EXIOBASE

Analysing environmental impacts of the global, interlinked economy

Konstantin Stadler, Richard Wood

Industrial Ecology Programme, NTNU, Norway

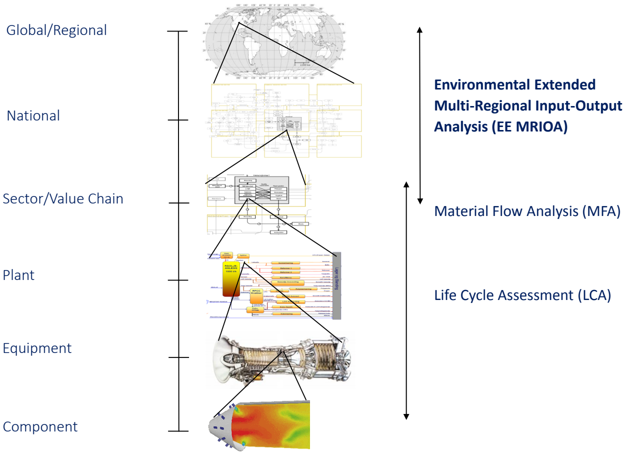
Systems Ecological Perspectives on Sustainabilty, 26$^{\text{th}}$ September 2014

Industrial Ecology

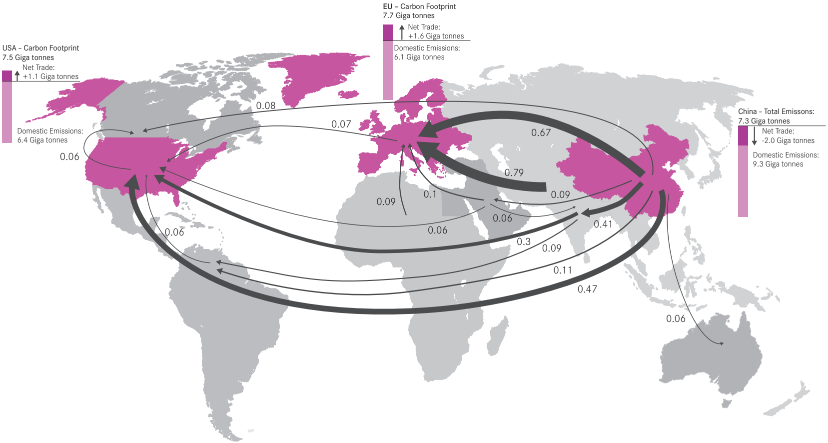
- Analyse interactions between the socioeconomic and environmental system
- Close loops in anthropogenic resource and energy flows
- Minimize environmental impacts of economic activities

Industrial Ecology

- Analyse interactions between the socioeconomic and environmental system
- Close loops in anthropogenic resource and energy flows
- Minimize environmental impacts of economic activities
- Focus on systems analysis on various scales



Largest Global Carbon Flows



Outline

1. How do we estimate these flows?
   - Short introduction to EE MRIO Analysis
2. EXIOBASE 2
   - An open EE MRIO database
   - Development and Structure
   - Results
3. How can you use EXIOBASE?
   - pymrio
4. Future research
   - EXIOBASE 3
   - Ongoing projects

Basic IO model

A basic **input output** model for one region - absolute flows

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	10	3	0	0	2	3	Mill. €
	sec 2	0	25	5	0	14	8	Mill. €
	sec 3	0	10	20	0	10	5	Mill. €
	sec 4	0	2	0	15	16	7	Mill. €
Satellite Accounts	Value added	8	12	20	25			Mill. €
	Emissions	22	17	19	9			CO_2 eq.
	Land Use	57	12	0	0			km^2

Basic IO model

A basic **input** **output** model for one region - absolute flows

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	10	3	0	0	2	3	Mill. €
	sec 2	0	25	5	0	14	8	Mill. €
	sec 3	0	10	20	0	10	5	Mill. €
	sec 4	0	2	0	15	16	7	Mill. €
Satellite Accounts	Value added	8	12	20	25			Mill. €
	Emissions	22	17	19	9			CO_2 eq.
	Land Use	57	12	0	0			km^2

Basic IO model

A basic **input** **output** model for one region - absolute flows

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	10	3	0	0	2	3	Mill. €
	sec 2	0	25	5	0	14	8	Mill. €
	sec 3	0	10	20	0	10	5	Mill. €
	sec 4	0	2	0	15	16	7	Mill. €
Satellite Accounts	Value added	8	12	20	25			Mill. €
	Emissions	22	17	19	9			CO_2 eq.
	Land Use	57	12	0	0			km^2

