EPFL

ENV 501 / GR A3 30

Material Flow Analysis and resource management

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Fall 2024

Last session

- Principles and examples of Dynamic MFA modelling
- Links to socio-economic metabolism
- Practical approach to Dynamic MFA
- Tools for Dynamic MFA
  - Inflow-driven modelling
  - Stock-driven modelling

Course outline

Block	Week	8:15 - 9:00 and 9:15 - 10:00		13:15 - 14:00	14:15 - 15:00
Block I: EW-MFA global / national	W1 - Sep 12	Introduction to the course and general concepts	All	Exercise	Project
	W2 - Sep 19	EW – MFA and EW – MFA in different countries	FMC	Exercise	Project
	W3 – Sep 26	EW – MFA in the Swiss context, Urban Metabolism	External Guest – Florian Kohler	Exercise	Project
	W4 - Oct 03	EW – MFA in the Swiss context: Cantons and Circular Economy	FMC	Exercise	Project
Block II: MFA regional / urban	W5 - Oct 10	The Service-Stock-Flows Nexus	FMC	Exercise	Project
	W6 - Oct 17	Dynamic MFA	External Guest – Stefan Pauliuk	Exercise	Project
	Oct 24	Autumn break			
	W7 - Oct 31	Spatial MFA	FMC	Exercise	Project
	W8 - Nov 07	Input-Output Analysis and Material Flow Cost Accounting	External Guest – Vincent Moreau	Exercise	Project
	W9 - Nov 14	MFA and Uncertainty	External guest – Stefan Pauliuk	Exercise	Project
	W10 - Nov 21	Case studies: Waste management in Indonesia / Critical Raw Materials in the Swiss context	GF & FMC	Exercise	Project
Block III: Social sciences and public policy	W11 - Nov 28	Social Metabolism	CRB	Exercise	Project
	W12 - Dec 05	Agent-based model	CRB, FMC, MAH, SLC	Past exam	Project
	W13 - Dec 12	Group Project Presentation	CRB, FMC, MAH	Project	Project
	W14 - Dec 19	Group Project Presentation	CRB, FMC, MAH	Project	Project

Content of lecture

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- Different spatial approaches
- Temporal analysis
- Spatial stock analysis

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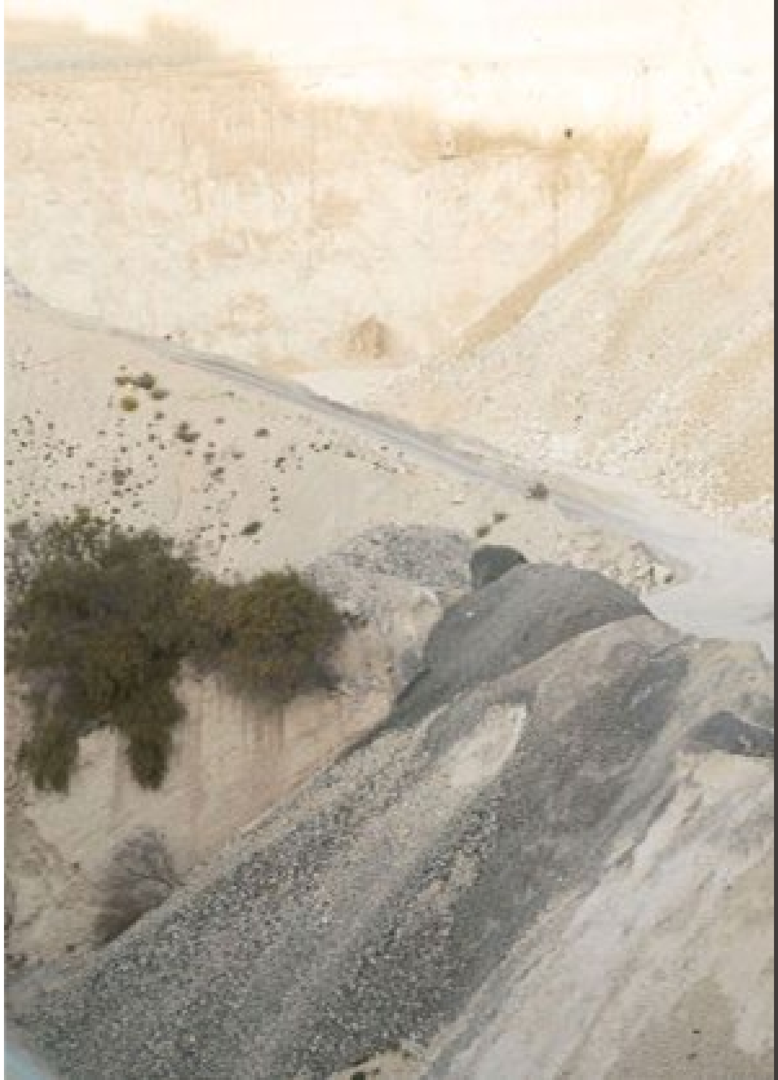

Different spatial approaches

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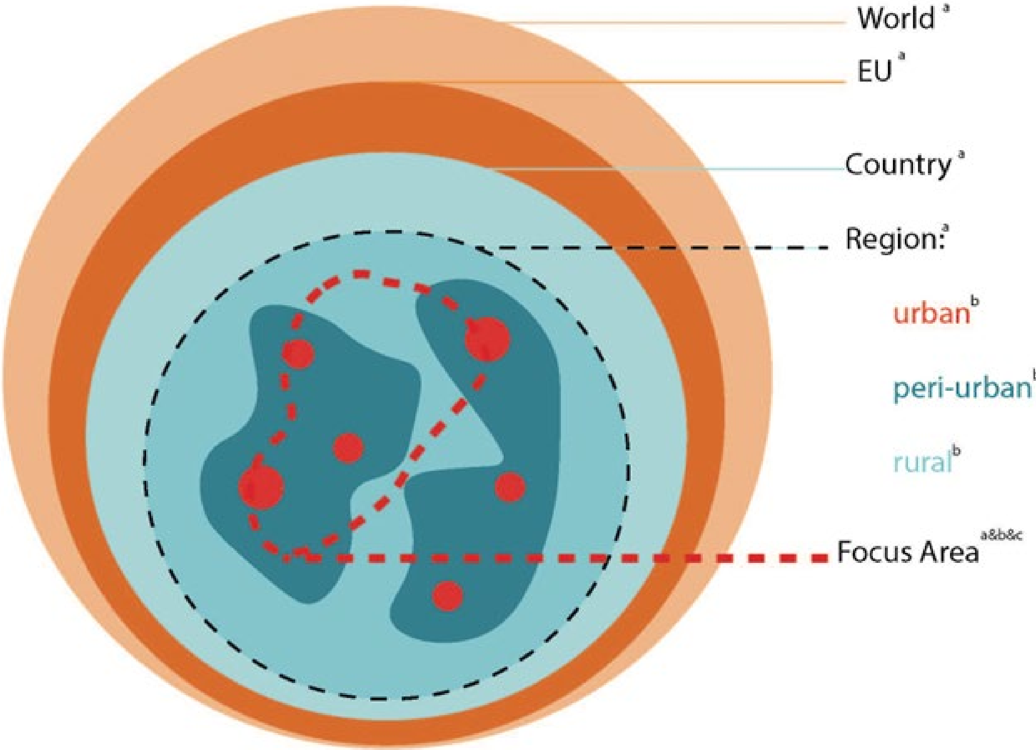
Different spatial approaches



[a] Areas based on administrative boundaries
[b] Areas based on demographic and land cover data
[c] Areas based on qualitative assessment

Spatial data (geographic)

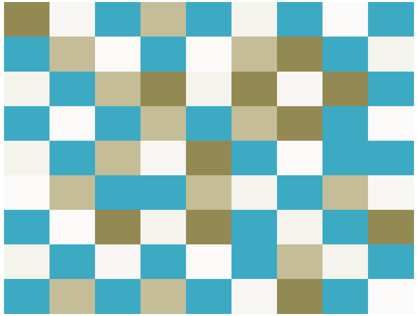
- Place (location)
- Time
- Attributes:
  - Rooftop area
  - Absolute resource consumption
  - Land-use type
  - Quantity and quality of resource stocks,etc.

Source: REPAiR project (https://h2020repair.eu/)

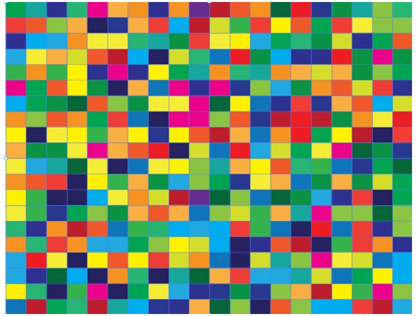
Different spatial approaches

Region/country

Cities/Metropolitan area



Local Government areas



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Different spatial approaches

Boundary	Relevance for policies
Region	Includes immediate hinterland, productive and extractive activities, etc.
Metropolis	Represents the labourforce and residential hinterland. Accounts for commuting
City	Official administrative boundaries, most available data
Local government/Communes	Small administrative areas. Can regulate building permits, land use zoning, transportation, etc.
Neighbourhood	Homogeneous spatial entity, sense of identity, proximity to schools, entertainment, food consumption
Buildings/households	Relation between socio-economic status and resource use, can be aggregated to any other spatial scale

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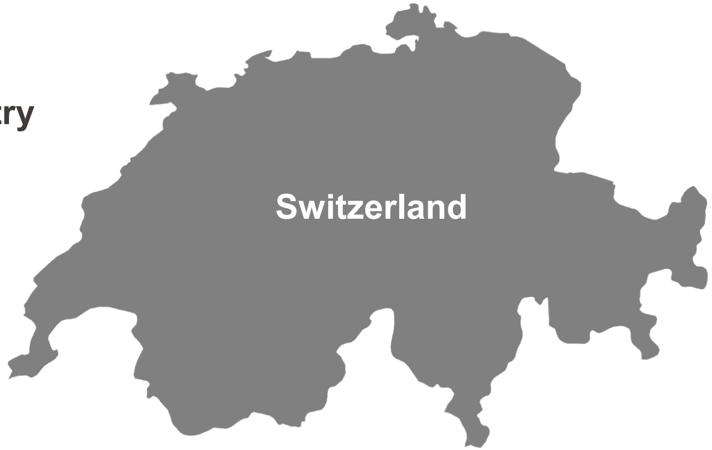
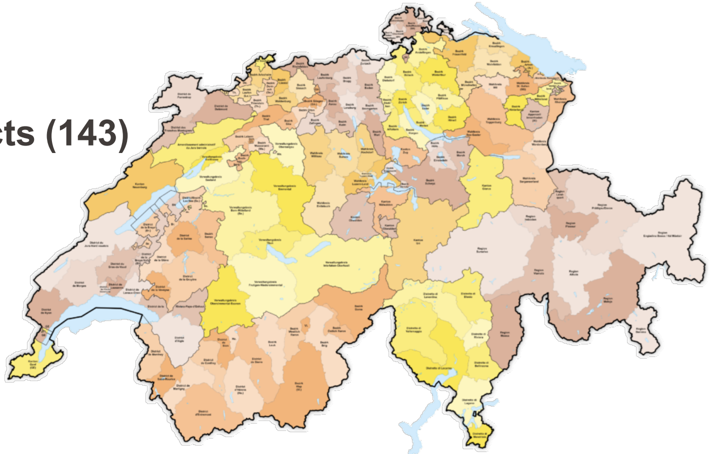
Different spatial approaches

Country



Cantons (26)

Districts (143)



Communes (2222)

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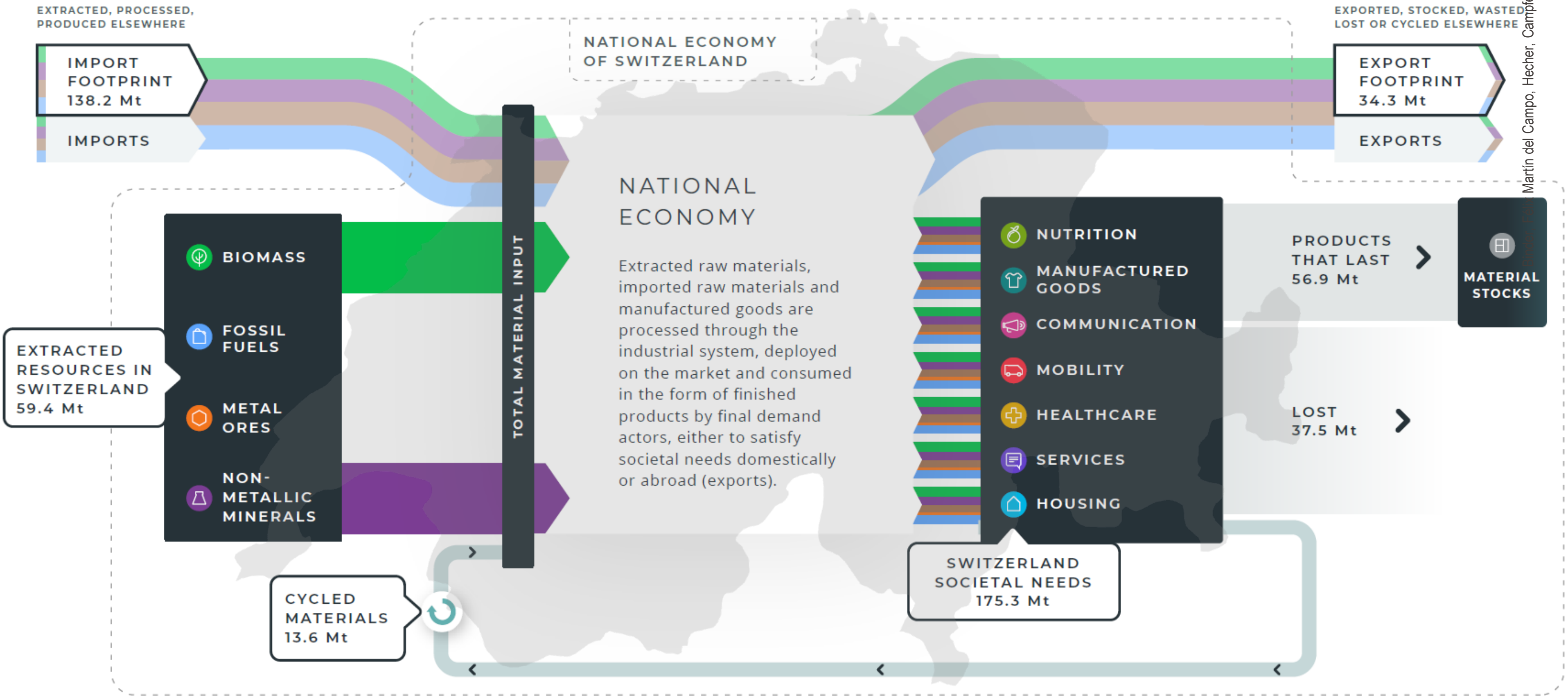
Source: Office Fédéral de la statistique (au 1.1.2018). https://www.bfs.admin.ch/bfs/en/home/services/geostat/swiss-federal-statistics-geodata.html

Switzerland's Circularity gap



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Source: Circle Economy, (2023)

EW-MFA Canton Vaud in 2019

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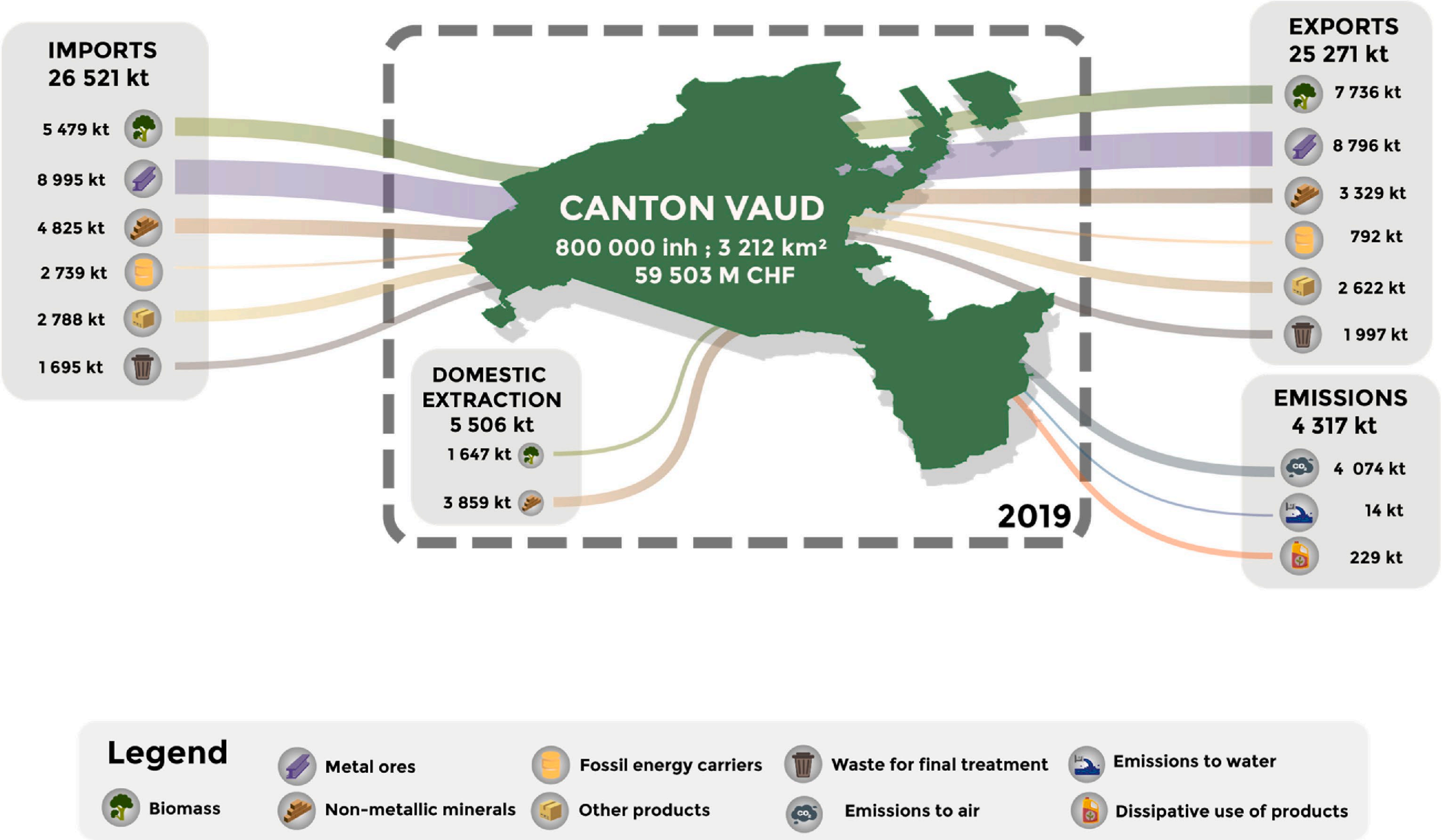

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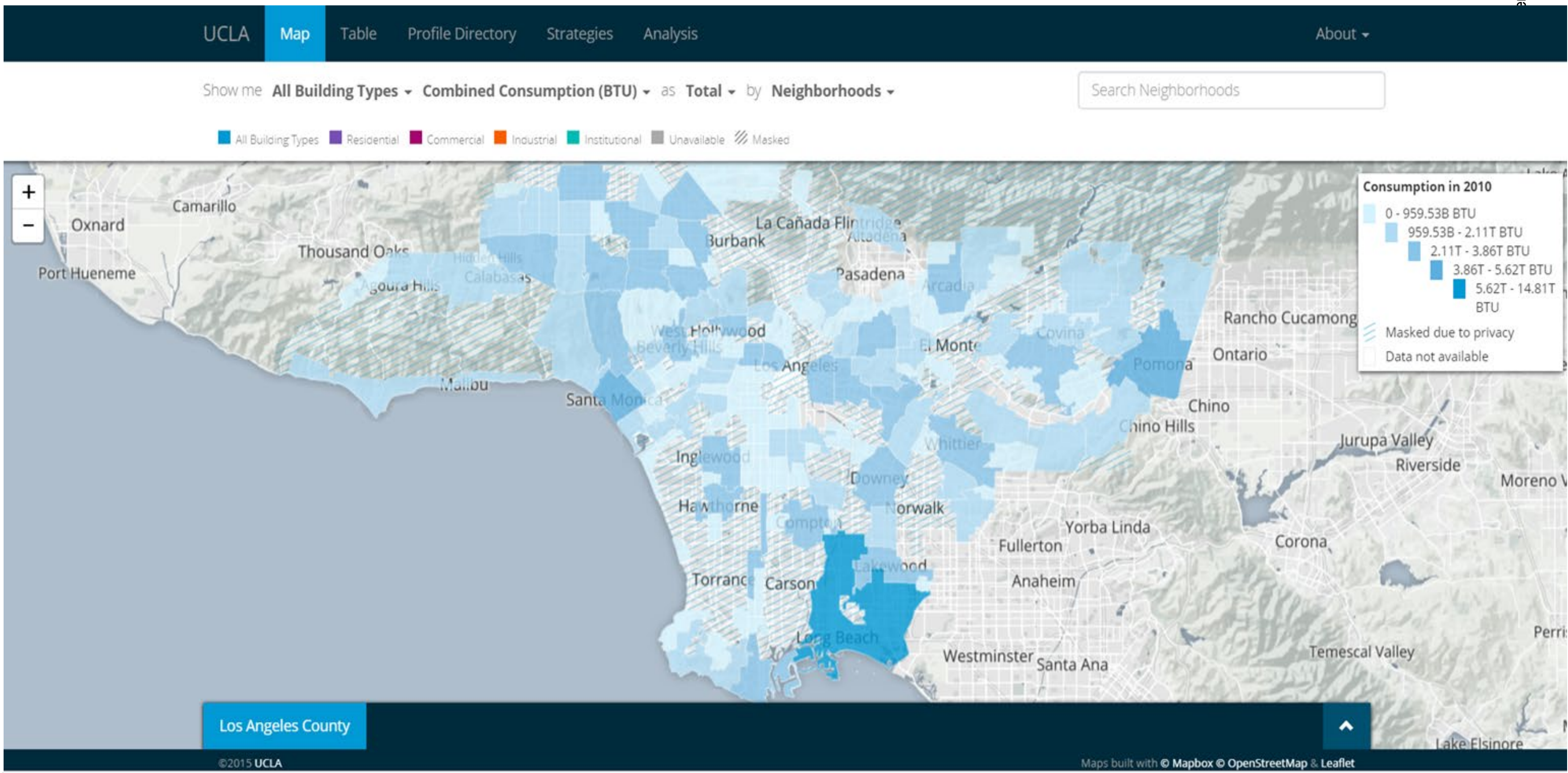
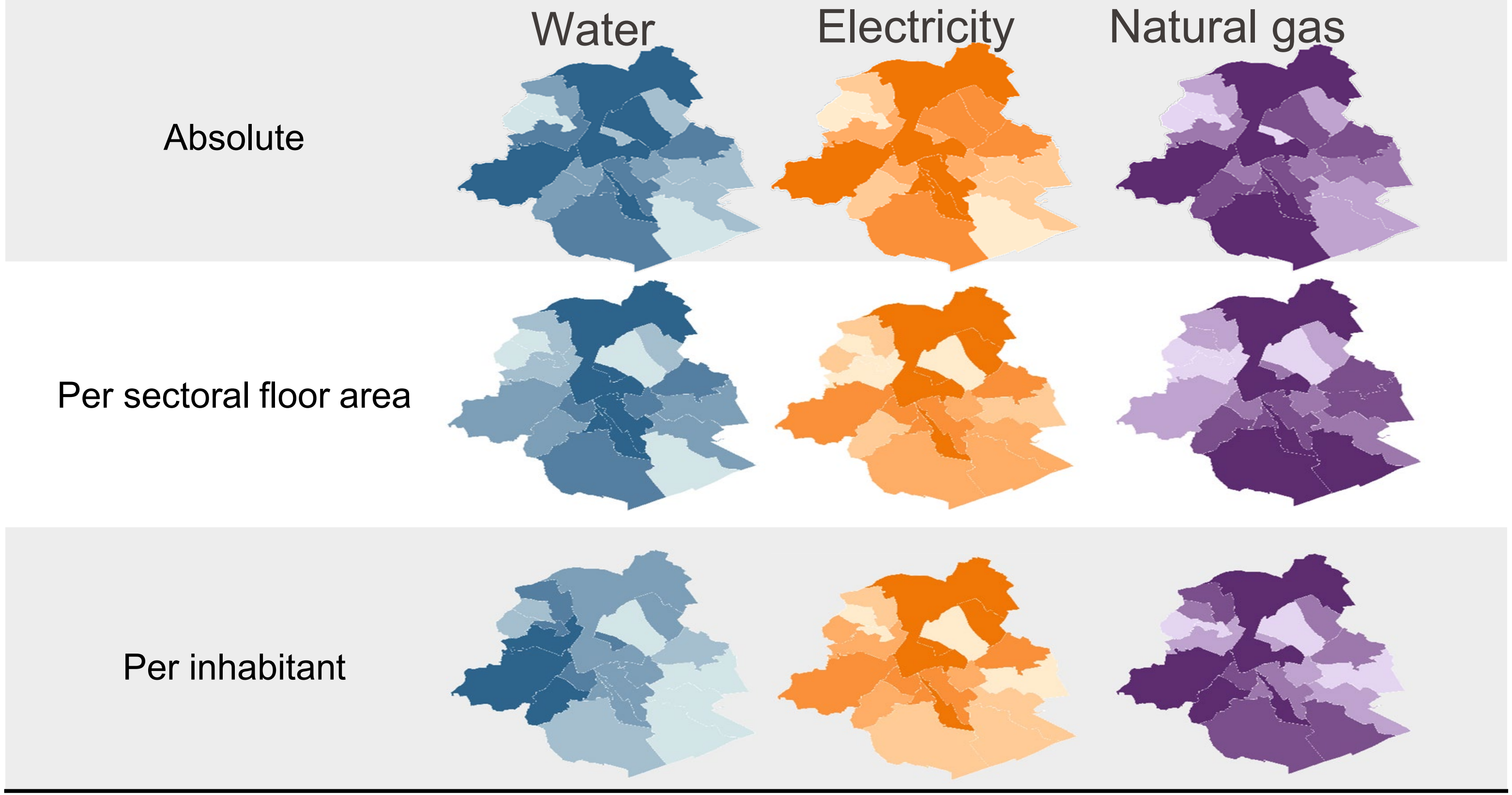
Examples: Energy Atlas of Los Angeles



