TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

INSTITUT FÜR WASSERGÜTE, RESSOURCENMANAGEMENT UND ABFALLWIRTSCHAFT

INSTITUTE FOR WATER QUALITY, RESOURCES AND WASTE MANAGEMENT

Calculation of material cycles for environmental technology

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   - early recognition of env. loadings and resource depletion/accumulation
   - setting priorities for remedial measures
   - designing goal oriented recycling systems

Goals of ET

1. (Long term) protection of environment
2. (Long term) resources conservation
3. No intentional export of pollution in space (hinterland) and time
4. Economic recycling concepts (no long-term subsidies)

Material Flow Analysis (MFA)

Aims of material flow analysis:

- physical base for early recognition, evaluation and design
- to describe and analyse metabolic systems for decision making
- As simple as possible but still valid for decision making

Austrian standard for MFA

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VORSCHLAG

ÖNORM

S 2096-1

Ausgabe: 2003-09-09

Normengruppe S3 und U2

ICS

Stoffflussanalyse
Teil 1: Anwendung in der Abfallwirtschaft
Begriffe

engl.

franz.

ÖNORM S 2096-2: Teil 2: Anwendung in der Abfallwirtschaft - Methodik

Six fundamental terms

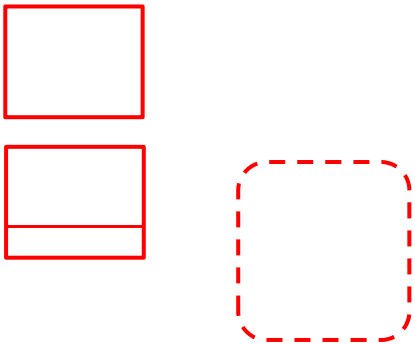
Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within an arbitrarily complex system defined in space and time.

6 fundamental terms and symbols:

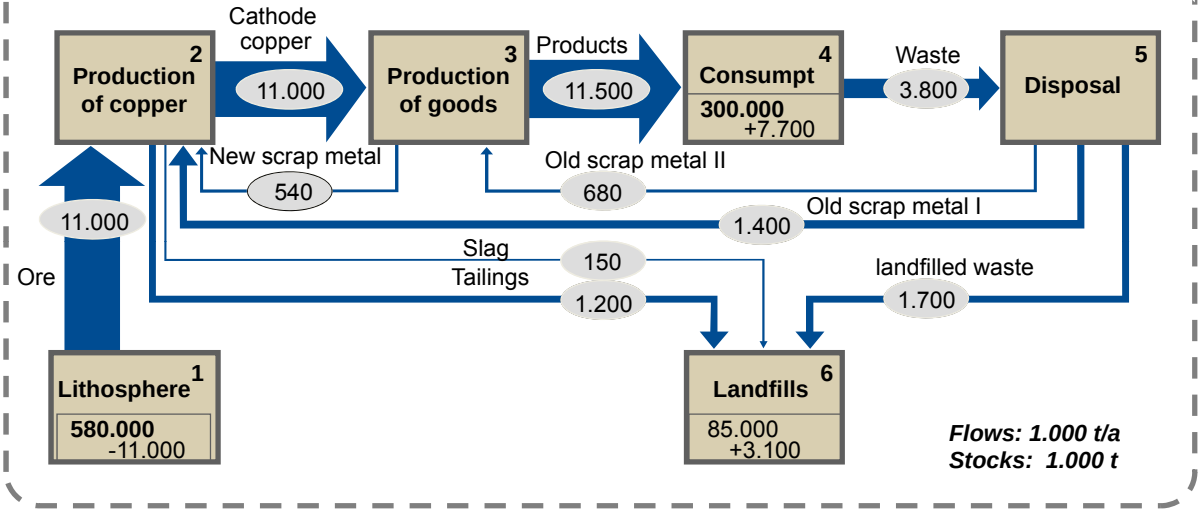
- substance
- good
- process

} material

- flows/fluxes
- stocks
- system



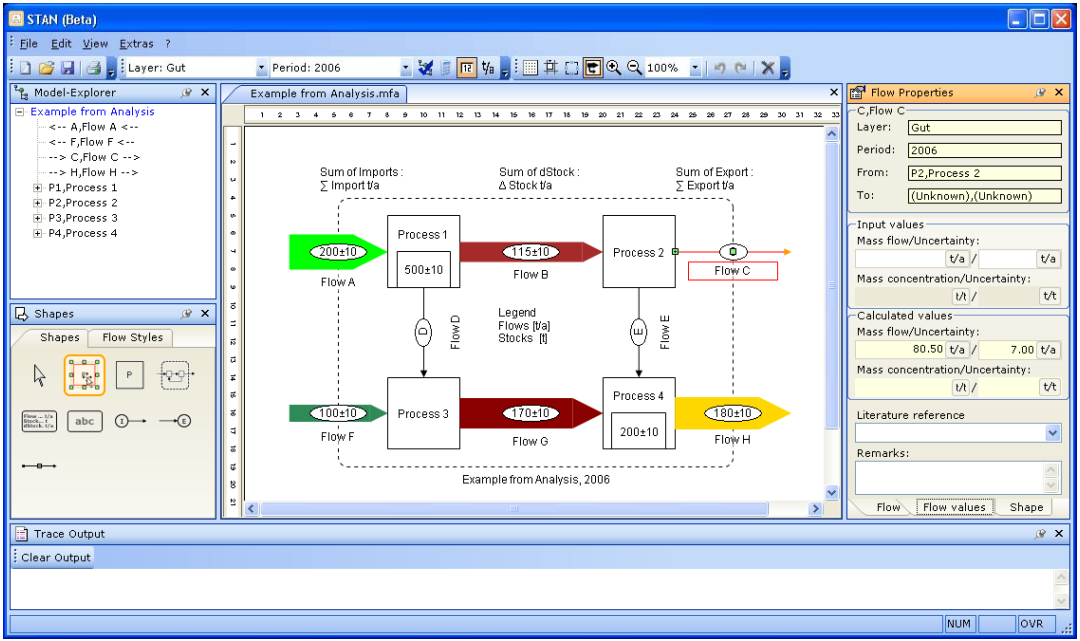
Result of an MFA: global cycle of copper



System boundary "World 1994"

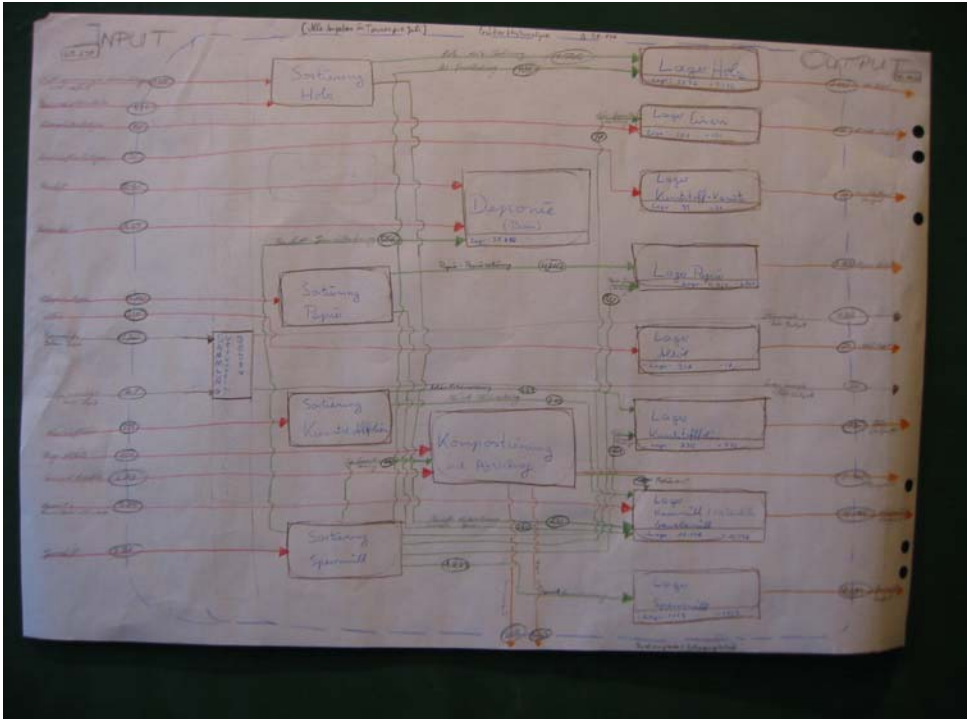
Source: Graedel et al. 2002 (completed)

