



ENV 501 / GR A3 30

Material Flow Analysis and resource management

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- EW-MFA in Switzerland: key indicators
- EW-MFA Cross-country comparisons
- EW-MFA and adaptability to other boundaries
- Example of Swiss Cantons
- Validation of methodology and insights

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 11

Introduction to the course and general concepts

All

Exercise

Project

W2 - Sep 18

EW – MFA and EW – MFA in the Swiss context

External Guest –
Florian Kohler

Exercise

Project

W3 – Sep 25

Examples of EW – MFA. Scaling EW-MFA to Cantons

FMC

Exercise

Project

W4 - Oct 02

Urban Metabolism and Circular Economy

FMC

Exercise

Project

W5 - Oct 09

MFA method and the Stock-Flows-Service Nexus

CRB

Exercise

Project

W6 - Oct 16

Dynamic MFA

CRB

Exercise

Project

Oct 23

Autumn break

Block II:
MFA
regional /
urban

W7 - Oct 30

Applications of MFA – case study

External Guest –
Guillaume Massard

Exercise

Project

W8 - Nov 06

Input-Output Analysis and Material Flow Cost Accounting

External Guest –
Vincent Moreau

Exercise

Project

W9 - Nov 13

Spatial MFA

FMC

Exercise

Project

W10 - Nov 20

Combined approaches: MFA + LCA; MFA + sociodemographics.

AS & FMC

Exercise

Project

Block III:
Social
sciences
and
public
policy

W11 - Nov 27

Combined approaches: MFA + surveys; Quasi-dynamic MFA

GF & FMC

Exercise

Project

W12 - Dec 04

Social metabolism

CRB

Past exam

Project

W13 - Dec 11

Agent-based model

CRB, FMC, MAH,
SLC

Project

Project

W14 - Dec 18

Group Project Presentation

All

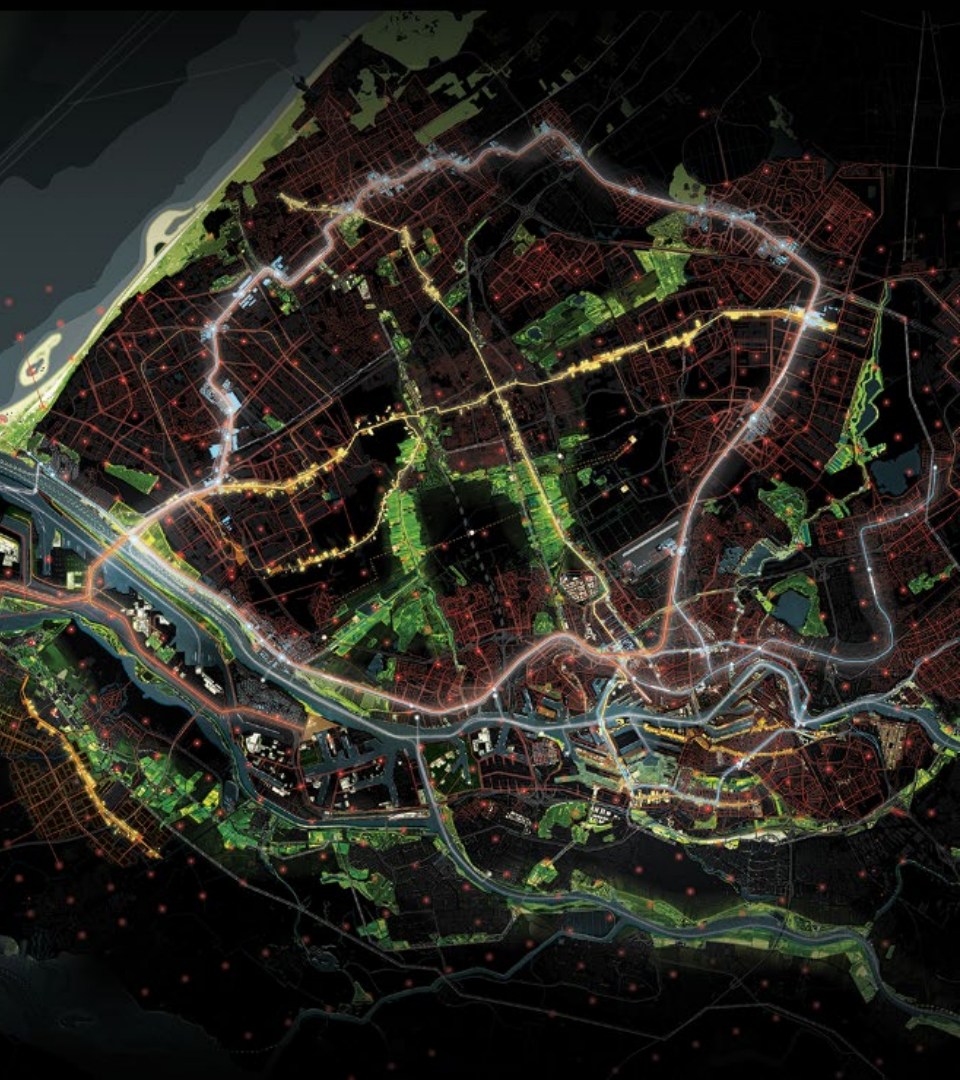
Project

Project



Content of lecture

- Urban Metabolism vs. Urban MFA
- System boundaries of cities
- Accounting approaches
- Where to find data
- Urban metabolism examples
- Circular economy and MFA
- Circular economy policies and insights

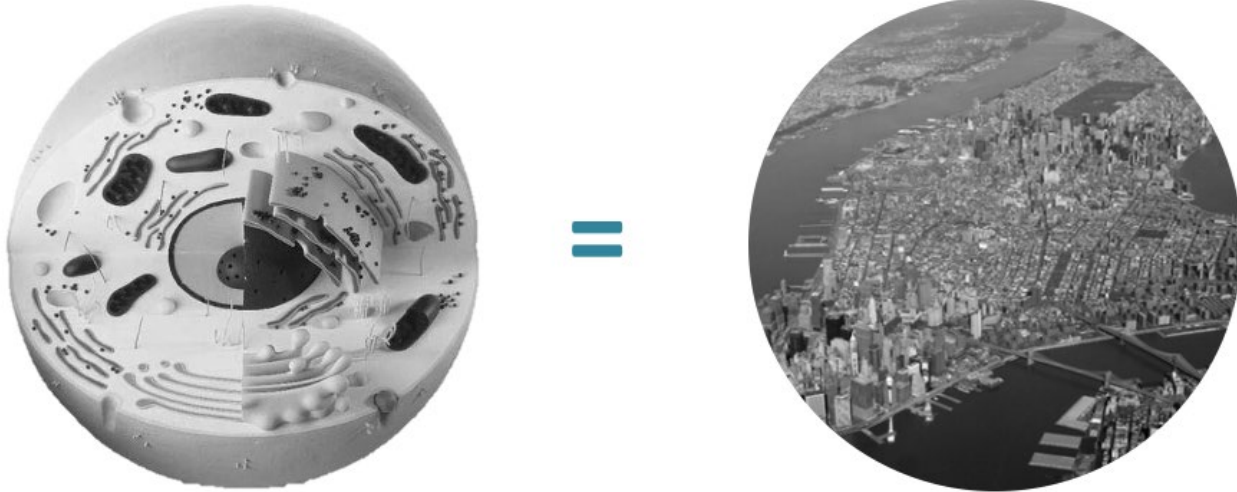


Urban Metabolism vs Urban MFA

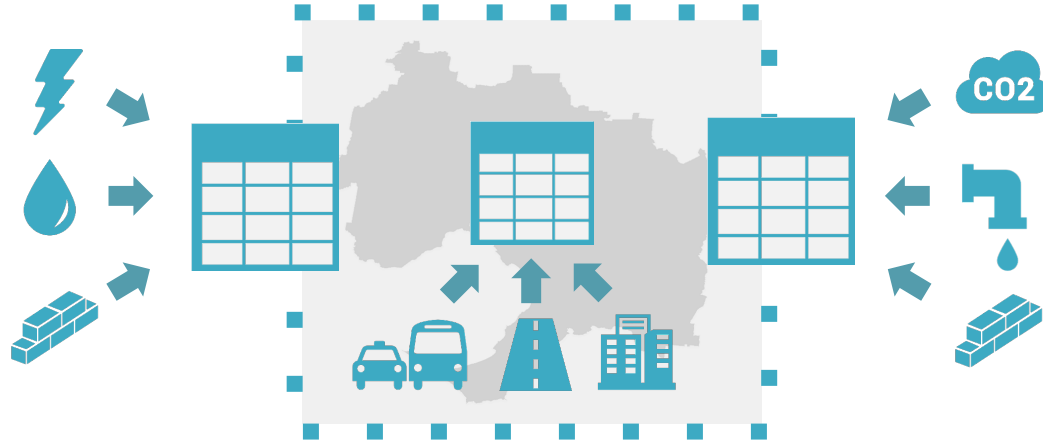
Definitions, relevance

Urban Metabolism \neq Urban MFA

What is Urban Metabolism?

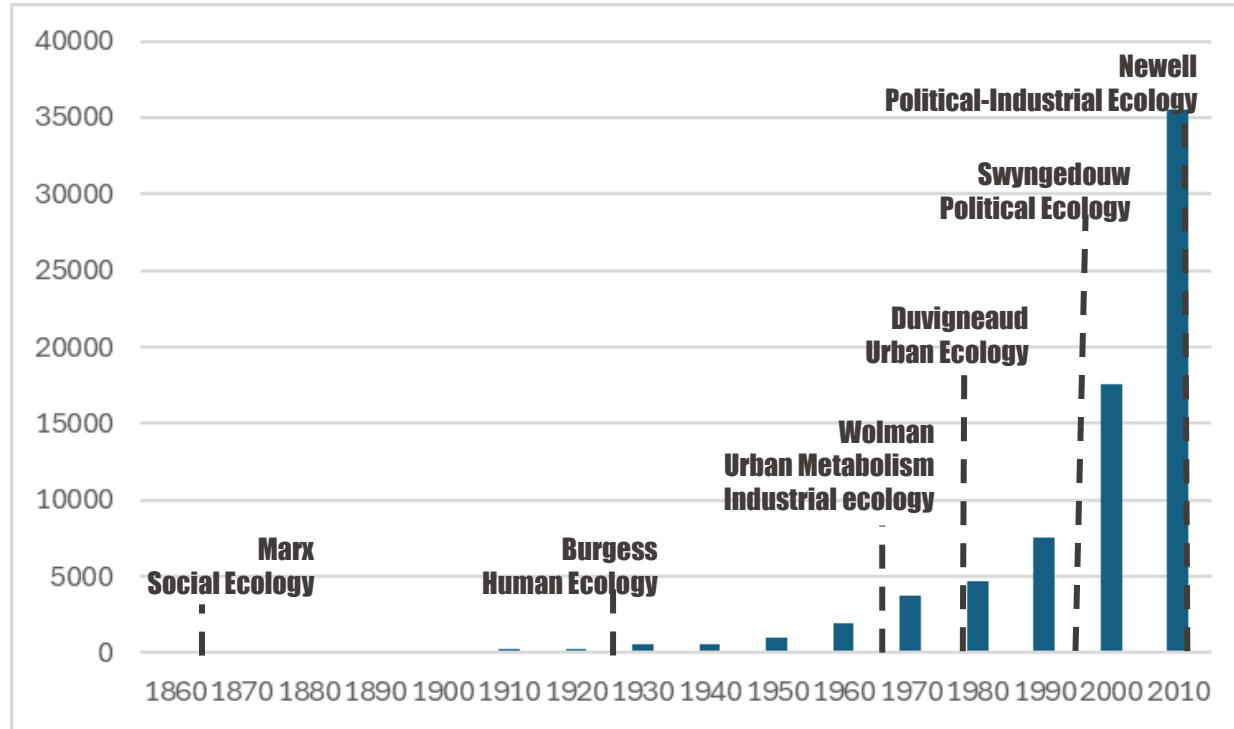


What is Urban Metabolism?



