Introduction: Input-Output Models, and Consumption Land Use Matrix results for Slovenia

Global Footprint Network
Advancing the Science of Sustainability

David Lin
Global Footprint Network

What is Input Output (IO) Modeling

Input-Output modeling is an economic technique

- Model of the interrelationship of economic sectors in the production of goods and services
- Wassily Leontif received the Nobel Prize in Economics for this technique.

What is Input Output (IO) Modeling

An Input output table defines the flow of economic value through an economy.

OUTPUTS

INPUTS

	Agriculture	*Manufactures*	*Services*	*Final demand*	*Total*
Agriculture	30	40	0	30	100
Manufactures	10	200	50	140	400
Services	20	80	200	200	500
Other sources	40	80	250	230	600
Total	100	400	500	600	1600

Most national governments produce National IO tables – See Slovenia

What is Multi-Region Input Output (IO) Modeling

Economic model of the flow of money from all sectors of all economies of the world to all other sectors of the world.

Major Global Models:

- Global Trade Analysis Project (GTAP)
- World Input Output Database (WIOD)
- EORA
- OECD*

How is MRIO related to Ecological Footprint?

Environmentally Extended MRIO or EE-MRIO

Widely used application

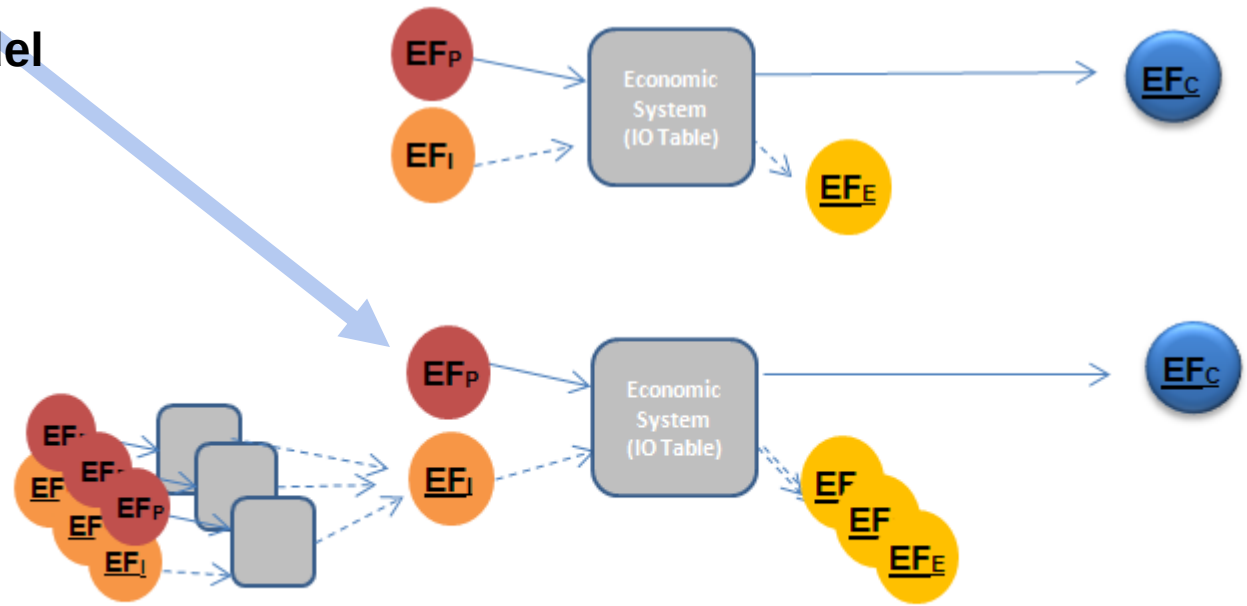
- Carbon Emissons
- Ecological Footprint (MRIO-FA)
- Water Footprint

NFA,IO, and MRIO models

1.National Footprint Account (NFA)

2.Single IO model

3. MRIO model



NFA vs MRIO-FA 2 Approaches, Same Goal

1 Goal:

Ecological Footprint (Consumption) at the country level.

1. National Footprint Accounts:

Physical Accounting (See workbook)

- Bottom up
- Physical flows of trade

2 Approaches, Same Goal

1 Goal:

Ecological Footprint (Consumption) at the country level.

