



The weight of nations

National-scale material stock maps based on Sentinel-1+2, OSM, and material intensity factors

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The MAT_STOCKS project

Understanding the Role of Material Stock Patterns for the Transformation to a Sustainable Society (MAT_STOCKS) is locating patterns of material stock distribution.

Project is based in the **Institute for Social Ecology (SEC)** at **University of Natural Resources and Life Sciences (BOKU)** in Vienna.

Project Websites

https://www.geographie.hu-berlin.de/en/professorships/eol/projects/matstocks/mat_stocks

<https://boku.ac.at/understanding-the-role-of-material-stock-patterns-for-the-transformation-to-a-sustainable-society-mat-stocks>

The screenshot shows the official website for the MAT_STOCKS project. The top navigation bar includes links for "Contact", "Staff", "Research", "Follow us on @HumboldtKlimaBens", "Name", "Interests", and "Services". The main content area features a large image of a satellite in space. Below it, a section titled "Shuttle" discusses the project's aim to understand material stock patterns for transformation to a sustainable society. It highlights the use of Earth Observation data from space to advance terrestrial Earth observation. The text explains that the project involves developing methods to estimate material stocks and related changes related to land systems. It also mentions the creation of a spatially explicit dataset for material stocks and their dynamics, including data from agriculture (including cropland and grassland), over forest and grassland. The project will use data from the Geography Department's Earth Observation Lab and the Institute for Social Ecology's Institute for Ecological Economics, Sustainability and Climate Change. The methodology will be performed in a high-performance computing environment by leveraging the massive data processing required to create such novel information. Human-made infrastructures and the raw materials required to create such structures will be used to map and analyze material stock patterns. The project will also involve the use of remote sensing data (e.g., Copernicus High Resolution Layer, SRTM) and other datasets (e.g., Google Earth Engine). The methodology will be developed for both rural and urban areas and the analysis of material stocks will be used to create fine-scale maps of both material stocks and temporal variations from 1970 to 2010. These spatial and temporal cover maps will form the basis for the subsequent transformation function type generation. Finally, available datasets on spectral and spatial features related to land use and socio-cultural contexts, as well as regional data, will be aggregated to typologies that allow analyzing material stocks with ecology flow analyses, e.g., based on a spatial-temporal database. The project aims to contribute to the development of a sustainable society by identifying opportunities and challenges in material stock management.



What are societies' material stocks?



Metals

- Iron / steel
- copper
- aluminium

Minerals

- Concrete
- Bricks
- Glass
- Aggregate

Biomass

- Timber

Petroleum products

- Bitumen

Insulation





What are societies' material stocks?



Mobility infrastructure

- Motorways
- Primary streets
- Footpaths
- Railways
- Subways
- Parking spaces

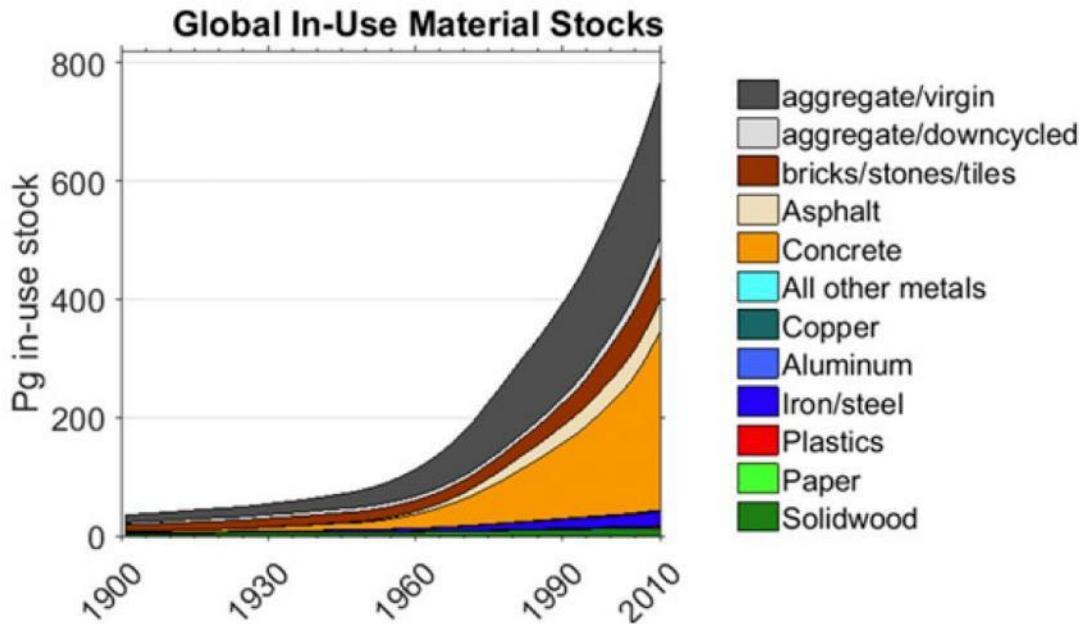
Buildings

- Residential buildings
- Commercial buildings
- Skyscrapers
- Industrial buildings
- Lightweight buildings





The great acceleration



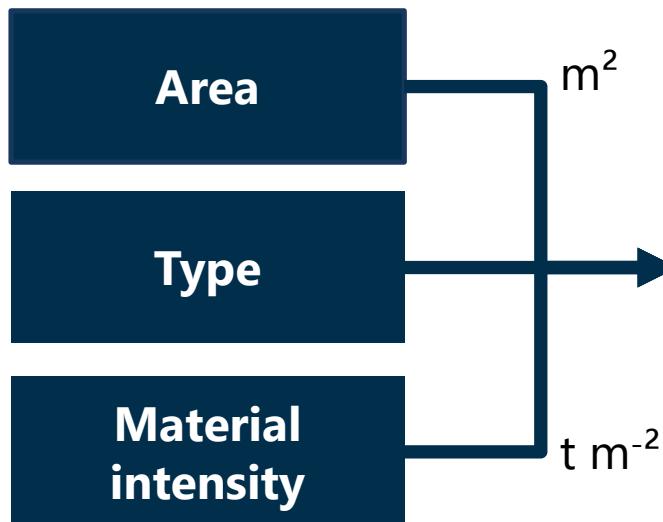
- Global **material stocks accumulation** since 1950
- Besides **concrete**, sand/gravel, metals and asphalt are the most used materials for stock accumulation.
- There are **regional differences**.
- Currently on a **nation-wide** level only



