



ENV 370 (GR A332 – GRB001)

Environmental system analysis and assessment – Evaluation et analyse environnementale systémique

Aristide Athanassiadis / aristide.athanassiadis@epfl.ch

Jérôme Payet / jerome.payet@epfl.ch

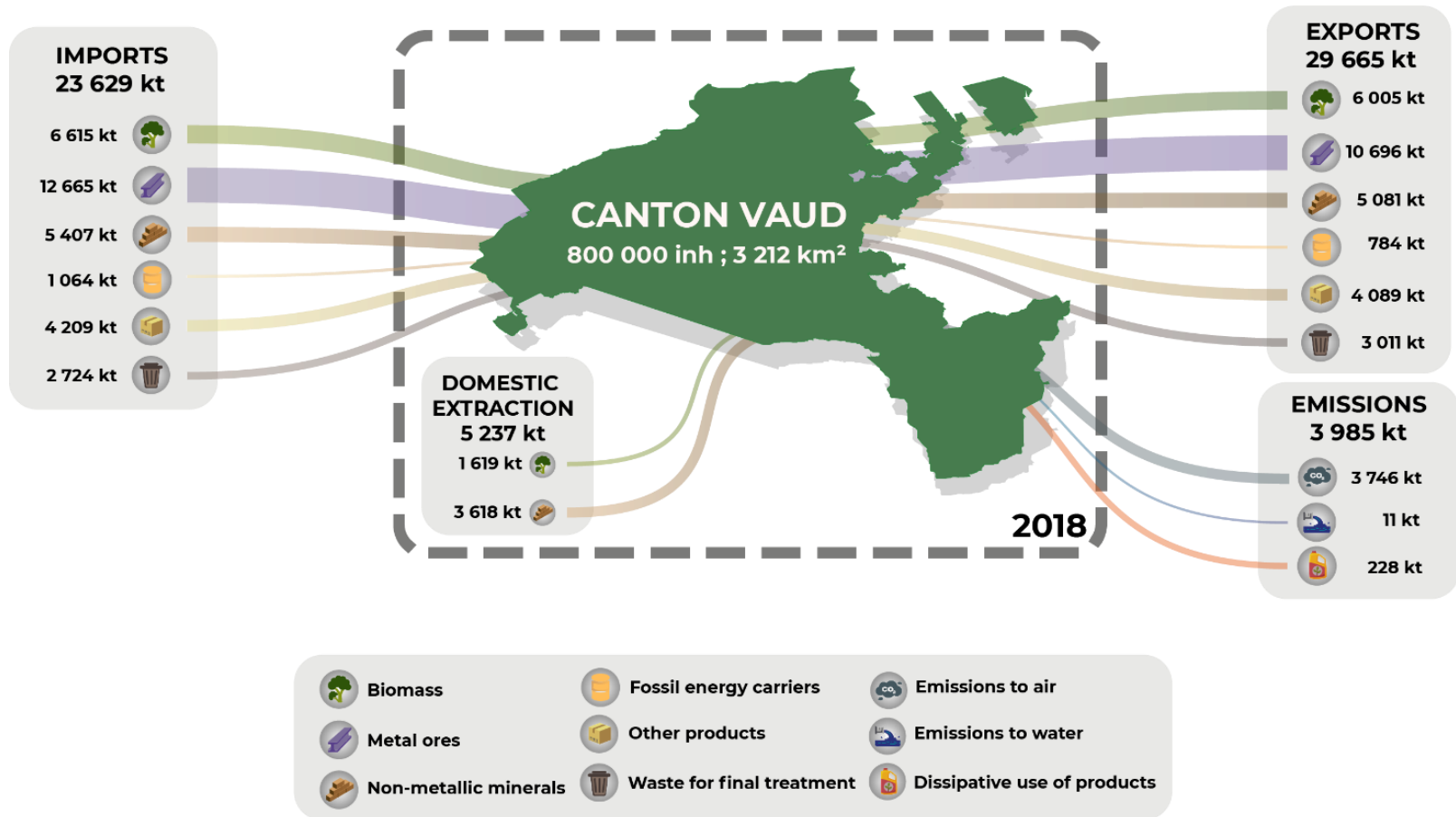
Claudia R. Binder / claudia.binder@epfl.ch

EPFL - Spring 2025

Merci pour votre participation

Aim of the course

Enable you to carry out environmental system analyses and assessments
(through using different assessment methods for different scales)

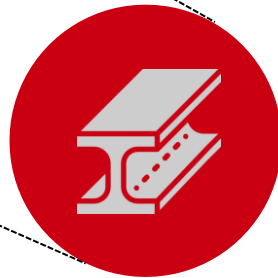
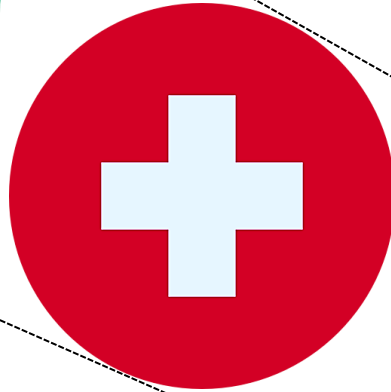
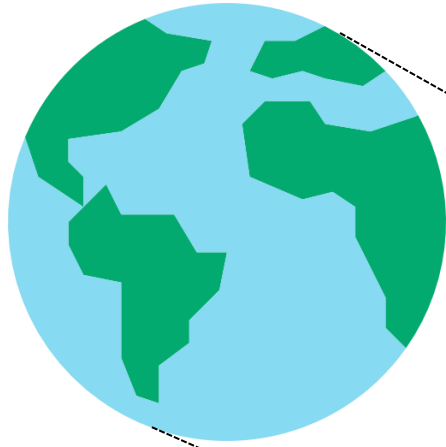


Questions ?

Question ?

1. Par rapport au contenu de la semaine passé?
2. Par rapport à l'organisation du cours?
3. Vous avez digéré les chiffres?

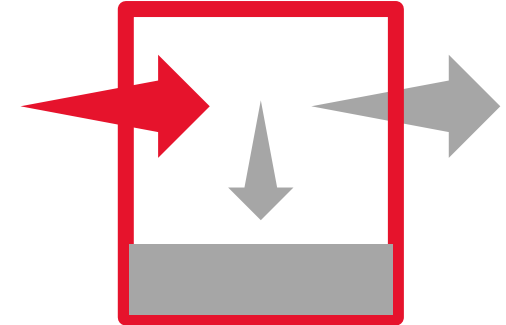
RECAP



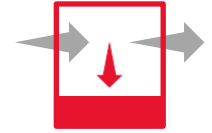
Recap – what number surprised you the most?

From 1900-2015

- Population: 4.6x
- Rural Population: 2.6x
- Urban Population: 14x
- Global primary energy consumption: 15x/year
- Global freshwater use: 6x/year
- Global material extraction: 12x/year
- Material stocks: 27x
- Waste/Outflows: 11x/year
- CO₂ emissions: 15x/year
- GDP : 27x



RECAP – Stocks vs Flows



Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y. M., & Milo, R. (2020). Global human-made mass exceeds all living biomass. *Nature*, 588(7838), 442-444.

Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, 52, 131-140.

RECAP - Global inequalities over use

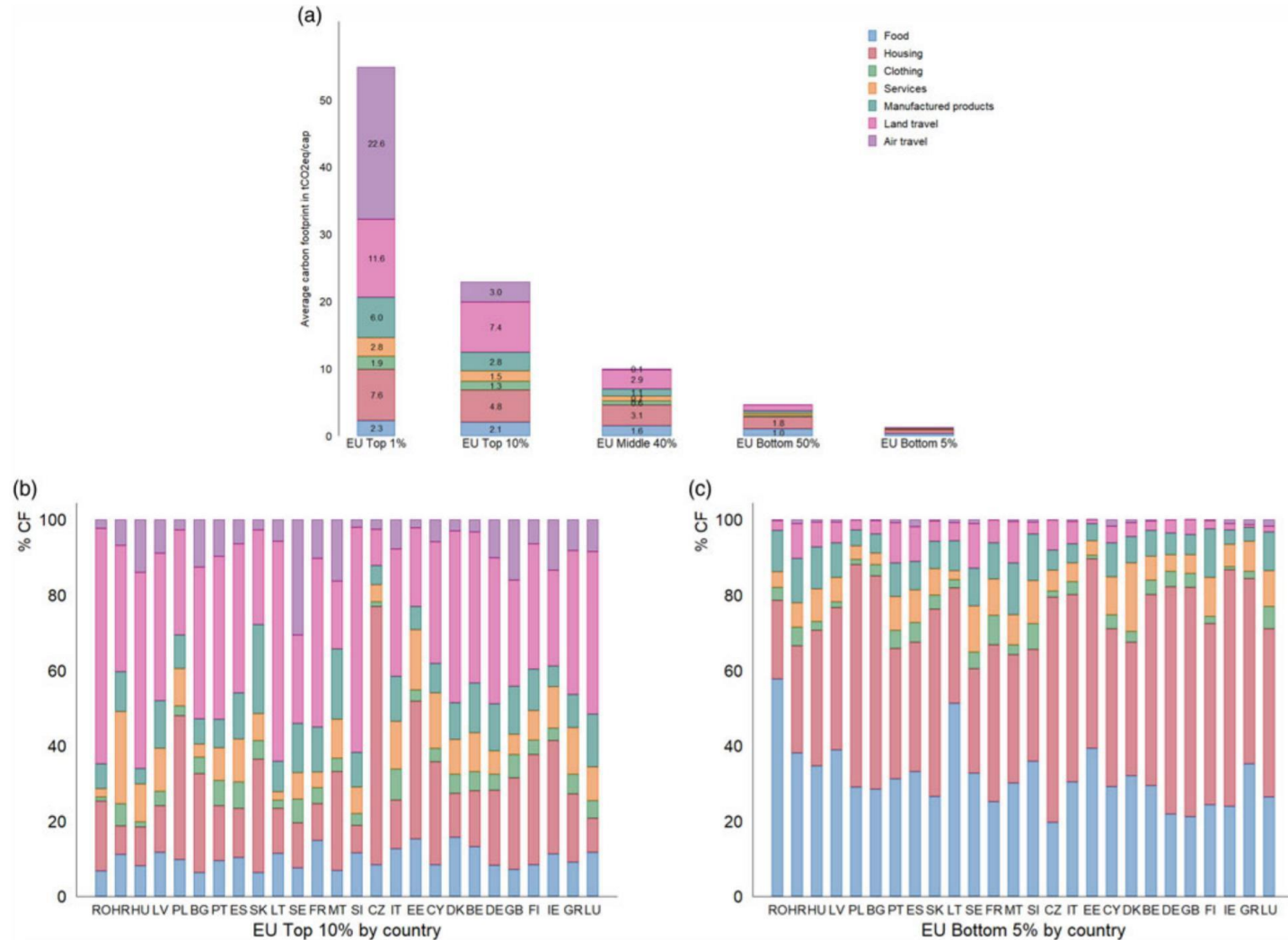


Fig. 3. Average carbon footprint (CF) distribution by consumption category in the European Union (EU) (top). The bottom graph depicts the average CF shares by consumption category and countries of EU top 10% emitters on the left (with CF >15 tCO₂eq/cap) and EU bottom 5% of emitters on the right (with CF <2.5 tCO₂eq/cap). See SI4 for country averages. EU household weights applied. See Section 2 for country codes.

Source: Ivanova D, Wüstenhagen R (2020). The unequal distribution of household carbon footprints in Europe and its link to sustainability. Global Sustainability 3, e18, 1–12. <https://doi.org/10.1017/sus.2020.12>

What about Energy Transition ?

National 4+ categories
material flows

National 13+
categories material
flows

National material
totals and ratios

Filter countries

Clear filter

World x

Filter categories

Clear filter

Fossil fuels x

Metal ores x

Filter flow types

Clear filter

DE (Domestic Extraction,... x

Country ^	Category ⇅	Flow ⇅	2020 ⇅	2021 ⇅	2022 ⇅	2023 ⇅	2024 ⇅
World	Fossil fuels	DE	362,033,658	15,823,307,613	15,915,740,174	15,998,218,386	16,102,490,158
World	Metal ores	DE	405,077,100	9,830,519,158	10,070,051,181	10,321,586,529	10,619,770,397

<https://www.resourcepanel.org/global-material-flows-database>

What about Energy Transition ?



All the Metals We Mined IN ONE CHART

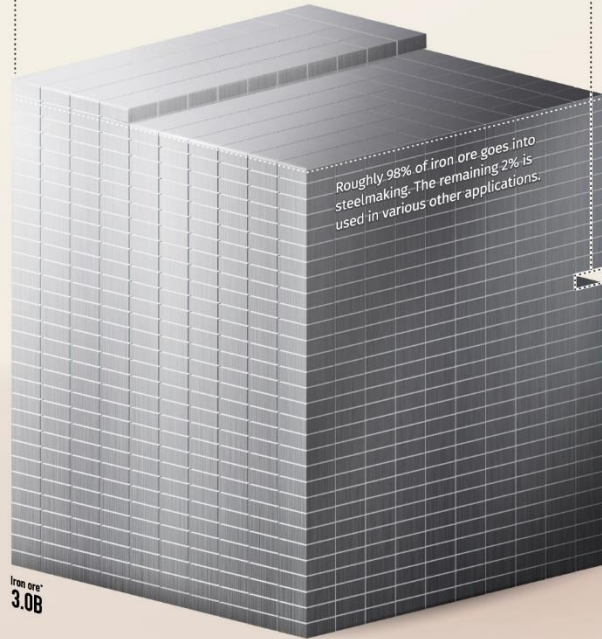
Iron ore*
3,040,000,000 tonnes



Iron ore made up roughly 94% of the 3.2 billion tonnes of metals mined in 2019.



= 1,000,000 tonnes



Industrial metals 207,478,486 tonnes



Aluminum is the world's second-most used metal after iron, found in everything from electronic devices to aircraft parts.



Manganese is mainly used in iron and steel manufacturing and is a key ingredient in lithium-ion batteries.



Copper production is one-third that of aluminum, though it has several uses ranging from wiring to construction.



Chromium enhances the hardenability and corrosion resistance of stainless steel.



Total Metals 3,248,814,334 tonnes

Metals are the building blocks of the global economy. From iron ore to rare earths, here are all the metals we mined in 2019.



Metals vs. Ores

Ores are naturally occurring rocks that contain metals or metal compounds.

Metals are the valuable parts of ores that can be extracted and sold.

Tech and precious metals 1,335,848 tonnes



Niobium is a rare metal used in superalloys for jet and rocket engines.



Lithium and cobalt are critical ingredients of lithium-ion batteries for electric vehicles.



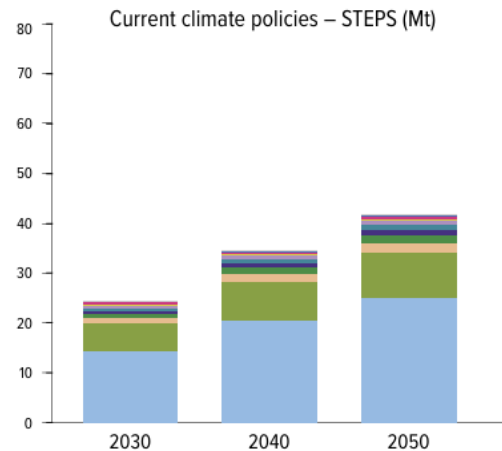
Indium is used to make indium tin oxide, an important part of touch screens, TVs, and solar panels.



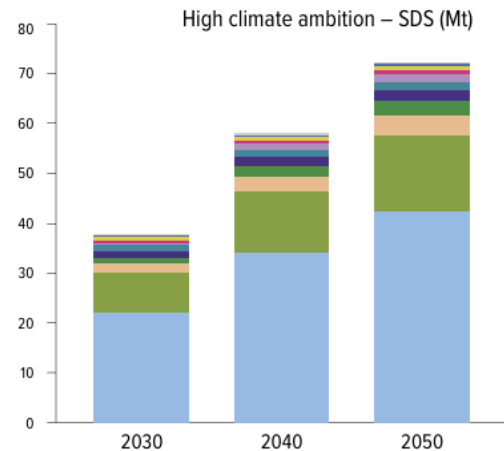
<https://www.visualcapitalist.com/all-the-metals-we-mined-in-one-visualization/>

What about Energy Transition ? Metal needs

Global metal demand by commodity for clean energy technologies in a STEPS and SDS scenario respectively (Mt*)



2050 Metals demand
Current climate policy | **45Mt**



2050 Metals demand
Ambitious climate policy | **75Mt**

*Mt = million tonnes, annual (including lithium expressed as metal equivalent)

% metal required in 2050 for clean energy technologies vs. 2020 overall use (Global SDS ambitious climate scenario).** †

Al	Lithium	2,109%	Silicon	62%
Cu	Dysprosium	433%	Terbium	62%
Ni	Cobalt	403%	Copper	51%
Zn	Tellurium	277%	Aluminium	43%
Pb	Scandium	204%	Tin	28%
Si	Nickel	168%	Germanium	24%
Li	Praseodymium	110%	Molybdenum	22%
Mn	Gallium	77%	Lead	22%
Cr	Neodymium	66%	Indium	17%
Co	Platinum	64%	Zinc	14%
Oth	Iridium	63%	Silver	10%

<https://www.eurometaux.eu/media/hr2ftbp3/2022-policymaker-summary-report-final-13-5-22.pdf>

What about Energy Transition ? (Lithium need in EU x35)

World Mine Production and Reserves: Reserves for Argentina, Australia, Brazil, China, the United States, and “Other countries” were revised based on company and Government reports.

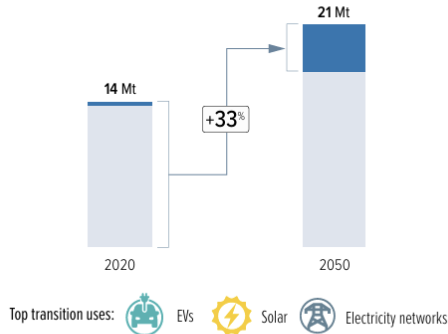
	Mine production		Reserves ⁴
	<u>2022</u>	<u>2023^e</u>	
United States	W	W	1,100,000
Argentina	6,590	9,600	3,600,000
Australia	74,700	86,000	⁵ 6,200,000
Brazil	^e 2,630	4,900	390,000
Canada	^e 520	3,400	930,000
Chile	38,000	44,000	9,300,000
China	^e 22,600	33,000	3,000,000
Portugal	^e 380	380	60,000
Zimbabwe	^e 1,030	3,400	310,000
Other countries ⁶	—	—	<u>2,800,000</u>
World total (rounded)	<u>⁷146,000</u>	<u>⁷180,000</u>	28,000,000

<https://www.usgs.gov/centers/national-minerals-information-center/lithium-statistics-and-information>

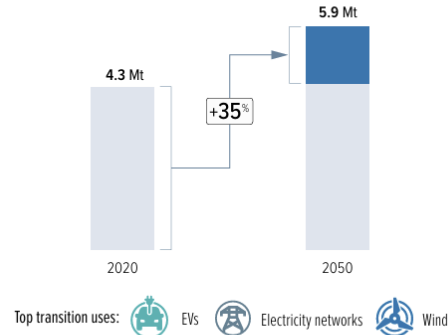
What about Energy Transition ? In Eu ? Opening of new Mines ?

● Energy transition uses ● Other uses

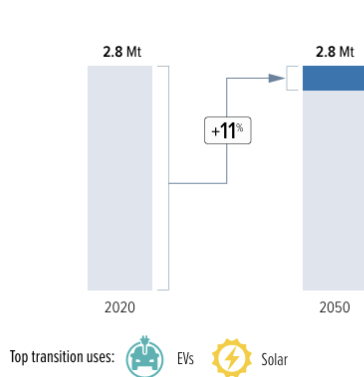
Aluminium (Mt)



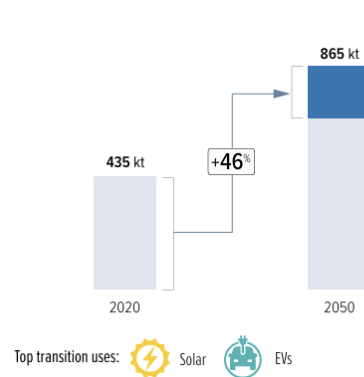
Copper (Mt)



Zinc (Mt)



Silicon (kt)



BATTERY METALS

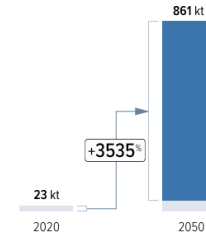
Europe will require significant new supplies of nickel, lithium, and cobalt for its domestic battery cathode manufacturing plans. Of these metals, Europe only has a significant existing market for nickel, which is mainly used in stainless steel.

By 2050, batteries will be Europe's major use for lithium, nickel, and cobalt under all the study's scenarios, with new demand

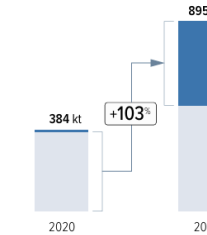
reaching up to 3500% of Europe's lithium consumption today, 330% of cobalt, and more than 100% of nickel.

Uncertain technology developments after 2030 will likely impact these long-term projections. Regular attention is required to the battery market and potential breakthrough technologies.

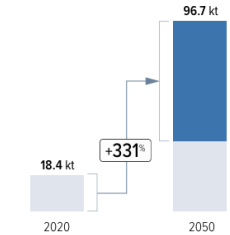
Lithium (kt, LCE)



Nickel (kt)



Cobalt (kt)



Top transition uses (all battery metals): EVs, Battery storage

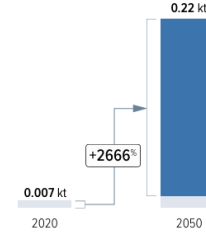
RARE EARTH METALS

Significant volumes of rare earth elements in permanent magnets will be required in Europe's electric vehicles and wind turbines.

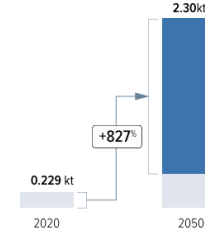
But Europe will only require new supplies of rare earth metals if it is successful in building up domestic permanent magnets production – competing against China's near monopoly of the rare earths/permanent magnets market.

Even a moderate level of European domestic magnets production would transform the European rare earths market, requiring between 600% and 2700% extra compared with Europe's consumption today.

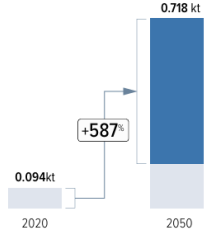
Dysprosium (kt)



Neodymium (kt)



Praseodymium (kt)



Top transition uses (rare earth elements): EVs, Wind

<https://www.eurometaux.eu/media/hr2ftbp3/2022-policymaker-summary-report-final-13-5-22.pdf>

Opening of new Mines ? What to consider ?

[Actualités](#)[Économie](#)[Vidéos](#)[Débats](#)[Culture](#)[Le Goût du Monde](#)[Services](#)

ÉCONOMIE • INDUSTRIE

Une première mine de lithium va être exploitée en France, avec l'ambition d'équiper 700 000 véhicules en batteries par an

Le leader mondial des spécialités minérales pour l'industrie Imerys a annoncé, lundi, le lancement d'un important projet d'exploitation à Echassières, dans l'Allier.

Par Jean-Yves Vif (Moulins, correspondant)

Publié le 24 octobre 2022 à 08h01, modifié le 25 octobre 2022 à 06h01 • Lecture 3 min. • [Read in English](#)

Lire plus tard



Article réservé aux abonnés



Les études et carottages prévoient la présence en profondeur de fortes concentrations d'hydroxyde de lithium, au total un million de tonnes d'une teneur entre 0,9 % et 1 % d'oxyde, confirmant les estimations du Bureau de recherches géologiques et minières (BRGM). Ce gisement permettra l'extraction de 34 000 tonnes pendant vingt-cinq ans. Imerys deviendra ainsi un fournisseur de premier plan du marché européen, avec une capacité d'équipement de 700 000 véhicules en batteries lithium-ion par an.

Lire aussi : [Réindustrialisation : « Le gouvernement a lancé la machine, mais il reste le plus dur, changer les esprits »](#)



Outre les études déjà réalisées pour 30 millions d'euros, le projet nécessitera un investissement minimum d'un milliard d'euros, sur la base d'un coût de production du lithium estimé entre 7 euros et 9 euros le kilo. Imerys le juge « très compétitif, en particulier sur le

https://www.lemonde.fr/economie/article/2022/10/24/imerys-annonce-l-ouverture-de-la-premiere-production-de-lithium-en-france-qui-fera-de-l-entreprise-un-acteur-de-poids-du-marche-europeen_6147060_3234.html

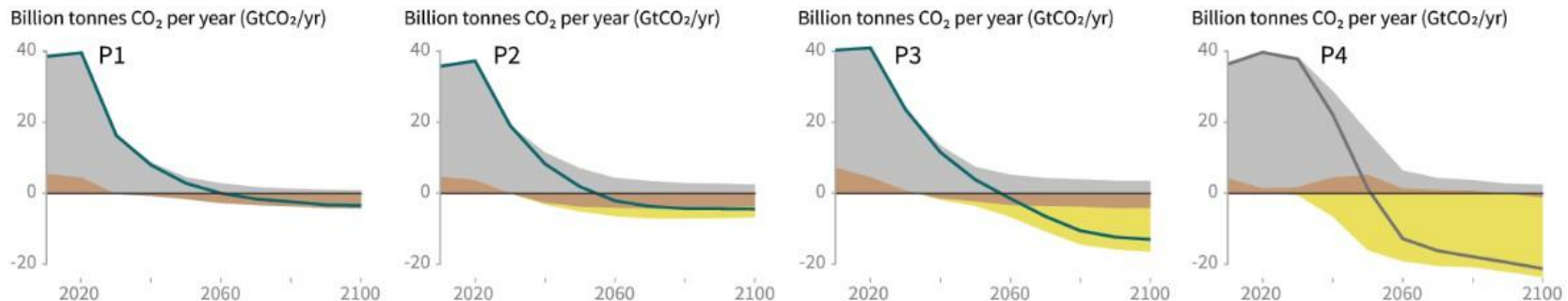
IPCC Pathways that stay under 1,5 C

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways

● Fossil fuel and industry ● AFOLU ● BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

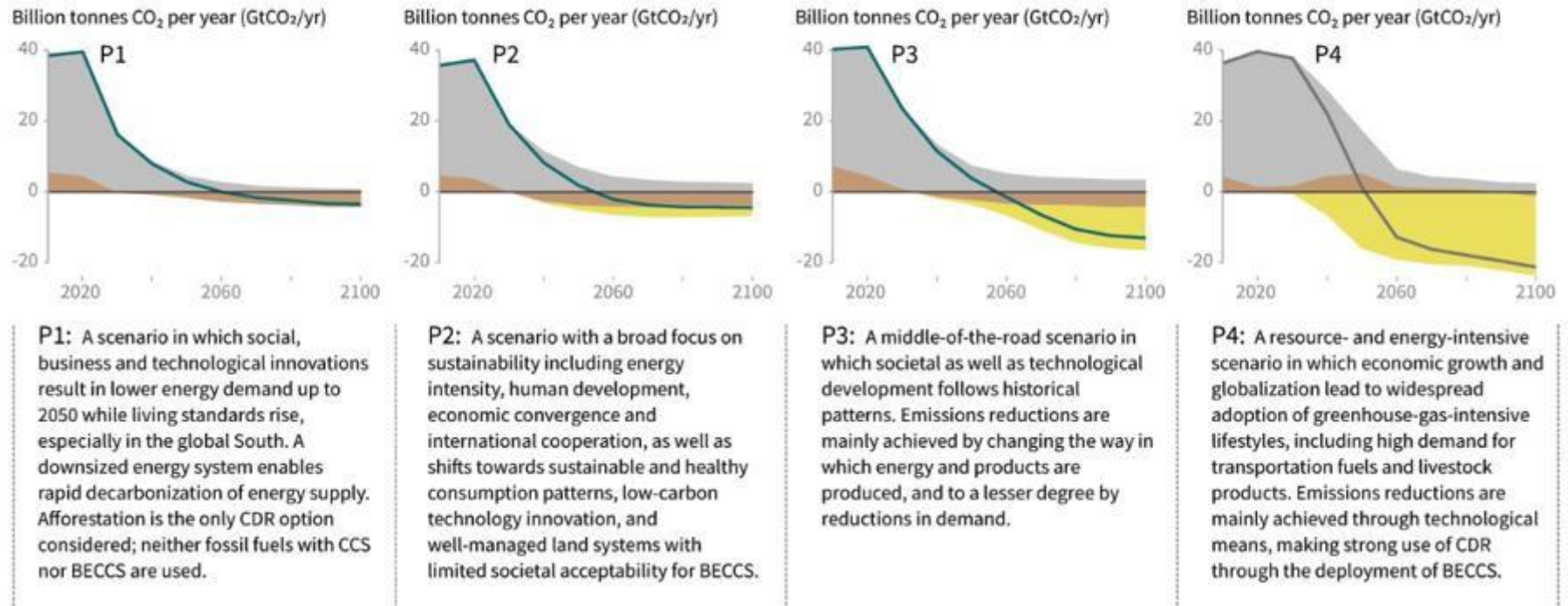
P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Source: IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:[10.1017/9781009157940.001](https://doi.org/10.1017/9781009157940.001).