1. Environmentally Extended Economic Model
   - Production from NFA
   - Trade calculated from using Footprint intensity (per dollar)

Differences

MRIO-FA:

based on Global Trade Analysis Project (GTAP) model (Purdue)

- Limited years: 2004, 2007, 2011
- Sector Resolution (57)
- Supply Chain included
- Country - Sector Consumption

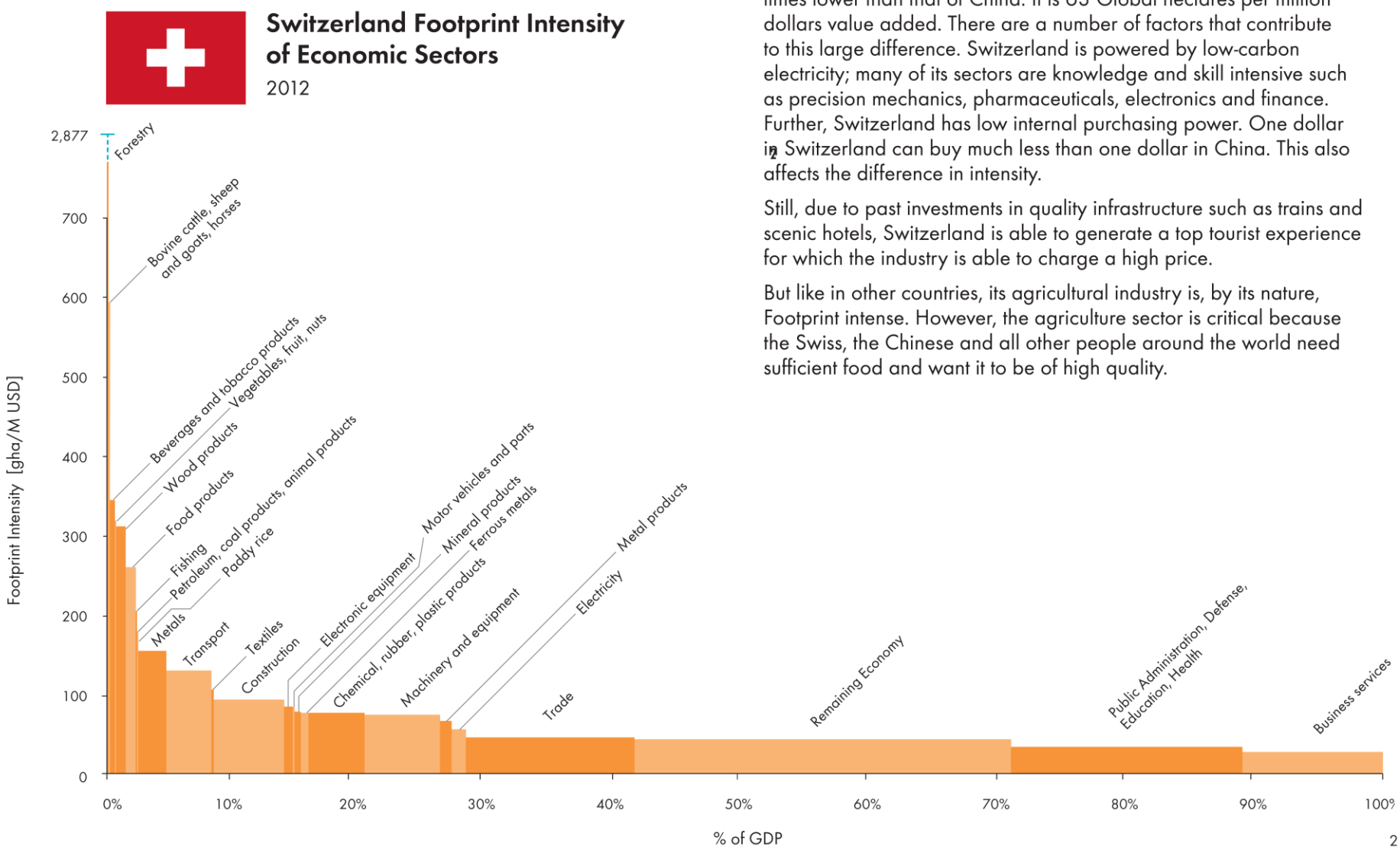
NFA:

- 1961 – 2014 or ~(T-3)
- Product level resolution
- Tracking across borders only (limited supply chain)
- Land Use and Product

GTAP 9.0

See GTAP 57 sectors

PRODUCTION FOOTPRINT ASSOCIATED WITH GENERATING GDP IN SWITZERLAND



Switzerland is also analyzed through the lens of 57 economic sectors. These sectors are also tracked by Global Footprint Network's multi-regional input-output analysis (2012). For clarity, the graph shows the top 26 sectors and depicts the others as "remaining economy".

The Swiss economy's average Footprint intensity is nearly ten times lower than that of China: It is 63 Global hectares per million dollars value added. There are a number of factors that contribute to this large difference. Switzerland is powered by low-carbon electricity; many of its sectors are knowledge and skill intensive such as precision mechanics, pharmaceuticals, electronics and finance. Further, Switzerland has low internal purchasing power. One dollar in Switzerland can buy much less than one dollar in China. This also affects the difference in intensity.

Still, due to past investments in quality infrastructure such as trains and scenic hotels, Switzerland is able to generate a top tourist experience for which the industry is able to charge a high price.

But like in other countries, its agricultural industry is, by its nature, Footprint intense. However, the agriculture sector is critical because the Swiss, the Chinese and all other people around the world need sufficient food and want it to be of high quality.