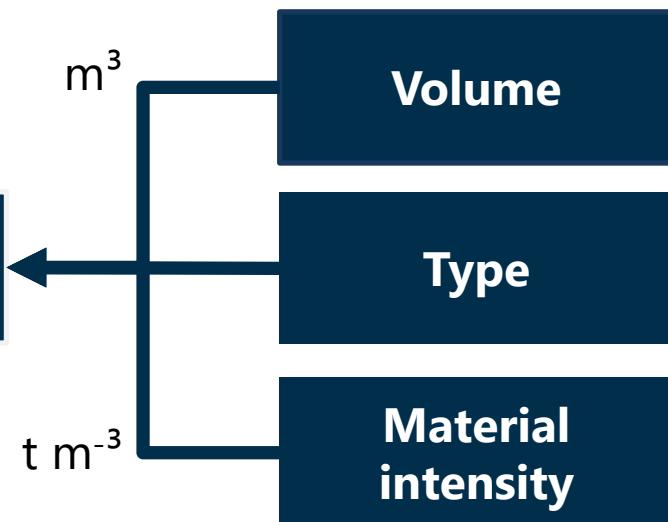


Stock-driven bottom-up mapping

Mobility Infrastructure



Buildings





Mobility infrastructure: crowd-sourced GIS data

PLOS ONE

The world's user-generated road map is more than 80% complete



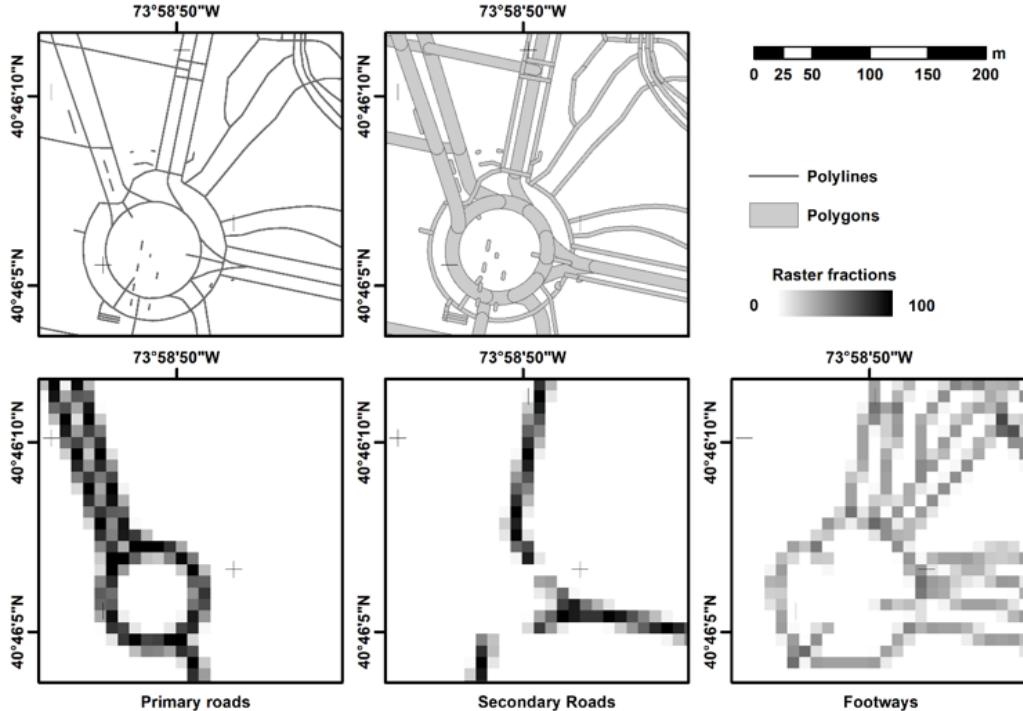
Fig 5. Completeness of the OSM dataset, by country, January 2016. The fraction complete is estimated by the parametric model, where that estimate falls within five percentage points or the 95% confidence interval of the multilevel model. Otherwise, the multilevel model is used.

<https://doi.org/10.1371/journal.pone.0180698.g005>





Mobility infrastructure: crowd-sourced GIS data



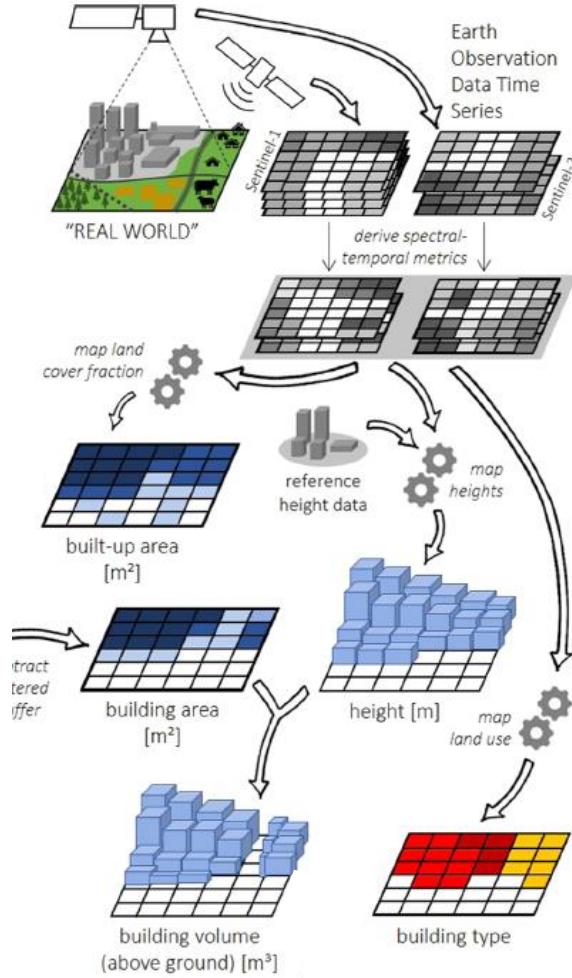
- Road and rail network extracted from **OSM**
- Type-specific Buffer widths from construction design manuals and regulations
- Reclassified to key categories
- Converted to raster with fractional cover resampling → 100% = 100m²
- **area for each road and rail category [m²]**





Buildings: Earth Observation

H. Haberl, D. Wiedenhofer, F. Schug, **D. Frantz**, D. Virág, C. Plutzar, K. Gruhler, J. Lederer, G. Schiller, T. Fishman, M. Lanau, A. Gattringer, T. Kemper, G. Liu, H. Tanikawa, S. van der Linden & P. Hostert (2021): High-Resolution Maps of Material Stocks in Buildings and Infrastructures in Austria and Germany. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.0c05642>