An (unconsolidated) field studying urban flow/stocks and actors from a systemic perspective

What is Urban Metabolism?



Use of « urban metabolism » over time

Source : Constellate

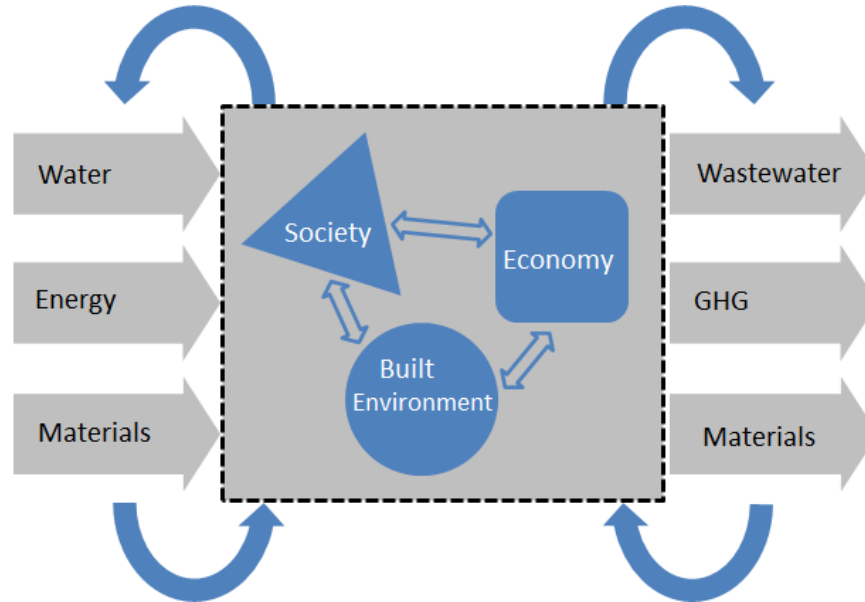
Definitions: Urban Metabolism

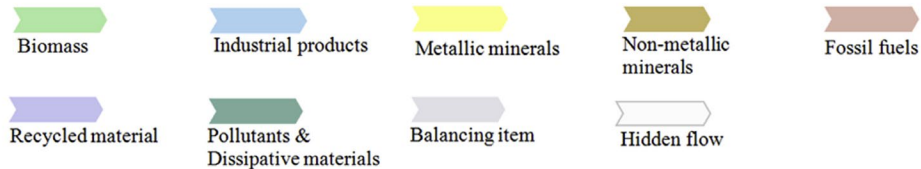
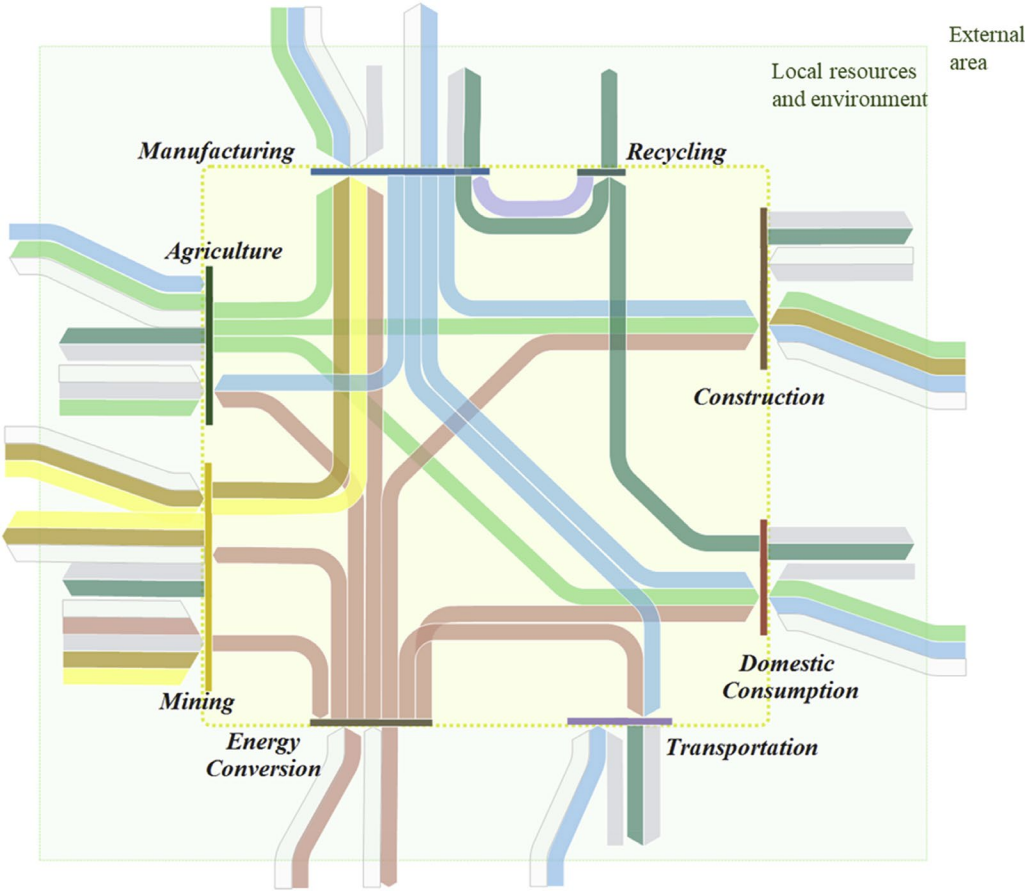
- ... a model to facilitate the description and analysis of the flows of the materials and energy within cities (material flow analysis of a city).
- **Industrial ecology:** UM as the total technical and socio-economic processes within a city. Mass-balance accounting (MFA) of the related flows of water, materials and energy, input-output; city-hinterland.
- **Marxist ecology / Urban political ecology (Human geography):** UM to characterize alienation of nature from society under capitalist regimes and urbanization, social power and the shaping of urban space. Qualitative analyses of the socioeconomic relations shaping the infrastructure, space and metabolism; dialectic nature-society.
- **Urban ecology:** UM as a complex system, the urban system as an ecosystem, structure and function, transformative processes emerging from system properties. Complex system models; nature-society hybridity.

Source : [Newell & Cousins 2016](#); [Broto et al. 2012](#)

Why is Urban Metabolism relevant?

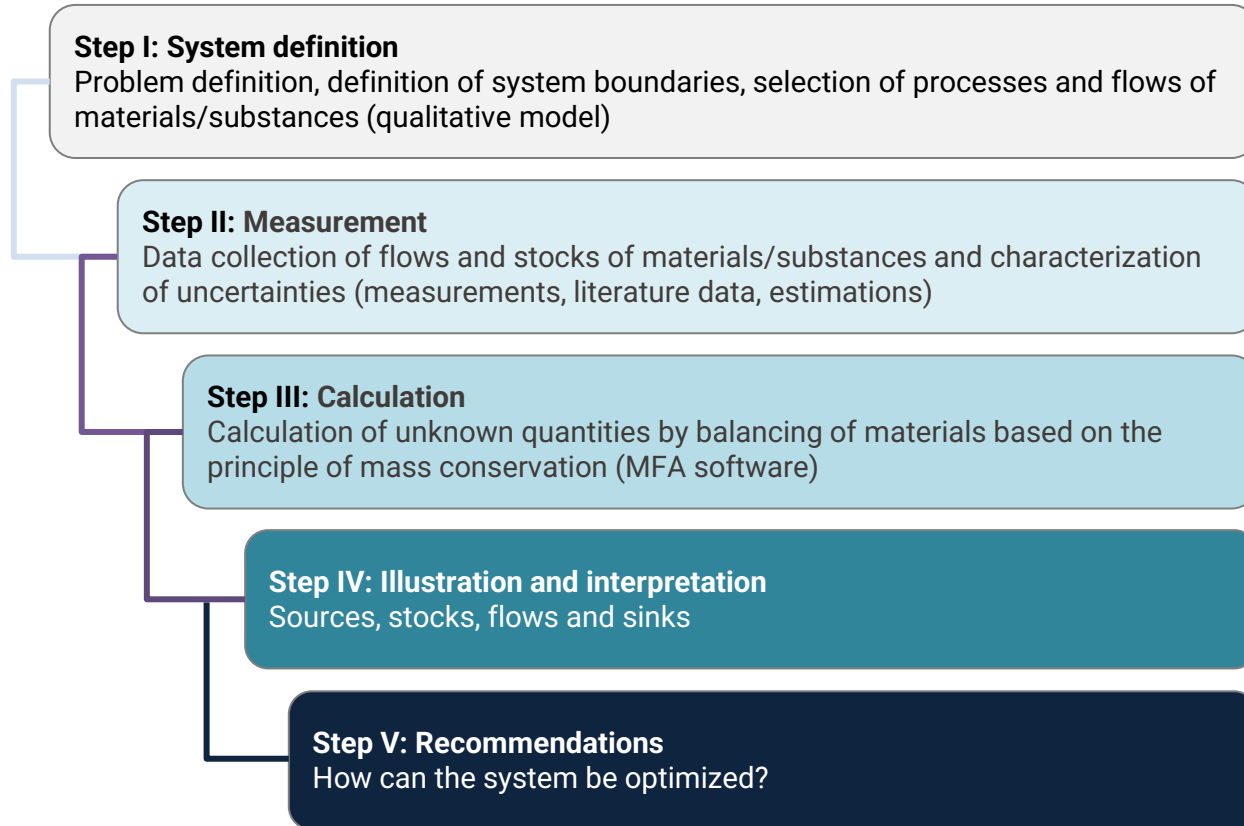
Interrelationship between urban activities and flows



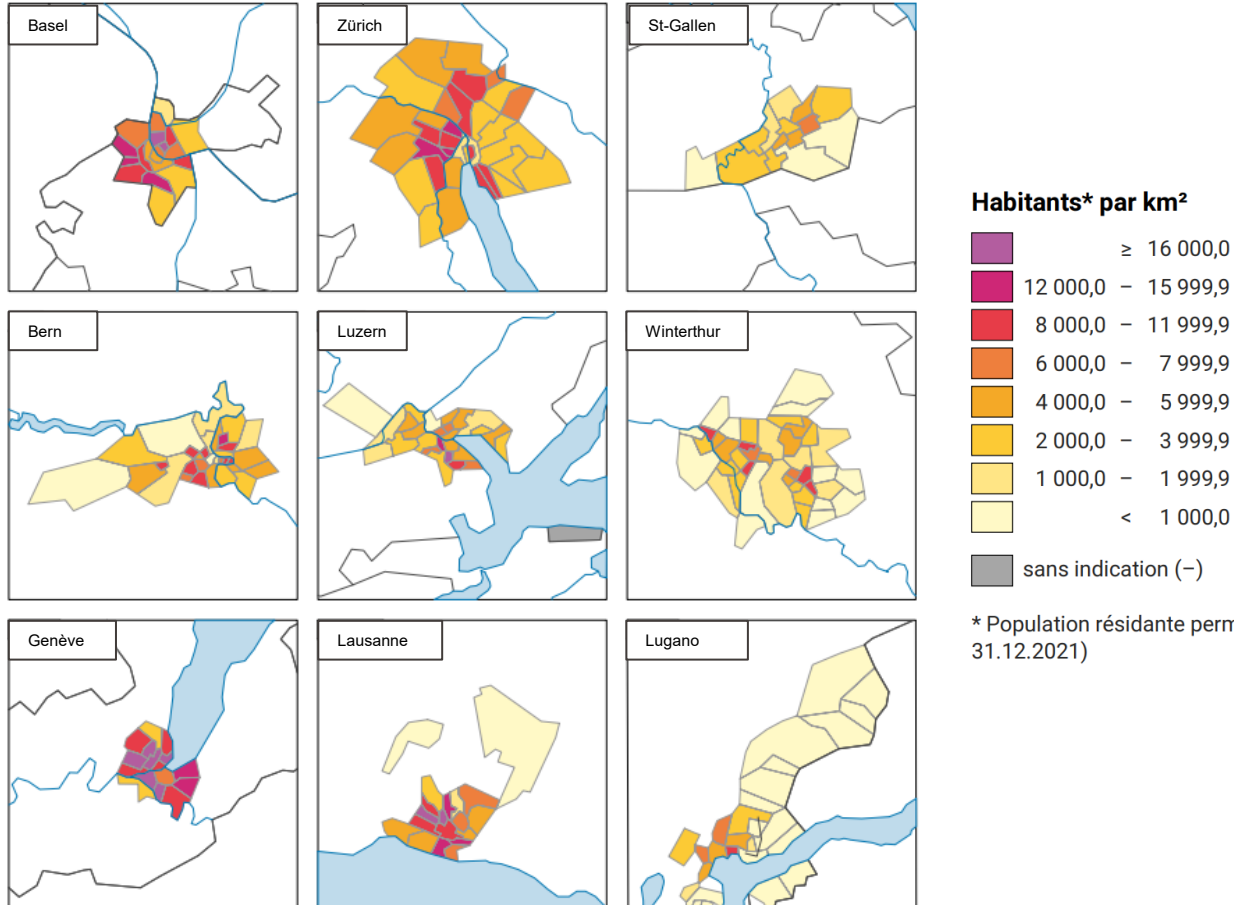


System boundaries of cities

Reminder: Steps of MFA



What is a city?



