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Iron and steel in Chinese residential buildings: A dynamic analysis

Mingming Hu[a,b,*], Stefan Pauliuk[c], Tao Wang[c], Gjalt Huppes[b], Ester van der Voet[b], Daniel B. Müller[c]

[a] Faculty of Construction Management and Real Estate, Chongqing University, Chongqing 400015, PR China
[b] CML – Institute of Environmental Sciences, Leiden University, Einsteinweg 2, 2333 CC Leiden, The Netherlands
[c] Department of Hydraulic and Environmental Engineering, Norwegian University of Science and Technology, S P Andersens vei 5, 7491 Trondheim, Norway

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ABSTRACT

The rise of China to become world largest iron and steel producer and consumer since the late 1990s can be largely attributed to urbanization, with about 20% of China's steel output used by residential buildings, and about 50% for the construction sector as a whole. Previously, a dynamic material flow analysis (MFA) model was developed to analyze the dynamics of the rural and the urban housing systems in China. This model is expanded here to specifically analyze iron and steel demand and scrap availability from the housing sector. The evolution of China's housing stock and related steel is simulated from 1900 through 2100. For almost all scenarios, the simulation results indicate a strong drop in steel demand for new housing construction over the next decades, due to the expected lengthening of the – presently extremely short – life span of residential buildings. From an environmental as well as a resource conservation point of view, this is a reassuring conclusion. Calculations for the farther future indicate that the demand for steel will not just decrease but will rather oscillate: the longer the life spans of buildings, the stronger the oscillation. The downside of this development would be the overcapacities in steel production. A scenario with slightly lower life spans but a strong emphasis on secondary steel production might reduce the oscillation at moderate environmental costs.

1. Introduction

The sharp increase in material demand in China has grown the country the largest iron and steel consumer as well as the largest producer in the world. China's annual use of iron per capita has risen from 90 kg/year in 2000 to 370 kg/year in 2008, while the world's per capita iron use increased in the same period from 130 kg/year to 190 kg/year (CISA, 2008; WSA, 2008, 2009). Along with that, production volume in China has more than tripled, from 129 to 500 Mt (million metric tons) between 2000 and 2008, which now accounts for 38% of world crude steel production (Price et al., 2002; WSA, 2009). China has very limited domestic scrap supply (Lu, 2002) and limited quantity and quality of iron ore. For this reason, China's steel production mainly relies on virgin minerals, which are largely imported (Wang et al., 2007, 2008). How China's demand will develop in the future will inevitable exert an influence on the global raw material market. Moreover, the extraction and production of iron and steel impose considerable energy and environmental consequences, which is especially true for the iron ore based[1] production in China. Therefore, it is important to understand the development mechanism of steel demand and scrap supply in China, and its economic and environmental implications.

The recent rise of steel demand in China can be largely attributed to the unprecedented urbanization in the country. In 2004, apparent steel consumption in China was 286 Mt/year, half of which is used in the construction industry while residential buildings account for 19% (Fig. 1). A short-term forecast for China's future steel demand has been made by the Development Research Center of the State Council of China (DRCSCC), which indicates that steel demand in China will further increase by 50% from 2005 to 2010 (DRCSCC, 2005).

An effort for long-term projection has been done by Yang and Kohler (2008) for the mass input and output of China's building and infrastructure systems. This research analyses the historical evolution of the Chinese building and infrastructure stock from 1978 to 2005 and estimates the future mass input and output through 2050. It provides valuable information about China's building stock. However, this model neglects the ageing of the building stock and

* Corresponding author at: Room 6.27, Faculty of Civil Engineering and Geosciences, Section Materials & Environment, Stevinweg 1, 2628 CN Delft, The Netherlands. Tel.: +31 015 278 85 69; fax: +31 015 278 81 62.
E-mail addresses: Hu@cml.leidenuniv.nl, mming.hu@gmail.com (M. Hu).

[1] Primary steel is produced by basic oxygen furnace (BOF), whose scrap input is rather small, typically 10–25% (Price et al., 2002). Secondary steel is produced in an electric arc furnace (EAF) using scrap. In 2002, 84.5% of Chinese steel production is primary steel using mainly iron ore, while only 15.42% is secondary steel using scrap (Wang, 2004).

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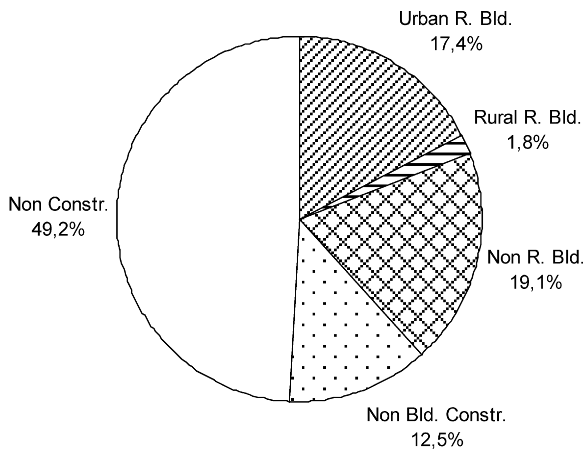

Fig. 1. Apparent steel consumption in China 2004. Non Constr. = Non-construction; Non Bld. Constr. = Non-building construction; Non R. Bld. = Non-residential building; Rural R. Bld. = Rural residential building; Urban R. Bld. = Urban residential building. *Source*: DRCSCC (2005).

assumes that the demolition rate is proportional to the total stock, and is therefore limited in its capacity to forecast long-term changes in construction and demolition activities and their related material flows.