Basic IO model

A basic **input output** model for one region - coefficients

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	0.56	0.058	0	0			€/€
	sec 2	0	0.48	0.11	0			€/€
	sec 3	0	0.19	0.44	0	1		€/€
	sec 4	0	0.04	0	0.38			€/€
Satellite Accounts	Value added	0.44	0.23	0.44	0.625			€/€
	Emissions	1.2	0.33	0.42	0.225			CO_2 eq./€
	Land Use	3.17	0.23	0	0			km^2/€

Basic IO model

A basic **input** **output** model for one region - coefficients

	Products/Sectors				Final demand		
	sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors							
sec 1	0.56	0.058	0	0			€/€
sec 2	0	0.48	0.11	0			€/€
sec 3	0	0.19	0.44	0	1		€/€
sec 4	0	0.04	0	0.38			€/€
Satellite Accounts							
Value added	0.44	0.23	0.44	0.625			€/€
Emissions	1.2	0.33	0.42	0.225			CO_2 eq./€
Land Use	3.17	0.23	0	0			km^2/€

Basic IO model

A basic **input** **output** model for one region - coefficients

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	0.56	0.058	0	0			€/€
	sec 2	0	0.48	0.11	0			€/€
	sec 3	0	0.19	0.44	0	1		€/€
	sec 4	0	0.04	0	0.38			€/€
Satellite Accounts	Value added	0.44	0.23	0.44	0.625			€/€
	Emissions	1.2	0.33	0.42	0.225			CO_2 eq./€
	Land Use	3.17	0.23	0	0			km^2/€

Basic IO model

A basic **input** **output** model for one region - coefficients

		Products/Sectors				Final demand		
		sec 1	sec 2	sec 3	sec 4	fd	exp	Unit
Products/Sectors	sec 1	0.56	0.058	0	0			€/€
	sec 2	0	0.48	0.11	0			€/€
	sec 3	0	0.19	0.44	0	1		€/€
	sec 4	0	0.04	0	0.38			€/€
Satellite Accounts	Value added	0.44	0.23	0.44	0.625			€/€
	Emissions	1.2	0.33	0.42	0.225			CO_2 eq./€
	Land Use	3.17	0.23	0	0			km^2/€

From IO to MRIOs

$$
\begin{array}{c|cccccccc||cc}
 & \multicolumn{4}{c}{\text{Region 1}} & \multicolumn{4}{c}{\text{Region 2}} & \multicolumn{2}{c}{\text{Final demand}} \\
\hline
 & a_{11} & a_{12} & a_{13} & a_{14} & tr_{15} & tr_{16} & tr_{17} & tr_{18} & y_{11}^{reg1} & y_{12}^{reg2} \\
\text{Region 1} & a_{21} & a_{22} & a_{23} & a_{24} & tr_{25} & tr_{26} & tr_{27} & tr_{28} & y_{21}^{reg1} & y_{22}^{reg2} \\
 & a_{31} & a_{32} & a_{33} & a_{34} & tr_{35} & tr_{36} & tr_{37} & tr_{38} & y_{31}^{reg1} & y_{32}^{reg2} \\
 & a_{41} & a_{42} & a_{43} & a_{44} & tr_{45} & tr_{46} & tr_{47} & tr_{48} & y_{41}^{reg1} & y_{42}^{reg2} \\
\hline
 & tr_{51} & tr_{52} & tr_{53} & tr_{54} & a_{55} & a_{56} & a_{57} & a_{58} & y_{51}^{reg1} & y_{52}^{reg2} \\
\text{Region 2} & tr_{61} & tr_{62} & tr_{63} & tr_{64} & a_{65} & a_{66} & a_{67} & a_{68} & y_{61}^{reg1} & y_{62}^{reg2} \\
 & tr_{71} & tr_{72} & tr_{73} & tr_{74} & a_{75} & a_{76} & a_{77} & a_{78} & y_{71}^{reg1} & y_{72}^{reg2} \\
 & tr_{81} & tr_{82} & tr_{83} & tr_{84} & a_{85} & a_{86} & a_{87} & a_{88} & y_{81}^{reg1} & y_{82}^{reg2} \\
\hline\hline
 & va_{11} & va_{12} & va_{13} & va_{14} & va_{15} & va_{16} & va_{17} & va_{18} & & \\
\text{Satellite Accounts} & ghg_{11} & ghg_{12} & ghg_{13} & ghg_{14} & ghg_{15} & ghg_{16} & ghg_{17} & ghg_{18} & & \\
 & lu_{11} & lu_{12} & lu_{13} & lu_{14} & lu_{15} & lu_{16} & lu_{17} & lu_{18} & &
\end{array}
$$