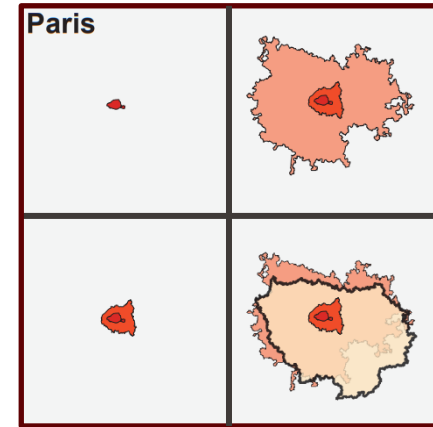
What is a city?

Spatial units

Data are collected for several levels:

- A **City** is a local administrative unit (LAU) where the majority of the population lives in an urban centre of at least 50 000 inhabitants. The city of Paris has approximately 2 200 000 inhabitants
- The **Greater city** is an approximation of the urban centre when this stretches far beyond the administrative city boundaries. The greater city of Paris has approximately 6 700 000 inhabitants.

- The **Functional Urban Area** consists of a city and its commuting zone. The functional urban area of Paris has approximately 11 800 000 inhabitants.
- **Metropolitan regions** are NUTS 3 regions or a combination of NUTS 3 regions which represent all agglomerations of at least 250 000 inhabitants. These agglomerations were identified using the Functional Urban Area (FUA). Each agglomeration is represented by at least one NUTS 3 region. If in an adjacent NUTS 3 region more than 50% of the population also lives within this agglomeration, it is included in the metropolitan region. The metropolitan region of Paris has approximately 12 000 000 inhabitants.

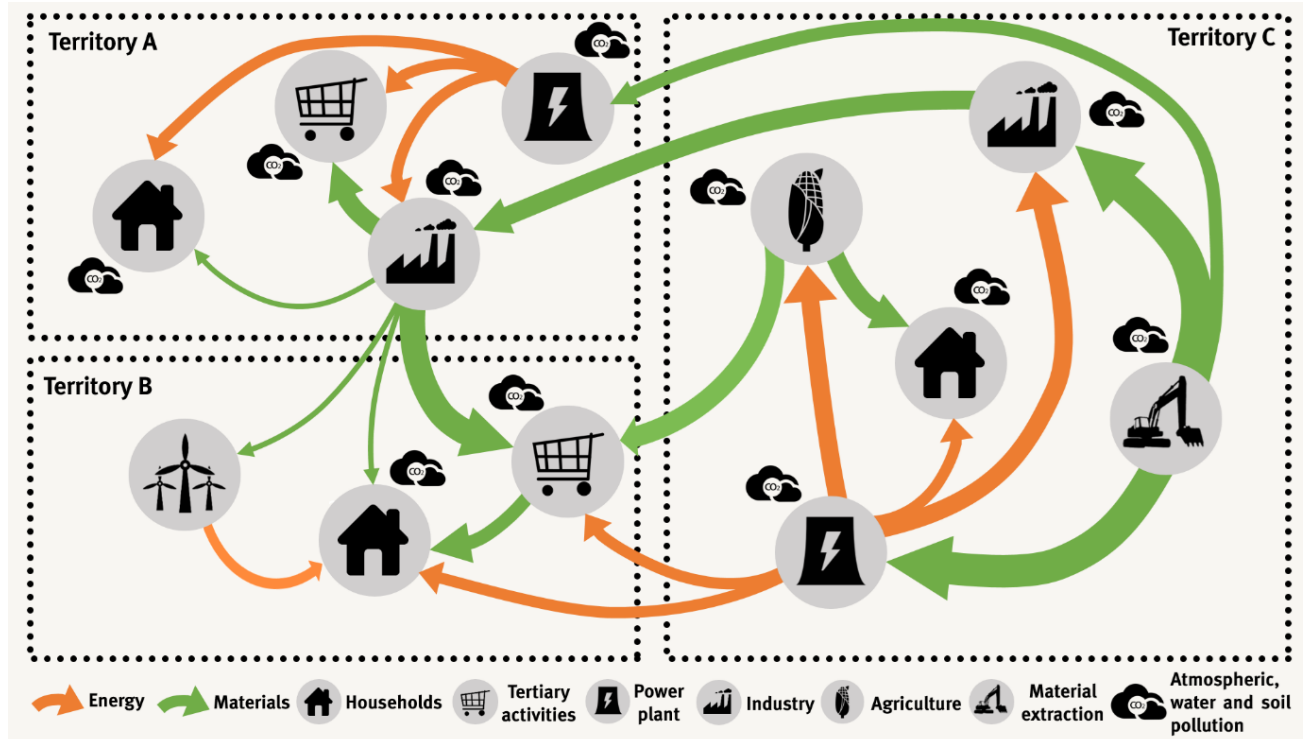


0 25 50 75 100 km

- City
- Greater city
- Functional urban area (FUA)
- Metropolitan region

Source : Eurostat, 2016

What boundaries to choose?

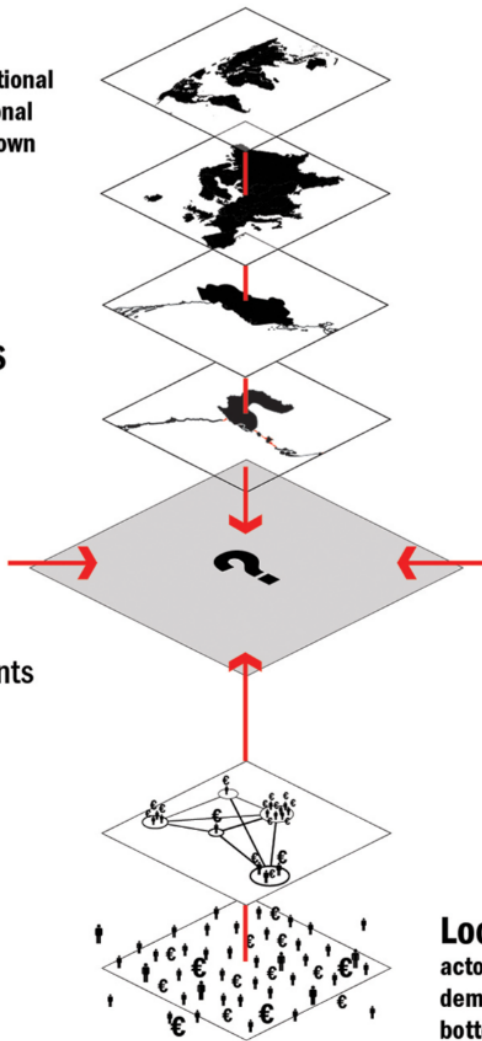


Global

trends and demands, international markets and actors and regional networks are projected top-down

FLOW ANALYSIS

Energy
Air & Heat
Water
Food
Cargo
Waste
Sand & Sediments
People
Biota
Data



AREA APPROACH

Densities
Public space
Waterfronts
Parks
Public transport
Street sections
Parking
Ownership
Employment
Health services

Local

actors and assets, urban trends and demands and personal networks arise bottom-up