MFA – software STAN

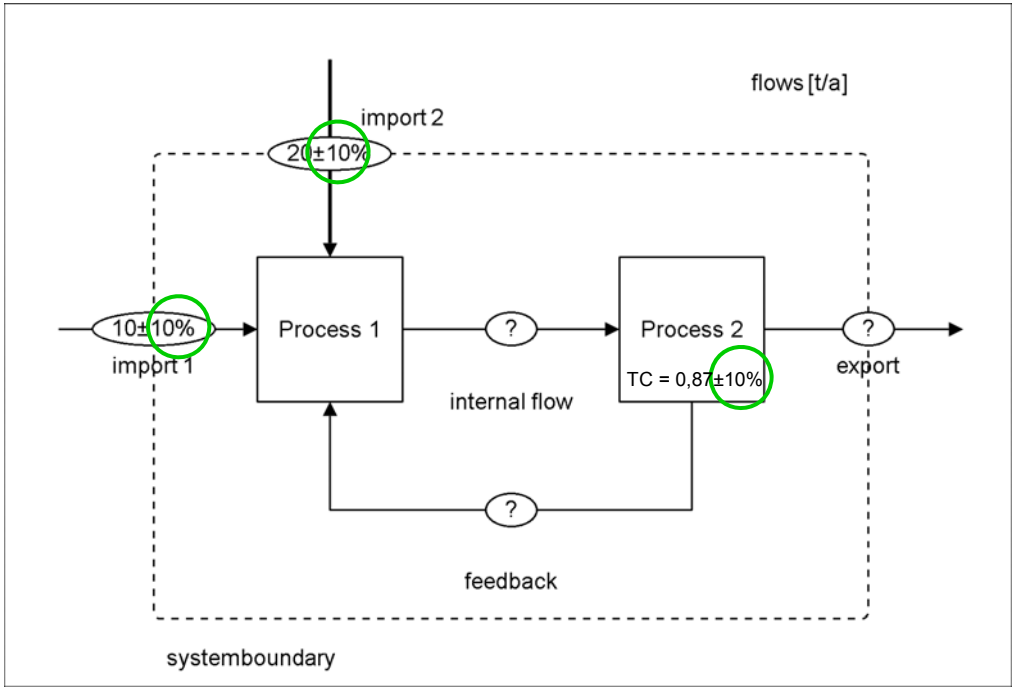


http://www.iwa.tuwien.ac.at/iwa226/stan.html

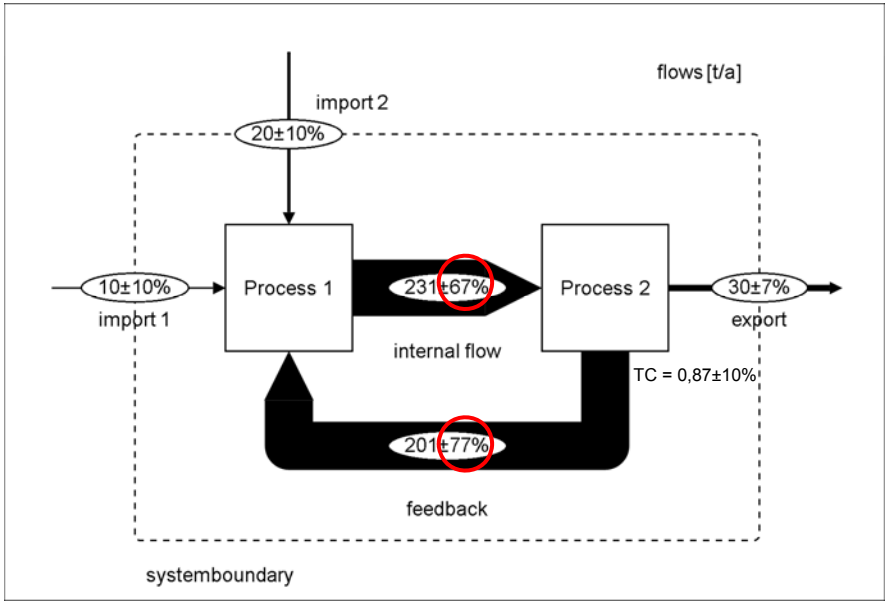
before STAN


INPUT
OUTPUT
Sortierung Holz
Lager Holz
Lager Eisen
Lager Kunststoff-Kunst
Deponie
Sortierung Papier
Lager Papier
Lager Kunststoffe
Kompostierung
Sortierung Sperrmüll

Limits of common sense (1)



Limits of common sense (2)



$$F_{FB} = \frac{TC \cdot (F_{I1} + F_{I2})}{1 - TC}$$

$$\left(\sigma_{F_{FB}}\right)^2 = \left(\frac{\partial F_{FB}}{\partial F_{I1}}\right)^2 \cdot \left(\sigma_{F_{I1}}\right)^2 + \left(\frac{\partial F_{FB}}{\partial F_{I2}}\right)^2 \cdot \left(\sigma_{F_{I2}}\right)^2 + \left(\frac{\partial F_{FB}}{\partial TC}\right)^2 \cdot \left(\sigma_{TC}\right)^2$$

Terms of MFA (overview 1)

substance
good
material
process
system
system boundaries
flow
stock
substance flow analysis (SFA)
material flow analysis (MFA)
balance (balance of goods and materials)
input-output-analysis
transfer function
transfer coefficient kx,j
materials accounting

Terms of MFA (overview 2)

activity
anthroposphere
anthropogenic substance flow
geogenic substance flow
regional substance flow
source
sink
final sink

Terms of MFA

A **substance** is any (chemical) element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogenous (e.g. N, C, Cu, NH_4^+, CO_2).

Using this definition makes clear that “drinking water” is not a substance. It is composed of substances such as pure water, calcium, and many trace elements. Even “PVC” is not a substance, because it consists of polyvinyl chloride and some additives.

Terms of MFA

Goods are defined as economic entities of matter with a positive or negative value (e.g. drinking water, fuel oil, and solid waste, sewage, respectively).

Some goods have no economic value, i.e. they are neutral in their values, e.g. air, rain.

Terms of MFA

The term **material** serves as an umbrella term for both substances and goods.

The term material is used in cases where goods **and** substances are considered, or when it is not yet clear at which level (goods or substances) an analysis will take place.

Terms of MFA

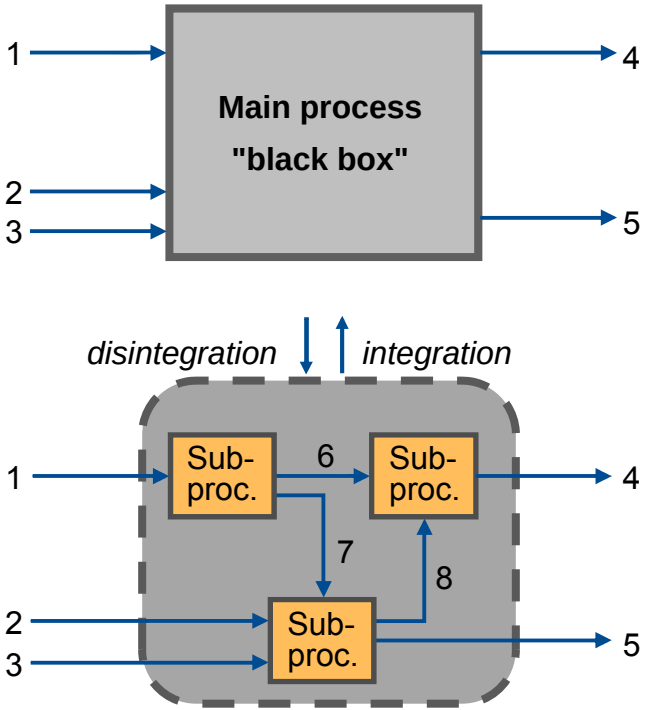
A process is defined as the transformation, transport, or storage of goods and substances.

Processes are:

- the metabolism of a city, human, or animal
- an activity in a household (e.g. waste separation), or plant (e.g. waste incineration furnace, paper mill, landfill)
- a compartment of the environmental (e.g. atmosphere, hydrosphere, or soil)
- a service (e.g. collection of residual waste)

Usually, processes are defined as black boxes, meaning that processes within the box are not taken into account. Only the inputs and outputs are of interest.
If the internal processes are of interest, the process must be divided into two ore more sub-processes.

