A Scenario of Construction Material Balance in Japan

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1. Introduction

Construction materials accumulate as buildings and infrastructure in society. As a country develops and its economy grows the amount of buildings and infrastructure also increases, as these construction developments form a basis for modern economy. However, the extraction of construction materials from the environment poses numerous environmental and sustainability issues. The accumulation of these materials as physical stocks and the eventual waste products of construction and demolition add to these hazards. In order to reduce environmental stress, more efficient usage of materials is necessary. This can be achieved by using less material, extending the functional lifetime of these materials, and reaching a balance between the amounts of input and output. The research field of Social Metabolism offers tools to examine the movement of materials in and out of society, and the accounting of the flows and stocks of materials provides researchers and policy makers the ability to better understand the interactions between material usage, economic activity, and social such as population changes (Eurostat 2001). The research presented in this paper explores the relations of the flows and stocks of construction materials in modern Japan using a model of stock accumulation based on inflow statistics. A scenario until the year 2050 is presented, offering a view of the challenges Japan is facing in order to achieve a more sustainable stock-based society.

2. Data and Methods

Statistical data of the material inputs of Japan, covering the years 1878-2005, has been compiled by Krausmann et al (2011). This database includes the amounts of construction materials that were input into the Japanese economy by domestic extraction and imports as well as exports. These materials are grouped into several main categories including timber, metals (iron, aluminum, etc.), and non-metallic minerals (sand, gravel, etc.). The total materials that are used for the construction of buildings, roads, bridges, and other civilian infrastructure can be considered as the Gross Addition to Stock (GAS) in a given year. These buildings and infrastructure accumulate over time as Material Stocks (MS), and eventually reach their end of life and get demolished. In this research, ejections of stocked material is estimated in yearly steps using survivability functions for each material group. Thus, the calculation of the total stock of materials in a given year is given by the following functions (Fishman et al. 2012):

$$GAS_i(t) = \left(DE_i(t) + IM_i(t) - EX_i(t)\right) \times r_i \quad (1)$$

$$MS_i(t) = \sum_{\tau=t-\tau}^{t} \left[GAS_i(\tau) \times \left(1 - \mathrm{F}(t-\tau; \mu_i, \sigma_i)\right)\right] \quad (2)$$

Where $GAS_i(t)$ is the Gross Addition to Stock of material i in year t, DE is the domestic extraction, IM is the import, EX is the export, and r is the rate of material i that becomes stocked in year t. $MS_i(t)$ is the total stock of construction material i in year t, calculated as a sum of the remaining amount of materials stocked in previous years $(t-\tau)<\tau<t$ based on the survivability function F, the cumulative distribution function of the normal distribution in the year $t-\tau$ with parameters μ_i and σ_i.

The Net Addition to Stock (NAS) is defined as the yearly change in total material stocks. By subtracting the net additions value from the gross additions value, the total demolished material (Deduction from Stock, DS) is revealed.

$$NAS_i(t) = MS_i(t) - MS_i(t-1) \quad (3)$$

$$DS_i(t) = GAS_i(t) - NAS_i(t) \quad (4)$$

Where $NAS_i(\tau)$ is the Net Addition to Stock of material i in year τ, and $DS_i(\tau)$ is the Deduction from Stock of material i in year τ. Initial stocks for the year 1930 are derived from a run of the model back to the first year of flow statistics, 1878. In 1930 the remaining material from 1878 is about 0.1%, meaning that any material from before 1878 is negligible. The period of 1930-2005 is based on the historical statistics described above, while material accumulation for the period of 2006-2050 follows a scenario of constant yearly material input, set as the average material input in the final 10 years of the historical series. This can be described as a "steady state" scenario, in which there are no changes to gross material inputs.

Population statistics for Japan for the years 1930-2005 are taken from Maddison (2008), and for 2005-2050 from the "medium variant" scenario of the National Institute of Population and Social Security Research (2003).

3. Results

As shown in figure 1, total Material Stocks ($\sum_i MS_i(t)$) have increased 42-fold from 1930 to 2005. The tremendous increases in MS were driven by a huge amount of yearly inflow: from the end of World War 2 until 1973, each year's GAS values have been higher than the previous year (figure 2). In comparison, yearly DS amounts in the same period were minor, causing NAS to be overwhelmingly positive. After 1973 there have been sharp changes in yearly GAS, but ever since the maximum inflow amount of 1991 it has been following a declining trend. At the same time, the materials stocked in the post-war period are reaching their end-of-life and demolition (DS) is gradually increasing, resulting in diminishing NAS.

