# GLOBAL WARMING POTENTIAL OF CHINA'S MANUFACTURING INDUSTRY AND ITS IMPLICATION ON CONSTRUCTION

**Peng Wu**[1]

*School of Design and the Built Environment, Curtin University, Kent Street, Bentley, Perth, WA 6102, Australia*

China's manufacturing industry accounts for 57.5% of the national total energy consumption in 2014, thus becoming the single largest contributor to global climate change in China. This paper therefore aims to investigate the global warming potential of China's manufacturing industry based on a decomposition analysis. The results indicate that since 1994, the global warming potential of China's manufacturing industry has increased by 5.3 billion-ton CO2e. The increase in production volume is the single biggest factor leading to the increase, with an estimated value of 11.8 billion-ton CO2e. At the meantime, effective strategies to reduce the global warming potential of the industry include lower energy intensity, cleaner industry structure, cleaner fuel consumption structure and lower emission factors of fuel, with estimated reduction values of 4.6 billion ton, 1.1 billion ton, 0.7 billion ton and 31.3 million ton respectively. As for the implications on the construction industry, while emission factors and energy intensity are believed to be useful in reducing the global warming potential of the construction industry, the usefulness of development density and fuel mix should be further investigated.

Keywords: global warming, carbon dioxide, manufacturing, decomposition analysis

## INTRODUCTION

Global climate change has been recognized as one of the biggest environmental impacts and it is commonly agreed that global climate change is mainly caused by human activity (Wu *et al.,* 2017). Intergovernmental Panel on Climate Change (IPCC) (2013) stated that the atmospheric carbon emissions concentration has been relatively stable before the industrial era. The CO2 concentration is currently at 408.8 parts per million (ppm) (June 2017), which is much higher than the average CO2 concentration in the past two centuries (around 280 ppm) (American Chemical Society, 2017). Global climate change can cause serious disruption to human development in terms of rising sea level rise (Meehl *et al.,* 2005), extreme weather events and food security (Lobell *et al.,* 2008). Consequently, there is a growing interest to manage carbon emissions globally (Wang *et al.,* 2018).

According to the Boden *et al.,* (2017), China is the largest carbon dioxide emitters since 2008. Fossil fuel combustion and industrial processes of China account for almost 30% of global carbon dioxide emissions (Boden *et al.,* 2017). According to the National Bureau of Statistics of China (2016), the manufacturing industry accounts

[1] peng.wu@curtin.edu.au

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for 57.5% of the national total energy consumption in 2014, thus becoming the single largest contributor to global climate change in China. Ensuring a sustainable development of the manufacturing industry is of critical importance for China to meet the target of 40%-45% emissions reduction from 2005 to 2020 (China Climate Change Info-Net, 2016).

Hammond and Norman (2012) pointed out that the past trend of carbon emissions is useful to understand the current situation and make future decisions on achieving carbon reduction target. As such, many studies have been conducted on analysing how the level of carbon emissions has been changing over the past few decades. For example, Xu *et al.,* (2014) investigated the influence of five factors, including energy structure, energy intensity, industry structure, economic output and population scale, on energy-induced carbon emissions of China. Similarly, Feng *et al.,* (2012) used structural decomposition analysis (SDA) to analyse the impact of five factors, including population, urbanization level, industrial structure, technology and household consumption behaviour on China's regional carbon emissions. It should be noted that as "factory of the world", China's manufacturing industry plays a significant role in achieving its reduction target. However, the manufacturing industry is characterized by its large variability related to the energy types and consumption ways (Hammond and Norman, 2012). As such, very limited studies have been conducted on analysing the influencing factors of the carbon emissions from China's manufacturing industry through decomposition analysis. Wan *et al.,* (2016) only investigated the equipment manufacturing industry in China and Liu *et al.,* (2015) investigated the influencing factors of China's 28 manufacturing subsectors using gross domestic product (GDP). It should be noted that there are several problems with previous decomposition analyses. Compared to GDP, value added, which involves the subtraction of cost of inputs, can better reflect physical production and does not have an issue of double counting (Hammond and Norman, 2012). In addition, the National Bureau of Statistics of China classifies the manufacturing industry into 29 subsectors. More importantly, methane (CH4) and nitrous oxide (N2O) have global warming potentials which are 28-36 and 265-298 times higher than that of carbon emissions (Qu *et al.,* 2011). It is therefore necessary to use global warming potential, which is a consistent evaluation criterion for climate change impact across different gases (Wang *et al.,* 2018).