Processes and sub-processes



Terms of MFA

The total amount of materials stored in a process is designated as the „stock of materials“.

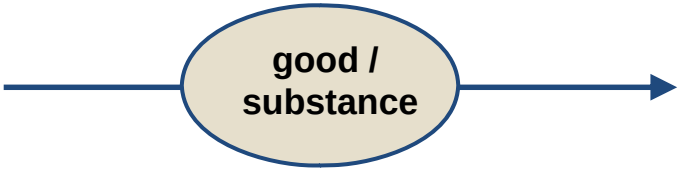
There are two different types of stocks:

- e.g. the waste in an incineration plant – new waste results in an increase of the stock, incineration leads to a decrease of the stock
- e.g. the building as part of the infrastructure – a new building results in an increase of the stock, the demolition of a building makes a decrease of the stock

Terms of MFA

A flow is defined as a “mass flow rate”, i.e. the ratio of mass per time that flows through a conductor, e.g. a water pipe. The physical unit of flow might be given in units of kg/sec or t/yr.

A flux is defined as a flow per “cross section”. In MFA, commonly used cross sections are a person, the surface area of the system, or an entity such as a private household or enterprise. The flux might be given in units like kg/(sec.m²).



Terms of MFA

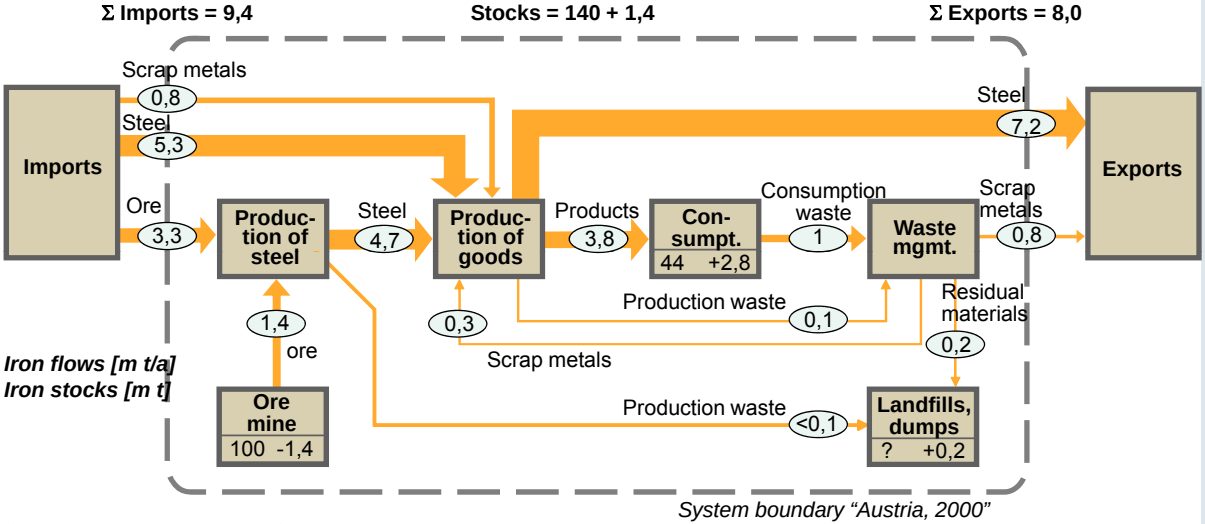
A system is defined by a group of elements, and the interaction between these elements.

In MFA, the elements of a system are named processes and flows.

A system might be an enterprise (e.g. waste incineration plant), a region, a nation, or a private household.

In an MFA-system every good is clearly identified through a process of origin and a target process.

Example of a system



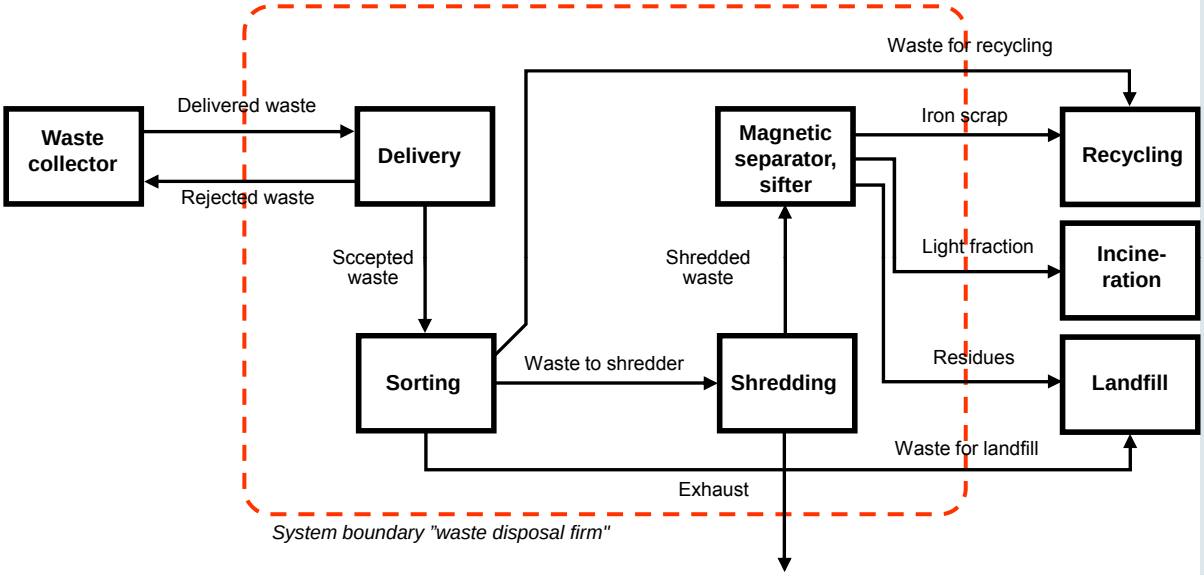
Source: own estimation on basis of Daxbeck et al. 2003

Terms of MFA

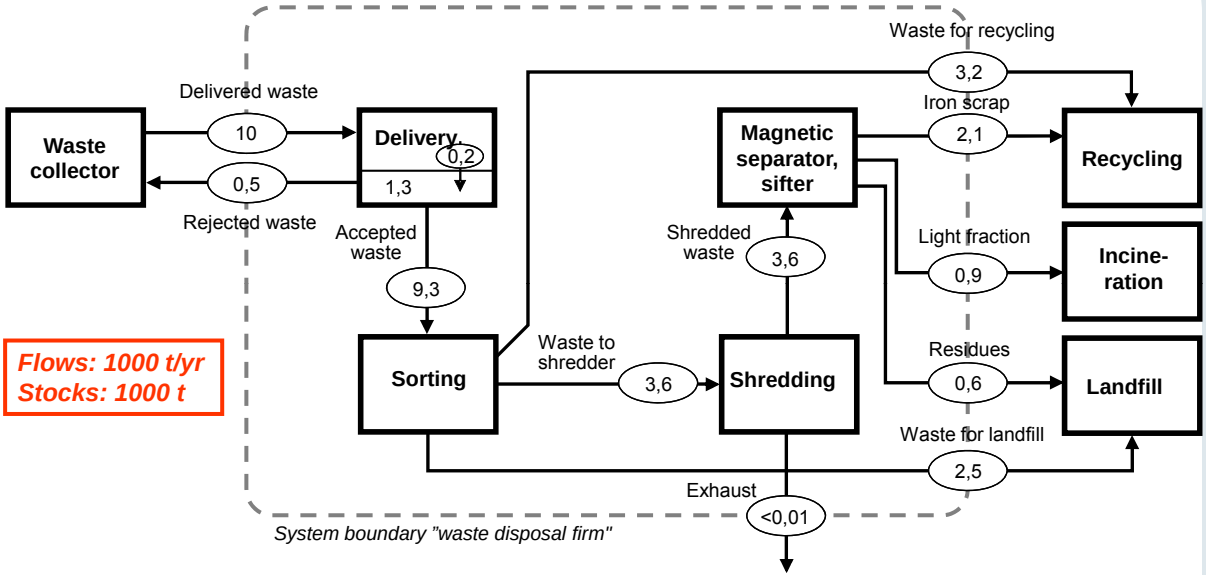
The system boundaries are defined in time and space (temporal and spatial system boundaries). Commonly applied temporal boundaries for anthropogenic systems such as an enterprise, a city, or a nation, periods of 1 year are chosen for reasons of data availability. The spatial system boundary is usually fixed by the geographical area in which the processes are located.