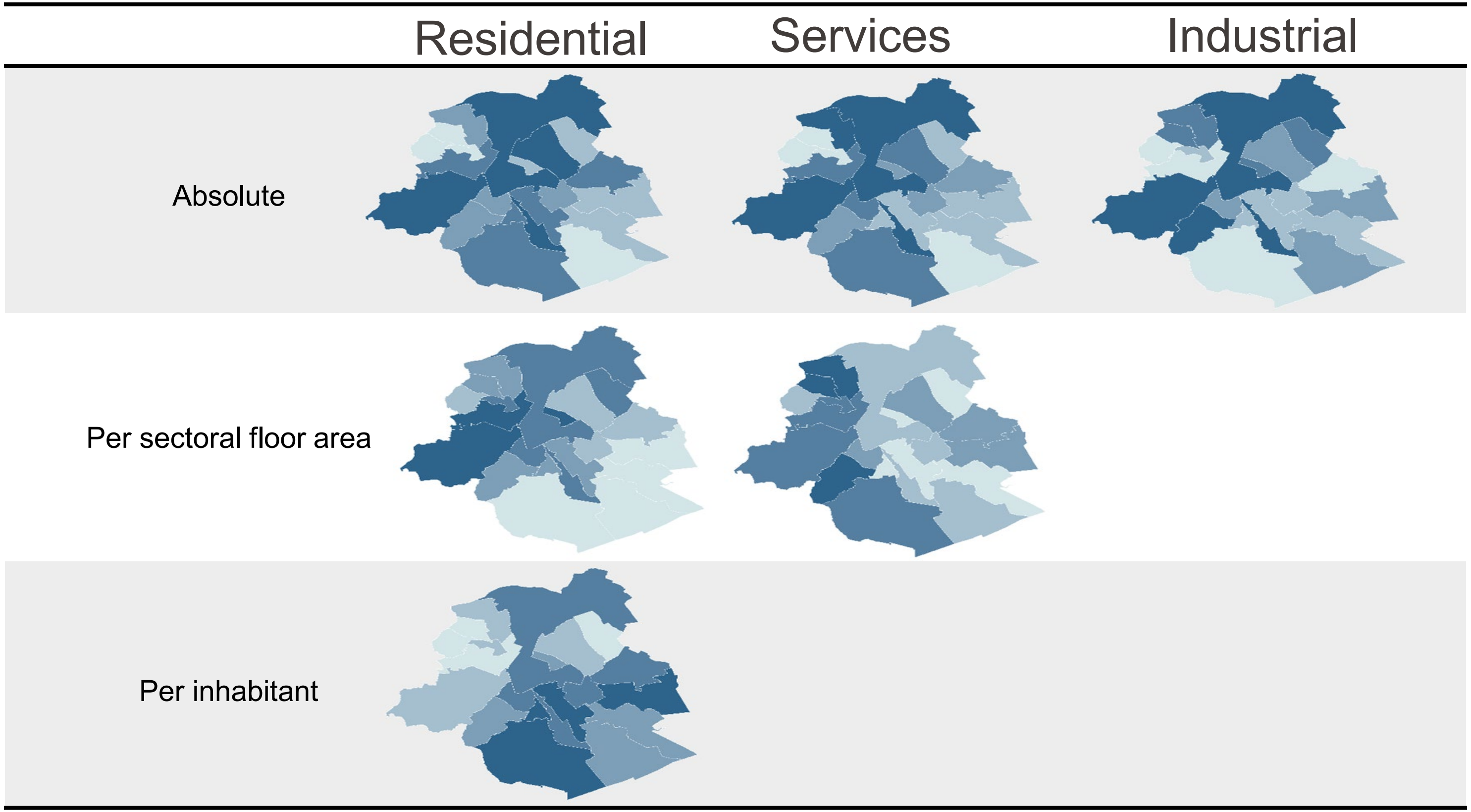
http://www.energyatlas.ucla.edu/

Other examples: Metabolic flows of Brussels



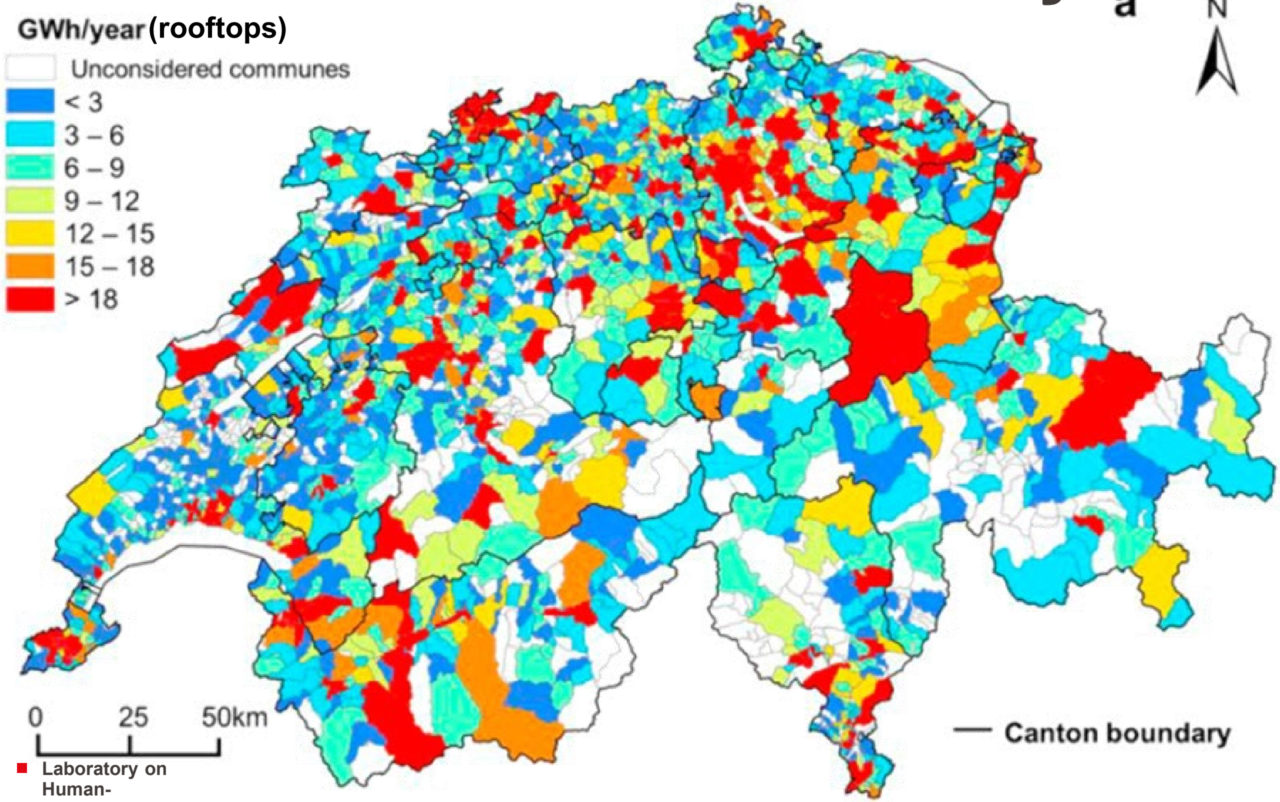
Athanassiadis, A. 2016. Towards more comprehensive urban environmental assessments. Exploring the complex relationship between urban and metabolic profiles. PhD Thesis, Université Libre de Bruxelles, The University of Melbourne.

Other examples: Water flows of Brussels



Athanassiadis, A. 2016. Towards more comprehensive urban environmental assessments. Exploring the complex relationship between urban and metabolic profiles. PhD Thesis, Université Libre de Bruxelles, The University of Melbourne.

Other examples:
Potential PV electricity flows in Switzerland



Spatially explicit characteristics:

- Population
- Number of buildings
- Floor area
- Rooftop inclination
- Etc.

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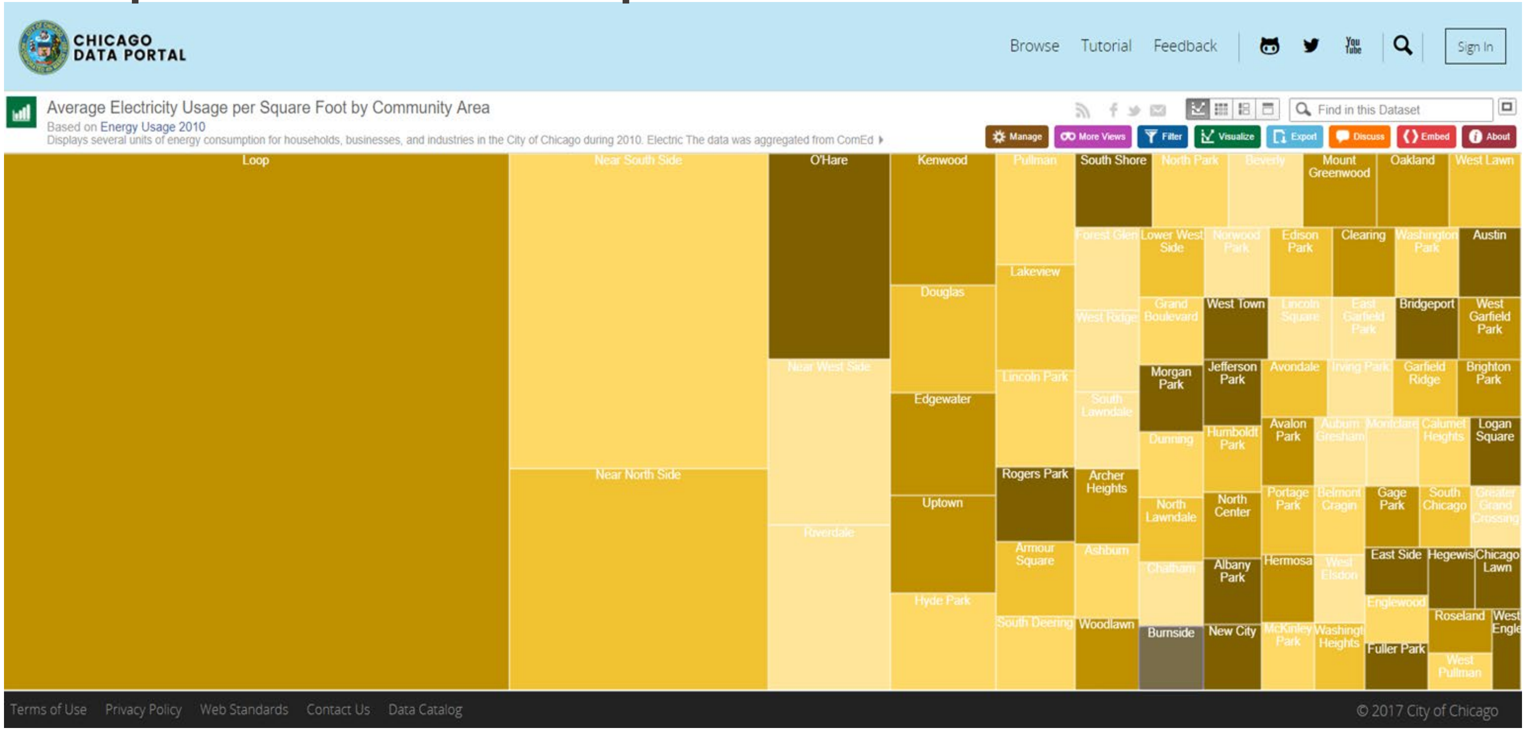
Mohajeri et al. (2017) – Effects of city size on the large-scale decentralized solar energy potential. CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Where to find data

- Open data portals of cities
- Top-down and bottom-up estimations



https://data.cityofchicago.org/Environment-Sustainable-Development/Average-Electricity-Usage-per-Square-Foot-by-Commu/usfg-z9mx

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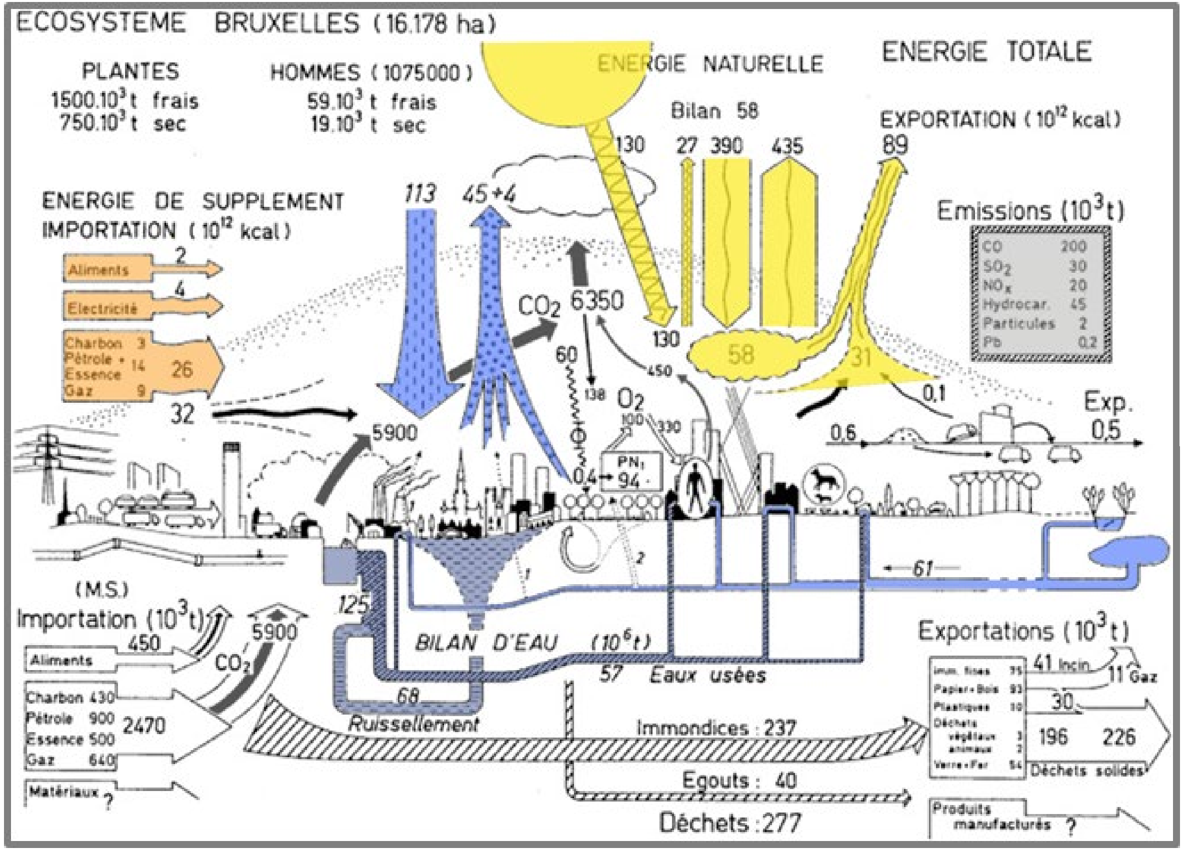
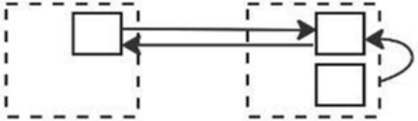
Different spatial approaches: Hinterland



City -hinterland relationship



Hinterland:
“Area lying beyond what is visible or known”

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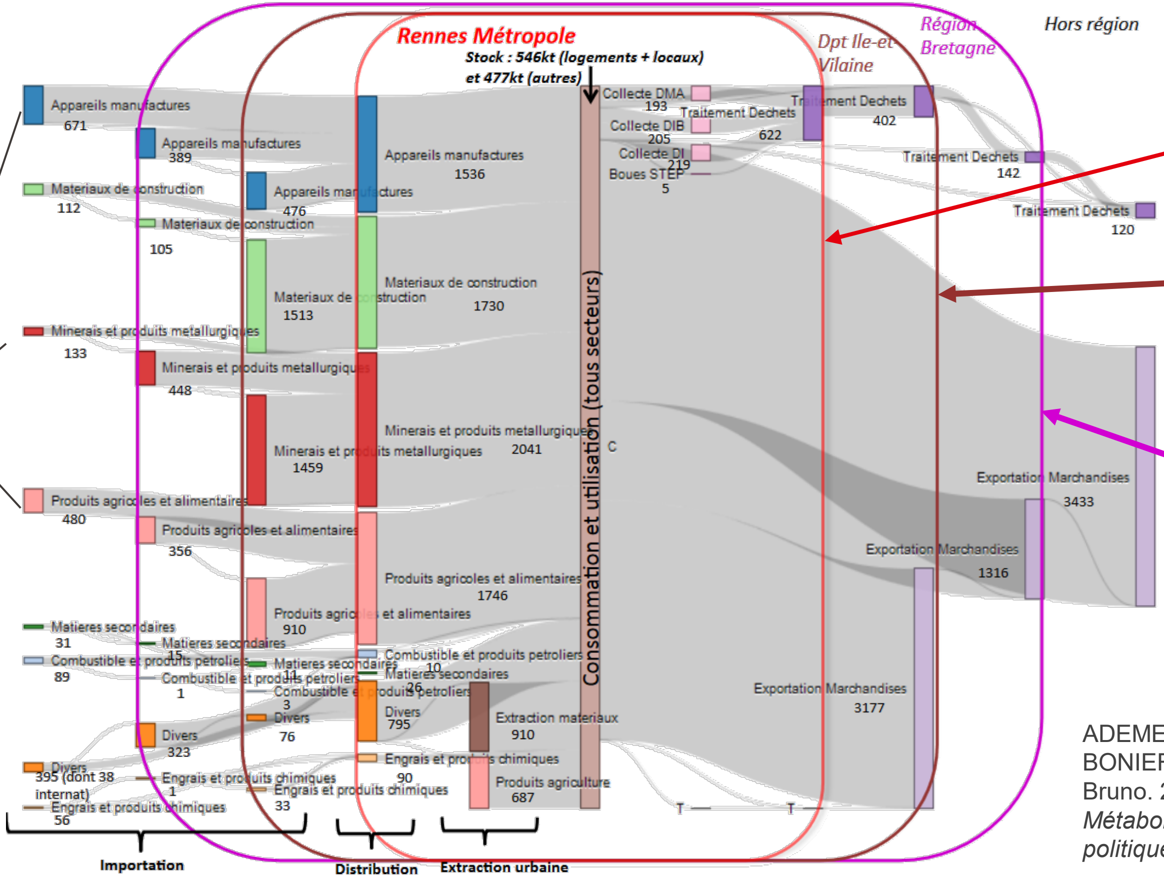
Different spatial approaches: Rennes' hinterland

Beyond delimited boundaries



Delimited boundaries

Urban metabolism - Rennes Métropole

Extended metabolism – Dpt. Ile-et-Vilaine

Extended metabolism – Région Bretagne

ADEME. DURAND Mathieu, BAHERS Jean-Baptiste, BONIERBALE Thomas, BERAUD Hélène, BARROCA Bruno. 2016. *Vers une économie circulaire… de proximité ; Métabolisme urbain, empreinte environnementale et politique de gestion des déchets* – Rapport. 90p.

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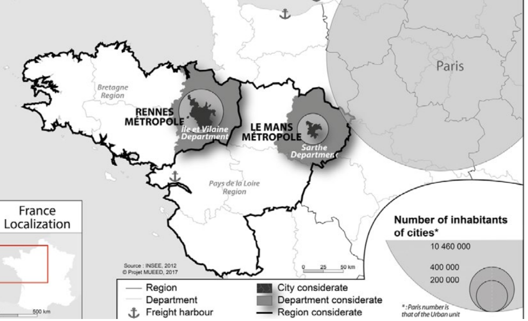
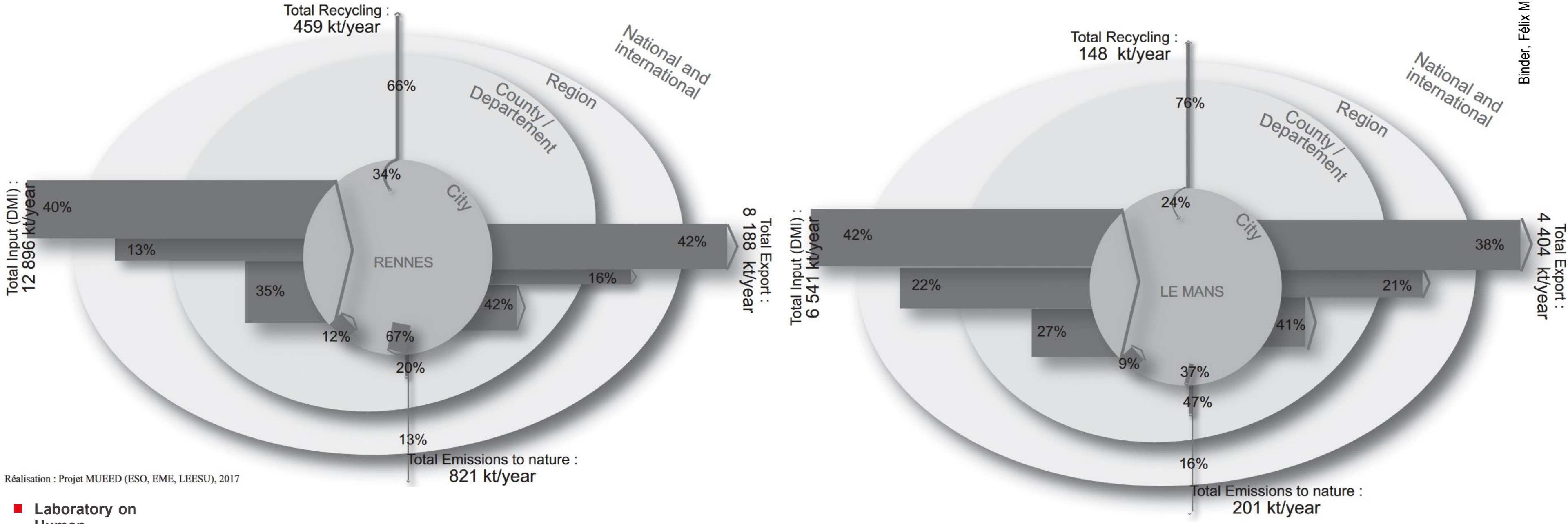
Rennes' and Le Mans' hinterland

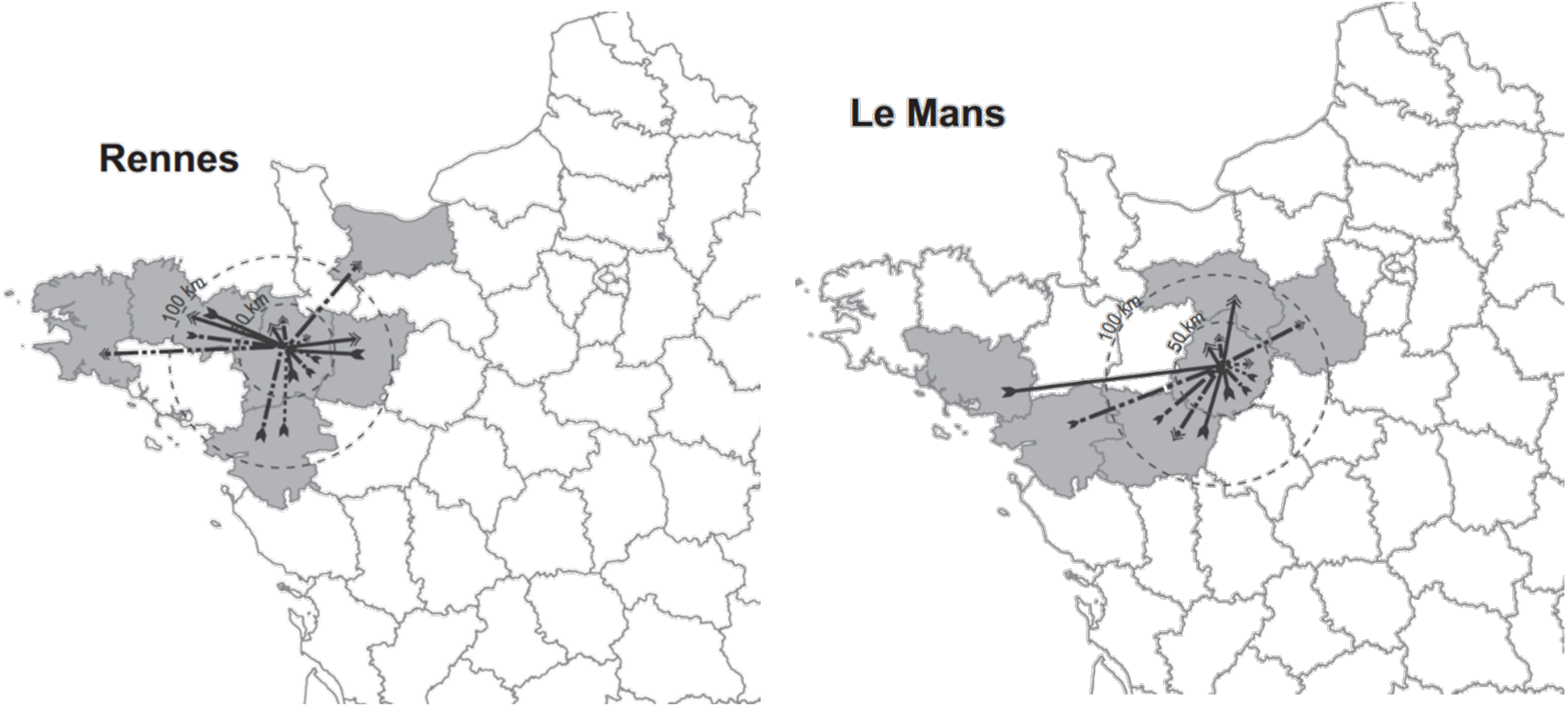


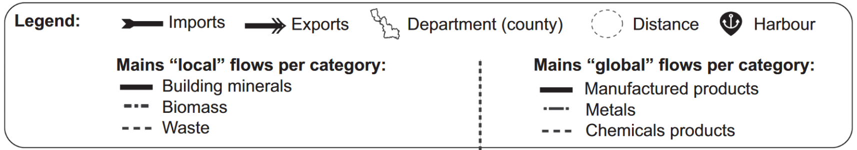


- **Laboratory on Human-Environment Relations in Urban Systems**

Bahers, J. B., Barles, S., & Durand, M. (2019). Urban Metabolism of Intermediate Cities: The Material Flow Analysis, Hinterlands and the Logistics-Hub Function of Rennes and Le Mans (France). *Journal of Industrial Ecology*, *23*(3), 686-698.

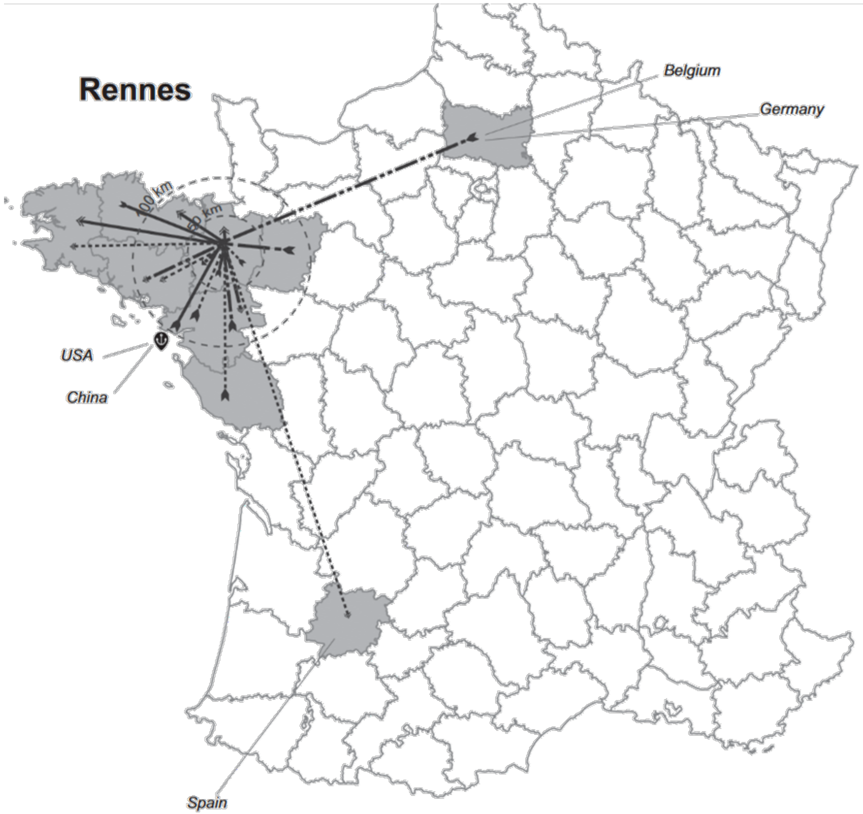
Rennes' and Le Mans' Local Flows

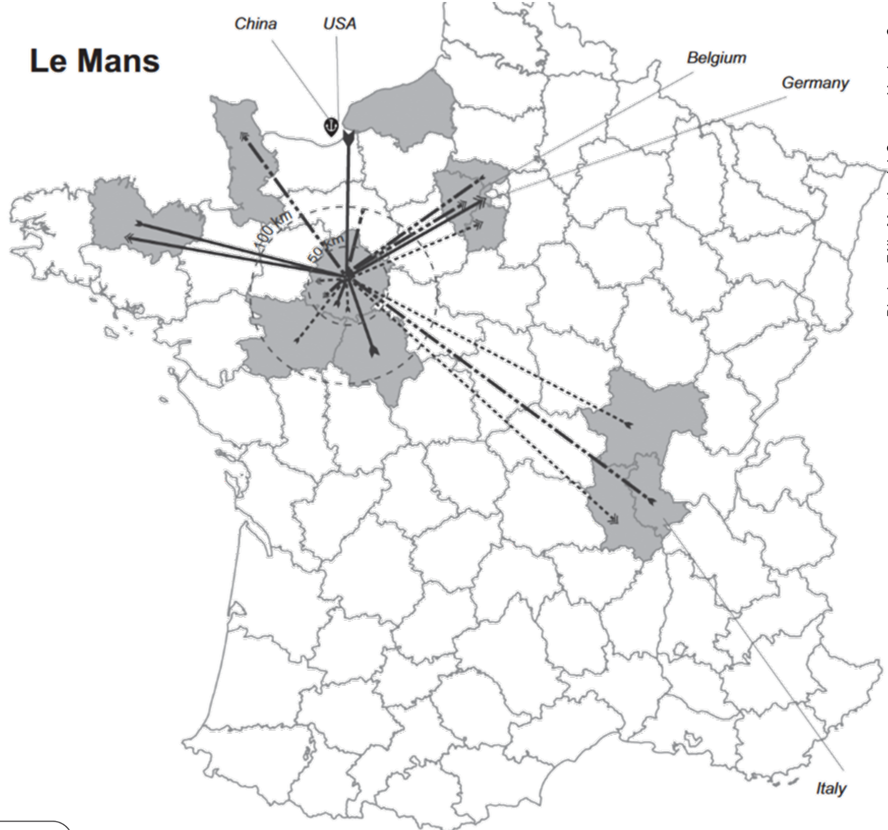




Bahers, J. B., Barles, S., & Durand, M. (2019). Urban Metabolism of Intermediate Cities: The Material Flow Analysis, Hinterlands and the Logistics-Hub Function of Rennes and Le Mans (France). *Journal of Industrial Ecology*, *23*(3), 686-698.

