Material Consumption of Building Construction with Land Use Change in China: A Socioeconomic and Geographical Analysis

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Abstract: In this study, we analyze domestic material consumption (DMC) in building sector and employed an index decomposition analysis method to find out the driving force of material consumption during 1996-2009. We also conducted semi-parametric analysis to estimate the relationship between urban area change and DMC change. The results revealed several findings: (1) the contribution rate of per capita GDP growth was arrived at 102.54%, it was the main driver of growth in material consumption of building construction. (2) the increase in the DMC is one of the reasons that lead to the increase of farmland transformation into urban area, but the transformations from water, grassland and wetland to urban areas decreased.

Key Words: DMC, land use change, IDA, Semi-parametric analysis

INTRODUCTION

Human material use is one of the major drivers of global environmental change (Julia et al., 2010). Many environmental problems such as global warming, soil pollution occurred during the processing of material production and consumption. In recent years, efficient use of material and reduction of material consumption has become one of the most important issues aimed at controlling environmental problems.

As the largest developing country in the world, China has been experiencing unheard-of economic development. The demand for material increased rapidly, especially in the construction sectors. Since the 1990s, great quantities of buildings have been constructed and the total building floor space in China increased from 10.2 billion m² in 1980 to 52.7 billion m² in 2008 (NBSC, 2005). Meanwhile, China’s cement and steel needs have reached a high level. China has been the largest producer and consumer of cement in the world since 1985 and of steel since 2000 (NBSC, 2005). China’s material production has a large contribution to environmental impacts. Increase in demand and consumption of buildings and infrastructures (which were quantified as domestic material consumption of construction sector in this study) also resulted in land use change. People modified forest and farmland to Urban to satisfy the material demand. But it accelerated many problems such as global warming. Therefore, to clear which land types were changed to urban areas with the material consumption can effectively predict environmental problems.

In recent years, reduction of material consumption and improvement of efficient material use has attracted many researchers’ attention. Numerous studies have discussed the material use and driving force of material consumption at regional and global scale (Heinz et al., 2010; Hashimoto et al., 2008; Julia et al., 2010). But most of the researchers just focused on the driving force of material consumption alone ignoring the related environment changes such as land use change brought by human activities (such as material
consumption). Otherwise, limited studies estimate the material consumption based on spatial level. However, more detailed regional information to estimate environmental problems is critical. In this study, we applied index decomposition analysis to clear the main driving force of construction material consumption based on statistical data, then distributed the material consumption to spatial scale by using Night-time lights data. Finally, we employed semi-parametric analysis to discuss the relationship between material consumption and land use change (especially in urban area change) based on spatial scale. We clarified which land use types were converted into urban areas that if material consumption reached at different levels.

1. METHODOLOGY

1.1 Domestic Material Consumption (DMC)

With the rapid population increase and urban expansion, the demand for building and infrastructure has also increased rapidly. This has resulted in the mass consumption of construction materials and environmental issues. The DMC of buildings accounts for approximately 75% of the total construction sector. Therefore, this study focuses on DMC of buildings. Construction material is the single largest category of material flow, and also one of the most poorly recorded for many of the main constituent materials. Because different types of buildings have different DMC intensities, in order to calculate DMC of buildings more accurately, we divided China’s buildings into two types: residential building and non-residential building. Then we calculated the areas of different types of buildings. Finally, we calculated the DMC multiplying building areas by material intensity, which was listed in Construction Project Investment Estimation Handbook (Yu and Li, 1999) between 1996 and 2009.

1.2 Index Decomposition Analysis (IDA)

In order to understand how much materials have been used to present, and what trajectory it could takes in future, it was very important to analyze driving forces independently (Heinz et al., 2010). This study employed IDA to understand the drivers of DMC. IDA is a popular analytical tool to decompose changes in aggregate energy use or energy intensity into changes in economic structure and changes in sectorial energy intensity or efficiency (Ang and Zhang, 2000). It includes several different methods, but this study used the log-mean divisia index (LMDI) method (Ang and Liu, 2001) that does not leave a residual term. The decomposition equation was as follows:

\[ D_t = P_t \times A_t \times T_t \times G_t \]  

(1)

Where D represents the DMC of buildings; P is population; A is defined as economical level (GDP/Population). T represents material efficiency, calculated as DMC divided by GDP of architectural sector, it is also regarded as a technologic factor; G is defined as GDP contribution of architectural sector to total GDP and is calculated as GDP of architectural sector divided by total GDP, t represents the year.