Flows into a system are called imports, flows leaving a system are exports.

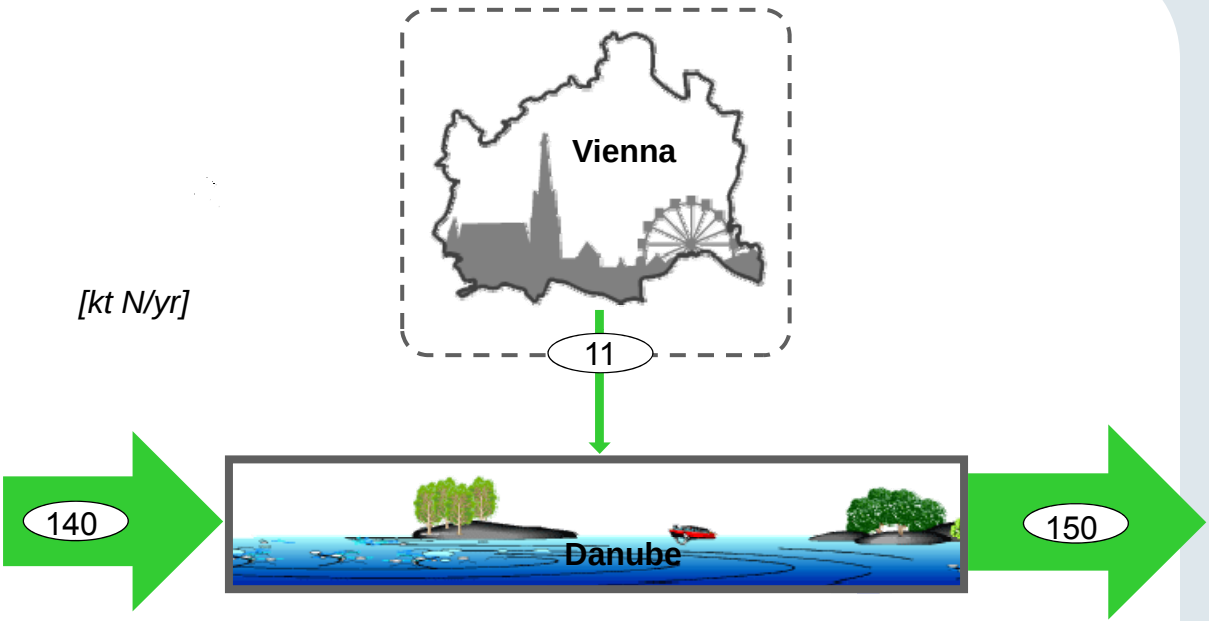
Spatial system boundary



Temporal system boundary

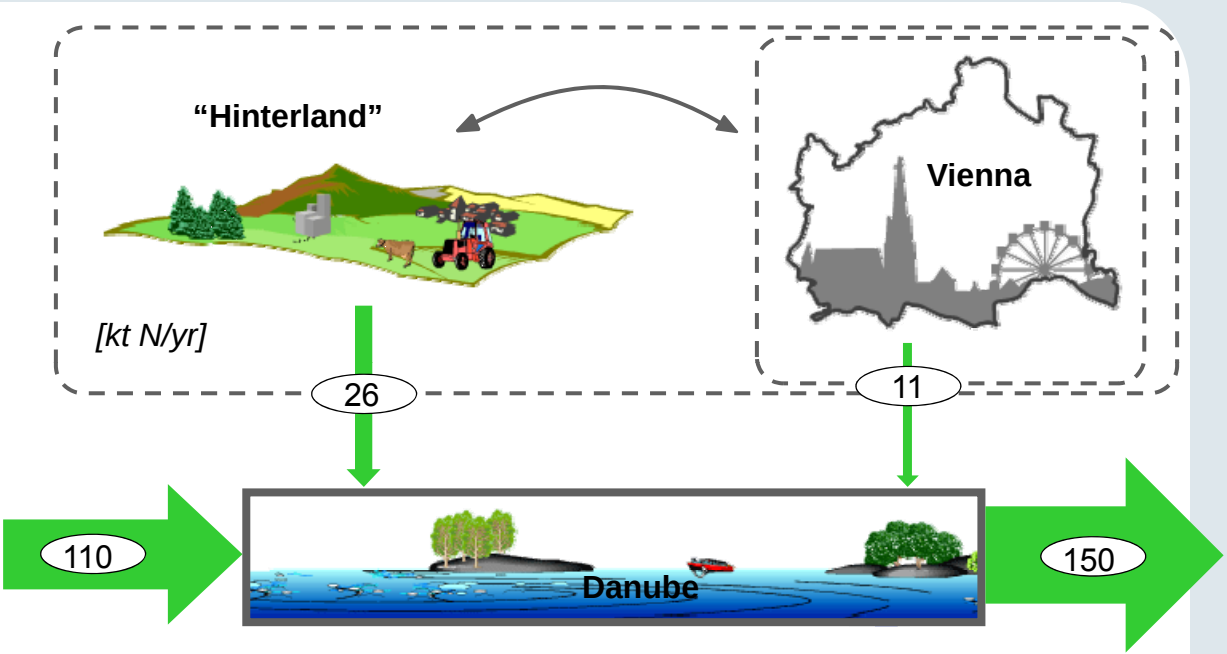


The right choice of the spatial system boundary



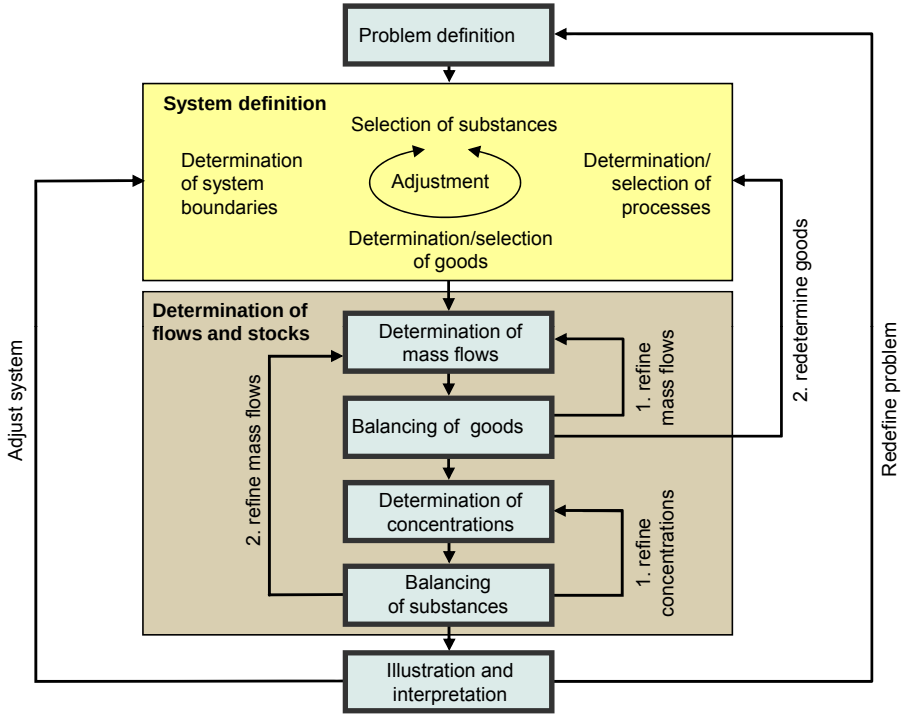
Source: Hendriks & Obernosterer 1998, adapted

The right choice of the spatial system boundary



Source: Hendriks & Obernosterer 1998, adapted

Procedures of an MFA



Choice of substances

The choice of substances depends on the problem

Problem:

The influence of composting organic materials on the nutrient balance in an Austrian region

Selected substances: N, P, (K), …, heavy metals (?)