PRODUCTION FOOTPRINT ASSOCIATED WITH GENERATING GDP IN CHINA

For the world as a whole, the Ecological Footprint of producing all goods and services is exactly the same as the Footprint of consuming these goods and services. All is produced to be consumed. Nations, however, do not consume the same amount that they produce because they can trade.

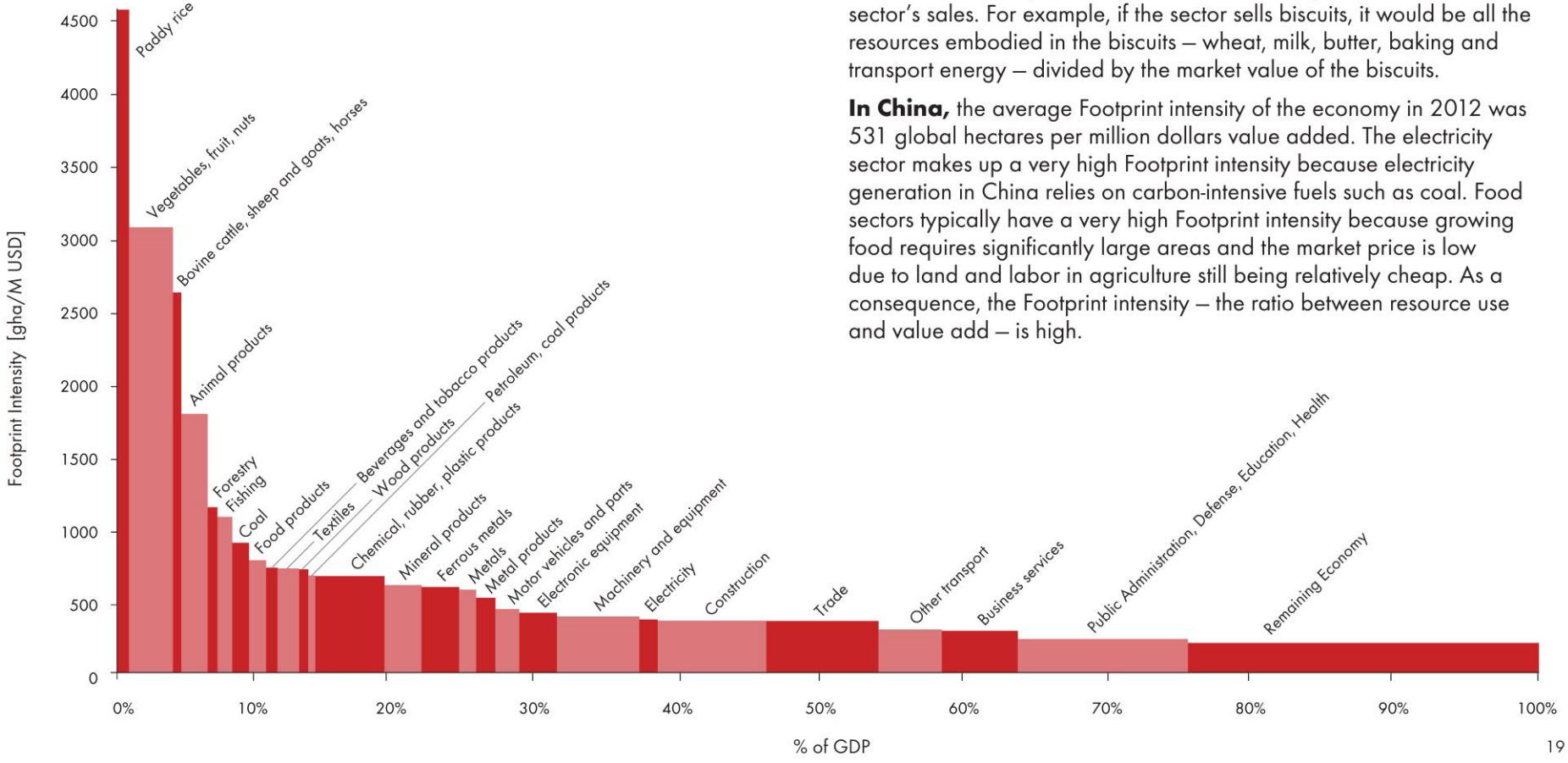
The graph below compares the Footprint intensity of China and Switzerland's 57 economic sectors. These sectors are tracked by Global Footprint Network's multi-regional input-output analysis (for 2012). For clarity, the graph shows the top 26 sectors and depicts the others as "remaining economy".

Footprint intensity is the Footprint embodied in the entire value chain of all the output sold by a sector divided by the value of a sector's sales. For example, if the sector sells biscuits, it would be all the resources embodied in the biscuits – wheat, milk, butter, baking and transport energy – divided by the market value of the biscuits.