Following the assumptions described in the previous section, stocks are projected to continue to increase until at least 2050, albeit at a slower rate. This reduced rate is a result of continuously increasing DS quantities, counterbalancing the fixed amount of GAS and reducing the NAS towards zero. In such a scenario, by the year 2050 the amounts of input and output would be almost equal, bringing net additions to stock close to zero- which can be described as a steady-state system.

4. Discussion

The population of Japan has increased from 64 million people in 1930 to 127 million in 2005. However, current population projections by the Japanese government forecast this to be a peak which will be followed by a rapid decline. In the past, the growth of materials has outpaced the growth of people, causing increasing quantities of material per person. On the other hand, recent years have been characterized by a reduction in material flows in both absolute numbers and per-capita terms (figure 3). The scenario in this paper assumes steady inflows of materials in the future, but coupled with decreasing population this will actually bring about a renewed increase in per-capita gross additions to stocks, reversing the current trend. However, the quantities of demolished materials per capita are also proportionally increased, maintaining the possibility of reaching near-zero NAS per person in 2050. Nevertheless, the question of increasing GAS per person remains open, suggesting that further improvements in material efficiency might be possible.

5. Conclusions

It is said that in order to achieve a sustainable economy, there should be a balance between inflows and outflows of materials, that is- the net additions to stock should be as close to zero as possible. The scenario put forward in this paper suggests that a stable inflow of materials can help to achieve this objective in Japan by the year 2050. As discussed in the previous section, this scenario results in increasing GAS per capita, which is inverse to current trends and is environmentally and economically ill-advised. The main assumptions in this scenario are based on steady levels of input in the future, despite a trend of decreasing inputs in all three material categories in recent times. In other words, if the trends of recent years continue, (characterized by decreasing inflows of materials), reductions in GAS per capita as well as a reduced time towards material balance could be achieved. This scenario should be studied in future research, together with an integration of recycling and economic considerations into the model.

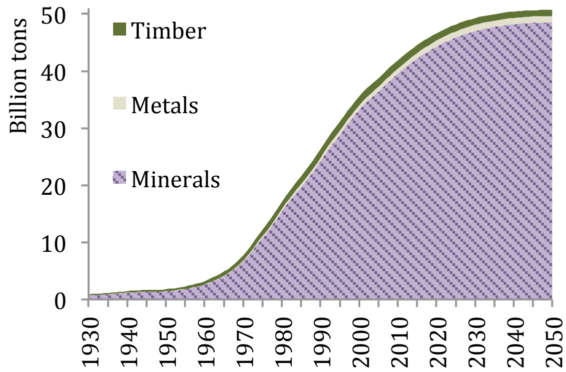

Fig.1: Stocks of construction materials, 1930-2050.

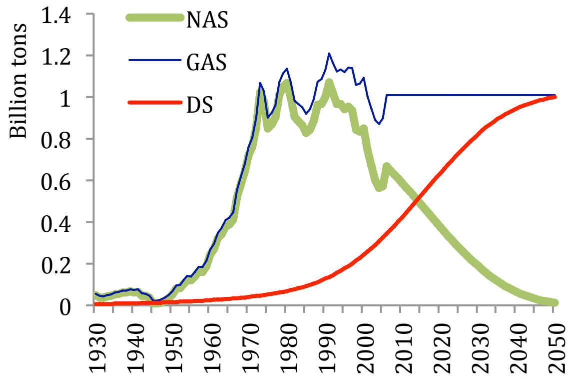

Fig.2: Flows of construction materials, 1930-2050.

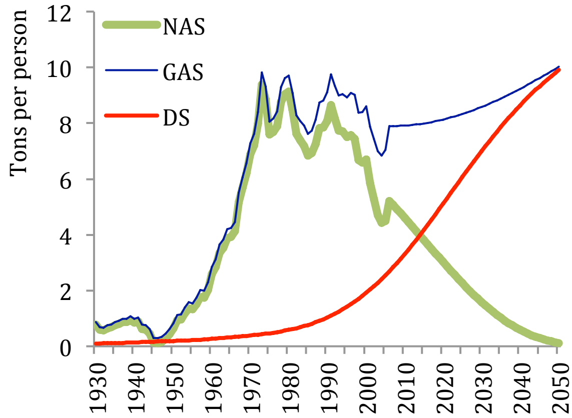

Fig.3: Flows of construction per person, 1930-2050.

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