This paper therefore aims to: 1) investigate the GWP of China's manufacturing industry from 1994 - 2014; and 2) evaluate the policy implications on the construction industry to achieve the reduction target, given the close relationship between the manufacturing industry and the construction industry. The construction industry uses various materials, the extraction and manufacturing of which have heavy impact on the emissions level. A close examination of the emissions from the manufacturing industry would therefore be able to help understand the emissions and patterns from the construction industry. More importantly, China's manufacturing industry is one of the first industries where heavy regulations related to emissions reduction are in place. The examination of the industry would benefit the construction industry which is now facing increasing pressure to achieve emission reduction.

# RESEARCH METHOD

### Factors Influencing the GWP of China's Manufacturing Industry

The changes of energy-related emissions are usually driven by multiple factors such as energy consumption, energy intensity, energy structure, economic output, population, investment, and other factors (Cansino *et al.,* 2015). The manufacturing industry is one of the most energy intensive industries that produce emissions (Akbostancı *et al.,* 2011; Wang *et al.,* 2014). The influencing factors of carbon emissions from the manufacturing industry have been studied by a few researchers from different countries.

One of the most commonly adopted influencing factors is production. It refers to the value added of manufacturing output. This factor can best track the physical production of products. In addition, the factors is widely reported and does not have the issue of double counting (Hammond and Norman, 2012). Energy intensity refers to the average energy consumption per unit of value added. The factor represents the cost of converting energy into value added. High energy intensity indicates a high cost of the conversion process. Industry structure represents the composition of the manufacturing industry. As some subsectors, e.g. smelting and pressing of ferrous metals, are energy intensive, an increase in the relative size of these subsectors will lead to an increase in emissions. Fuel mix also plays an important role. Different fuels have different calorific values and emission factors. For example, the calorific value of diesel is two times of coal, reported by China's National Standard GB/T 2589-2008: General Rules for Comprehensive Energy Consumption Calculation. The emission factor of different fuel types may change. The emission factors of fuel are normally fixed in previous studies (Hammond and Norman, 2012). The emission factor of electricity normally changes, because the composition of power generation changes and the process of coal-fired electricity generation improves every year. Some important sources of carbon emissions, such as the use of aluminium and glass, was excluded from previous studies in the construction industry (Wu *et al.,* 2019). Wu *et al.,* (2019) argued that such exclusion can affect the accuracy of the carbon analysis and subsequent decision making related to emission reduction. It is therefore important to understand the emission levels of the manufacturing industry to decide which sectors should be included in the analysis of the construction industry.

**Modelling Approach**

Index decomposition analysis (IDA) based on statistical data and structural decomposition analysis (SDA) which employs input-output tables are the two common methodologies used by researchers to study drivers of changes in energy-related emissions (Wang *et al.,* 2017). Compared to SDA, IDA has the advantages of simplicity and the availability of data (Hammond and Norman, 2012). All IDA techniques are generally divided into two categories: technique linked to Divisia index and technique linked to Laspeyres index (Howarth *et al.,* 1991). Generally speaking, the Divisia index technique is preferred because it is more scientific (Ang, 2004). Although the Laspeyres index technique is easier to understand and commonly used by energy researchers in the 1990s, this technique often gives a large residual, thus affecting the estimated effects. Therefore, the Divisia index technique is adopted in this study as it delivers perfect decomposition whereby no unexplained residual term exist in the results. The Divisia index techniques can be further divided into two groups: namely multiplicative decomposition (Ang and Liu, 2001) and additive decomposition (Ang *et al.,* 1998). The arithmetic mean Divisia index methods (AMDI) and the log mean Divisia methods (LMDI) (Ang *et al.,* 1998) are widely applied by both groups. Although the formulae of AMDI is simpler compared to LMDI, increasing number of studies (Akbostancı *et al.,* 2011) selected LMDI to conduct decomposition analysis for emissions changes as LMDI gives perfect decomposition and can handle the value zero in the data set (Ang *et al.,* 1998). Based on these literature review, LMDI is herein selected as the decomposition analysis technique in this study.