Choice of substances

The choice of substances depends on

the problem

the legal regulations

Problem:

Environmental impact assessment of a waste incineration plant

Selection: suitable legal regulations (on emissions, on landfills, on sewage emissions, and legal notification)

Choice of substances

The choice of substances depends on

the problem

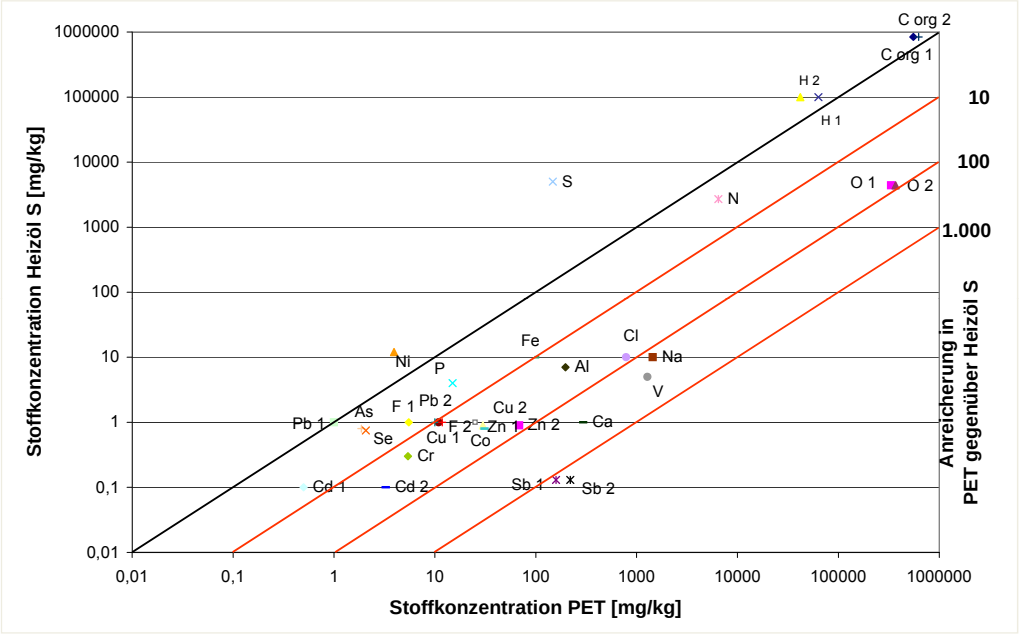
the legal regulation

the potential of resources / pollutants

Problem:
Evaluation of using PET-bottles in an incineration process

		new PET -bottles		PET-bottles in the waste	
element	unit	Analyse A	Analyse B	IVV 1999 (DSD-fraction)	Ecoinvent 2003
Cd	mg/kg		0,20	0,6	3,25
Tl	mg/kg		<0,40	0,3	0,39
Hg	mg/kg		<0,20	1	0,089
Sb	mg/kg	220	220	211	159
As	mg/kg		<1,0	0,4	1,87
Pb	mg/kg		<1,0	2	5,52
Cr	mg/kg		3,8	1	5,42
Co	mg/kg		27	26	31,10
Cu	mg/kg	25	23	12	11,83
Mn	mg/kg		4,2	16	17,74
Ni	mg/kg		1	4	3,94
Vn	mg/kg		<1,0	1	1281
Se	mg/kg			0,5	2,07
Sn	mg/kg			1	0,99
Te	mg/kg			0,5	
Zn	mg/kg			29	68,68

Choice of substances



Choice of substances

The choice of substances depends on

the problem

the legal regulation

the potential of resources / pollutants

the property of substances as an indicator

indicator substances:

similar chemical-physical behaviour

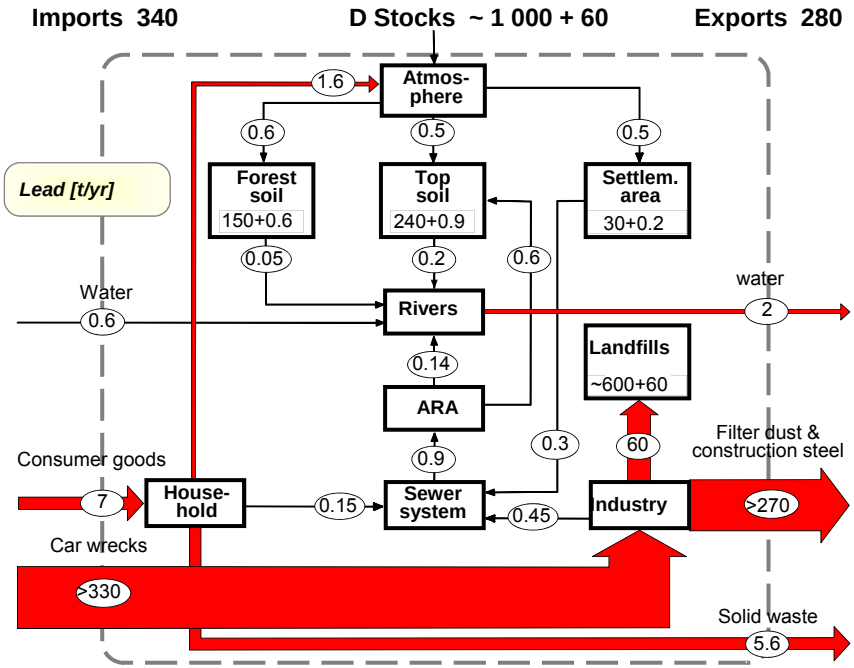
similar toxic behaviour (Sb, As)

trace element

matrix element

As few as possible but as many as necessary.

Example of a regional MFA (1)



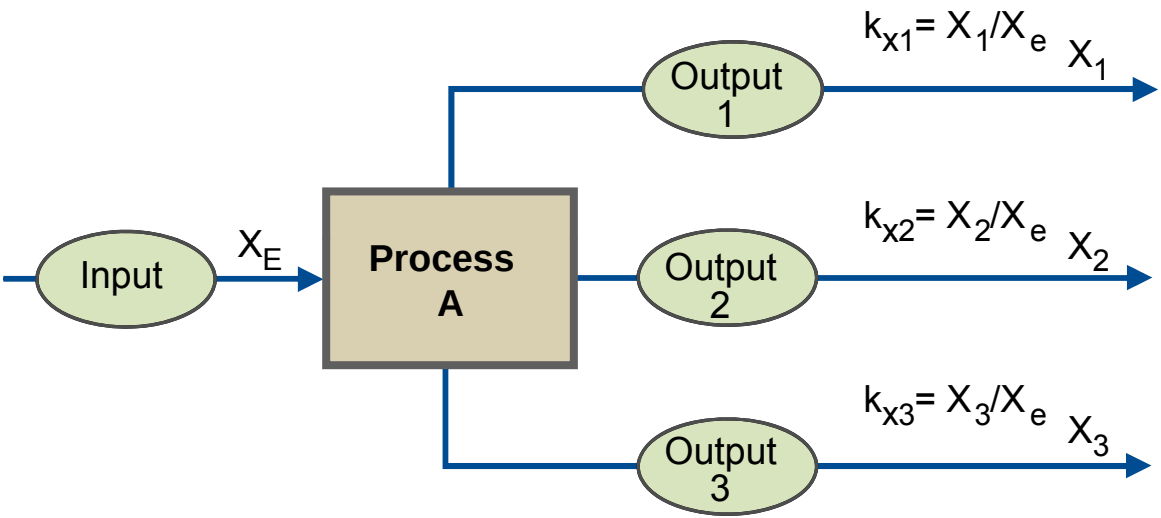
Terms of MFA

The **transfer coefficient** kx,j describes the partitioning of a substance x within a process, and it's transfer into a specific output good j.

The sum of the transfer coefficients of all output goods must be 1, considering that transfers into the stocks are also counted as outputs.

Depending on the problem, it is possible to count only partial input for the calculation of transfer coefficients, e.g. to calculate the efficiency of oxidation within a waste incineration plant we only count the C in the waste, not the C in the air.

Transfer coefficients



Terms of MFA

Materials accounting is a recurring and cost-efficient way of measuring the amount of all important good and substance flows within a system, presuming that by measuring only a few key flows & stocks we know all substance flows in the whole system.

The base for material accounting is an MFA, which serves in understanding the system of study and in identifying the appropriate parameters. Compared to repeatedly performed MFA's the gain of information is cheaper when performing materials accounting.