In China, the average Footprint intensity of the economy in 2012 was 531 global hectares per million dollars value added. The electricity sector makes up a very high Footprint intensity because electricity generation in China relies on carbon-intensive fuels such as coal. Food sectors typically have a very high Footprint intensity because growing food requires significantly large areas and the market price is low due to land and labor in agriculture still being relatively cheap. As a consequence, the Footprint intensity – the ratio between resource use and value add – is high.

China Footprint Intensity of Economic Sectors

2012

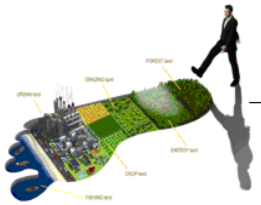


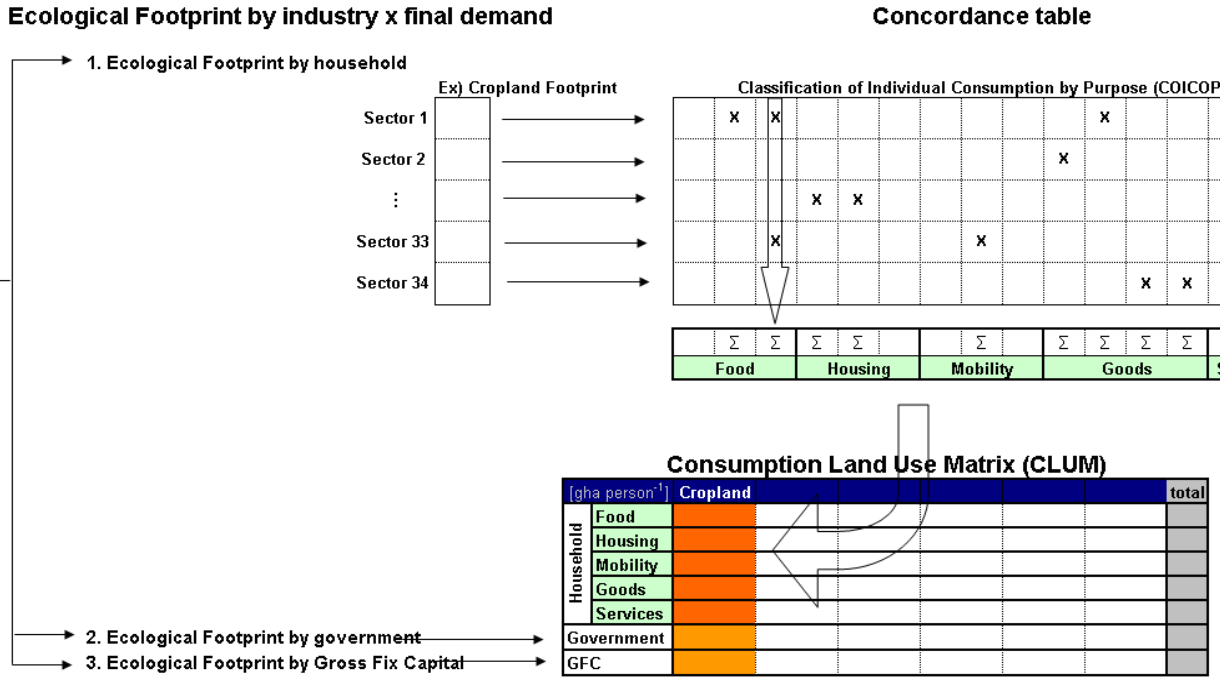
Economic Sectors -> Household Consumption

Once we are operating and making calculations within an economic framework and based on Footprint intensities (Footprint/$) we can view the data in different ways.

UN COICOP: "Classifications **o**f **I**ndividual **C**onsumption **A**ccording to **P**urpose"

Economic Sectors to Household Consumption





1. Sector based Footprints were redistributed in IO/COICPI concordance table, and then **Footprints by COICOP category** were obtain by summing the number in each column in the concordance table.
2. Finally, **Footprints by COICOP** in each land type were set in **CLUM table** accordingly.

Consumption Land-Use Matrix (CLUM)