From IO to MRIOs

	Region 1				Region 2				Final demand	
Region 1	a_{11}	a_{12}	a_{13}	a_{14}	tr_{15}	tr_{16}	tr_{17}	tr_{18}	y_{11}^{reg1}	y_{12}^{reg2}
	a_{21}	a_{22}	a_{23}	a_{24}	tr_{25}	tr_{26}	tr_{27}	tr_{28}	y_{21}^{reg1}	y_{22}^{reg2}
	a_{31}	a_{32}	a_{33}	a_{34}	tr_{35}	tr_{36}	tr_{37}	tr_{38}	y_{31}^{reg1}	y_{32}^{reg2}
	a_{41}	a_{42}	a_{43}	a_{44}	tr_{45}	tr_{46}	tr_{47}	tr_{48}	y_{41}^{reg1}	y_{42}^{reg2}
Region 2	tr_{51}	tr_{52}	tr_{53}	tr_{54}	a_{55}	a_{56}	a_{57}	a_{58}	y_{51}^{reg1}	y_{52}^{reg2}
	tr_{61}	tr_{62}	tr_{63}	tr_{64}	a_{65}	a_{66}	a_{67}	a_{68}	y_{61}^{reg1}	y_{62}^{reg2}
	tr_{71}	tr_{72}	tr_{73}	tr_{74}	a_{75}	a_{76}	a_{77}	a_{78}	y_{71}^{reg1}	y_{72}^{reg2}
	tr_{81}	tr_{82}	tr_{83}	tr_{84}	a_{85}	a_{86}	a_{87}	a_{88}	y_{81}^{reg1}	y_{82}^{reg2}
Satellite Accounts	va_{11}	va_{12}	va_{13}	va_{14}	va_{15}	va_{16}	va_{17}	va_{18}		
	ghg_{11}	ghg_{12}	ghg_{13}	ghg_{14}	ghg_{15}	ghg_{16}	ghg_{17}	ghg_{18}		
	lu_{11}	lu_{12}	lu_{13}	lu_{14}	lu_{15}	lu_{16}	lu_{17}	lu_{18}		

From IO to MRIOs

	Region 1				Region 2				Final demand	
Region 1	a_{11}	a_{12}	a_{13}	a_{14}	tr_{15}	tr_{16}	tr_{17}	tr_{18}	y_{11}^{reg1}	y_{12}^{reg2}
	a_{21}	a_{22}	a_{23}	a_{24}	tr_{25}	tr_{26}	tr_{27}	tr_{28}	y_{21}^{reg1}	y_{22}^{reg2}
	a_{31}	a_{32}	a_{33}	a_{34}	tr_{35}	tr_{36}	tr_{37}	tr_{38}	y_{31}^{reg1}	y_{32}^{reg2}
	a_{41}	a_{42}	a_{43}	a_{44}	tr_{45}	tr_{46}	tr_{47}	tr_{48}	y_{41}^{reg1}	y_{42}^{reg2}
Region 2	tr_{51}	tr_{52}	tr_{53}	tr_{54}	a_{55}	a_{56}	a_{57}	a_{58}	y_{51}^{reg1}	y_{52}^{reg2}
	tr_{61}	tr_{62}	tr_{63}	tr_{64}	a_{65}	a_{66}	a_{67}	a_{68}	y_{61}^{reg1}	y_{62}^{reg2}
	tr_{71}	tr_{72}	tr_{73}	tr_{74}	a_{75}	a_{76}	a_{77}	a_{78}	y_{71}^{reg1}	y_{72}^{reg2}
	tr_{81}	tr_{82}	tr_{83}	tr_{84}	a_{85}	a_{86}	a_{87}	a_{88}	y_{81}^{reg1}	y_{82}^{reg2}
Satellite Accounts	va_{11}	va_{12}	va_{13}	va_{14}	va_{15}	va_{16}	va_{17}	va_{18}		
	ghg_{11}	ghg_{12}	ghg_{13}	ghg_{14}	ghg_{15}	ghg_{16}	ghg_{17}	ghg_{18}		
	lu_{11}	lu_{12}	lu_{13}	lu_{14}	lu_{15}	lu_{16}	lu_{17}	lu_{18}		