Accounting approaches and methods

Accounting approaches and methods

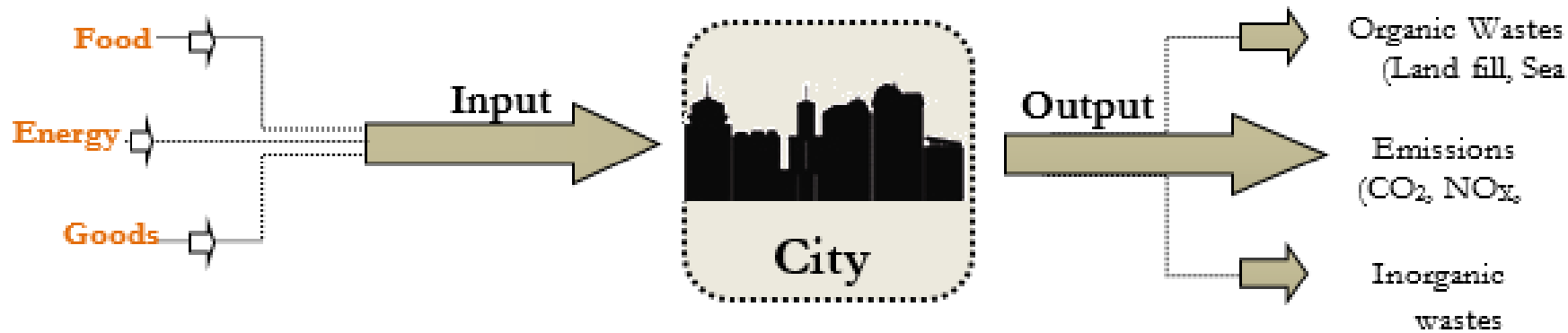
- Top-down
- Bottom-up

- Territorial-based
- Consumption-based

Top-down vs Bottom-up

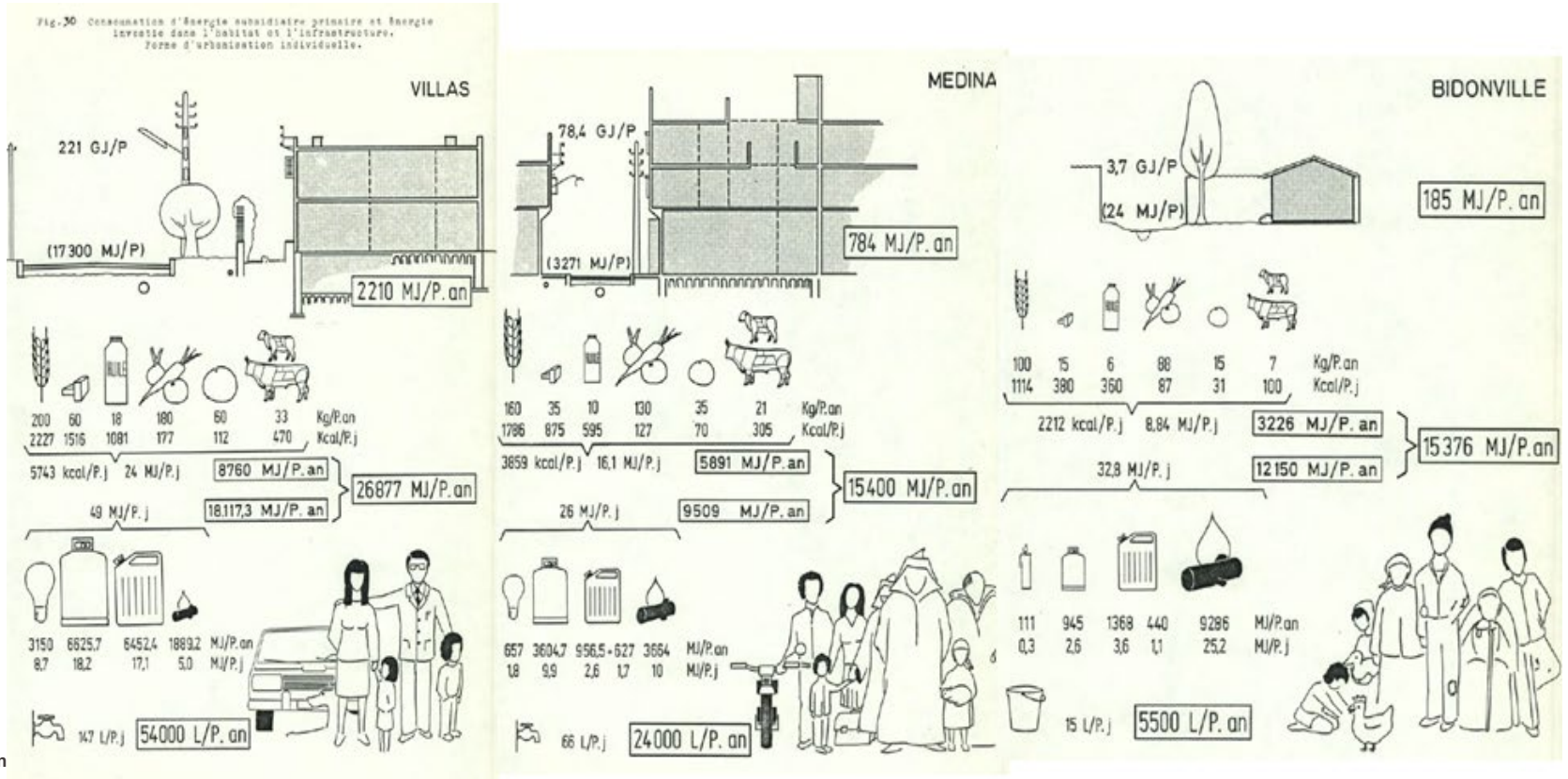


Top-down accounting



Bottom-up accounting

Kenitra, Morocco, 1982



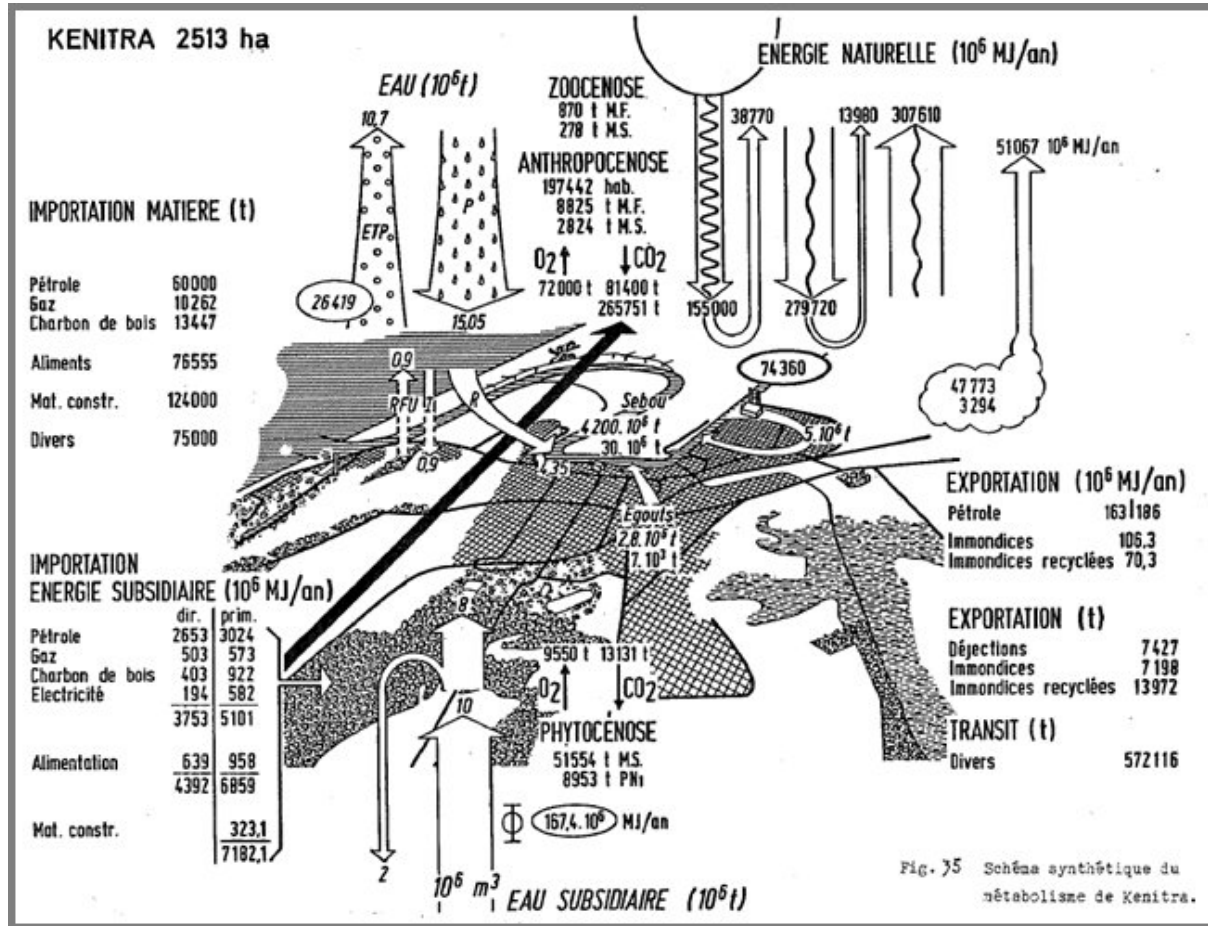


Fig. 75 Schéma synthétique du métabolisme de Kenitra.

Source : Kempeneers, 1982

Top-down vs Bottom-up.

Pro's of top-down

- Comparable to other years/cities
- Frequently published data
- Comparable to economic & urban data

Pro's of bottom-up

- Reliable data
- Relatively easy to develop
- Provides behavioural aspects

Con's of top-down

- Not available in data scarce environments
- Treats city homogeneously
- Requires institutional infrastructure
- Not always enough knowledge on what's measured

Con's of bottom-up

- Difficult to reproduce
- Time consuming

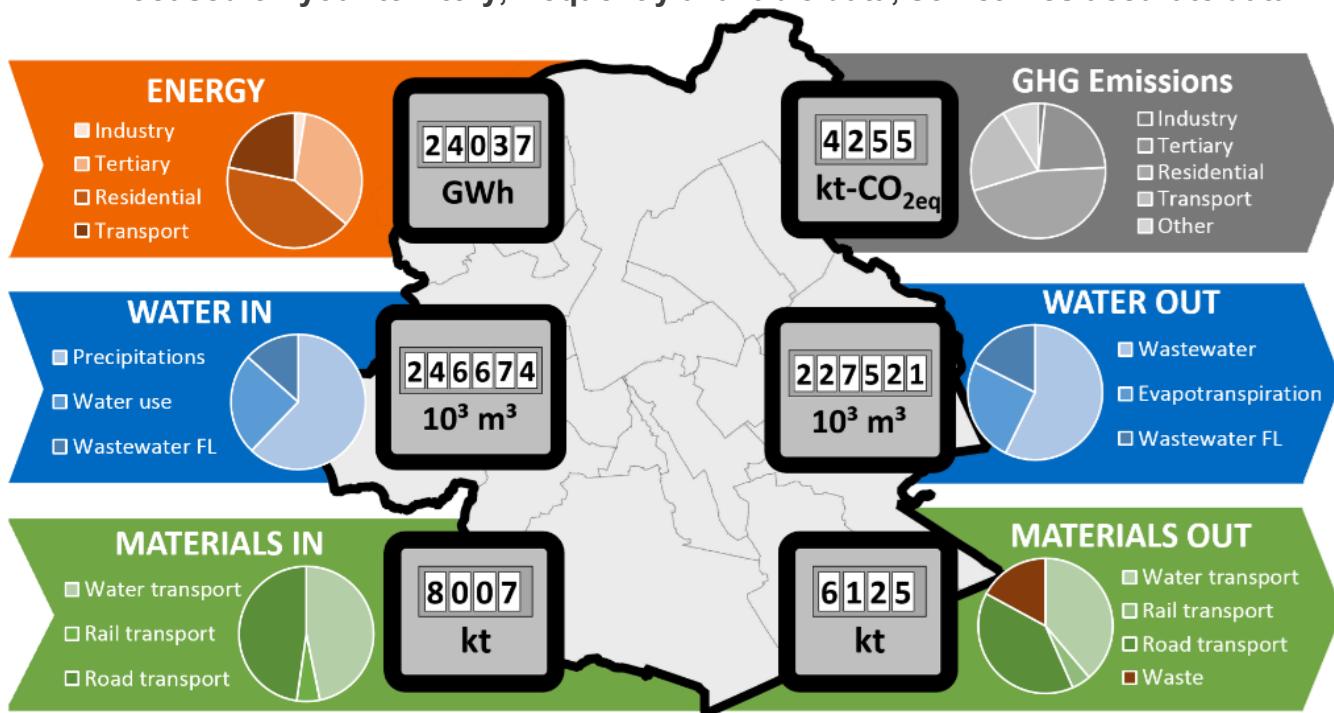
Territorial/production vs Consumption-based accounting



Territorial/production vs Consumption-based accounting

Brussels, 2010

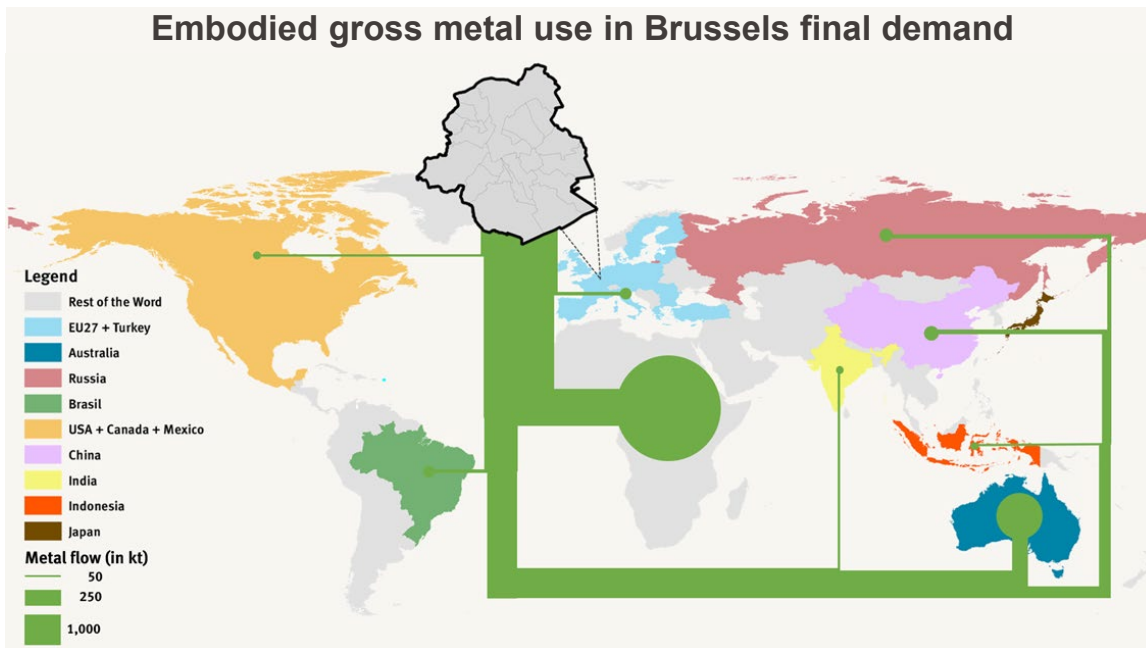
Focused on your territory, frequently available data, sometimes accurate data