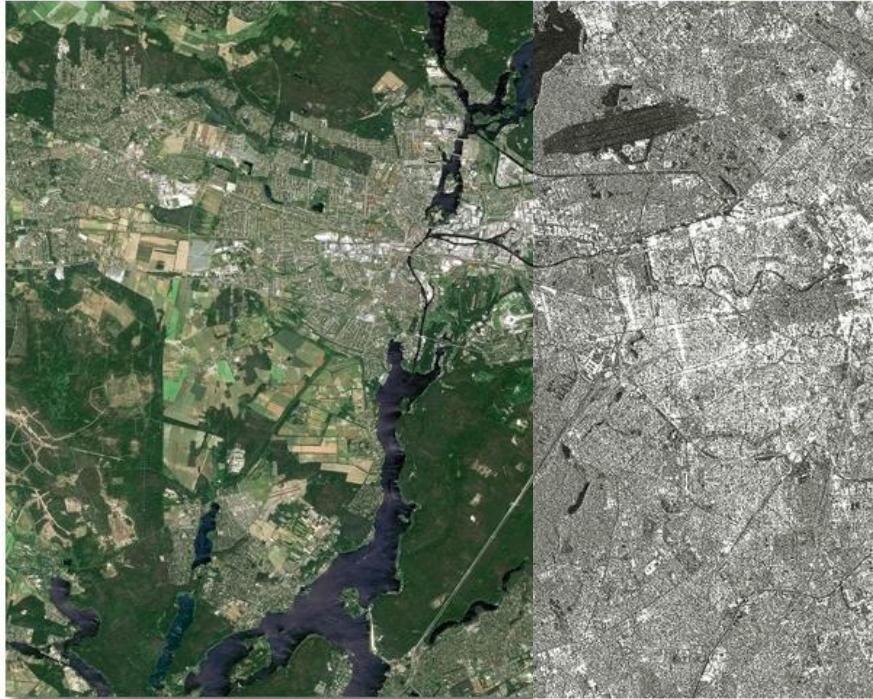


#GeoWoche2021





Earth Observation data: Sentinel-1+2A/B



Synthetic Aperture Radar (SAR)
Multispectral imager

~5 days repeat frequency

10-20m spatial resolution

10 spectral bands
2 polarizations



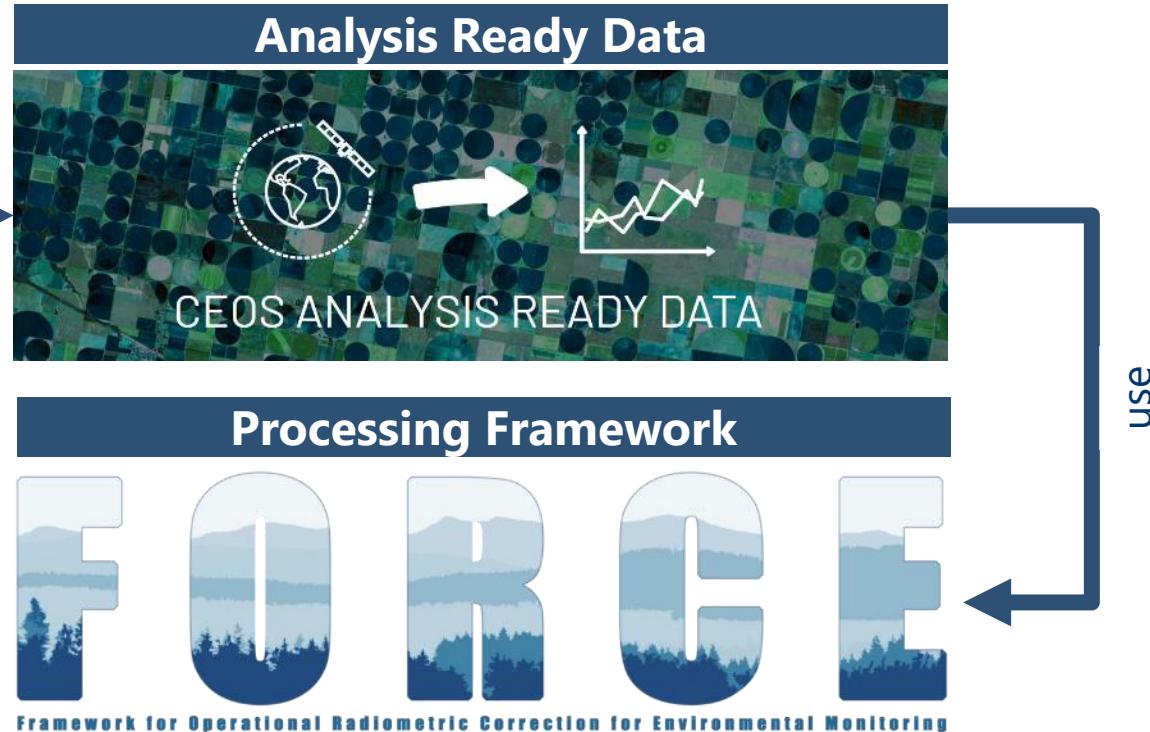


Sentinel-2A/B ARD



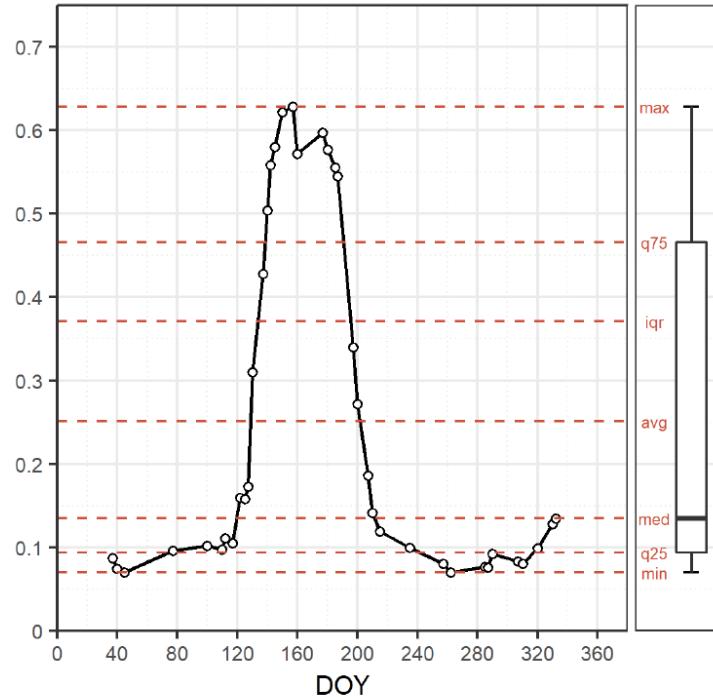


Sentinel-1A/B ARD-like





EO features



Spectral Temporal Metrics =
statistical aggregation of all observations

A full year of data

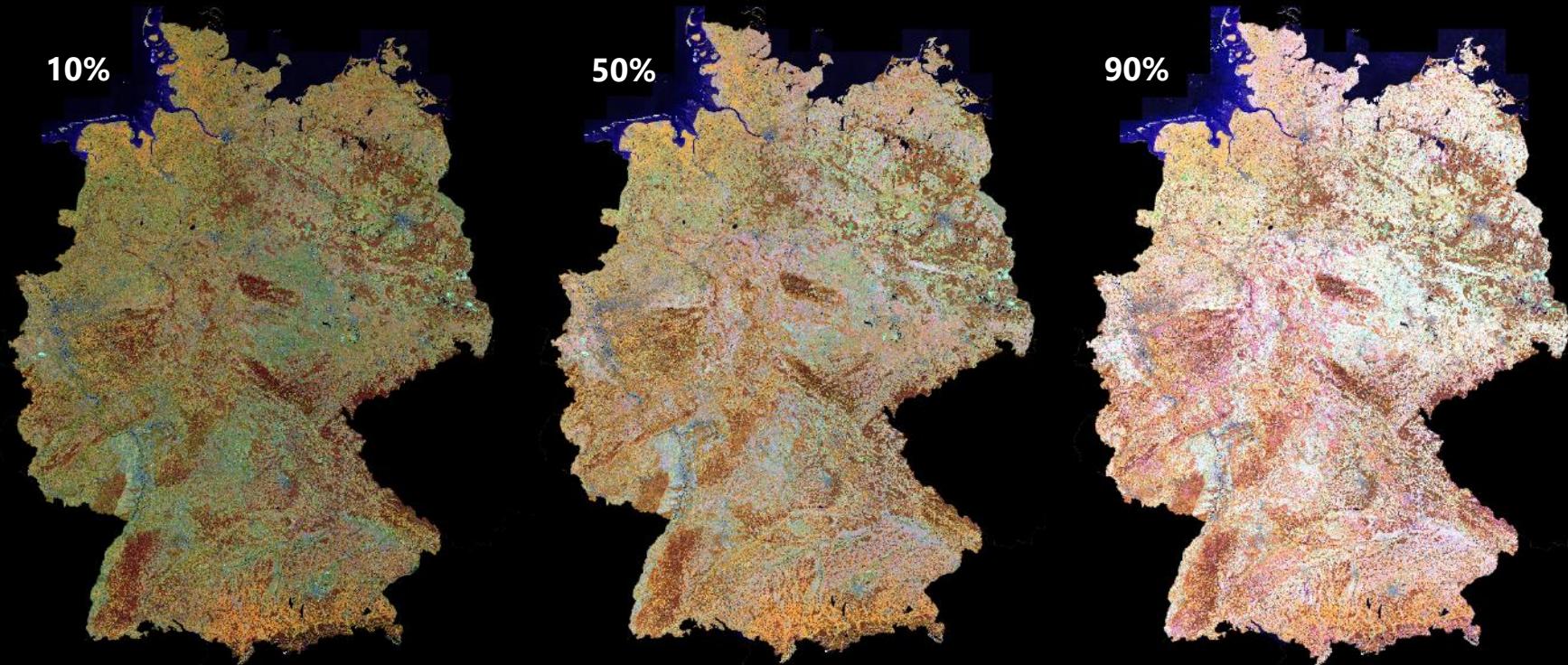
Sentinel-1: all observations