Terms of MFA

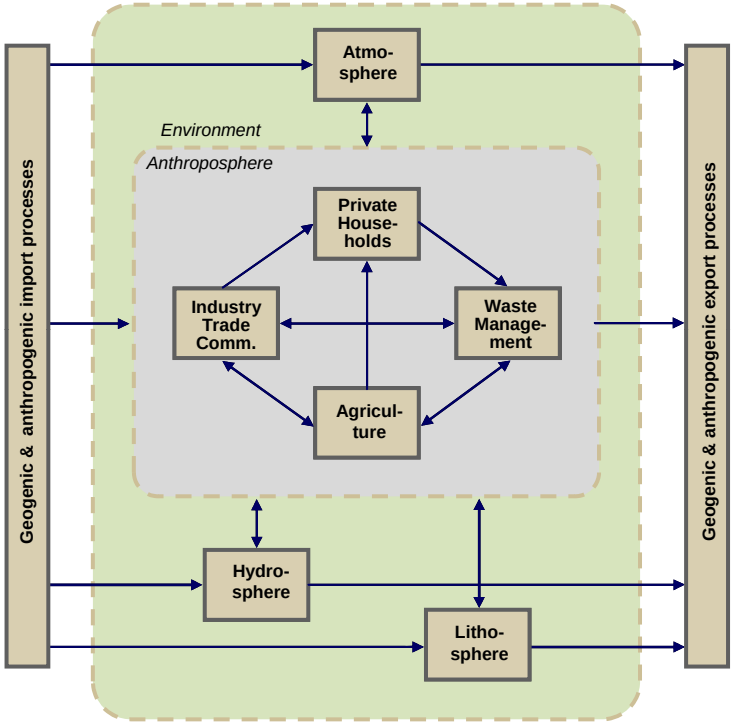
The human sphere of life – a complex system of energy, material, and information in space – is called the „anthroposphere“.

It contains the whole territory that is driven and influenced by mankind.

Substances enter the anthroposphere by raw materials production and are released as waste or emissions to the environment.

The term “anthroposphere” often is used as a synonym for “technosphere” or “bioshpere”.

Terms of MFA


Atmo-
sphere
Environment
Anthroposphere
Private
House-
holds
Industry
Trade
Comm.
Waste
Manage-
ment
Agricul-
ture
Geogenic & anthropogenic import processes
Geogenic & anthropogenic export processes
Hydro-
sphere
Litho-
sphere
System Boundary "Region"

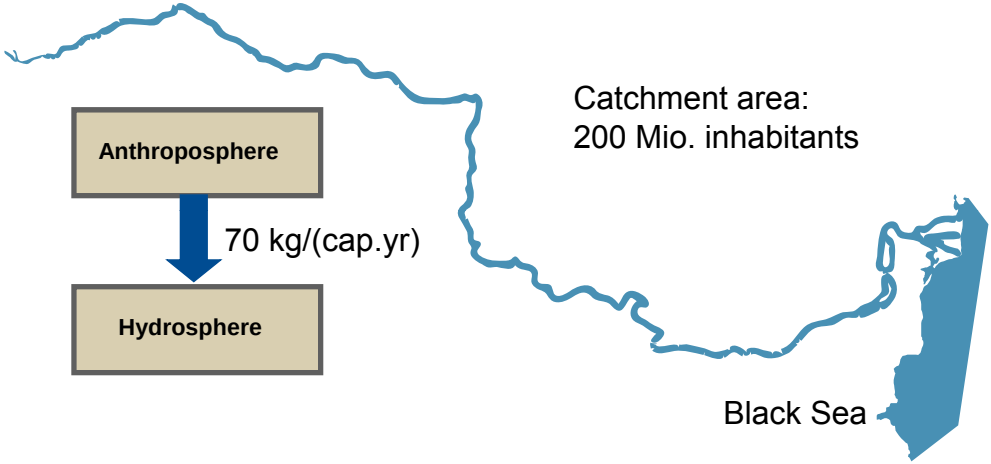
Terms of MFA

An anthropogenic substance flow is the flow of a substance caused by mankind. A geogenic substance flow is the natural flow of a substance.

E.g. the emissions of CO_2 from a composting plant into the atmosphere is an anthropogenic substance flow; the corresponding flow of the good is the whole exhaust from the plant. CO_2 emissions from a forest fire are either anthropogenic or geogenic.

Final sink

Black Sea for Chlorid



after 10 000 years: salinity +0,1%

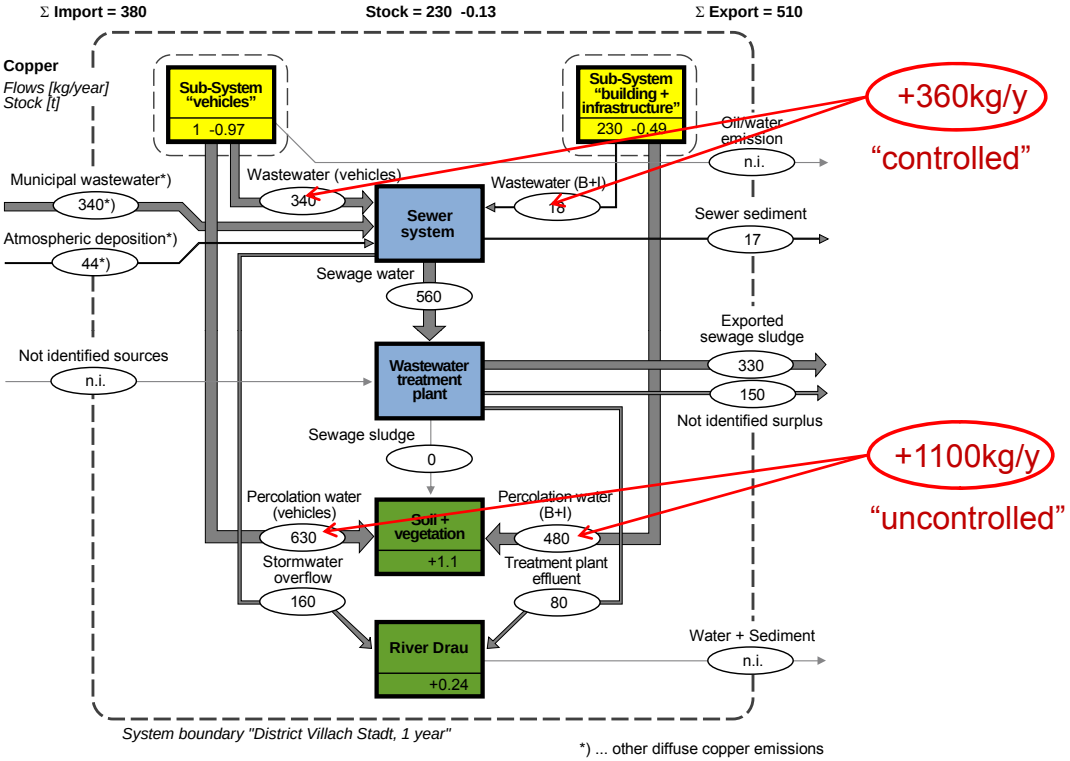
Source: AWS, 2001

The Activity concept

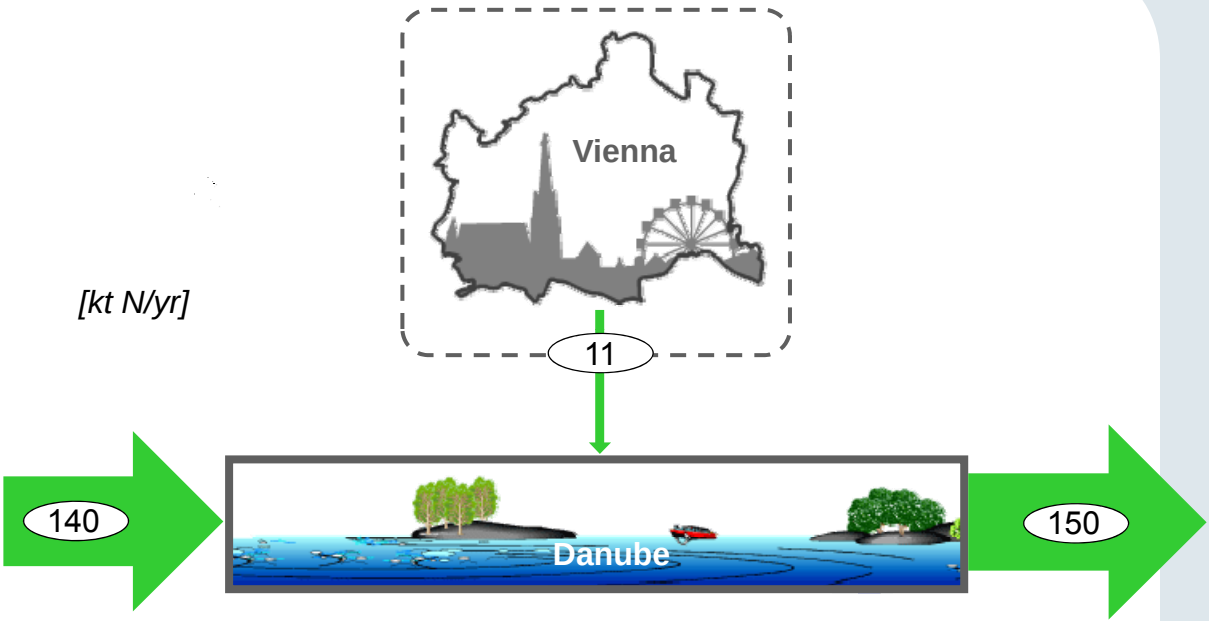
Fluxes of goods through households

Activity	Input	Output			Stock
	[t/c.y]	Sewage	Off gas *[t/c.y]*	Solid residues	*[t/c]*
To nourish	5,7	0,9	4,7	0,1	< 0,1
To clean	60	60	0	0,02	0,1
To reside	10	0	7,6	1	100 + 1
To transport	10	0	6	1,6	160 + 2
Total	86	61	19	2,7	260 + 3