1.3 DMC Spatial Distribution

In order to obtain the socio-economic and geographical conditions in more detailed, we distributed the statistic data into spatial scale. First, we calculated DMC per capita of buildings for each prefecture in China based on statistic data of 2000 and 2009, and then divided the statistic

![Fig.1 DMC (2000)](21016 tons)

![Fig.2 DMC (2009)](448391 tons)
material data into the map by using the spatial population data. Here we use the 1km Night-time lights data (The National Oceanic and Atmospheric Administration) to estimate spatial population distribution. We extracted each pixel’s digital number (DN) value of cities of the Night-time lights data, and calculated total DN value of each prefecture. Then we built relational equations between DN value and statistic population of each province. Next, DN value of each pixel was put into the equations and spatial population data was obtained. In order to ensure its accuracy, we use the actual population data to revise the spatial population data. Tao and Xinqi described the detailed method in 2010. Finally, we use the per capita DMC of different regions and spatial population data to calculate the spatial DMC data. Fig.1 and Fig.2 show the spatial DMC distribution of 2000 and 2009.

In order to accomplish the semi-parametric analysis, we calculated total material consumption in each 1-degree mesh grid (110km).

1.4 Land Use Change
Since the time series land use data was lacking, so we used 500-meter MODIS (The Moderate Resolution Imaging Spectroradiometer) data, which was produced by National Aeronautics and Space Administration. In order to convert it to suit the available data, the MODIS data was processed by ArcView GIS software.

The original data includes 17 land use types. Each land use type of the data is subdivided into several types. But this study only focuses on the urban areas: it doesn’t need such a detailed classification. Here we reclassified the 17 types to 8 types (Fig.3 and Fig.4). And then calculated the land use change (500-meter mesh numbers of change) in each 1 degree mesh scale. Given the scope of this study limited by building construction material, we just estimated urban areas changes.

1.5 Semi-Parametric Analysis
In this study, a semi-parametric analysis was employed to explore relationships between land use change and DMC. A semi-parametric model combines parametric and nonparametric components. It is often used in situations where a fully nonparametric model might not perform well, or the researcher wishes to use a parametric model, but the functional form with respect to a subset of the repressors or the density of the errors is unknown. The form of the equation is assumed to be:

\[ L = S(E) + \delta \tag{2} \]

Where L denotes the land use change in each 1-degree mesh grid cell and E indicates the total DMC of building construction by each grid cell. Although there are many reasons for land use change, here we focused on the relation between DMC and urban area change. Therefore, we set the

**Table 1 Results of material consumption decomposition in China, 1996-2009**

<table>
<thead>
<tr>
<th></th>
<th>∆D(t)</th>
<th>∆P</th>
<th>∆T</th>
<th>∆G</th>
<th>∆A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-2000</td>
<td>682195548</td>
<td>14.69%</td>
<td>-1.73%</td>
<td>-46.49%</td>
<td>133.53%</td>
</tr>
<tr>
<td>2000-2005</td>
<td>4165752035</td>
<td>3.98%</td>
<td>15.63%</td>
<td>0.55%</td>
<td>79.83%</td>
</tr>
<tr>
<td>2005-2009</td>
<td>5050765903</td>
<td>4.16%</td>
<td>-55.99%</td>
<td>34.75%</td>
<td>117.09%</td>
</tr>
<tr>
<td>1996-2009</td>
<td>9898713486</td>
<td>4.81%</td>
<td>-22.11%</td>
<td>-14.75%</td>
<td>102.54%</td>
</tr>
</tbody>
</table>

Fig.3 Image of Land use in 2001 (500m)

Fig.4 Image of Land use in 2009 (500m)
climate factors such as temperature, precipitation; social economic factors such as road length, and distance to river, ocean as the control variables (6).

2. RESULTS

2.1 DMC and material efficiency

Fig.5 shows the DMC between 1996 and 2009. It was calculated using material intensity and building areas and estimated total quantities of steel, wood, cement, brick, gravel, sand, asphalt lime and glass. The DMC of buildings in China increased rapidly. Until 2009, the DMC in building construction sector increased to 1.268,39×10^10 tons.

Fig.6 shows the economical material intensity changes between 1996 and 2009. It was defined as DMC of buildings divided by building construction sector’s GDP. In this study, economical material intensity was used to measure material efficiency. The lower the economical material intensity, the higher the efficiency. According to the result, material efficiency was low before 2003, but it increased rapidly from 2005 onwards.

2.2 Decomposition results

This study applied the Index Decomposition analysis to explain the domestic material consumption and uncover the driving forces. Table-1 lists the DMC changes and related determinants from 1996 and 2009.

According to Table 1, from 1996 to 2000, DMC in China increased by 6.822×10^8 tons. Between 2000 and 2005, DMC growth was about 4.1658×10^8 tons and during 1996 to 2009, about 5.0508×10^8 tons’ material was consumed. Through all three periods, ∆A (GDP/capita) was the main driver of growth in material consumption of building construction. The contribution rate of GDP per capita arrived at 102.54%, which led to an increase in material consumption.