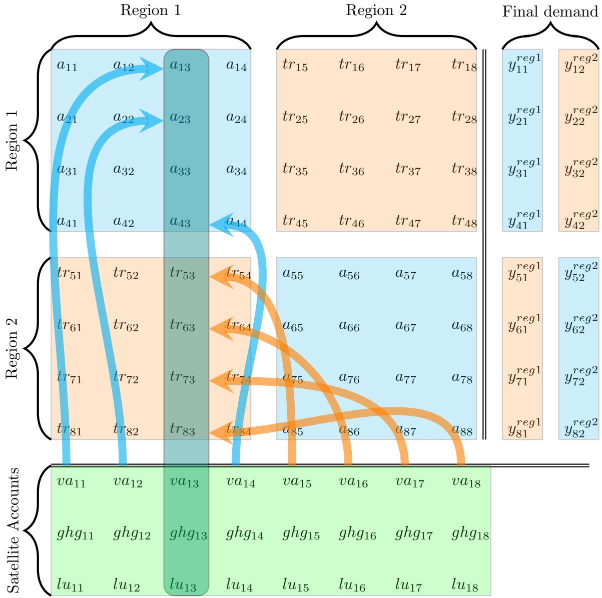
From IO to MRIOs

	Region 1				Region 2				Final demand	
Region 1	a_{11}	a_{12}	a_{13}	a_{14}	tr_{15}	tr_{16}	tr_{17}	tr_{18}	y_{11}^{reg1}	y_{12}^{reg2}
	a_{21}	a_{22}	a_{23}	a_{24}	tr_{25}	tr_{26}	tr_{27}	tr_{28}	y_{21}^{reg1}	y_{22}^{reg2}
	a_{31}	a_{32}	a_{33}	a_{34}	tr_{35}	tr_{36}	tr_{37}	tr_{38}	y_{31}^{reg1}	y_{32}^{reg2}
	a_{41}	a_{42}	a_{43}	a_{44}	tr_{45}	tr_{46}	tr_{47}	tr_{48}	y_{41}^{reg1}	y_{42}^{reg2}
Region 2	tr_{51}	tr_{52}	tr_{53}	tr_{54}	a_{55}	a_{56}	a_{57}	a_{58}	y_{51}^{reg1}	y_{52}^{reg2}
	tr_{61}	tr_{62}	tr_{63}	tr_{64}	a_{65}	a_{66}	a_{67}	a_{68}	y_{61}^{reg1}	y_{62}^{reg2}
	tr_{71}	tr_{72}	tr_{73}	tr_{74}	a_{75}	a_{76}	a_{77}	a_{78}	y_{71}^{reg1}	y_{72}^{reg2}
	tr_{81}	tr_{82}	tr_{83}	tr_{84}	a_{85}	a_{86}	a_{87}	a_{88}	y_{81}^{reg1}	y_{82}^{reg2}
Satellite Accounts	va_{11}	va_{12}	va_{13}	va_{14}	va_{15}	va_{16}	va_{17}	va_{18}		
	ghg_{11}	ghg_{12}	ghg_{13}	ghg_{14}	ghg_{15}	ghg_{16}	ghg_{17}	ghg_{18}		
	lu_{11}	lu_{12}	lu_{13}	lu_{14}	lu_{15}	lu_{16}	lu_{17}	lu_{18}		