What Scenario is most desirable ?

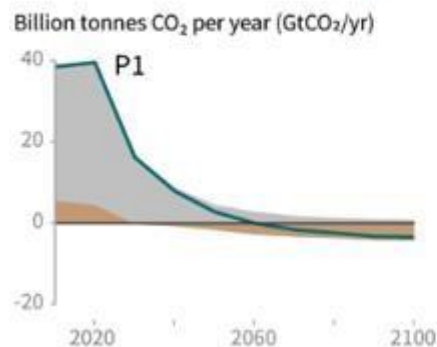
● Fossil fuel and industry ● AFOLU ● BECCS



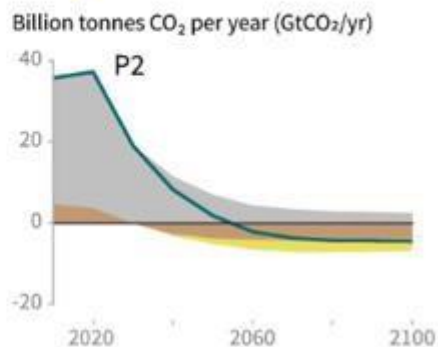
Source: IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:[10.1017/9781009157940.001](https://doi.org/10.1017/9781009157940.001).

What Scenario is most likely ?

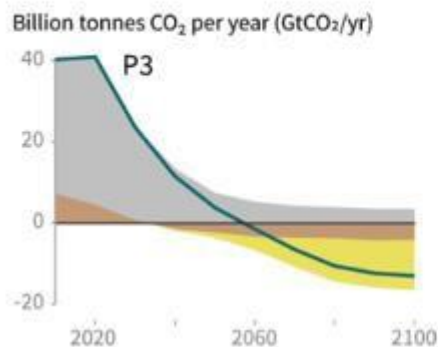
● Fossil fuel and industry ● AFOLU ● BECCS



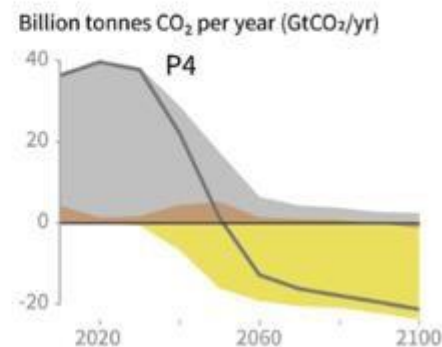
P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.



P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.



P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.



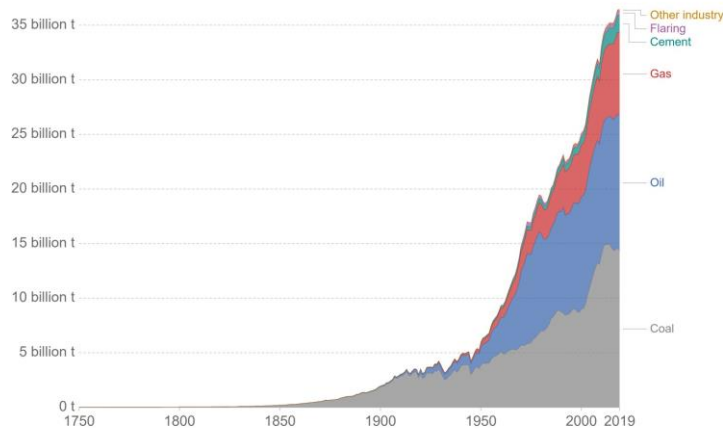
P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Source: IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:[10.1017/9781009157940.001](https://doi.org/10.1017/9781009157940.001).

What solutions do we have ? Technologies

CO₂ emissions by fuel type, World

Annual carbon dioxide (CO₂) emissions from different fuel types, measured in tonnes per year.



Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.

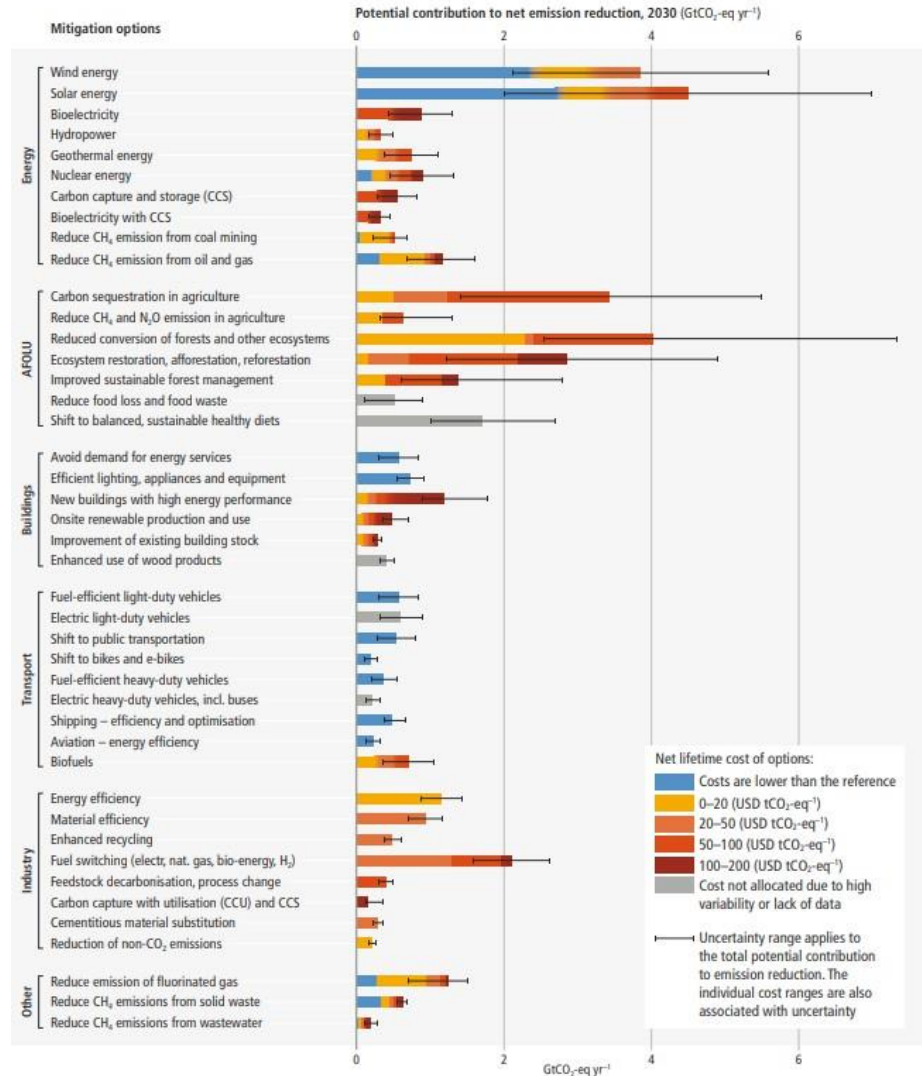


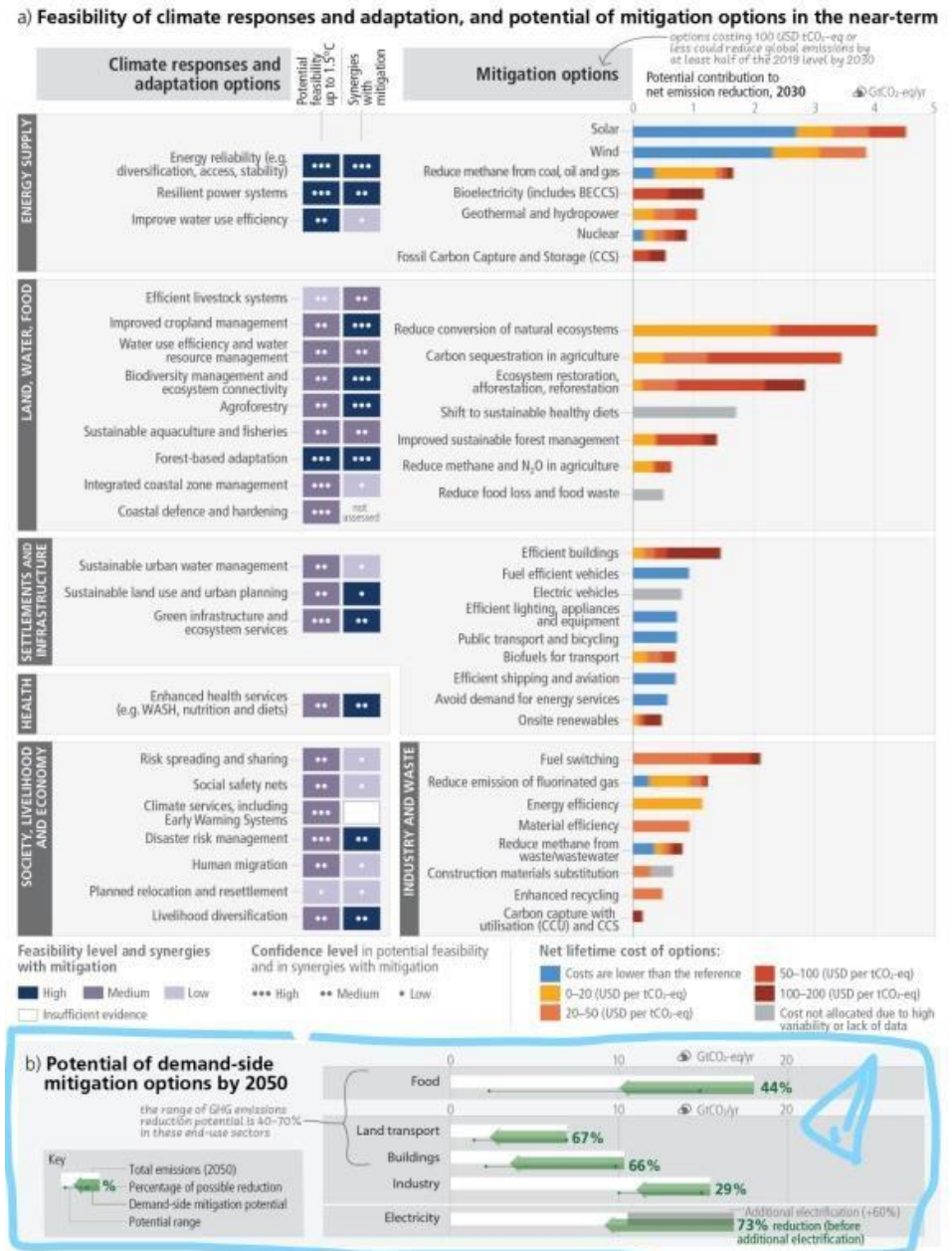
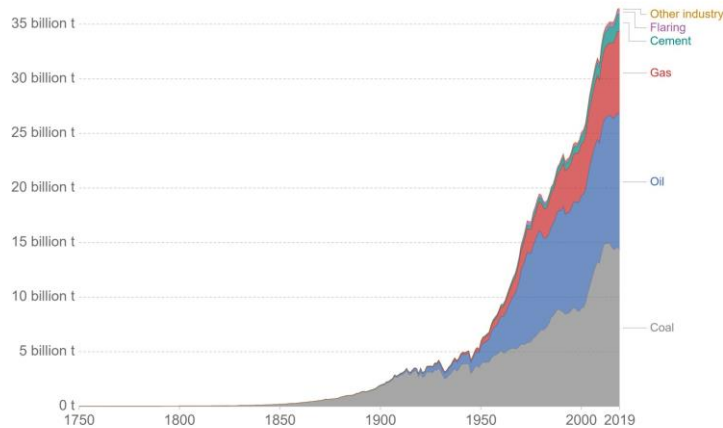
Figure SPM.7 | Overview of mitigation options and their estimated ranges of costs and potentials in 2030.

Source: IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

What solutions do we have ? Technologies

CO₂ emissions by fuel type, World

Annual carbon dioxide (CO₂) emissions from different fuel types, measured in tonnes per year.

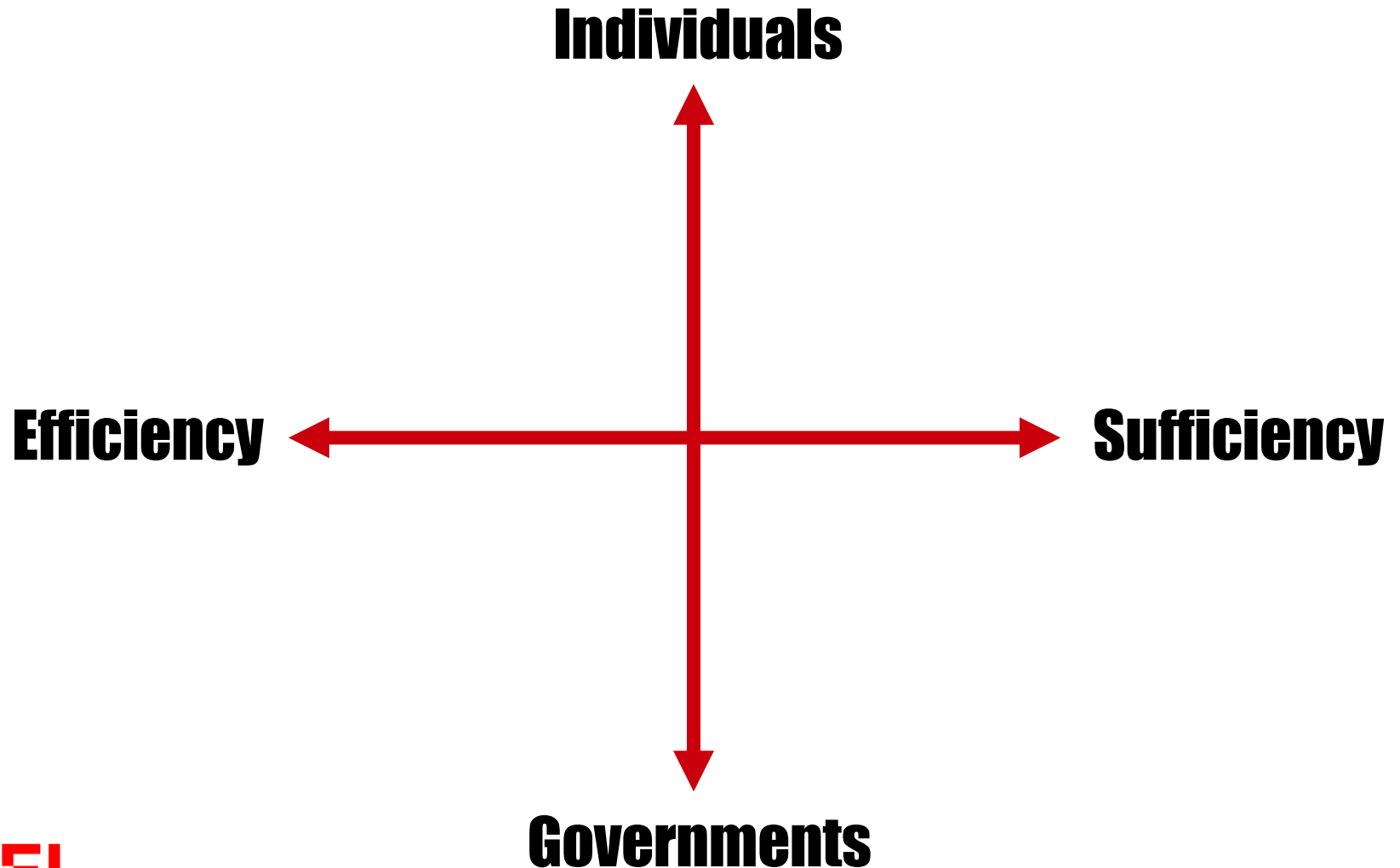


Source: IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

Who has to do something about it ?

How to do it ?

Give me some solutions ?



What is happening ? Paris agreement (2015)



SDGs (2030)



Green New Deal



EU Green New Deal



Examples at a city level (Lausanne climat)

 Ville de Lausanne



Plan climat

0% carbone

100% solidaire



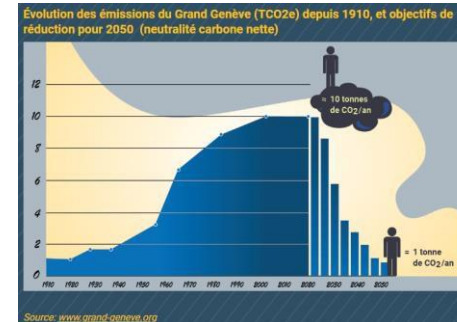
PLAN CLIMAT CANTONAL 2030

2^e GÉNÉRATION



PARTIE I: Objectifs et stratégie

PARTIE II: Plan de mesures 2021-2023



Source: <https://www.ge.ch/teaser/plan-climat-cantonal-geneve-2030/plan-climat>

Source: <https://www.ge.ch/document/24973/telecharger>

Examples at a city level (Transition Towns)



Select Language ▼



Search...

Login / Register

Donate

Get involved

About the Movement

Transition Near me

Stories

Do Transition

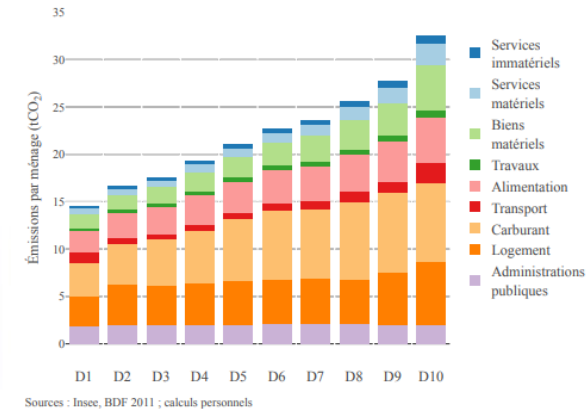
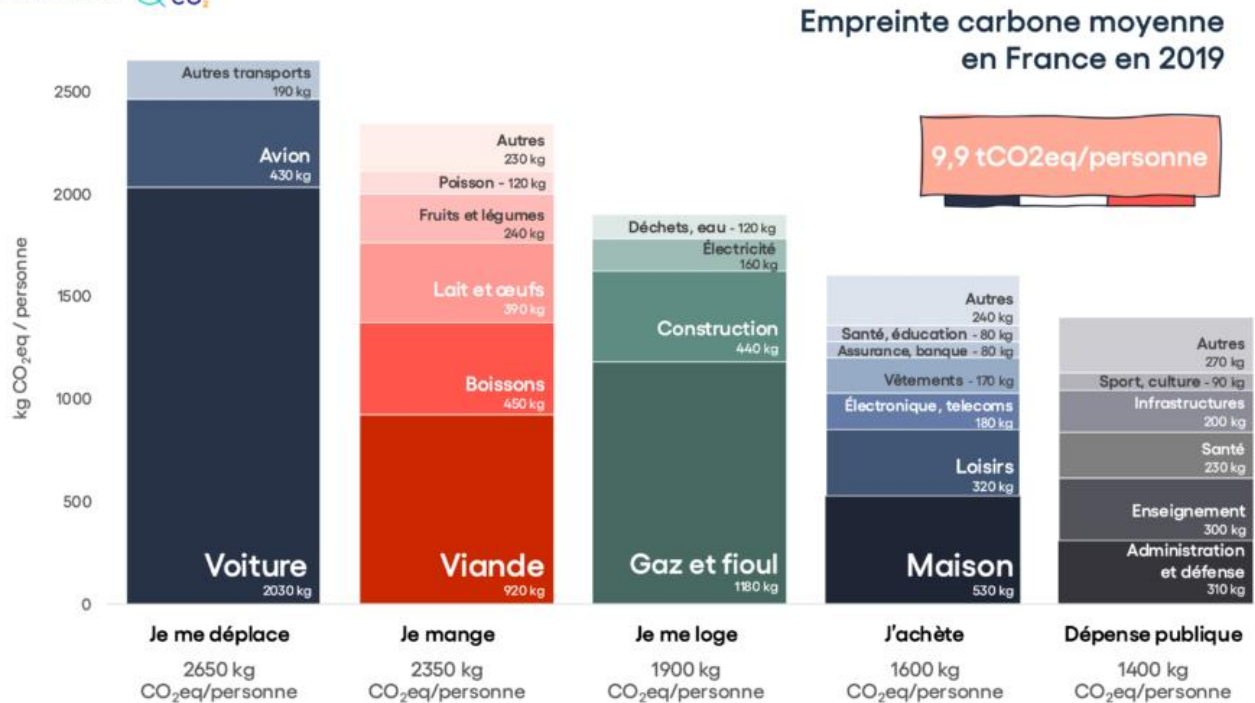
News and blog

A movement of communities coming together to reimagine and rebuild our world



<https://transitionnetwork.org/>

Everyday choices – what can you cut off?



Gaz inclus : CO₂ (hors UTCATF France), CH₄, N₂O, HFC, SF₆, PFC, H₂O (trainées de condensation).
Source : MyCO₂ par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

Source: <https://bonpote.com/comment-calculer-son-empreinte-carbone/>

Source: Pottier, A., Combet, E., Cayla, J. M., de Lauretis, S., & Nadaud, F. (2020). Qui émet du CO₂? Panorama critique des inégalités écologiques en France. *Revue de l'OFCE*, 169(5), 73-132.

Where to now? Let's vote

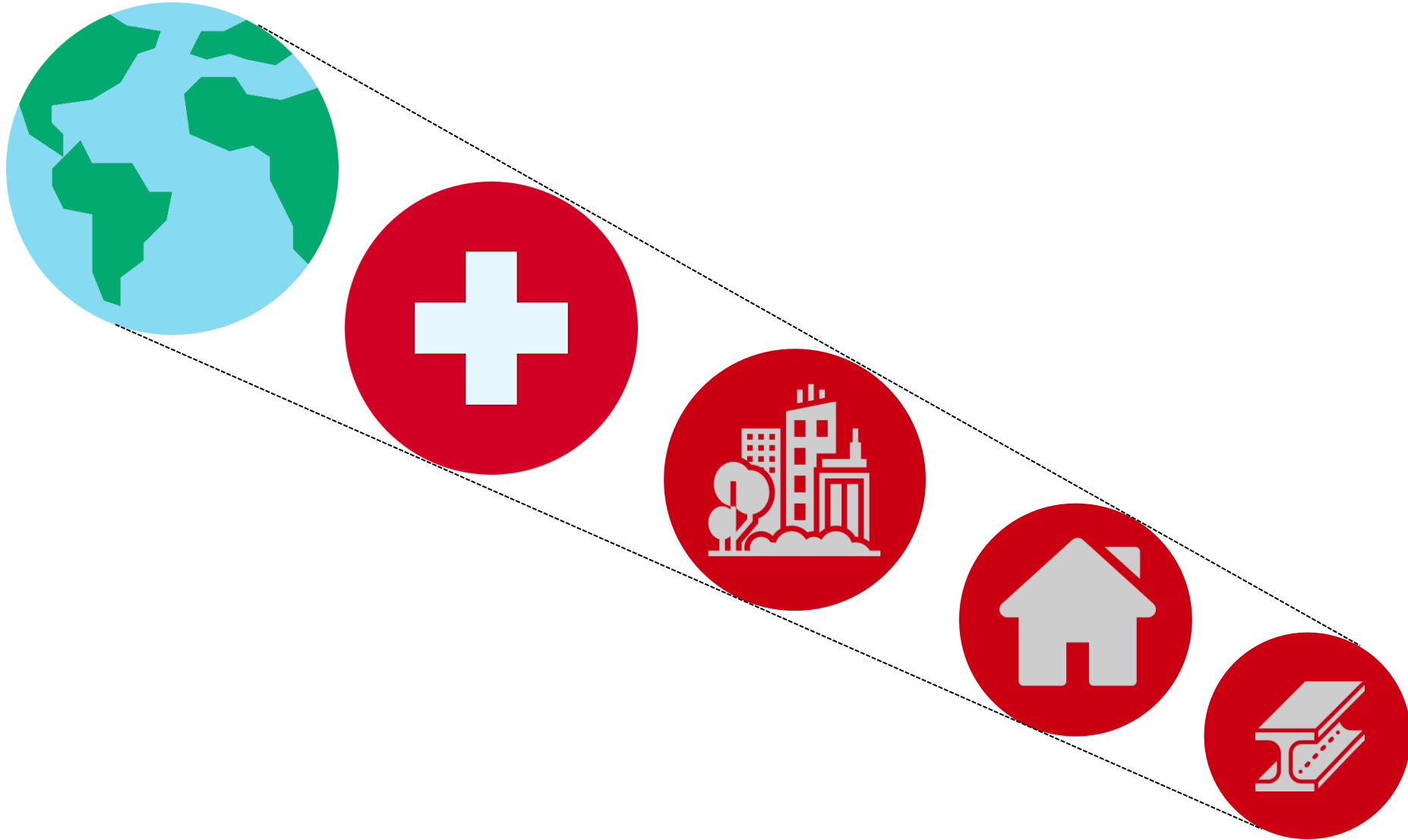


- Degrowth
- Technological fix
- Policy vs everyday choices

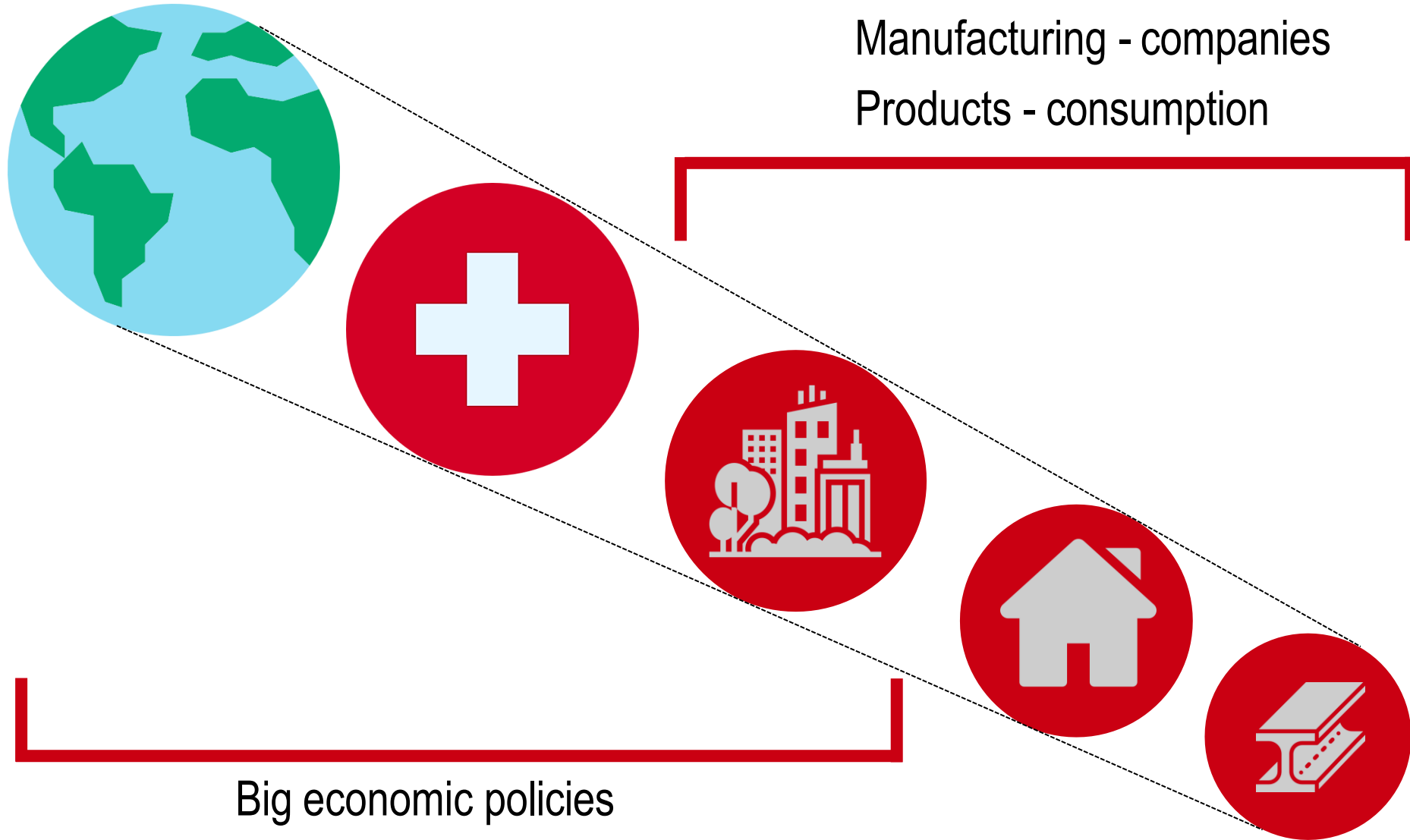
	Degrowth	Technofix
Individual	A	B
Policy	C	D



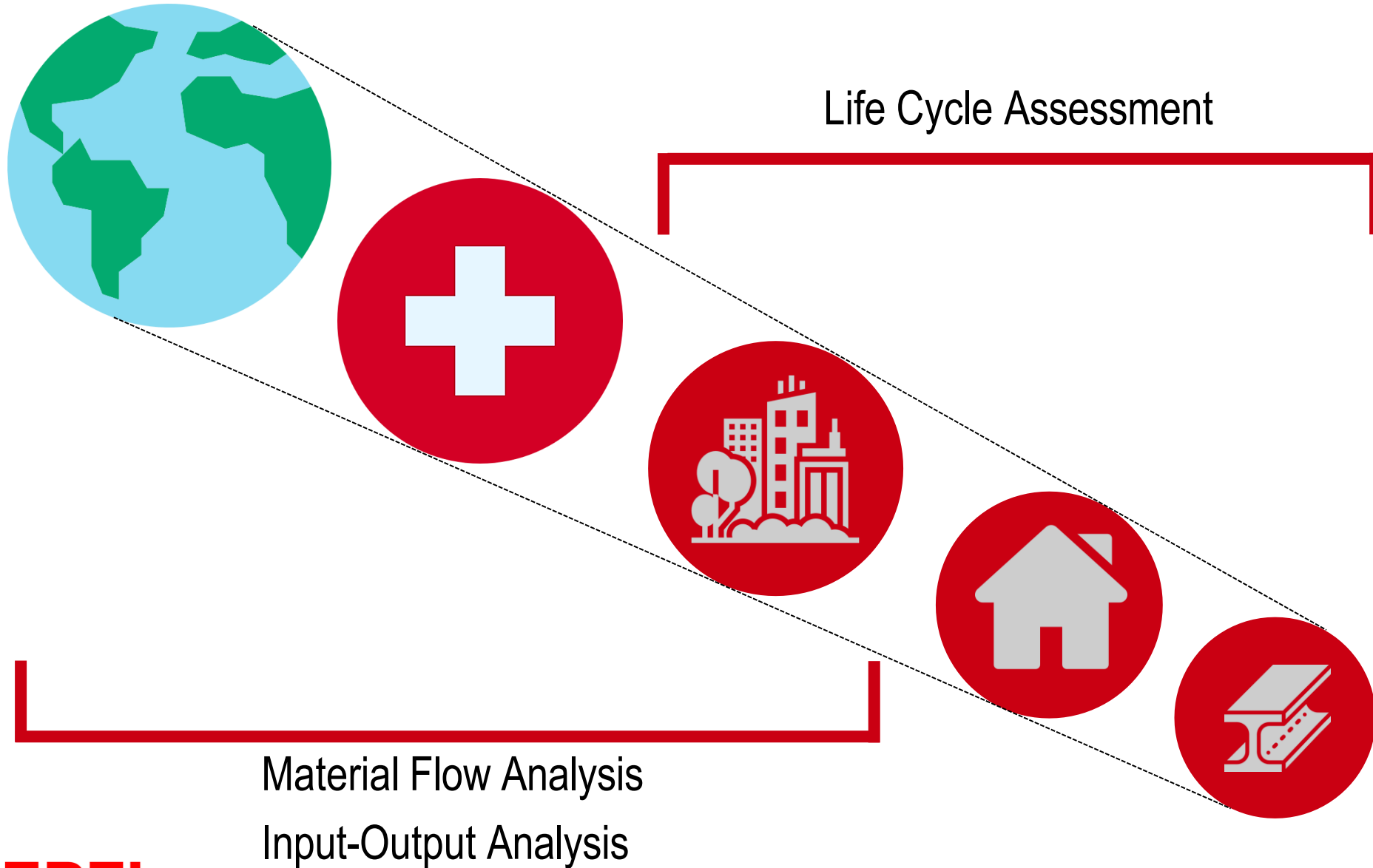
Link from Planet to Product



Link from Planet to Product – what systemic vantage point?



