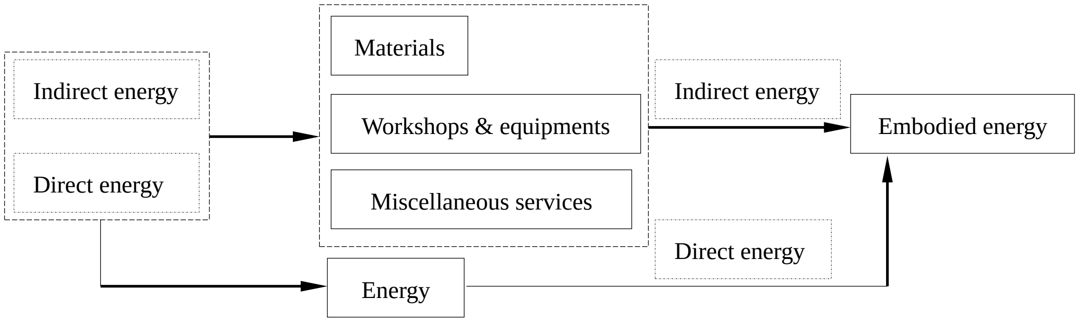

Fig.1. Graphical representation of embodied energy

2.2Newly added embodied energy inventory

According to the concept of embodied energy, every kind of product and service has embodied energy in it. The discrepancy lies that while energy embodied in producing a product has a period time of life cycle, energy consumed to provide a service is instant consumption with the energy's complete depletion. Taking a house for example, if you want to build a house, it would consume large amount of energy including direct energy used in the construct and assembly process, and the indirect energy that is required to manufacture the materials and components of the building [13]. However, if you luckily already have a house, we have every reason to regard that we still have large amount of energy embodied in the house, which can be vividly referred to as embodied energy inventory.

Fixed assets usually have long period of life cycle of about 10 to 100 years, so in a sense, the energy embodied in them has not been depleted at one time. In other words, as the fixed assets depreciate, the embodied energy inventory gradually decreases. Not until the fixed assets were declared worthless had the embodied energy been used up. Therefore, embodied energy inventory can be defined as the direct and indirect energy consumed in the entire industrial chains including all the necessary upstream processes for materials such as mining, refining, manufacturing, transportation, and the like [14]. Thus, embodied energy inventory is always changing. As the time goes, the fixed assets depreciate and the embodied energy inventory decreases until the demolitions of the architectures or equipments.

In national economic activities, there are newly added fixed assets each year. Therefore, there is NAEEI each year. In this paper, the authors try to calculate NAEEI and the proportion of it to the national aggregate primary energy consumption of China and the United States respectively. If there is a huge gap of the results between the two countries, this paper tries to analyze and discuss the policy implications of it.

2.3Current research on embodied energy

Great importance has been attached to the research on embodied energy because of the severe energy deficiency and global climate change. The existing research achievements can be divided into two directions. One direction emphasizes the embodied energy in international trade, calculating the specific energy imported and exported embodied in goods, focus on the embodied energy flow among countries as supplement of the direct energy import and export. The other direction tries to study domestic embodied energy, such as embodied energy in construction, infrastructure, manufacturing and building materials, et al., suggesting feasible methods to reduce or save embodied energy and improve energy efficiency.

Kahrl et al. calculated the embodied energy based on Chinese input-output data and energy consumption data, clarified the relationship between export and energy consumption. He concluded that export is the largest drive force of China's energy consumption growth [15]. Hongtao Liu et al. (2010) evaluated the energy embodied in goods produced in China during 1992–2005 and use input–output structural decomposition analysis to identify five key factors causing the changes of energy embodied in exports. Results show that China is a net exporter of energy, and the energy embodied in exports tends to increase overtime [16]. Liu Feng calculated China's embodied energy export from 2001 to 2005, which accounts for 24%-33% of the national aggregate primary energy consumption, with net export of embodied energy accounting for 20%-27% [17]. Qi Ye also calculated the embodied energy in international trade of 2001 to 2006 based on input-output method. The research showed that the directly imported energy from abroad again has been exported to the other countries in terms of embodied energy through exporting goods. Hence, China has not consumed more extra energy from abroad [18]. Chen Ying et al. concluded that China is a net exporter of embodied energy according to calculation results. In 2002, 410 million tons of coal equivalents (tce) were exported through international trade, while only 170 million tce was imported [12].