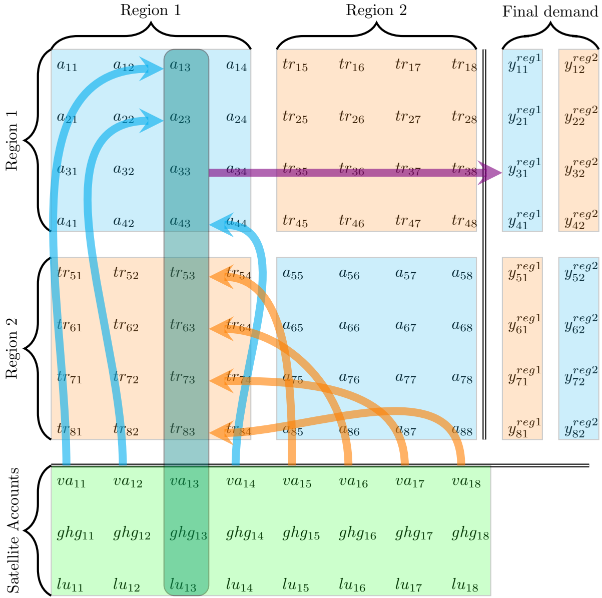
From IO to MRIOs

	Region 1				Region 2				Final demand	
Region 1	a_{11}	a_{12}	a_{13}	a_{14}	tr_{15}	tr_{16}	tr_{17}	tr_{18}	y_{11}^{reg1}	y_{12}^{reg2}
	a_{21}	a_{22}	a_{23}	a_{24}	tr_{25}	tr_{26}	tr_{27}	tr_{28}	y_{21}^{reg1}	y_{22}^{reg2}
	a_{31}	a_{32}	a_{33}	a_{34}	tr_{35}	tr_{36}	tr_{37}	tr_{38}	y_{31}^{reg1}	y_{32}^{reg2}
	a_{41}	a_{42}	a_{43}	a_{44}	tr_{45}	tr_{46}	tr_{47}	tr_{48}	y_{41}^{reg1}	y_{42}^{reg2}
Region 2	tr_{51}	tr_{52}	tr_{53}	tr_{54}	a_{55}	a_{56}	a_{57}	a_{58}	y_{51}^{reg1}	y_{52}^{reg2}
	tr_{61}	tr_{62}	tr_{63}	tr_{64}	a_{65}	a_{66}	a_{67}	a_{68}	y_{61}^{reg1}	y_{62}^{reg2}
	tr_{71}	tr_{72}	tr_{73}	tr_{74}	a_{75}	a_{76}	a_{77}	a_{78}	y_{71}^{reg1}	y_{72}^{reg2}
	tr_{81}	tr_{82}	tr_{83}	tr_{84}	a_{85}	a_{86}	a_{87}	a_{88}	y_{81}^{reg1}	y_{82}^{reg2}
Satellite Accounts	va_{11}	va_{12}	va_{13}	va_{14}	va_{15}	va_{16}	va_{17}	va_{18}		
	ghg_{11}	ghg_{12}	ghg_{13}	ghg_{14}	ghg_{15}	ghg_{16}	ghg_{17}	ghg_{18}		
	lu_{11}	lu_{12}	lu_{13}	lu_{14}	lu_{15}	lu_{16}	lu_{17}	lu_{18}		

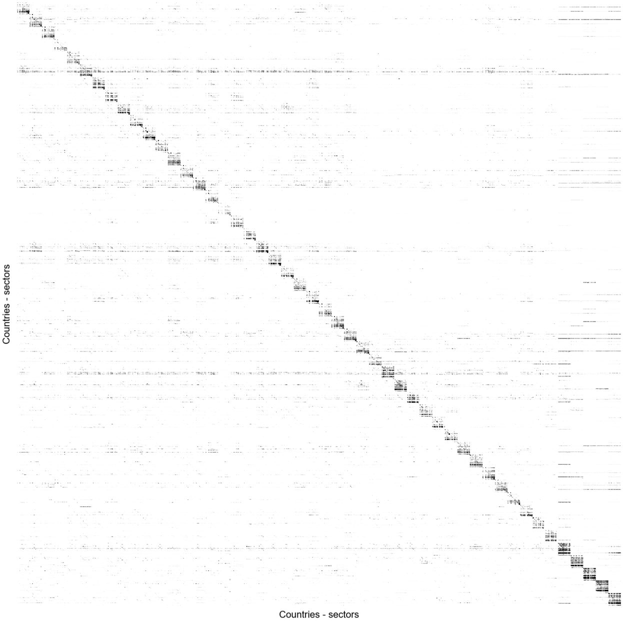
From IO to MRIOs



From IO to MRIOs



EXIOBASE overview



EXIOBASE development

EXIOBASE 1

- outcome of the EU fp6 project EXIOPOL
- base year 2000

EXIOBASE development

EXIOBASE 1

- outcome of the EU fp6 project EXIOPOL
- base year 2000

EXIOBASE 2

- First major update (March 2014)
- Outcome of the fp7 project CREEA
- Base year 2007
- 48 countries/regions
  - EU27
  - US, JP, CN, CA, KR, BR, IN, MX, RU, AU, CH, TR, TW, NO, ID, ZA
  - 5 RoW
- High sector detail
  - 163 industries
  - 200 products
- Coupled with a global physical MRIO

EXIOBASE: Sectors

- Agriculture
  - 19 sectors
- Mining
  - 15 sectors
- Manufacturing
  - 61 sectors
  - Several re-processing and recycling sectors
- Electricity, gas and water
  - 17 sectors
  - Hydro, wind, solar, ...
- Construction
  - 2 sectors
- Wholesale retail, repair
  - 5 sectors
- Transport, storage and communication
  - 8 sectors
- Others
  - 36 sectors
  - Incineration: 7 sectors
  - Biogasification: 3 sectors
  - Composting: 2 sectors
  - Waste water treatment: 2 sectors
  - Landfill: 6 sectors

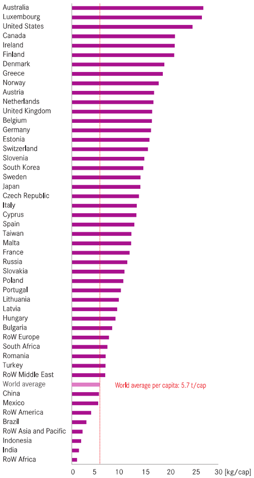
EXIOBASE: Extensions

Among others ...