Rennes' and Le Mans' Global Flows





Legend: Imports · Exports · Department (county) · Distance · Harbour

Mains "local" flows per category:
- Building minerals
- Biomass
- Waste

Mains "global" flows per category:
- Manufactured products
- Metals
- Chemicals products

Bahers, J. B., Barles, S., & Durand, M. (2019). Urban Metabolism of Intermediate Cities: The Material Flow Analysis, Hinterlands and the Logistics-Hub Function of Rennes and Le Mans (France). *Journal of Industrial Ecology*, *23*(3), 686-698.

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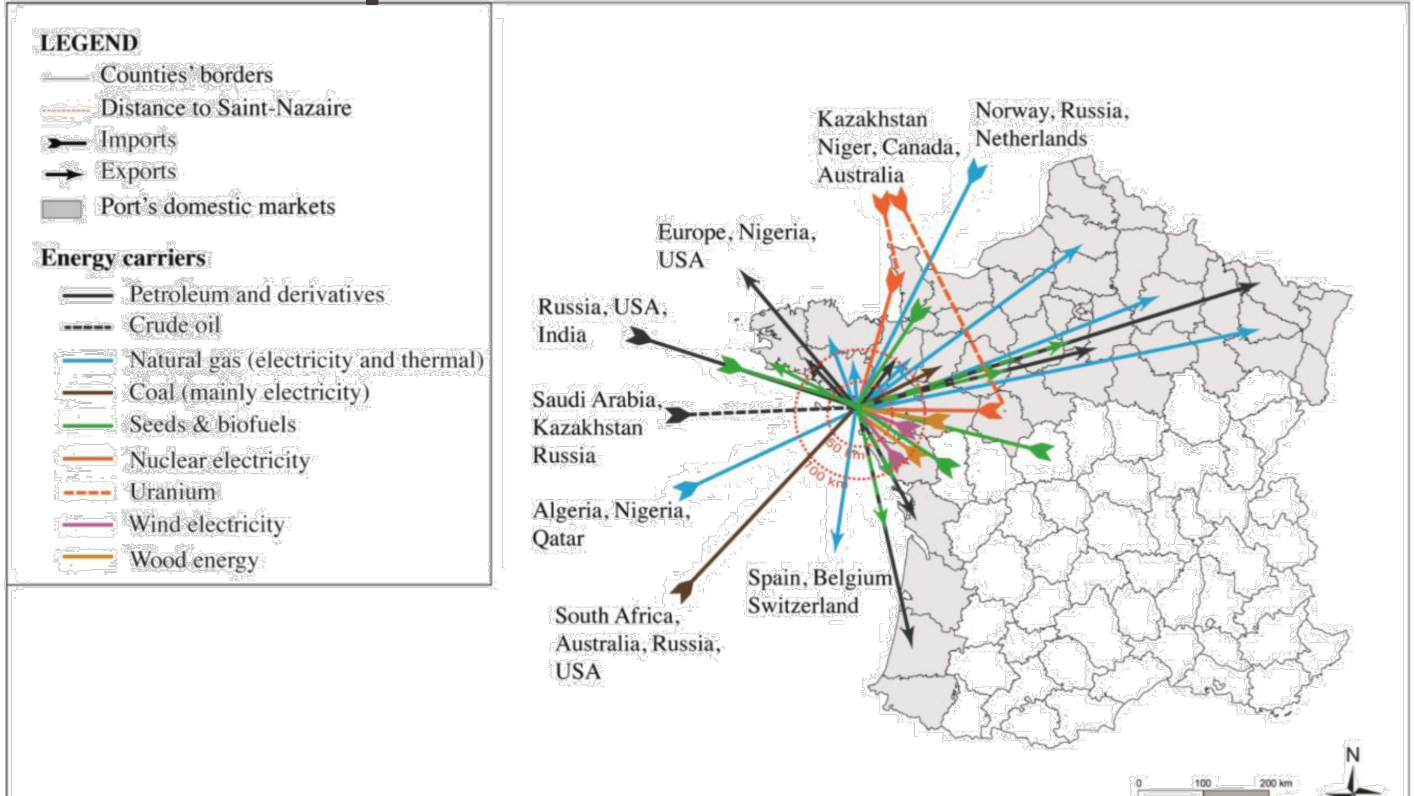
Energy metabolism of Saint-Nazaire's port



Tanguy, A., Bahers, J. B., & Athanassiadis, A. (2020). Outsourcing of urban metabolisms and its consequences: A multiscale energy flow analysis of a French port-city. *Resources, Conservation and Recycling*, *161*, 104951.

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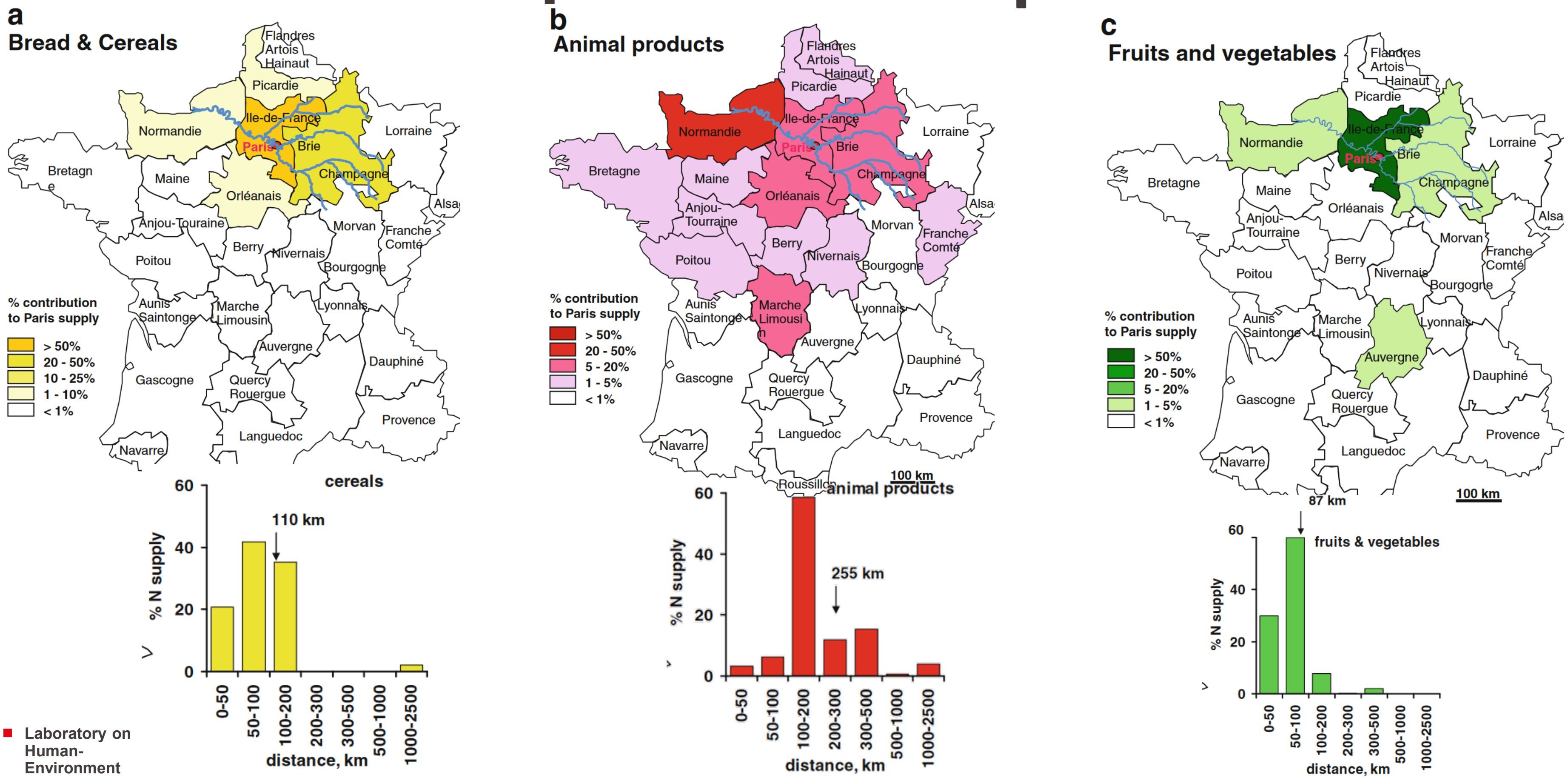
Some examples: Paris' footprint 1786



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Billen, G., S. Barles, P. Chatzimpiros, and J. Garnier. 2012. Grain, meat and vegetables to feed Paris: where did and do they come from? Localising Paris food supply areas from the eighteenth to the twenty-first century. Regional Environmental Change 12(2): 325-335..

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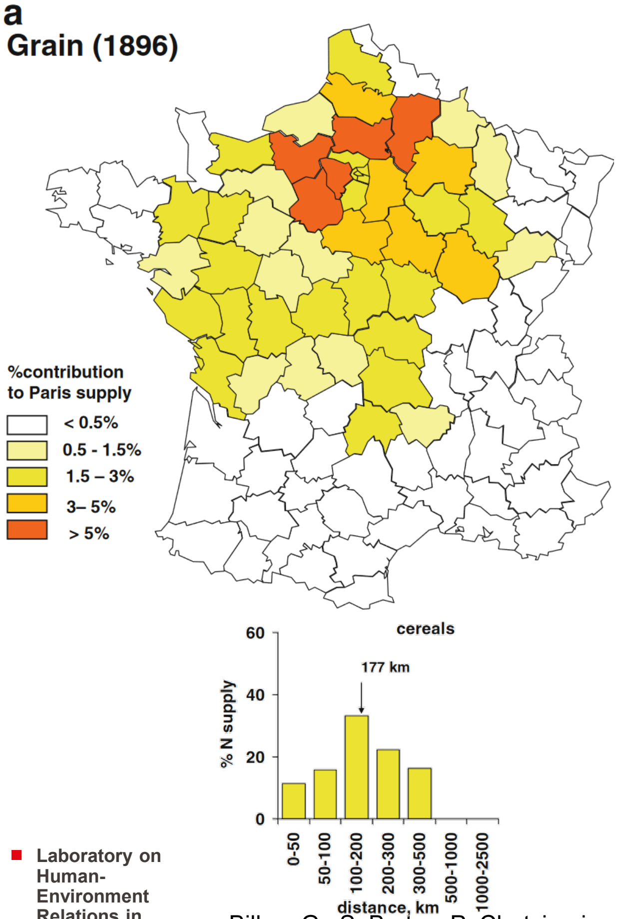
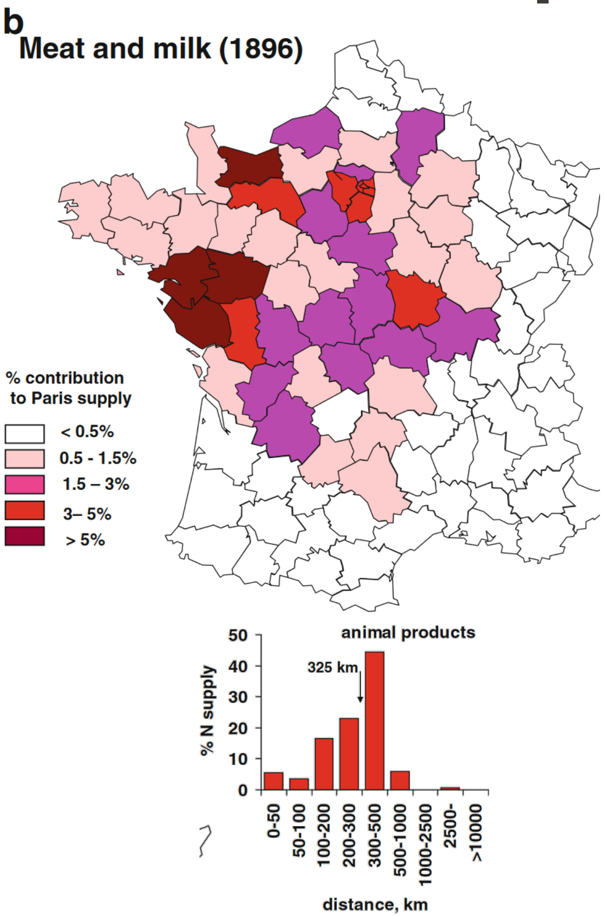
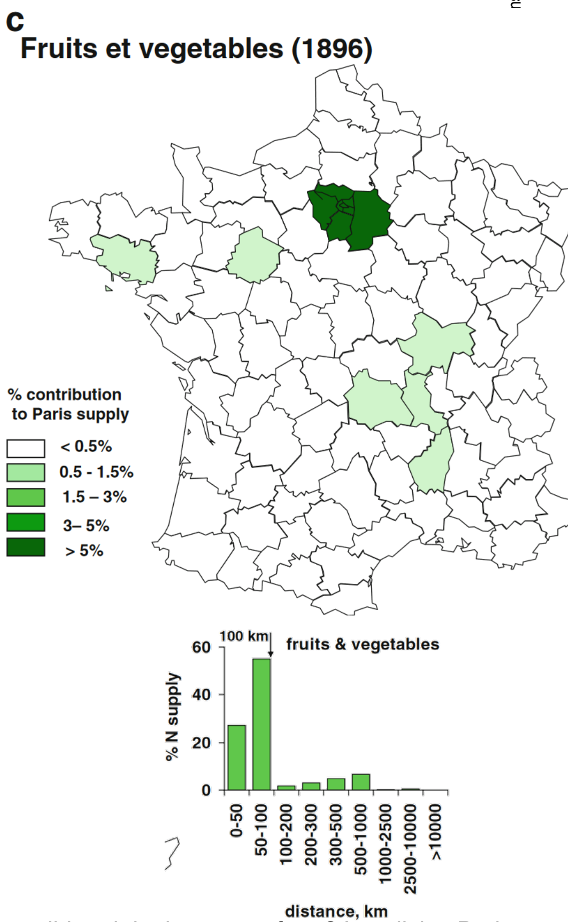
Some examples: Paris' footprint 1896







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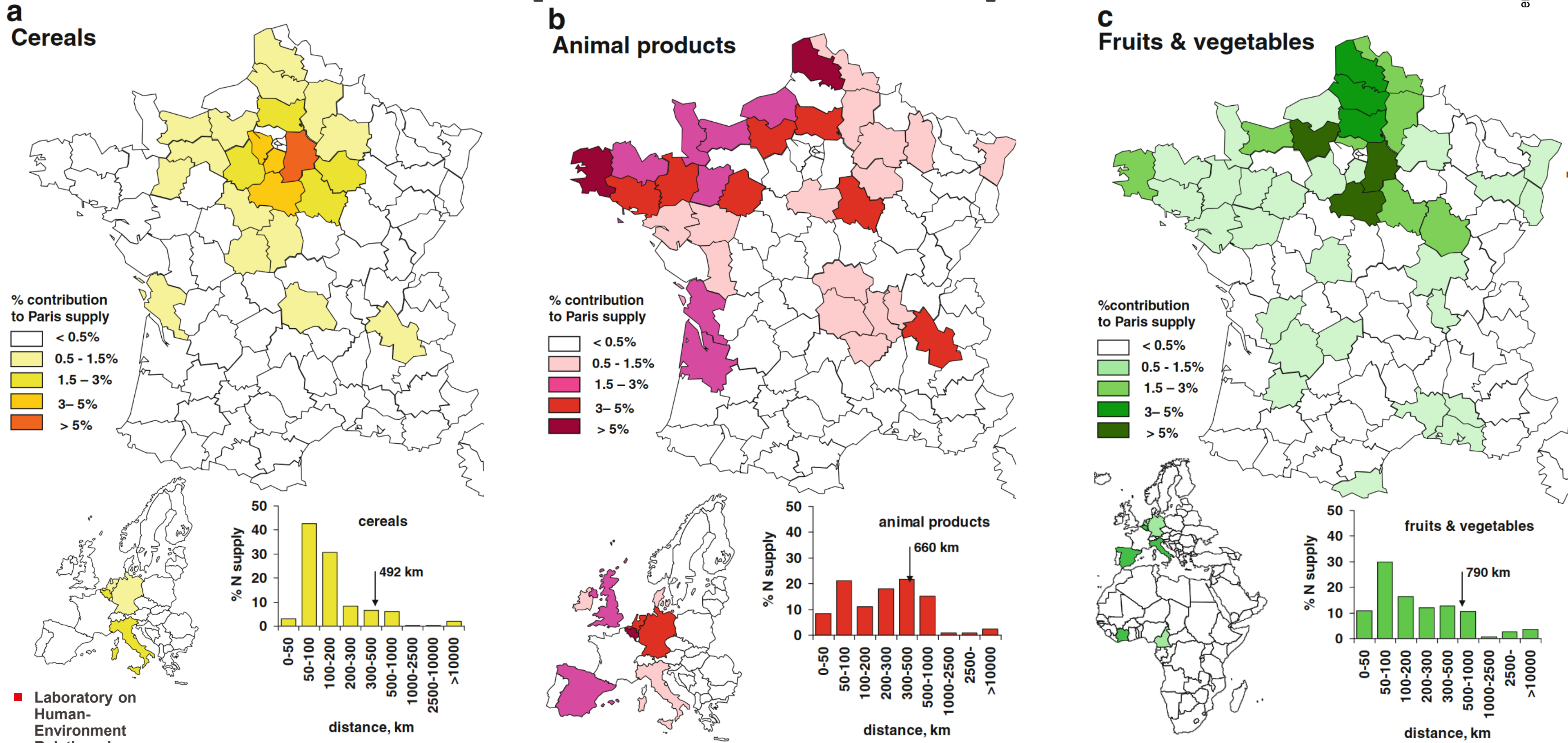
Some examples: Paris’ footprint 2006



Billen, G., S. Barles, P. Chatzimpiros, and J. Garnier. 2012. Grain, meat and vegetables to feed Paris: where did and do they come from? Localising Paris food supply areas from the eighteenth to the twenty-first century. Regional Environmental Change 12(2): 325-335..

Where to find data

- **Freight and logistics data (national / international)**

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European Commission > Eurostat > Transport > Overview

Transport – Overview

INTRODUCTION

Which are the transport modes covered?

Eurostat data on transport cover **five main types of transport modes**:

- Air
- Inland waterway
- Rail
- Road
- Maritime (Sea)

In addition, specific data are collected for oil pipelines.

What is measured?

In general, transport statistics cover:

- Transport of goods
- Transport of people
- Traffic
- Transport safety

Other available data include aggregated statistics on **businesses, employment, infrastructure** and **equipment**.

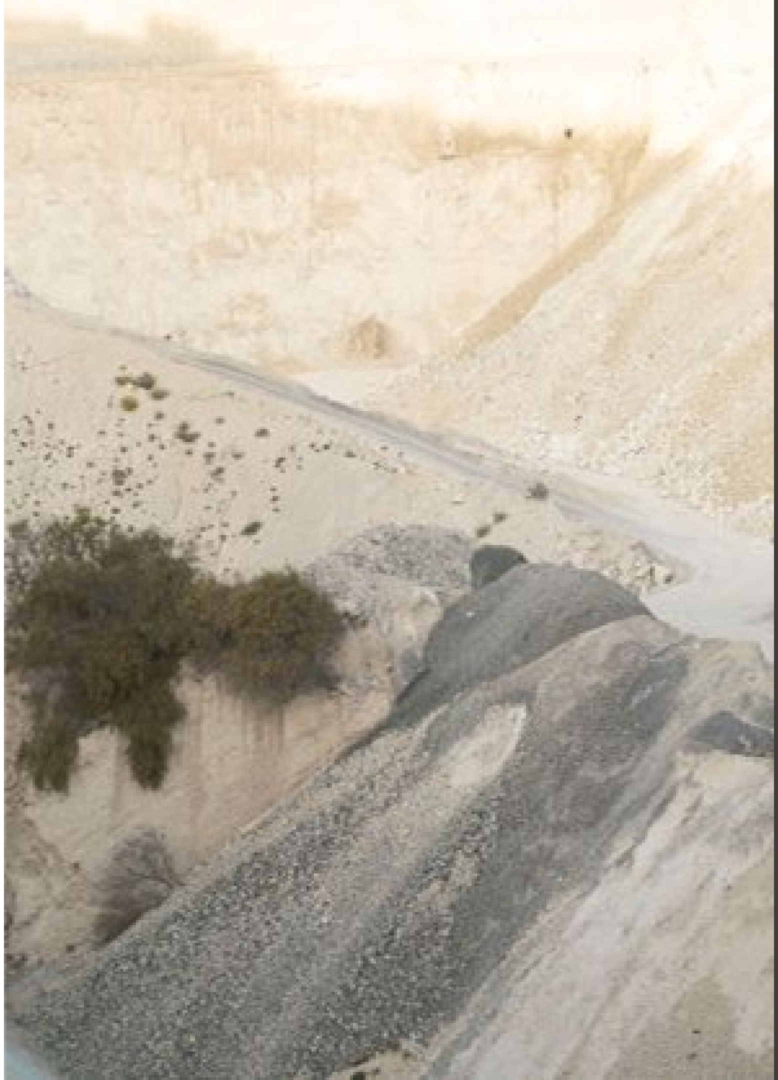
Some data collections go back to 1980, while others start more recently.

> read more

MAIN TABLES

- Transport
  - Regional transport statistics (t_tran_r) M
    - Maritime transport of passengers by NUTS 2 regions (tgs00075)
    - Maritime transport of freight by NUTS 2 regions (tgs00076)
    - Air transport of passengers by NUTS 2 regions (tgs00077)
    - Air transport of freight by NUTS 2 regions (tgs00078)
    - Rail network by NUTS 2 regions (tgs00113)
    - Motorways network by NUTS 2 regions (tgs00114)
  - Transport, volume and modal split (t_tran_hv)
    - Volume of passenger transport relative to GDP (ttr00001)
    - Modal split of passenger transport (t2020_rk310) M
    - Modal split of freight transport (t2020_rk320) M
  - Railway transport (t_rail)
    - Total length of railway lines (ttr00003)
    - Rail transport of passengers (ttr00015)
    - Goods transport by rail (ttr00006)
  - Road transport (t_road)
    - Total length of motorways (ttr00002)
    - Goods transport by road (ttr00005)
    - People killed in road accidents (source: DG MOVE) (sdg_11_40) M
  - Inland waterways transport (t_iww) M
    - Goods transport by inland waterways (ttr00007)
  - Maritime transport (t_mar)
    - Sea transport of goods (ttr00009)
  - Air transport (t_avia)
    - Air transport of goods by country (yearly data) (ttr00011)
    - Air transport of passengers by country (yearly data) (ttr00012) Updated
    - Air transport of passengers by country and type of transport (monthly data) (ttr00016) Updated
    - Air transport of passengers by airport and type of transport (monthly data) (ttr00017) Updated

https://ec.europa.eu/eurostat/web/transport



MFA: Temporal analysis

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MFA: Temporal analysis

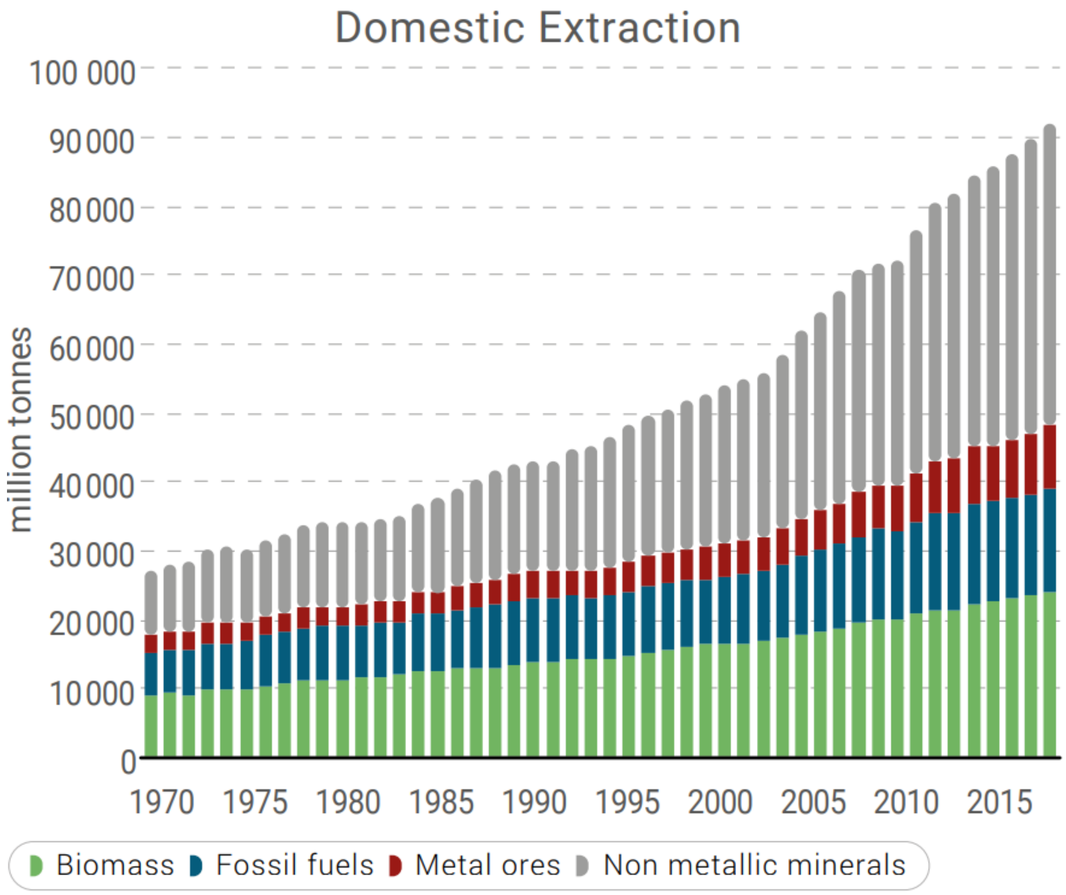
The growth in resource use has caused a sharp increase in global material extraction, particularly of non-renewable materials.