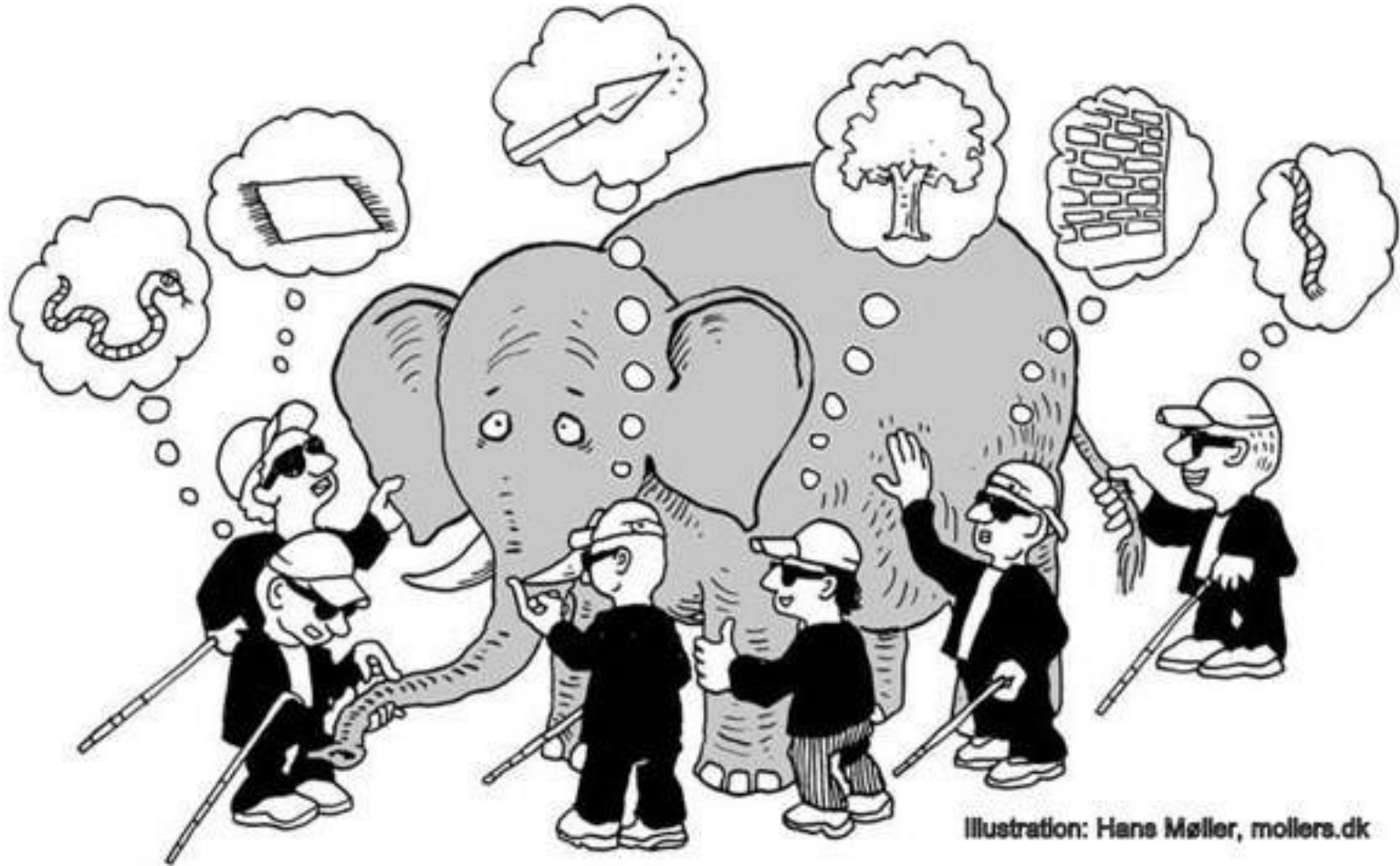
Link from Planet to Product – accounting methods



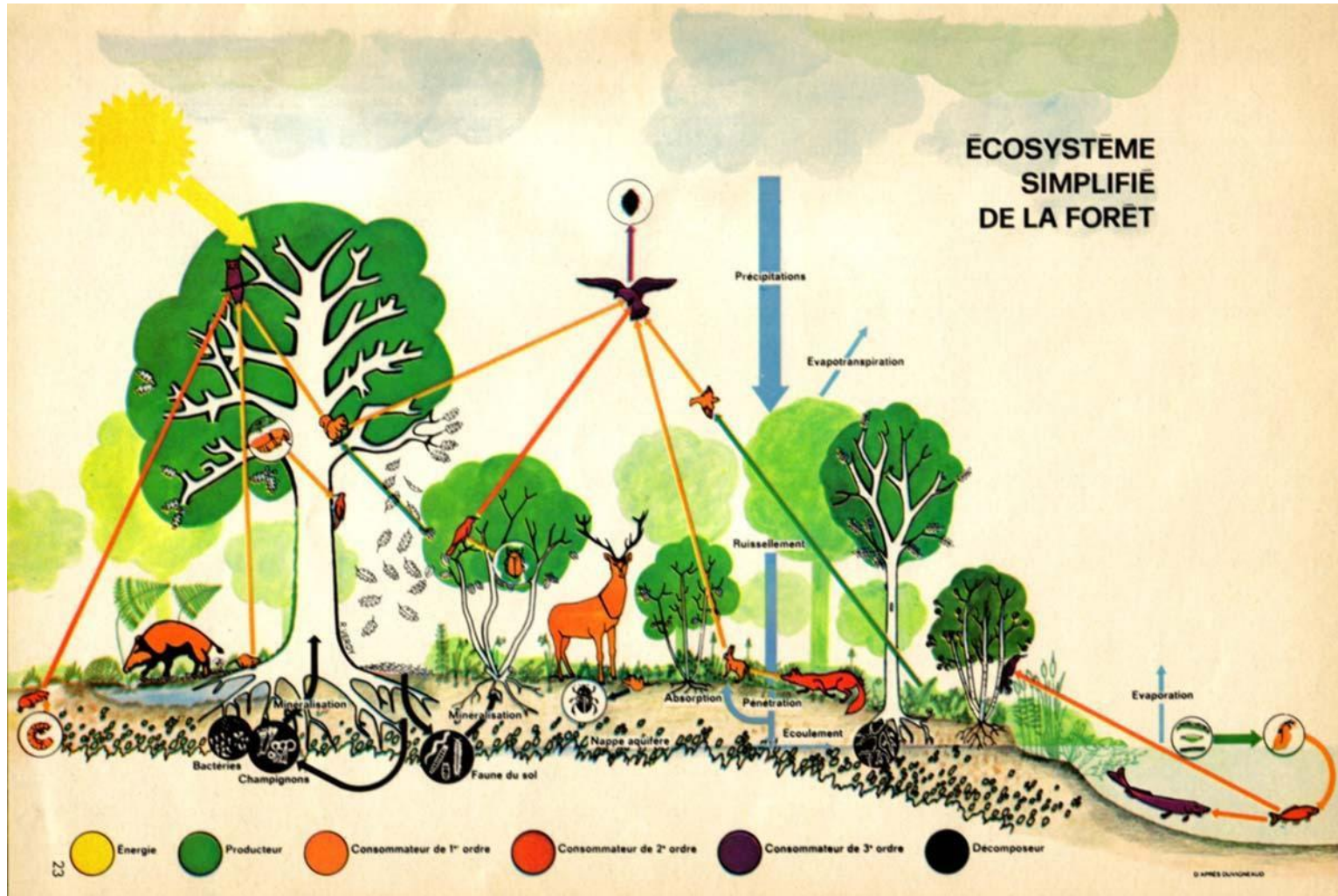
Systems thinking

What is a system?

The elephant and the blind men – what is a system?



What is a system?



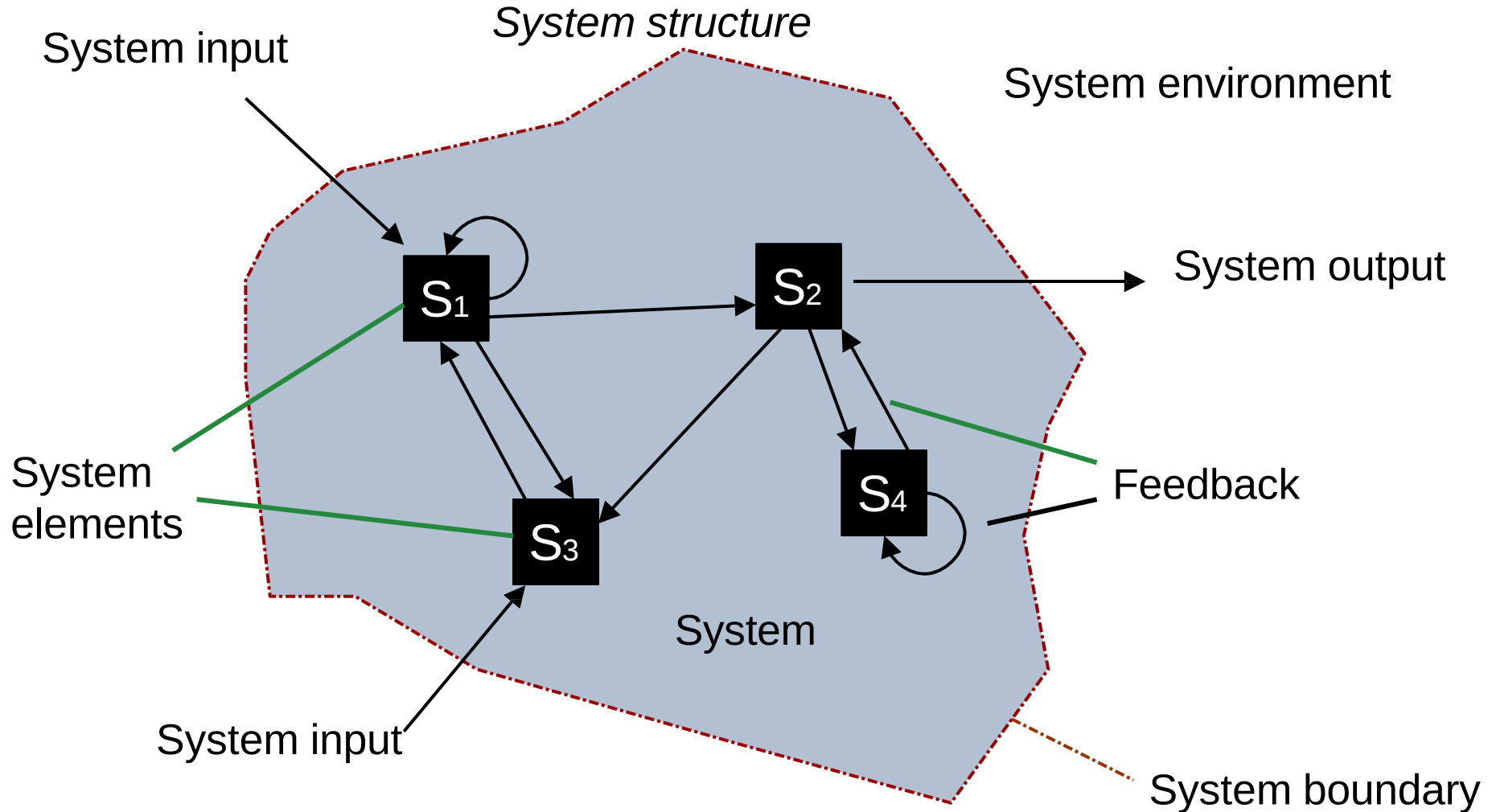
Duvigneaud, P. (1974). A synthesis of ecology: populations, communities, ecosystems, biosphere and noosphere. Doin, éditeurs..

What is a system?

A **system** is anything that is composed of system **elements** connected in a characteristic system **structure**. This configuration of system elements allows it to perform specific system **functions** in its system **environment**.

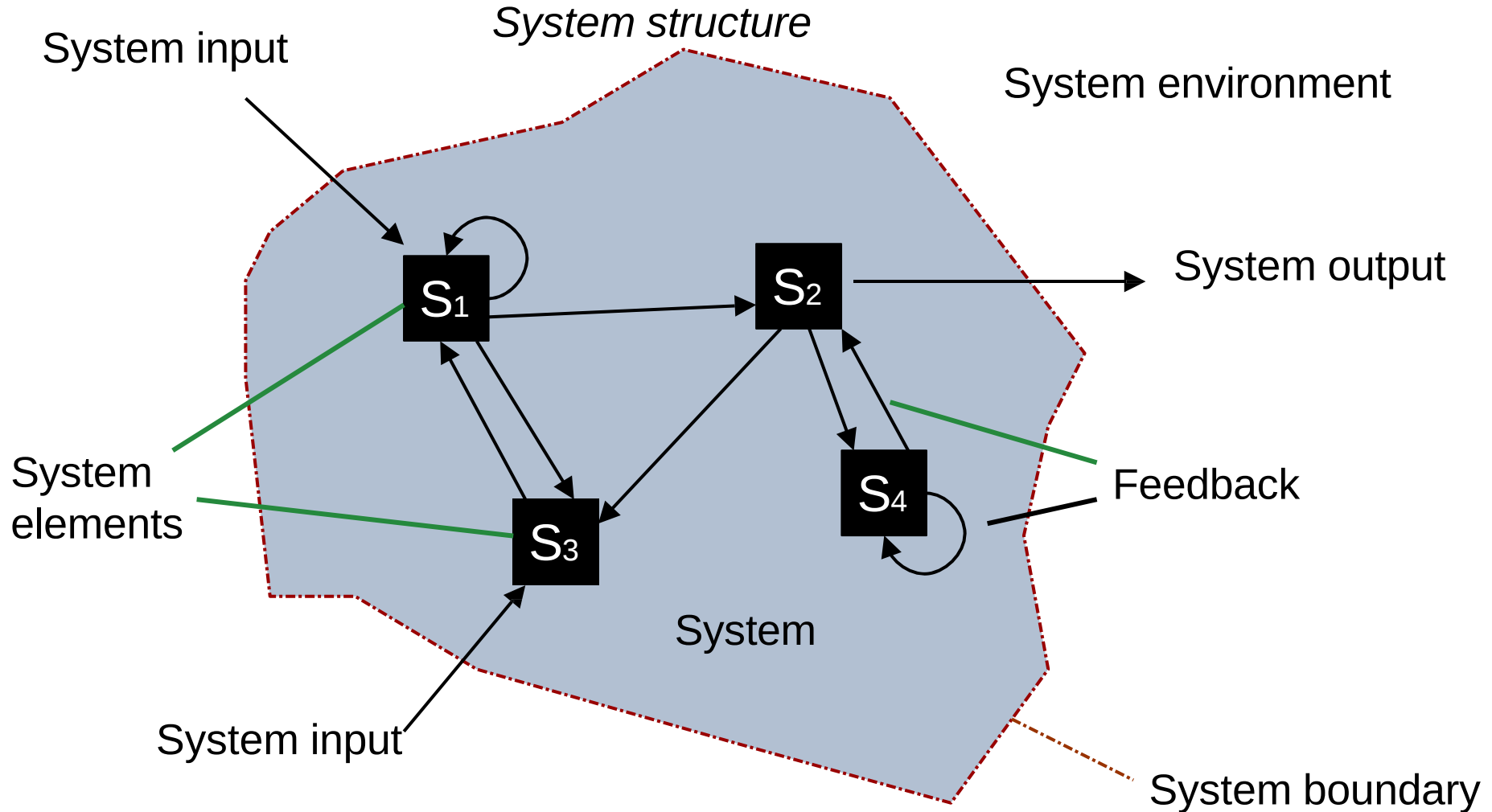
These functions can be interpreted as serving a distinct system **purpose**. The system **boundary** is permeable for **inputs** from and **outputs** to the environment. It defines the system's **identity** and **autonomy**. (Bossel, 1999)

What is a system? Elements, interrelations, system boundaries



After Bossel, 2004; Mrotzek, 2009

Let's say this is a city: what are the functions ? what are elements ?
What are the feedbacks ? What are the boundaries ?

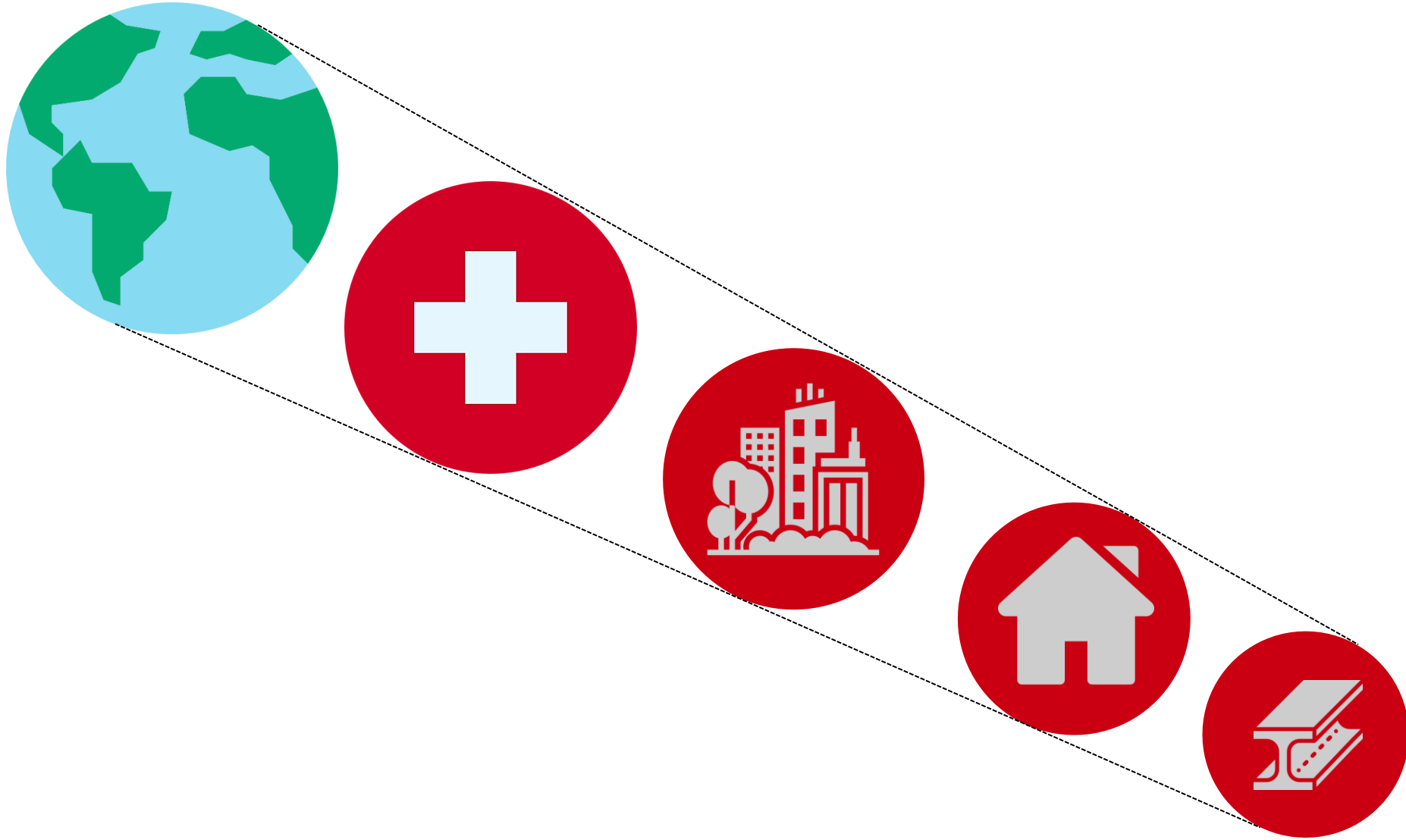


After Bossel, 2004; Mrotzek, 2009

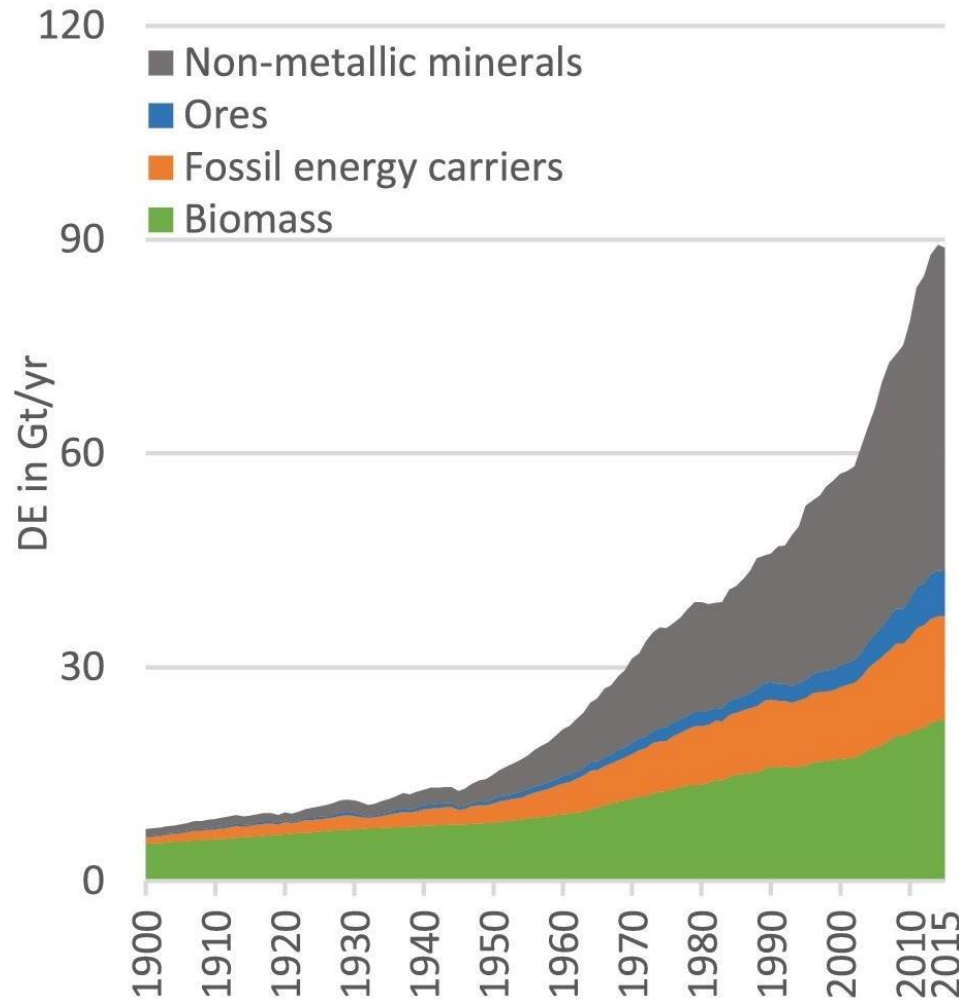
What is a system? System boundary

- Defines what is inside of the system to be analysed and what belongs to the system context
- Defines inputs and outputs of the system
- Elements of a system boundary: space and time.