With respect to domestic embodied energy, Monahan J et al. estimated the embodied energy and its matching embodied carbon of modern methods of construction in housing from design to completion of the house based on life cycle analysis (LCA). A semi-detached house with three bedrooms usually contains embodied energy of 34.6 tons CO_2 [19]. B.V Venkatarama Reddy et al. focused around some issues pertaining to embodied energy in buildings particularly in the Indian context discussing energy consumption in the production of basic building materials (such as cement, steel, etc.) and different types of materials used for construction. A comparison of energy in different types of masonry has been made. It has been shown that total embodied energy of load bearing masonry buildings can be reduced by 50% when energy efficient or alternative building materials are used [20]. T.Y. Chen et al. have developed a model for estimating the intensities of the embodied and demolition energy for buildings. The results of the analysis provide an insight into the embodied energy usage profile in residential buildings in Hong Kong, and conclude that building components like steel and aluminum have significant potential for reduction in embodied energy demand [21]. Hongtao Liu et al. (2012) researched on embodied energy from a new perspective. They calculated the embodied energy of China's infrastructure construction from 1992 to 2007, and found that the embodied energy of China's infrastructure construction accounts for 14.0% of the national aggregate energy consumption. They concluded that irrational infrastructure construction is kind of wasting energy [22]. In addition, Yuan Chang et al. and M Lenzen et al., carried out research on embodied energy in construction and buildings

[23-24].

Combined with life cycle analysis (LCA) method and input-output approach, S Kara et al. evaluated the influences of embodied energy of products to global manufacturing, shows that production sites, transportation weight and distance, conveyance are the main crucial factors affecting embodied energy. Hence, choosing local suppliers, adopting energy efficient transportation can remarkably reduce embodied energy of a product [10]. S. Rahimifard et al. believed that embodied energy calculation could improve the transparency of energy utilization and efficiency [9].

The current research subjects of the embodied energy are been labeled in Table 1. Many scholars have kept their eyes on embodied energy in international trade or export, and the same input-output approach was used. Other scholars tried to do research on domestic embodied energy or find ways to reduce embodied energy of a product and improve energy efficiency.

Table 1 Current research on embodied energy

Subject	Method	Conclusions	Year	Representative authors
Embodied energy in international trade or export	Input-output approach	Embodied energy import or export through international trade should not be neglected when discussing a country's energy consumption.	2007-2011	Kahrl et al.; Hongtao Liu et al.; Liu Feng; Qi Ye; Chen Ying et al.
Embodied energy in infrastructure or residential building	Input-output approach; Life cycle analysis (LCA)	Embodied energy or carbon of infrastructure construction was calculated, which accounts for large proportion of national aggregate primary energy. Irrational infrastructure construction is kind of wasting energy. Ways to reduce embodied energy	2003-2012	Monahan J et al.; B.V Venkatarama Reddy et al.; T.Y. Chen, et al.; Hongtao Liu; Yuan Chang et al.; M Lenzen et al.
How to reduce embodied energy of a product?	Life cycle analysis (LCA)	Choosing local suppliers, adopting energy efficient transportation can remarkably reduce embodied energy of a product.	2010	S Kara et al.
Minimizing Embodied Product Energy to Support Energy Efficient	Life cycle analysis (LCA)	Embodied energy calculation could improve the transparency of energy utilization and efficiency.	2010	Rahimifard et al.

Manufacturing				

At present, there is little relevant research on NAEEI, which is very crucial in interpreting a country's energy consumption structure, stage of economic and social development, and promotion of energy conservation. Concerning several countries with same amount of energy consumption, newly added embodied energy can be taken as an important indicator evaluating economic development. A country with large amount of NAEEI each year implies that the country is rapidly developing and consuming huge energy in fixed assets. Nevertheless, a country with extremely low amount of NAEEI usually hints a highly developed country with perfect infrastructure, or completely opposite, an extremely poor country that has no resources and power to develop at all.

Although there is no essay talking about NAEEI, calculation methods like input-output approach and life cycle analysis, ideas and thoughts from embodied energy research can provide excellence and inspiration. Hence, based on previous research on embodied energy home and abroad, this paper tries to calculate NAEEI and its proportion to national aggregate primary energy consumption based on the improved input-output analysis approach.