**Mathematical Representation of the GWP**

The GHGs (including CO2, CH4 and N2O) of energy consumption (excluding electricity consumption) are calculated based on CO2 equivalent. Considering that CH4 and N2O have higher GWP than CO2, the GHG of the manufacturing industry can be calculated by:

$$GHG_{Manufacturing} = CO_{2,Manufacturing} + 23\ CH_{4,Manufacturing} + 296\ N_2O_{Manufacturing} \quad (1)$$

The National Bureau of Statistics of China reports the annual energy consumption by sector in the China Statistics Yearbook. The GHG emissions of the annual energy consumption are calculated by:

$$CO_{2,t} = \sum_{i=1}^{29}\sum_{j=1}^{8} CO_{2,ij,t} = \sum_{i=1}^{29}\sum_{j=1}^{8} E_{ij,t} \times EF_{CO_2,j} \times V_j \quad (2)$$

$$CH_{4,t} = \sum_{i=1}^{29}\sum_{j=1}^{8} CH_{4,ij,t} = \sum_{i=1}^{29}\sum_{j=1}^{8} E_{ij,t} \times EF_{CH_4,j} \times V_j \quad (3)$$

$$N_2O_t = \sum_{i=1}^{29}\sum_{j=1}^{8} N_2O_{ij,t} = \sum_{i=1}^{29}\sum_{j=1}^{8} E_{ij,t} \times EF_{N_2O,j} \times V_j \quad (4)$$

where:

CO2, t, CH4, t, and N2Ot refer to the total CO2, CH4 and N2O emissions in year t;

i refers to the sectors within the manufacturing industry following the industry classification codes in the China Statistical Yearbook. A total of 29 sub-sectors are recorded;

j refers to the types of energy consumption, including (raw coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas and electricity);

Eij,t refers to the energy consumption of source j from sector i in year t;

$EF_{CO_2,j}$, $EF_{CH_4,j}$ and $EF_{N_2O,j}$is the emission factors of energy source j on a net calorific basis reported by IPCC (2006); and

Vj is the Chinese specific low-calorific value of energy source j (excluding electricity), reported in the National Standard GB/T 2589-2008: General Rules for Comprehensive Energy Consumption Calculation.

**Decomposition model**

This study uses LMDI method to analyze the contribution of each influencing factor to the GWP of China's manufacturing industry. LMDI uses a logarithmic weight function instead of arithmetic weight function.

Following the LMDI method, the GWP of China' manufacturing industry can be calculated by:

$$GWP = \sum_i\sum_j GWP_{ij} = \sum_i\sum_j Q\frac{Q_i}{Q}\frac{E_i}{Q_i}\frac{E_{ij}}{E_i}\frac{GWP_{ij}}{E_{ij}} = \sum_i\sum_j Q \cdot IS_i \cdot EI_i \cdot FM_{ij} \cdot EF_{ij} \quad (5)$$

where:

Q is the value added of the manufacturing industry; Qi is the value added of the subsector i; Ei is the energy consumption of subsector i; Eij is the fuel consumption from source j in subsector i; GWPij is the global warming potential of fuel source j of subsector i; ISi is the activity share of subsector i in terms of value added; EIi is the energy intensity of subsector i; and FMij is the fuel mix in subsector i.

Consequently, the change in GWP of China's manufacturing industry can be decomposed into the changes of the five influencing factors, by:

$$\Delta GWP = \Delta GWP_Q + \Delta GWP_{IS} + \Delta GWP_{EI} + \Delta GWP_{FM} + \Delta GWP_{EF} \quad (6)$$

$$\Delta GWP_Q = \sum_{i=1}^{28}\sum_{j=1}^{9} L\left(GWP_{ij}^{T}, GWP_{ij}^{0}\right) \ln\frac{Q^T}{Q^0} = \sum_{i=1}^{28}\sum_{j=1}^{9} \frac{GWP_{ij}^{T}-GWP_{ij}^{0}}{\ln GWP_{ij}^{T}-\ln GWP_{ij}^{0}} \ln\frac{Q^T}{Q^0} \quad (7)$$

$$\Delta GWP_{IS} = \sum_{i=1}^{28}\sum_{j=1}^{9} L\left(GWP_{ij}^{T}, GWP_{ij}^{0}\right) \ln\frac{IS_i^T}{IS_i^0} = \sum_{i=1}^{28}\sum_{j=1}^{9} \frac{GWP_{ij}^{T}-GWP_{ij}^{0}}{\ln GWP_{ij}^{T}-\ln GWP_{ij}^{0}} \ln\frac{IS_i^T}{IS_i^0} \quad (8)$$