Sentinel-2: all clear-sky observations (excl.
clouds, cloud shadows and snow)





EO features

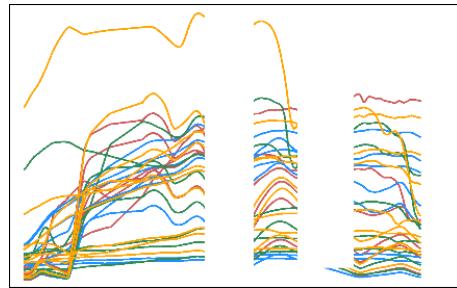




Impervious area

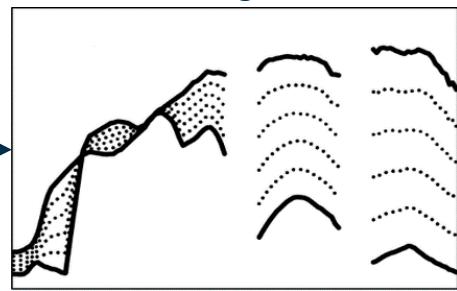
Regression-based unmixing

Endmember library

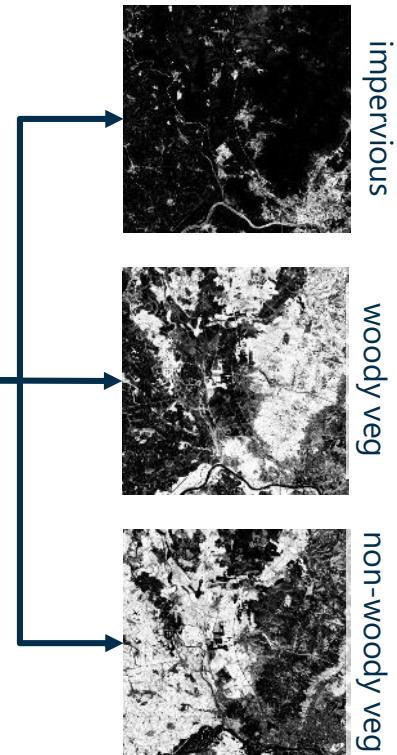


SynthMix

Synthetically mixed
training data



ML regression
(SVM)

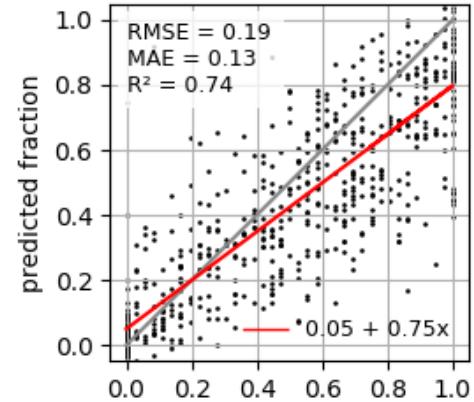
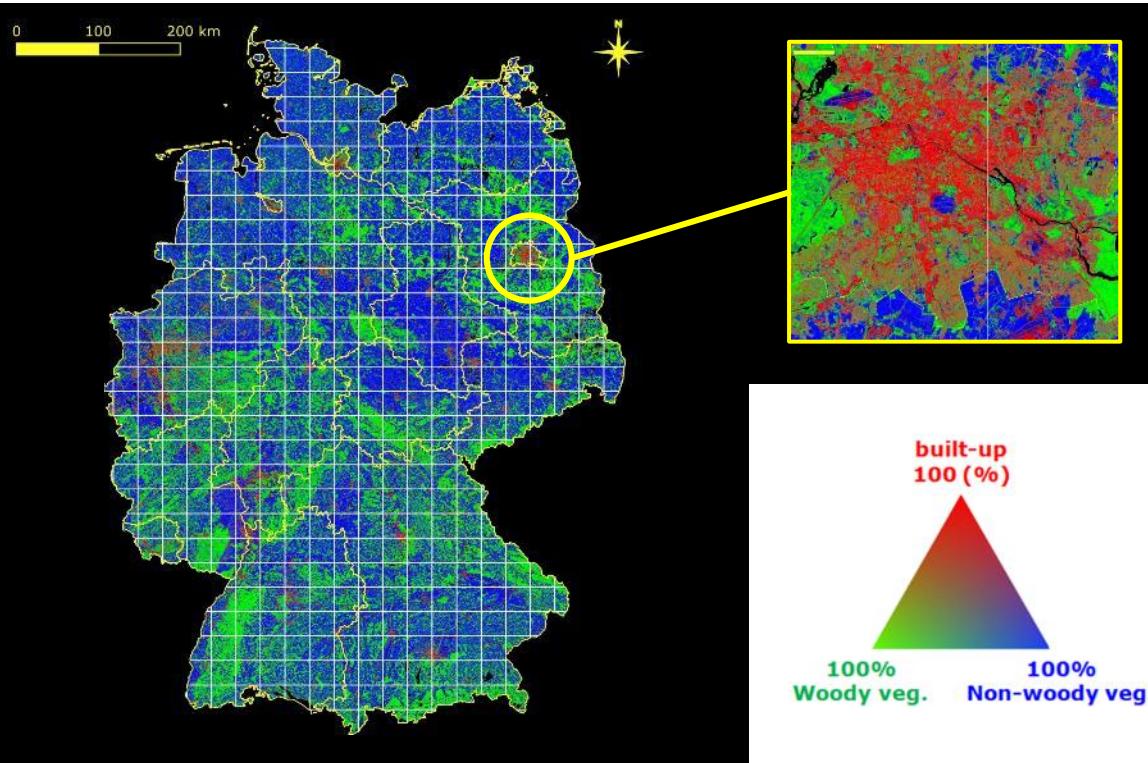


EO features instead of
hyperspectral signatures





Impervious area





Impervious area → Building area

Impervious area [m^2]