3Methodology and data sources

3.1Modeling method

Input-output model, an analysis approach for clarifying the numerical relationship between input and output in an economic system, can be adjusted to calculate NAEEI. Assuming that a country has n industries, x_i represents the total output of *No.i* industry, y_i represents the final products of *No.i* industry, x_{ij} represents the products of *No.i* industry consumed by *No.j* industry.

Table 2 (Basic structure of input-output table) can be divided into 4 quadrants. The 1st and 2nd quadrants reflect the distribution of products of different industries: one part is the intermediate products as materials for other industries; the other part as the final products for consumption, investment and other. The relation can be expressed as follows:

$$x_i=\sum_{i=1}^{n} xij + y_i = \sum_{i=1}^{n}(aij \cdot xi) + y_i \qquad (i=1,2,\ldots,n)$$

Where, $a_{ij}=x_{ij}/x_i$, which is the direct consumption coefficient in the input-output table. The column vector of total output of different industries x_i is X, the final products y_i is Y, the direct consumption coefficient a_{ij} is A, there is:

$$X=AX+Y$$

$$X=(I-A)^{-1}\cdot Y$$

Of this, $(I-A)^{-1}$is called Leontief Inverse Matrix. $B=(b_{ij})$ is called the complete consumption coefficient matrix, which represents the direct and indirect consumption of products of *No.i* industry when producing one unit product of *No.j* industry. B can be expressed as below:

$$B=(I-A)^{-1}-I$$

Table 2 Basic structure of input-output table

		Intermediate product sector				Final products					Total output
		Sector1	2	…j…	n	Consumption	The formation of fixed investment	Changes In stock	Other	Subtotal	
Intermediate inputs	Sector1			x_{1j}						y_1	x_1
	2			x_{2j}						y_2	x_2
	…i…			x_{ij}						…	…
	n			x_{nj}						y_3	x_3
Added value	Compensation Of employees										
	Depreciation										
	...										
Total value											

According to the life cycle theory, the NAEEI of fixed assets contains two separate parts: direct energy consumption and indirect energy consumption. On the one hand, energy such as refined petroleum products, nuclear fuel, electricity and gas must be consumed during formation of fixed assets. It can be referred to direct energy consumption. On the other hand, other products and services except energy products, such as textile products, chemical products, as well as transport and storage service etc. equally contribute a lot to form fixed assets, which also consume energy during the procedure of production. This part is the indirect energy consumption for fixed assets.

Theoretically, the direct energy consumption (*DE*) of the NAEEI of the fixed assets can be calculated as below:

$$DE=\sum_{i=1}^{n} FAi \cdot Ci \qquad (i=1,2,\dots,n)$$

Where, FA_i is the output value of the *No.i* fixed asset sector. *Ci* is energy consumption coefficient, which means the energy embodied in per unit of output value. The crucial point lies in establishing the specific C_i. Assuming a value-energy converter coefficient (V_i):

$$V_i=EC_{statistical}/ECV_{statistical}$$

Where, $EC_{statistical}$ is aggregate primary energy consumption of a country, while $ECV_{statistical}$ is gross domestic products (GDP) of the same country.

Combine input-output analysis approach with value-energy converter coefficient, C_i can be expressed as below:

$$C_i = b_{ij} \cdot V_i \qquad (i=1,2,\ldots,n)$$

$$DE = \sum_{i=1}^{n} FAi \cdot b_{ij} \cdot V_i \qquad (i=1,2,\ldots,n)$$

Utilizing the same thoughts, the indirect energy consumption (*IDE*) of the NAEEI of the fixed assets can be calculated with two steps. First, the intermediate inputs (*II*) of sectors except energy should be calculated by the following formula:

$$II = \sum_{i=1}^{n} FAi \cdot bij \qquad (i=1,2,\ldots,n)$$

Then, the indirect energy consumption (*IDE*) of the NAEEI of the fixed assets will be:

$$IDE = II \cdot C_i = \sum_{i=1}^{n} (FAi \cdot bij) \cdot b_{ij} \cdot V_i \qquad (i=1,2,\ldots,n)$$

In conclusion, the NAEEI of the fixed assets is equal to the sum of direct energy consumption and indirect energy consumption.

$$NAEEI = DE + IDE$$

$$= \sum_{i=1}^{n} FAi \cdot b_{ij} \cdot V_i + \sum_{i=1}^{n} (FAi \cdot bij) \cdot b_{ij} \cdot V_i \qquad (i=1,2,\ldots,n)$$

At present, NAEEI is a new concept and there is no off-the-peg research method about it. In this paper, the main innovation lies in the combination of improved economic input-output approach and LCA.