	[gha person $^{-1}$]	Cropland	Grazing Land	Forest Land	Fishing Grounds	Built-up Land	Carbon	TOTAL
Household	**Food**	**0.63**	**0.18**	**0.07**	**0.08**	**0.02**	**0.31**	**1.29**
	Food	0.52	0.17	0.05	0.08	0.01	0.22	1.05
	Non-alcoholic beverages	0.09	0.00	0.02	0.00	0.00	0.08	0.20
	Alcoholic beverages	0.02	0.00	0.00	0.00	0.00	0.02	0.05
	Housing	**0.06**	**0.01**	**0.21**	**0.01**	**0.03**	**1.08**	**1.40**
	Actual rentals for housing	0.00	0.00	0.04	0.00	0.00	0.03	0.07
	Imputed rentals for housing	0.01	0.00	0.04	0.00	0.01	0.07	0.13
	Maintenance and repair of the dwelling	0.00	0.00	0.01	0.00	0.00	0.03	0.04
	Water supply and miscellaneous dwelling service	0.02	0.01	0.07	0.00	0.01	0.21	0.32
	Electricity, gas other fuels	0.02	0.00	0.06	0.00	0.01	0.75	0.84
	Service for household maintenance	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Personal Transportation	**0.04**	**0.01**	**0.08**	**0.00**	**0.02**	**1.13**	**1.29**
	Purchase of vehicles	0.01	0.00	0.01	0.00	0.00	0.08	0.11
	Operation of personal transport equipment	0.02	0.00	0.04	0.00	0.01	0.71	0.77
	Transport services	0.01	0.00	0.03	0.00	0.01	0.35	0.41
	Goods	**0.20**	**0.03**	**0.12**	**0.01**	**0.03**	**0.55**	**0.95**
	Clothing	0.07	0.01	0.02	0.00	0.01	0.14	0.24
	Footwear	0.02	0.00	0.00	0.00	0.00	0.03	0.05
	Furniture, furnishings, carpets etc.	0.00	0.00	0.01	0.00	0.00	0.01	0.02
	Household textiles	0.00	0.00	0.00	0.00	0.00	0.01	0.02
	Household appliances	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Glassware, tableware & household utensils	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Tools and equipment for house & garden	0.00	0.00	0.00	0.00	0.00	0.01	0.02
	Medical products, appliances & equipment	0.02	0.00	0.01	0.00	0.00	0.07	0.11
	Telephone & telefax equipment	0.00	0.00	0.00	0.00	0.00	0.02	0.03
	Audio-visual, photo & info. Processing equipment	0.02	0.00	0.02	0.00	0.01	0.10	0.15
	Other major durables for recreation & culture	0.01	0.00	0.01	0.00	0.00	0.04	0.05
	Other recreational equipment etc.	0.00	0.00	0.01	0.00	0.00	0.03	0.04
	Newspapers, books & stationery	0.00	0.00	0.04	0.00	0.00	0.03	0.08
	Goods for household maintenance	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Tobacco	0.05	0.00	0.01	0.00	0.00	0.04	0.09
	Services	**0.06**	**0.02**	**0.07**	**0.01**	**0.02**	**0.44**	**0.61**
	Out-patient services	0.01	0.00	0.01	0.00	0.00	0.06	0.08
	Hospital services	0.01	0.00	0.01	0.00	0.00	0.06	0.08
	Postal services	0.00	0.00	0.00	0.00	0.00	0.02	0.03
	Telephone & telefax services	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Recreational & cultural services	0.00	0.00	0.00	0.00	0.00	0.02	0.03
	Package holidays	0.00	0.00	0.00	0.00	0.00	0.02	0.03
	Education	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Catering services	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Accommodation services	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Personal care	0.00	0.00	0.00	0.00	0.00	0.01	0.02
	Personal effects nec	0.01	0.01	0.01	0.00	0.00	0.06	0.09
	Social protection	0.01	0.00	0.01	0.00	0.00	0.05	0.06
	Insurance	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Financial services nec	0.01	0.00	0.01	0.00	0.00	0.06	0.08
	Other services nec	0.01	0.00	0.01	0.00	0.00	0.06	0.08
	Sub-total Household Consumption	**0.99**	**0.25**	**0.55**	**0.11**	**0.12**	**3.52**	**5.54**
Government		0.05	0.01	0.05	0.00	0.01	0.45	**0.59**
Gross Fixed Capital Formation		0.10	0.02	0.42	0.01	0.06	1.10	**1.71**
Total		**1.14**	**0.29**	**1.03**	**0.12**	**0.19**	**5.07**	**7.85**

Top-Down Ecological Footprint Calculations are based on CLUM data, which is derived from the NFA through an EE-MRIO analysis

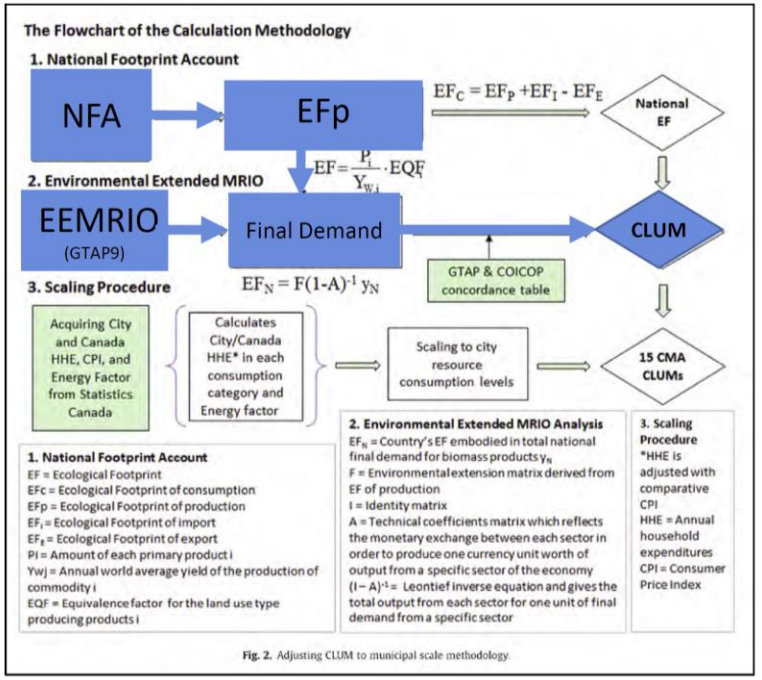


Fig. 2. Adjusting CLUM to municipal scale methodology.