A generic dynamic MFA model for simultaneously determining the resource demand and waste generation through estimations of the population, its lifestyle, technology, and product lifetime has been proposed by Müller (2004, 2006). This model uses stock dynamics approach that tracks all vintage classes (year by year) individually and computes the demolition activities based on the estimates of probability distribution functions for the lifetimes of all vintage classes, and therefore provides a better framework to analyze the material diffusion in long lifespan goods, such as residential buildings. Based on the approach, Hu et al. (2009) developed a dynamic MFA model to simulate the evolution of the floor area stocks in China's urban and rural housing systems from 1900 through 2100. This model is expanded in this study to specifically cover China's iron and steel demand for residential construction and the scrap availability from housing demolition.

Through the dynamic MFA for steel in China's housing stock, this study aims to answer the following questions: (1) how the housing related steel demand in China will likely develop in the future; (2) what the implications of such development are for the steel industry and how the potentially negative impacts on the industry could be mitigated; and (3) what the environmental consequences are for various options for mitigating the impacts.

2. Methods

2.1. System definition

The model presented in Fig. 2 represents a material flow analysis (MFA) for the floor area and selected construction material (steel) in China's residential building stock. The system is divided into two sub-systems reflecting the rural and urban housing stocks. The two sub-systems are linked through migration flows from rural to urban areas (m_u) and vice versa (m_r). Each sub-system involves three types of processes, illustrated with rectangles: population within the region (P), housing floor area of the region (A) and related material (M). All the processes have a state variable (P_r, A_r, M_r for rural area or P_u, A_u, M_u for urban area) and a derivative, which is the net stock accumulation (dP_r/dt, dA_r/dt, dM_r/dt or dP_u/dt, dA_u/dt, dM_u/dt). Each population process has three pairs of input and output flows which are denoted, respectively, as: b and d for annual inflow and outflow of population led by birth and death, i and e for annual immigration and emigration crossing China's border, and m_u and m_r for internal migration flows from rural to urban and vice versa. The integrated effect of these flows on the share of people living in rural and urban can be indicated by the urbanization rate. In this study, the urbanization rate (u) and the total national population (P) are used as determinants for China's rural (P_r) and urban (P_u) population. Each housing floor area process has an input ($dA_{r,in}$ or $dA_{u,in}$) and an output flow ($dA_{r,out}$ or $dA_{u,out}$), represented with straight-line arrows and ovals. Housing floor area stock is shaped by population (P_r or P_u) and per capita floor area (A_{rc} or A_{uc}); output flow is the delay of past input, determined by building lifetime function ($L_r \sim N(\tau_r, \sigma_r)$ or $L_u \sim N(\tau_u, \sigma_u)$); and the future input flow is formed to maintain the demanded size of in-use housing floor area stock. Input flow of material ($dM_{r,in}$ or $dM_{u,in}$) is coupled with floor area through the material intensity (M_{ra} or M_{ua}), and the output flow of material ($dM_{r,out}$ or $dM_{u,out}$) is determined by delaying the input. The underlying equations are given in Appendix A and the eight external parameters for the model are listed as follows:

P	National total population
u	Urbanization rate = P_u/P
A_{rc}	Per capita floor area in rural region
A_{uc}	Per capita floor area in urban system
L_r	Lifetime distribution of rural housing ($L_r \sim N(\tau_r, \sigma_r)$)
L_u	Lifetime distribution of urban housing ($L_u \sim N(\tau_u, \sigma_u)$)
M_{ra}	Material intensity per unit floor area in rural region
M_{ua}	Material intensity per unit floor area in urban system

2.2. Model parameter quantification

2.2.1. Steel intensity

Very few data are available for the steel intensity in different dwelling vintages. Little iron and steel was used in Chinese housing construction before 1950s when concrete structure became popular in urban residential construction. Typical Chinese dwellings at the beginning of 20th century were one or two-floor buildings built from local materials such as clay, bricks, wood, bamboo et al. A recent survey estimates the average steel intensity in China's urban residential construction in 2004 to be 36.5 kg/m^2 (DRCSCC, 2005). Due to the promotion of steel structures, the same study expects the steel intensity in urban residential construction to further increase to 41.3 kg/m^2 by 2010 (DRCSCC, 2005; illustrated as dots in Fig. 3b), however, the trend for the longer term is less clear. From one side, the steel intensity may continue to rise if China's high steel production capacity will lead to low cost construction steel, or if the increase of high residential buildings will employ more high steel content structures in residential construction. From another side, technical innovation may minimize the steel use in concrete structure, which is dominant in China's urban residential buildings. For instance, the steel content in concrete may be substituted by glass fiber, if the technical development will drop the cost of glass fiber to be competitive, or when developments in the steel market will cause the steel prices to rise significantly. We therefore assume that the steel intensity in China's residential construction follows a (double) logistic curve with initial level zero, with the measured level of 2004, and with different assumed saturation levels. Three potential future paths are investigated, representing trends of increasing, decreasing, and stabilizing steel intensity (Fig. 3b).

The variance for steel intensity in urban housing construction is based on a survey for 100 residential buildings in Beijing (Liu and Hu, 2006). The survey shows the shearing-force structure dwellings have the highest steel intensity as 97.1 kg/m^2, while the brick-concrete structure dwellings have the lowest value as 23.4 kg/m^2. We assume that by 2100, for increasing path, due to the increase of high dwellings and the promotion of steel intensive structure in residential construction, the average steel intensity in China's urban