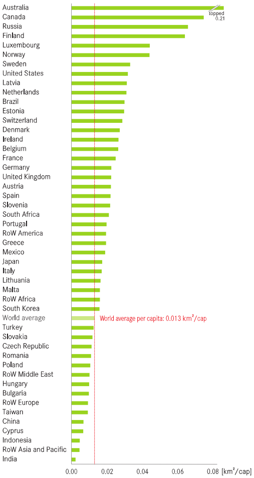
- Employment
  - Three skill levels
  - Hours worked and employees
- Emissions
  - To air and water
  - Total: 46 stressors
- Material
  - Domestic extraction used: 45 categories
  - Unused domestic extraction: 38 categories
  - Water consumption: 47 categories
  - Gross energy supply/use
  - Emission relevant energy use
- Natural land use
  - Arable Land: 13 categories
  - Pasture and wood land

EXIOBASE results - Footprint of Nations

Carbon footprint per capita



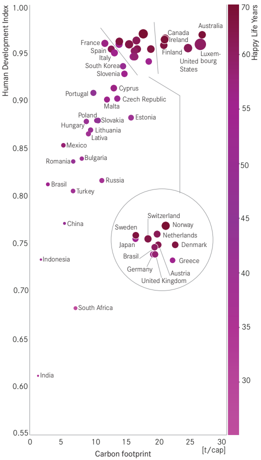
Land footprint per capita



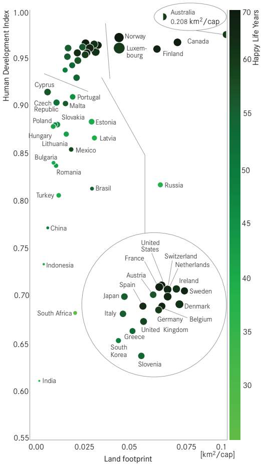
Water footprint per capita

Human development, well-being and footprints

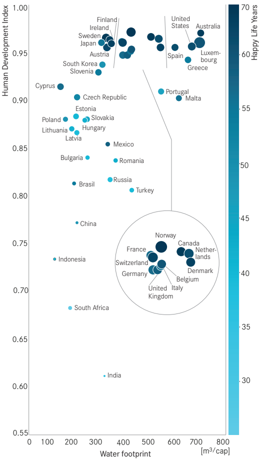
Carbon



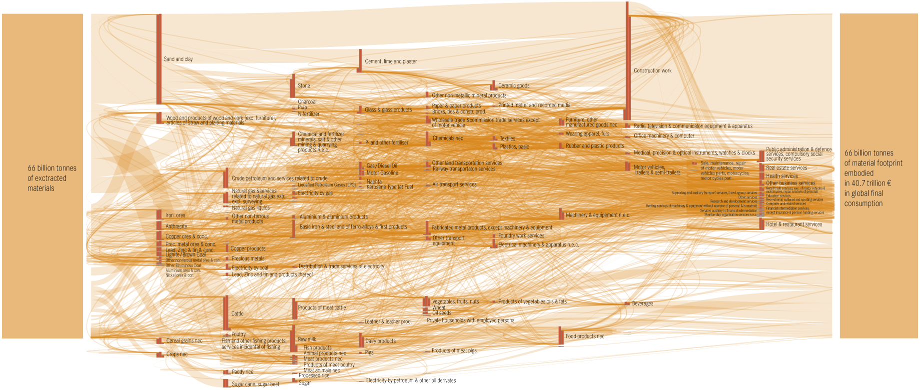
Land use



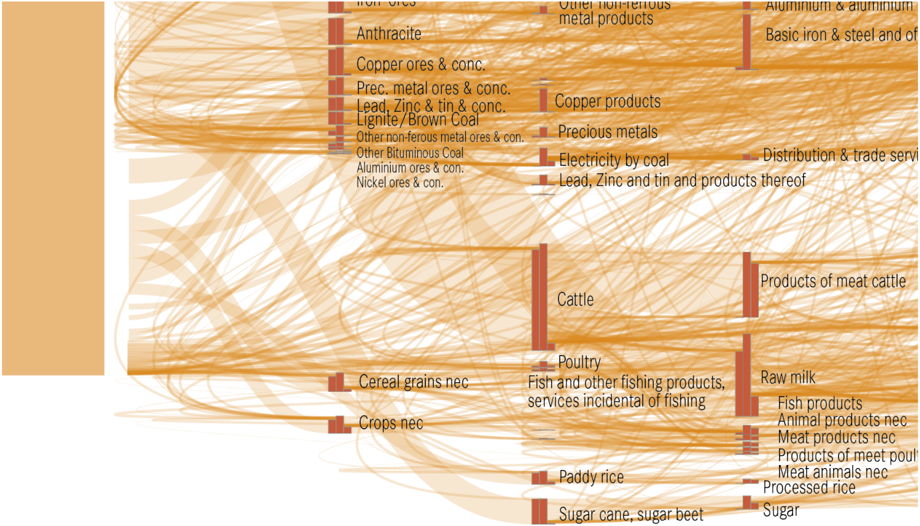
Water use



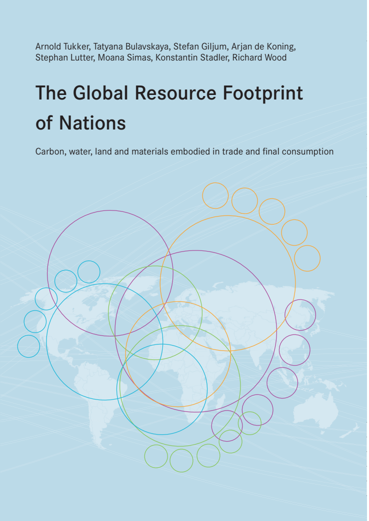
Global material flows

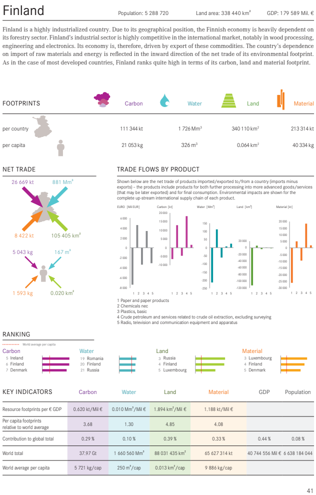


Global material flows



Booklet





Finland

Population: 5 288 720 Land area: 338 440 km² GDP: 179 589 Mil. €

Finland is a highly industrialized country. Due to its geographical position, the Finnish economy is heavily dependent on its forestry sector. Finland's industrial sector is highly competitive in the international market, notably in wood processing, engineering and electronics. Its economy is, therefore, driven by export of these commodities. The country's dependence on import of raw materials and energy is reflected in the inward direction of the net trade of its environmental footprint. As in the case of most developed countries, Finland ranks quite high in terms of its carbon, land and material footprint.