$$\Delta GWP_{EI} = \sum_{i=1}^{28}\sum_{j=1}^{9} L\left(GWP_{ij}^{T}, GWP_{ij}^{0}\right) \ln\frac{EI_i^T}{EI_i^0} = \sum_{i=1}^{28}\sum_{j=1}^{9} \frac{GWP_{ij}^{T}-GWP_{ij}^{0}}{\ln GWP_{ij}^{T}-\ln GWP_{ij}^{0}} \ln\frac{EI_i^T}{EI_i^0} \quad (9)$$

$$\Delta GWP_{FM} = \sum_{i=1}^{28}\sum_{j=1}^{9} L\left(GWP_{ij}^{T}, GWP_{ij}^{0}\right) \ln\frac{FM_i^T}{FM_i^0} = \sum_{i=1}^{28}\sum_{j=1}^{9} \frac{GWP_{ij}^{T}-GWP_{ij}^{0}}{\ln GWP_{ij}^{T}-\ln GWP_{ij}^{0}} \ln\frac{FM_i^T}{FM_i^0} \quad (10)$$

$$\Delta GWP_{EF} = \sum_{i=1}^{28}\sum_{j=1}^{9} L\left(GWP_{ij}^{T}, GWP_{ij}^{0}\right) \ln\frac{EF_i^T}{EF_i^0} = \sum_{i=1}^{28}\sum_{j=1}^{9} \frac{GWP_{ij}^{T}-GWP_{ij}^{0}}{\ln GWP_{ij}^{T}-\ln GWP_{ij}^{0}} \ln\frac{EF_i^T}{EF_i^0} \quad (11)$$

The outputs of Equations 7-11 represent the contribution of the influencing factors of output, industry structure, energy intensity, fuel mix, and emission factor respectively.

# RESULTS

## Energy-Related GWP of China's Manufacturing Industry

The energy-related GWP of China' manufacturing industry and corresponding percentage of China's total GWP from 1994-2014 are shown in Figure 1(A). The GWP of China's manufacturing industry shows an upward trend from 2.31 billion t CO2e in 1994 to 8.71 billion t CO2e in 2014. The GWP growth from 2003-2004 has the largest growth rate of 22.17%. The contribution of China's manufacturing industry to the overall GWP decreases to the lowest of 48.11% in 2003. Its contribution has been increasing since then and sits at 54.77% in 2014, demonstrating the importance of China's manufacturing industry to the country's overall GWP. The contributions of CO2, CH4 and N2O to China' GWP are fairly stable, at around 99.55%, 0.15% and 0.30% respectively.

The top five subsectors (in terms of GWP contribution) in the manufacturing industry are presented in Figure 1(B). From 1994-1995, the top five subsectors are smelting and pressing of ferrous metals (22.99%-23.30%), petroleum processing and coking products (20.50%-21.50%), raw chemical materials and chemical products (15.97%-16.00%), non-metal mineral products (13.70%-13.63%), and textile (3.46%-3.30%). Starting from 1996, smelting and pressing nonferrous metals has taken over textile as the fifth largest manufacturing subsectors in terms of GWP contribution. From 1996-2014, the top five subsectors of GWP in manufacturing are petroleum processing and coking products (21.52%-29.00%), smelting and pressing of ferrous metals (22.71%-26.38%), raw chemical materials and chemical products (17.66%-13.14%), non-metal mineral products (13.55%-10.76%), and smelting and pressing of nonferrous metals (3.01%-6.20%).