Extraction in **1970**:
+**20** billion tonnes

Extraction in **2020**:
+**100** billion tonnes

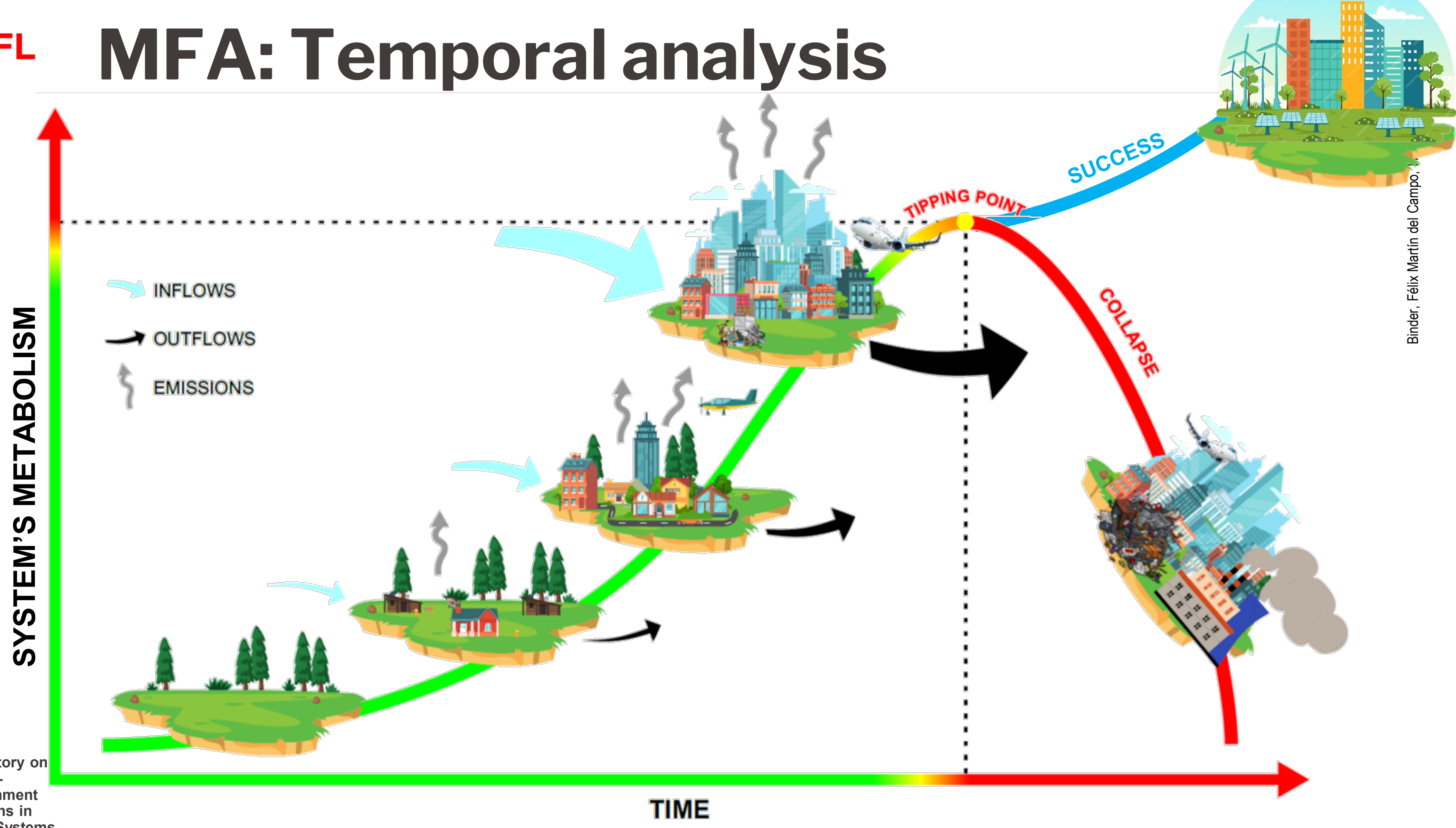
Projections by **2050**:
+**180** billion tonnes

Recycling rates in **2020**:
8.6%



Source: UNEP & IRP, 2018

MFA: Temporal analysis



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Source: Martin del Campo (2023)

MFA: Temporal analysis - Samothraki

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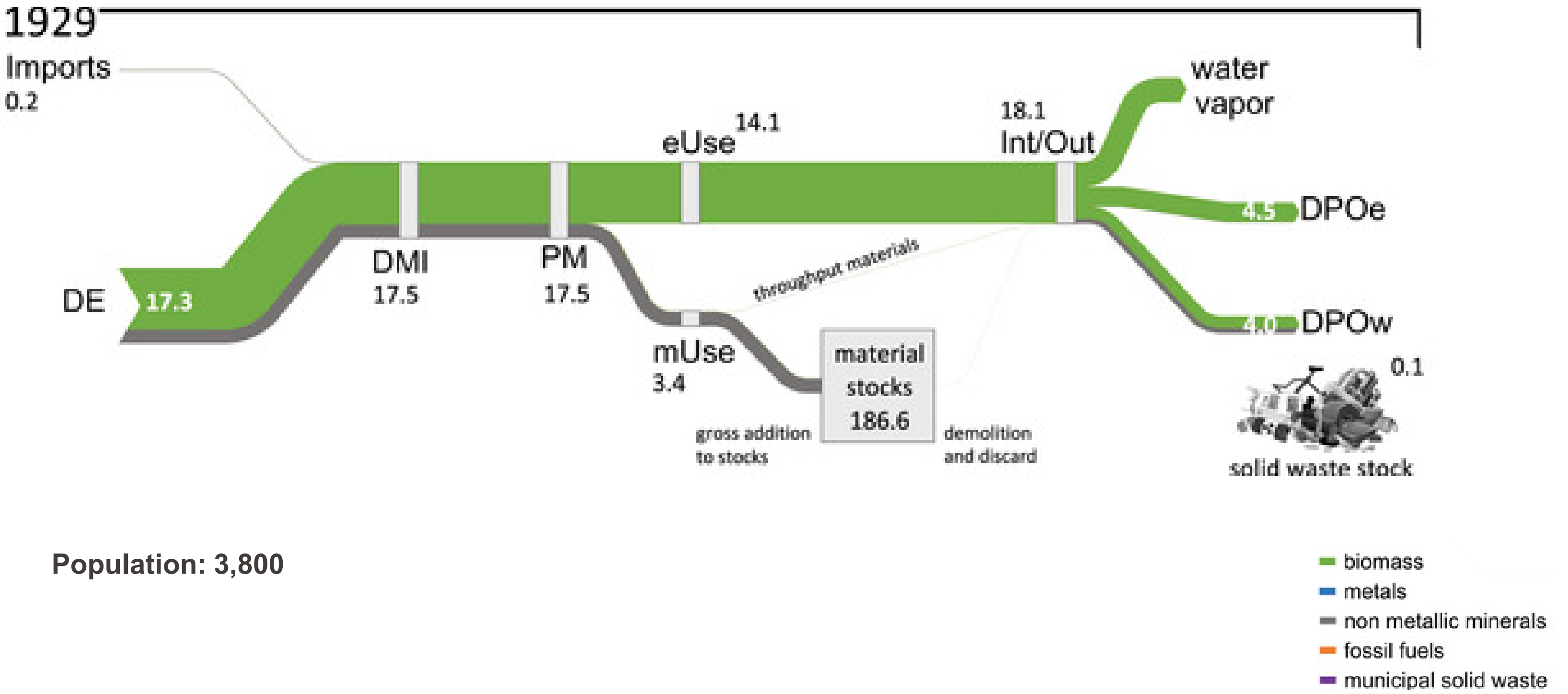

Population: 3,800

In *kt/yr* for material stocks and *kt* for solid waste stock

Population: 3,100

Noll et al. (2021) - The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. Journal of Industrial Ecology, 26(2), 577-591

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MFA: Temporal analysis - Samothraki

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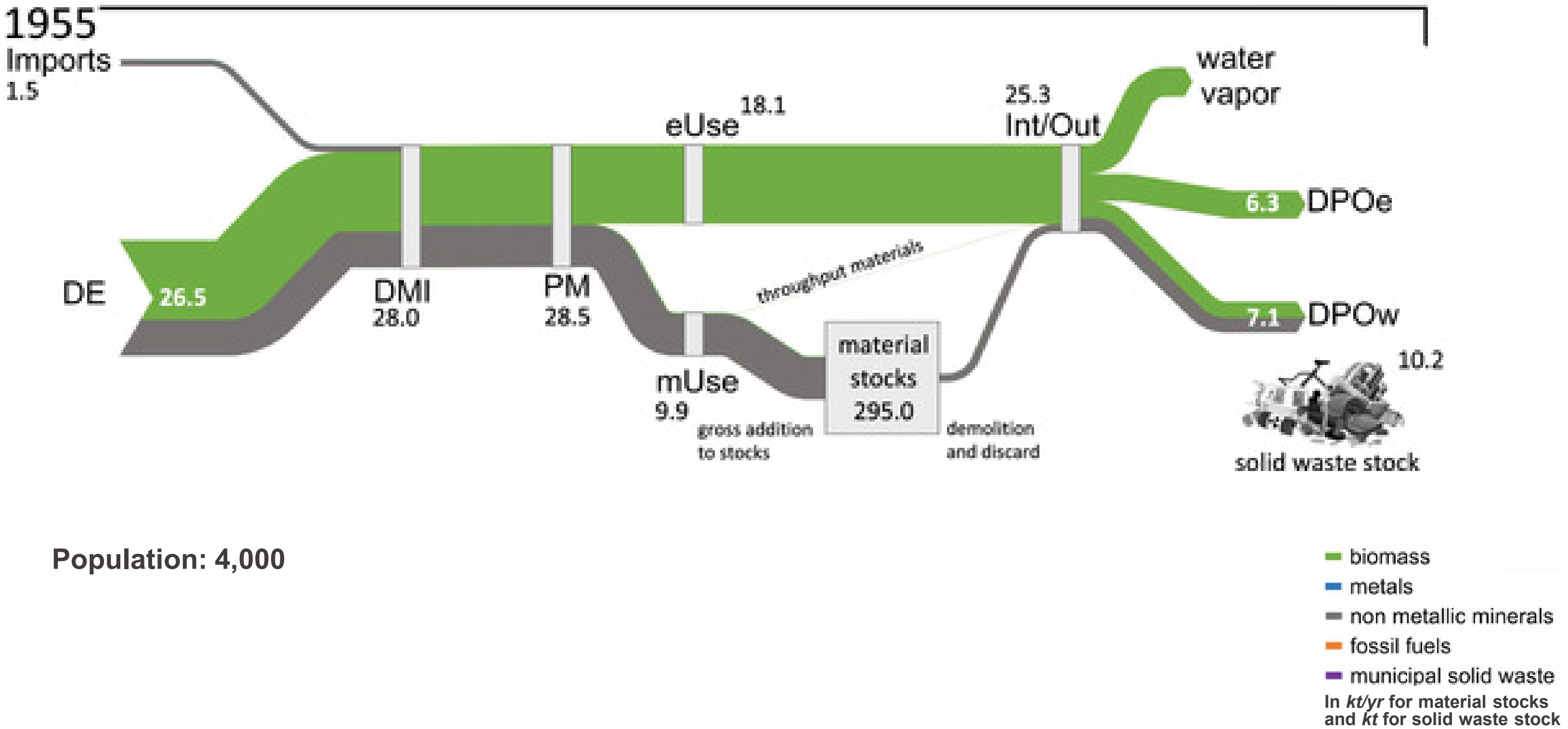

Population: 4,000

Population: 3,100

Noll et al. (2021) - The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. Journal of Industrial Ecology, 26(2), 577-591

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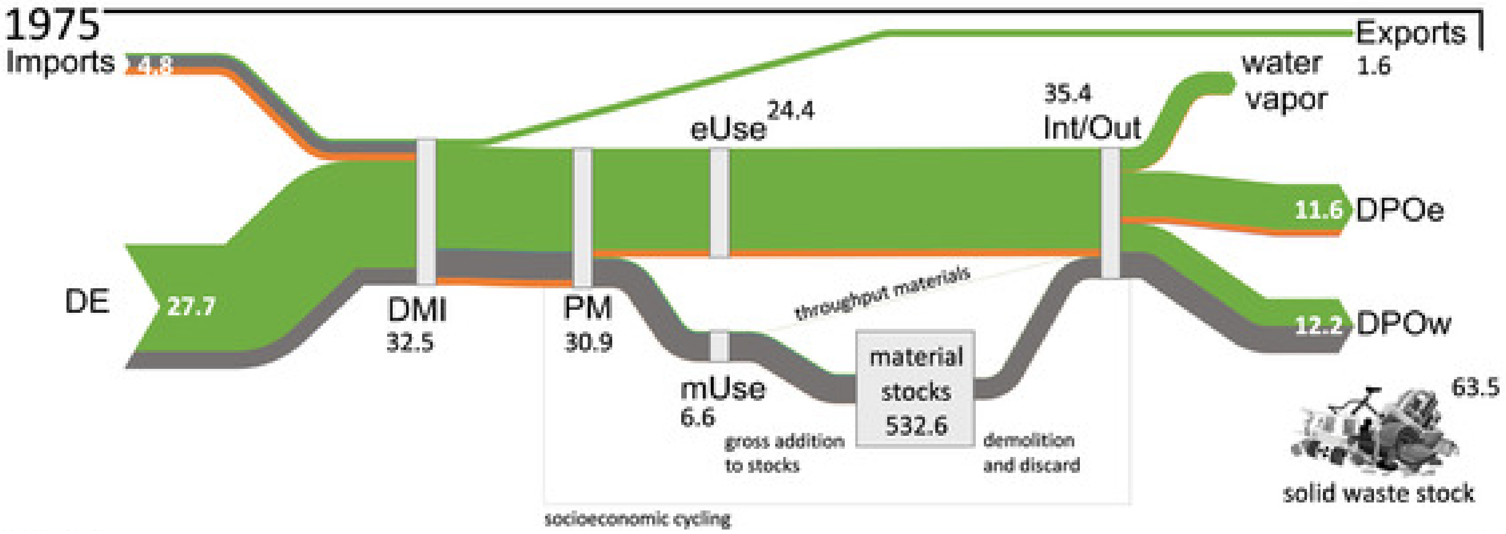

Population: 2,800

- biomass
- metals
- non metallic minerals
- fossil fuels
- municipal solid waste

In *kt/yr* for material stocks and *kt* for solid waste stock

Population: 3,100

Noll et al. (2021) - The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. Journal of Industrial Ecology, 26(2), 577-591

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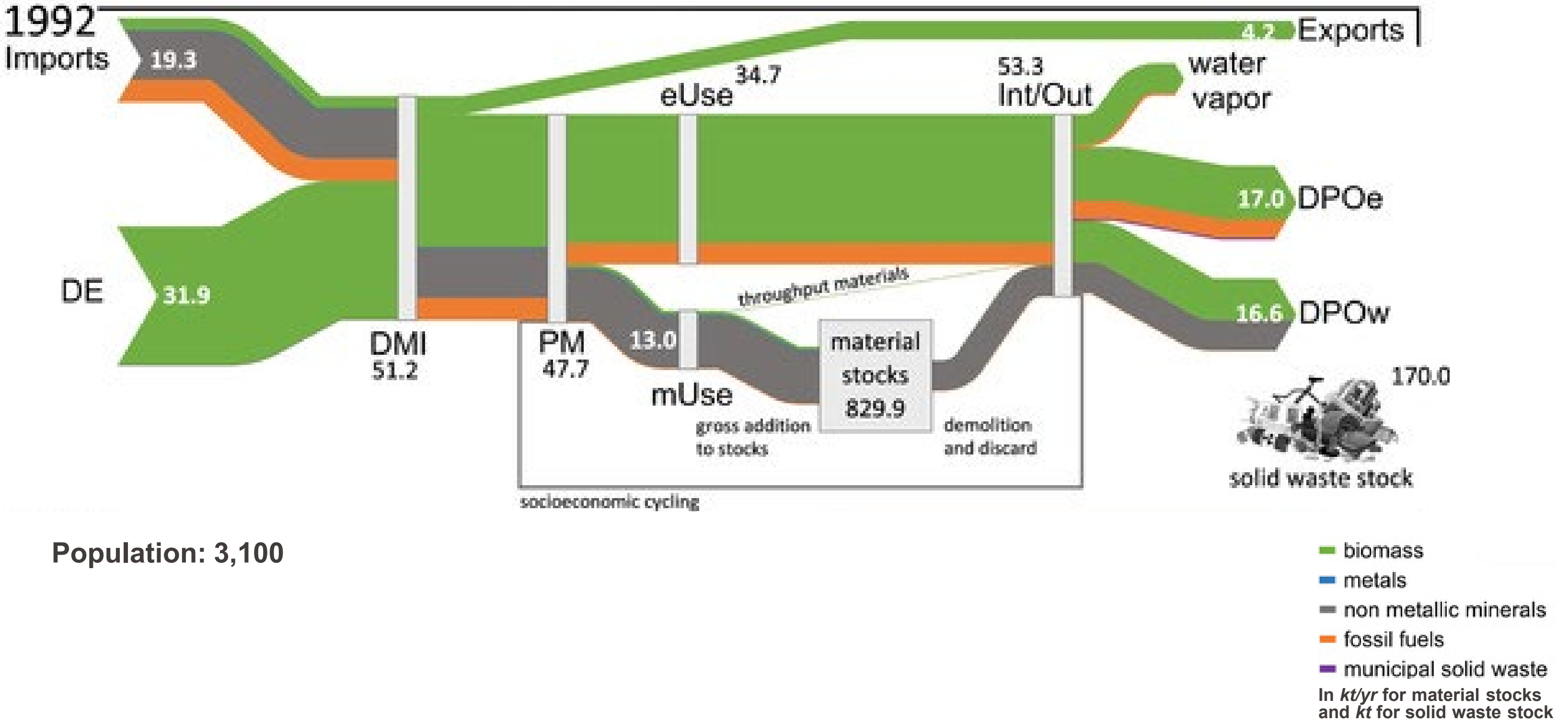

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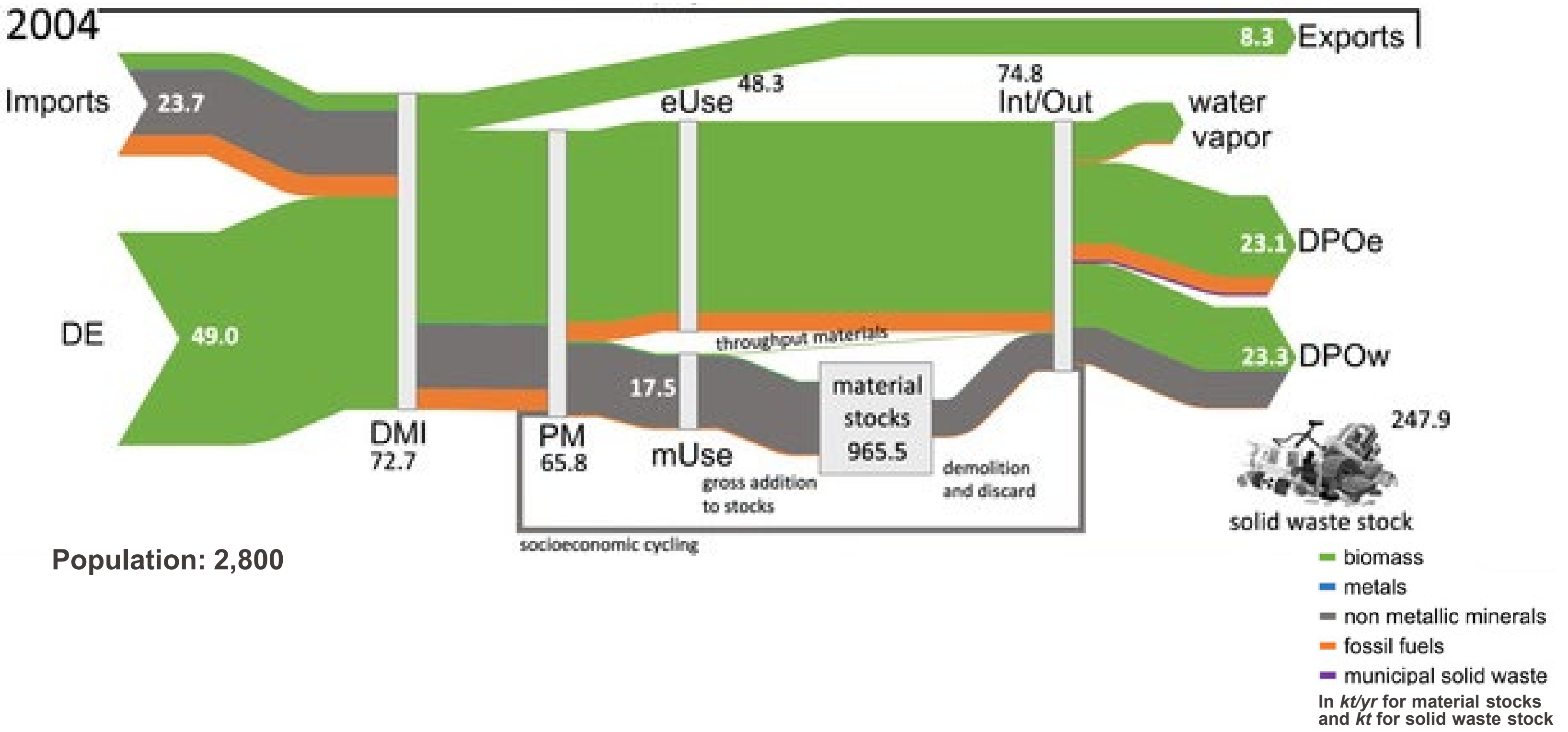

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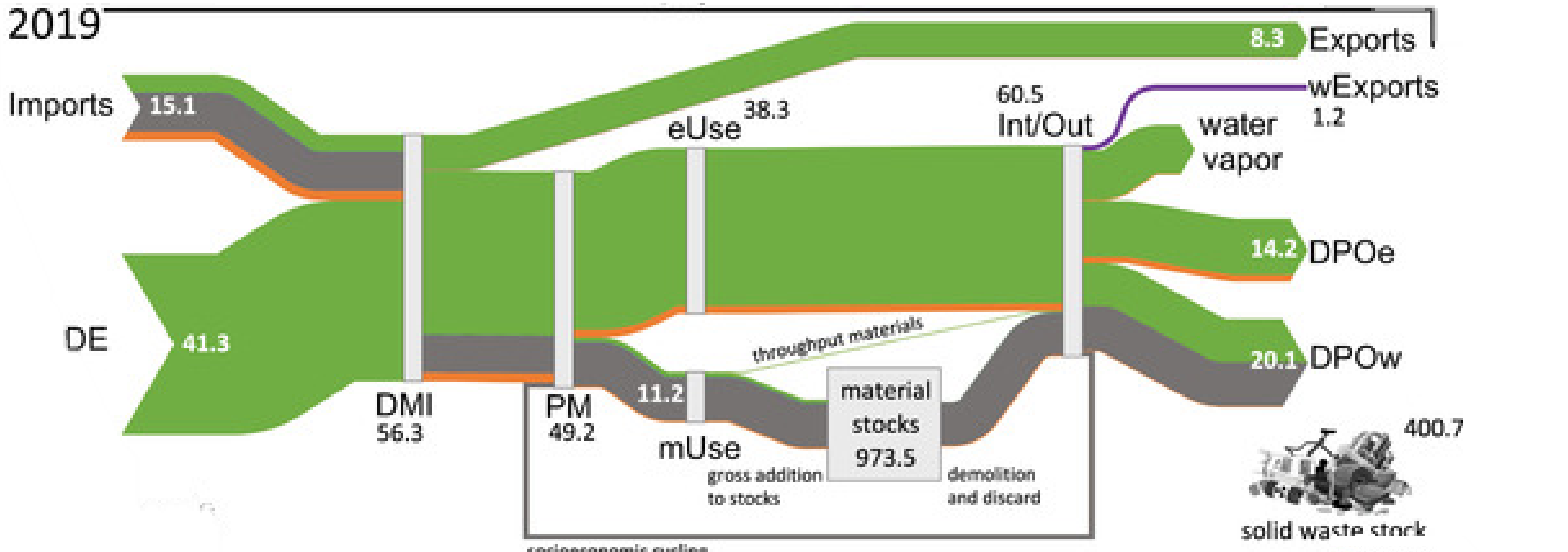

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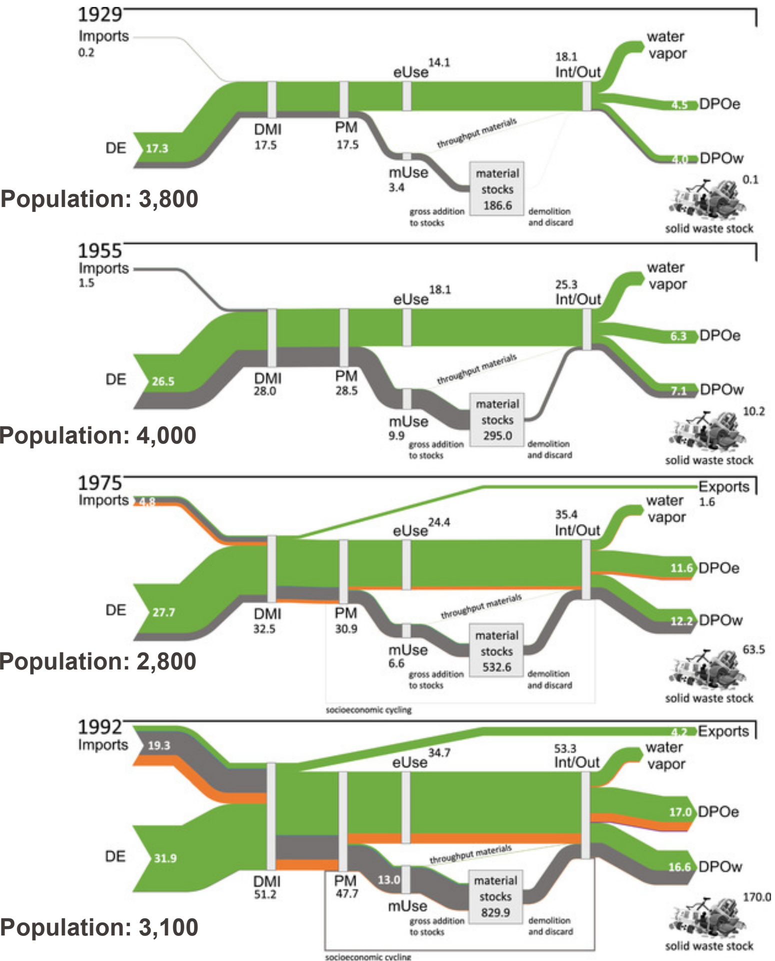
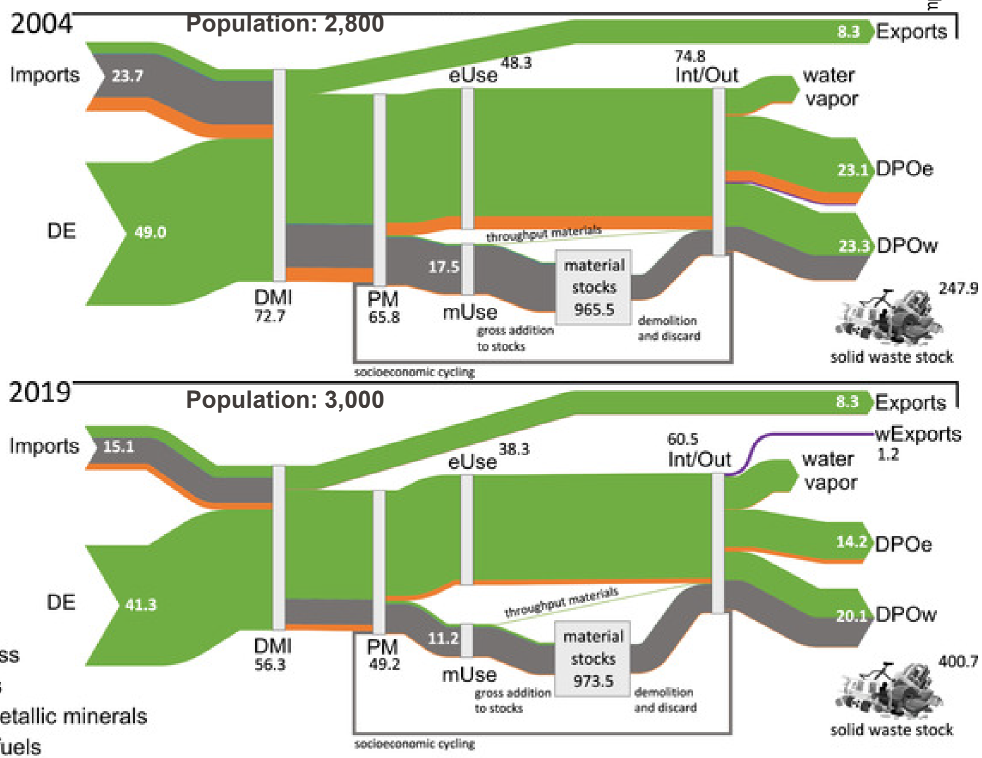
Noll et al. (2021) - The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. Journal of Industrial Ecology, 26(2), 577-591

MFA: Temporal analysis - Samothraki





- biomass
- metals
- non metallic minerals
- fossil fuels
- municipal solid waste

In *kt/yr* for material stocks and *kt* for solid waste stock

Noll et al. (2021) - The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. Journal of Industrial Ecology, 26(2), 577-591

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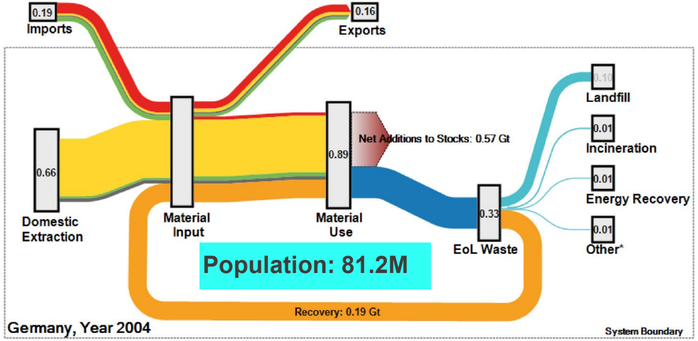
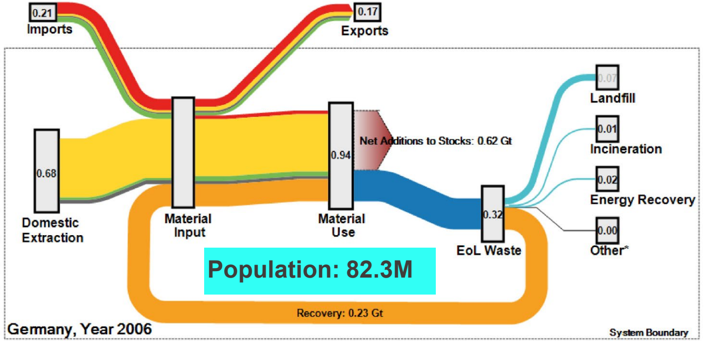
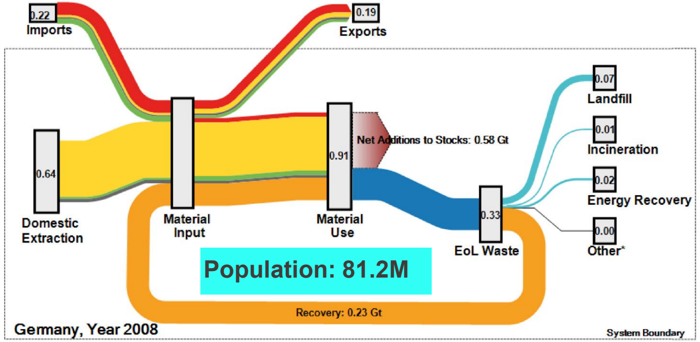
Germany