3.2Sources of data

Three types of data have been collected for calculating NAEEI in both China and the United States: the GDP by industry of China and the United States; the Leontief inverse matrix of China and the United States during the period early 2000s and mid-2000s covering 2001-2010; the national aggregate primary energy consumption of two countries.

The data used in this paper are mainly from the following sources: the data of the GDP of the United States are from the website of Bureau of Economic Analysis, U.S. Department of Commerce [25]; the data of the GDP of China are from *China Statistical Yearbook 2012*; the Leontief inverse matrixes are downloaded from website of Organization for Co-operation and Development; the data of the national aggregate primary energy consumption of two countries are from *World Energy Statistical Review 2011* and *World Energy Statistics 2005 (Chinese Version)*.

3.3Technological processing

Technological processing is necessary because of different data sources and mismatching.

(1)According to China’s GDP data by industry, 10 industries that can form fixed assets have been selected for calculation, which are: non-metallic mineral products, black metal smelting and rolling processing industry, nonferrous metal smelting and rolling processing industry, metal products, general equipment products, special equipment products, transport equipment products, electrical machinery and apparatus, communication equipment, computer and other electronic equipment products, and construction. The same data of the United Stated are: other non-metallic mineral products, basic metals, fabricated metal products except machinery and equipment, machinery and equipment, office, accounting and computing machinery, electrical machinery and apparatus, motor vehicles, trailers and semi-trailers, other transport equipment, manufacturing and recycling, and construction. The one to one correspondence among industries of China’s GDP data, the United States’ GDP data, and Leontief inverse matrix are shown in Table 3.

Table 3 One to one correspondence between GDP and Leontief inverse matrix

Category	**China GDP by industry**	**Leontief inverse matrix**	**The United States GDP by industry**
1	Non-metallic mineral products	Other non-metallic mineral products	Nonmetallic mineral products
2	Black metal smelting and rolling processing industry	Basic metals	Primary metals
	Nonferrous metal smelting and rolling processing industry		
3	Metal products	Fabricated metal products except machinery and equipment	Fabricated metal products
4	General equipment products	Machinery and equipment	Machinery
	Special equipment products		
5	Communication equipment, computer and other electronic equipment products	Office, accounting and computing machinery	Computer and electronic products
6	Electrical machinery and apparatus	Electrical machinery and apparatus	Electrical equipment, appliances, and components
7	Transport equipment products	Motor vehicles, trailers and semi-trailers	Motor vehicles, bodies and trailers, and parts
8		Other transport equipment	Other transportation equipment
9		Manufacturing and recycling	Miscellaneous manufacturing
10	Construction	Construction	Construction

(2)Based on the Leontief inverse matrix, three energy industries have been chosen to calculate direction energy consumption (*DE*) of the NAEEI of the fixed assets. They are: mining and quarrying; coke, refined petroleum products and nuclear fuel; electricity, gas and water supply.

(3)Refer to the latest database of OECD website, only two Leontief inverse matrixes can be selected during the period of 2001-2010. The early 2000s Leontief inverse matrix has been chosen to calculate the NAEEI from 2001-2005, and the mid-2000s one for 2006-2010.

4Calculation results

4.1NAEEI of China

Based on the input-output approach, the NAEEI of China from 2001 to 2010 was calculated. As we can see from Fig.2, during the first decade of the 21st century, the annual NAEEI increased steadily from 199.98 million toe in 2001 to 908.50 million toe, with a average annual growth rate of 92.69%. The proportion of NAEEI to the national aggregate primary energy consumption increased correspondingly. In 2001, NAEEI accounts for 23.87%. When it comes to 2010, the figure grew to 37.35%, showing a rapid growth of NAEEI, which implies more and more energy embodied in fixed assets, such as infrastructure and construction due to the high-speed economic and social development.

From Fig.2, it is easy to recognize that the year of 2004 is an inflection point. In 2003, the proportion of NAEEI is 28.95%. In 2004, this figure soared to 39.24%, turning out to be the biggest proportion in ten years from 2001 to 2010. Through further research on the GDP data by industry, we could find out that the product value of nonferrous metal smelting and rolling processing industry, metal products, general equipment products, communication equipment, computer and other electrical equipment products of 2004 is twice compared to the value of 2003.