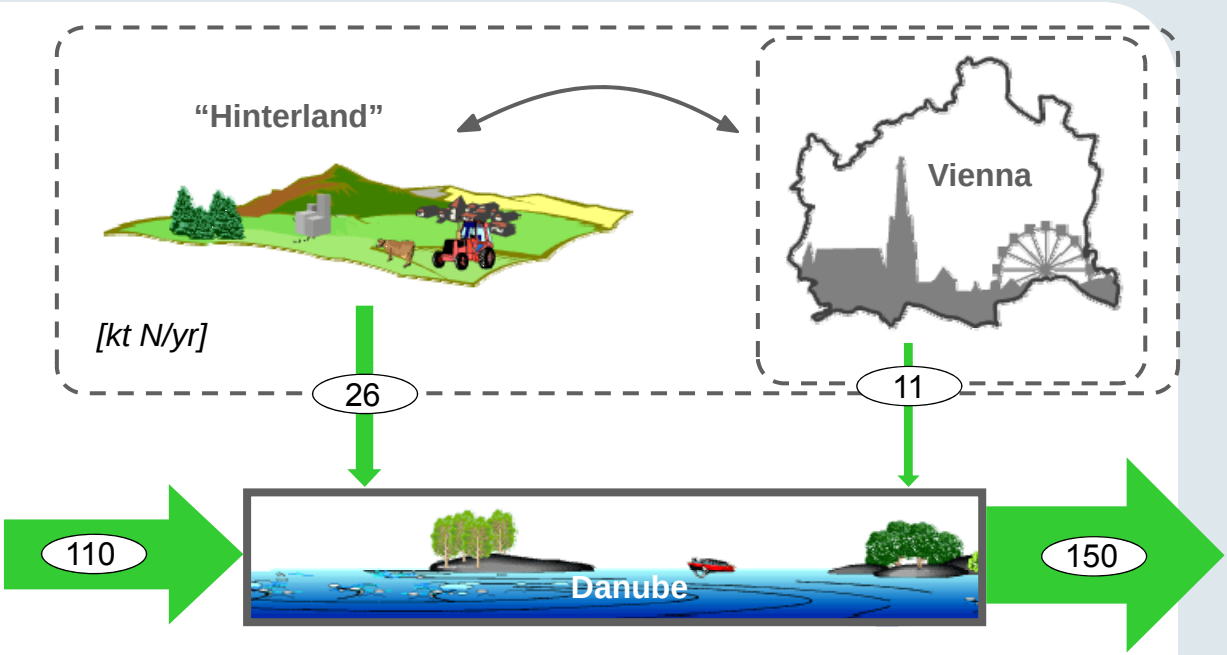
Cities have large surface areas releasing substances to the environment



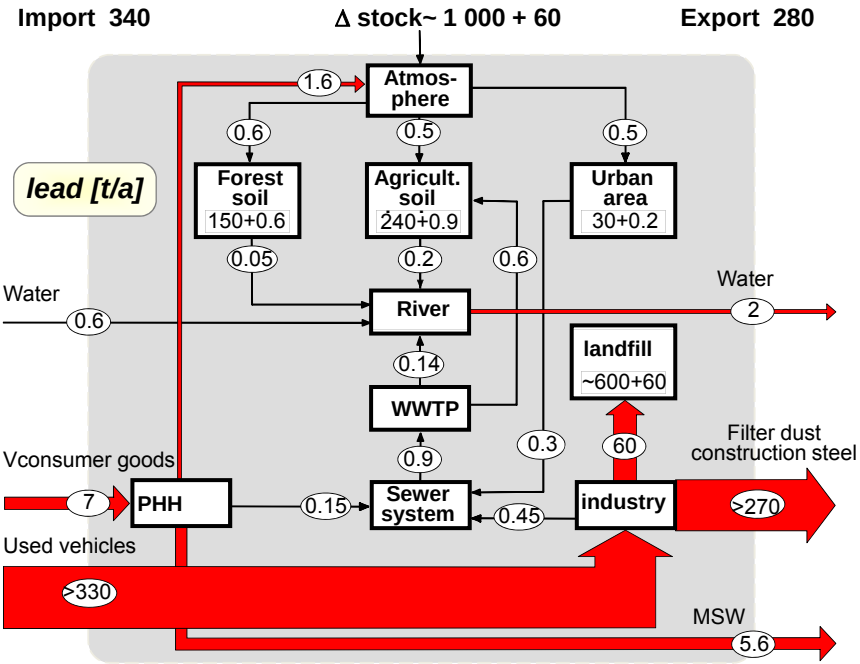
Scale: region and Hinterland



Scale: region and Hinterland



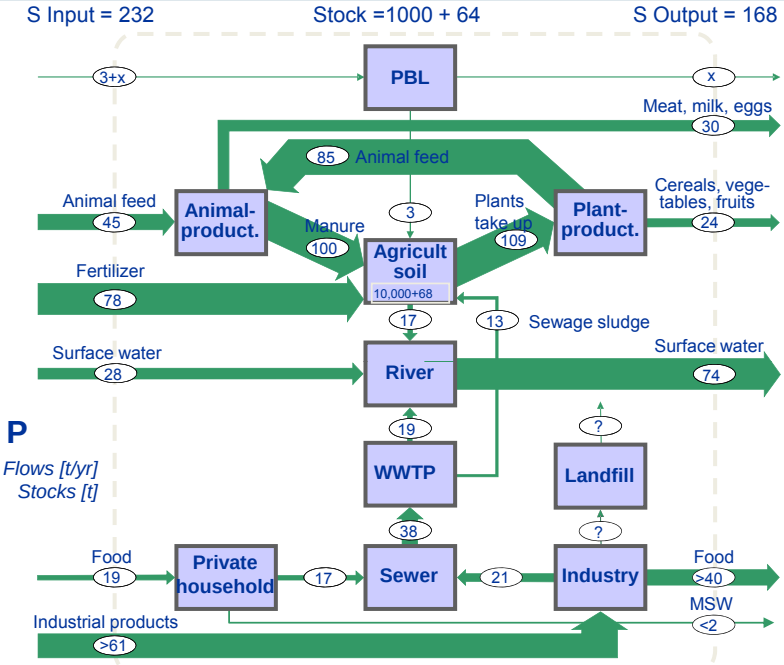
Regional cycles, flows and stocks of Pb



System boundary „Lower Bunz Valley“

1. How to get data about „industry“?
2. How much Pb may be emitted to the river?
3. EIS for landfill: mobility of Pb
4. Which soils is most loaded?
5. Why does Pb in the river not balance?
6. What do you suggest to do with the landfilled shredder residue?

