Aggregate consumption and economic development: a cross-country comparison.

Empirical studies about material flows and stocks indicate that so far there have been no signs of a reduction of material accumulation in any country of the world [1–3]. While some developed countries are slowing their yearly material accumulation [4–6], developing countries, such as China, Brazil, or India, are experiencing an unprecedented period of rapid growth in materials use [6–9]. Their booming economies cause a large increase in the trade volume of materials, as well as fast increasing material stock, because of the need for modern infrastructure, new buildings, and a general improvement in the lifestyle and material standard of living of the population. To satisfy the very large infrastructure demand the production of steel and cement is higher than ever [10, 11].

The development of new buildings and roads not only requires cement and steel, but also aggregate, including sand, gravel, and crushed stone. Construction materials are low economic value-high volume material flows, and they are absolutely essential for the construction of buildings and transport infrastructure. They make up about 50% of industrial metabolism of many countries[1–9] and yet a sensitivity analysis of the accounts for aggregates is missing in material flow studies. Accounting methods for aggregates in material flow studies have relied on simplistic and generalised assumptions that do not take into account the technological complexity and engineering knowledge of concrete, roads, and brick production[4–7, 9, 12–14]. Even though the order of scale seems to be correct, aggregate consumption is arguably the material flow category with the highest uncertainty.

The growing global demand for aggregates causes the movement of million of tonnes of rock from the natural environment, which are used to build cities, transport and industrial infrastructure. This causes several problems which include the economic and environmental costs of hidden material flows; anthropogenic disturbance, i.e. the artificial movement of material that leads to the alteration of natural landscapes; and increased material stock in the cities, which will have to be maintained and eventually will be dismantled causing very large construction waste flows.
Considering the high level of energy and CO_2 embedded in construction materials [15], a more precise calculation of the quantity of aggregate used may enable policy makers to tackle with greater effectiveness the impending problem of CO_2 reduction. Since the quantity of material stocked in urbanised areas is incessantly growing, it is essential to have a clear knowledge of its yearly consumption. Moreover, because of the sheer volume of material involved, recycling policies will need be established, otherwise the anthropogenic disturbance of the natural environment might alter irreversibly the habitat of countless species, contributing further to biodiversity loss.

The objective of this research is to increase the precision of construction material flow accounts on the global scale and for every country and relate it to growth indicators. This interdisciplinary research involves experts from different fields including industrial ecologists, economists, statisticians, and civil & building engineers, and relies on information from manufacturers of construction materials to obtain realistic data for the aggregate intensity for the production of concrete, roads, and bricks. Using data for the apparent consumption of cement, bitumen, and bricks and applying factors for the aggregate intensity of those from a significant number of case studies

from across the world, we calculate the aggregate flows required for every country. This enables us to identify average aggregate consumption and obtain complex statistics, which give us a good sense of the uncertainty and variance in the extraction and production of construction materials.
Furthermore, the relation between aggregate consumption and economic activity is analysed for a number of key countries (e.g. developed European and Asian countries, and developing Asian and African countries), to unpack the linkage between the wealth and growth of a nation and its material metabolism. This research will help improve the accuracy and robustness of one of the most underexplored data areas in MFA, and may assist managing the extraction, usage, recycling, and disposal of sand, gravel, and crushed stones in a sustainable way.

References

1. Krausmann, F. *et al.* Growth in global materials use, GDP and population during the 20th century. *Ecological Economics* **68,** 2696–2705 (2009).
2. Fishman, T., Schandl, H., Tanikawa, H., Walker, P. & Krausmann, F. Accounting for the Material Stock of Nations. *Journal of Industrial Ecology* **18,** 407–420 (2014).
3. Tanikawa, H., Fishman, T., Okuoka, K. & Sugimoto, K. The weight of society over time and space: a comprehensive account of the construction material stock of Japan, 1945-2010. *Journal of Industrial Ecology* **In Press,** (2014).
4. Gierlinger, S. & Krausmann, F. The Physical Economy of the United States of America. *Journal of Industrial Ecology* **16,** 365–377 (2012).
5. Krausmann, F., Gingrich, S. & Nourbakhch-Sabet, R. The Metabolic Transition in Japan. *Journal of Industrial Ecology* **15,** 877–892 (2011).
6. Schandl, H. & West, J. Material flows and material productivity in China, Australia, and Japan. *Journal of Industrial Ecology* **16,** 352–364 (2012).
7. Singh, S. J. *et al.* India's biophysical economy, 1961–2008. Sustainability in a national and global context. *Ecological Economics* **76,** 60–69 (2012).
8. West, J., Schandl, H., Heyenga, S. & Chen, S. *Resource Efficiency: Economics and Outlook for China*. (UNEP, 2013).

9. West, J. & Schandl, H. Material use and material efficiency in Latin America and the Caribbean. *Ecological Economics* **94,** 19–27 (2013).
10. U.S. geological survey, 2011 minerals yearbook. *Minerals yearbook* **2011,** 16.33 (2014).
11. World steel association, Crude steel production 1980-2013. *Steel statistical yearbook* **2014,** 1-2 (2014).
12. Krausmann, F., Richter, R. & Eisenmenger, N. Resource Use in Small Island States. *Journal of Industrial Ecology* **18,** 294–305 (2014).
13. Schandl, H. & West, J. Resource use and resource efficiency in the Asia–Pacific region. *Global Environmental Change* **20,** 636–647 (2010).
14. West, J., Schandl, H., Krausmann, F., Kovanda, J. & Hak, T. Patterns of change in material use and material efficiency in the successor states of the former Soviet Union. *Ecological Economics* **105,** 211 – 219 (2014).
15. Hammond, G. P. & Jones, C. I. Embodied energy and carbon in construction materials. *Proceedings of the Institution of Civil Engineers - Energy* **161,** 87–98(11) (2008).