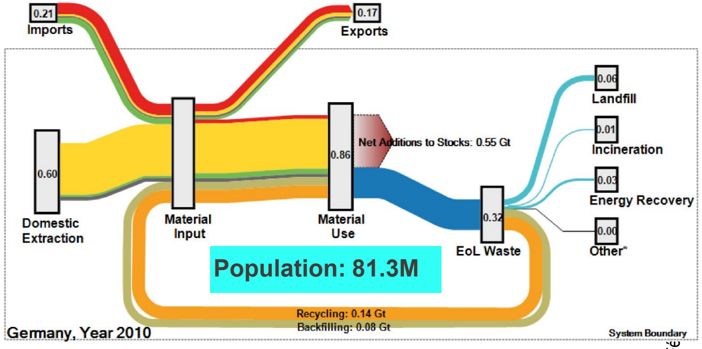
Gt/yr

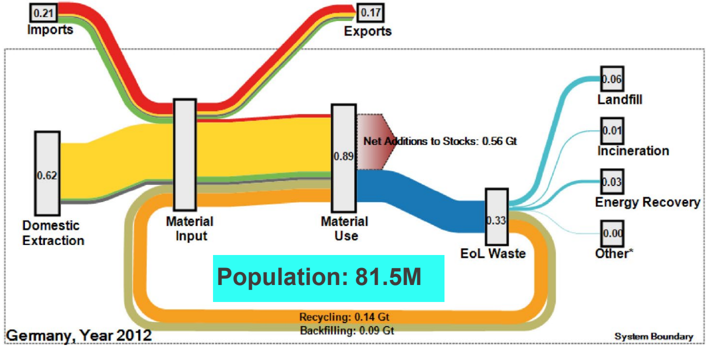
- Metals
- Constr. Minerals
- Biomass
- Industr. Minerals
- Waste Generation
- Waste Treatment
- Recycling
- Backfilling

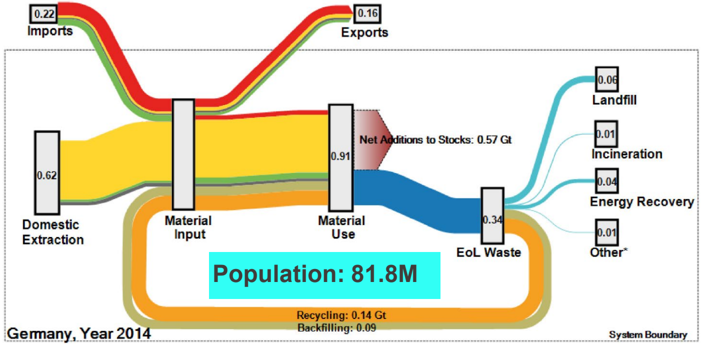










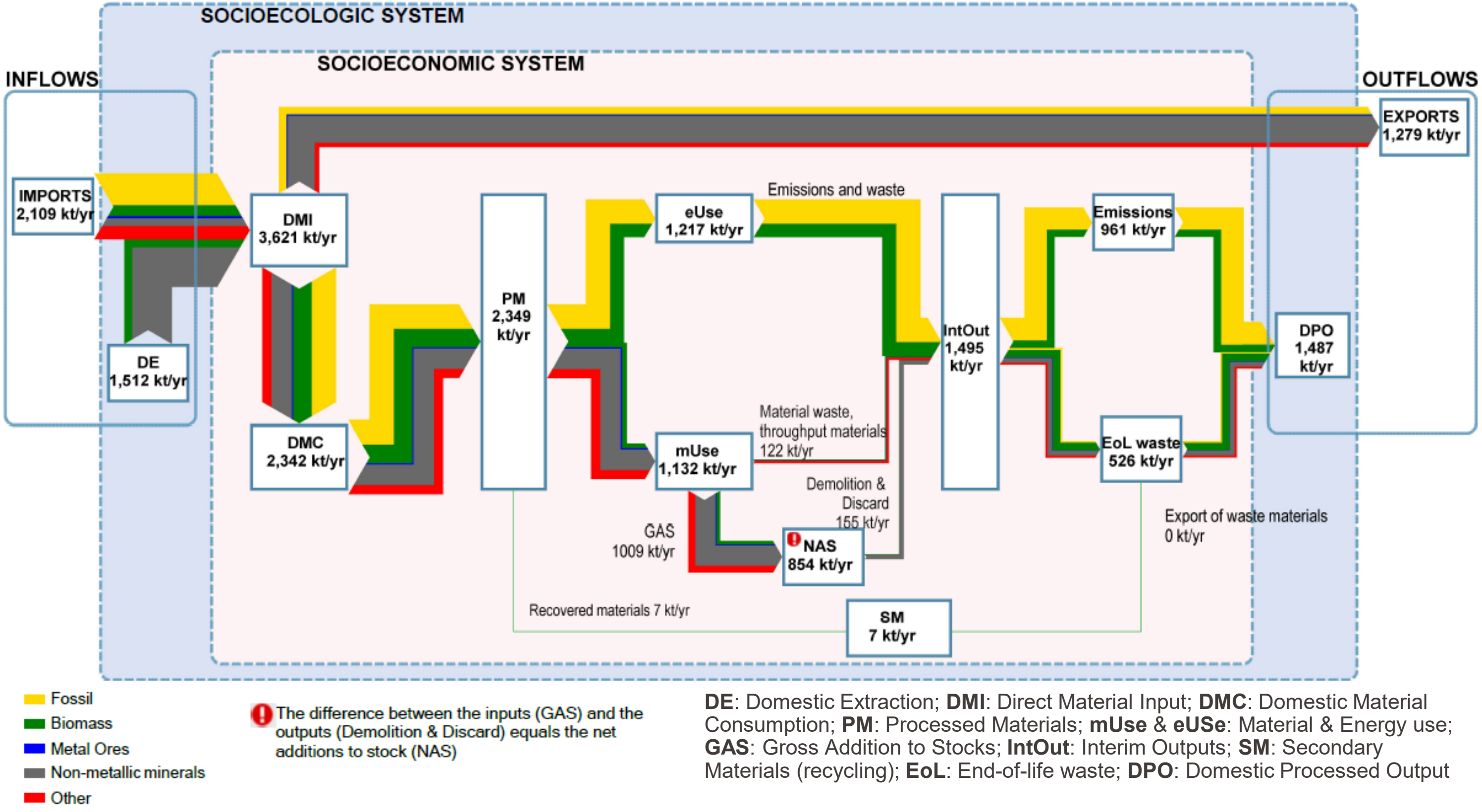


Source: European Commission 2017

- Laboratory on Human-Environment Relations in Urban Systems

MFA: Temporal analysis

EW-MFA for The Bahamas in 2018 by Main Material Categories



DE: Domestic Extraction; **DMI**: Direct Material Input; **DMC**: Domestic Material Consumption; **PM**: Processed Materials; **mUse** & **eUSe**: Material & Energy use; **GAS**: Gross Addition to Stocks; **IntOut**: Interim Outputs; **SM**: Secondary Materials (recycling); **EoL**: End-of-life waste; **DPO**: Domestic Processed Output

Martin del Campo et al. (2023) – Can a small island nation build resilience? The significance of resource-use patterns and socio-metabolic risks in The Bahamas. Journal of Industrial Ecology, 27(2), 491-507

Binder, Félix Martín del Campo, Hecher, Campfens

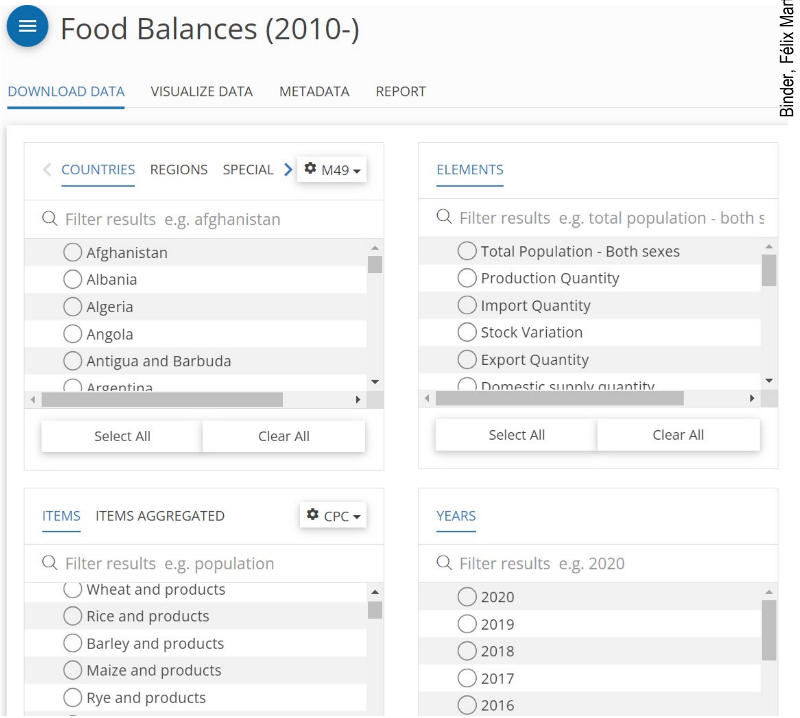
Where to find data

- Open data portals (UN Comtrade database; FAOSTAT, etc.)
- Country/city statistics, Specialized reports

UN Comtrade Database   Data   Bulk Files   Visualization   Metadata   Publications   Ref

Showing 1 to 3 of 3 Results

Period	Trade Flow	Reporter	Partner	2nd Partner	Customs Desc	Transport Mode	Commodity Code	Trade Value (US$)	Net Weight(kg)
2020	M	Cambodia	Switzerland	World	TOTAL CPC	TOTAL MOT	270111	$2,472	110
2020	M	India	Switzerland	World	TOTAL CPC	TOTAL MOT	270111	$17,392,404	165253000
2020	M	South Africa	Switzerland	World	TOTAL CPC	TOTAL MOT	270111	$11,537	110000

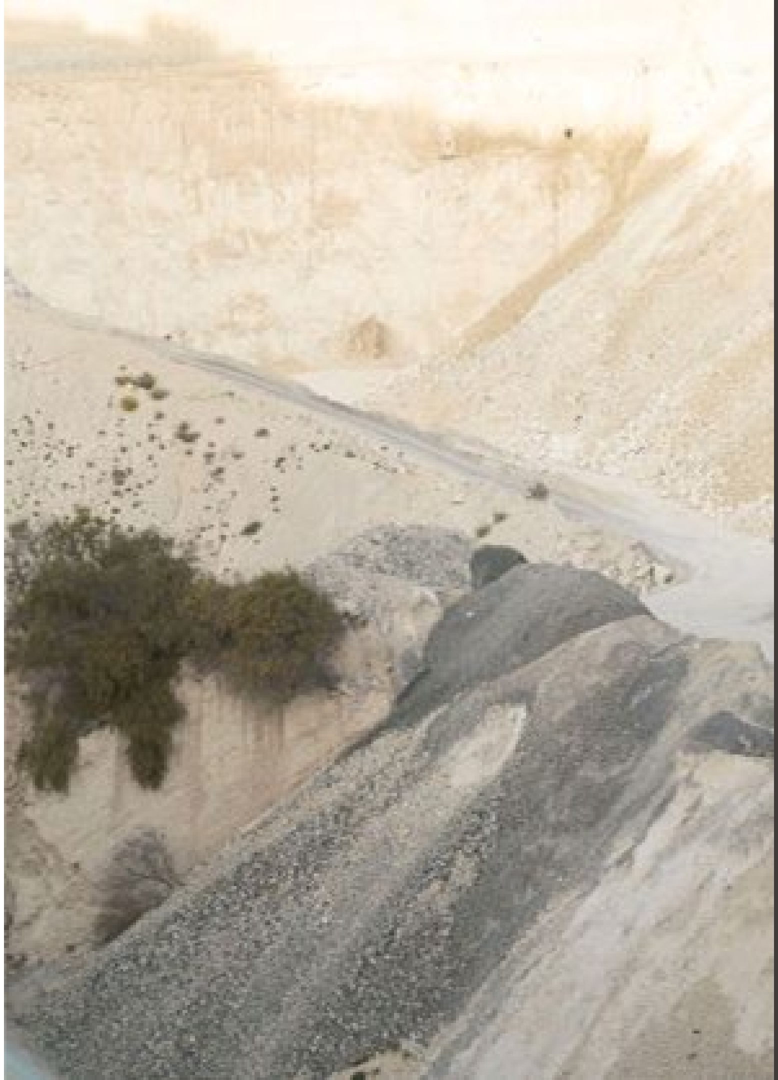


World mineral production 2017-21

Production of crude steel

tonnes (metric)

Country	2017	2018	2019	2020	2021
Austria	8 134 600	6 885 000	7 423 500	6 765 100	7 920 000
Azerbaijan	387 258	381 617	325 895	264 506	304 077
Belarus	2 432 580	2 572 862	2 717 705	2 559 577	2 390 000
Belgium	7 842 300	7 980 000	7 760 000	6 120 000	6 910 000
Bosnia & Herzegovina	734 518	677 443	800 600	740 194	774 832
Bulgaria	652 400	666 100	565 900	483 800	547 500
Croatia	—	135 800	69 126	45 273	185 143
Czech Republic	4 553 000	4 966 000	4 600 000	2 900 000	4 700 000
Finland	4 003 634	4 100 000	3 511 000	3 482 000	4 322 000
France	15 504 683	15 387 355	14 449 651	11 595 698	13 946 700



Spatial Stock Analysis (bottom-up)

Laboratory on Human-Environment Relations in Urban Systems

Material stock definition (recap)

What is a **stock**?

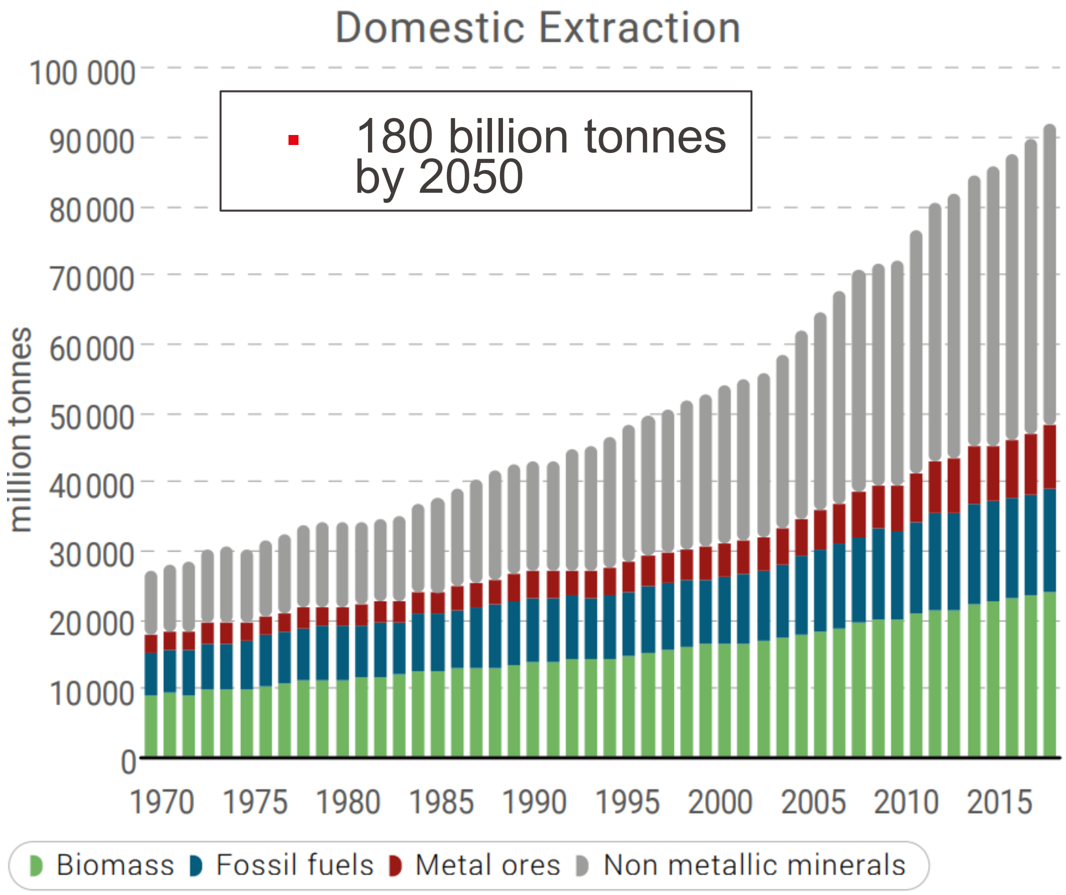
- A **stock** represents the **accumulated quantity** of a material, resource, or product present in a **defined system or boundary** at a given point in **time**.
- In industrial ecology, stocks can refer to physical assets such as buildings, infrastructure, machinery, or the amount of a resource stored within a particular environment (e.g., metal stock in urban buildings).
- Stocks are crucial because they influence how materials are used, maintained, and eventually released back into the environment.

Material Stocks

- In 2015, **75%** of all **extracted materials** were linked to **material stocks**
  - Buildings
  - Infrastructures
  - Machinery, etc.

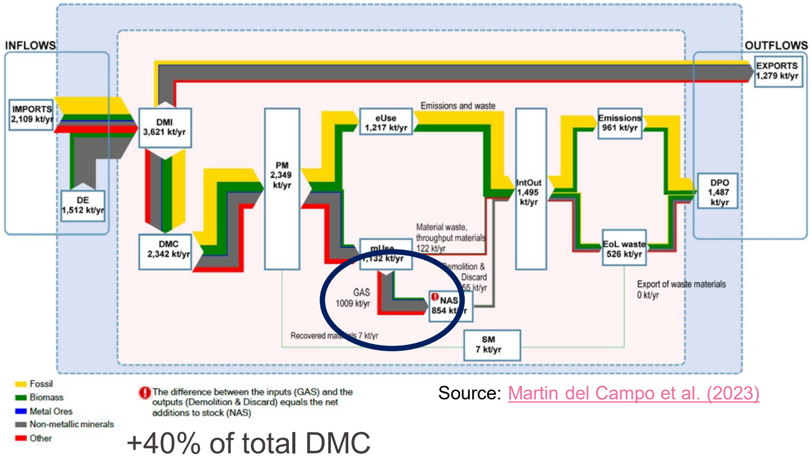
- Utilized for **building** and **maintaining** these, or for **operating** them and **providing services**

Krausmann et al. (2020) - Growing stocks of buildings, infrastructures and machinery as key challenge for compliance with climate targets. Global Environmental Change, 61(2020), 102034



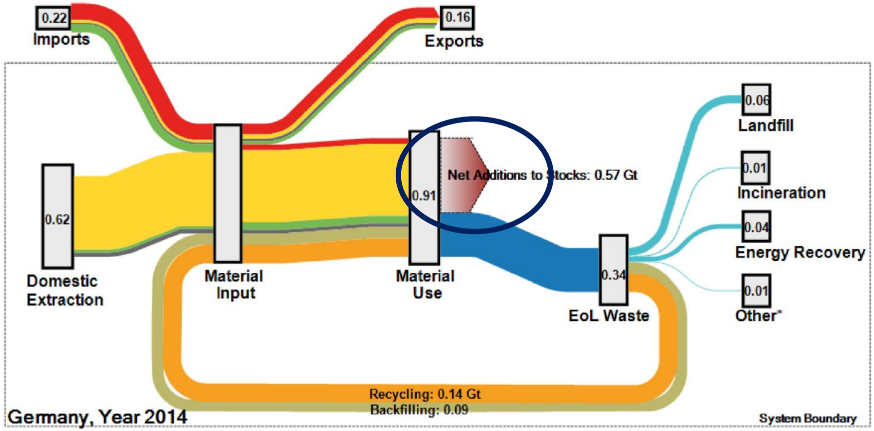
Source: UNEP & IRP, 2018

Material Stocks



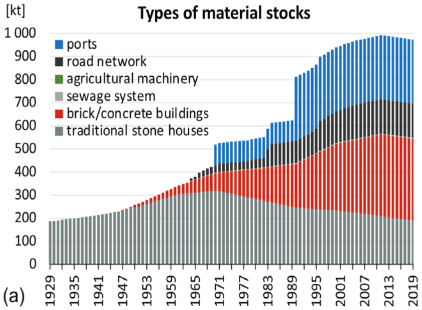
Source: Martin del Campo et al. (2023)

+40% of total DMC
+90% goes to buildings
Non-metallic minerals, Metals, Industrial roundwood

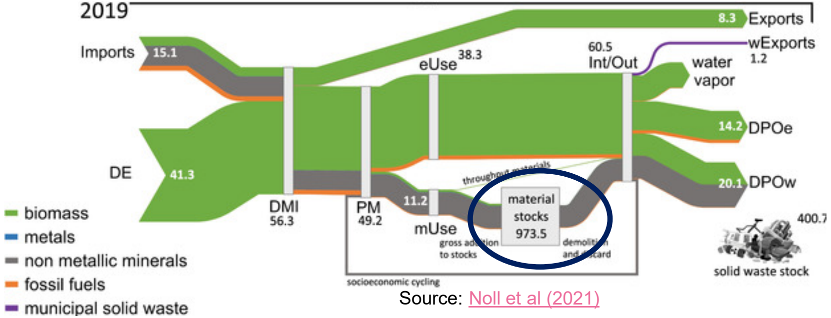


+83% of total DMC
In-use infrastructure

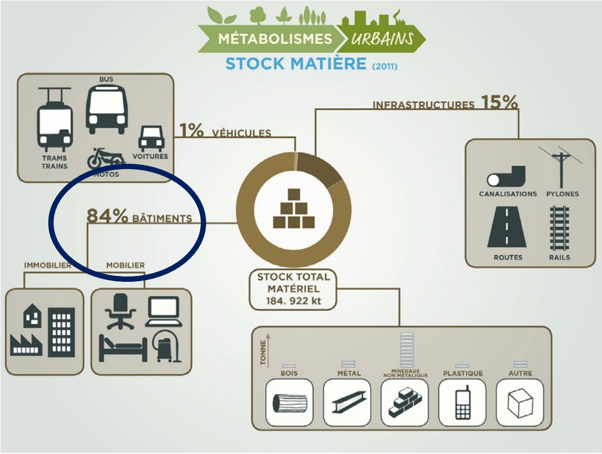
Source: European Commission (2017)



+20% of total DMC
+56% buildings, +43% infrastructure
Non-metallic minerals, Metals



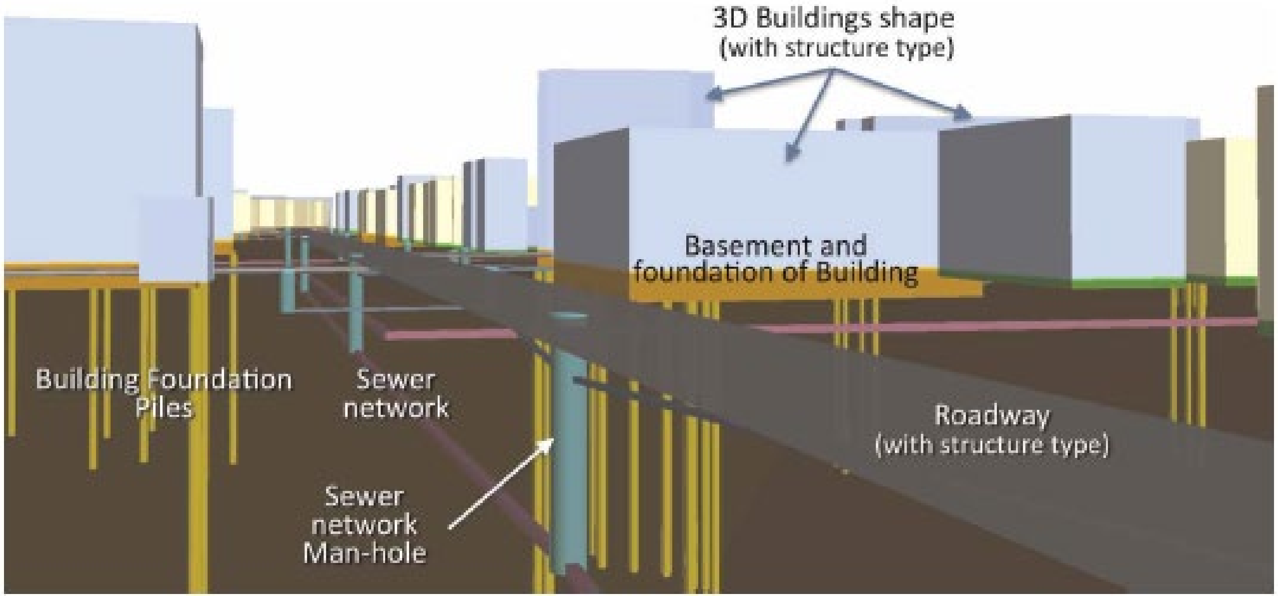
Source: Noll et al (2021)



Source: Bruxelles Environnement (2015).

Material stocks: What does it look like?

Binder, Félix Martín del Campo, Hecher, Campfens



Tanikawa, H., & Hashimoto, S. (2009). Urban stock over time: spatial material stock analysis using 4d-GIS. Building Research & Information, 37(5-6), 483-502.

- Buildings
  - Foundations
  - Walls, roof
  - Furniture…
- Road network
  - Sub-base material
  - Base material
  - Surface course…
- Sewer network
  - Drains
  - Connections
  - Treatment plant…

Material stocks: What does it look like?

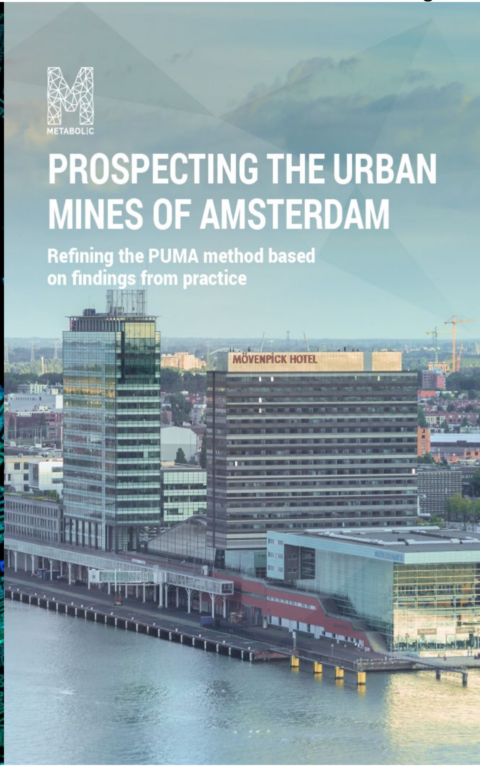
Circular Economy at large

Buildings
- Iron & steel, concrete…

Cables/pipes
- Copper

Window frames
- Aluminum

Electronics
- Gold



Metabolic (2017). Prospecting the urban mines of Amsterdam. Refining the PUMA method based on findings from Practice

https://code.waag.org/puma/data/Prospecting_the_urban_mines_of_Amsterdam_v03_CB-lg.pdf

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Material stocks: Examples

Material Stocks

Cities Contribute Publications Account

Publications

Show 10 entries

Search:

Title	Type	Author(s)	Year
Islands at Risk - Analyzing Resource-use ...	Thesis	Francisco Xavier Félix Martín del Campo	2023
Materials used in the building stock of M...	Dataset	Haapea K. Järvinen J.	2023
The Bahamas at risk: Material stocks, se...	Journal Article	Martin del Campo *et al.*	2023
Urban Circularity Assessment Porto	Report	Carla Santos	2023
What is the UCA?	Video Recording	Athanassiadis and Bellstedt	2023
3D GIS Modelling of Road and Building ...	Thesis	Lingfei Ye	2022
Map of Building Material Stock in Porto ...	Image	Carla Santos	2022
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https://library.metabolismofcities.org/?

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Material stocks: Why is it important?

Binder, Félix Martín del Campo, Hecher, Campfens

- Material stocks induce long-term dynamics of resource use
- Material stocks can predict and localize future waste/resources
- Secondary materials mine (urban mining)
- Reduce embodied environmental impacts of the construction sector

How to measure material stocks?

Campfens

Table 1
Summary presentation of selected studies.

