Arbeitskreis Fernerkundung

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The weight of nations - national-scale material stock maps based on Sentinel-1+2, OSM, and material intensity factors

Abstract

The construction and maintenance of societies' material stocks requires large amounts of resources. We here define societies' material stocks as materials accumulated in structures like buildings, streets, or rails, i.e. the human-made infrastructures on which our societies depend. Yearly flows of stock-building materials amount to ~60% of all materials used by humanity. Moreover, buildings and infrastructures shape social practices of production and consumption, thereby creating path dependencies for future resource use, which generates a positive feedback loop. As of now, global societies' material stocks are already heavier than all pools of biomass on the Earth's lands.

The quantification of societies' material stocks gained traction throughout the last decade. Inflow-driven top-down approaches quantify material stocks from reported inflows, service lifetime distributions and outflows of material, yet, they lack spatial differentiation. Stock-driven approaches are used to "map" material stocks bottom-up and flows can then be modelled from these estimates. These approaches are commonly either highly detailed but localized (cadaster-based), or regional-to-global using crude physical assumptions (e.g. based on the link between night-time-lights and material stocks).

We here present an inter-disciplinary bottom-up approach that bridges between high-detail and broad-scale by combining Copernicus EO data with the crowd-sourced OpenStreetMap (OSM) to map material stocks at 10m spatial resolution. Using machine learning approaches, we derive the building type, building area, and building height from analysis-ready data cubes of Sentinel-2A/B and Sentinel-1A/B time series. These are combined into aboveground building volume per building type [m^3]. Infrastructure area per street and rail type [m^2] are derived from OSM using type-specific lane widths sourced from construction design manuals. Eventually, the mass of material stocks is computed via material intensity factors [kg/m^3 or kg/m^2] that model the mass of buildings and infrastructures based on their type and physical dimensions.

Using this approach, we consistently map material stocks at high resolution for entire countries, e.g., Germany, Austria, or the conterminous United States. Material stocks are mapped and reported for each infrastructure category, e.g., residential buildings, motorways, or subways, as well as for each material category, e.g., concrete or steel. We will present results as maps, as well as on aggregated spatial scales, which underpin the large resource allocation and diversity societies build upon: each Austrian, German, or US citizen has an average material stock footprint of ~550t, ~450t, and ~390t, respectively. Resource use efficiency differs spatially to a huge extent. As an extreme example, in Manhattan, NY, an extraordinary mass of ~4 Mio t/km^2 was built up, but with ~190 t/cap, it is used rather efficiently.

At the other extreme, Loving, TX, the US county with the lowest population, has a resource usage of 25,000-43,000 t/cap, mostly allocated in local roads that connect the widespread housing units and oil/gas drill sites.

Summarizing, our approach offers radically new insights into spatially explicit human resource allocation and hence novel opportunities for pathways towards sustainable land use. For the first time, we thereby offer a consistent and reproducible high-resolution approach into societal material stocks mapping.