Adapted from Isman et al. / Journal of Cleaner Production 174 (2018) 1032-1043

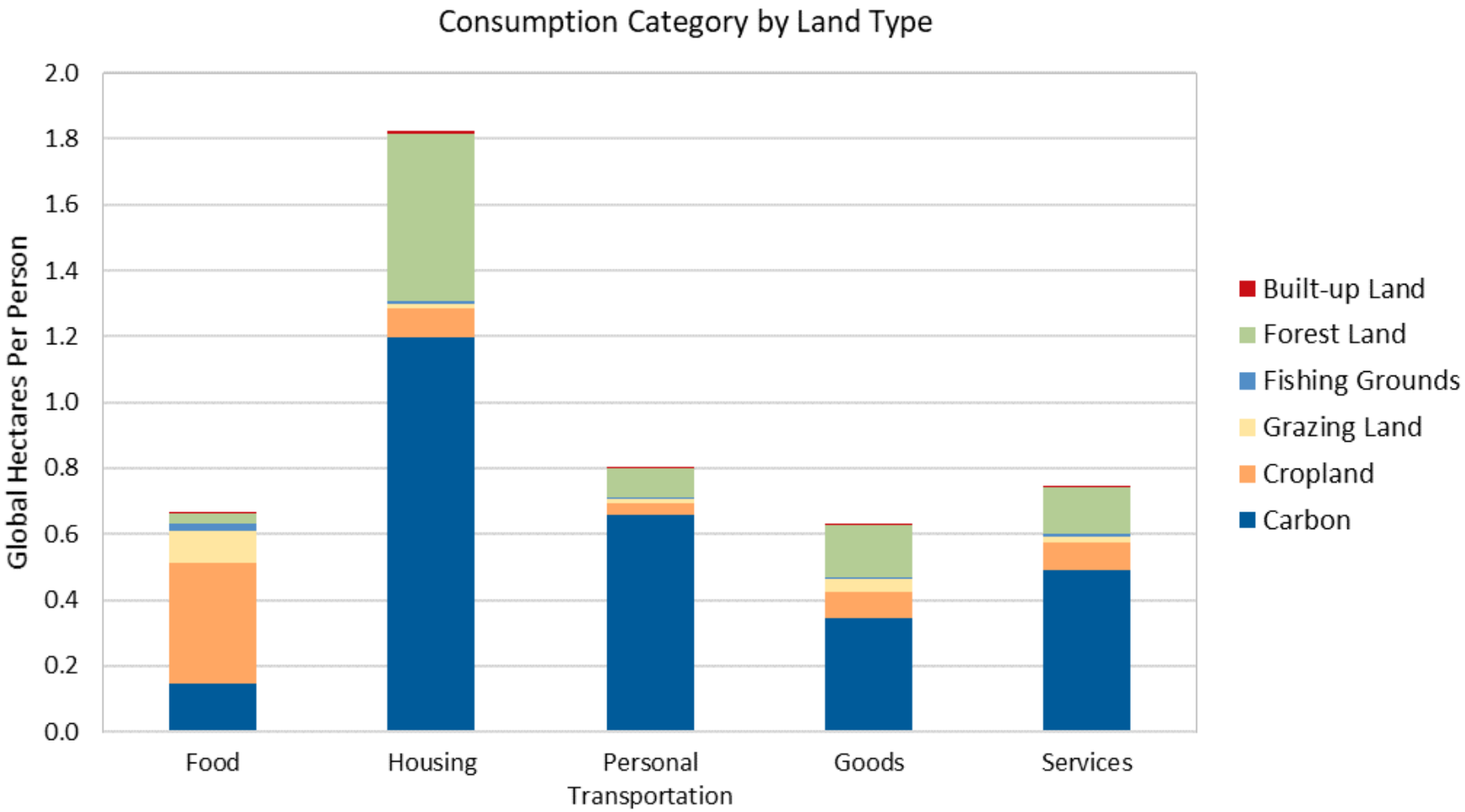
Consumption Land-Use Matrix (CLUM)