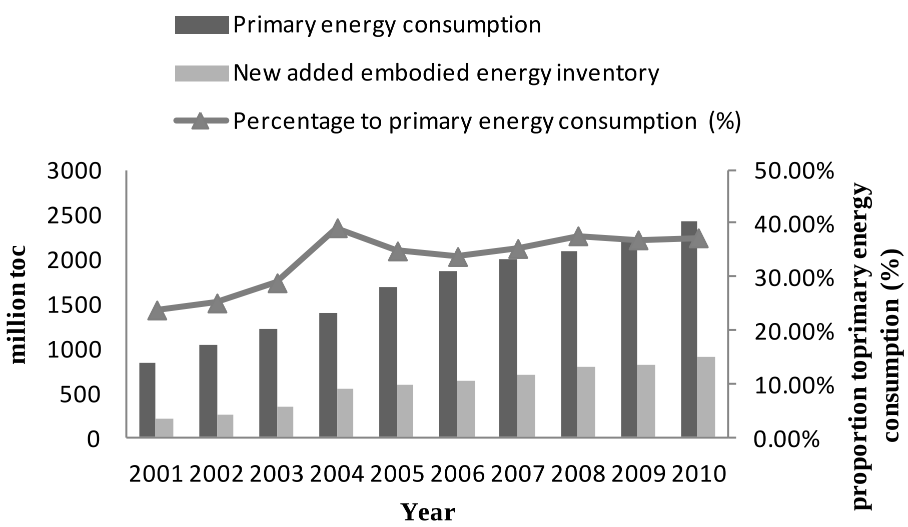

Fig.2. China's NAEEI

4.2NAEEI of the United States

According to Fig.3, the national aggregate primary energy consumption of the United States during the past decade has kept almost constant with 2256.3 million toe in 2001 and 2285.7 million toe in 2010, showing only a 1.3% increase. Compared to the giant and constant primary energy consumption, NAEEI seems to be relatively small. In 2001, the NAEEI is 37.29 million toe, accounting for merely 1.65% of the total energy consumption of the country. In 2010, the situation did not transform, with the NAEEI of 32.38 million toe accounting for 1.42%, slightly decreased compared to 2001.

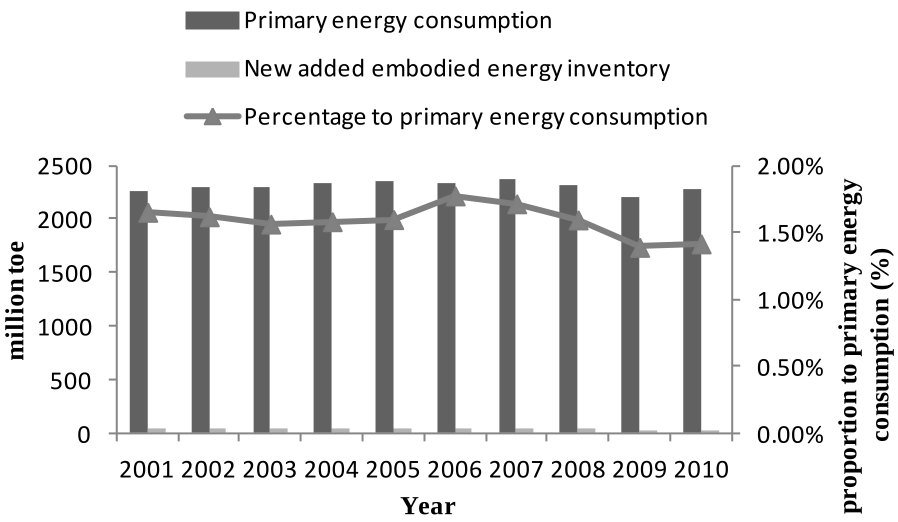

Fig.3. The United States' NAEEI

From Fig.3, we can see that the curve of the proportion of NAEEI presents inconspicuous decline trend as a whole, which means that investment of fixed assets is very small and even has a sign to further decline.

As one of the most developed countries in the world, the vast majority of energy has been used for daily life consumption instead of devoting to infrastructure construction.