1. System boundary – importance of space

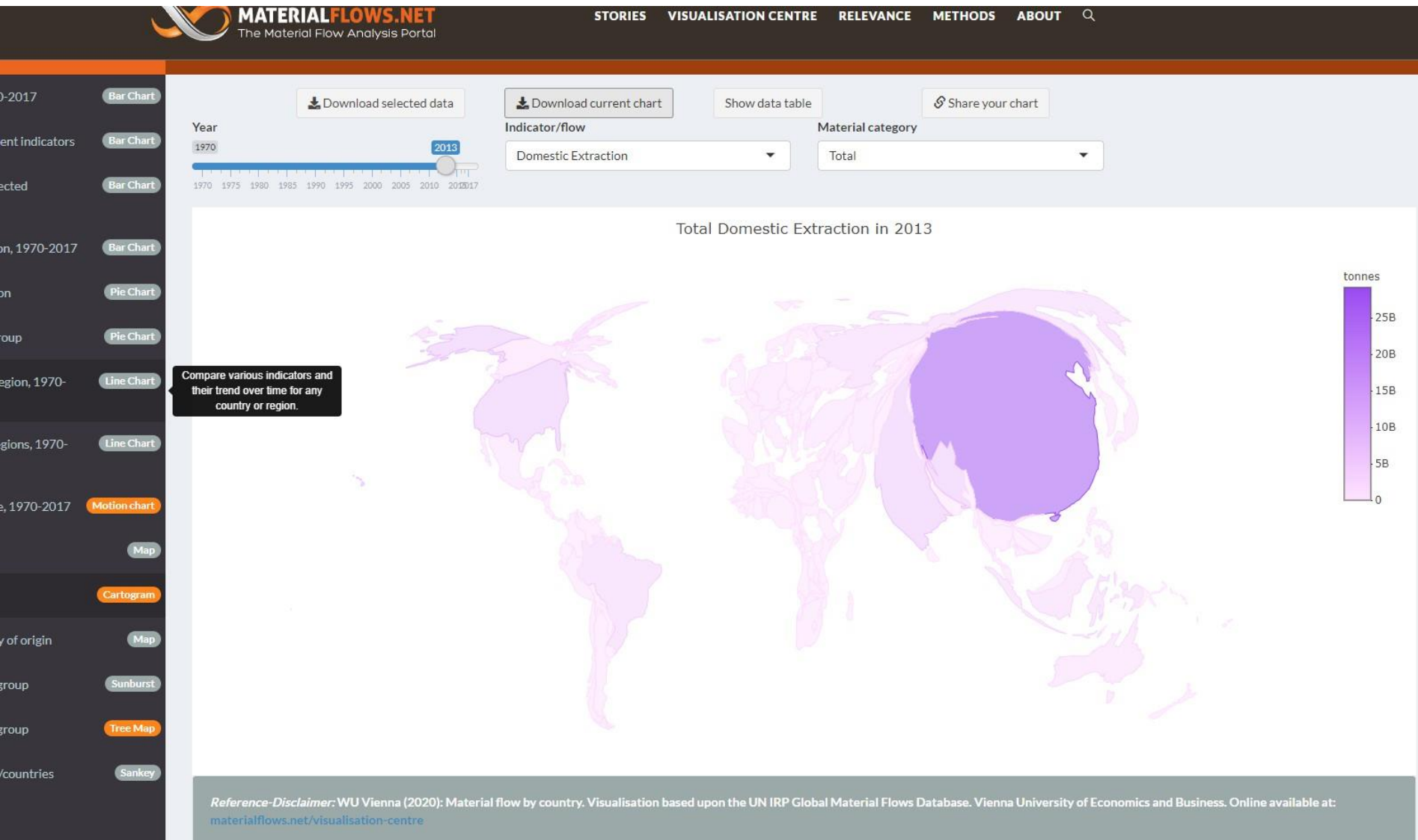


1. System boundary – importance of space



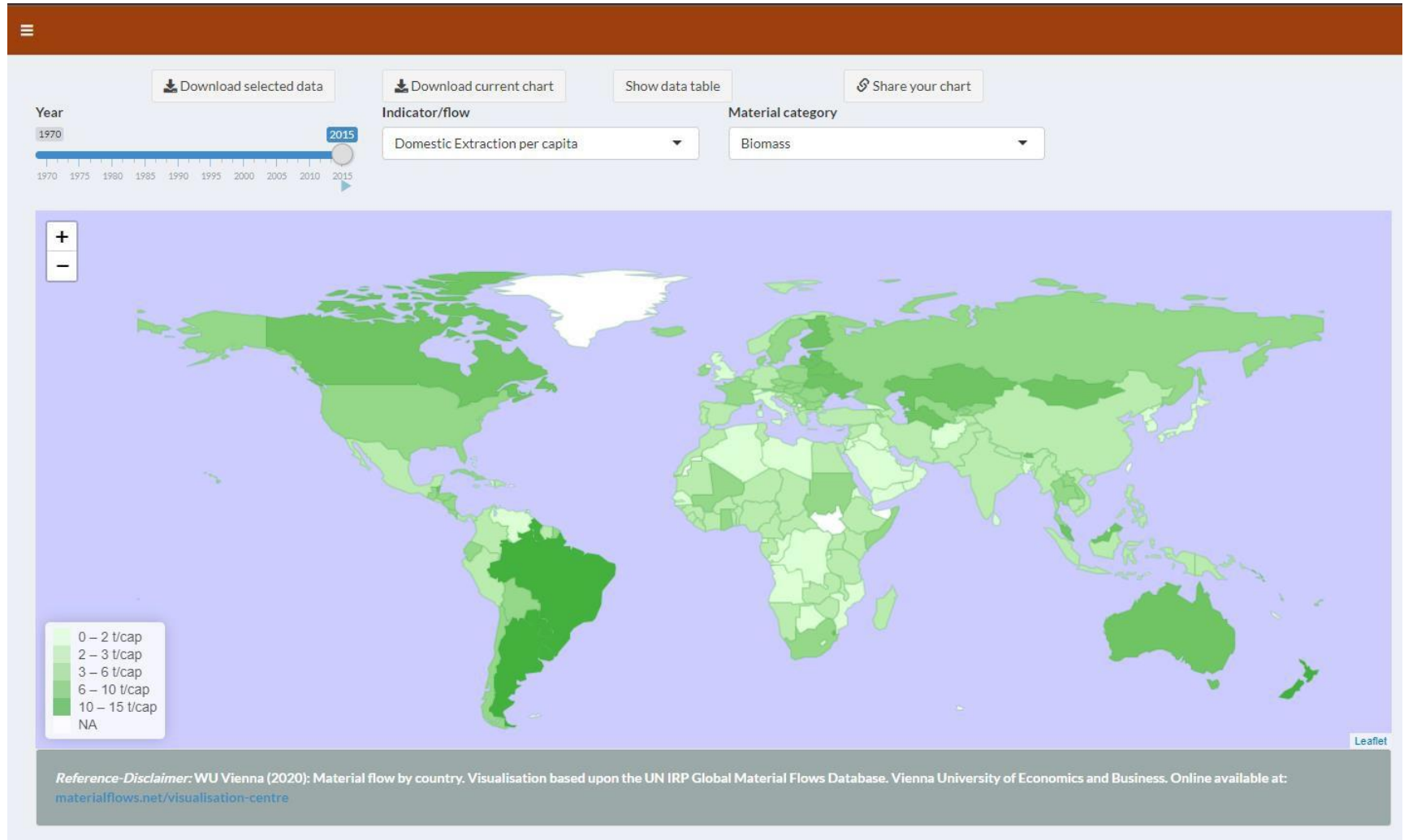
Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, 52, 131-140.

From world to countries



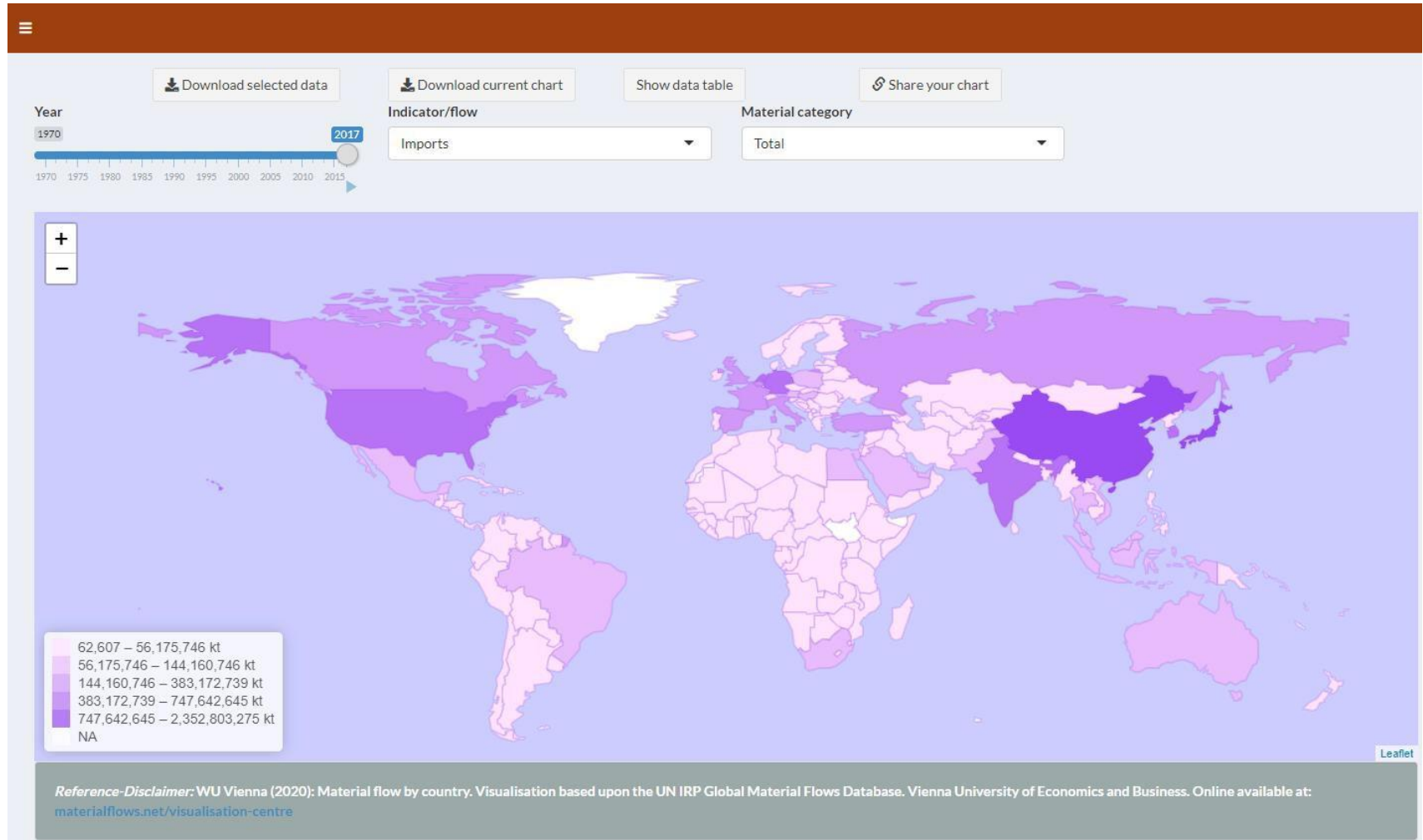
Source: <http://www.materialflows.net/visualisation-centre/data-visualisations>

From world to countries (why some countries extract more?)



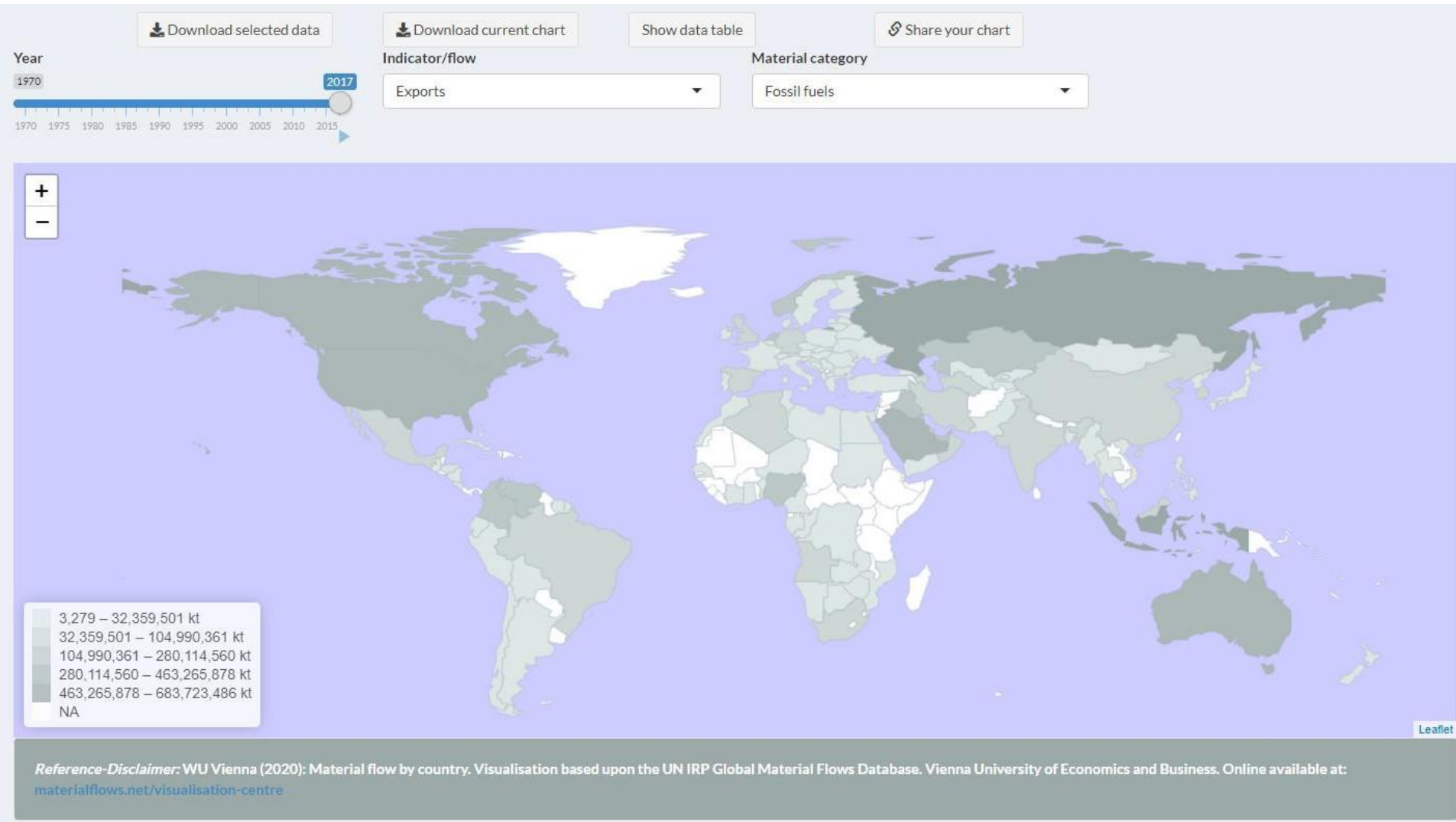
Source: <http://www.materialflows.net/visualisation-centre/data-visualisations>

From world to countries (internal flows)

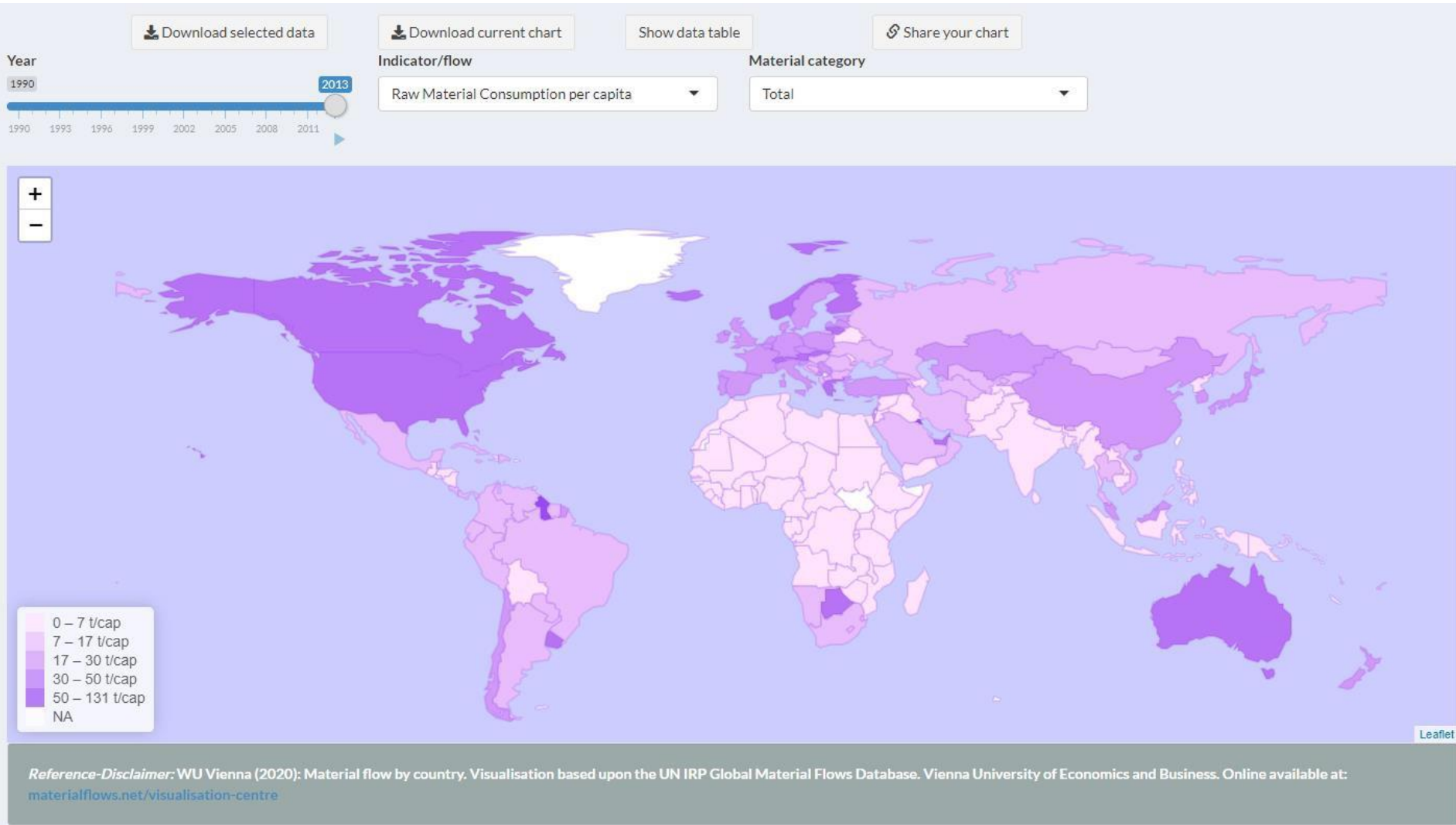


Source: <http://www.materialflows.net/visualisation-centre/data-visualisations>

From world to countries (internal flows)

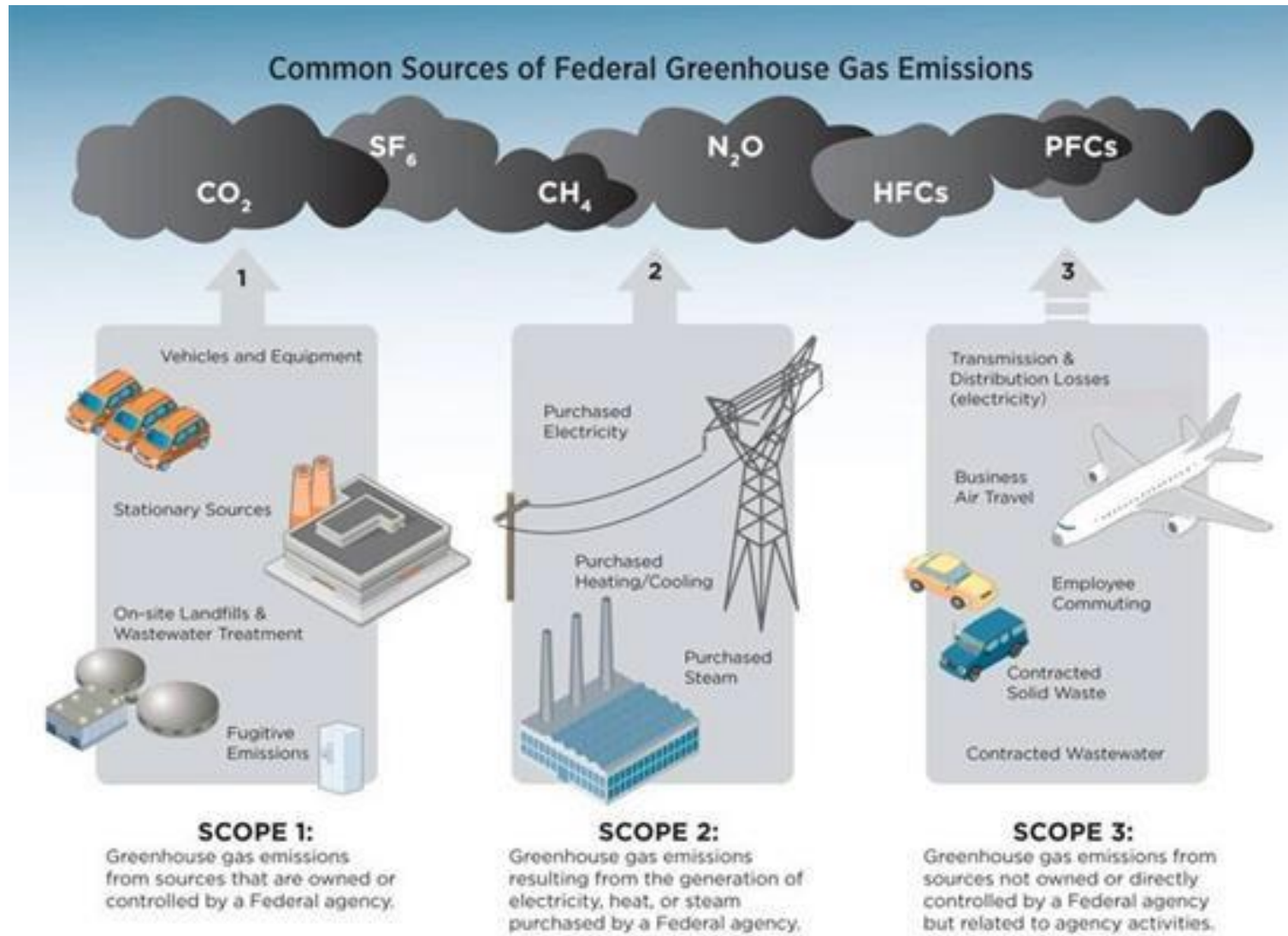


From world to countries (indirect flows)



Source: <http://www.materialflows.net/visualisation-centre/data-visualisations>

From world to countries (indirect flows)

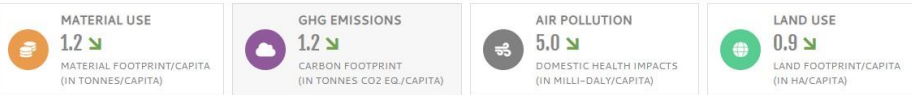


https://www.wbdg.org/images/greenhousegas_fb_03.jpg

Individual countries

Country Profile for Afghanistan

Download data for all section



Country Profile for Switzerland

Download data for all sections

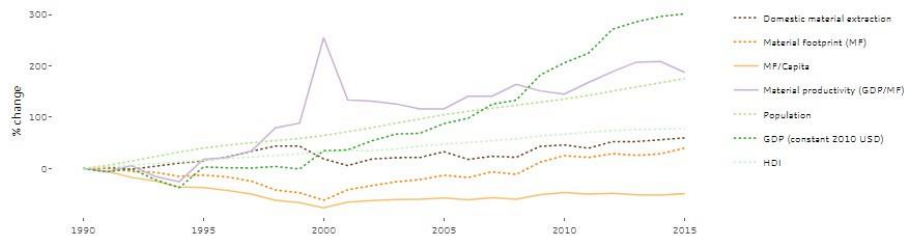


Material use and development

1

To achieve sustainable raw material use, it is essential to decouple a society's development, measured by means of GDP or HDI, from the use of raw materials. One indicator used to evaluate the use of raw materials by society and the achievement of the related SDGs is the "material footprint", measuring the sum of all raw materials used along the supply chains of goods and services consumed in a country.

Raw material use trends, Afghanistan, 1990-2015

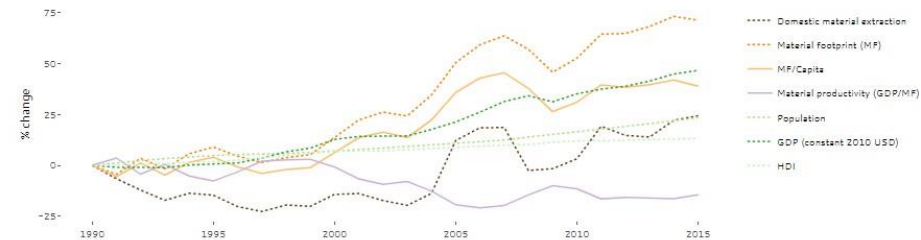


Material use and development

1

To achieve sustainable raw material use, it is essential to decouple a society's development, measured by means of GDP or HDI, from the use of raw materials. One indicator used to evaluate the use of raw materials by society and the achievement of the related SDGs is the "material footprint", measuring the sum of all raw materials used along the supply chains of goods and services consumed in a country.

Raw material use trends, Switzerland, 1990-2015



Sustainability trend (1990-2015)

1

Afghanistan achieved **relative decoupling** of economic development from raw material consumption.

Trade in raw materials (2015)

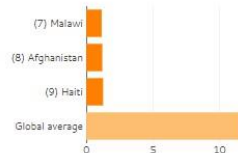
1



Imports | Exports
(in Million Tonnes)

Country comparison (2015)

1



Sustainability trend (1990-2015)

1

Switzerland achieved **no decoupling** of economic development from raw material consumption.

Trade in raw materials (2015)

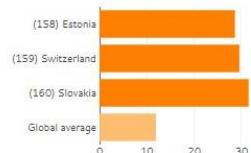
1



Imports | Exports
(in Million Tonnes)

Country comparison (2015)

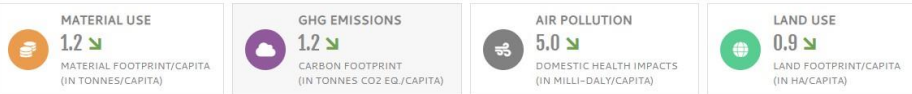
1



Individual countries

Country Profile for Afghanistan

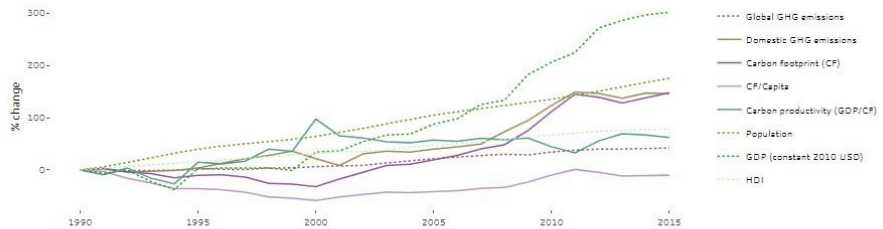
Download data for all section



GHG emissions and development

To reduce societies' contribution to climate change it is of utmost importance to reduce GHG emissions produced, while at the same time achieving development of different kinds – e.g. measured by GDP or HDI. Hotspot areas are mobility, housing and nutrition. Apart from the emissions produced within a country (domestic GHG emissions), it is important to also account for the sum of all GHG emissions produced along the supply chains of goods and services consumed in a country ("carbon footprint"). Both domestic emissions and the carbon footprint can be translated via characterisation factors into their "global warming potential".

GHG emissions trends, Afghanistan, 1990–2015



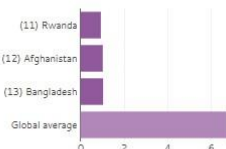
Sustainability trend

Afghanistan achieved relative decoupling of economic development from supply-chain wide GHG emissions (carbon footprint).

Trade in GHG emissions (2015)



Country comparison (2015)



Country Profile for Switzerland

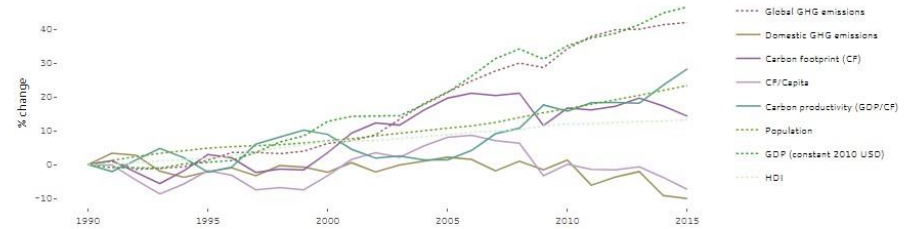
Download data for all sections



GHG emissions and development

To reduce societies' contribution to climate change it is of utmost importance to reduce GHG emissions produced, while at the same time achieving development of different kinds – e.g. measured by GDP or HDI. Hotspot areas are mobility, housing and nutrition. Apart from the emissions produced within a country (domestic GHG emissions), it is important to also account for the sum of all GHG emissions produced along the supply chains of goods and services consumed in a country ("carbon footprint"). Both domestic emissions and the carbon footprint can be translated via characterisation factors into their "global warming potential".

GHG emissions trends, Switzerland, 1990–2015



Sustainability trend

Switzerland achieved relative decoupling of economic development from supply-chain wide GHG emissions (carbon footprint).

Trade in GHG emissions (2015)



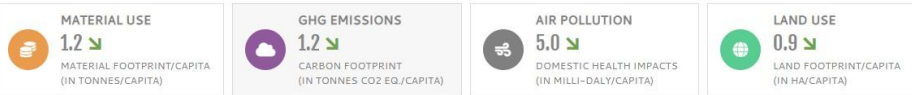
Country comparison (2015)



Individual countries

Country Profile for Afghanistan

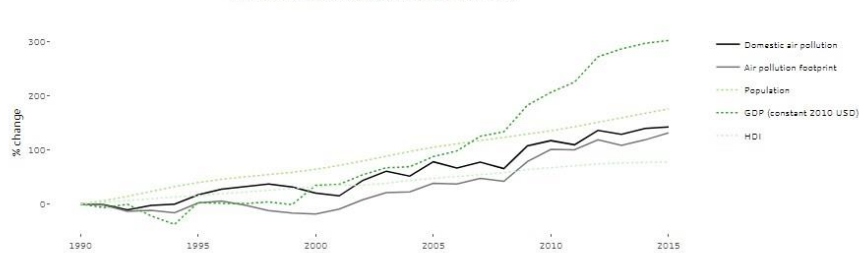
Download data for all section



Air pollution and development

As economies develop, an increase in air pollution can be observed. The main goal is to decrease relevant emissions especially from the main sources such as vehicle emissions and coal-fired power plants. By that means, health and environmental impacts of air pollution shall be reduced and decoupled from human and economic development (HDI and GDP, respectively). To measure progress, the amount of air pollutants emitted, both domestically as well as along the supply chains of consumed goods, can be used as pressure indicator. The main indicator is DALY – disability-adjusted life years, as consequence of air pollution.