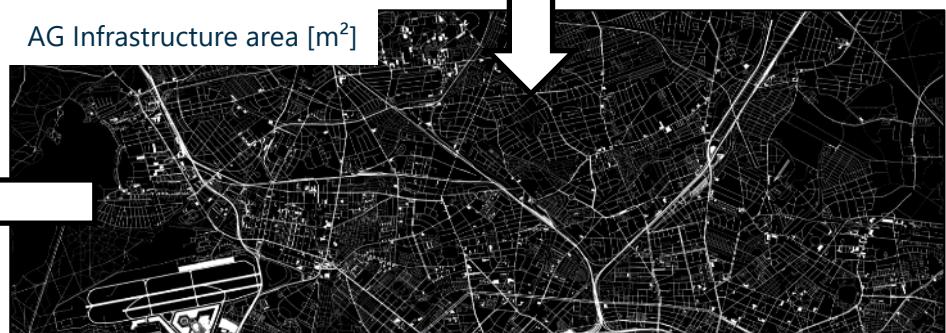
OSM infrastructure



Building area [m^2]

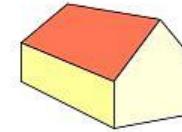
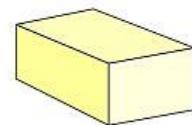


AG Infrastructure area [m^2]



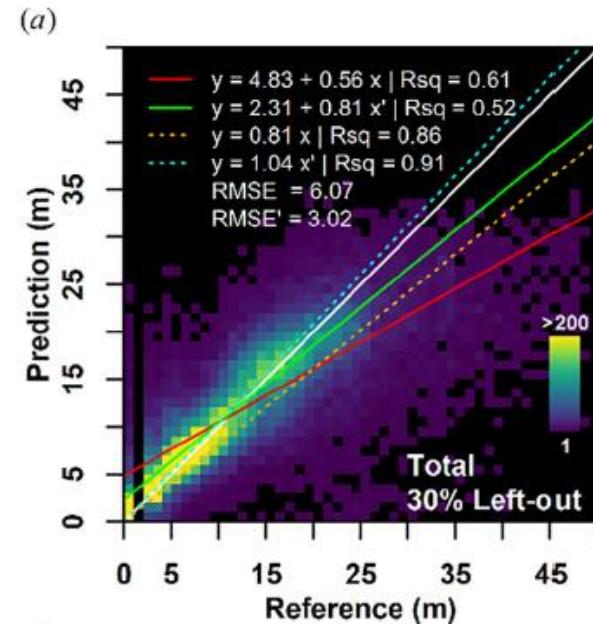


Building height



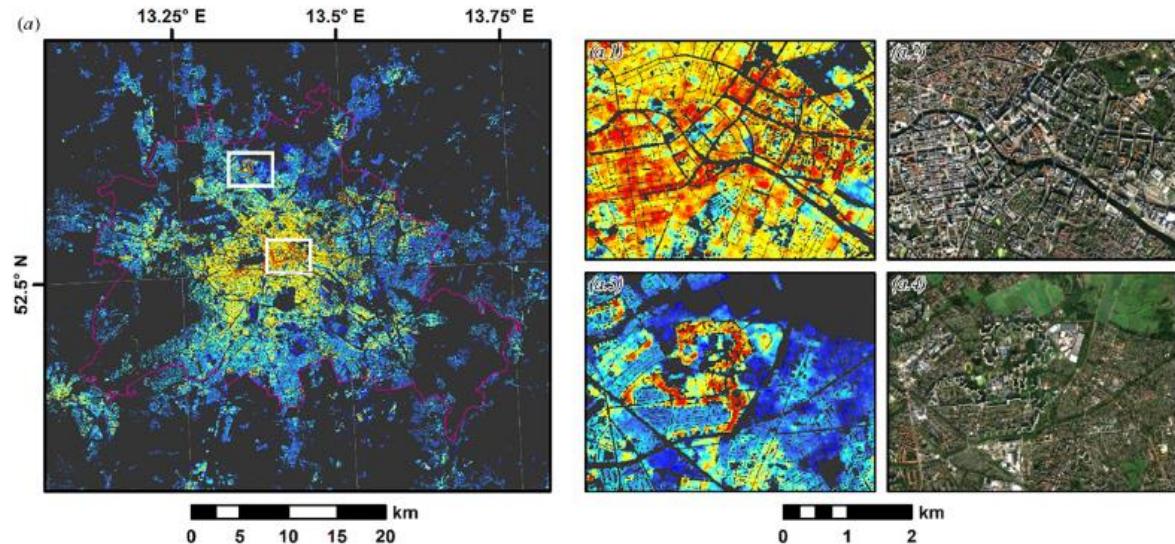
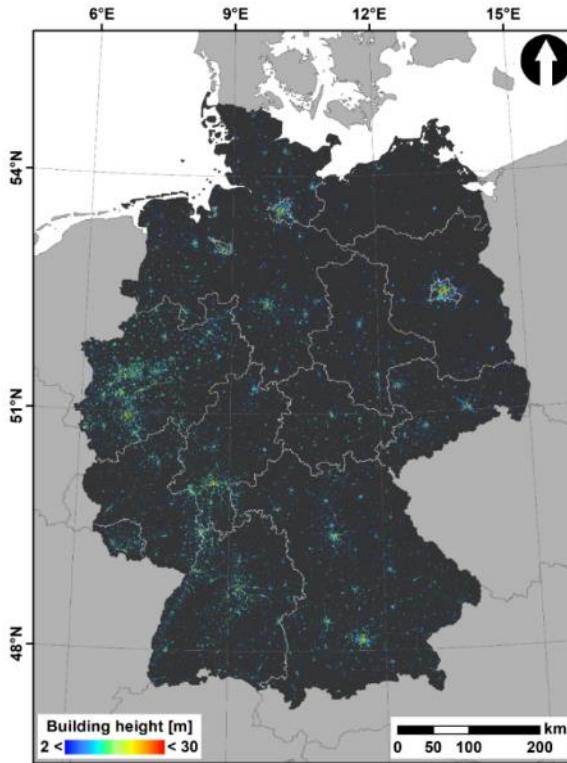
Training and validation from 3D Building Models, based on cadastre and airborne laser scanning

Site	Year	Buildings
Berlin	2014 (99.9%)	
	2015 (0.1%)	540,172
Hamburg	2016	374,99
Potsdam	2012	44,832
North Rhine Westphalia	2018 (39%)	
	2019 (61%)	11,498,734
Thuringia	2018 (13%)	
	2019 (57%)	2,241,792
	2020 (30%)	





Building height



#GeoWoche2021

Frantz, Schug, Okujeni, Navacchi, Wagner, van der Linden, Hostert (2021):
National-scale mapping of building height using Sentinel-1 and Sentinel-2
time series. *Remote Sensing of Environment* 252.