Studies	Purpose	Space and time scales, built works, materials and dissipative flows	Main methodological approach for studying current flows and stock	Main methodological approach for forecasting
Obernosterer et al. (1998)	Studying urban metabolism Estimating the present stock	Urban (Vienna in Austria) 1991 All constructions All materials, metals in detail (iron, aluminium, zinc, lead)	Bottom-up stock analysis Static bottom-up flow analysis	No forecasting
Kolher and Hassler (2002), Kohler and Yang (2007), Yang and Kohler (2008)	Forecasting and comparing future input and output flows Studying the influence of several parameters on future flows Estimating the future stock	National (Germany and China) 1992, until 2030 (Germany); 2005, since 1978, until 2050 (China) Buildings; road (including bridges and tunnels), rail, water, gas and electricity networks Cement, steel, wood, bricks, sand, aggregates, bitumen, glass, plastics, non-ferrous metals	Static bottom-up flow analysis Static top-down flow analysis	Dynamic flow analysis: stock-driven model
Faist Emmenegger and Frischknecht (2003)	Studying urban metabolism Estimating the present stock	Urban (canton of Geneva in Switzerland) 2000 Buildings; road, rail, water, gas and electricity networks Gravel/sand, concrete, bitumen, bricks, plastics, wood, iron, copper, aluminium	Bottom-up stock analysis Static bottom-up flow analysis	No forecasting
Muller et al. (2004), Muller (2006)	Forecasting and comparing future input and output flows Studying the influence of several parameters on future flows	Regional (Kreuzung Schweizer Mittelland in Switzerland) and national (Netherlands) 1900–1997, 1997–2100 (Kreuzung Schweizer Mittelland); 1900–2003, 2003–2100 (Netherlands) Housing Wood (Kreuzung Schweizer Mittelland); Concrete and wood (Netherlands)	Retrospective dynamic flow analysis: stock-driven model	Prospective dynamic flow analysis: stock-driven model

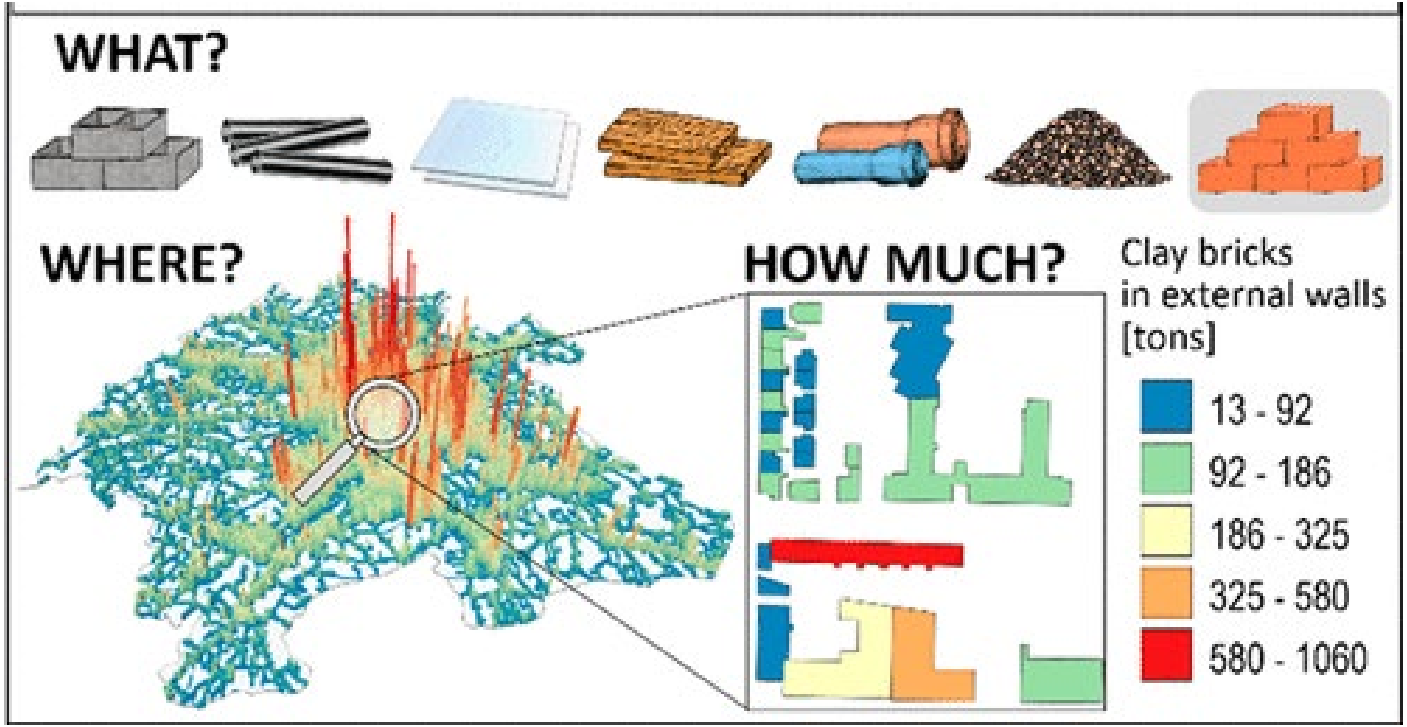
Author	Method Applied	Scale	Type of Project	Summary
Guo et al. [14]	Bottom-Up	City	Roads	An integrated model was developed that estimated the material stock of all roads (expressways, major and minor roads), intersection structure and ancillary structure. The author used GIS to avoid double count and to estimate better.
Wang et al. [15]	Bottom-Up	City	Building	Combining the data of material flow and stock analysis with the GIS to show the spatiotemporal features of the buildings.
Surahman et al. [8]	Bottom-Up	City	Buildings	The researchers estimated the material stock using the on the ground estimation of the buildings than estimating the CO_2 and embodied energy emission using the scenarios of recycling/reuse rates
Miatto et al. [16]	Bottom-Up	Country	Roads	The study quantified the road material stock in the United States using the historical data of material flow.
Stephan and Athanassiadis [17]	Bottom-Up	City	Buildings	The study used the bottom-up approach to quantify the material stock of each building in Melbourne. Then it quantified its embodied energy.
Tanikawa et al. [18]	Top-Down	Region	Building and roads	The author found the material stock lost in both the buildings and road due to the earthquake.
Arora et al. [19]	Bottom-Up	City	Buildings	The study estimated the material stock of building in Singapore at the component level. In contrast, previous research focused on the material level.
Guoa et al. [20]	Bottom-Up	City	Buildings	The study used the existing GIS data to estimate the material stock of an Eastern Chinese City.
Chen et al. [21]	Top-Down	Region	Buildings	The study found the floor area, material intensity, material flow, and demolition curve of the material stock. The study showed the results on a 4D GIS map.
Gontia et al. [22]	Top-Down	City	Buildings, roads, and pipes	In this research, the study used an innovative technique to find the material stock. The author found the material stock at the neighborhood level and then clustered them based upon similar

Augiseau, V., & Barles, S. (2017) - Studying construction materials flows and stock: A review. Resources, Conservation and Recycling. doi: http://dx.doi.org/10.1016/j.resconrec.2016.09.002

Rezvan Mohammadiziazi and Melissa M. Bilec 2022 Environ. Res.: Infrastruct. Sustain. 2 032001. https://iopscience.iop.org/article/10.1088/2634-4505/ac6d08/pdf

Spatial Stock Analysis (bottom-up)

Bottom-up approach consists of measuring the current dimensions of the infrastructure (e.g., building, road) and converting them into mass



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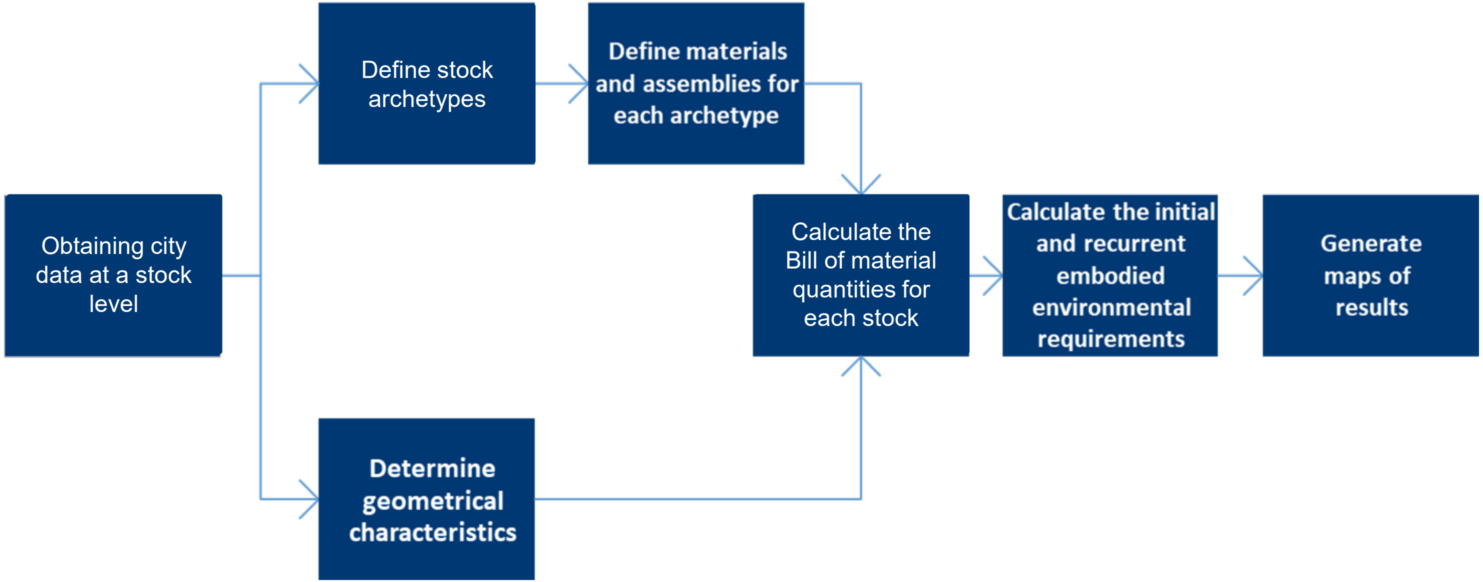
Spatial Stock Analysis (bottom-up)

- General steps



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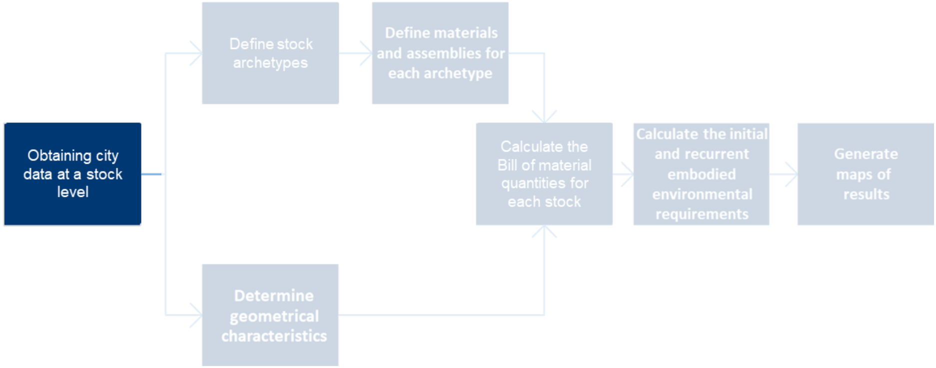
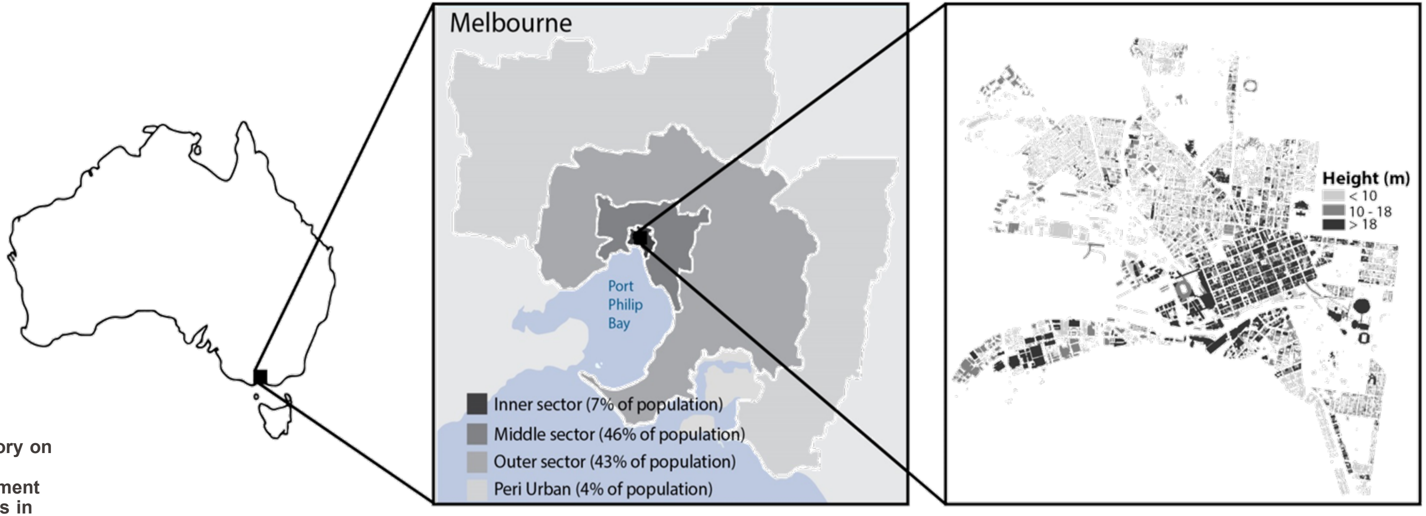
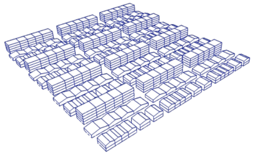
Spatial Stock Analysis (bottom-up)



Stock data

- Year built,
- Classification,
- Height…





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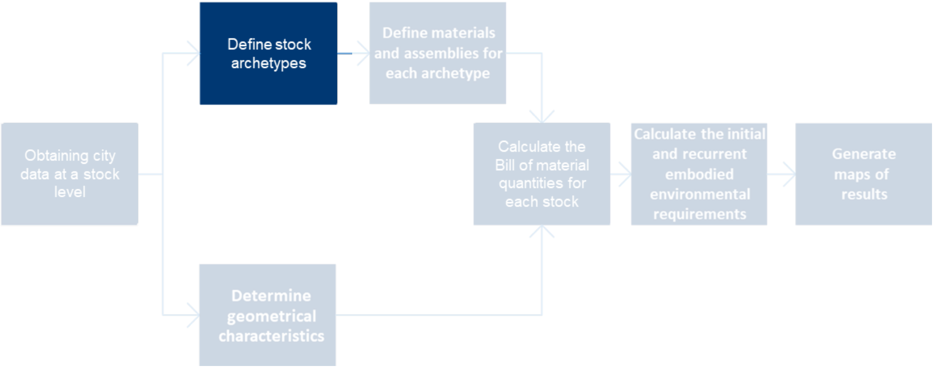
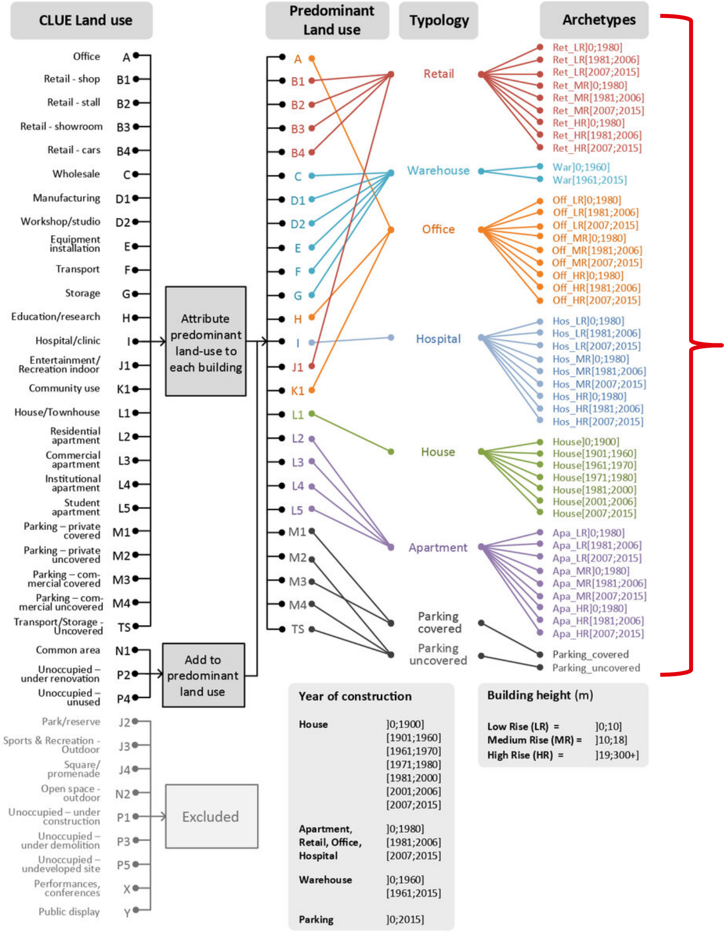
- **Laboratory on Human-Environment Relations in Urban Systems**

Spatial Stock Analysis (bottom-up)



Archetypes

- 30 predominant land-uses
- 8 typologies
- 7 construction time periods
- 3 heights



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- Laboratory on Human-Environment Relations in Urban Systems

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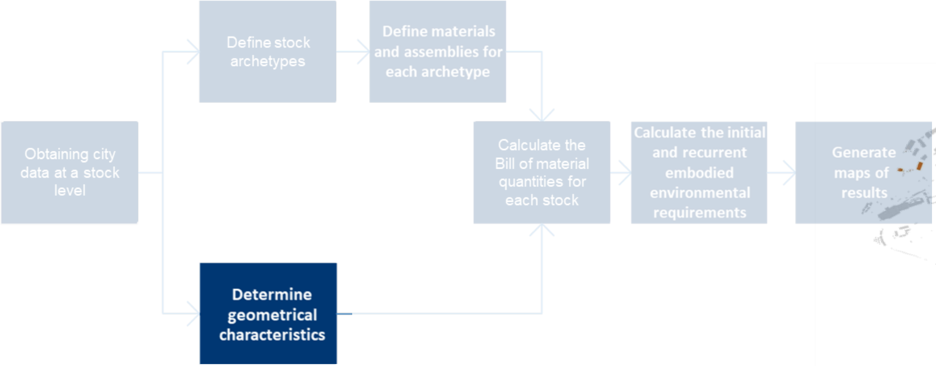
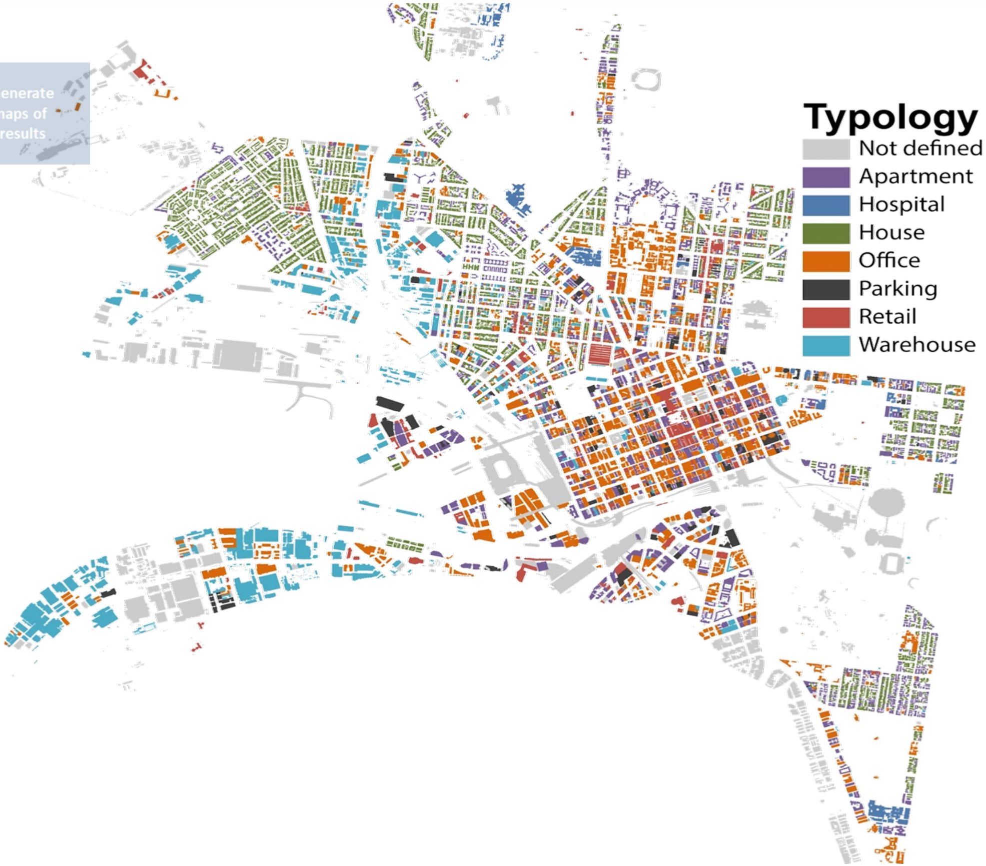
Spatial Stock Analysis (bottom-up)





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Geometries

- Points,
- Lines & lenght,
- Polygons & area,
- Elevations…

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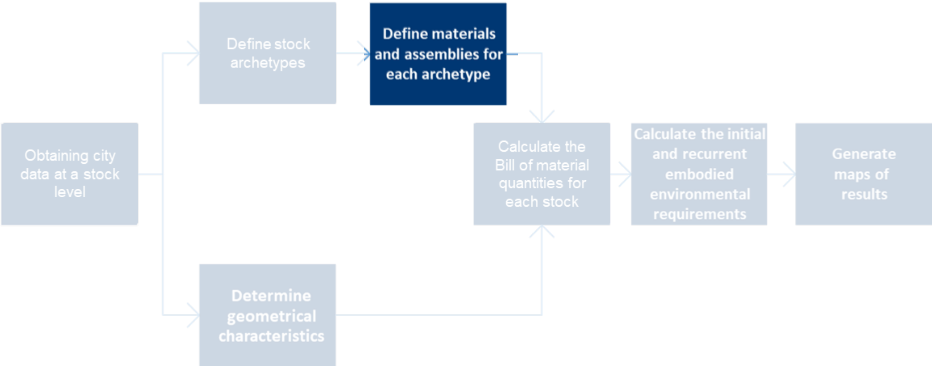
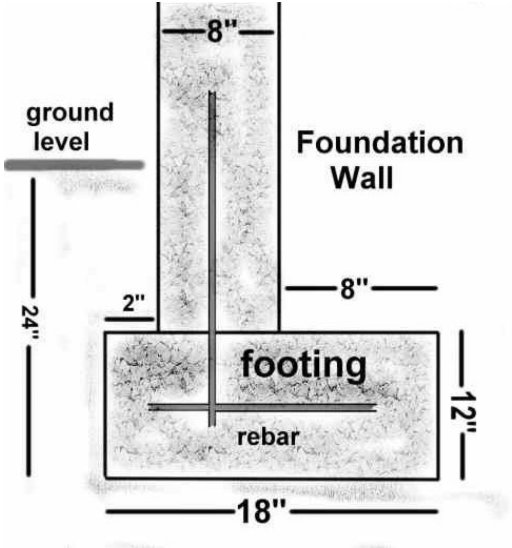
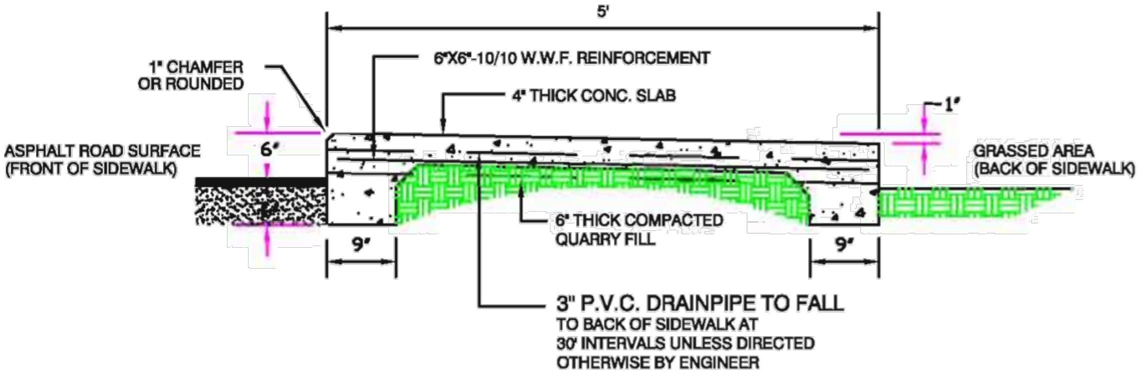
Spatial Stock Analysis (bottom-up)





Assemblies & materials

- Concrete,
- Gravel,
- Steel,
- Bricks…



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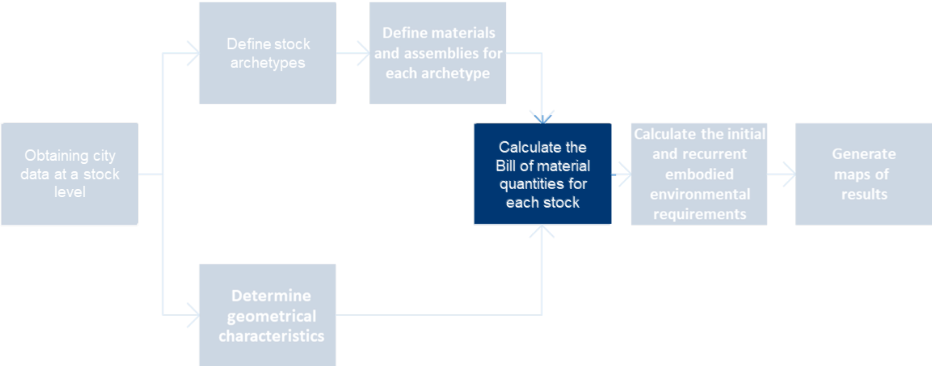
Spatial Stock Analysis (bottom-up)



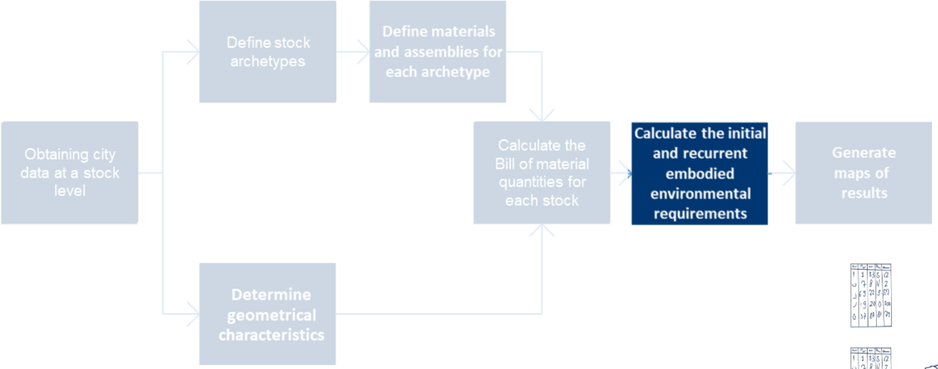
Road archetype 1		Road archetype 2	
Surface road		**Surface Road**	
Asphalt thickness (cm)	4	Asphalt thickness (cm)	4
Asphalt length (cm)	732	Asphalt length (cm)	610
Total Area (m2)	0.29	Total Area (m2)	0.24
Total Volume per 1 ml (m3)	0.29	Total Volume per 1 ml (m3)	0.24
Density of Asphalt (kg/m3)	2,300	Density of Asphalt (kg/m3)	2,300
Total weight per 1 ml (kg)	**667**	**Total weight per 1 ml (kg)**	**552**
Base material		**Base material**	
Base thickness (cm)	20	Base thickness (cm)	20
Base length (cm)	732	Base length (cm)	610
Basel Area (m2)	1.46	Basel Area (m2)	1.22
Base Volume per 1 ml (m3)	1.46	Base Volume per 1 ml (m3)	1.22
Density of Base (kg/m3)	1,680	Density of Base (kg/m3)	1,680
Total weight per 1 ml (kg)	**2,453**	**Total weight per 1 ml (kg)**	**2,050**
Sidewalk		**Sidewalk (Not applicable)**	
Concrete Slab thickness (cm)	10		
Concrete slab length (cm)	183		
Total Area slab (m2)	0.18		
Total slab volume per 1 ml (m3)	0.18		
Concrete kerb thickness (cm)	15		
Concrete kerb height (cm)	23		
Total Area 2 kerbs (m2)	0.07		
Total kerb volume per 1 ml (m3)	0.07		
Density of Concrete (kg/m3)	2,400		
Total weight per 1 ml (kg)	**598**		

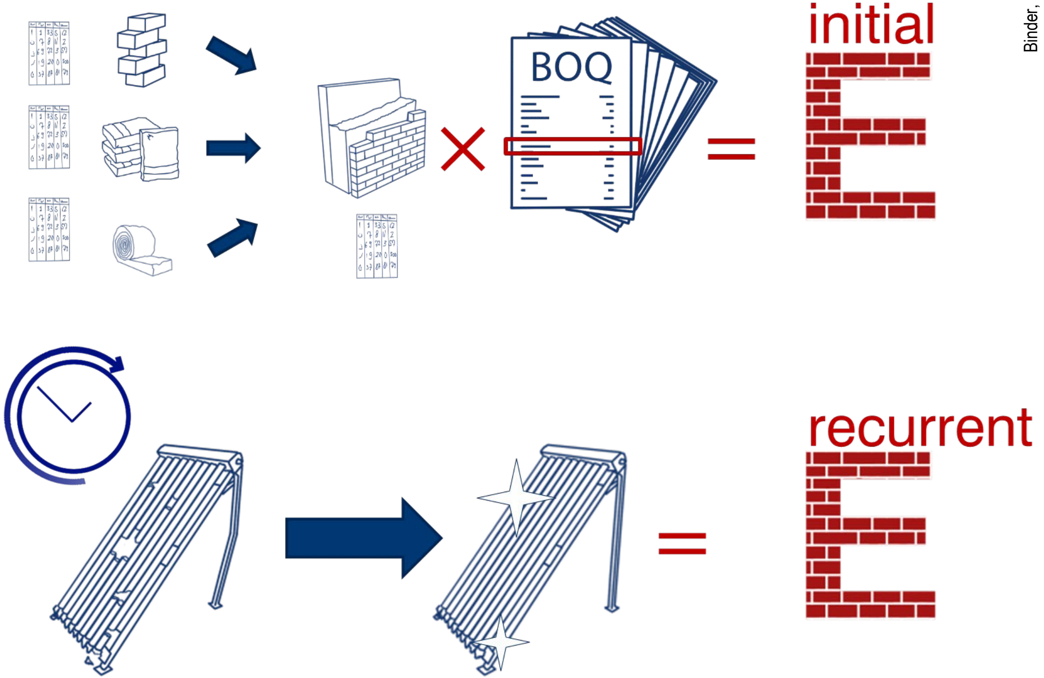
Bill of quantities (BoQ)

- Total concrete,
- Gravel,
- Steel,
- Bricks…

cher, Campfens

Spatial Stock Analysis (bottom-up)





Initial & recurrent requirements

- To build (Initial BoQ)
- To maintain,
- To operate

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Spatial Stock Analysis (bottom-up)

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Table 1
Properties of main construction materials used in the model.