Air pollution trends, Afghanistan, 1990–2015



Sustainability trend

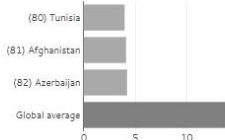
Afghanistan achieved relative decoupling of economic development from supply-chain wide health impacts.

Trade in air pollution (2015)



Imports | Exports
(in kilo-DALY)

Country comparison (2015)



Country Profile for Switzerland

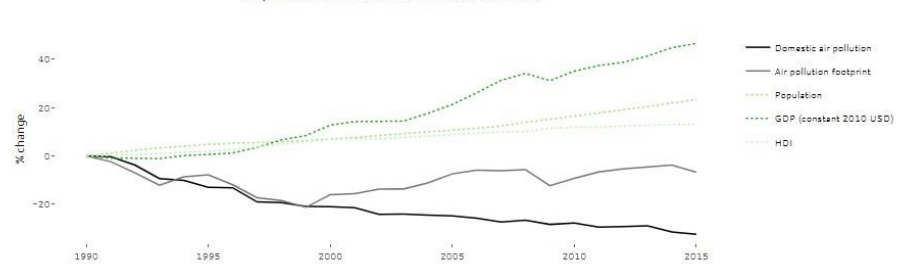
Download data for all sections



Air pollution and development

As economies develop, an increase in air pollution can be observed. The main goal is to decrease relevant emissions especially from the main sources such as vehicle emissions and coal-fired power plants. By that means, health and environmental impacts of air pollution shall be reduced and decoupled from human and economic development (HDI and GDP, respectively). To measure progress, the amount of air pollutants emitted, both domestically as well as along the supply chains of consumed goods, can be used as pressure indicator. The main indicator is DALY – disability-adjusted life years, as consequence of air pollution.

Air pollution trends, Switzerland, 1990–2015



Sustainability trend

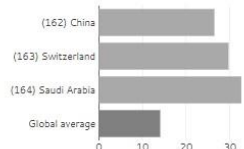
Switzerland achieved absolute decoupling of economic development from supply-chain wide health impacts.

Trade in air pollution (2015)



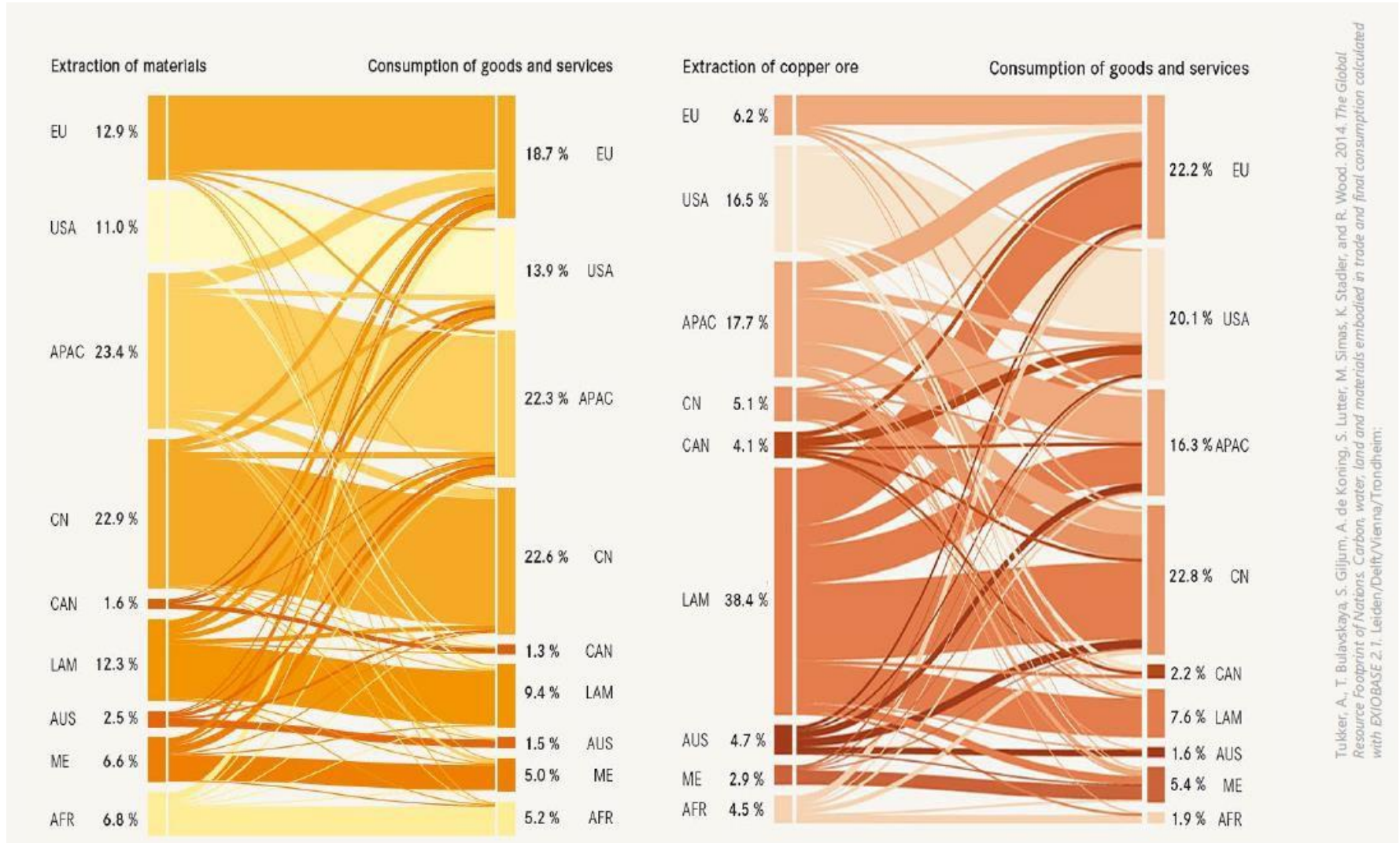
Imports | Exports
(in kilo-DALY)

Country comparison (2015)



What are some additional insights that you can see at country level? (which were invisible at global level)

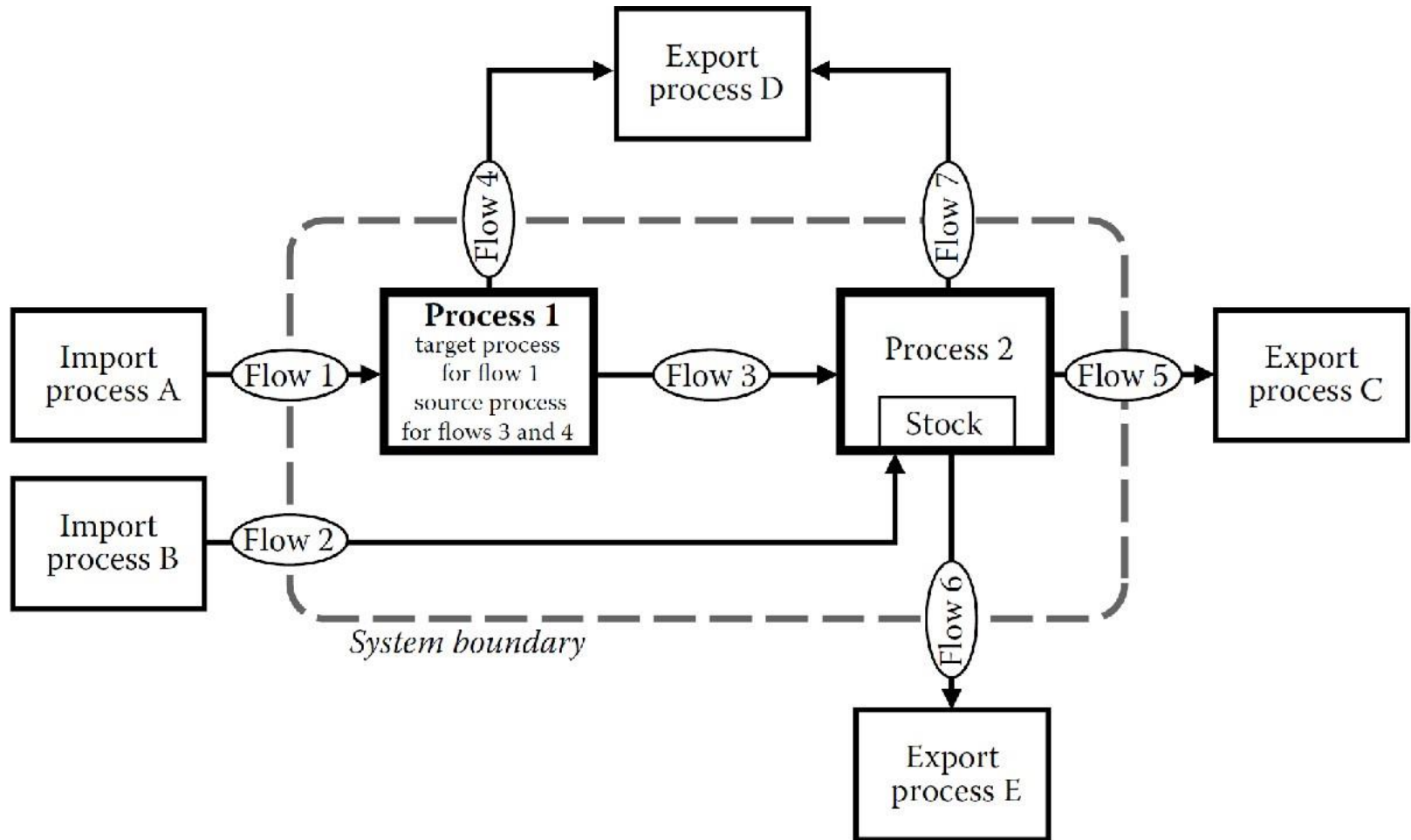
Production (extraction) vs. Consumption



So who is responsible ?

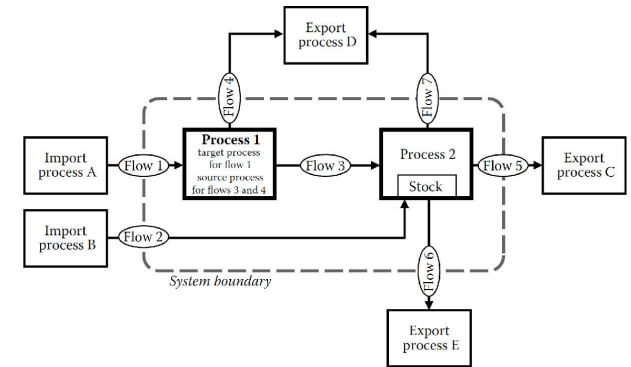
Material Flow Analysis

First method to include in your arsenal: MFA



Brunner & Rechberger, 2016

Definition of MFA



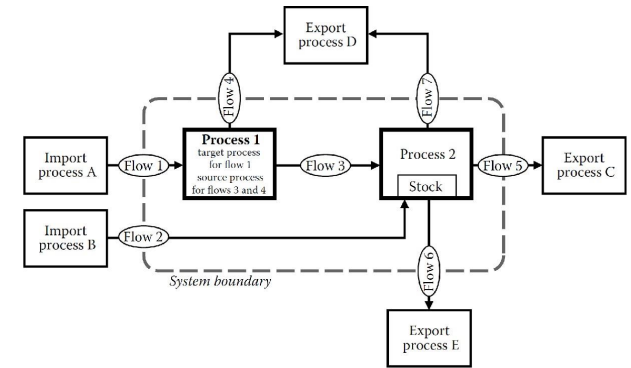
Material Flow Analysis (MFA) is a systematic assessment of the **flows and stocks of materials** within a system defined in **space and time** .

- MFA connects the **sources, pathways and sinks** of a material.
- MFA results can be controlled by a **mass balance** comparing all inputs, stocks, and outputs of a process/system measured in kg (principle of mass conservation).

Brunner & Rechberger, 2016

History of MFA

- **Santorio Santorio (1561–1636)**
Human metabolism
- **Antoine Lavoisier (1743–1794)**
Law of mass conservation in chemical processes
- **Wassily W. Leontief (1906–1999)**
Economic input-output tables
- **Abel Wolman (1965), Duvigneaud & Denayeyer-De Smet (1975), Newcombe, Kalma & Aston (1978)**
Metabolism of cities: hypothetical American city, Brussels, Hong Kong



Brunner & Rechberger, 2016

Santorio's analysis of the human metabolism



Inputs: food, beverages
Outputs: excretions

Brunner & Rechberger, 2016

Santorio's analysis of the human metabolism



Brunner & Rechberger, 2016

Inputs: food, beverages

Outputs: excretions

Mass balance: input $\neq$ output ???



Santorio's analysis of the human metabolism



Brunner & Rechberger, 2016

Inputs: food, beverages

Outputs: excretions

Mass balance: input $\neq$ output

Air in and out was not measured!

What is the purpose of MFA ??

Purpose of MFA

- **Early detection** of harmful/useful material accumulation or depletion in anthropogenic/natural subsystems (e.g. metal enrichment in landfills due to the deposition of slag).
- **Prediction** of future quantities in anthropogenic/natural subsystems.
- **Identification of the need for action** in the areas of environmental, resource, waste and policy management.
- **Evaluation** of the effectiveness of current/planned measures.
- **Design** of ecologically-optimized products, processes and systems
(e.g. green design, eco-design).

Steps of MFA

Step I: System definition

Problem definition, definition of system boundaries, selection of processes and flows of materials/substances (qualitative model)

Step II: Measurement

Data collection of flows and stocks of materials/substances and characterization of uncertainties (measurements, literature data, estimations)

Step III: Calculation

Calculation of unknown quantities by balancing of materials based on the principle of mass conservation (MFA software)

Step IV: Illustration and interpretation

Sources, stocks, flows and sinks

Step V: Recommendations

How can the system be optimized?

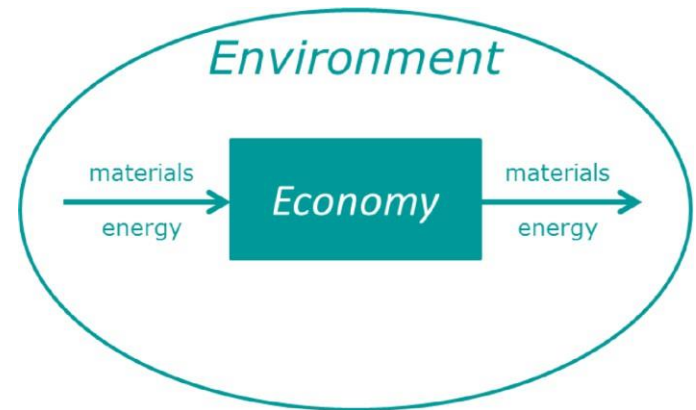
**Method 1:
EUROSTAT
Economy–Wide
Material Flow Analysis**

First way to perform a MFA: EW-MFA Definition

- **Economy-wide material flow accounting and analysis (EW-MFA)**

is the quantification of the material flows into and out of an economy (socio-economic metabolism).

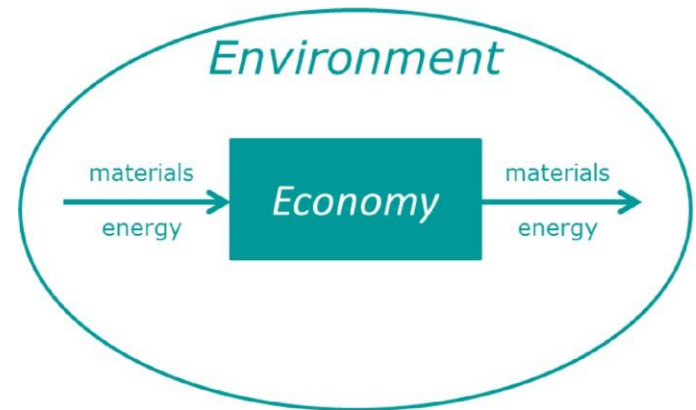
- **EW-MFA** describes the interaction of the domestic economy with the natural environment and the rest of the world economy.



Eurostat, 2018

First way to perform a MFA: EW-MFA Definition

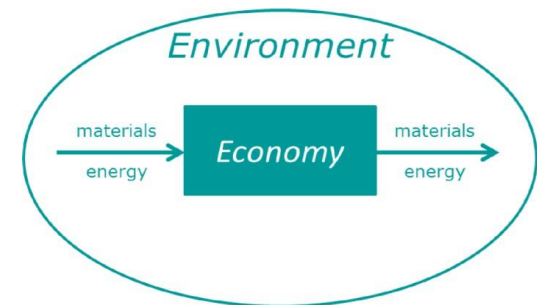
- **EW-MFA** represents national accounts in physical instead of monetary terms.
- **EW-MFA** are compatible with other national accounts, enabling integrated analyses of environmental and economic aspects.



Eurostat, 2018

History of EW-MFA (in Europe)

- **1990s:** European Statistical System (ESS) started its work on the integration of environmental and economic information systems.
- **2000:** Eurostat task force developed a methodological framework to record material flows and defined material flow indicators.
- **2004-2006:** Eurostat task force developed a classification of materials, standard tables and harmonized compilation procedures.
- **2011:** EU Regulation No. 691/2011 for member states to report the EW-MFA data to Eurostat.
- **2013:** First mandatory annual data collection.
- **2018:** Latest methodology out



Eurostat, 2018

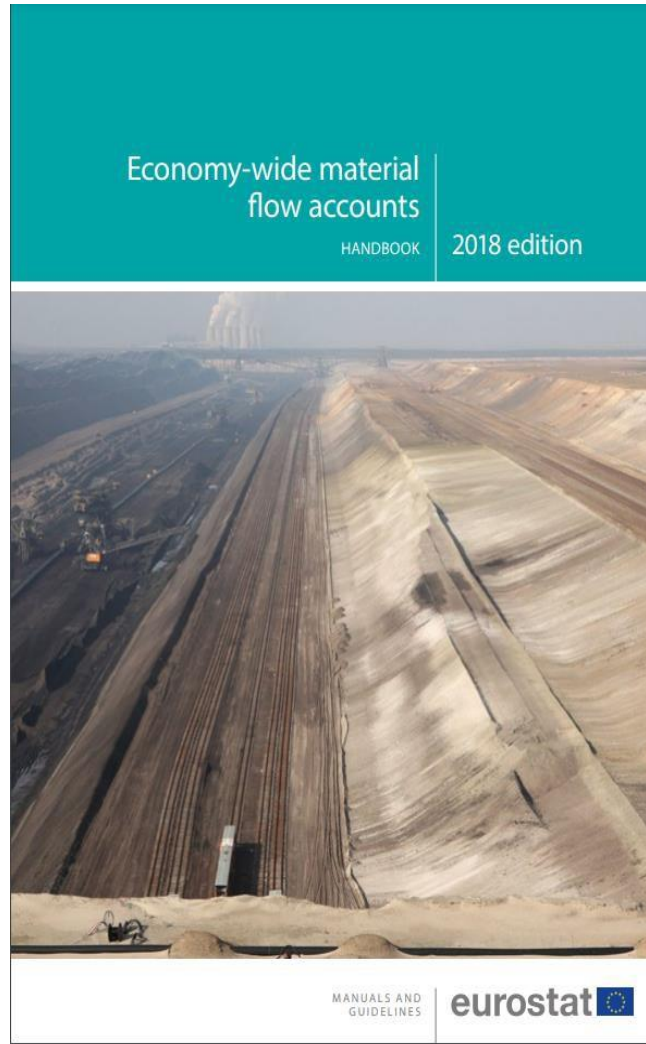
EW-MFA (globally -2021)



<https://www.resourcepanel.org/reports/global-manual-economy-wide-material-flow-accounting>

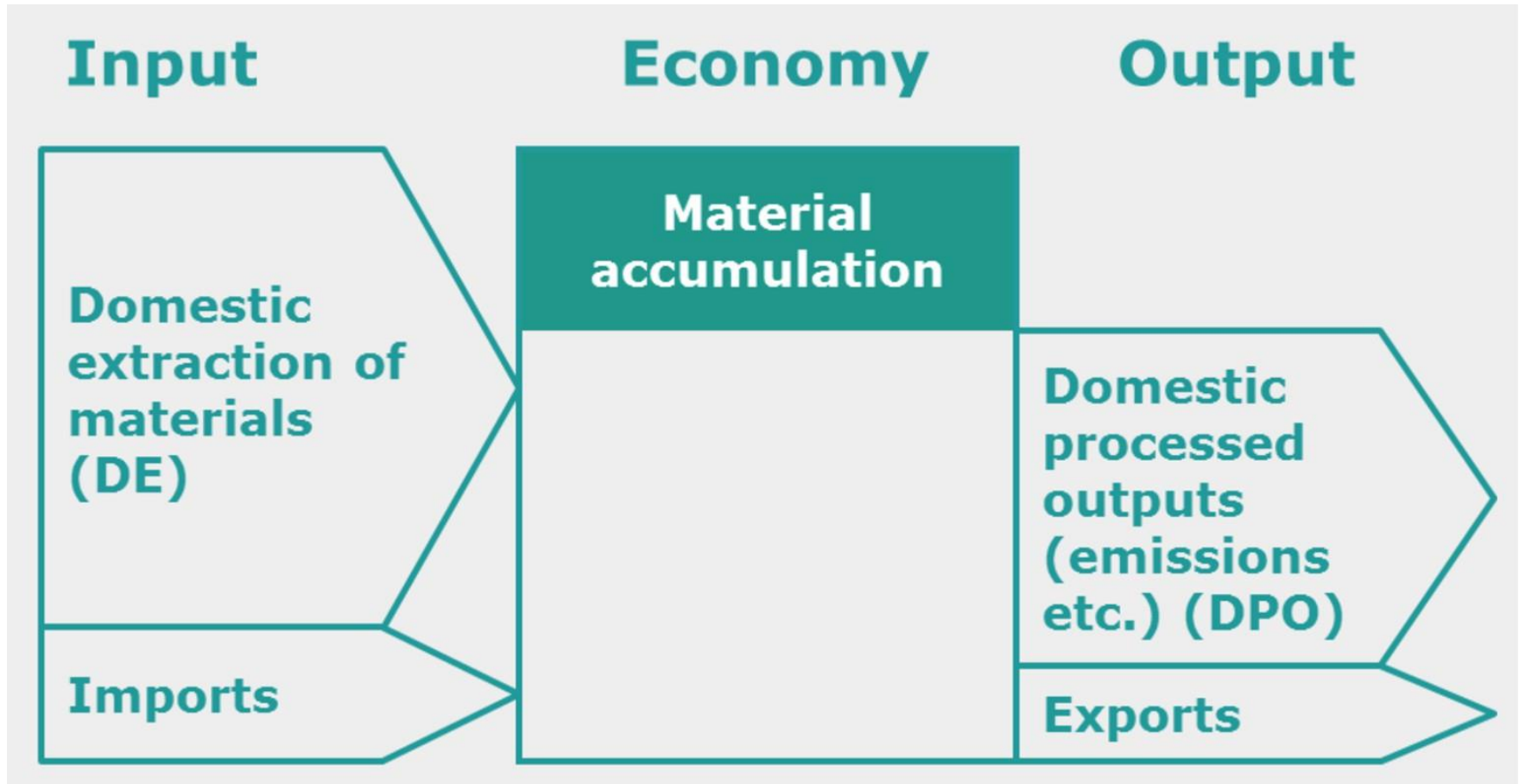


EW-MFA (in Europe): detailed method



Source: <https://ec.europa.eu/eurostat/documents/3859598/9117556/KS-GQ-18-006-EN-N.pdf/b621b8ce-2792-47ff-9d10-067d2b8aac4b?t=1537260841000>

EW-MFA (in Europe): detailed method



Material flows within the economy, Water flows and electricity flows are not represented in EW-MFA

EW-MFA (in Europe): detailed method

eurostat 

☐ Enable automatic checks when closing workbook

Economy-wide material flow accounts (EW-MFA)
2020 EW-MFA questionnaire

Check the whole questionnaire

INTRODUCTION

version 25 August 2020

This is Eurostat's electronic questionnaire for the 2020 data collection on **economy-wide material flow accounts (EW-MFA)**. It includes a number of sheets – an overview is provided in sheet '**structure**'. Reporting Tables A, B, and D are based on Regulation (EU) No. 691/2011.

Please specify your country by selecting from the drop-down list:

Deadline for returning back the 2020 EW-MFA questionnaire is: **31 December 2020**

The sheet '**instructions**' provides you with detailed information on filling in the questionnaire. Please address any questions to the following e-mail address:

ESTAT-MFA@ec.europa.eu

This electronic questionnaire shall be submitted to Eurostat using the **EDAMIS** reporting system (Electronic Data files Administration and Management Information System). Please ensure that the following [EDAMIS parameters](#) are entered:

Domain: **ENVPFLAC**

Data set: **ENVPFLAC_MFA_A**

Year: **2018** (which is the most recent legally mandatory reference year). Eurostat greatly appreciates receiving EW-MFA data starting from 2000 ranging up to 2019.

The eDAMIS system has been installed in all National Statistical Institutes and your local eDAMIS coordinator will give you a user-id and password.

Should you have any questions regarding data transmission, please contact your local eDAMIS coordinator or the Eurostat eDAMIS helpdesk at:

estat-support-edamis@ec.europa.eu

or call +352 4301 33213.