Consumption-based accounting

Brussels, 2010

Indirect/embodied flows, hinterland, need of local IO tables

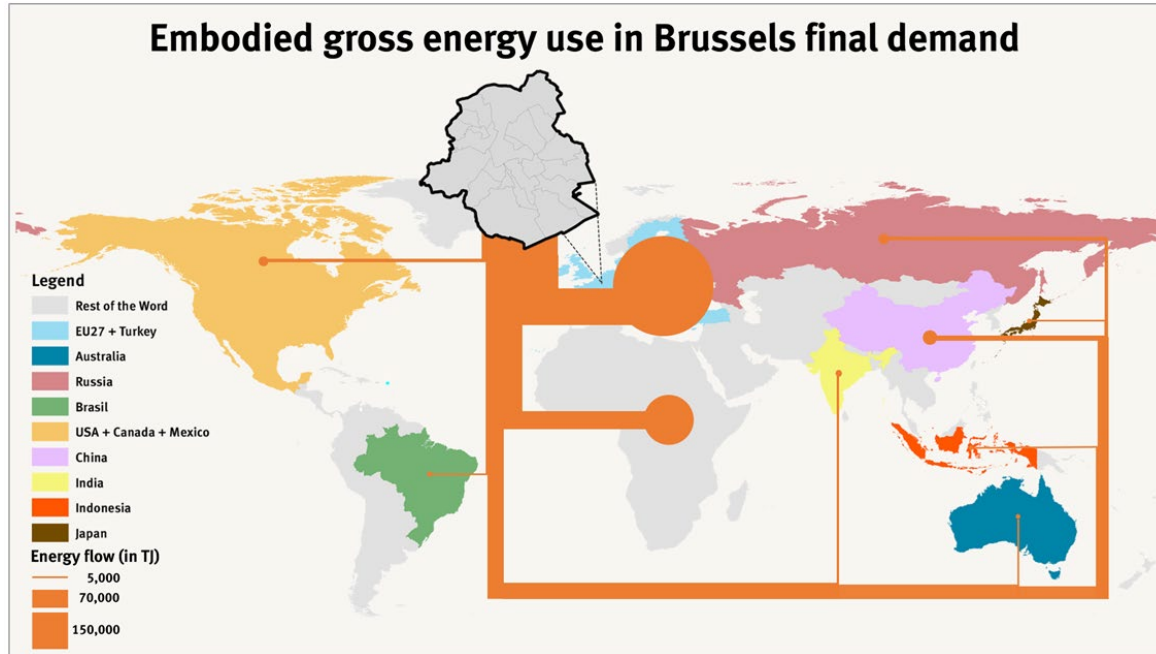


Source : Athanassiadis, et al., 2017

Consumption-based accounting

Brussels, 2010

Indirect/embodied flows, hinterland, need of local IO tables



Territorial/production vs Consumption-based accounting

Pro's of "territorial"

- Accurate data
- Frequently published data
- Enables time series
- Appropriate at urban scale
- Easy to use
- Large pool of case studies
- Available spatial data

Pro's of "consumption"

- Indirect flows
- Spatialises hinterland
- Link global-local
- Systemic overview

Con's of "territorial"

- No indirect flows
- No standard methodology
- Some flows are not available

Con's of "consumption"

- Uncertainties
- No IO tables at urban level
- Needs experts to use them







No unique accounting method

THE METABOLISM OF CITIES
LIBRARY

Library ▾ Case studies ▾ Journals Authors News Account ▾

Material accounting methods

This section provides an overview of the principal material accounting methods used in urban metabolism literature. These methods are grouped in broader categories, which can be seen below. Learn more about each category, the relevant individual methods, and the case studies undertaken using these methods by exploring this section.

		
Energy assessment methods	Flow analysis methods	Footprint methods
		
Hybrid methods	Input/output methods	Life cycle assessment methods

- Depending on the available data (bottom-up, top-down, local IO tables, etc.)
- Depending on the research question (what are you trying to answer?)

No unique accounting method

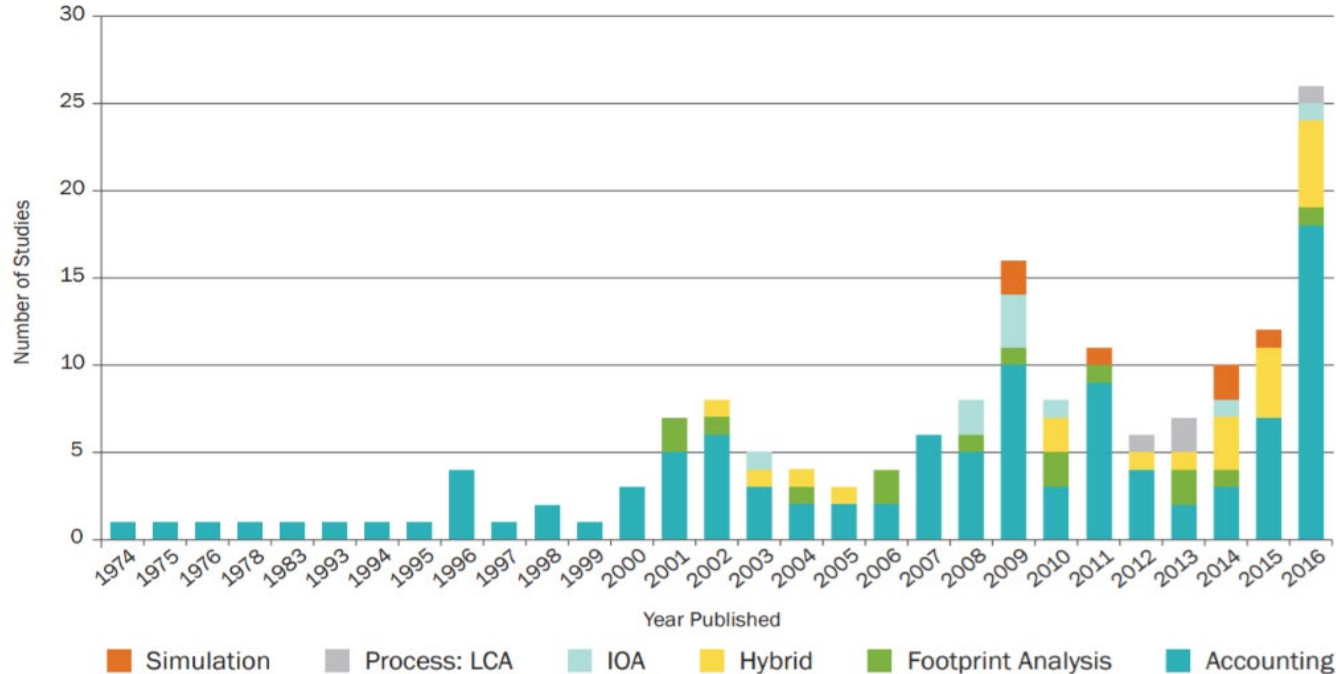


Figure 5: Number of urban metabolism assessment studies over time, showing the increasing diversity of approaches utilised.

Source : Musango et al., 2017



**Where to find
data?**

Urban metabolism studies



- Laboratory on Human-Environment Relations in Urban Systems

Source : [Metabolism of Cities](#)

Where to find data?

80+ urban metabolism studies using specifically MFA methods

Publication	Year	Location	Method(s)
Baselining for a circular Toronto: Material Flow Analysis Report Circle Economy	2021	Toronto	MFA
Circular Àmbit B30 Report Circle Economy	2020	Barcelona	MFA
Circular Kongsvinger Region Report Circle Economy	2020		MFA
Using spatially explicit commodity flow and truck activity data to map urban material flows Journal Article Lynette Cheah Lih Wei Yeow	2019	Singapore	MFA
Integrating lifecycle assessment and urban metabolism at city level: Comparison between Spanish cities Journal Article González-García and Díaz	2019	Bilbao Sevilla	Hybrid MFA-LCA
Incorporating Metabolic Thinking into Regional Planning: The Case of the Sierra Calderona Strategic Plan Journal Article Daniela Perrotti Juanjo Galan	2019	Valencia	EF Energy Accounting MFA
Examining urban metabolism: A material flow perspective on cities and their sustainability Journal Article Cui <i>et al.</i>	2019	Guangzhou	EW-MFA

Where to find data?



Lausanne
Switzerland

📍 212 documents

🏠 Context 🔄

🏗️ Biophysical characteristics 🔄

📊 Infrastructure 🔄

🔗 Stocks and flows 🔄

✓ 83% data collection completion

🏠 Explore city 🔄 Contribute



Geneva
Switzerland

📍 266 documents

🏠 Context 🔄

🏗️ Biophysical characteristics 🔄

📊 Infrastructure 🔄

🔗 Stocks and flows 🔄

✓ 97% data collection completion

🏠 Explore city 🔄 Contribute



Zurich
Switzerland

📍 69 documents

🏠 Context 🔄

🏗️ Biophysical characteristics 🔄

📊 Infrastructure 🔄

🔗 Stocks and flows 🔄

✓ 51% data collection completion

🏠 Explore city 🔄 Contribute

Where to find data?

THE METABOLISM OF CITIES
DATA HUB

Cities Data layers Library Community About Account

Data inventory: layer overview

- Layer 1: Context
- Layer 2: Biophysical characteristics
- Layer 3: Infrastructure
- Layer 4: Stocks and flows

1.1. Administrative boundaries	151
1.2. Economic activity - descriptions	113
1.3. Economic activity - figures	126
1.4. Population	182
1.5. Policy documents	141
1.6. Actors	22

View all

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Where to find data?

THE METABOLISM OF CITIES
DATA HUB

Cities Data layers Library Community About Account

Data inventory: layer overview

- Layer 1: Context
- Layer 2: Biophysical characteristics
- Layer 3: Infrastructure**
- Layer 4: Stocks and flows

3.00. Land Use	120
3.01. Agriculture	110
3.02. Construction	59
3.03. Electricity generation	90
3.04. Electricity transmission and distribution	60
3.05. Energy storage	26
3.06. Fossil fuel production and distribution	52
3.07. Fishing	33
3.08. Food service	35
3.09. Forestry	37
3.10. Hotels and lodging	37
3.11. Manufacturing: food products	43
3.12. Manufacturing: beverages	29
3.13. Manufacturing: textiles and clothing	30

Source : Metabolism of Cities

Table 6 Comparison between Cape Town, Paris, Hamburg, Vienna and Leipzig. All indicators are t/cap

	Hamburg 2001	Vienna 2001	Leipzig 2001	Paris (PPC) 2003	Paris (Île-de-France) 2003	Cape Town 2010*	Cape Town 2013
Total population (million)	3.26	2.12	1.09	6.32	11.3	3.50	3.85
Total km ²	8,616	4,596	4,386	762	12,012		2,461
Density (capita/km ²)	379	461	249	8,295	937	12,059	1,564
Domestic material consumption	11.4	8.8	25.3	4.6	7.1	11.3	3.5
Domestic extraction used				0.0	2.1		1.6
Imports				11.0	10.2		5.8**
Exports				7.9	5.2		3.9**
Domestic processed output				4.3	6.8		2.3
Physical trade balance				3.1	5.0		1.9
Direct material input				11.0	12.3		6.2**
Direct material output				12.2	12.0		7.3**
Net addition to stock				0.7	2.6		2.5

Note: *This study was published in 2010 but the data sources date back to previous years. **These figures include throughput.