Material	Type	Unit	Weight (kg/unit)	Service life (years)
Aluminium	Reflective foil	m^2	0.31	30
Aluminium	Roof coating	m^2	0.15	5
Aluminium	Interior shutters	m^2	0.34	12
Aluminium	Gutter	m	1.08	20
Aluminium	Frame	m	1.66	40
Aluminium	Door handle	no.	0.229	30
Aluminium	Exterior shutters	m^2	0.34	40
Aluminium	Virgin	t	1000	35
Aluminium	Sill	t	1000	40
Bitumen	Plain	m^3	1020	20
Carpet	Wool	m^2	2.5	10
Carpet	Nylon	m^2	2.5	10
Ceramics	Clay bricks (110 mm)	m^2	158	Not replaced
Ceramics	Tiles	m^2	23.2	50
Ceramics	Terracotta roof tiles (20 mm)	m^2	38.44	50
Ceramics	Fibre cement sheet (4.5 mm)	m^2	6.12	30
Ceramics	Fibre cement sheet (6 mm)	m^2	8.16	30
Ceramics	Toilet suite	no.	60	40
Ceramics	Basin	no.	14	35
Concrete	15 MPa	m^3	2400	Not replaced
Concrete	20 MPa	m^3	2400	Not replaced
Concrete	25 MPa	m^3	2400	Not replaced
Concrete	32 MPa	m^3	2400	Not replaced
Concrete	Aerated block (200 mm)	m^2	181.5	Not replaced
Concrete	Cement (structural)	t	1000	Not replaced
Concrete	Cement (other)	t	1000	25
Concrete	Hollow block (200 mm)	m^2	148.5	Not replaced
Concrete	Roof tile (20 mm)	m^2	38.44	50
Concrete	Mortar	m^3	1600	Not replaced
Concrete	Precast	m^3	2400	Not replaced
Concrete	Hollow block (100 mm)	m^2	74.25	Not replaced
Concrete	Hollow block (180 mm)	m^2	133.65	Not replaced
Concrete	25 MPa (low waste)	m^3	2400	Not replaced

Material	Type	Unit	Weight (kg/unit)	Service life (years)
Ceramics	Basin	no.	14	35
Concrete	15 MPa	m^3	2400	Not replaced
Concrete	20 MPa	m^3	2400	Not replaced
Concrete	25 MPa	m^3	2400	Not replaced
Concrete	32 MPa	m^3	2400	Not replaced
Concrete	Aerated block (200 mm)	m^2	181.5	Not replaced
Concrete	Cement (structural)	t	1000	Not replaced
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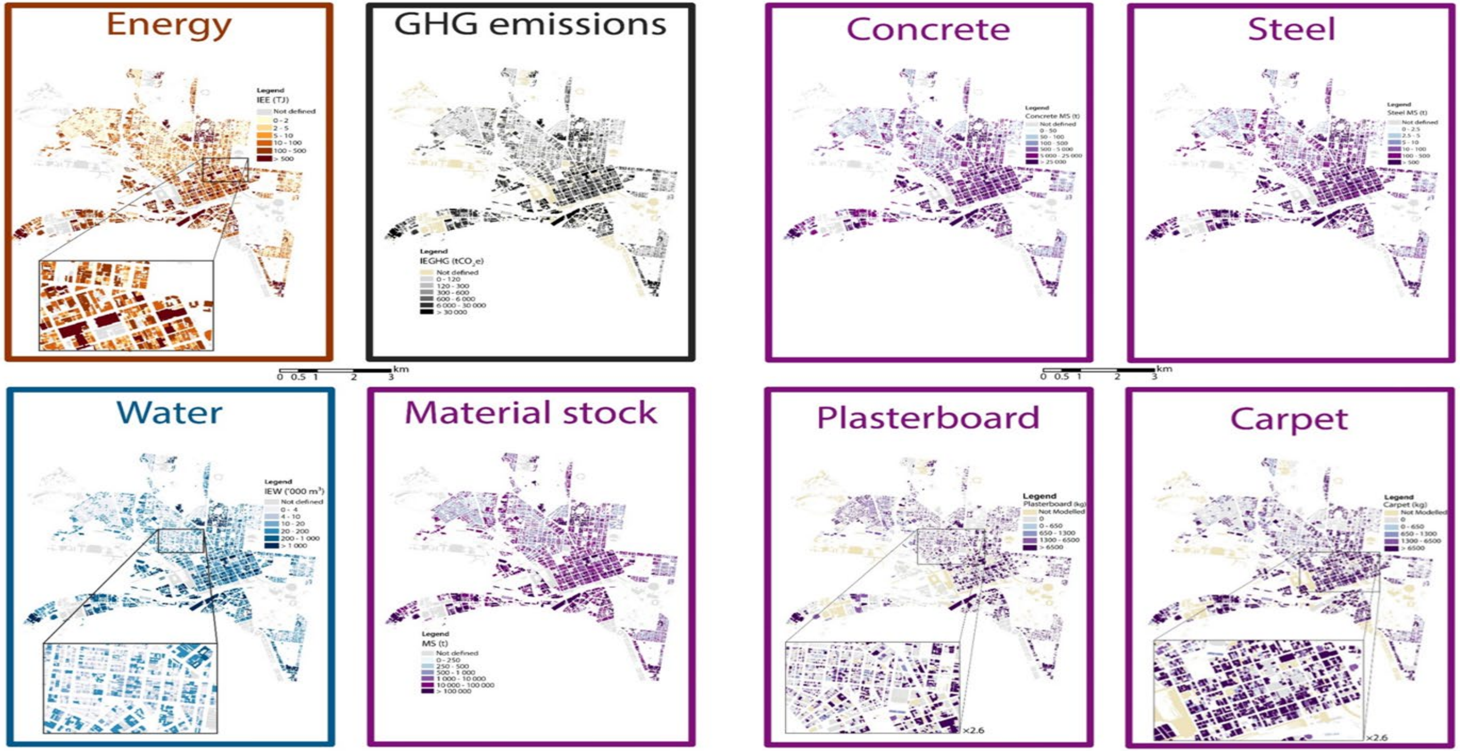
Concrete	Precast	m^3	2400	Not replaced
Concrete	Hollow block (100 mm)	m^2	74.25	Not replaced
Concrete	Hollow block (180 mm)	m^2	133.65	Not replaced
Concrete	25 MPa (low waste)	m^3	2400	Not replaced
Copper	Pipe	m	0.082	30
Copper	Wire	t	1000	30
Glass	Clear float (4 mm) window pane	m^2	10	40
Glass	Toughened glass (6 mm)	m^2	16.2	40
Glass	Toughened glass (12 mm)	m^2	32.4	40
Insulation	Expanded polystyrene	m^3	24	50
Insulation	Fibreglass	m^3	12	30
Insulation	EPS (sandwich panel fill)	m^3	24	50
Paint	oil-based	m^2	0.069	10
Paint	water-based	m^2	0.077	10
Plasterboard	(10 mm)	m^2	12	30
Plasterboard	(13 mm)	m^2	15.6	30
Plastics	General (PVC)	t	1000	30
Plastics	Laminate (1 mm)	m^2	0.8	10
Plastics	Plastic membrane (1 mm)	m^2	0.8	100
Plastics	Polystyrene (structural)	m^3	240	100
Plastics	PVC water pipe (20 mm)	m	0.05	25
Plastics	UPVC pipe (100 mm)	m	1.325	25

Stephan, A. and A. Athanassiadis (2018) – Towards a more circular construction sector: Estimating and spatializing current and future non-structural material replacement flows to maintain urban building stocks. *Resources, Conservation and Recycling*, 129:248-262

Stocks of Melbourne & embodied impacts

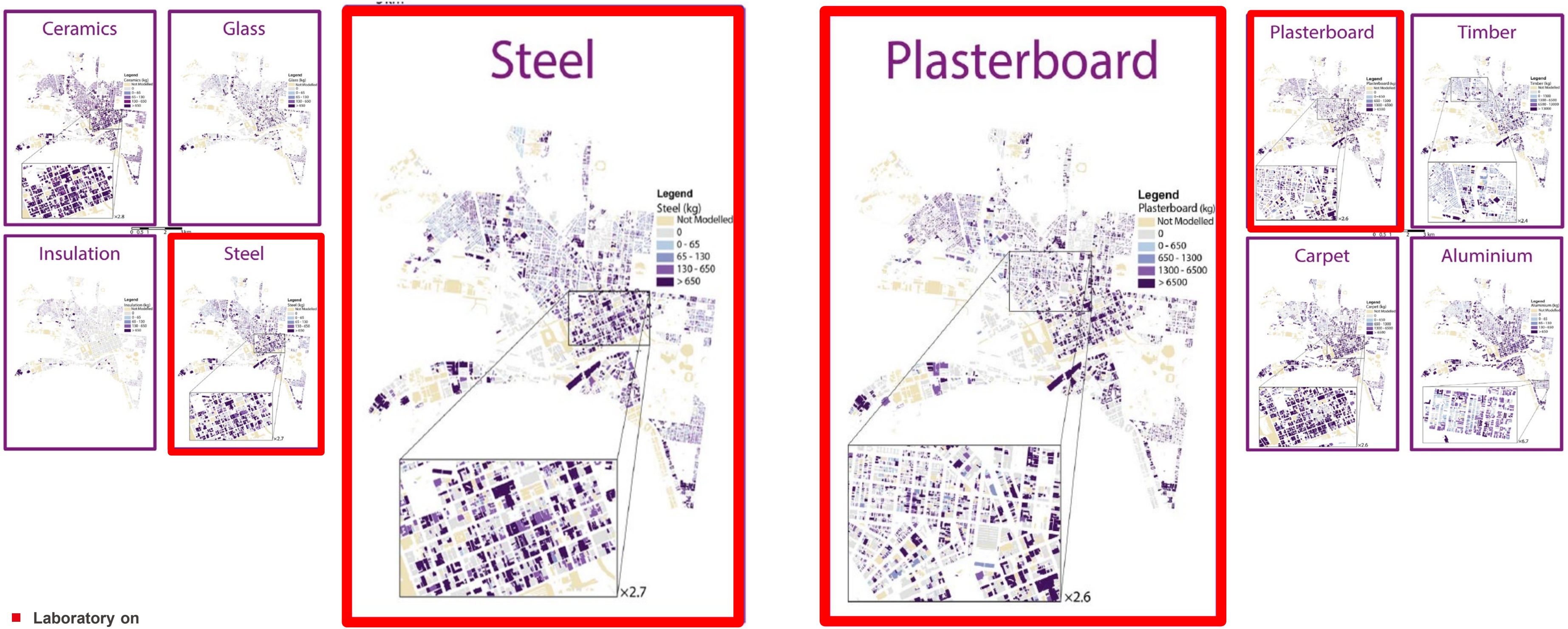
Binder, Félix Martín del Campo, Hecher, Campfens



Stephan, A. and A. Athanassiadis (2018) – Towards a more circular construction sector: Estimating and spatializing current and future non-structural material replacement flows to maintain urban building stocks. *Resources, Conservation and Recycling*, 129:248-262

Locating exiting flows (urban mining)

Estimated accumulated building material replacement flows in the City of Melbourne from 2018 to 2030



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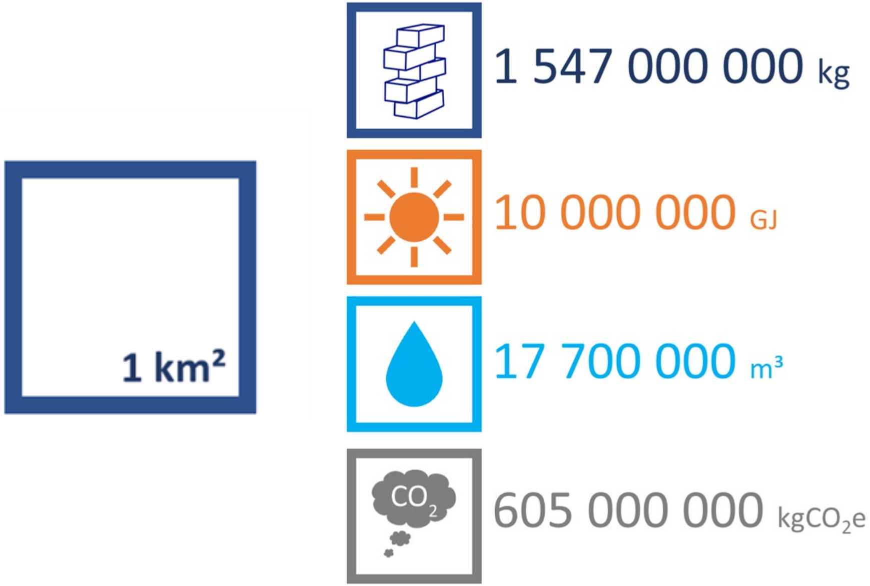
Stephan, A. and A. Athanassiadis (2018) – Towards a more circular construction sector: Estimating and spatializing current and future non-structural material replacement flows to maintain urban building stocks. *Resources, Conservation and Recycling*, 129:248-262

Binder, Félix Martín del Campo, Hecher, Campfens

Some insights

- Rebuilding the city of Melbourne would require…



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Material stock of Lausanne

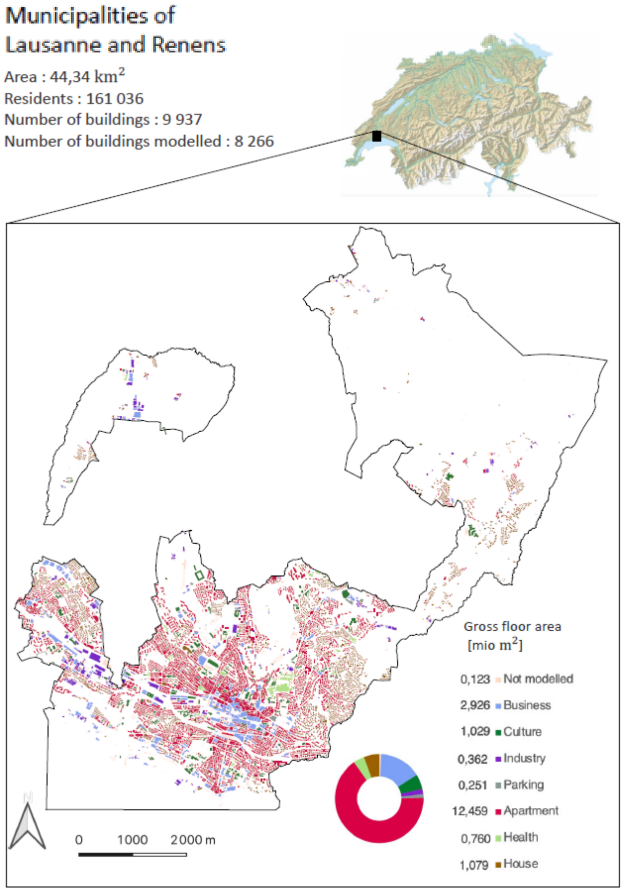
Binder, Félix Martín del Campo, Hecher, Campfens

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SUPERVISOR: ARISTIDE ATHANASSIADIS

Material and energy flow analysis for building construction in Lausanne

Estelle Droz and Lara Bernath



3: Location and map of Lausanne and Renens municipalities with building classified according to typology

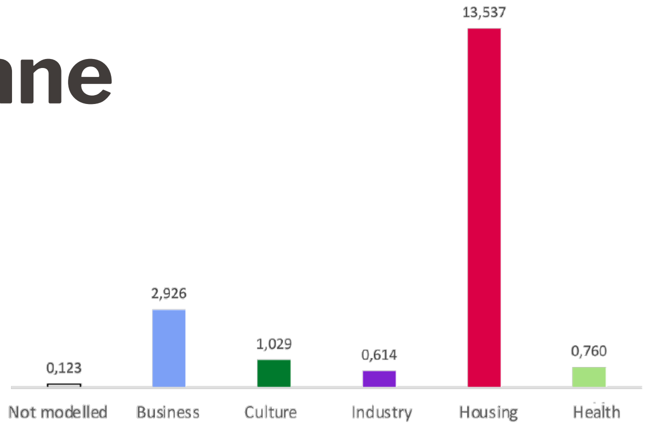


Figure 11: Gross floor area [mio m²] for each typology

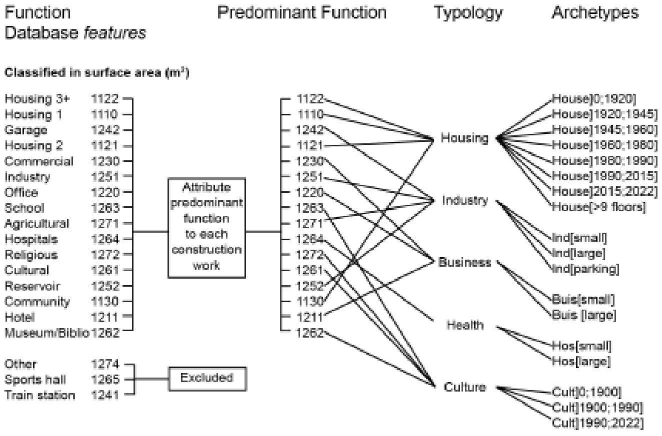


Figure 14: Data processing used to convert the database into building archetypes

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Material stock of Lausanne

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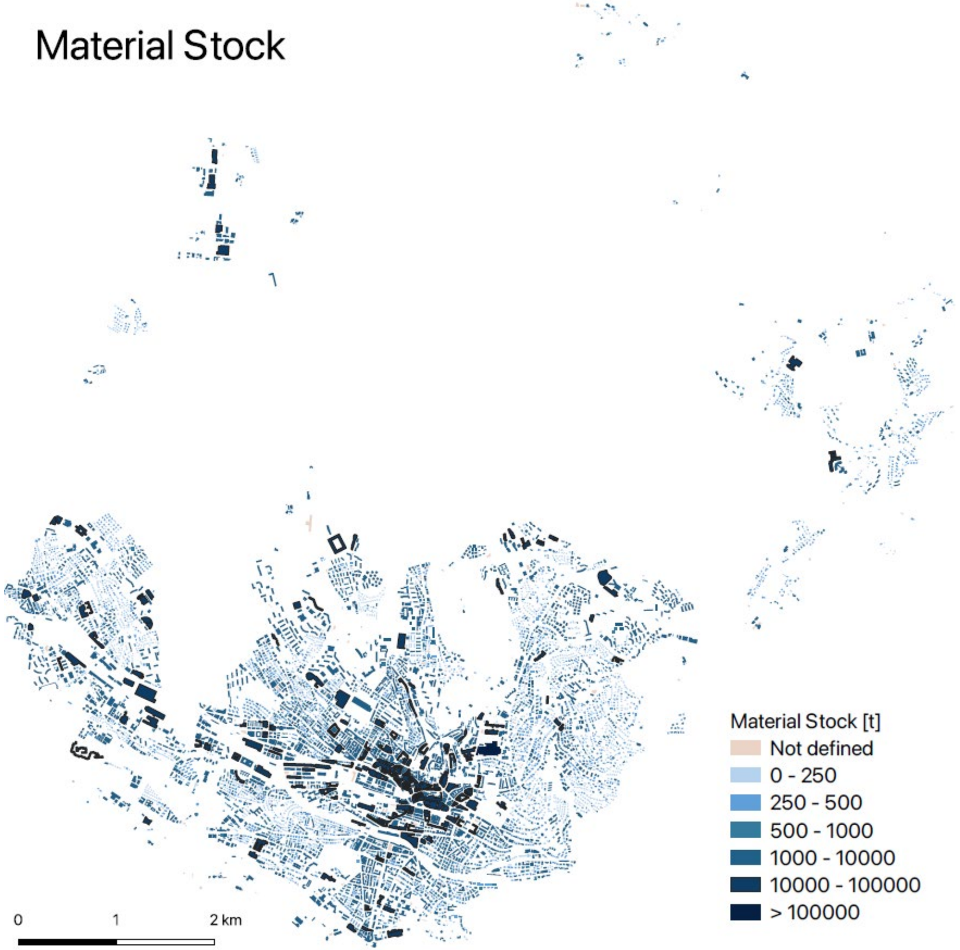
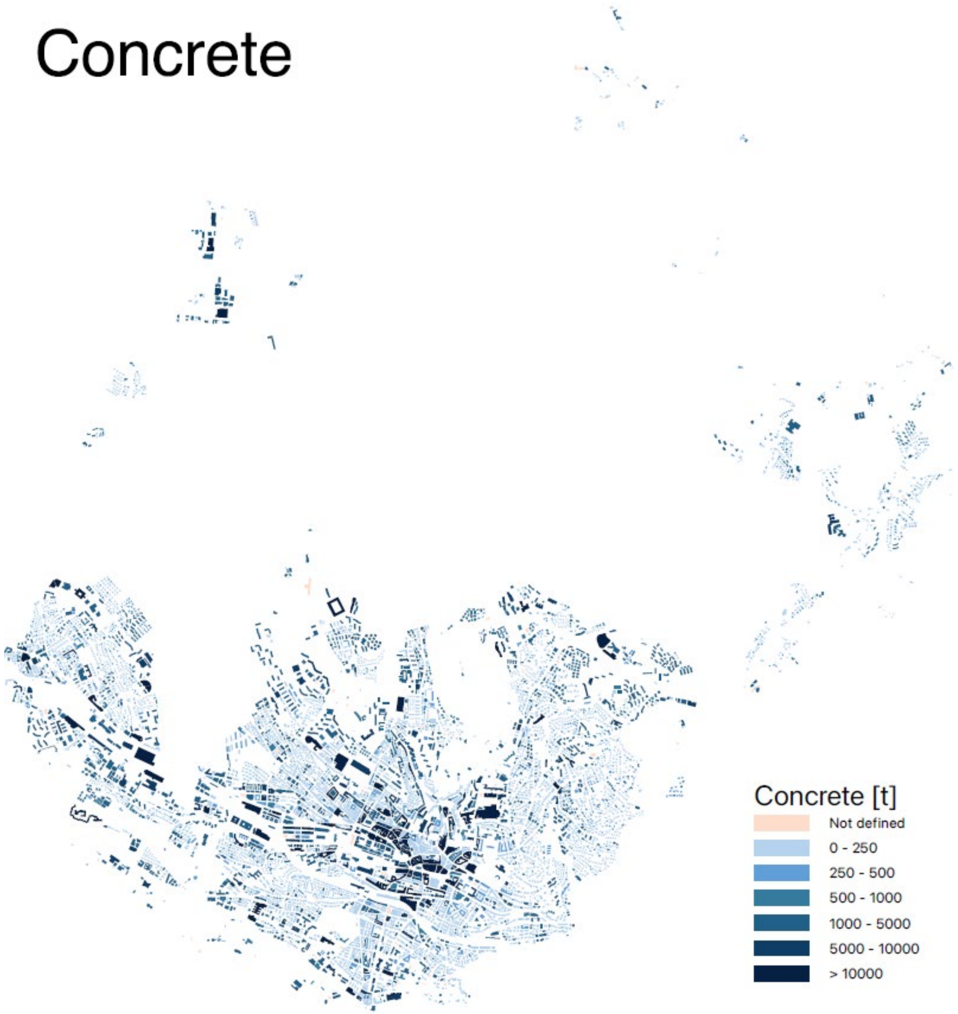


EPFL

Concrete



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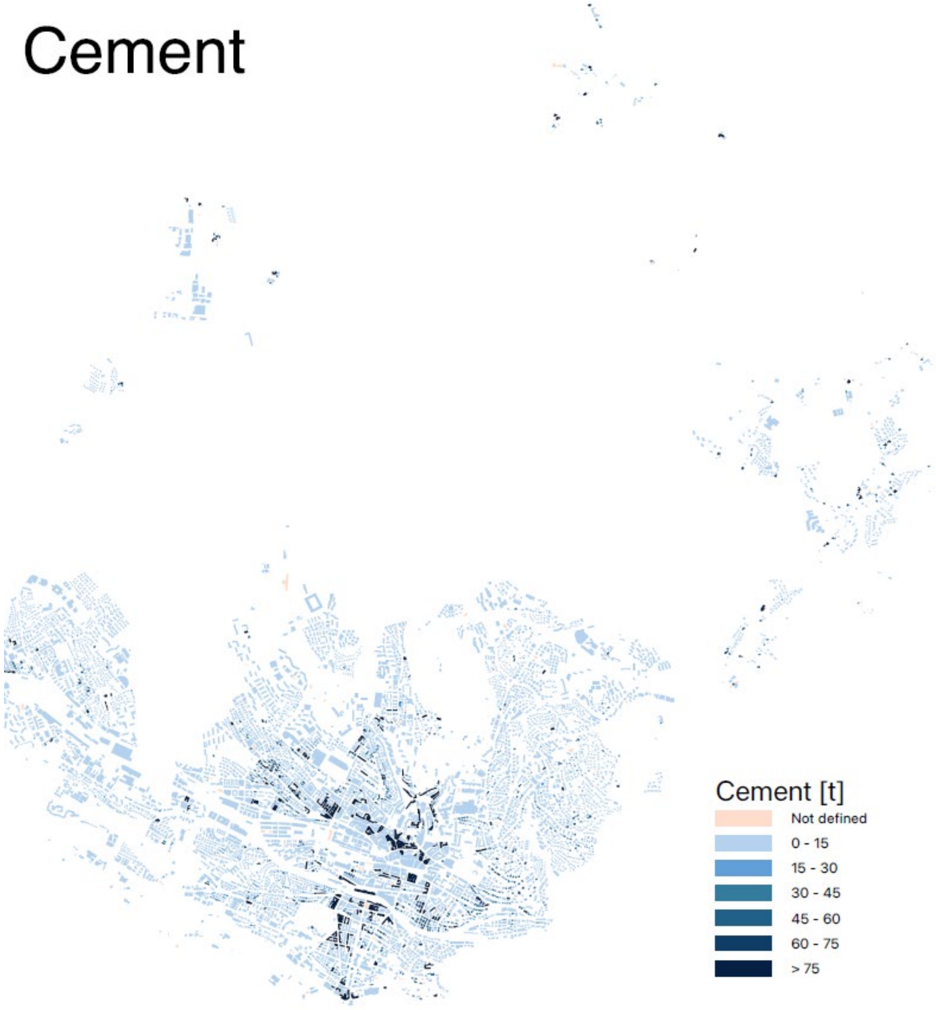
Cement