4.3Sources of inaccuracy

This study tries to use improved input-output analysis approach to carry out a more reliable calculation of NAEEI of China and the United States, and then figure out the difference and implication of the two countries in energy utilization and economic characteristics. However, due to the limited available data and time, the current study still has three aspects of shortcomings that may cause inaccuracy.

Firstly, there are import and export of equipment and traffic facilities in both China and the United States. The NAEEI of the export products should be eliminated from the previous calculation results. Due to the mismatching of the detailed equipment and corresponding complete energy consumption coefficient, it is difficult to calculate the NAEEI exporting to foreign countries. So the actual results should be a little smaller.

Secondly, the calculation needs a large amount of various data, such as GDP data by industry from 2001 to 2010 of China and the United States, Leontief inverse matrixes, and energy consumption data. Although the data have been processed in order to make them match well, the data from different sources still may not fit perfectly. China's energy and economic statistics are frequently adjusted, which may also bring some deviations to the calculation results.

Thirdly, Leontief inverse matrices are not compiled for each year. The latest existing ones are two Leontief inverse matrixes for each country: one for early 2000s, the other for mid-2000s. In this paper, early 2000s matrix is used to calculate NAEEI from 2001-2005, and mid-2000s matrix for calculation from 2006-2010. This handling may also cause deviation.

5Policy implications

5.1Different energy consumption patterns of China and the United States

According to the calculation results, China's NAEEI accounts for about 24%-39% of the national aggregate primary energy consumption, much higher than the proportion of 1.5% of the United States. Fig.4 clearly shows the big difference of energy usage between China and the United States. The proportion of NAEEI to national aggregate primary energy consumption in China had kept a smooth increasing trend, while that of the United States had kept almost unchanged.

The United States is one of the most developed countries with fully equipped infrastructure, such as transportation facilities, housing. Vast majority of energy has been consumed improving daily life like using various household electrical appliances. In comparison, China is a typical developing country further promoting infrastructure construction and urbanization, which consumes large amount of energy. At present, China's energy consumption for daily life is small with only 346 million tons coal equivalent in 2010 accounting for 10% of the national total energy consumption. Due to China's giant population, energy consumption per capita for daily life is only 258.3kg tons coal equivalent.

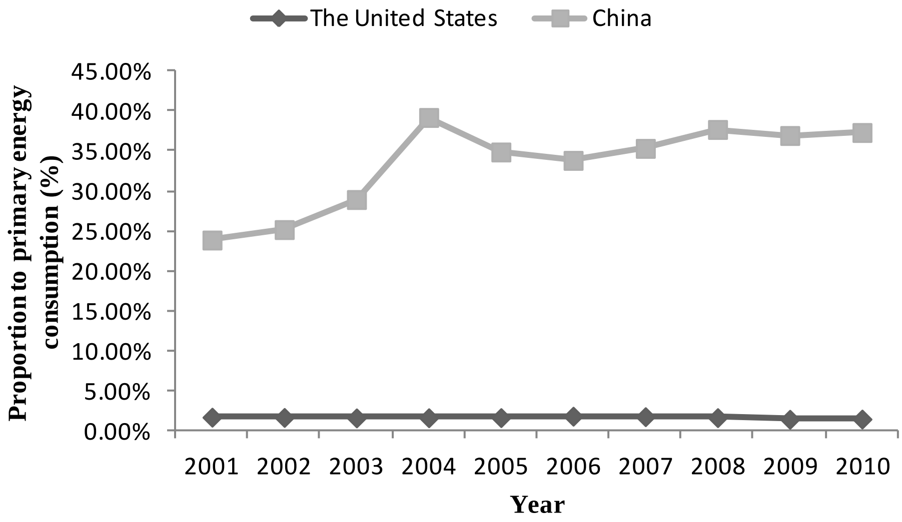

Fig.4. Comparison analysis of NAEEI of China and the United States

During the past decade, the total newly added embodied energy consumption in China amounts to 5781.05 million toe, accounting for 25.70% of the national total energy consumption. By contrast, the total newly added embodied energy consumption of the United States is only 367.04 million toe, accounting for 1.57% of the national energy consumption (see Fig.5). The total NAEEI of China is 15.75 times compared to the United States.