Examples of Urban Metabolism studies

- Laboratory on Human-Environment Relations in Urban Systems

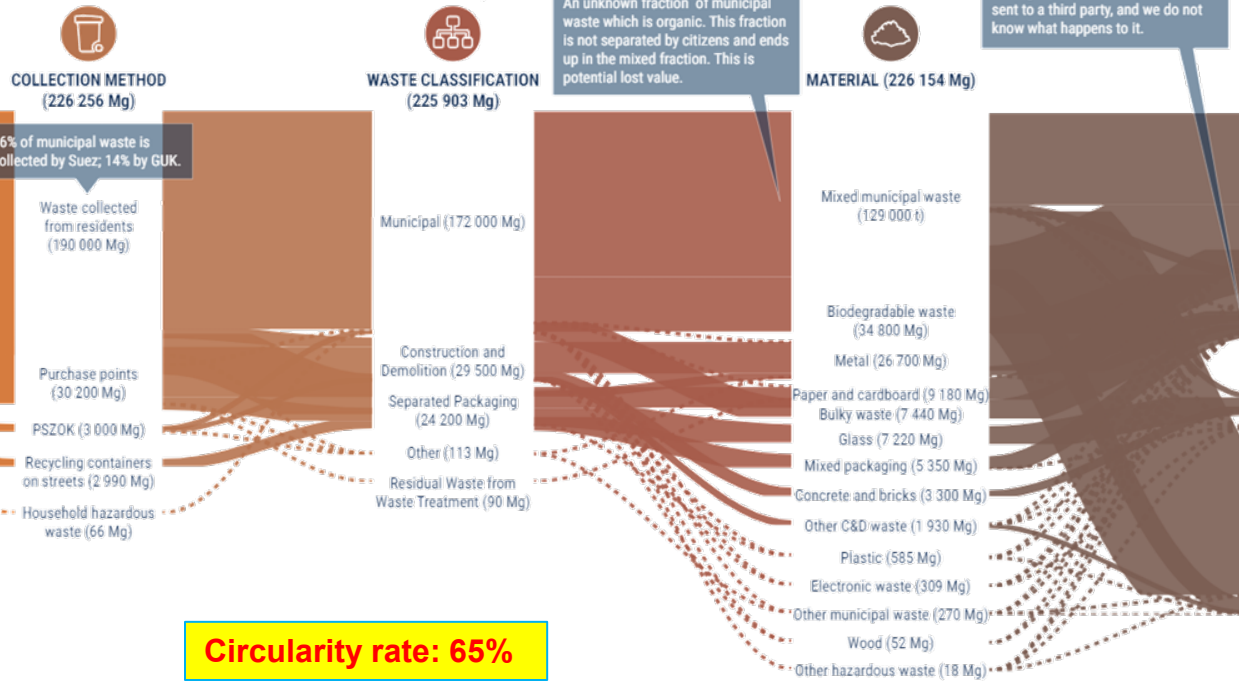
Heat recovery by the Utilization Plant was not taken into consideration due to lack of data.

GDANSK MUNICIPAL WASTE (226 000 Mg)

Comparison municipal vs industrial waste: 226 000 Mg vs 319 000 Mg respectively.

Mg= Megagrams = 1 ton

LEGEND
 ---- less than 1 000 Mg
 Laboratory on Human-Environment Relations in Urban Systems



Classification of waste and material was based on European Waste Catalogue (EWC) codes, and might therefore differ slightly from locally used categories.

An unknown fraction of municipal waste which is organic. This fraction is not separated by citizens and ends up in the mixed fraction. This is potential lost value.

- 44% Bulky waste
- 29% Mixed packaging
- 22% Mixed
- 2% Other C&D waste
- 2% Plastic
- 2% Text
- 1% Other municipal waste

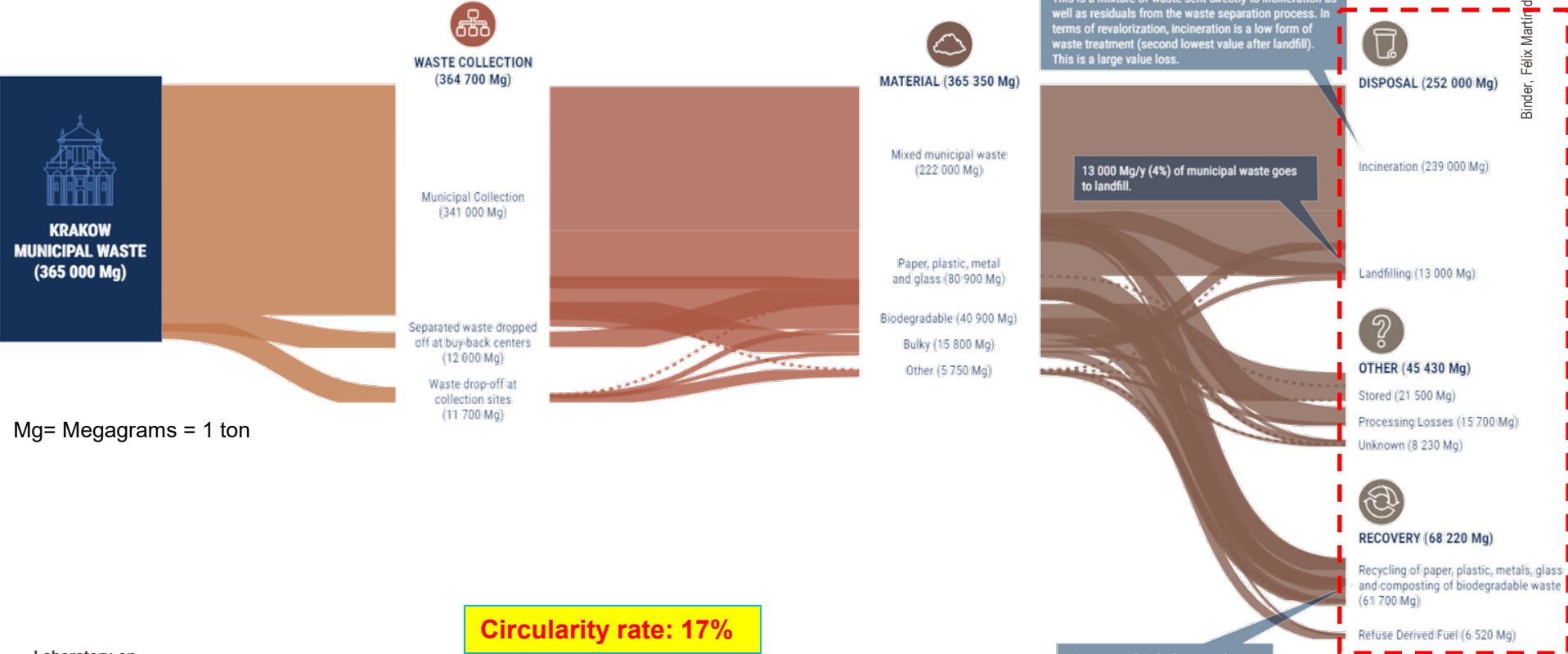
The fraction of municipal waste that undergoes the 'Unknown' treatment is sent to a third party, and we do not know what happens to it.