Please provide the **primary contact person for EW-MFA in your country** (*institution, unit, name, email, telephone*):



[intro](#) [structure](#) [instructions](#) [footnote instructions](#) [footnotes_list](#) [Table_A](#) [Table_B](#) [Table_C](#) [Table_D](#) [Table_E](#) [Table_F](#) [Table_G](#) [Table_H](#) [Table_I](#)

Source: <https://ec.europa.eu/eurostat/documents/1798247/6191533/Economy-wide+material+flow+accounts+%28EW-MFA%29+questionnaire>

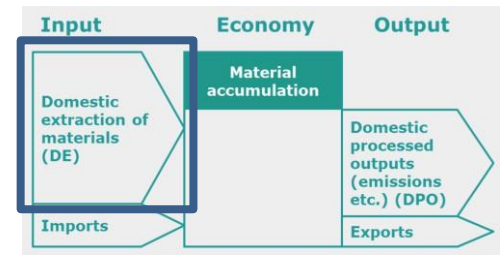
EW-MFA (in Europe): detailed method

1	Country:	Go to Footnotes	Show Footnote	Check Data
2	Unit	1000 Metric tonnes	Clean Checks	
3	TABLE A: DOMESTIC EXTRACTION			
4	MF.1 Biomass	2019	2020	
5	MF.1.1 Crops (excluding fodder crops)			
6	MF.1.1.1 Cereals			
7	MF.1.1.2 Roots, tubers			
8	MF.1.1.3 Sugar crops			
9	MF.1.1.4 Pulses			
10	MF.1.1.5 Nuts			
11	MF.1.1.6 Oil-bearing crops			
12	MF.1.1.7 Vegetables			
13	MF.1.1.8 Fruits			
14	MF.1.1.9 Fibres			
15	MF.1.1.A Other crops (excluding fodder crops) n.e.o.			
16	MF.1.2 Crop residues (used), fodder crops and grazed biomass			
17	MF.1.2.1 Crop residues (used)			
18	MF.1.2.1.1 Straw			
19	MF.1.2.1.2 Other crop residues (sugar and fodder beet leaves, etc.)			
20	MF.1.2.2 Fodder crops and grazed biomass			
21	MF.1.2.2.1 Fodder crops (including biomass harvest from grassland)			
22	MF.1.2.2.2 Grazed biomass			
23	MF.1.3 Wood			
24	MF.1.3.1 Timber (industrial roundwood)			
25	MF.1.3.2 Wood fuel and other extraction			
26	MF.1.3.3 MEMO: Net increment of timber stock (memo item)			
27	MF.1.4 Wild fish catch, aquatic plants and animals, hunting and gathering			
28	MF.1.4.1 Wild fish catch			
29	MF.1.4.2 All other aquatic animals and plants			
30	MF.1.4.3 Hunting and gathering			
31	MF.2 Metal ores (gross ores)			
32	MF.2.1 Iron			
33	MF.2.2 Non-ferrous metal			
34	MF.2.2.1 Copper			
35	MF.2.2.1 MEMO Copper - metal content			
36	MF.2.2.2 Nickel			
37	MF.2.2.2 MEMO Nickel - metal content			
38	MF.2.2.3 Lead			
39	MF.2.2.3 MEMO Lead - metal content			
40	MF.2.2.4 Zinc			
41	MF.2.2.4 MEMO Zinc - metal content			
42	MF.2.2.5 Tin			
intro structure instructions footnote instructions footnotes_list Table_A Table_B Table				

Country:	Go to Footnotes	Show Footnote	Check Data
Unit	1000 Metric tonnes	Clean Checks	
Table B: Imports - total trade (intra + extra EU-28 trade)			
MF.1 Biomass	1990		
MF.1.1 Crops (excluding fodder crops)			
MF.1.1.1 Cereals			
MF.1.1.2 Roots, tubers			
MF.1.1.3 Sugar crops			
MF.1.1.4 Pulses			
MF.1.1.5 Nuts			
MF.1.1.6 Oil-bearing crops			
MF.1.1.7 Vegetables			
MF.1.1.8 Fruits			
MF.1.1.9 Fibres			
MF.1.1.A Other crops (excluding fodder crops) n.e.o.			
MF.1.2 Crop residues (used) and fodder crops			
MF.1.2.1 Crop residues (used)			
MF.1.2.1.1 Straw			
MF.1.2.1.2 Other crop residues (sugar and fodder beet leaves, etc.)			
MF.1.2.2 Fodder crops and grazed biomass			
MF.1.2.2.1 Fodder crops (including biomass harvest from grassland)			
MF.1.3 Wood			
MF.1.3.1 Timber (industrial roundwood)			
MF.1.3.2 Wood fuel and other extraction			
MF.1.4 Wild fish catch, aquatic plants and animals, hunting and gathering			
MF.1.4.1 Wild fish catch			
MF.1.4.2 All other aquatic animals and plants			
MF.1.5 Live animals and animal products (excluding wild fish, aquatic plants and animals, hunted and gathered animals)			
MF.1.5.1 Live animals (excluding wild fish, aquatic plants and animals, hunted and gathered animals)			
MF.1.5.2 Meat and meat preparations			
MF.1.5.3 Dairy products, birds eggs, and honey			
MF.1.5.4 Other products from animals (animal fibres, skins, furs, leather etc.)			
MF.1.6 Products mainly from biomass			
MF.2 Metal ores (gross ores)			
MF.2.1 Iron			
MF.2.2 Non-ferrous metal			
MF.2.2.1 Copper			
MF.2.2.2 Nickel			
MF.2.2.3 Lead			
MF.2.2.4 Zinc			
MF.2.2.5 Tin			
MF.2.2.6 Gold, silver, platinum and other precious metal			
intro structure instructions footnote instructions footnotes_list Table_A Table_B			

Source: <https://ec.europa.eu/eurostat/documents/1798247/6191533/Economy-wide+material+flow+accounts+%28EW-MFA%29+questionnaire>

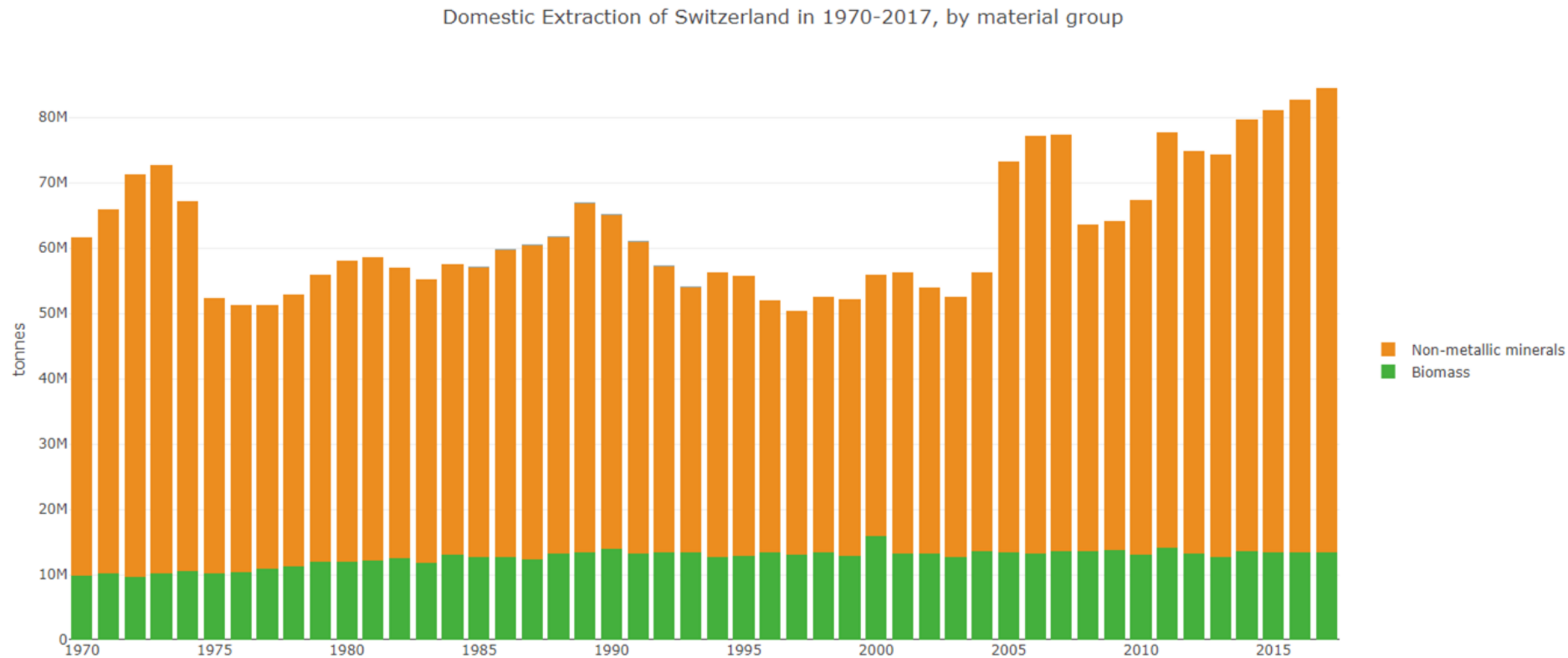
EW-MFA: Domestic Extraction



- **Domestic extraction (DE):** all raw materials that are extracted from the domestic environment and further used in production processes (excluding air and water).
- **Raw material classification**
 - Biomass (crops, wood, animals, etc.)
 - Metal ores (iron, copper, zinc, etc.)
 - Fossil energy materials/carriers (coal, oil, natural gas etc.)
 - Non-metallic minerals (limestone, sand, salt etc.)
- **Data sources:** national extraction/mining statistics, e.g. crop, forestry or mining statistics. (for instance FAO, USGS, ...)

Domestic extraction in CH

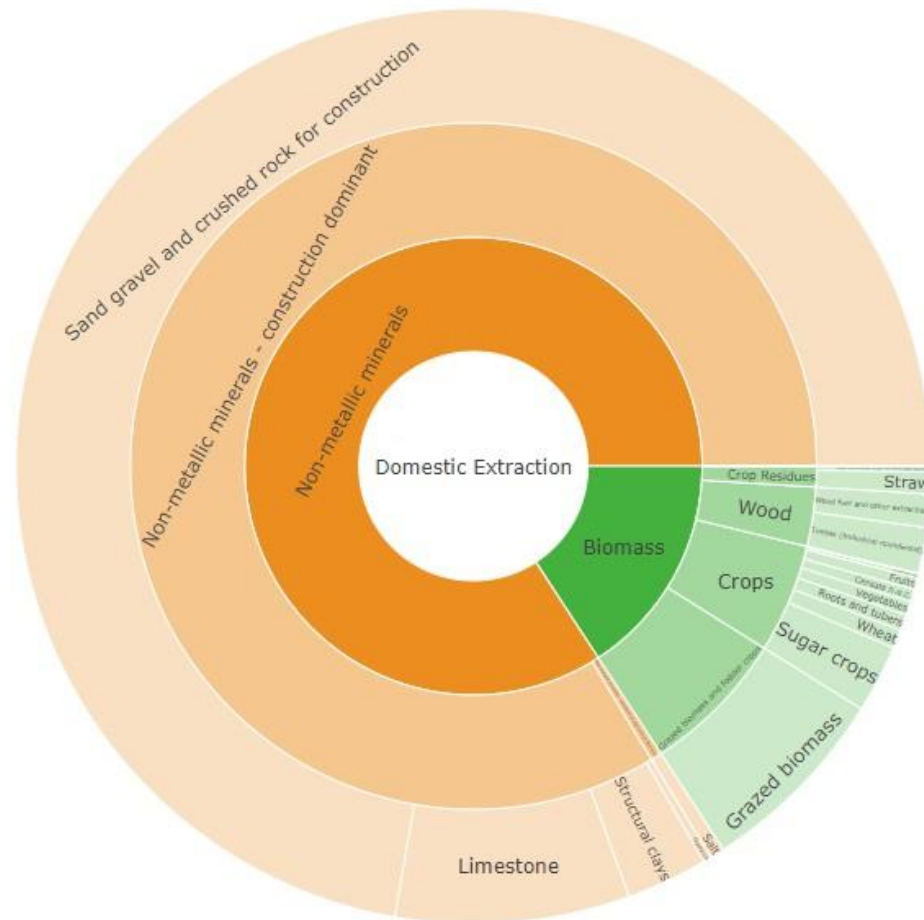
What quantities of raw materials are domestically extracted to sustain economic activities?
Which raw material groups contribute most to the domestic extraction and how has this changed over time?



<http://www.materialflows.net/>

Domestic extraction in CH

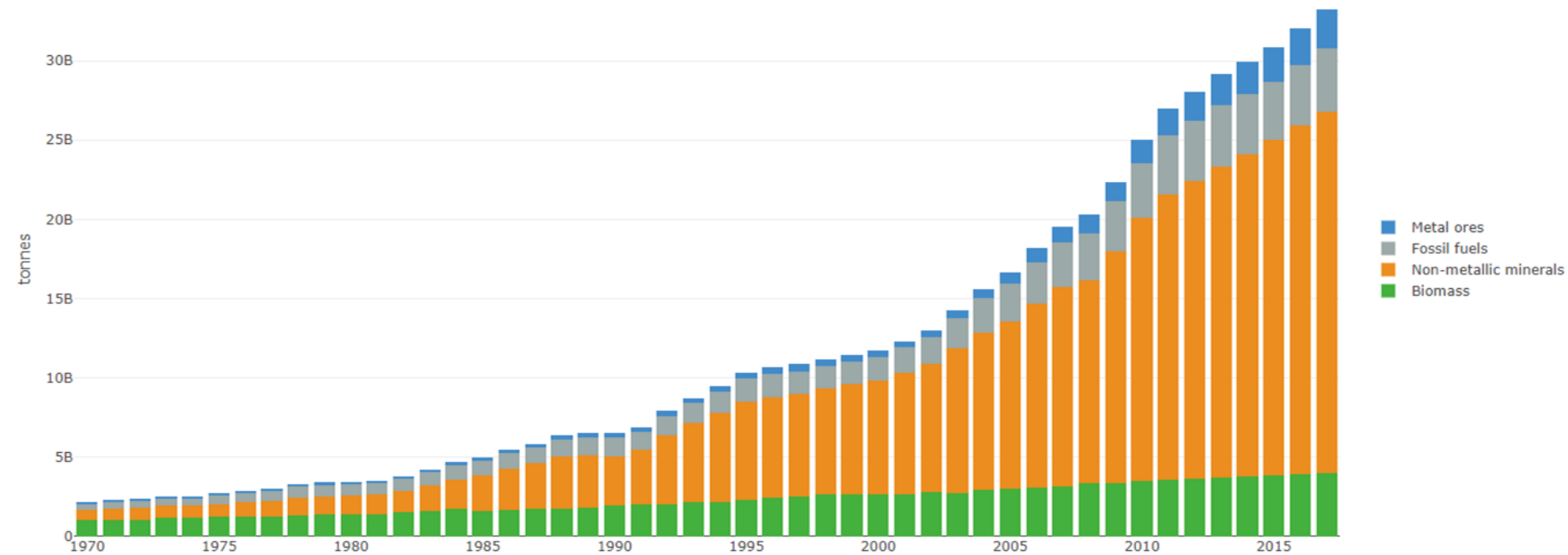
Domestic Extraction of Switzerland in 2017, by material group



<http://www.materialflows.net/>

Domestic extraction in China

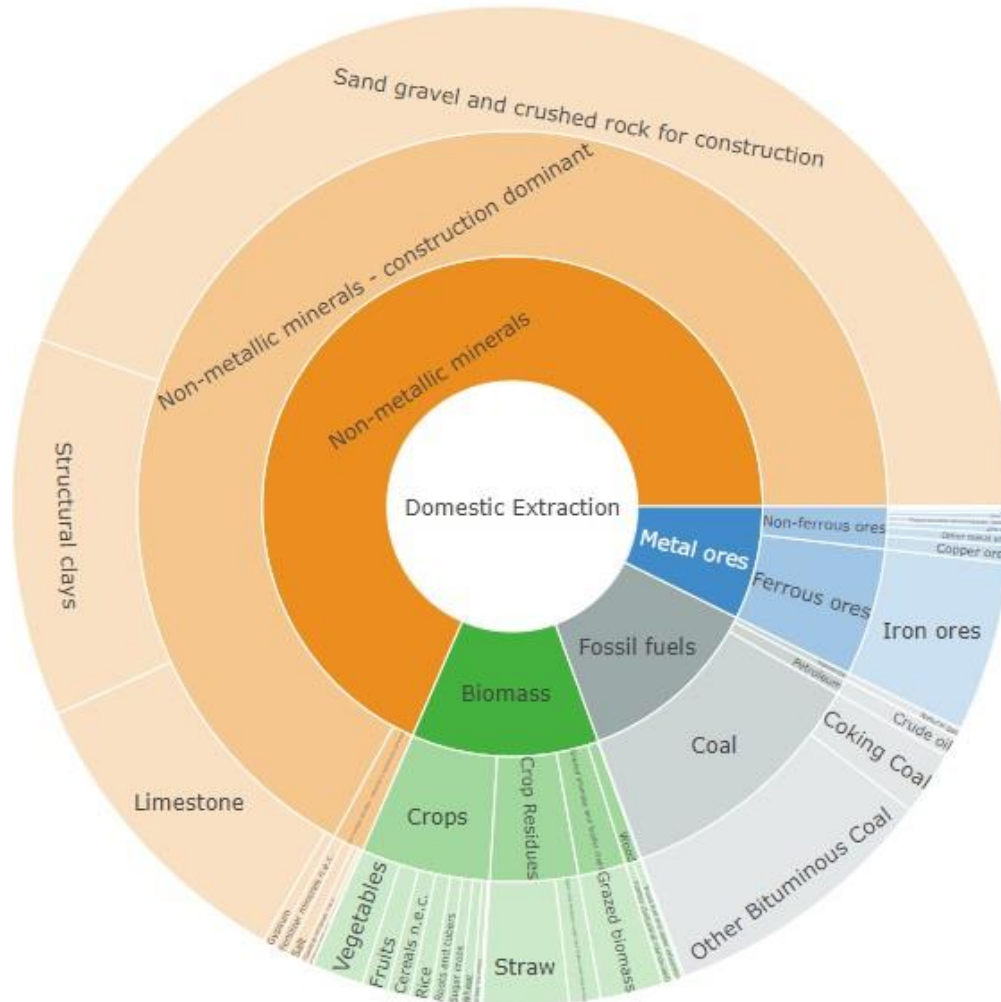
Domestic Extraction of China in 1970-2017, by material group



<http://www.materialflows.net/>

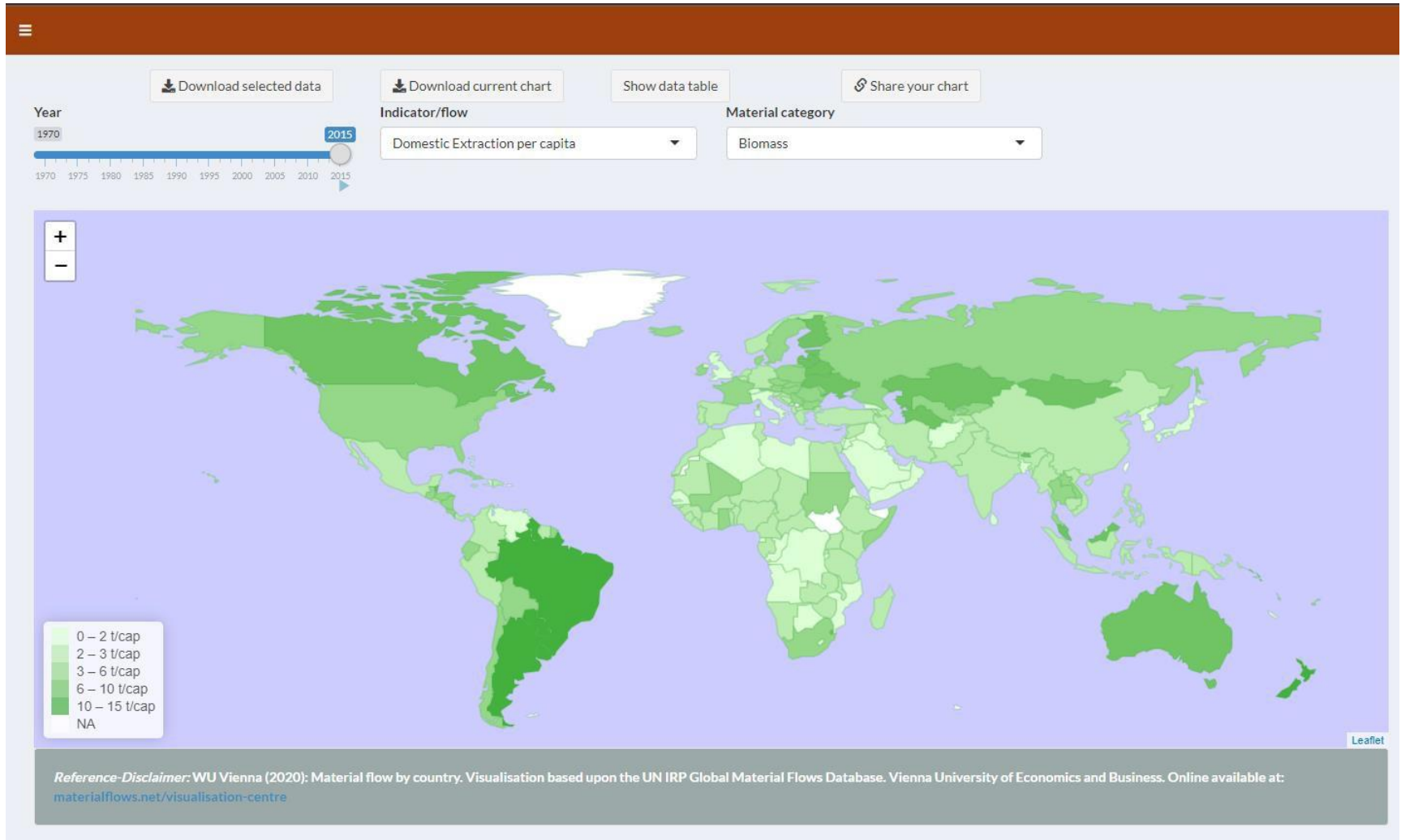
Domestic extraction in China

Domestic Extraction of China in 2017, by material group



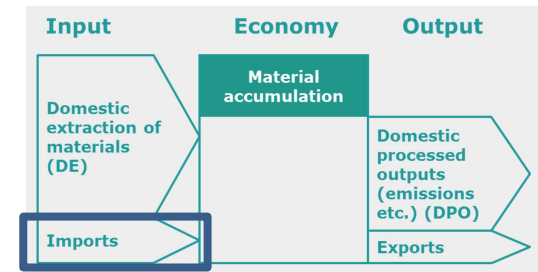
<http://www.materialflows.net/>

Domestic extraction in countries



<http://www.materialflows.net/>

MFA (Eurostat): imports

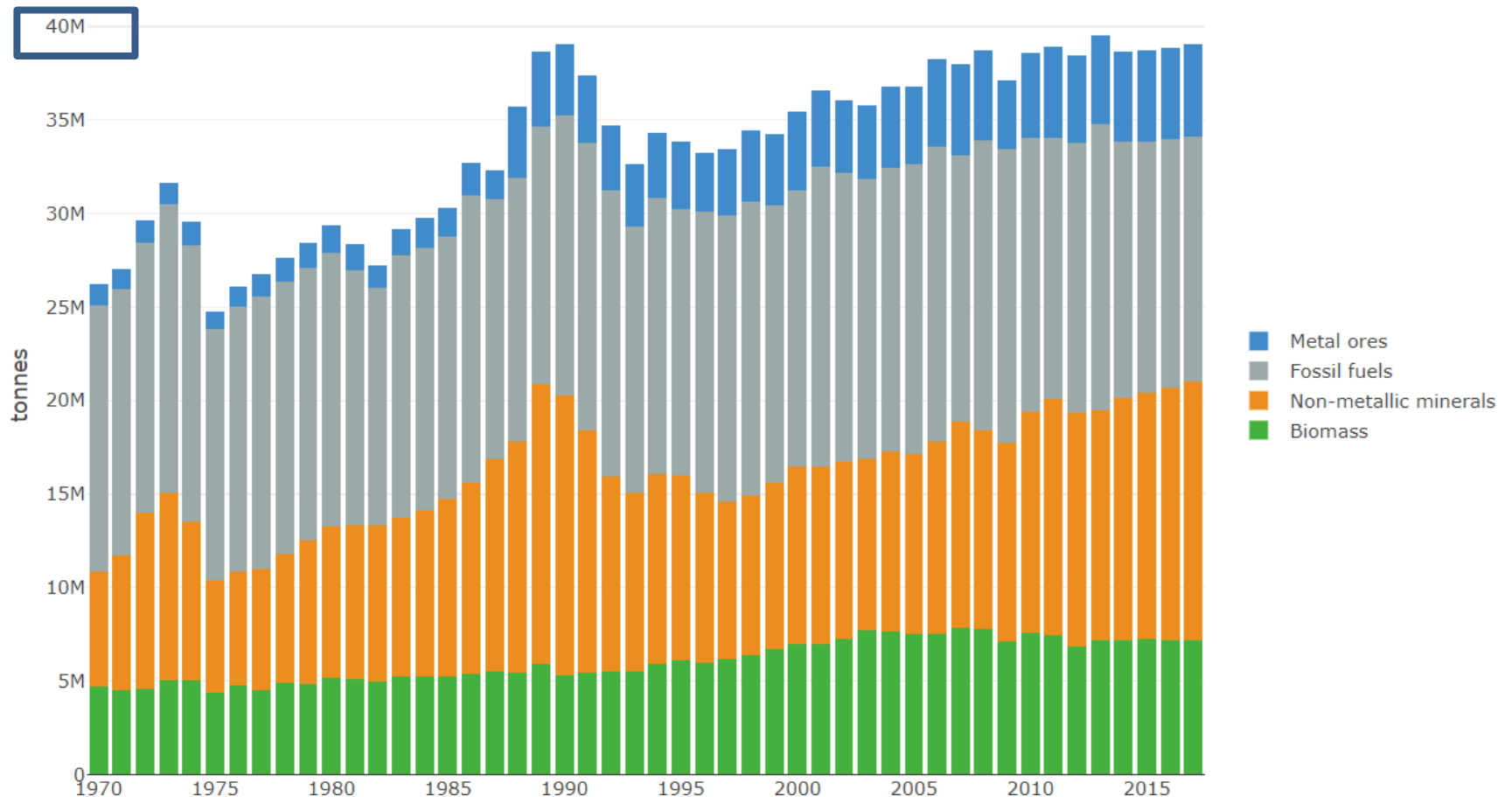


- **Imports (IMP):** imported and traded goods at all stages of processing, from raw materials to highly processed products.
- **Methods:** products are allocated to specific material categories, e.g. imported car produced from steel as the main component is allocated to iron ore.
- **Data sources:** foreign trade statistics, either from national or international (EU, UN) statistical sources. (see COMEXT, CN, NST)

Imports in CH

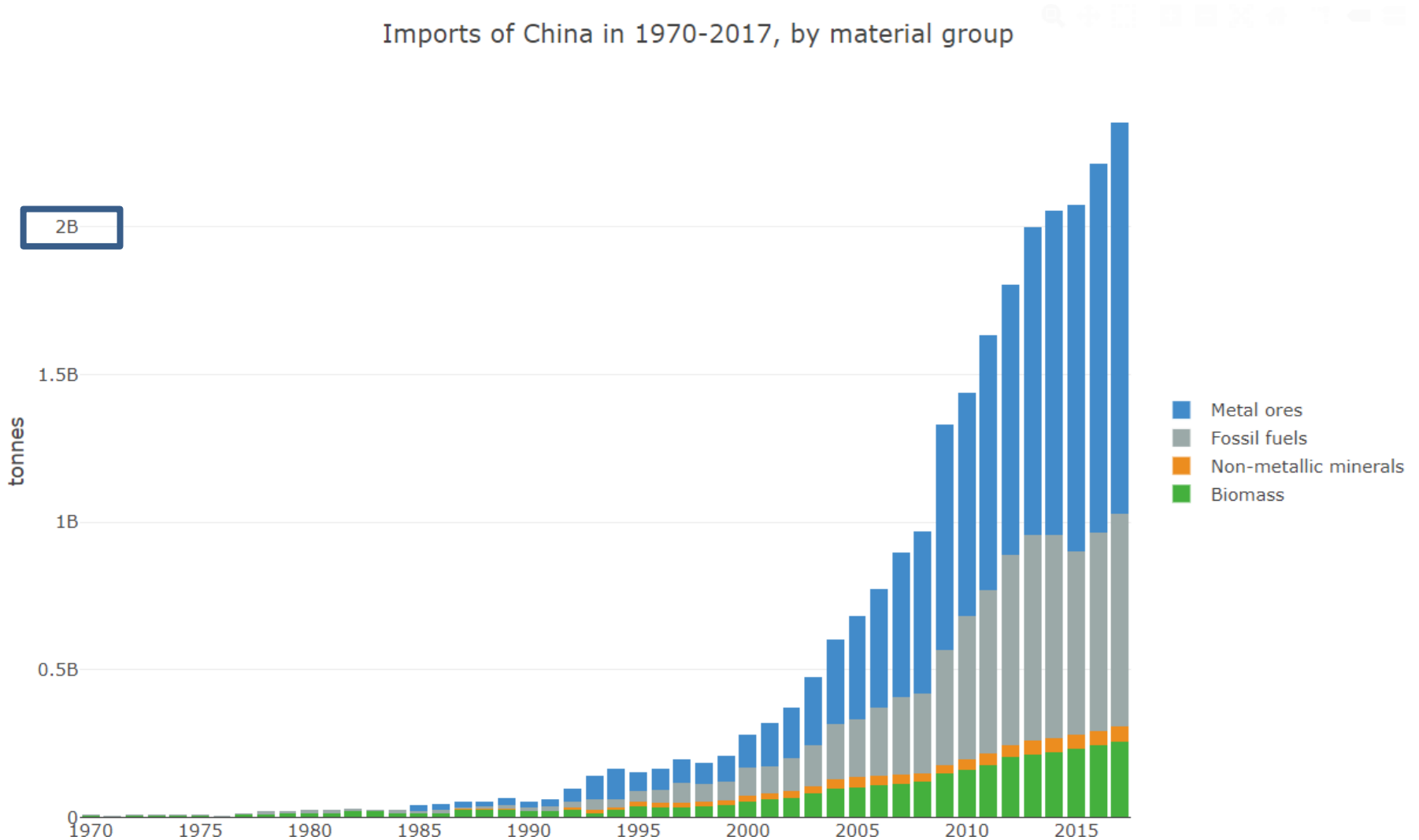
How many goods is a country importing in addition to domestic extraction?
How dependent is the productive sector of an economy on raw material imports?

Imports of Switzerland in 1970-2017, by material group

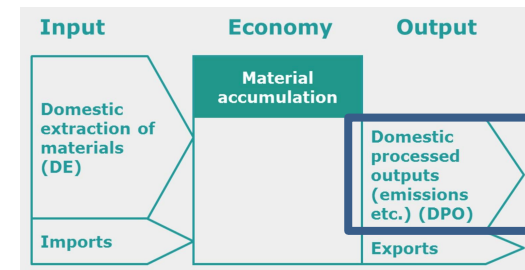


Imports in China

Imports of China in 1970-2017, by material group

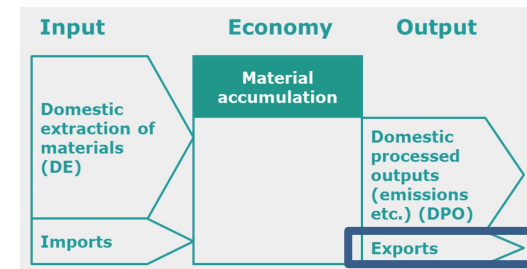


MFA (Eurostat): domestic processed output



- **Domestic processed output (DPO):** total mass of waste materials generated along the value added chain, including resource extraction, processing, manufacturing use, and waste management.
- DPO includes emissions to air, water, and landfill.