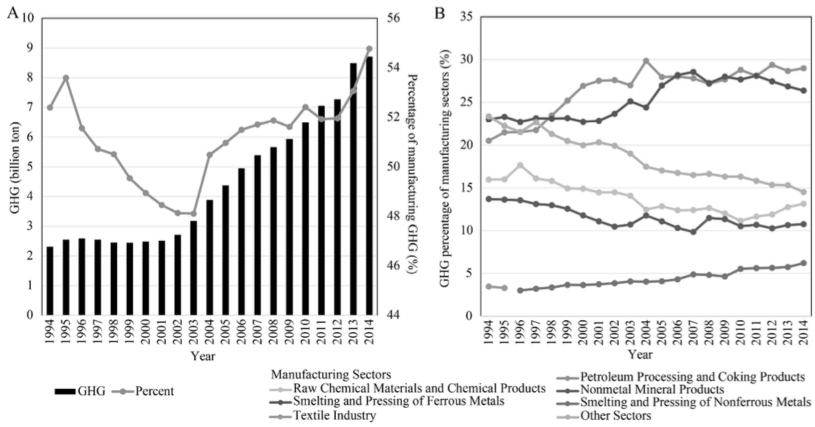



*Figure 1: The GWP of China's manufacturing industry. (A) The GWP of China's manufacturing industry and its corresponding percentage of China's total GWP; (B) The top five manufacturing subsectors (in terms of GWP contribution) of China from 1994-2014.*

The GWP of China' manufacturing industry has different pattern when compared with other industries, such as the construction industry. The carbon emissions of the construction industry reached the peak of 0.16 billion t in 2012. However, the magnitude of the GWP from the two industries varies significantly and it seems that the GWP of the manufacturing industry has not reached its peak in 2014. In addition, the manufacturing industry faces increasing pressure to manage its energy consumption and GWP as the government has announced that the annual growth of energy consumption cannot exceed 3.5% from 2015-2020 (Lu *et al.,* 2016). However, the average growth rate of energy consumption from 2010-2014 is 8.33% (see Figure 2).

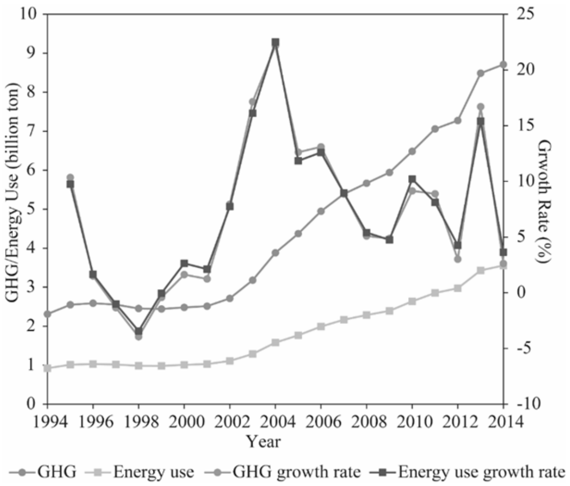



*Figure 2: The growth rate of annual GWP and energy consumption of China's manufacturing industry from 1994-2014*

**Decomposition Results**

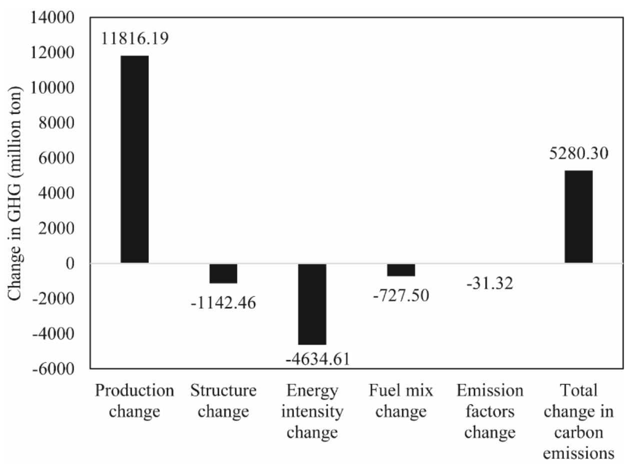
Figure 3 shows the results of the decomposition analysis from 1994-2014 in a cumulative way. From 1994-2004, the GWP of China's manufacturing industry has increased by 5280.30 million tCO2e. Production change because of increased value added is the largest contributor to the increase of GWP, accounting for 123% of the increase. On the other hand, energy intensity, industry structure, fuel mix and emission factor all contribute to the reduction of GWP, at 4643.61, 1142.46, 727.50 and 31.32 million tCO2e respectively.

Figure 4 shows the results of the decomposition analysis at a yearly basis. Three most notable years with significant reduction of annual GWP can be identified, including 2007-2008, 2011-2012 and 2013-2014.