Regional cycles, flows and stocks of P



System Boundary „Bunz Valley, 1987“

1. Calculate concentration of P in the river at the outlet and inlet

	Water	Phosphorous
Import river	~ 36x10^6 m^3/year	28 t P/year
Exort river	~ 67x10^6 m^3/year	74 t P/year
Net precipitation	~ 35x10^6 m^3/year	

Result

Import river	~ 0,8 mg P/l	(0,7778 mg P/l)
Exort river	~ 1,1 mg P/l	(1,1045 mg P/l)

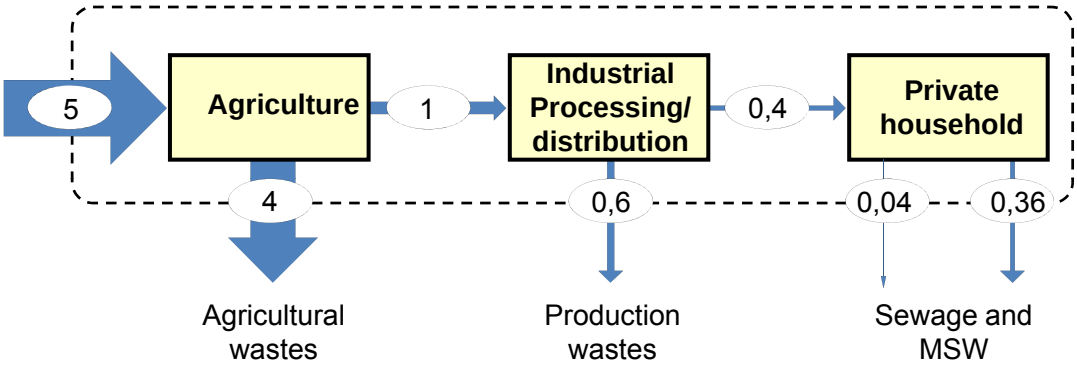
2. Define sustainable P loadings to the river: how much more or less P should be introduced into the river?

Import river	~ 28 t P/year	
Exort river	~ 52 t P/year	(74 t P/year - 52 t P/year =) **-22 t P/year**

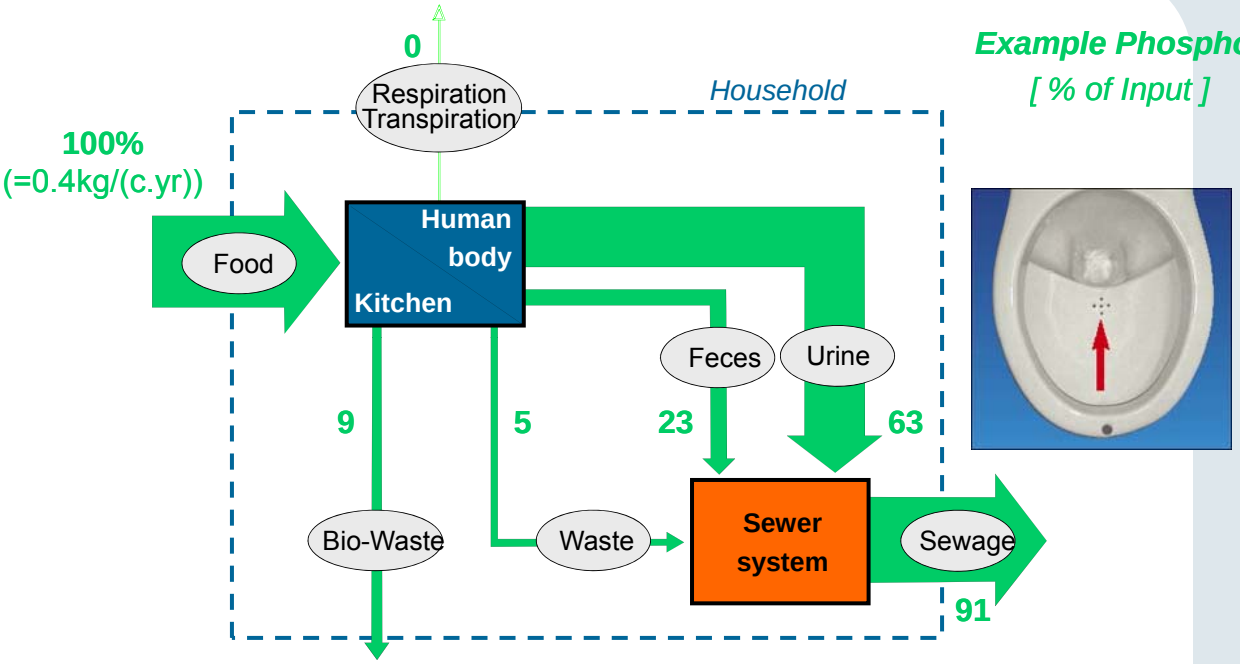
3. What is your suggestion: How can this be achieved?

P-flow for food production and consumption

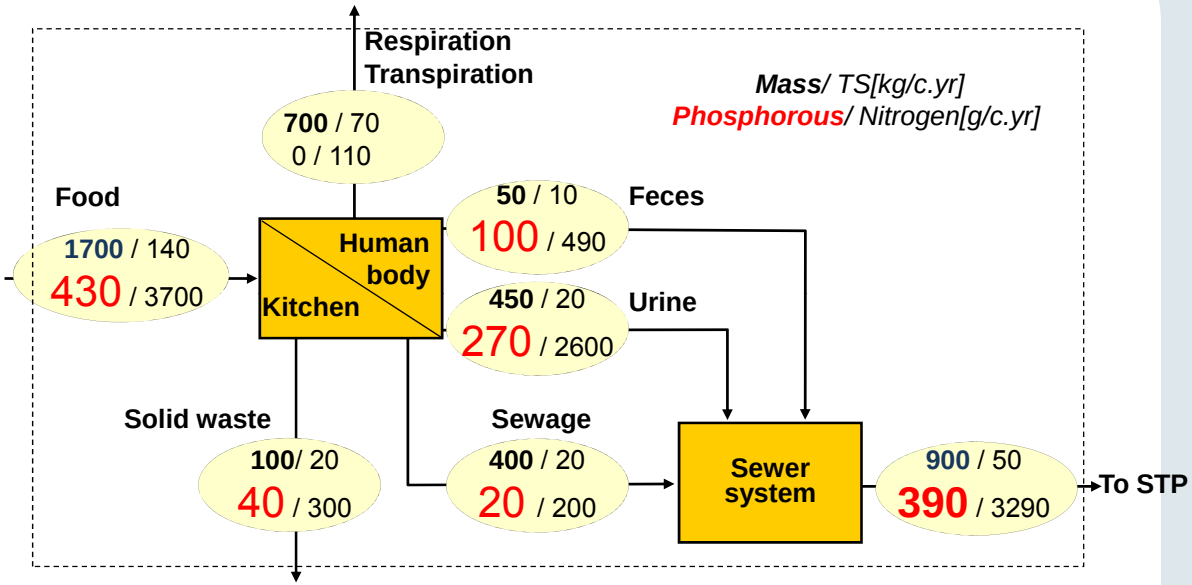
[kg/c.yr]



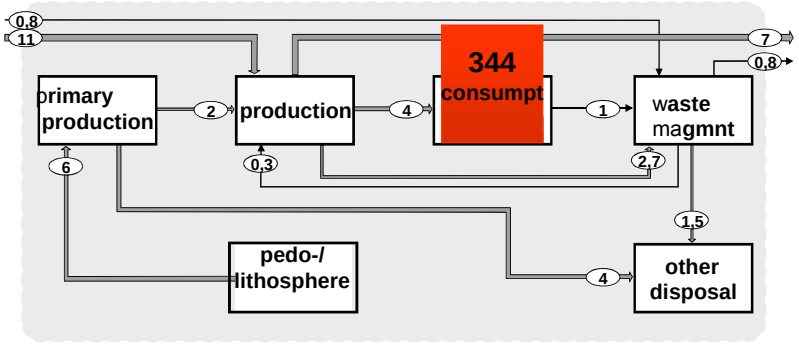
Phosphorous flow through private households

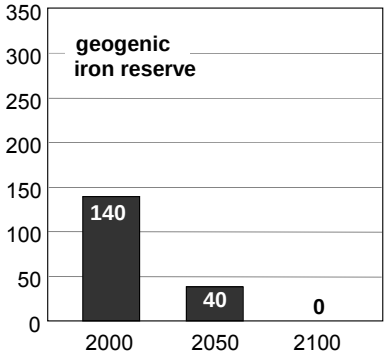


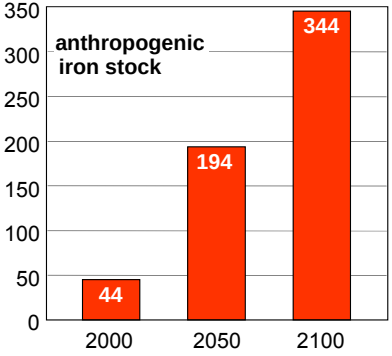
Material flows due to food in PHH



The stock – our future resource







Thank you