Consumption category

Land Use

[gha person^{-1}]	Cropland	Grazing Land	Forest Products	Fishing Grounds	Built-up Land	Carbon	TOTAL
Food	0.37	0.10	0.03	0.02	0.00	0.15	0.67
Housing	0.09	0.01	0.51	0.01	0.01	1.20	1.82
Personal Transportation	0.04	0.01	0.09	0.01	0.01	0.66	0.81
Goods	0.08	0.04	0.16	0.01	0.00	0.34	0.63
Services	0.08	0.02	0.14	0.01	0.01	0.49	0.75
TOTAL	**0.66**	**0.18**	**0.93**	**0.05**	**0.02**	**2.84**	**4.68**

Sectoral Analysis



Additional Applications

National Footprint Accounts

- Commodity level resolution
- Full Timeline (1961-2014)
- Physical Trade Accounting

MRIO

- Supply Chain Trade
- Economic sector analysis

Consumption Land Use Matrix

- Household Consumption by COICOP categories (Food, Transportation, Housing…)

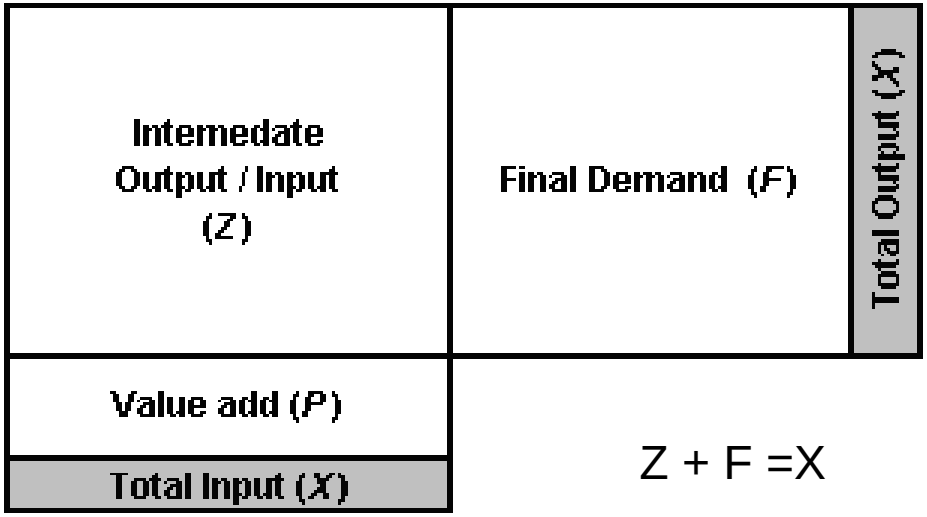
Summmary

- EE MRIO is an alternative calculation of Ecological Footprint with different advantages and disadvantages
- EF data can be analyzed by different economic sector through EEMRIO
- EF data can be analyzed by individual consumption category through the CLUM.

What is Input Output Analysis

Global Footprint Network
Advancing the Science of Sustainability

Basic Structure of Input-output table



(Intermediate output: ***Z*** + final demand: ***F***) = (intermediate input + value add)
= total output: ***X*** (or input).

Basic Structure of Input-output table

IO Sectors		1	2	….	33	34	Final Demand	
IO Sectors	1	$Z_{1.1}$	$Z_{1.2}$	$Z_{1.J}$	$Z_{1.33}$	$Z_{1.34}$	F_1	X_1
	2	$Z_{2.1}$	$Z_{2.2}$	$Z_{2.J}$	$Z_{2.33}$	$Z_{2.34}$	F_2	X_2
	⋮	$Z_{I.1}$	$Z_{I.2}$	$Z_{I.J}$	$Z_{I.33}$	$Z_{I.34}$	F_I	X_I
	33	$Z_{33.1}$	$Z_{33.2}$	$Z_{33.J}$	$Z_{33.33}$	$Z_{33.34}$	F_{33}	X_{33}
	34	$Z_{34.1}$	$Z_{34.2}$	$Z_{34.J}$	$Z_{34.33}$	$Z_{34.34}$	F_{34}	X_{34}
Value add		P_1	P_2	P_I	P_{33}	P_{34}		
Total Inputs		X_1	X_2	X_I	X_{33}	X_{34}		

Furthermore, **final demand section** is disaggregated into domestic final demand (consisting of household consumption, government consumption, and gross fixed capital formation) and trade related demand.

The value added part is mainly divided into tax, compensation of employees and operating surplus.

(Intermediate output: ***Z*** + final demand: ***F***) = (intermediate input + value add)
= total output: ***X*** (or input).