# DISCUSSIONS

## Influencing Factors of the GWP Change

The empirical results reveal that production change is the single largest contributor to the GWP of China's manufacturing industry. This is in accordance with China's economic growth over the analysis period. In order to offset such increase, a few strategies have proven to be effective. Reducing energy intensity, as an indicator of the average energy consumption per unit of value added, represents the most effective measure. Over the past 10 years (from 2004 to 2014), the energy intensity has reduced from 2531 g sce/usd to 784 g sce/usd, a 69% reduction. Other useful strategies include structure change, i.e. the shifting towards subsectors which utilise lower energy consumption. In addition, fuel mix is also a useful strategy through two improvement areas, i.e. relying less on coal-fired electricity generation and the improvement of coal-fired electricity generation in terms of energy efficiency. According to Wu *et al.,* (2019), the percentage of coal-fired electricity generation in China is gradually decreasing from 82.33% in 2000 to 74.24% in 2015. In addition, the standard coal consumption for producing 1 kwh electricity is reduced from 392 g sce to 315 g sce from 2000 to 2015.




## Implications for the Construction Industry

The GWP pattern of the manufacturing industry does provide some useful insights on the GWP pattern of the construction industry. First of all, it is expected that emission factors should be effective in reducing the GWP of the construction industry. Although emission factors of majority of the fuel, e.g. coal and diesel, remain unchanged, the emission factor of electricity, which is also an important source of energy in the construction industry, is gradually reducing. However, there are a few concerns that can only be addressed when further analysis is conducted in the construction industry. The most important difference between the construction industry and the manufacturing industry is that the construction industry does not have a detailed list of sub-sectors as the manufacturing industry.

*Figure 3: The cumulative contribution of the five influencing factors towards the GWP of China's manufacturing industry.*

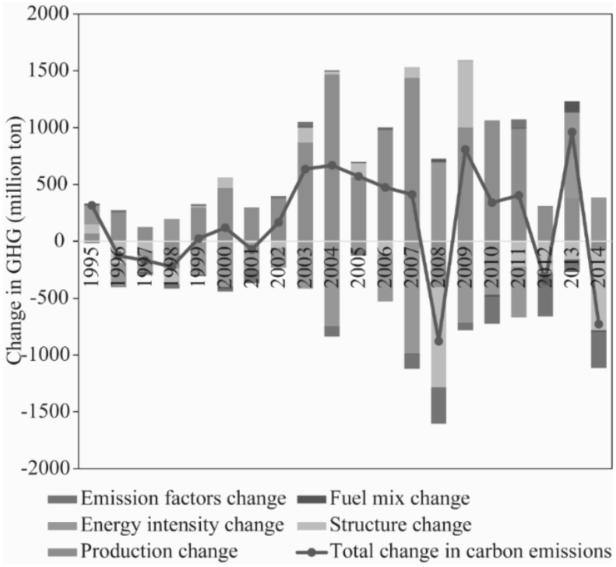



*Figure 4: The yearly contribution of the five influencing factors towards the GWP of China's manufacturing industry*

Therefore, it may be difficult to investigate the impact of structure change. One useful way is to analyse the phases of the construction industry, including extraction and use of raw materials, construction and operation. As new construction has slowed down over the past few years, it would be interesting to investigate whether a focus towards operation can help reduce the GWP of the industry. The next speculation is that fuel mix will not play as an important role in construction as it is in manufacturing. A preliminary investigation shows that there is a significant increase in the use of coals for building operation from 2000 to 2015. Some other indicators may also be interesting to be investigated. For example, how significant is the impact of urbanization on the GWP of the construction industry and is the increase in development density effectively effective to reduce GWP, because there is a common belief that low-density suburban development is more energy intensive.

# CONCLUSIONS

The main contribution of this study is to analyse the influence factors of the GWP of China's manufacturing industry. A total of five influence factors, including production, energy intensity, industry structure, fuel mix and emission factors, are investigated. The results show that the increase in production volume, in terms of value added, is the single most important factor that leads to an increase of GWP in this industry. Other factors are proven to be effective in reducing the GWP from 1994-2014. The results also provide some useful insights into how the GWP of the construction industry should be analysed and managed. Aluminium and glass, representing a significant portion of the industry's emissions, should not be overlooked. In addition, while emission factors and energy intensity are believed to be useful in reducing the GWP of the construction industry, the usefulness of development density and fuel mix should be further investigated.

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