Circularity rate: 65%

Source: Metabolic Institute

Urban Metabolism

City of Krakow, Poland, 2021



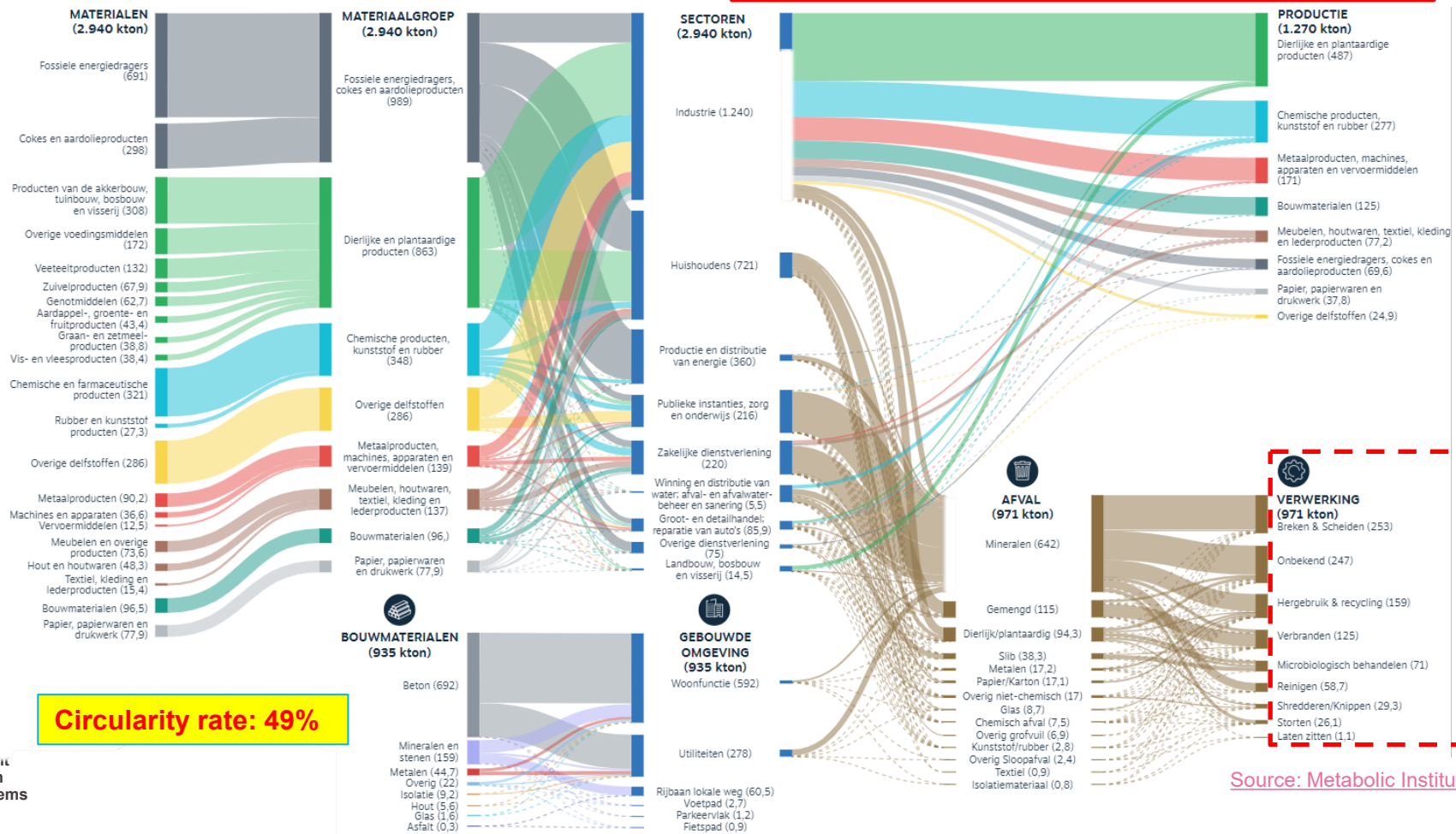
Circularity rate: 17%

Source: Metabolic Institute

Mg= Megagrams = 1 ton

Urban Metabolism

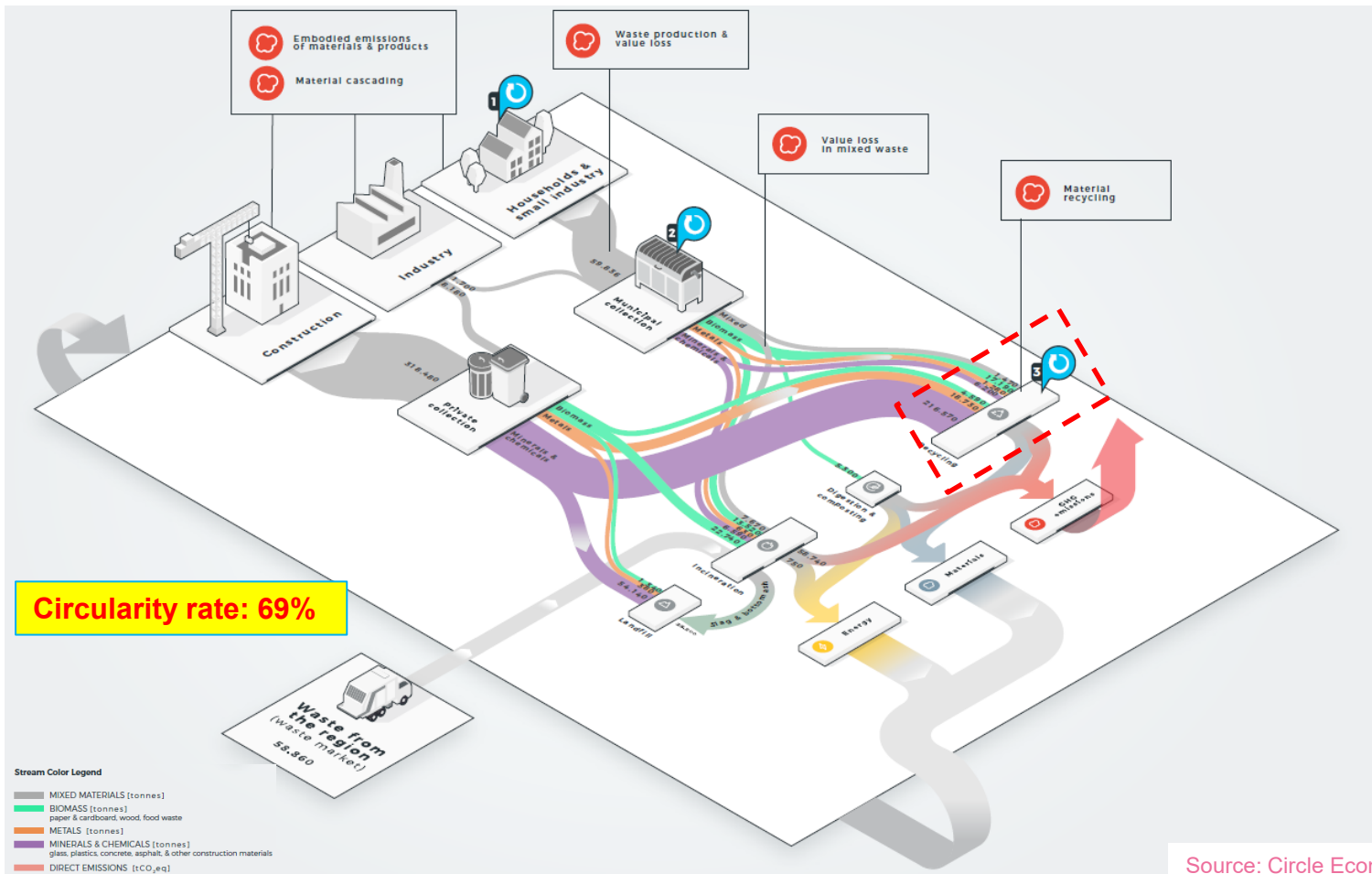
City of Utrecht, Netherlands, 2021

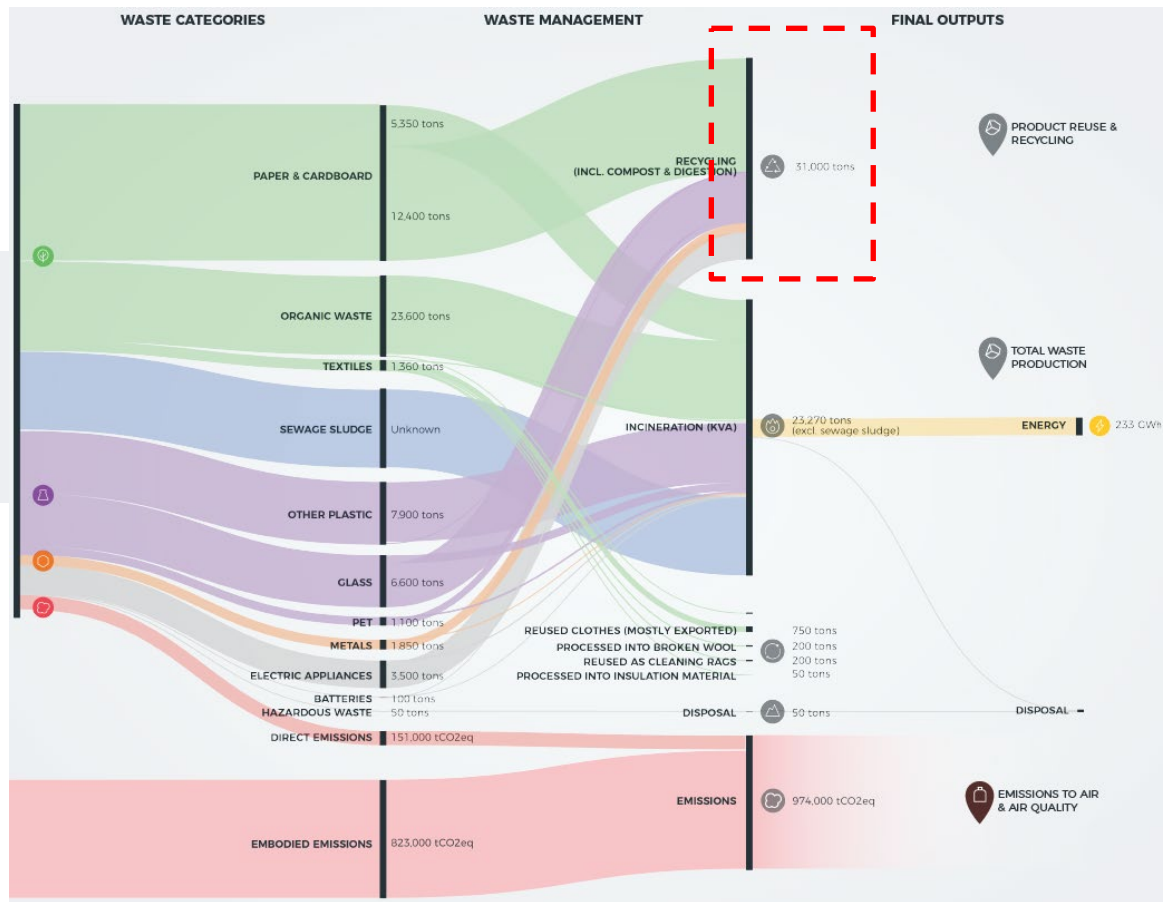


Circularity rate: 49%

Laborator Human-Environment Relations in Urban Systems

Source: Metabolic Institute





Circularity rate: 49%

Laboratory on Human-Environment Relations in Urban Systems



Circular Economy and MFA

- Laboratory on Human-Environment Relations in Urban Systems

“This [future world] will be a small, closed, limited, planetary society, almost certainly dependent on solar energy for its input or power, and it will have to recycle virtually all its materials into a circular economy, in which the dumps become the mines”

Circular Economy



Living things need food and water



Societies need cars, buildings, electronics, etc.



- Modern societies:
Linear “take-make-dispose”
economy



Definition of Circular Economy

“Economic system of production, trade and consumption that, from the design of a product through to its end of life, is designed to optimize the use of resources and reduce the impact of economic activity on the environment”



Characteristics of Circular Economy: Link to MFA

- Restorative and regenerative economic model
- Aim: keep products, materials, and resources in use for as long as possible
- Core strategies:
 - Narrowing flows: resource efficiency, less input per service
 - Slowing flows: extend product lifetimes, reuse, repair, sharing
 - Closing loops: recycling, recovery, return to production
- **Not only about waste management!** It also concerns design, business models, and governance

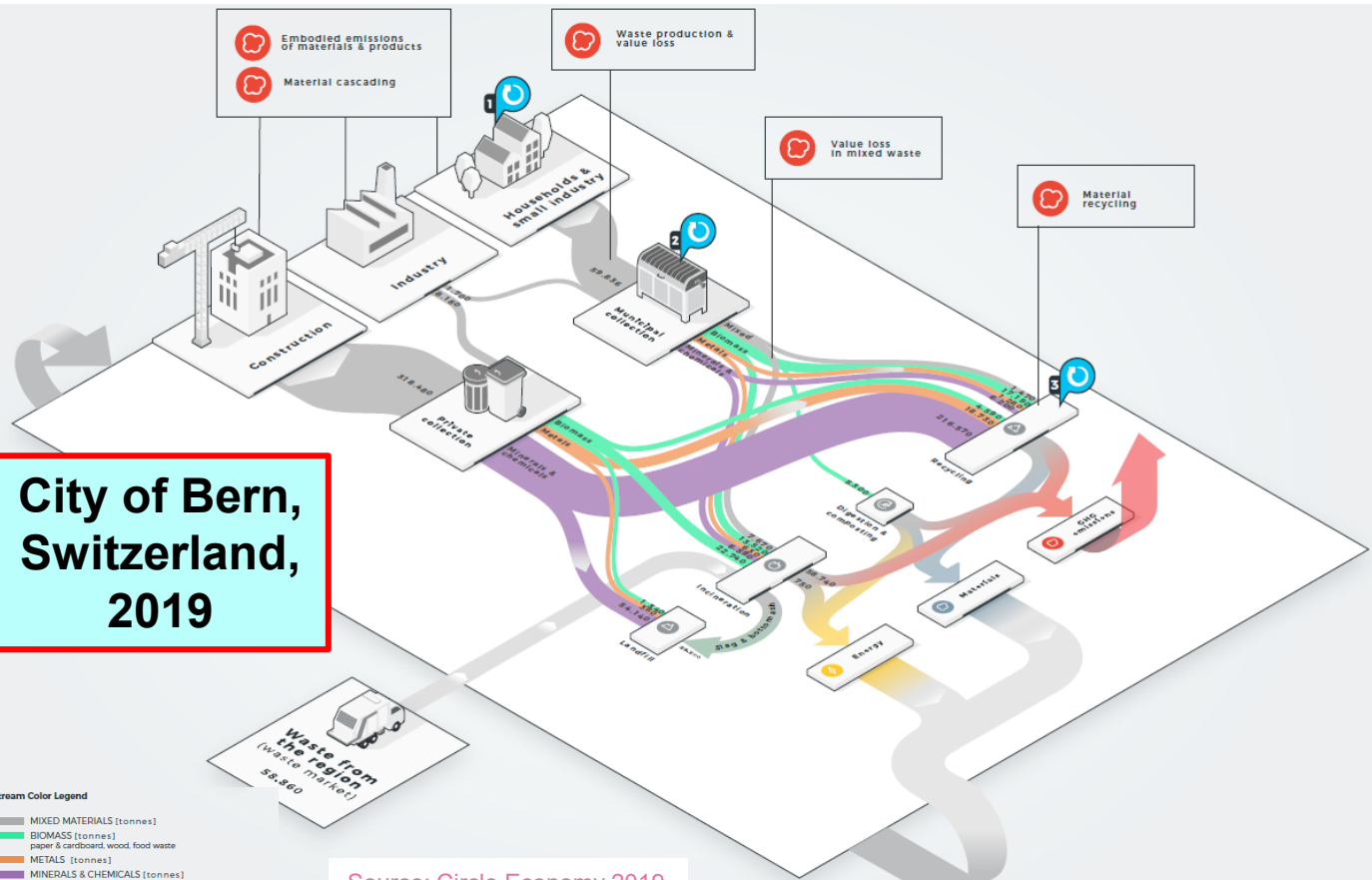
MFA, Urban metabolism & Circular Economy

- **MFA (method):** *Analytical lens* → Tracks flows and stocks, identifies hotspots
- **MFA** answers “what is happening in the city?”
- **UM (concept):** systemic view of flows, stocks, actors
- **UM:** Broad, multidisciplinary field (industrial, social, political ecology)
- **CE:** *Normative framework* → Proposes strategies for intervention
- **CE** answers “how should we intervene?”
- **Together: Diagnosis (UM/MFA) + prescription (CE)**

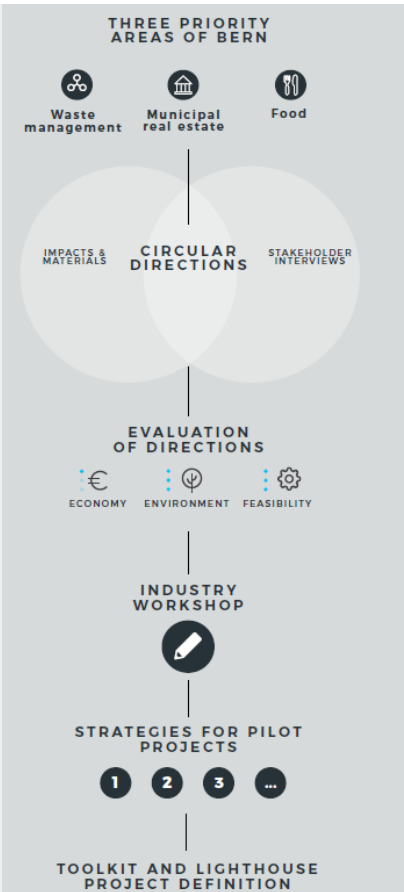
Circular Economy: strategies

- **Buildings and infrastructure**
 - Material passports, reuse hubs
- **Food systems**
 - Nutrient recovery, urban composting, redistribution
- **Mobility**
 - Shared fleets, repairable e-bikes, modular batteries
- **Energy**
 - Industrial symbiosis, cascading heat use, district loops
- **Consumer goods**
 - Reuse centres, repair cafés, etc.