Basic Structure of Input-output table

IO Sectors	1	2	….	33	34	Final Demand	
1	$Z_{1.1}$	$Z_{1.2}$	$Z_{1.J}$	$Z_{1.33}$	$Z_{1.34}$	F_1	X_1
2	$Z_{2.1}$	$Z_{2.2}$	$Z_{2.J}$	$Z_{2.33}$	$Z_{2.34}$	F_2	X_2
⋮	$Z_{I.1}$	$Z_{I.2}$	$Z_{I.J}$	$Z_{I.33}$	$Z_{I.34}$	F_I	X_I
33	$Z_{33.1}$	$Z_{33.2}$	$Z_{33.J}$	$Z_{33..33}$	$Z_{33.34}$	F_{33}	X_{33}
34	$Z_{34.1}$	$Z_{34.2}$	$Z_{34.J}$	$Z_{34.33}$	$Z_{34.34}$	F_{34}	X_{34}
Value add	P_1	P_2	P_I	P_{33}	P_{34}		
Total Inputs	X_1	X_2	X_I	X_{33}	X_{34}		

$$Z + F = X$$

$$AX + F = X$$

A Matrix =

	1	2	….	33	34
1	$Z_{1.1} / X_1$	$Z_{1.2} / X_2$	$Z_{1.J} / X_J$	$Z_{1.33} / X_{33}$	$Z_{1.34} / X_{34}$
2	$Z_{2.1} / X_1$	$Z_{2.2} / X_2$	$Z_{2.J} / X_J$	$Z_{2.33} / X_{33}$	$Z_{2.34} / X_{34}$
⋮	$Z_{I.1} / X_1$	$Z_{I.2} / X_2$	$Z_{I.J} / X_J$	$Z_{I.33} / X_{33}$	$Z_{I.34} / X_{34}$
33	$Z_{33.1} / X_1$	$Z_{33.2} / X_2$	$Z_{33.J} / X_J$	$Z_{33..33} / X_{33}$	$Z_{33.34} / X_{34}$
34	$Z_{34.1} / X_1$	$Z_{34.2} / X_2$	$Z_{34.J} / X_J$	$Z_{34.33} / X_{33}$	$Z_{34.34} / X_{34}$

$$A = Zj / Xj$$

Basic Structure of Input-output table

$Z + F = X$

$AX + F = X$

$(I - A) X = F$

$X = (I- A)^{-1} F$

$$X = (I- A)^{-1} F$$

Recipes of Economics **Final Demand**

Leontief Inverse Matrix = $(I - A)^{-1}$ where ***I*** is the identity Matrix and ***A*** is the technical Coefficient Matrix

Applications of Input Output Analysis

	Intermediate demand				Final Demand						
					Domestic demand						
	1. Agriculture	2.Manufacture	3.Service	Total intermediate	Final consumption		Gross fixed capital formation	Exports	Imports	Final demand	Total output
					Households	Government					
1. Agriculture											
2.Manufacture											
3.Service											
Intermediate consumption											
Surplus											
Salary											
taxes											
Value Added											
Industry Output											

With the concept of Leontief Inverse as main engine, IO tables can provide consistent and reproductive tools for economic analysis including of industrial structure, growth, and employment.

$$X = (I - A)^{-1} F$$

Recipes of Economics

Final Demand

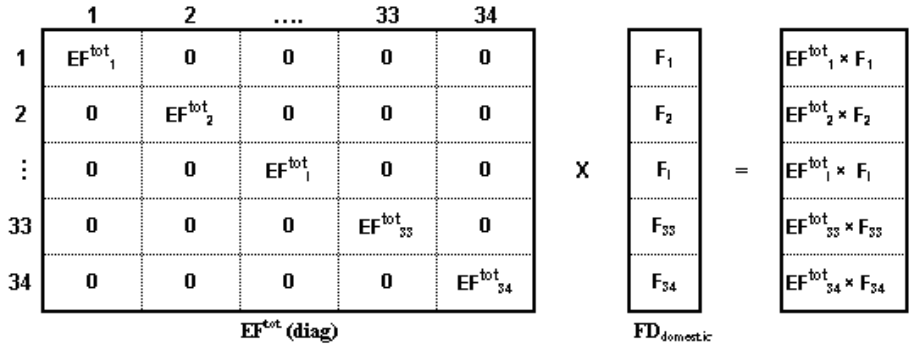
Applications of Input Output Analysis

Increasingly, input-output tables are applied to the environmental aspect, in what is called environmental extended input-output analysis (EEIO). EEIO can be used, for example, to measure direct and indirect CO2 emission by industry sectors in a given country.

$$\alpha X = \alpha (I - A)^{-1} F$$

where ***α*** is a physical co-efficiency vector which represents direct environmental pollutants such as carbon dioxide, methane, nitrous oxide, per unit currency.

Calculate Ecological Footprints of final demand categories, industry sector, and CLUM



Ecological Footprint by final demands = EF_{tot} (diag) * $FD_{domestic}$

where ***EF_{tot} (diag)*** is the diagonal matrix of Total Footprint Intensity, ***FDdomestic*** is the domestic final demand expressed separately as household consumption, government consumption, and gross fix capital.

Calculate Ecological Footprints of final demand categories, industry sector, and CLUM

The Ecological Footprint was redistributed to **a domestic final demand category** by multiplying EF_{tot} by domestic final demand, $FD_{domestic}$:

Domestic final demand mainly consists of **three components** such as household consumption, government consumption, gross fixed capital (GFC).

Ecological Footprint by final demand category can clearly show the responsibility of each player to entire National Footprint.