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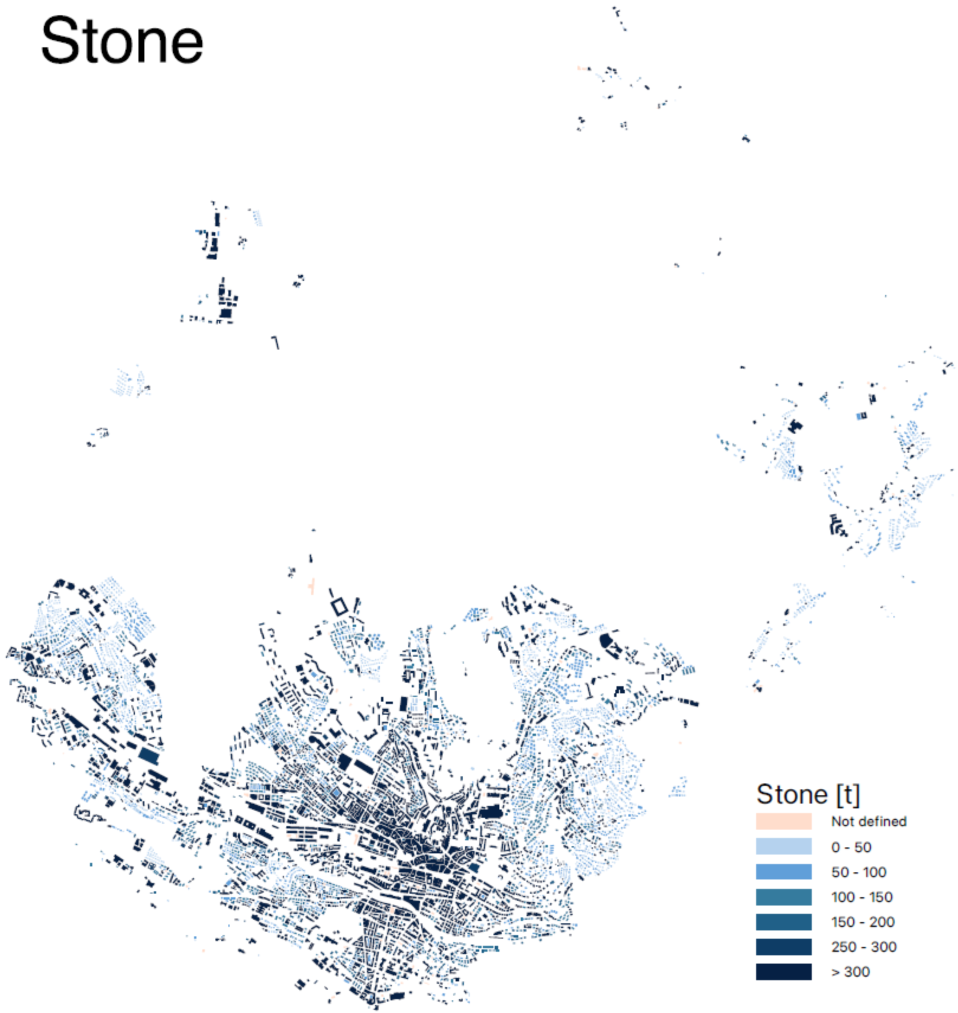
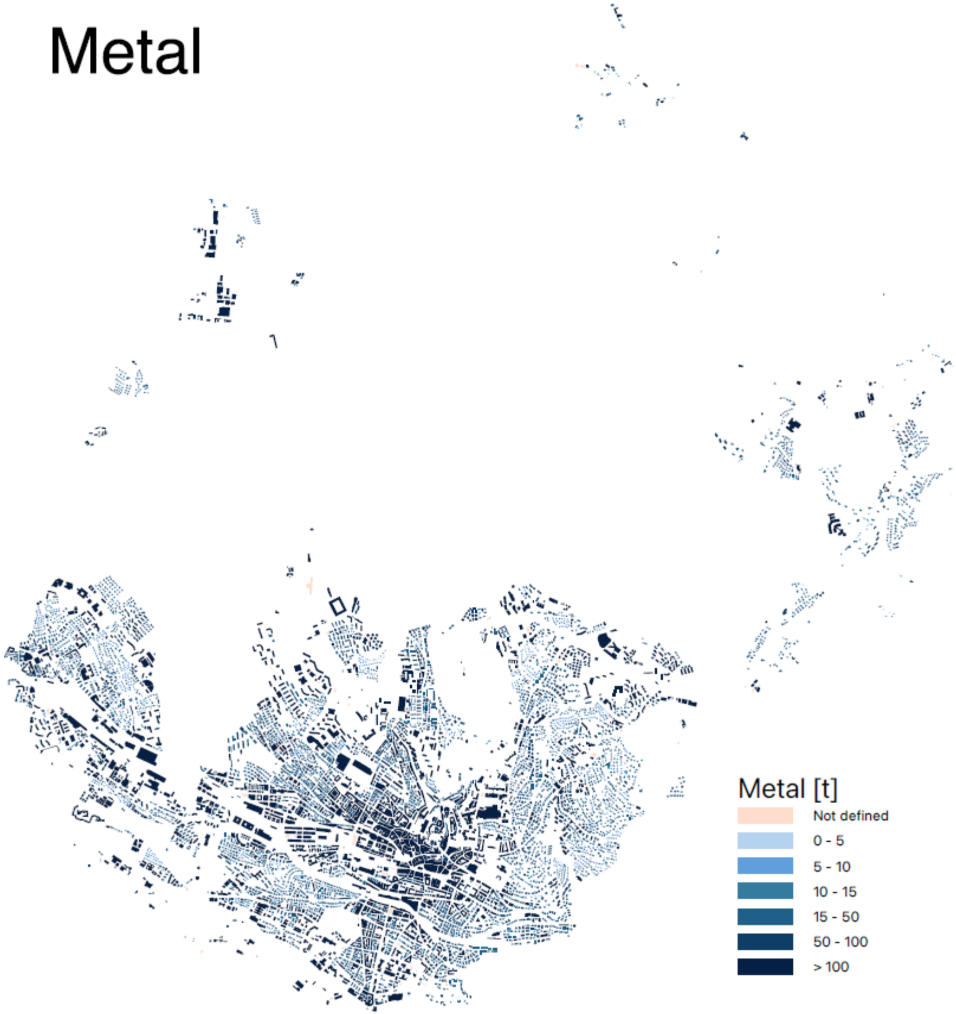
Stone



Metal



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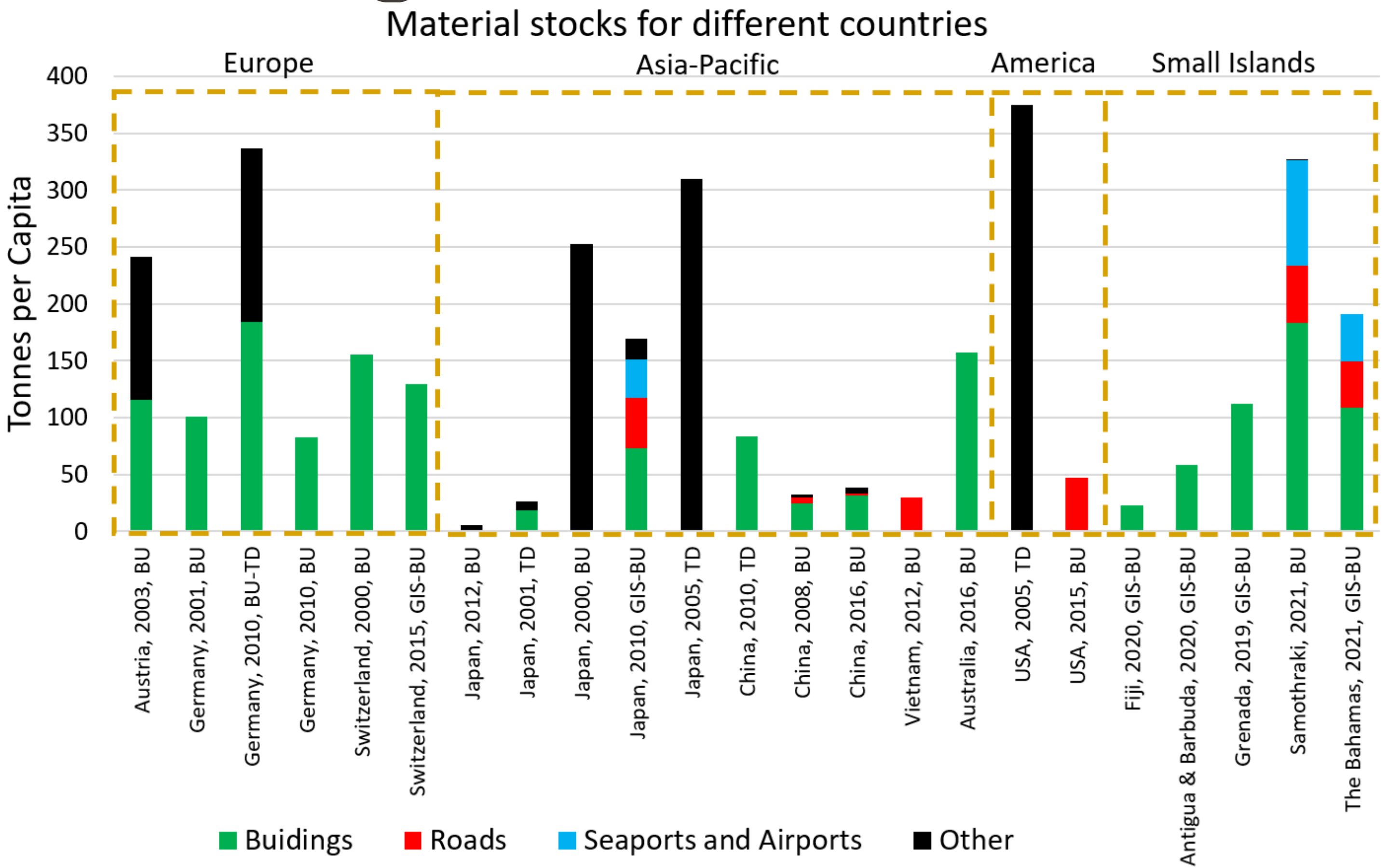
Some insights



Binder, Félix Martín del Campo, Hecher, Campfens

Martin del Campo et al. (2023) – The Bahamas at risk: Material stocks, sea-level rise, and the implications for development. *Journal of Industrial Ecology*, 27(4), 1165-1183. https://doi.org/10.1111/jiec.13402

Some insights

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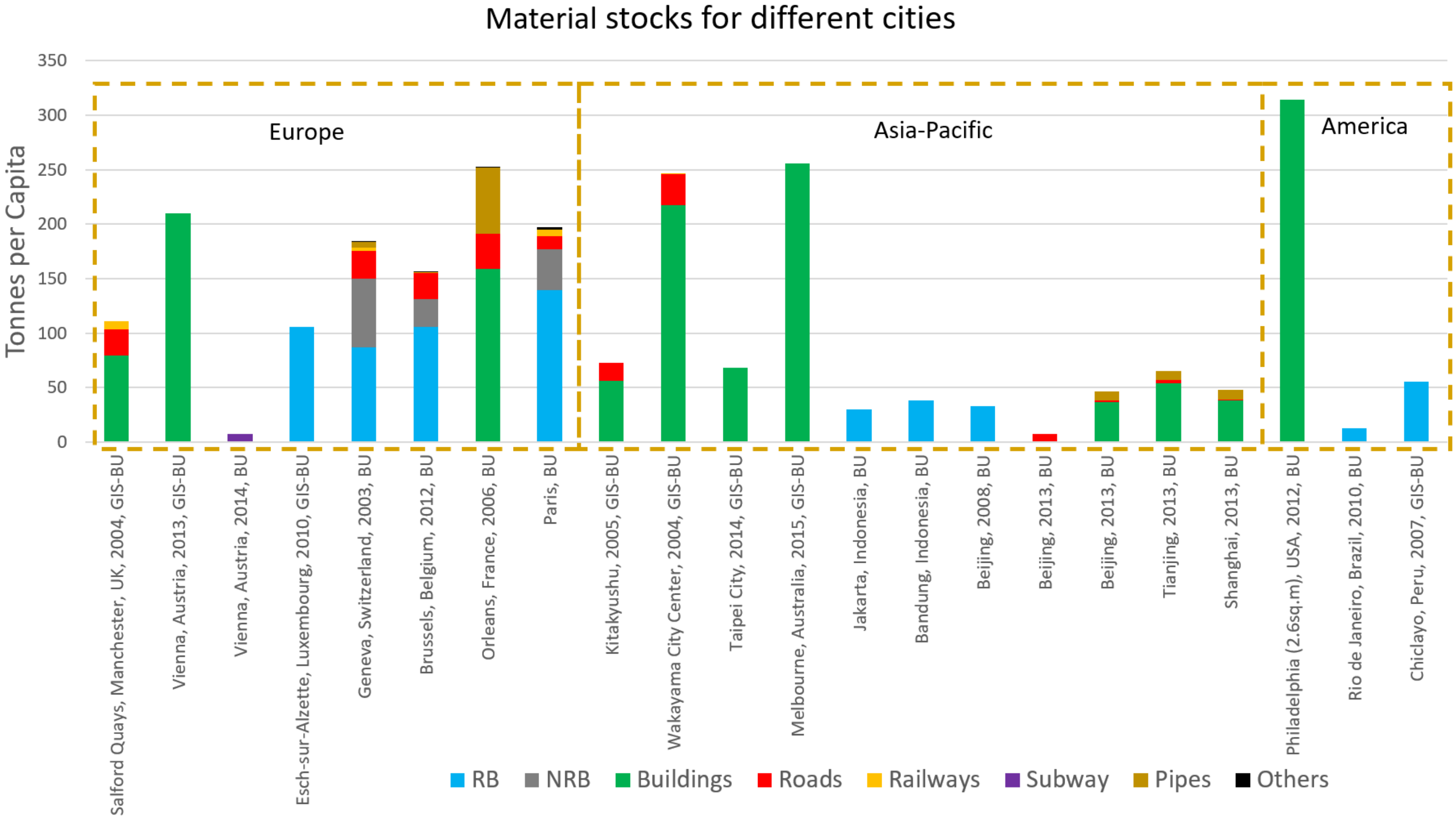

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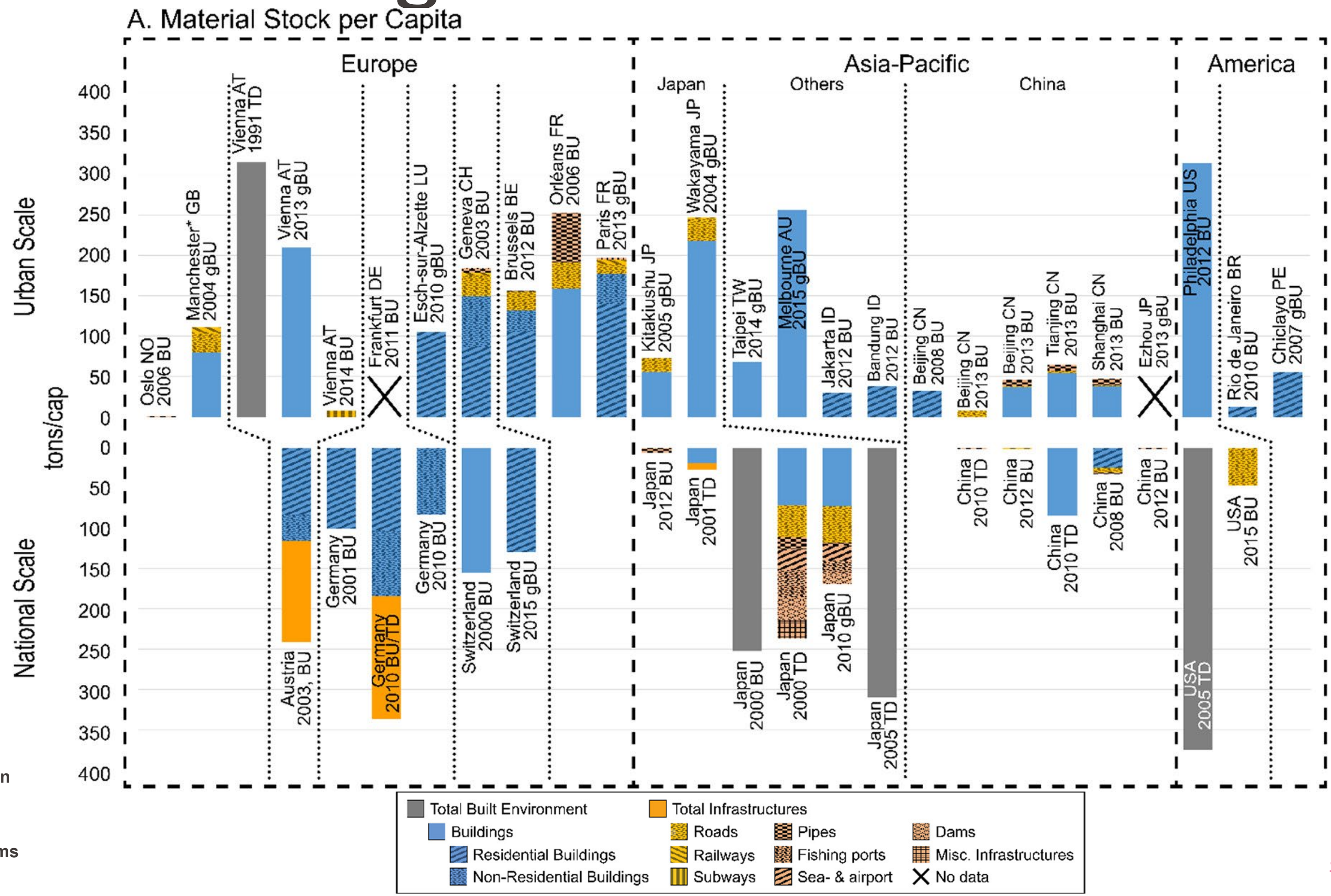
Adapted from Lanau et al. (2019) – Taking Stock of Built Environment Stock Studies: Progress and Prospects. *Environ. Sci. Technol.* 2019, 53, 15, 8499–8515. https://doi.org/10.1021/acs.est.8b06652

Some insights



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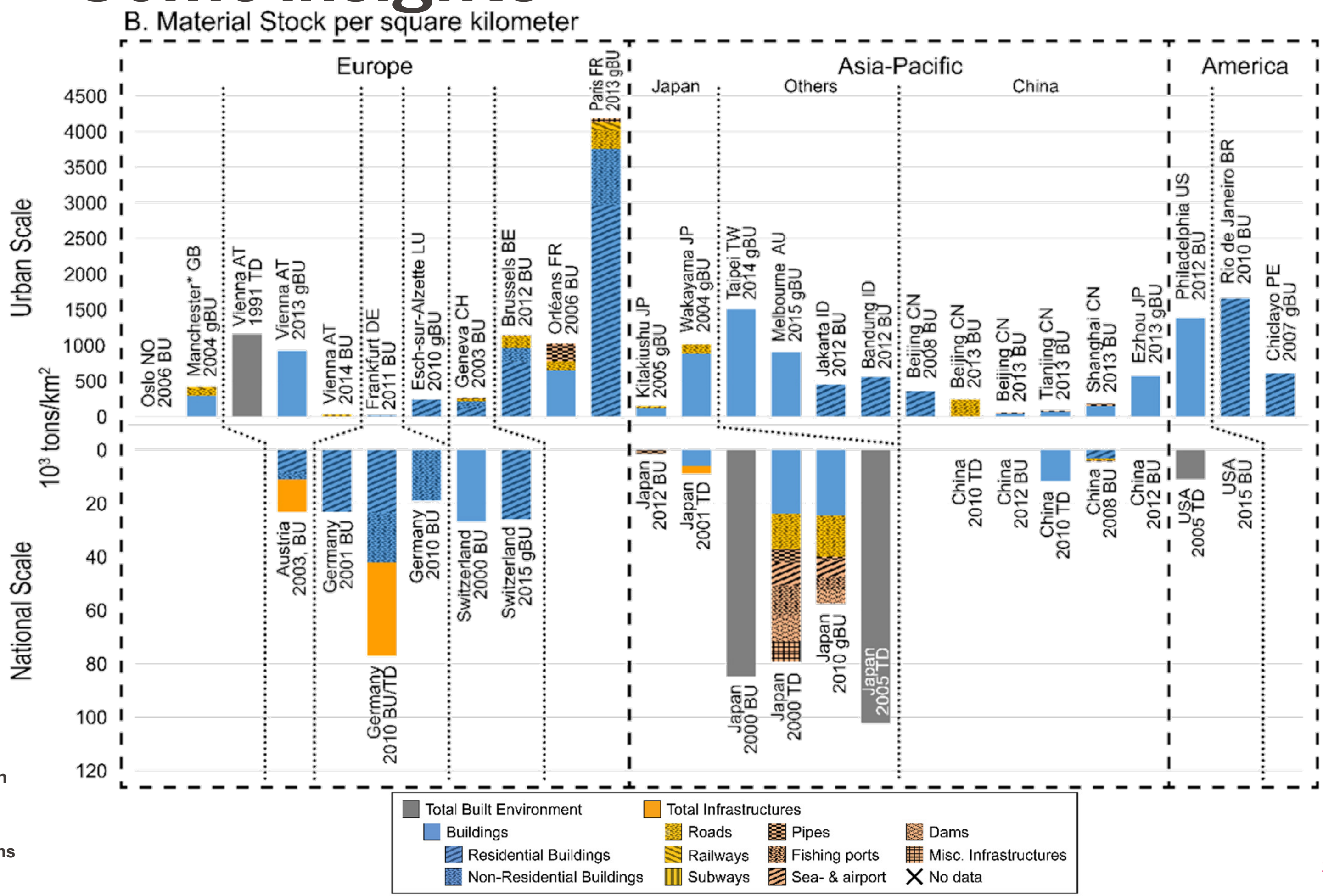
Source: Lanau et al. (2019)

Some insights



Binder, Félix Martín del Campo, Hecher, Campfens

Source: Lanau et al. (2019)

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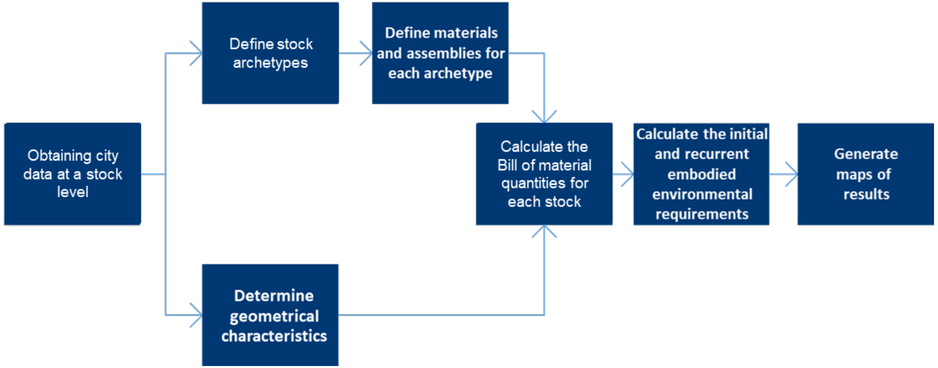
Where to find data?

Binder, Félix Martín del Campo, Hecher, Campfens



- **For building geometry (footprints):** national/local building cadaster, OpenStreetMap, etc.
- **For defining building archetypes:** architects, urban historians, urban development books, previous classifications, etc.
- **For material composition of buildings:** same as above + architectural plans (either archives or digital), BIM models, demolition quantities, visual identification, etc.
- **For embodied environmental requirements of materials:** LCA, EPiC database, Environmental Product Declaration database, etc.

EPFL

Where to find data?

*My data is in **length of roads** (km) that exist in the city. How do I convert it in **mass**?*

A: By applying Material Intensities (per unit of measure)

Here are different type of roads in the US and their mass per km
https://doi.org/10.1016/j.resconrec.2017.08.024

Type of road	Rammed earth (t/km)	Gravel (t/km)	Sand (t/km)	Cement (t/km)	Bitumen (t/km)	Total (t/km)
Unsurfaced pavement	32	0	0	0	0	32
Unpaved pavement	0	231	0	0	0	231
Low type pavement	0	444	0	0	4	447
Intermediate pavement	0	1722	0	0	11	1732
High flexible pavement	0	4607	0	0	27	4634
High composite pavement	0	3260	1728	522	19	5528
High rigid pavement	0	2862	1958	592	0	5412

Where to find data?

My data is in ***number of buildings*** *that exist in the city. How do I convert it in* ***mass****?*
A: By applying Material Intensities (per unit of measure)

For the conversion, you can use tables such as these, where there is a measure of t/m².

For Melbourne, here are some other figures from this article:

https://www.sciencedirect.com/science/article/pii/S0360132316304747

	Apartment	Hospital	House	Office	Parking	Retail	Warehouse
	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²
Concrete	1 526,4	1 723,1	360,2	1 545,0	1 332,2	1 785,1	383,9
Steel	52,8	49,2	16,3	45,0	33,6	48,6	44,9
Timber	16,0	17,0	79,8	5,6	0,3	12,5	5,6
Glass	16,0	17,0	79,8	5,6	0,3	12,5	5,6
Carpet	1,4	0,0	0,3	2,1	0,0	0,0	0,2
Insulation	0,2	0,1	1,3	0,2	0,0	0,1	0,2
Ceramics	114,4	59,8	195,6	35,8	2,8	95,3	78,0
Plastics	1,0	1,9	1,3	0,4	0,2	0,6	0,9
Aluminium	6,4	21,0	32,1	8,5	0,4	11,7	0,6
Others	0,6	0,6	0,4	0,8	0,1	0,7	0,3
TOTAL	**1 526,4**	**1 723,1**	**360,2**	**1 545,0**	**1 332,2**	**1 785,1**	**383,9**

Binder, Félix Martín del Campo, Hecher, Campfens

Where to find data?

*My data is in **number of buildings** that exist in the city. How do I convert it in **mass**?*

For the Dutch building stock:

https://onlinelibrary.wiley.com/doi/10.1111/jiec.13143

	Concrete	Clay brick	B-wood	Roof gravel	Aluminium	Steel	Glass	Ceramic	Gypsum	Bitumen	Plastic	Cast iron	Glass wool	Copper
Residential - Row House	353,2	124,1	69,27	0,00	6,05	14,8	0,00	21,29	10,26	0,00	7,65	4,90	0,00	0,00
Utility - Commercial	634,4	148,5	50,2	0,0	8,8	56,5	3,3	4,4	28,4	7,1	27,8	1,5	0,4	0,1
Residential - High rise	699,5	245,8	61,1	0,0	6,1	26,9	0,0	5,2	6,7	0,0	5,1	4,9	0,0	0,0
Utility - Other	625,6	317,1	37,0	98,9	8,8	56,2	10,5	23,0	22,1	7,1	24,0	1,5	0,4	0,1
Utility - Offices	676,6	363,7	24,3	51,7	8,8	58,0	15,3	4,4	9,0	7,1	23,1	1,5	6,9	0,1
Residential - Apartment	883,1	310,3	49,1	0,0	6,1	33,3	0,0	5,2	11,0	0,0	0,0	4,9	0,0	0,0
Residential - Single house	974,1	635,3	246,7	0,0	6,1	36,5	0,0	5,2	0,0	0,0	0,0	4,9	0,0	0,0

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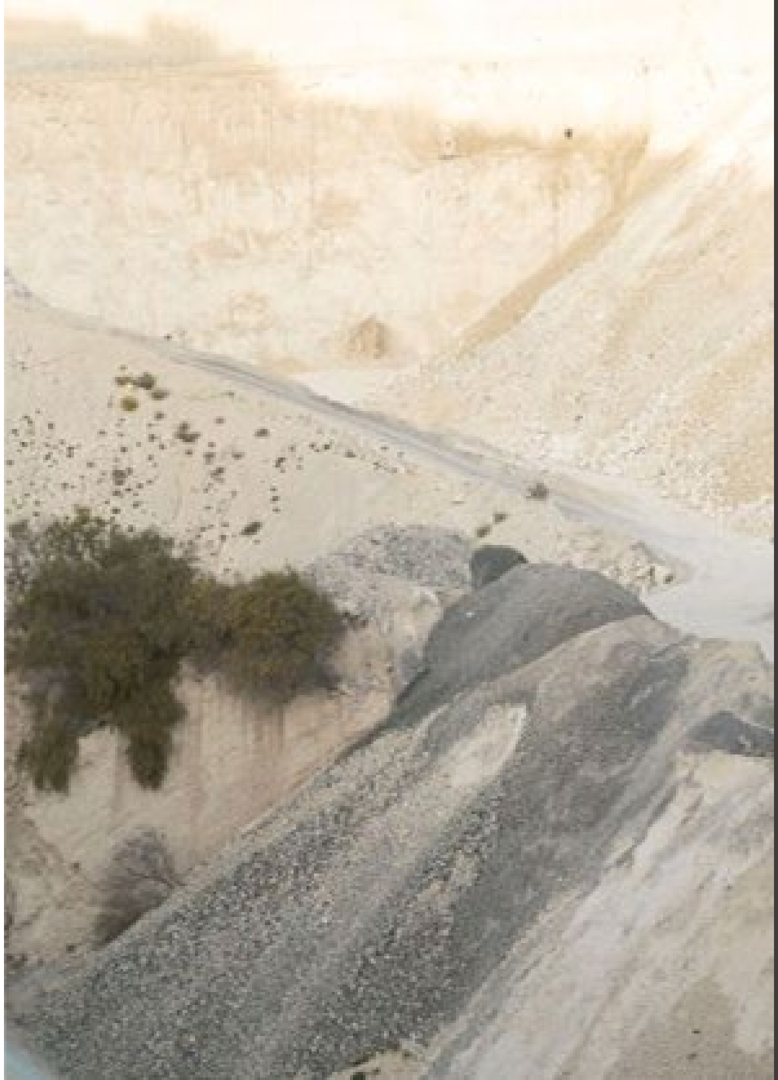

Thank you for your attention!