FOOTPRINTS	Carbon	Water	Land	Material
per country	111 344 kt	1 726 Mm³	340 110 km²	213 314 kt
per capita	21 053 kg	326 m³	0.064 km²	40 334 kg

NET TRADE

TRADE FLOWS BY PRODUCT

Shown below are the net trade of products imported/exported to/from a country (imports minus exports) – the products include products for both further processing into more advanced goods/services (that may be later exported) and for final consumption. Environmental impacts are shown for the complete up-stream international supply chain of each product.

1 Paper and paper products
2 Chemicals nec
3 Plastics, basic
4 Crude petroleum and services related to crude oil extraction, excluding surveying
5 Radio, television and communication equipment and apparatus

RANKING

World average per capita

Carbon	Water	Land	Material
5 Ireland	19 Romania	3 Russia	3 Luxembourg
6 Finland	20 Finland	4 Finland	4 Finland
7 Denmark	21 Russia	5 Luxembourg	5 Denmark

KEY INDICATORS	Carbon	Water	Land	Material	GDP	Population
Resource footprints per € GDP	0.620 kt/Mil €	0.010 Mm³/Mil €	1.894 km²/Mil €	1.188 kt/Mil €		
Per capita footprints relative to world average	3.68	1.30	4.85	4.08		
Contribution to global total	0.29 %	0.10 %	0.39 %	0.33 %	0.44 %	0.08 %
World total	37.97 Gt	1 660 560 Mm³	88 031 435 km²	65 627 314 kt	40 744 556 Mil €	6 638 184 044
World average per capita	5 721 kg/cap	250 m³/cap	0.013 km²/cap	9 886 kg/cap		