MFA (Eurostat): exports

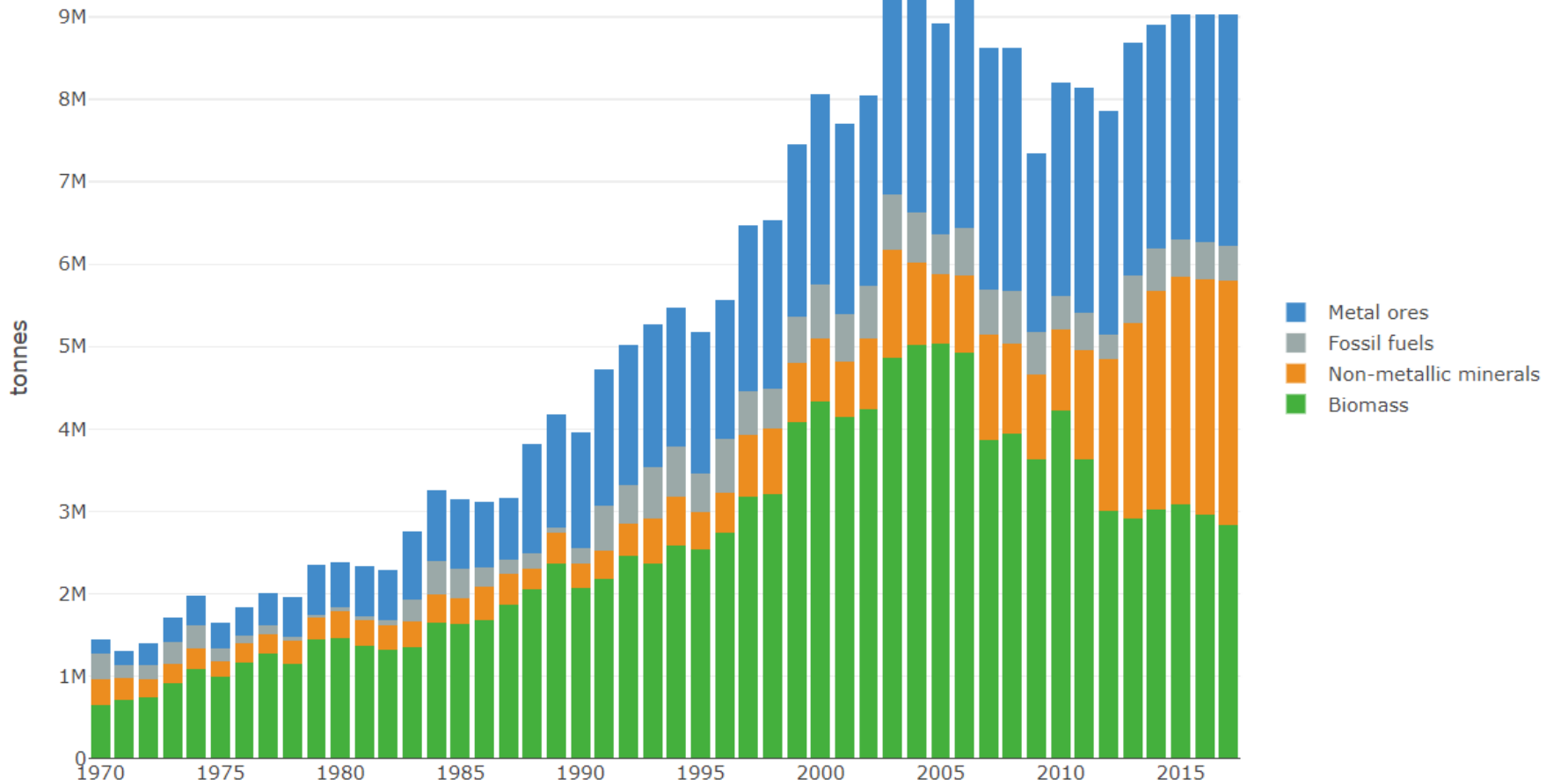


- **Exports (EXP):** exported and traded goods at all stages of processing, from raw materials to highly processed products.
- **Methods:** products are allocated to specific material categories, e.g. exported car produced from steel as the main component is allocated to iron ore.
- **Data sources:** foreign trade statistics, either from national or international (EU, UN) statistical sources.

Exports in CH

How many goods is a country exporting?
40M vs 9M

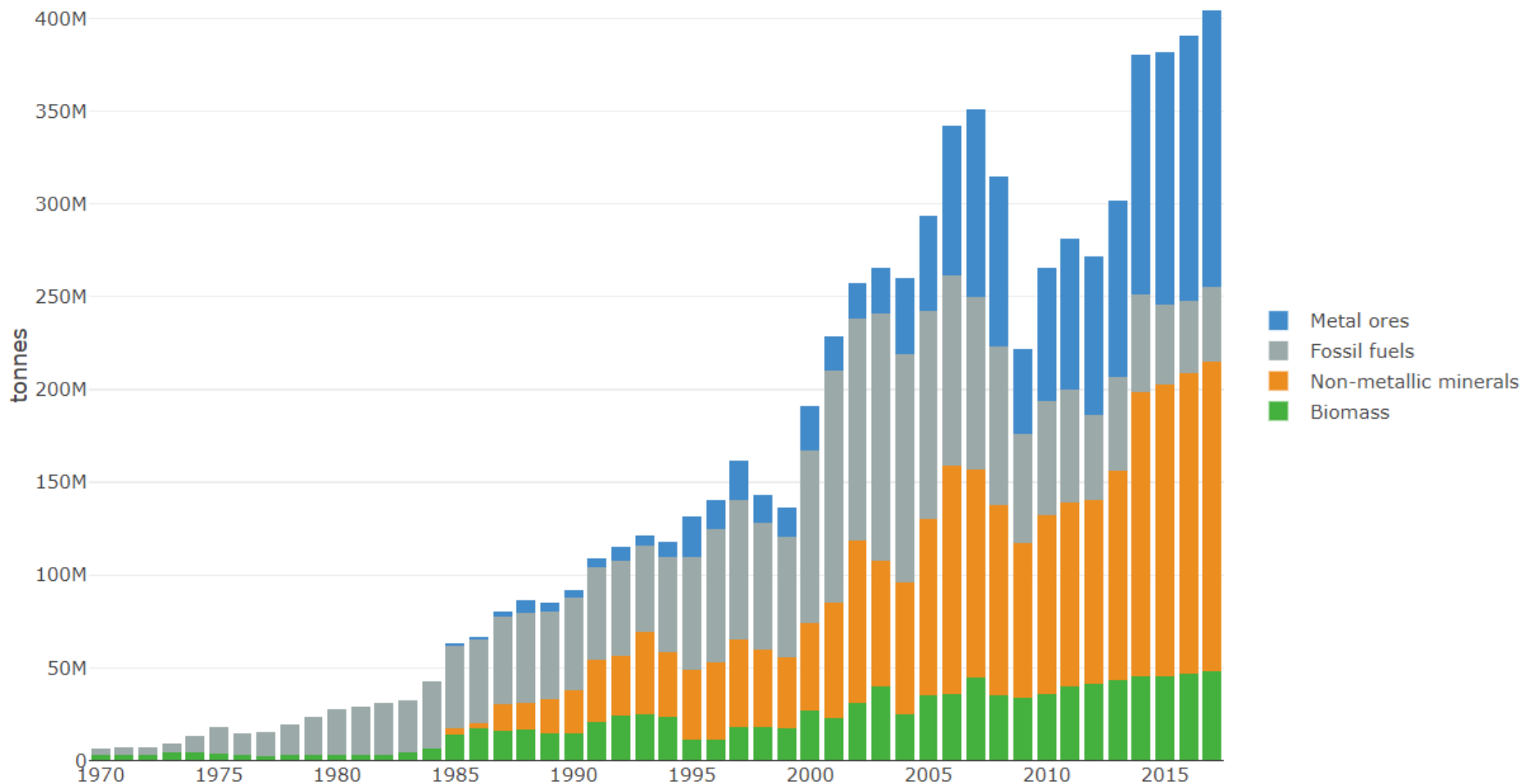
Exports of Switzerland in 1970-2017, by material group



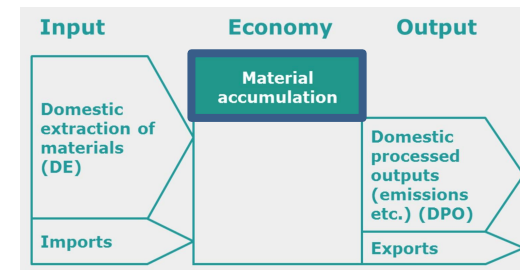
Exports in China

2,5B vs 400M

Exports of China in 1970-2017, by material group



MFA (Eurostat): material accumulation



- **Material accumulation or net additions to stock (NAS):** measure of physical growth in an economy.
- New materials in form of **buildings, infrastructures, durable goods** such as e.g. cars, industry machinery, or household appliances are added to the economy's material stock each year (**gross additions**).
- Old materials are removed from stock as buildings are demolished, and durable goods disposed of (**removals**).

MFA (Eurostat): indicators

Basic flow types

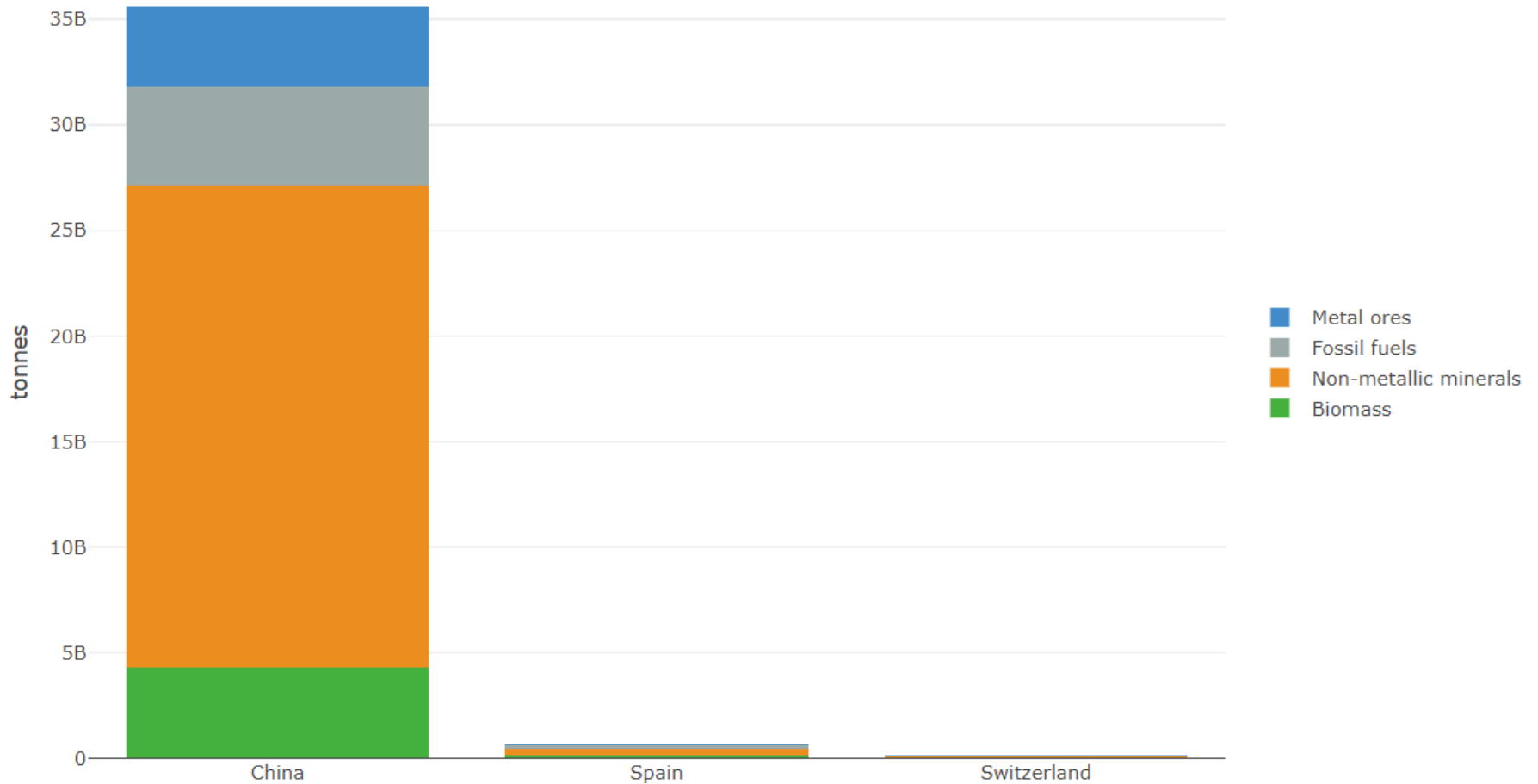
- Domestic extraction (DE)
- Domestic processed output (DPO)
- Imports (IMP)
- Exports (EXP)

Flows types are basis for indicators

- Domestic material input (DMI) = $DE + IMP$
- Domestic material consumption (DMC) = $DE + IMP - EXP$
- Physical trade balance (PTB) = $IMP - EXP$
- Net additions to stock = $DMI - DPO - EXP$

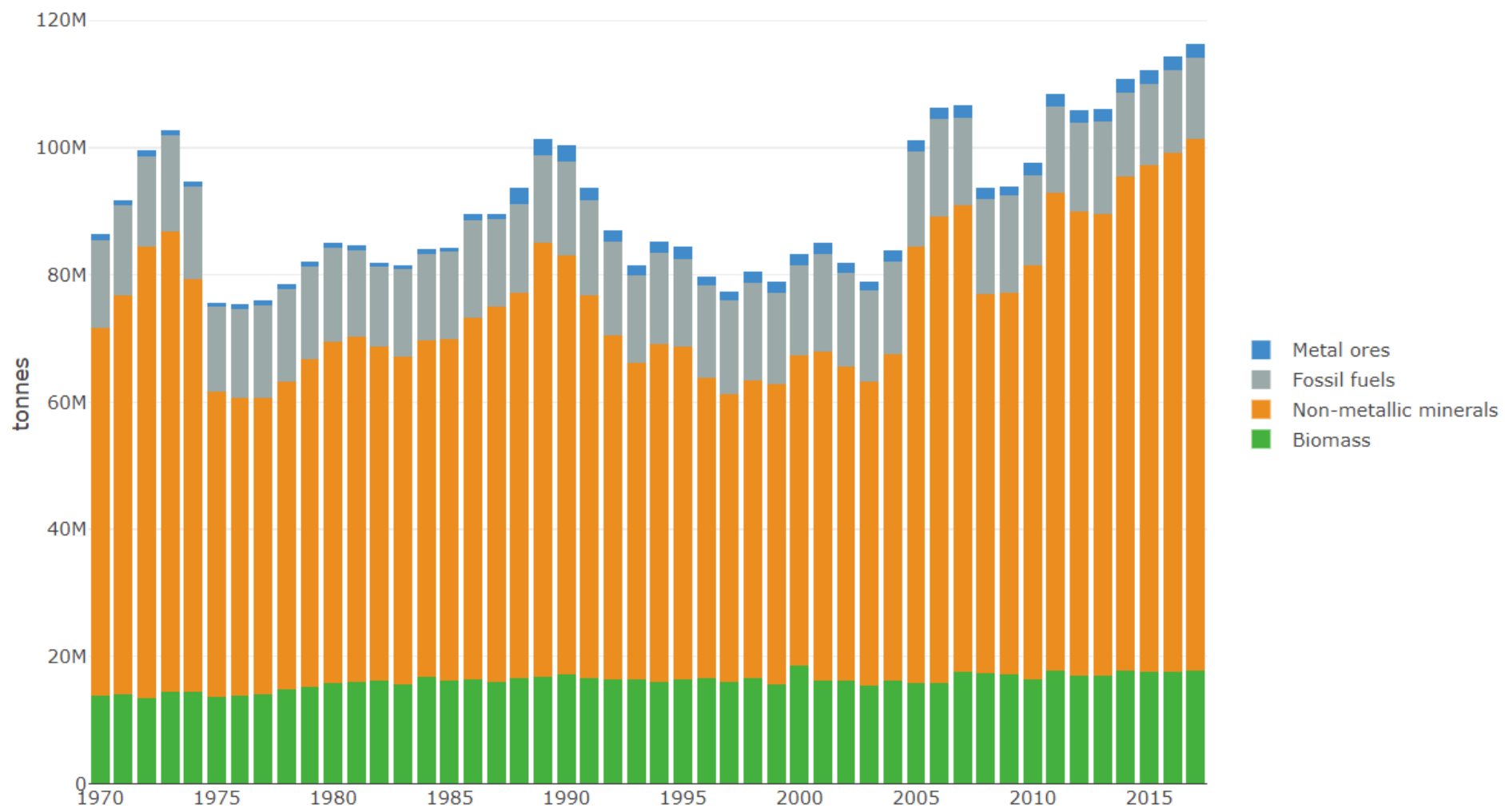
MFA (Eurostat): indicators DMI

Domestic Material Input in 2017, by country/region and material group



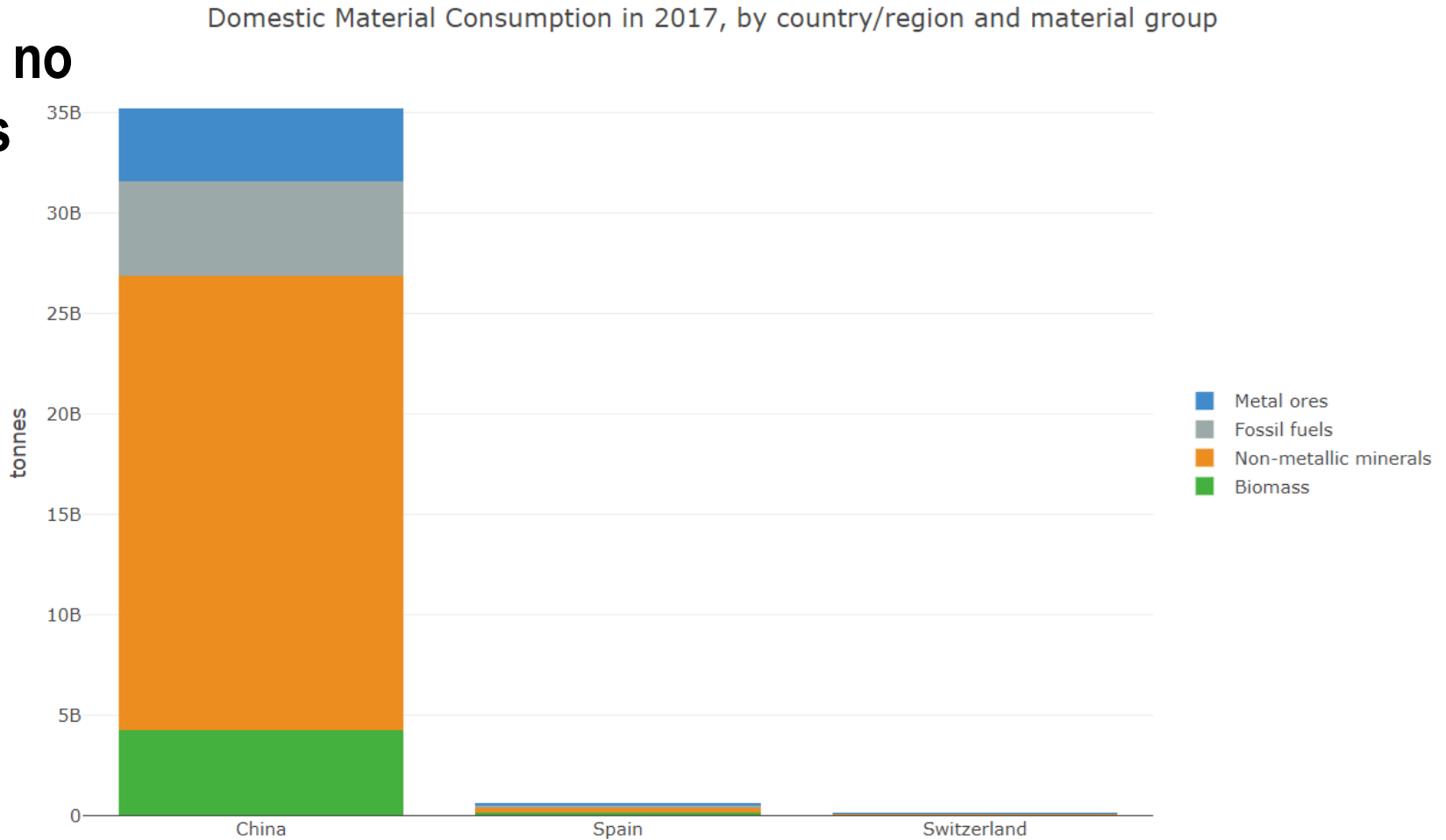
Domestic material consumption in CH

Domestic Material Consumption of Switzerland in 1970-2017, by material group



Domestic material consumption

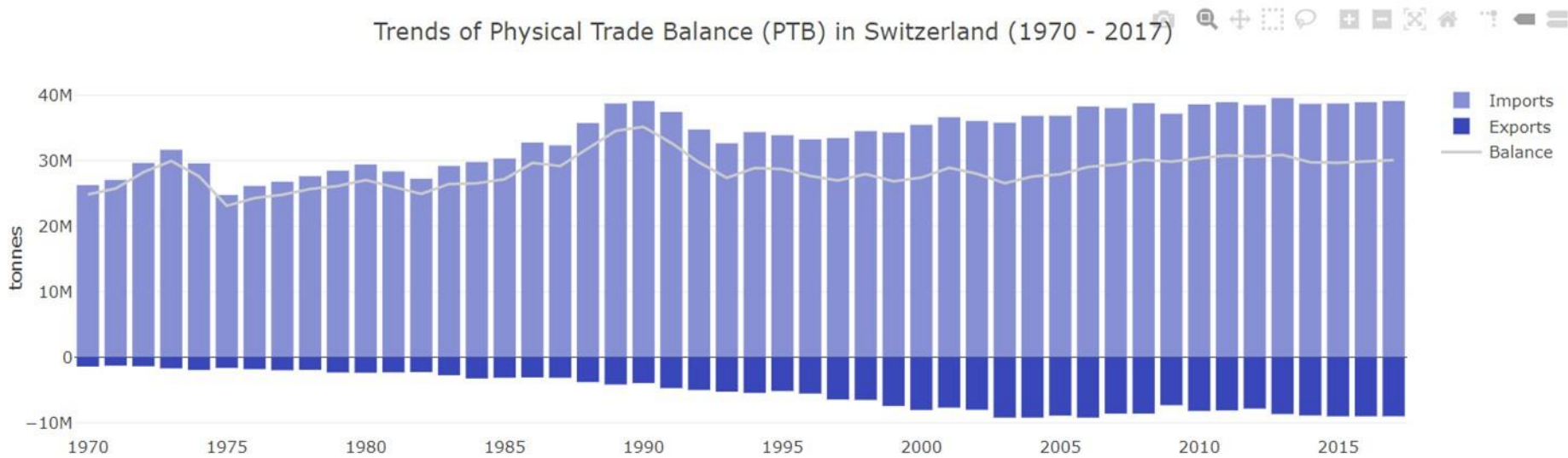
Almost no imports



PTB in CH

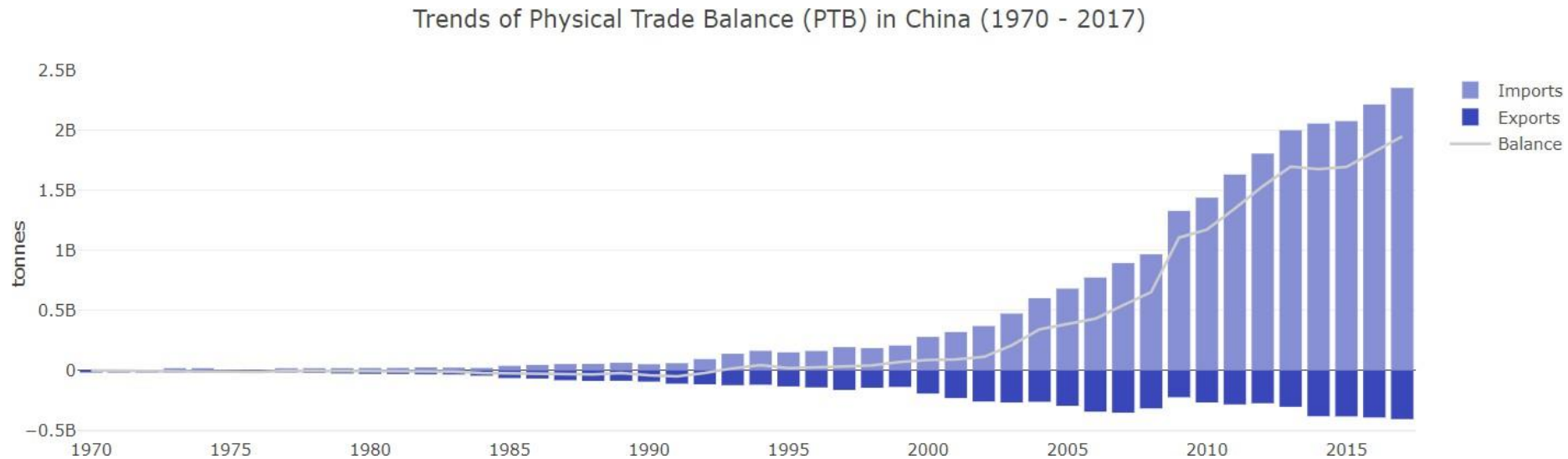
Is a country a physical net-importer or net-exporter of raw materials?

Trends of Physical Trade Balance (PTB) in Switzerland (1970 - 2017)



PTB in China

Is a country a physical net-importer or net-exporter of raw materials?



MFA (Eurostat): additional “monetary” indicators

Material productivity = $\text{GDP}_{[\text{€ of added value}]} / \text{DMC}_{[\text{t of material input}]}$

- **Material productivity:** measure of economic output (goods or services) per unit of material input.
- Increase in material productivity = decoupling material use and economic performance.

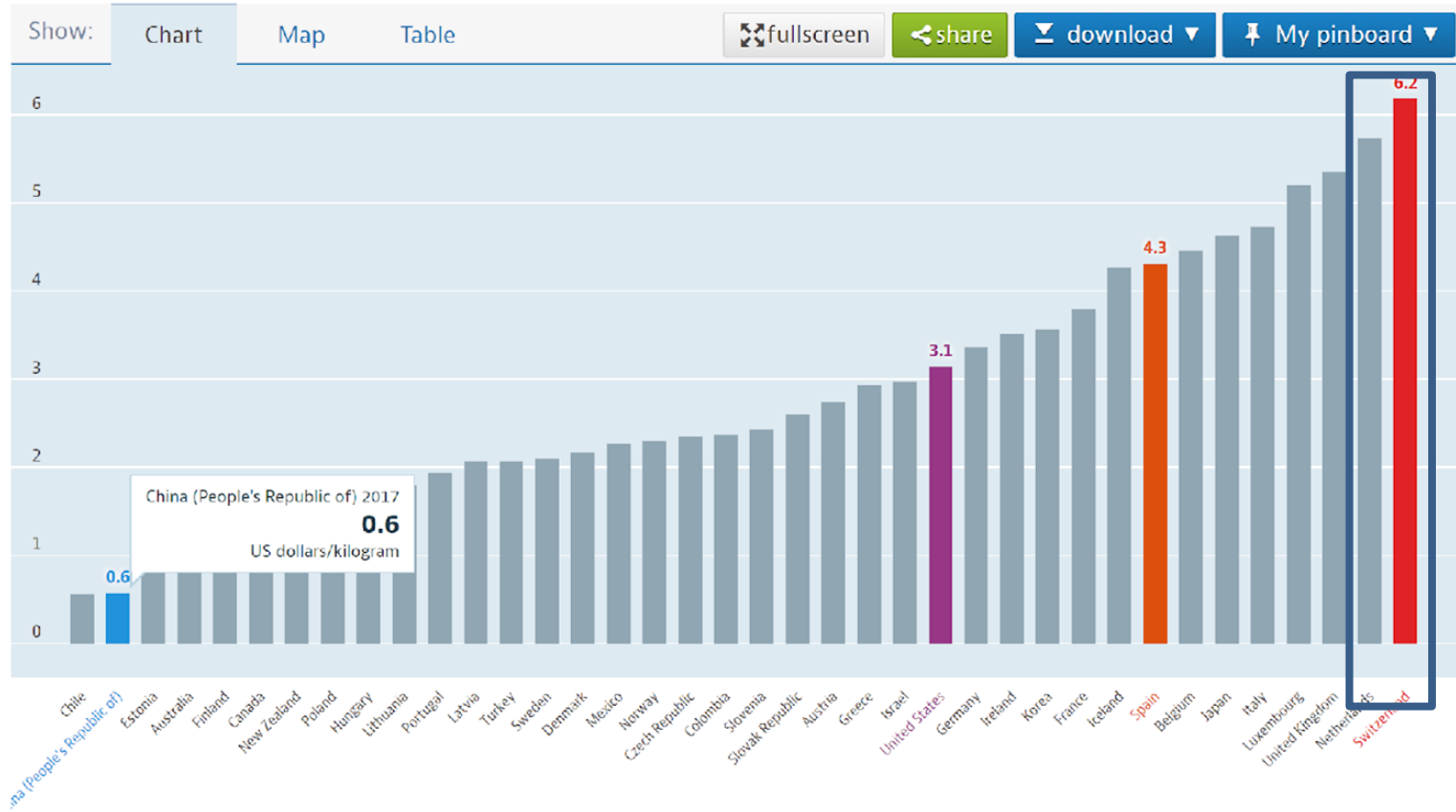
Material intensity = $\text{DMC}_{[\text{t of material input}]} / \text{GDP}_{[\text{€ of added value}]}$

- **Material intensity:** measure of material input used per economic output (good or service)
- Decrease in material intensity = more efficient material use.