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Building volume

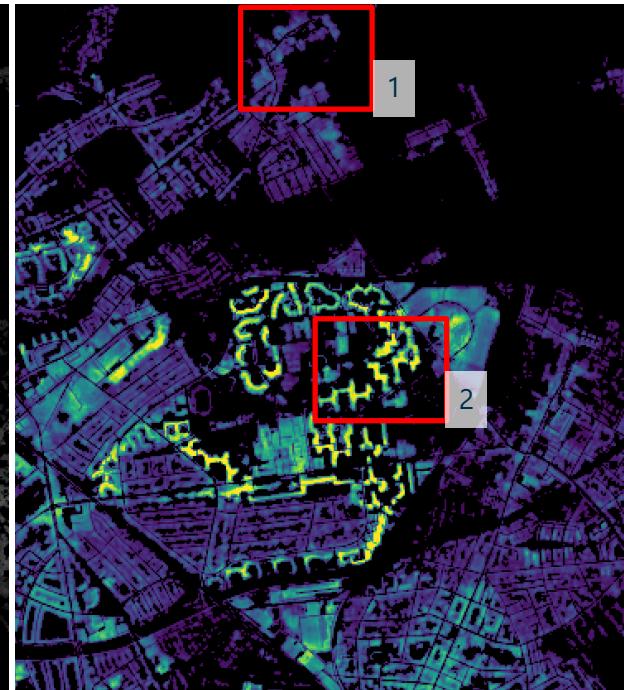
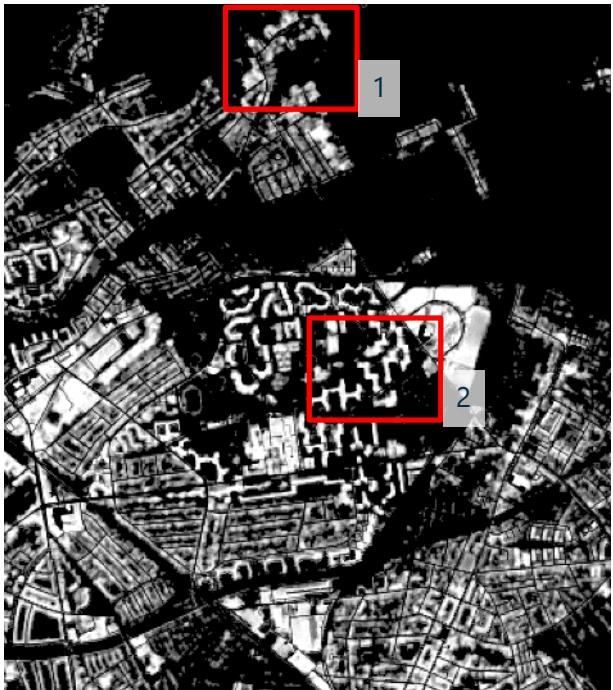
Building Area [m^2]

x

Building Height [m]

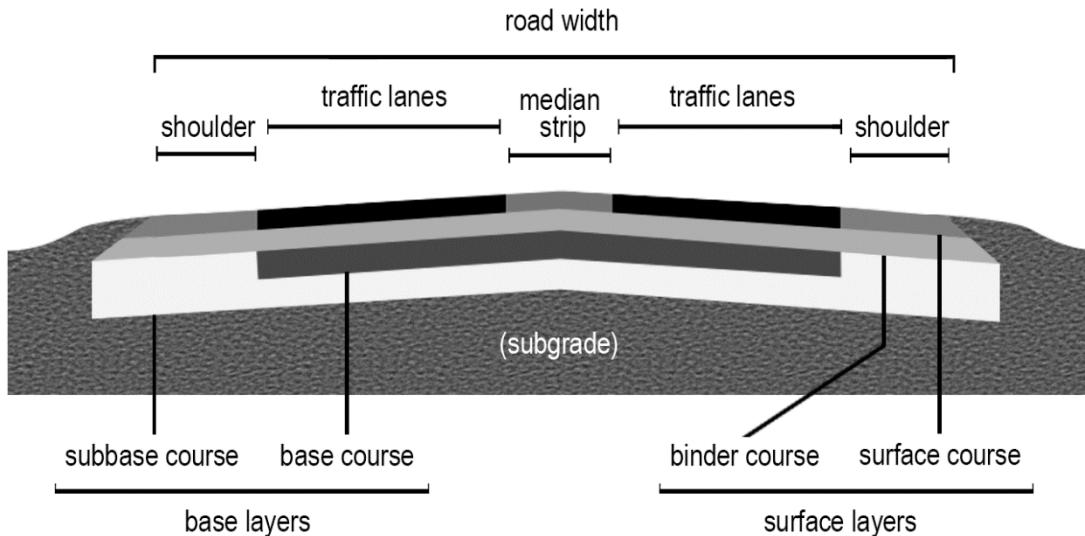
=

above-ground Building Volume [m^3]





Material Intensity (MI) factors



Screening of construction manuals, design guidelines and scientific literature

Recalculation to match EO/GIS-based definitions used in our study

MI per usable floor area or gross building volume to MI per aboveground building volume → $t \text{ m}^{-3}$

MI per street/rail km to MI per area → $t \text{ m}^{-2}$



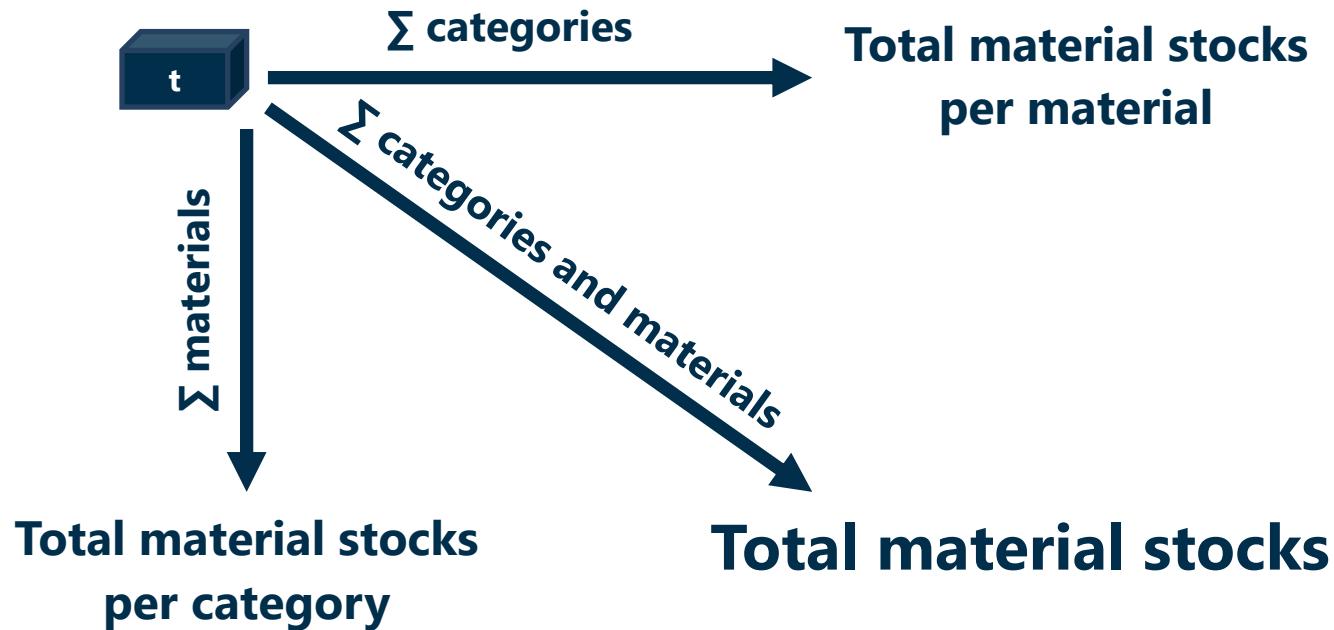


Material stocks

motorways m ²	x	MI concrete	MI bricks	MI steel	MI ...	=	t
primary roads m ²	x	MI concrete	MI bricks	MI steel	MI ...	=	t
foot paths m ²	x	MI concrete	MI bricks	MI steel	MI ...	=	t
rails m ²	x	MI concrete	MI bricks	MI steel	MI ...	=	t
subways m ²	x	MI concrete	MI bricks	MI steel	MI ...	=	t
single-family m ³	x	MI concrete	MI bricks	MI steel	MI ...	=	t
multi-family m ³	x	MI concrete	MI bricks	MI steel	MI ...	=	t
...	x	MI concrete	MI bricks	MI steel	MI ...	=	t