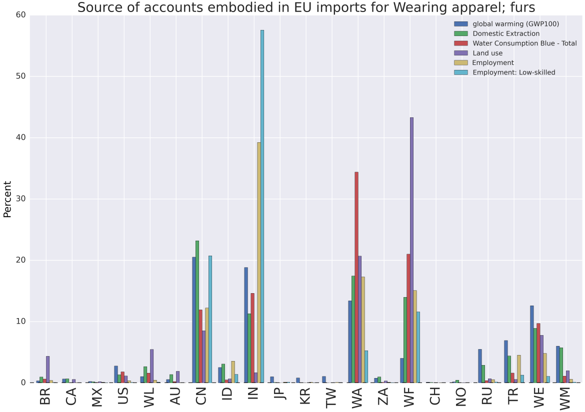
41

Free download at www.exiobase.eu

Product level analysis

The apparel sector in the EU

account	Territorial	Footprint	Unit
Global Warming (GWP100)	2.35e+09	7.2e+10	kg CO2 eq
Domestic Extraction	0	1.34e+05	kt
Water Consumption Blue - Total	119	3.83e+03	Mm3
Land use	0	1.68e+05	km2
Employment	1.6e+03	1.19e+04	1000 p.
Employment: Low-skilled	141	4.3e+03	1000 p



pymrio - introduction

Multi regional input output analysis in python

https://github.com/konstantinstadler/pymrio

pymrio - introduction

Multi regional input output analysis in python

- Open source (python)
- Fully documented
- Parsing global MRIO databases (EXIOBASE...)
- Calculation: top and low level methods
- Aggregation (sectors and regions)
- Exporting data (csv, xls, html)
- Visualization and reporting
- Contributions are very welcome (github)

https://github.com/konstantinstadler/pymrio

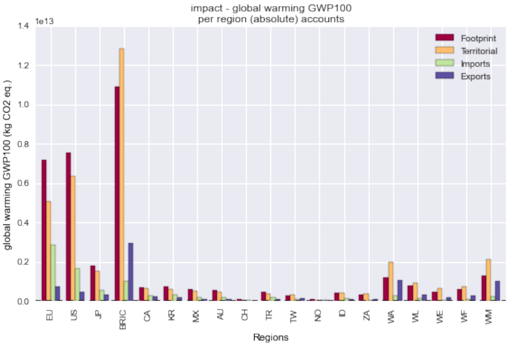
pymrio - example


```
import pymrio   # the module

# parse EXIOBASE 2 from the raw data download
pxp = pymrio.parse_exiobase22(
    path = r'S:\rawexio',
    iosystem = 'pxp', version = 'exiobase_2.2',
    charact = r'S:\rawexio\charac.xlsx')

# Aggregate the 48 countries of EXIOBASE
# to EU, BRIC and keep the remaining ones
reg_vector = mr.build_agg_vec(
        ['EU','BRIC','orig_regions'], path='exio2')
pxp.aggregate(region_agg=reg_vector, inplace = True)

# The following command checks for missing
# parts in the system and calculates them.
pxp.calc_all()

# Visualize some of the data
pxp.impacts.plot_account(['global_warming_(GWP100)'])
```

https://github.com/konstantinstadler/pymrio

pymrio - output

The visual output of the script:



Export to html, xlsx and other are also possible.

https://github.com/konstantinstadler/pymrio

EXIOBASE development - DESIRE

- **DE**velopment of a **S**ystem of **I**ndicators for a **R**esource efficient **E**urope (EU fp7)
- EXIOBASE 3
  - Time series of MRIO tables (1995 to 2012)
  - Closing the time gap (now-casting of MRIOs to the current year)
- Connections to the beyond GDP debate
- Incorporation of more biodiversity data[4]
  - Understand the indirect drivers of biodiversity loss
  - Reduction on species richness due to land use change (per country, per sector)
  - HANPP, SAR

[4] German Center f Integr. Biodiv. Res. - Biodiv. Conservation Group

Connected projects

1. CARBON CAP
    - **Carbon** emission mitigation by **C**onsumption-based **A**ccounting and **P**olicy (EU fp7)
    - Comparison and limitations of consumption based account databases
    - Assessing and reducing uncertainties
    - Assess the feasibility of consumption based accounting (footprints) for policy making

Connected projects

1. CARBON CAP
   - **C**arbon emission mitigation by **C**onsumption-based **A**ccounting and **P**olicy (EU fp7)
   - Comparison and limitations of consumption based account databases
   - Assessing and reducing uncertainties
   - Assess the feasibility of consumption based accounting (footprints) for policy making
2. GLAMURS
   - **G**reen **L**ifestyles, **A**lternative **M**odels and **U**pscaling **R**egional **S**ustainability (EU fp7)
   - Exploring the potential for lifestyle change
   - Providing recommendations for policy makers, stakeholders and citizens
   - Developing transition pathways to sustainable lifestyles and a green economy

Summary

- Environmental extended Multi-Regional Input-Output Analysis (EEMRIO)
  - Trace impacts from the producer to the consumer
  - Consumption based accounting (footprints) take into account the whole global supply chain
- EXIOBASE provides a highly detailed global MRIO
- EXIOBASE results (booklet): www.exiobase.eu
- pymrio: https://github.com/konstantinstadler/pymrio
- Further information: konstantin.stadler@ntnu.no