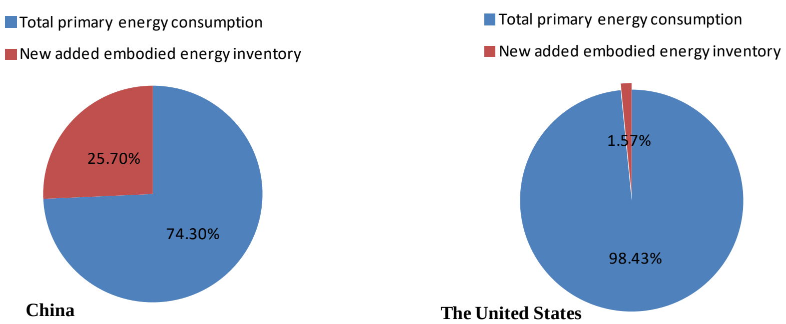

Fig.5. Comparison analysis of the proportion of NAEEI
of China and the United States (2001-2010)

According to the calculation results, there is a wide gap of NAEEI between China and the United States. During the first decade of the 21st century, the NAEEI of China increased from 199.98 million toe, accounting for 23.87% of the national total energy consumption, to 908.50 million toe, accounting for 37.35% of the national total energy consumption, reflecting accelerating accumulation of infrastructure construction. Meanwhile, the NAEEI of the United States in the year of 2010 is 32.38 million toe, which did not rise but decline comparing to 37.29 million toe in 2001, showing a reduction of 13%. The proportion of the NAEEI of the United States is extremely small, only about 1.5% of the national total energy consumption. The solid calculation results show two totally different energy consumption patterns: "*U.S. for heavy instant consumption-light accumulation energy consumption* *pattern*” and “*China for heavy accumulation-light instant consumption pattern*”.

5.2Different stages of economic and social development

The proportion of the NAEEI to national total energy consumption can be named embodied energy accumulation coefficient (hereinafter referred to as “EEA” coefficient), which would be a number ranging from zero to one (see Table 4). Embodied energy accumulation coefficient can be taken as a concise criterion to determine which economic development stage and energy consumption pattern a country is situated at. Bigger EEA coefficient implies more NAEEI accumulation and fast economic development (see Table 4).

Table 4 Value range of EEA coefficient and implication

EEA coefficient	**Accumulation and implication**
[0%,5%]	Extremely low embodied energy accumulation.
	Generally highly development country or very poor country.
(5%,10%]	Modest embodied energy accumulation.
	Generally developed countries or laggard developing country.
(10%,35%]	Large embodied energy accumulation.
	Generally developing country.
(35%,100%]	Huge amount of embodied energy accumulation.
	Generally fast developing economy.

Remarks: [a, b] means the interval of the value range of EEA coefficient.

The huge gap of EEA coefficient between China and the United States is quite comprehensible. China and the United States are in totally different stages of economic and social development. Since adopting the policy of reform and opening up, China has only experienced thirty years of industrial development until 2010. Restricted by the limited resources and largest population, China has a long way to go in the progress of economic development. At present, the infrastructure is far more from acceptable; people’s life should be further improved; industrialization and urbanization should be continuously boosted. In order to realize these tasks, vast amount of energy and energy-intensive products are needed. Since the Second Industrial Revolution, the United States have experienced rapid development of more than one hundred years with perfect infrastructure and advanced lifestyle, so energy consumption mainly focuses on instant consumption such as transportation and other daily uses.

5.3Diffenent political and investment-decision regimes

China and the United States have quite different political and investment-decision regimes. At present, China is constructing market economy with Chinese characteristics. The Chinese governments of all levels are committed to improve infrastructures such as high-speed railway, municipal expressway, housing construction, and further advance industrialization and urbanization. The government officials have enough motivation and driving force to promote infrastructure construction. Yet the United States is a free market economy emphasizing the law of private property protection. Whether a project is worthy of investment mainly depends on the private judgment of input-output efficiency. Usually the initial cost of the infrastructure construction is extremely large, and the payback period is quite long. Thus the private companies have less motivation and interest in continuously investing resources to improve infrastructure construction.

6Conclusions

Concerning the foreseeable future, China would be very likely to continue the policy of promoting infrastructure construction, and the fixed asset investment would consume even larger proportion of the national total energy consumption. The NAEEI and its proportion to the national total energy consumption would inevitably go on rising. On the contrary, the NAEEI and its proportion to national aggregate energy consumption of the United States would remain unchanged or even keep declining, as long as reindustrialization of the Unite States does not prosper and continue to import various kinds of commodities from abroad.

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