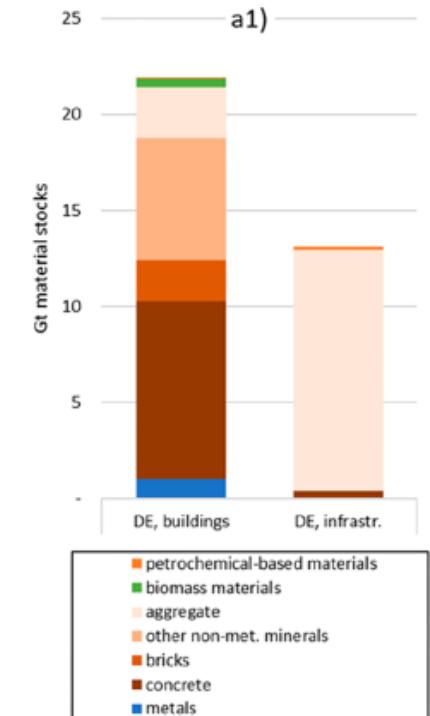
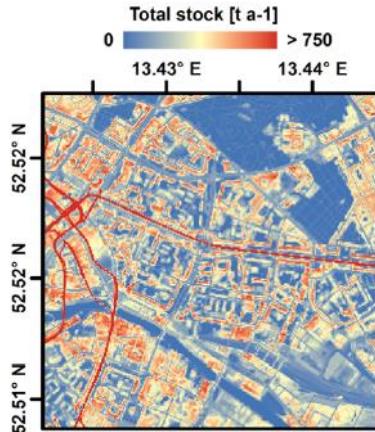
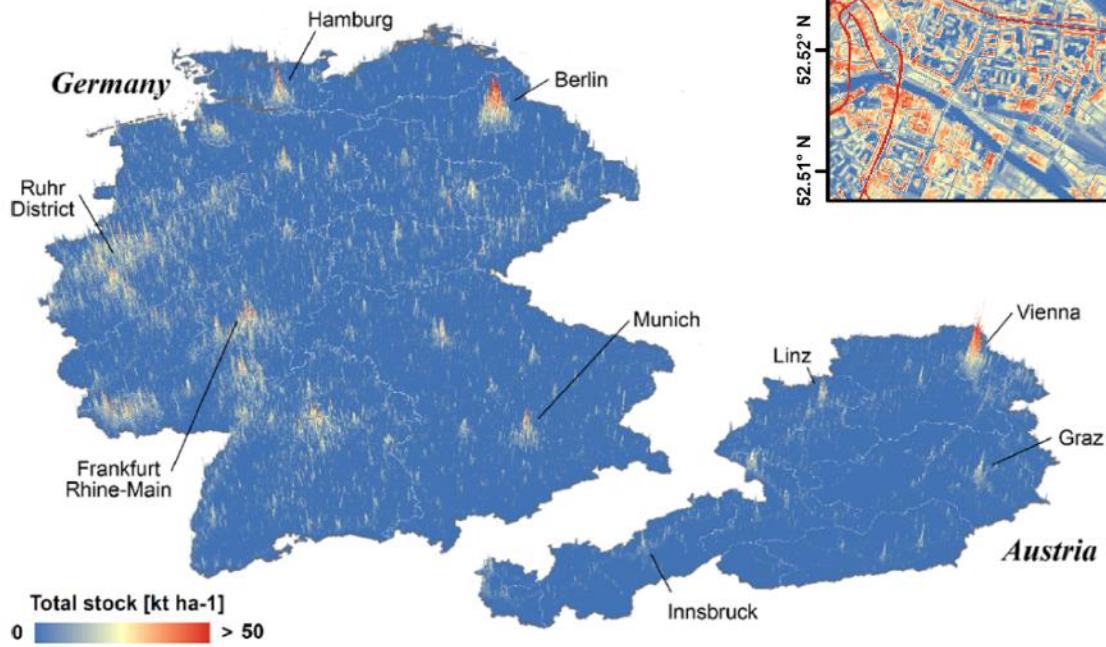