Material efficiency (economical material intensity) is regarded as technological factor in many studies of resource use. It is often seen as a mediating factor allowing for reductions in resource use through increased efficiency (Heinz, 2010). The contribution of material efficiency to DMC was not high during 1996-2009. In the period 2000 to 2005, material efficiency did positive contributes to DMC. But from 2005 to 2009, the contribution rate was -55.99%. We can conclude that if material efficiency is improved, the material consumption can be minimized to a certain extent. The population factor impacts on DMC reduction were very low.
during the three periods, just 4.81%.

2.3 Semi-parametric Analysis

In order to assess the correlation between land use change and domestic material consumption, we conducted the semi-parametric analysis on the building construction material categories and urban area changes.

The resulting scatter plots, shown in Fig.6–10, show the predicted contributions to the dependent variable from the independent variables. The central curve represents the estimated result and shows the predicted contribution to urban area changes from the DMC changes (calculated as DMC2009-DMC2000) by grid cell. The dotted lines express the confidence interval (95%). The results for urban area changes from other land use types are described below.

Fig.6 shows the result for urban area changes from forest. In the early stage of \( \Delta \text{DMC} \) in building construction sector, the urban area expansion from forest increased rapidly. When the DMC reached a high level, the changes from forest has stabilized.

Fig.7 shows the relationship between \( \Delta \text{DMC} \) and urban area increase, which was converted from grassland. This implies that the increases in \( \Delta \text{DMC} \) accelerated the changes from grassland to urban areas in low \( \Delta \text{DMC} \) areas. But there is a decreasing trend in high \( \Delta \text{DMC} \) areas.

Fig.8 shows the result for urban area changes from farmland. In low \( \Delta \text{DMC} \) change areas, the urban area expansion from farmland increased rapidly. In high \( \Delta \text{DMC} \) areas, it is different from other land use types. It shows an increasing trend of urban areas, which were transformed from farmland. China’s rapid urbanization increased consumption of building material, but it leads the farmland decreases.

Fig.9 shows the water conservation trend with the DMC change. In medium \( \Delta \text{DMC} \) area, it shows that the large quantities of water bodies were transformed into urban, but in high consumption areas, there was a decreasing trend of water conversion. We recognized that the lack of water resources in China couldn’t afford factitious destruction and reduction of water bodies.

Fig.10 shows the wetland conservation trend with the DMC change. The changes from wetland to urban areas are very close to water. When the \( \Delta \text{DMC} \) of buildings reached a high level, urban area changes from wetland was decreased rapidly.

This study discussed the driving force of DMC in building construction sector and estimated the relation between land use change and DMC change. It can effectively predict China’s current environmental and social development issues. It can also help governments to develop policies to ease the pressure of material consumptions.

3. DISCUSSIONS AND CONCLUSION

According to the results, material consumption of building construction in China is increased rapidly. Until 2009, DMC increased to \( 1.27 \times 10^{10} \) tons. This indicates that accelerated urbanization is still an important policy to develop economy in China. It brought a lot of problems such as material security,
greenhouse emissions in the process of material production and soil pollutions.

Index decomposition analysis was applied to discuss the influencing factors of DMC. Unlike other studies, we defined the economical material intensity as DMC of buildings divided by building construction sector’s GDP instead of total GDP. According to the results, the average of the contribution rate of GDP per capita is 102.54%; it is the main factor to affect the DMC in building construction sector in China. Due to the improvement of people’s economic level, realty business development was promoted. Some earners in high economic level regions own many house properties. The gap between the rich and poor increased. Improvement of house property tax to effectively control the increase of DMC should be considered. The contribution rate of material efficiency was -22%, its influence is smaller than GDP per capita, but if the material efficiency was improved, the material consumption can be controlled to a certain extent. The contribution of population in reducing material pressure is very small compared to other sector material.

DMC and land use change are closely related. According to the results of semi-parametric analysis, with the increase of DMC, land transformation from water bodies, grassland and wetland to urban area decreased. This verifies the Environmental Kuznets Curves that with economic development, people started to pay more attentions to environment problems and environment protections. When the domestic material consumption reached the amplitude, changes from forest have stabilized. But certain forest areas are transformed into urban areas in each year. This may be one of the reasons that made China become the world’s top producer of greenhouse gases. Therefore, policy makers should avoid forests decreases in the process of urban development. This is important to maintain the sustainability of society development.

The increase in the DMC has also led to reductions of in farmland. It was presumed that China would be transformed from grain exporter to importer. And with the population increase, food security issue may also appear during the coming decade. Government should therefore prevent rapid farmland contraction. Therefore, we conclude that the increase in house property tax, enactment of economic regulation and improvement of material efficiency can effectively inhibit the material consumption, as well as farmland and forest decrease. In addition, formulation of land use policy is also important to solve environmental problems.

In this study we focused on material consumption of buildings, and urban area changes. But construction materials also relate to other materials such as fossil fuels and other land use types. Other materials and land use type changes need to be discussed in future.

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