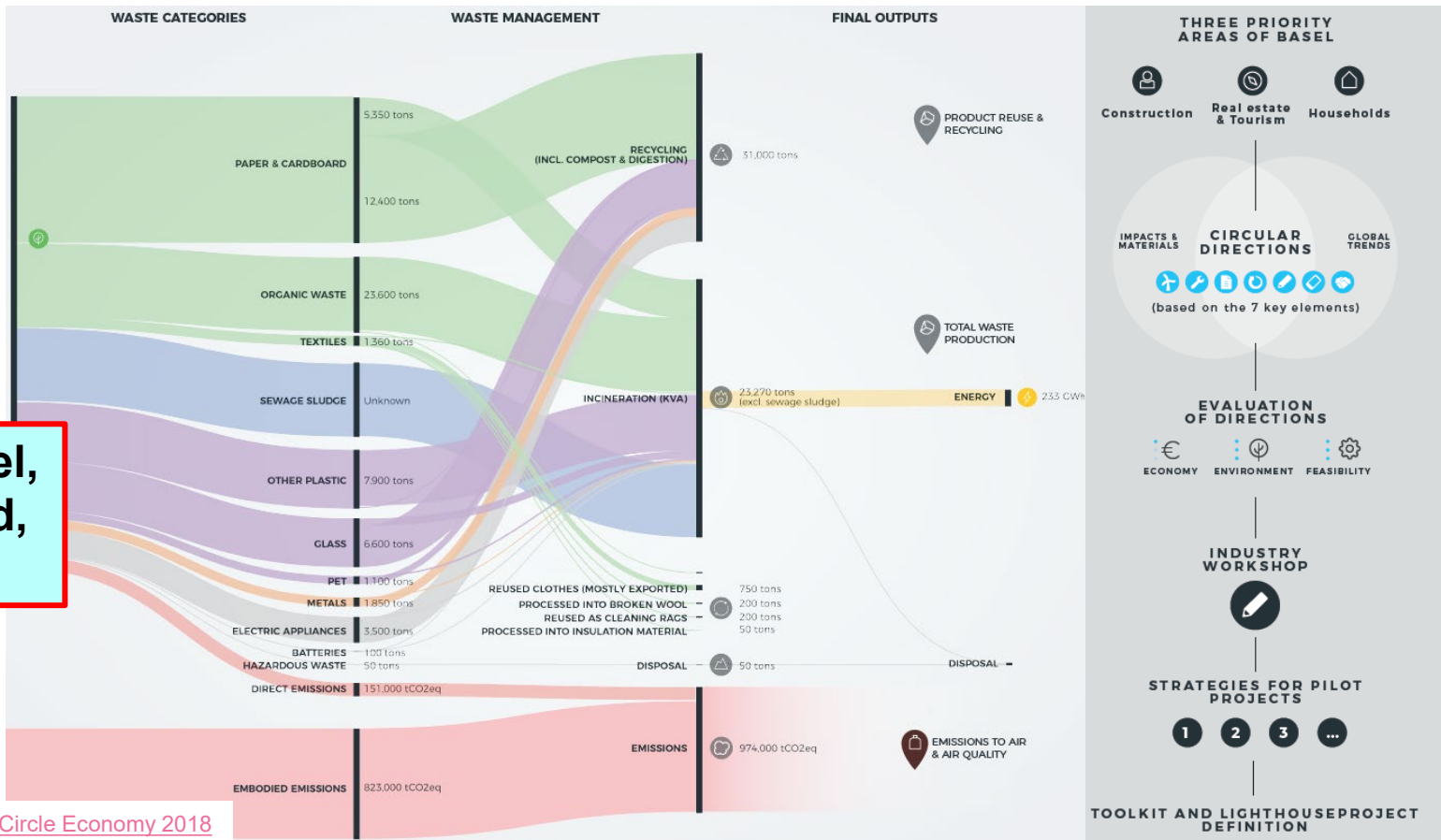
Circular Economy: strategies



Source: Circle Economy 2019



Circular Economy: strategies



City of Basel, Switzerland, 2018

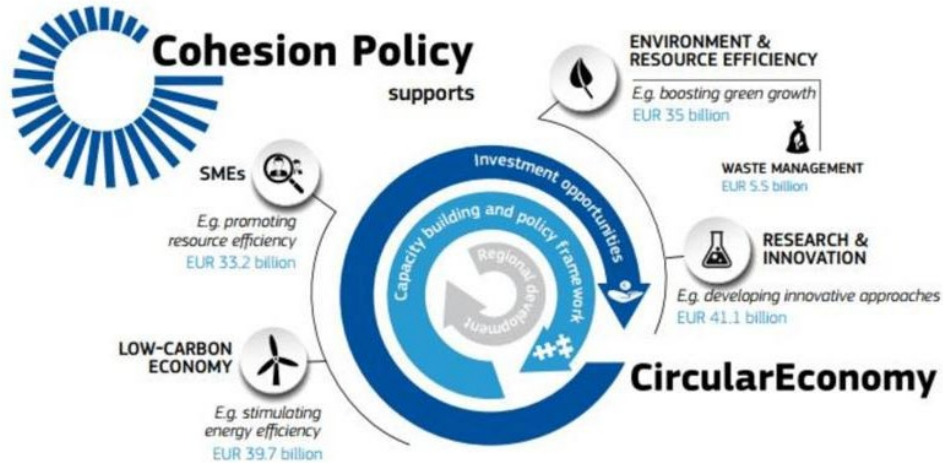
Laboratory on Human-Environment Relations in Urban Systems

Source: Circle Economy 2018

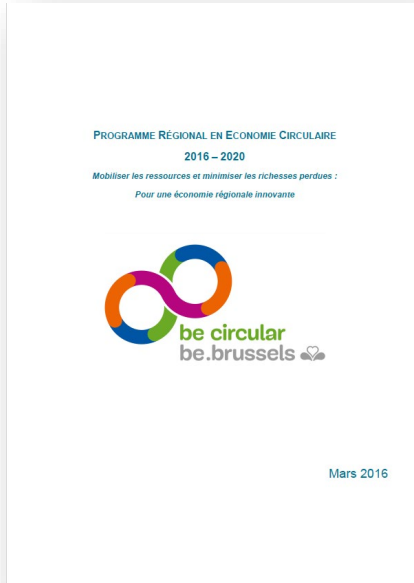
Measuring circularity

- **Circular material use rate:** Share of material inputs from secondary / recycled sources.
- **Waste (urban) per capita** (incinerated + separately collected materials): Gives baseline for how much waste and how well collection/sorting is done.
- **Recycling rates by material category** (e.g. packaging, construction materials, waste paper/glass/metal)
- **Material footprint per capita vs sustainable threshold:** gives sense of overuse relative to planetary limits.
- **Complement to MFA indicators: from “what is” to “how circular is”**

Circular economy - policies



Circular Economy policies at city scale



Circular Economy policies - Brussels

- **Urban metabolism study in 2014-2015**
- **3 ministries, 4 administrations**
- **4 strategic themes**
 - Transversal (43 measures): define a favorable normative and legal framework
 - Sectoral (48 measures): Construction (13), resources and wastes (24), logistics (7), retail (4)
 - Territorial (8 measures)
 - Governance (12 measures)

PROGRAMME RÉGIONAL EN ÉCONOMIE CIRCULAIRE
2016 – 2020

*Mobiliser les ressources et minimiser les richesses perdues :
Pour une économie régionale innovante*



Mars 2016

Circular Economy policies - Paris

- **Urban metabolism study in 2007**
- **Etats Généraux de l'Economie Circulaire in 2015**
(120 organisations proposed 65 initiatives)
- **First roadmap in 2017**
(15 actions for 3 scales)
 - Planning and construction (3)
 - Reduction, reuse and repair (4)
 - Support for actors (5)
 - Public procurement (2)
 - Responsible consumption (1)
- **Second roadmap from 2018 to 2019**



PLAN
**ÉCONOMIE
CIRCULAIRE**
de PARIS

ADOPTÉ AU CONSEIL DE PARIS
DES 3, 4 ET 5 JUILLET 2017

2017-2020

Circular Economy policies - London

- **Urban metabolism study in 2002**
- **ReLondon (formerly LWARB) governmental entity, CE Route map**
 - Built environment (13 actions): CE design (5), managing building materials (4), operation of buildings (4)
 - Food (9 actions): preventing avoidable food waste (3), valuing food waste and food surplus (3), maximising use of urban space for food growing (3)
 - Textiles (10 actions): design (1), embedding CE into the textile supply chain (6), re-use and recycling
 - Electricals (11): design (2), extending the life of products (6), and effective collection and recycling (3) aspects.
 - Plastics (7 actions)



Circular Economy policies at city scale

- **Local targets** is one of the drivers for secondary materials
- **Use of UM / MFA:** to identify hotspots and prioritize sectors (construction, food, plastics, textiles)
- **Potential expected outcomes:** reduced landfilling, new local value chains, pilot reuse facilities

Challenges and limits of CE in cities

- **Scale mismatch:** Cities depend also on global supply chains
- **Rebound effects:** efficiency gains could increase total consumption
- **Lack of standardized urban CE metrics:** examples of cities previously shown
- **CE strategies often framed as win-win:** risk of policy “greenwashing”
- **Need to address** not only materials, but also **behavior, equity, governance, etc.**, more **holistic**.

- Cities are **not** at all **self-sufficient**
 - The reliance on external flows highlights the vulnerability of cities to disruptions in supply chains and resource availability, especially as population growth and urbanization continue
- **Scale** matters
 - To optimize resource management and urban planning, it's crucial to understand the specific context of the scale at which material flows are being assessed
- Difficult to make **circular**
 - To create more circular systems, cities would need to redesign production, consumption, and waste processes. This includes strategies that prioritize infrastructure for material recovery, encouraging modular and reusable design, and shifting economic incentives toward resource conservation

- Cities are **not** at all **self-sufficient** – Need to prioritize local resources.
 - Policies that support localized systems for **food, energy, and material recovery** can significantly enhance urban resilience.
- **Scale matters** - Adapt Circular Economy strategies
 - A city-level strategy might prioritize **household recycling** and **community-based resource recovery**, while regional policies might target **industrial by-products** and broader recycling infrastructure
- Difficult to make **circular** - Support Circular Design and Waste Infrastructure.
 - Circular economy policies can drive **eco-design** and **modular construction** approaches, which reduce waste at the source and allow materials to be recovered more easily.



**Thank you for
your attention!**