Material productivity OECD-37

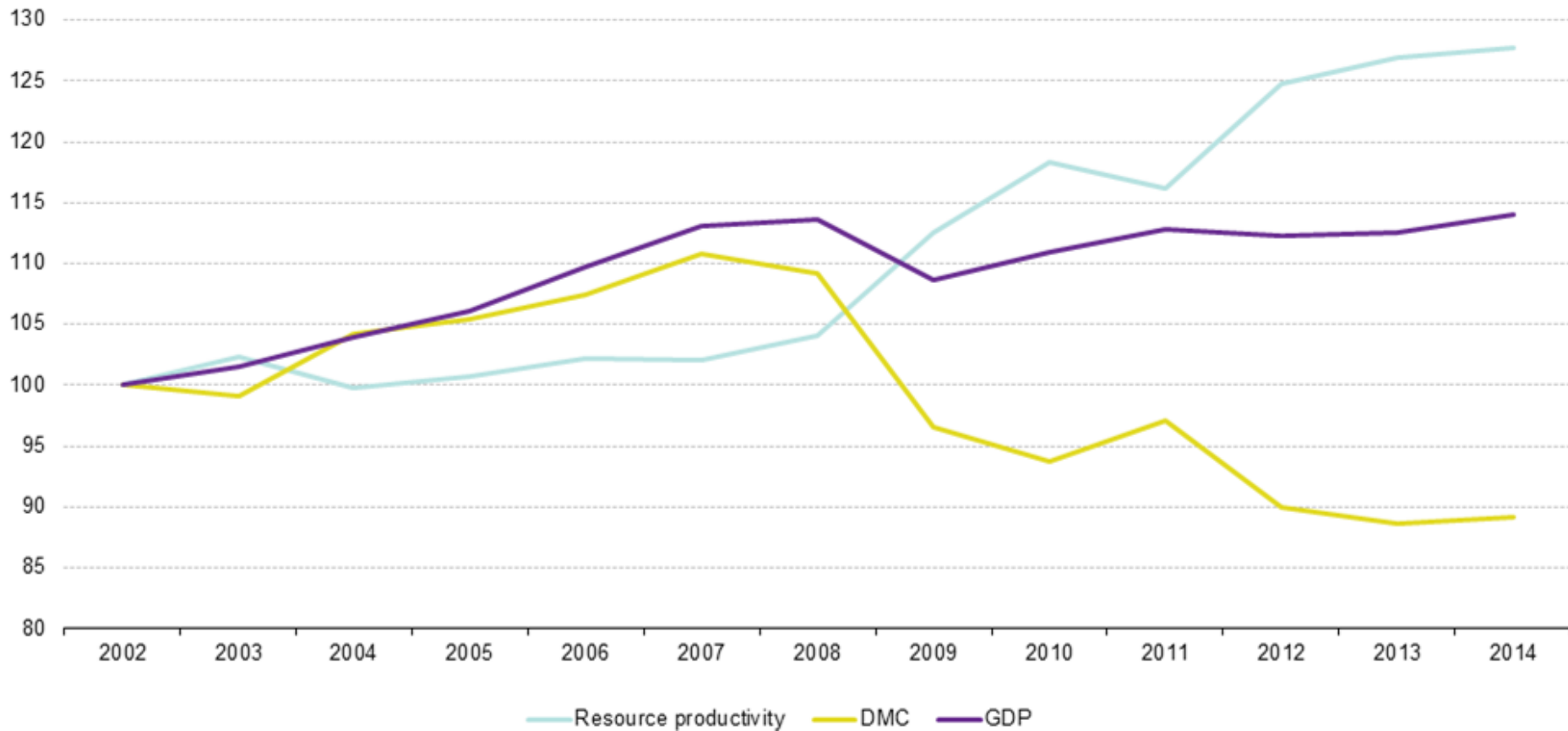
Material productivity Total materials, US dollars/kilogram, 2019 or latest available

Source: Material resources: Material resources



Why?

Let's talk about decoupling (absolute, relative, sufficient)



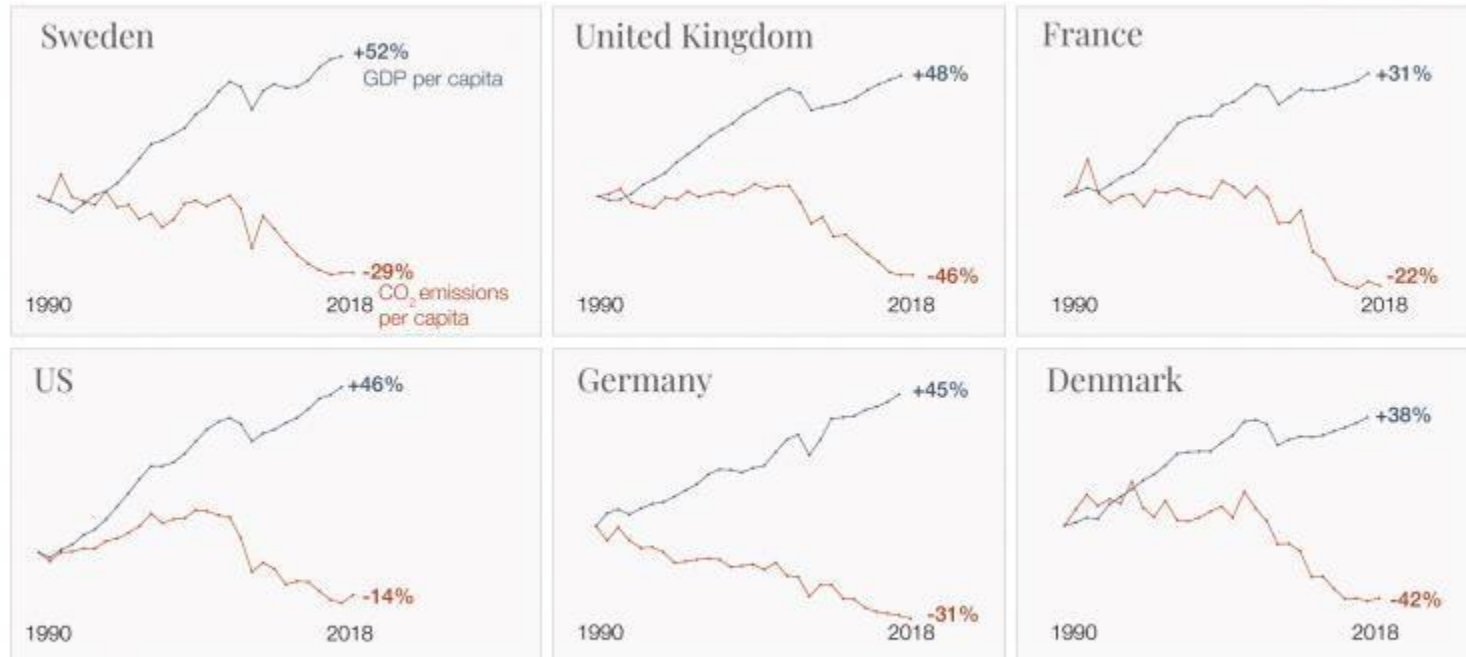
<https://data.oecd.org/materials/material-productivity.htm#indicator-chart>

Let's talk about decoupling (absolute, relative, sufficient)

Six countries that achieved strong economic growth while **reducing CO₂ emissions**



Emissions are adjusted for trade. This means that CO₂ emissions caused in the production of imported goods are added to its domestic emissions; for goods that are exported the emissions are subtracted.



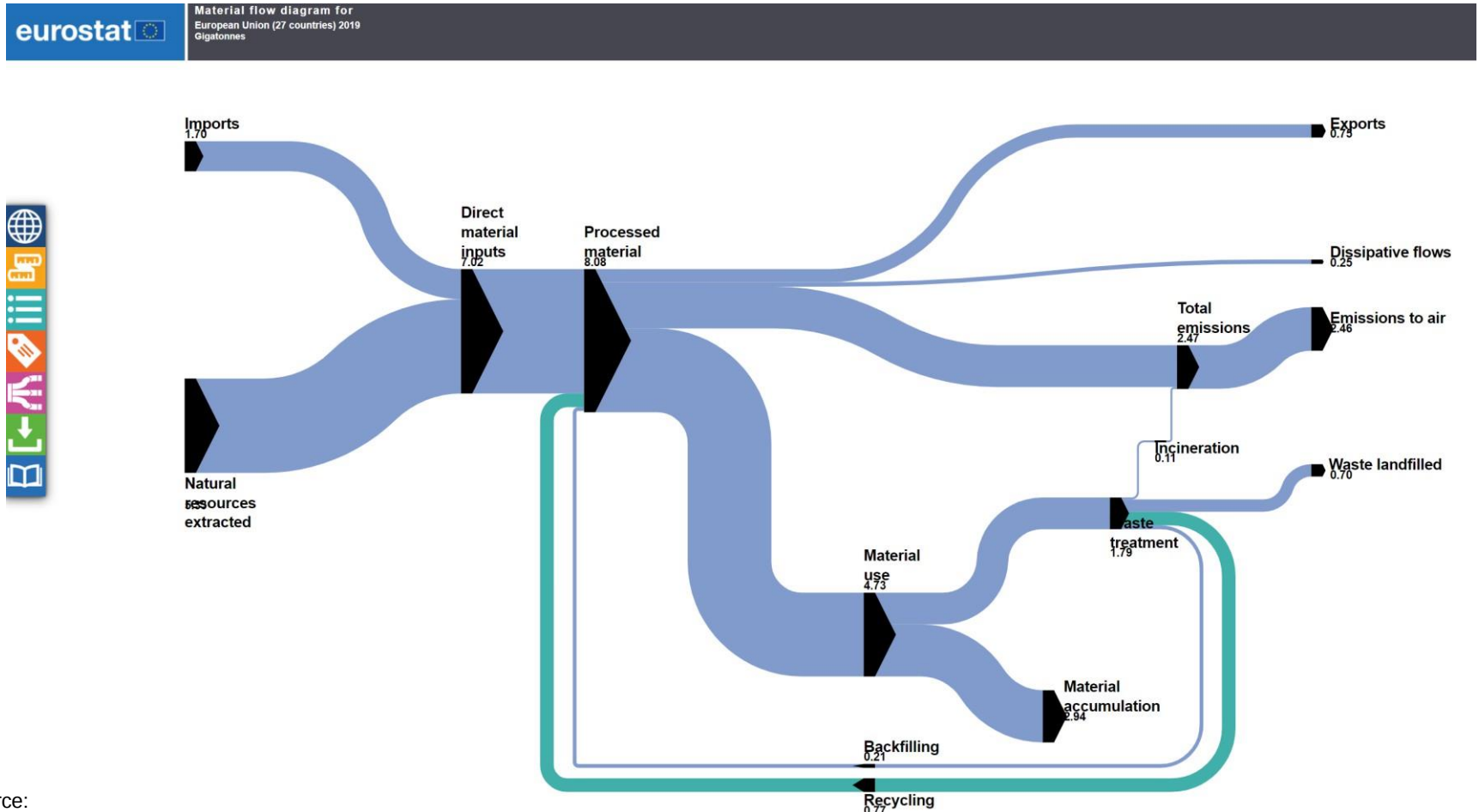
→ Other countries achieved the same. Data for more countries can be found on [OurWorldinData.org](https://ourworldindata.org)

Data source: Our World in Data based on Global Carbon Project; UN Population; and World Bank
[OurWorldinData.org](https://ourworldindata.org) - Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the author Max Roser

<https://ourworldindata.org/carbon-price>

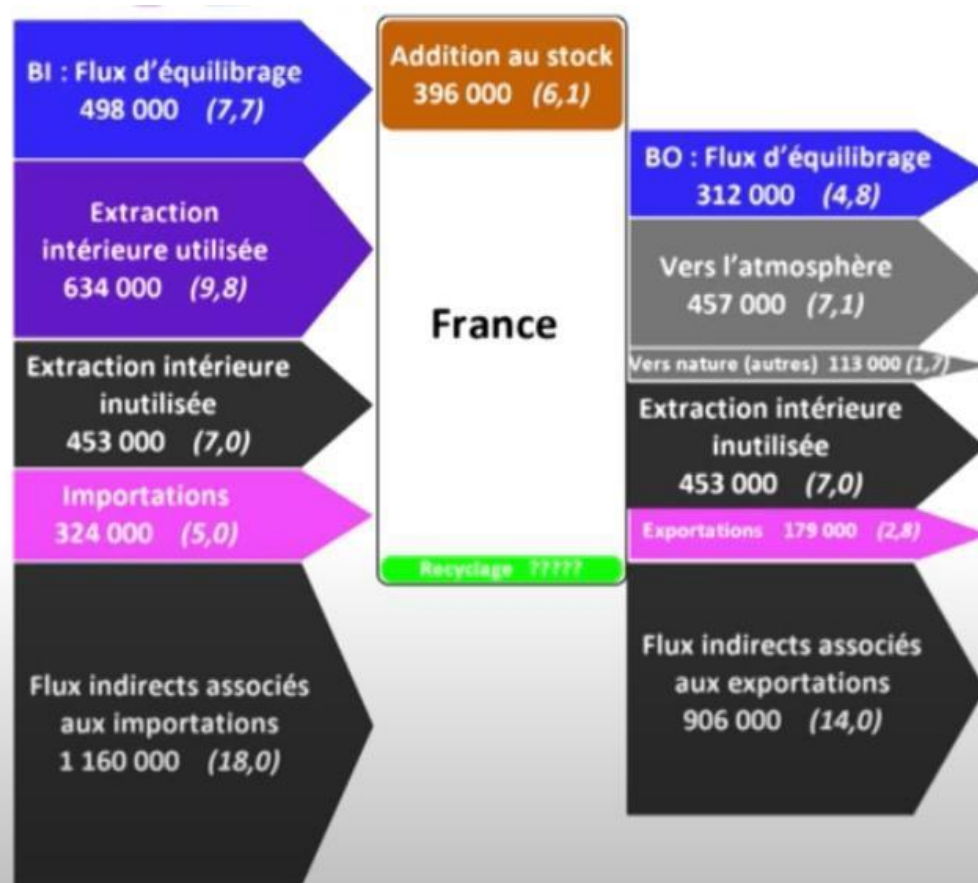
Circular Economy at a EU level



Source:

https://ec.europa.eu/eurostat/cache/sankey/circular_economy/sankey.html?geos=EU27&year=2019&unit=G_T&materials=TOTAL&highlight=0&nodeDisagg=0101100100&flowDisagg=false&translateX=200&translateY=70&scale=0.6&language=EN&xyz=89&material=TOTAL

EW-MFA: Use at a territorial level (French case study)



Bilan de matières brutes, France, 2010, milliers de tonnes
(tonnes par habitant)

Source: <https://www.youtube.com/watch?v=W1Fggh1xlaM&list=PLeU78T5dtVW6wH7xsbDc2KdU3QmnlT8RC>

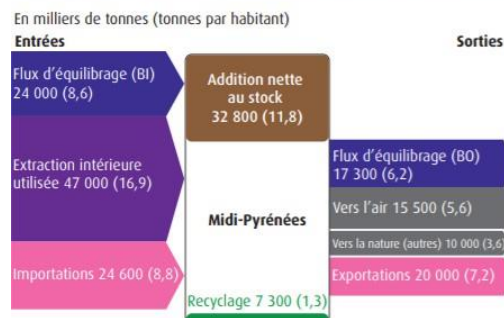
EW-MFA: Use at a territorial level (French case study)

Figure 3.3 : AFM de la région Île-de-France en 2003



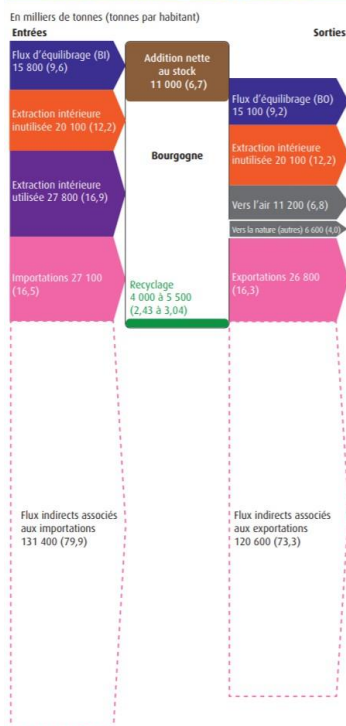
Source : S. Barles, 2009

Figure 3.4 : AFM de la région Midi-Pyrénées en 2006

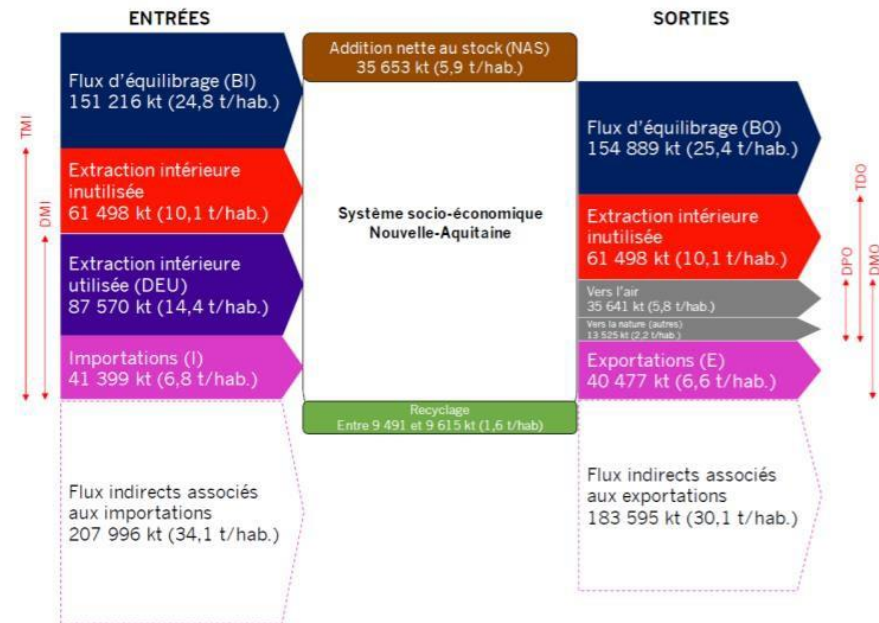


Source : S. Barles, 2014

Figure 3.5 : AFM de la région Bourgogne en 2010



Source : Allere Bourgogne, 2013



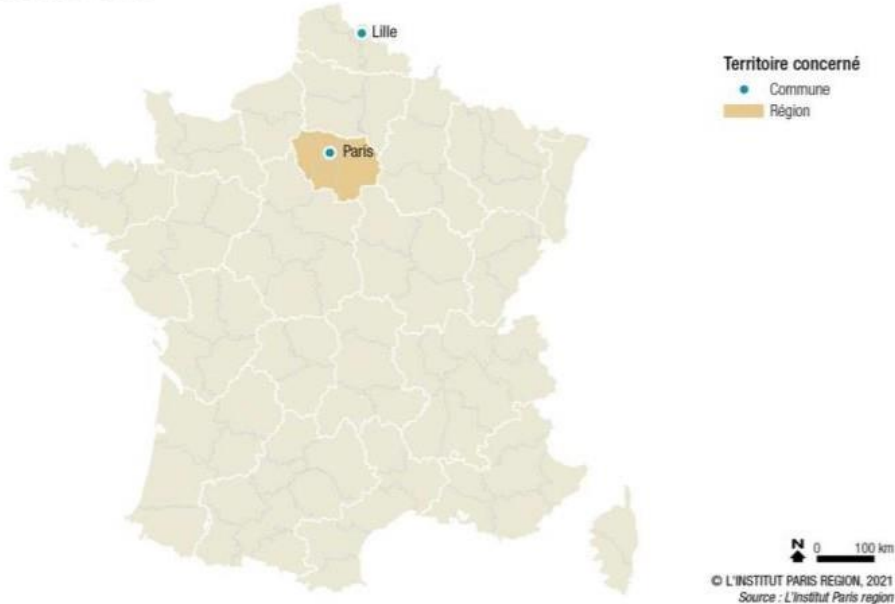
Source : AREC - Données 2017 - Edition 2020

Figure 6. Schéma de principe et principaux indicateurs de l'analyse de flux de matières de la Nouvelle-Aquitaine en 2017. Sources : « Analyse de flux de matières de la Nouvelle-Aquitaine ». Les synthèses de l'AREC - ORDEC Edition 2020 – année 2017.

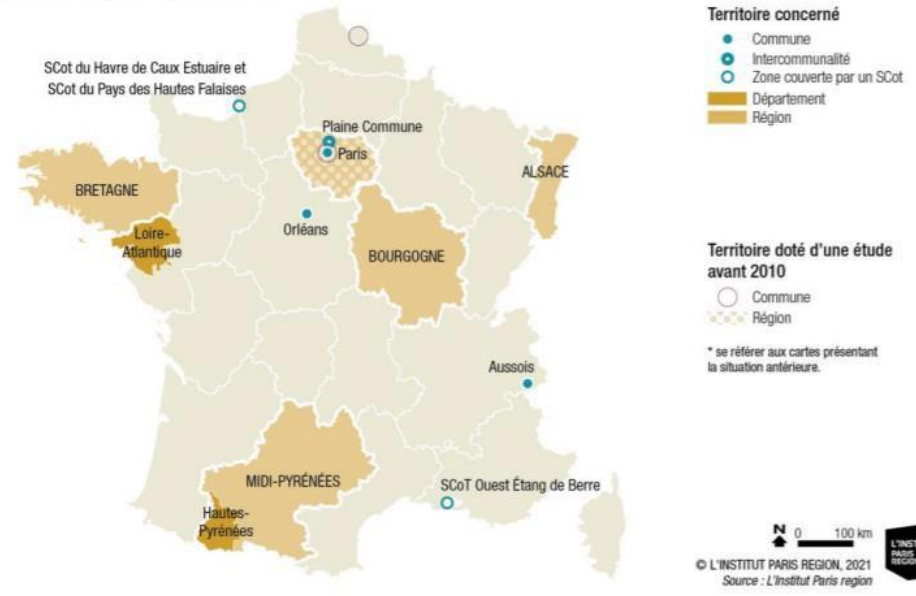
Source: <https://www.ecologie.gouv.fr/sites/default/files/EIT%20-%20comptabilite%20des%20flux%20de%20matieres.pdf> / https://www.institutparisregion.fr/fileadmin/NewEtudes/000pack2/Etude_2625/EtudesMetabolisme_Recensement_VF.pdf

EW-MFA: Use at a territorial level (French case study)

Les territoires dotés d'étude de métabolisme avant 2010



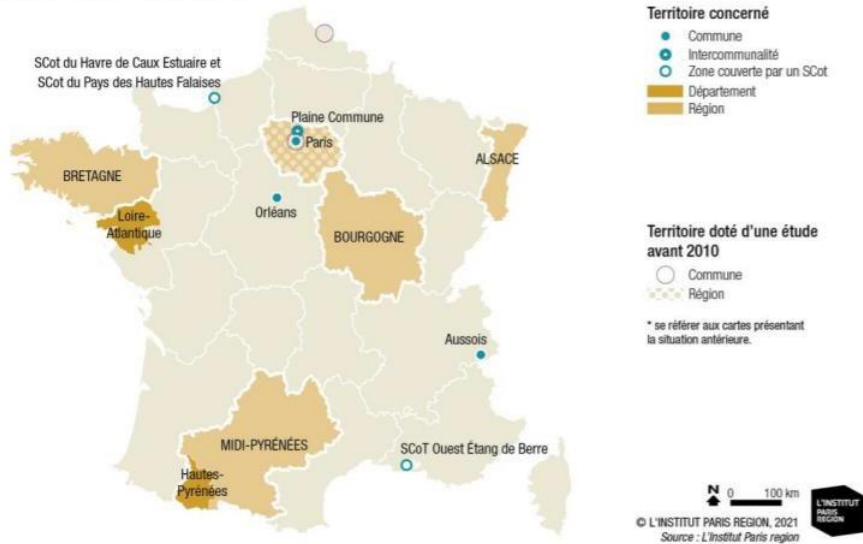
Les territoires dotés d'étude de métabolisme entre 2010 et 2015



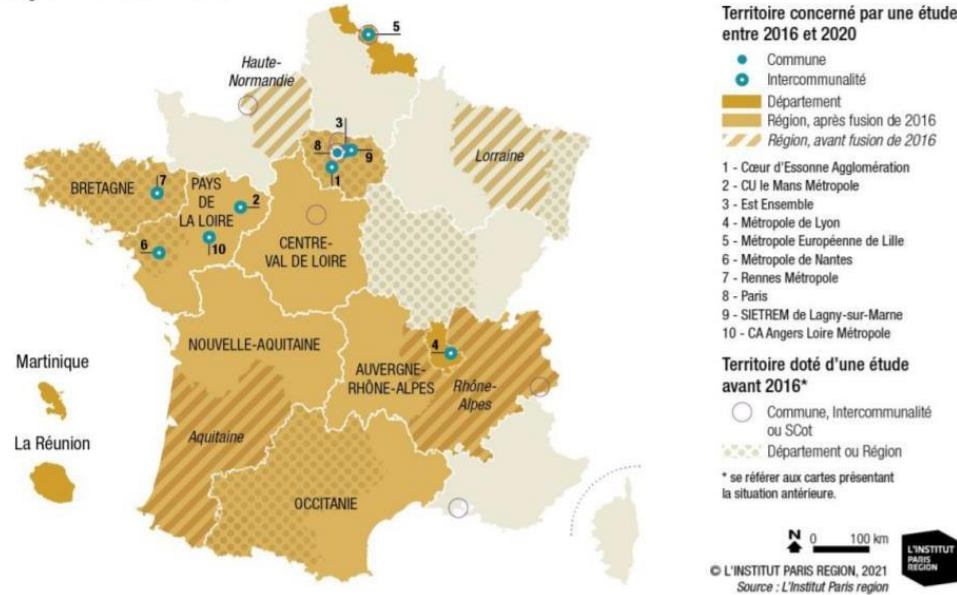
Source: https://www.institutparisregion.fr/fileadmin/NewEtudes/000pack2/Etude_2625/EtudesMetaboli sme_Recensement_VF.pdf

EW-MFA: Use at a territorial level (French case study)

Les territoires dotés d'étude de métabolisme entre 2010 et 2015



Les territoires dotés d'étude de métabolisme à partir de 2016



Carte n°3 : Etudes de métabolisme territorial en France métropolitaine en 2020

Source: https://www.institutparisregion.fr/fileadmin/NewEtudes/000pack2/Etude_2625/EtudesMetabolisme_Recensement_VF.pdf

EW-MFA: advantages vs. disadvantages

Advantages

- Trend representation within countries
- Identification of proportions and hotpots
- Comparative analysis across countries/regions
- Development of physical indicators which can be set in relation to economic indicators
- Monitoring and assessment of overarching policy goals (e.g. SDGs)
- Circular Economy monitoring

Disadvantages

- Black-box approach
- Difficulties in explaining trends
- Difficulties in deriving causalities
- None of the indicators show the full picture

EW-MFA: source

- **Eurostat**
<https://ec.europa.eu/eurostat/web/environment/material-flows-and-resource-productivity>
- **International Resource Panel (IRP)**
<https://www.resourcepanel.org/global-material-flows-database>
- **OECD Statistics**
<https://stats.oecd.org/>
- **World Resource Institute**
<http://www.wri.org/>
- **WU Vienna / CSIRO**
<http://www.materialflows.net/>
- **Material flows of Switzerland**
<https://www.bfs.admin.ch>

Course organisation

Aim of the course (I)



- Analyser un produit ou nu service avec l'ACV
- Calculer les impacts environnementaux d'un produit
- Anticiper les évolutions réglementaires en environnement
- Optimiser les performances environnementales des produits
- Critiquer une étude existante
- Elaborer des stratégies holistiques pour boucler les flux de matière
- Critiquer les stratégies et plans environnementaux des villes et pays
- Analyser les flux de ressources et de déchets

Aim of the course (II)



- Planifier des actions et les mener à bien de façon à faire un usage optimal du temps et des ressources à disposition.
- Recevoir du feedback (une critique) et y répondre de manière appropriée.
- Ecrire un rapport scientifique ou technique.
- Utiliser les outils informatiques courants ainsi que ceux spécifiques à leur discipline.
- Etre responsable des impacts environnementaux de ses actions et décisions.