Material stocks





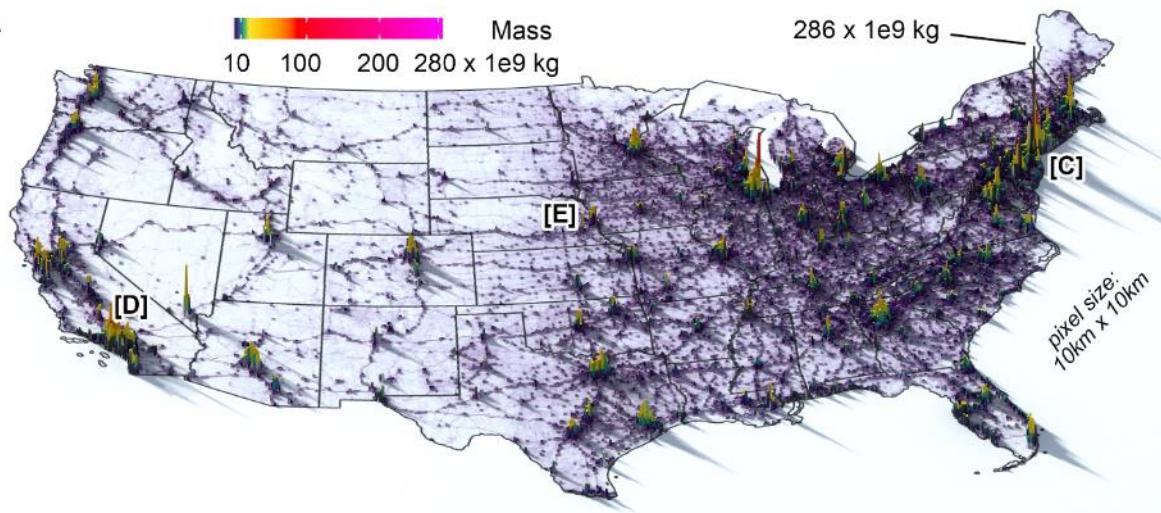
Material stocks



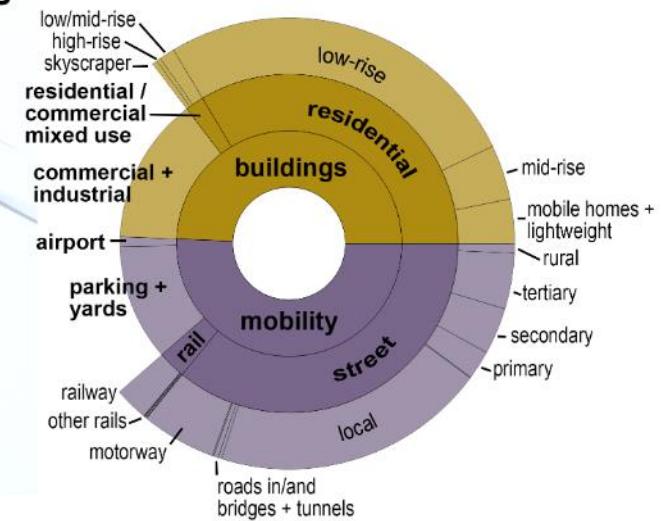


Material stocks for the CONUS

A



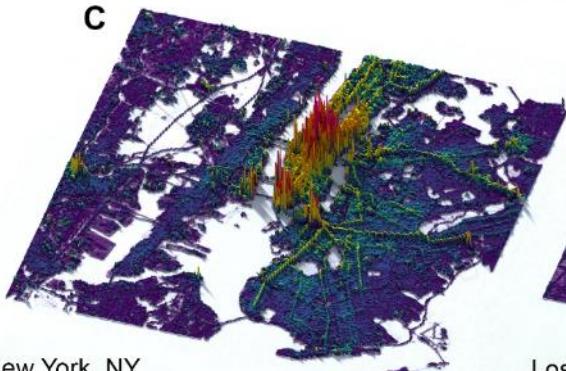
B





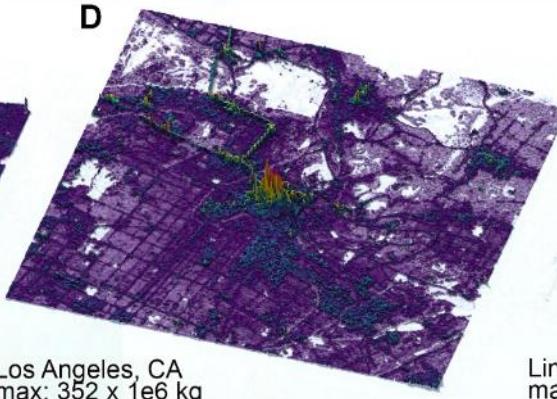
Material stocks for the CONUS

C



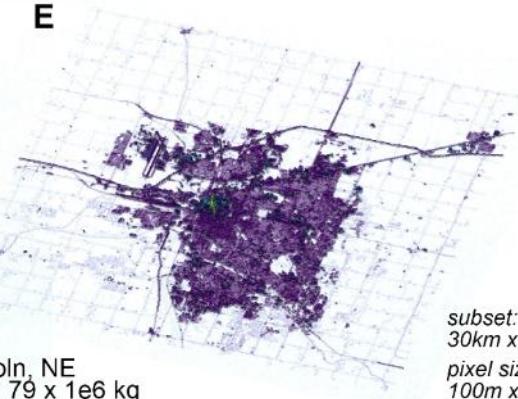
New York, NY
max: 618 x 1e6 kg

D



Los Angeles, CA
max: 352 x 1e6 kg

E



Lincoln, NE
max: 79 x 1e6 kg

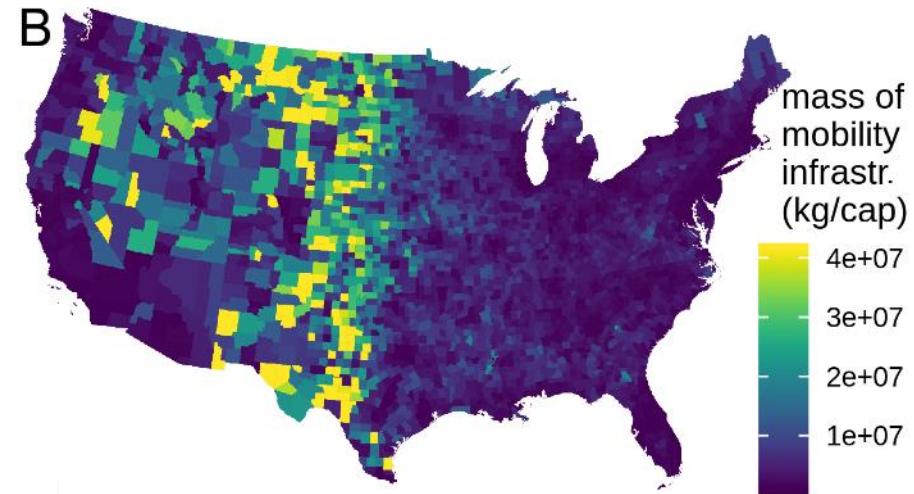
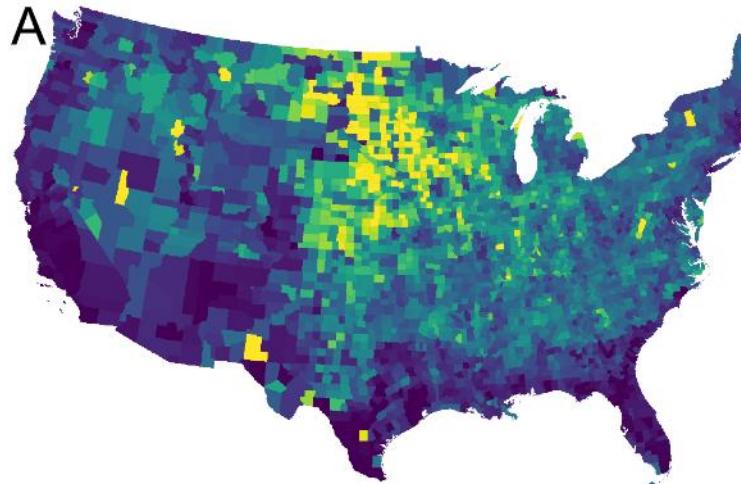
Mass
600
400
200
25 x 1e6 kg

subset:
30km x 30km
pixel size:
100m x 100m





Material stocks for the CONUS



Stock consumption:

AT: ~540 t/cap

DE: ~450 t/cap

US: ~390 t/cap





Thank you for your attention!

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Project Websites



https://www.geographie.hu-berlin.de/en/professorships/eol/projects/matstocks/mat_stocks



<https://boku.ac.at/understanding-the-role-of-material-stock-patterns-for-the-transformation-to-a-sustainable-society-mat-stocks>

Related Work:

- Frantz, D. (2019). FORCE – Landsat + Sentinel-2 Analysis Ready Data and beyond: Remote Sensing
- Frantz, D., et al. (2021). National-scale mapping of building height using Sentinel-1+2 time series. RSE
- Haberl, H., et al. (2021). High-Resolution Maps of Material Stocks in Buildings and Infrastructures in Austria and Germany. EST
- Okujeni, A., et al. (2017). Ensemble Learning From Synthetically Mixed Training Data for Quantifying Urban Land Cover With Support Vector Regression. IEEE JSTARS
- Schug, F., et al. (2020). Mapping urban-rural gradients of settlements and vegetation at national scale using Sentinel-2 spectral-temporal metrics and regression-based unmixing with synthetic training data. RSE
- Schug, F., et al. (2021): Gridded population mapping for Germany based on building density, height and type from Earth Observation data using census disaggregation and bottom-up estimates. *PLOS ONE*



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