Input-Output LCA

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Session Objectives

✓ To gain some insight into Environmental Input-Output LCA methodology.

✓ To understand the role of indirect upstream and downstream supply chain requirements to the total Environmental Impact of a product or organisation.
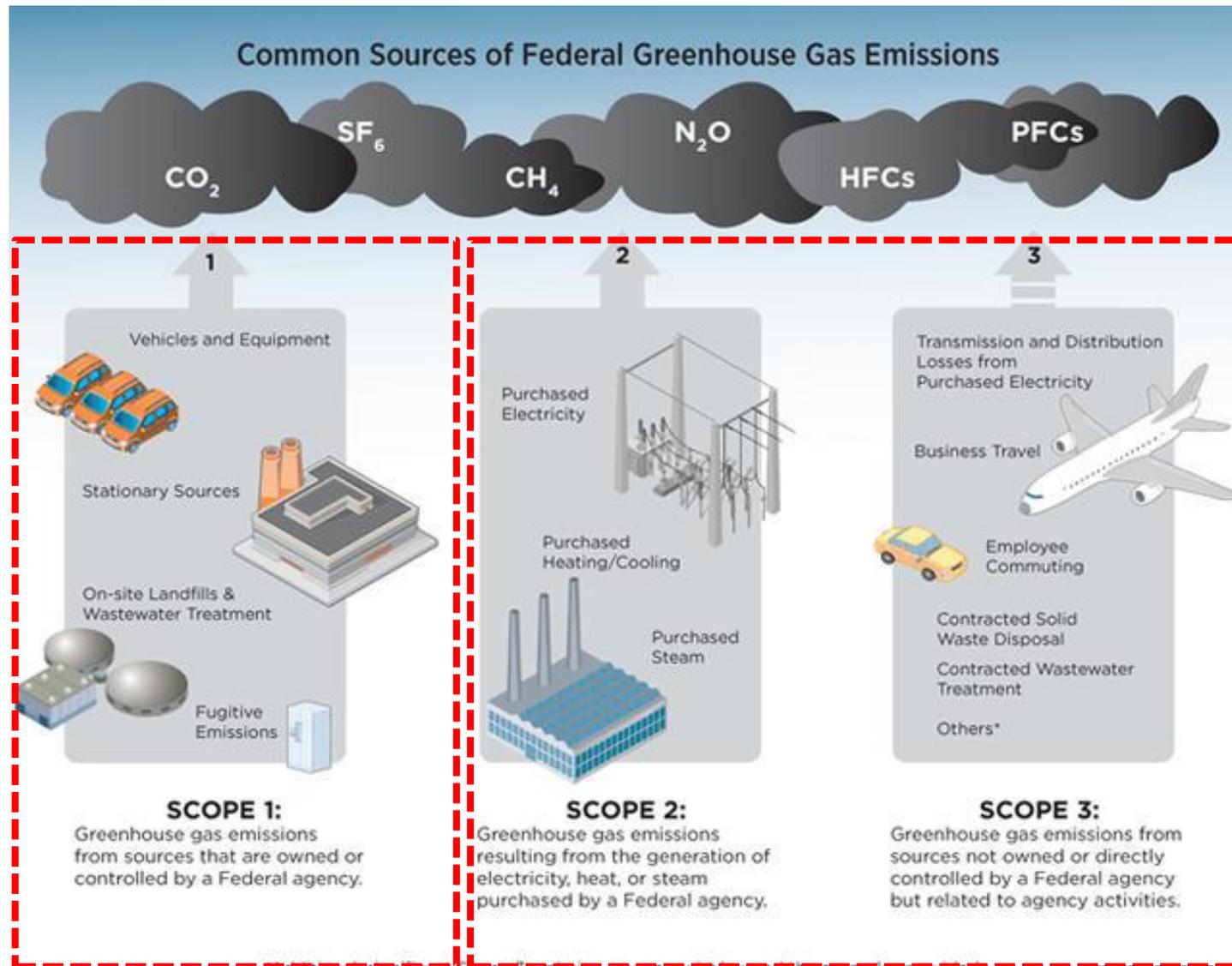
Issues with Measuring Environmental Impacts

Video Introduction

Scope of Carbon Emissions


Common Sources of Federal Greenhouse Gas Emissions

Scope of Carbon Emissions

Scope 1: All direct GHG emissions (Energy used on-site).

Scope 2: Indirect GHG emissions from consumption of
purchased electricity, heat or steam.

Scope 3: Other indirect supply chain emissions, such as the
extraction and production of purchased materials and
fuels, transport- related activities in vehicles not owned
or controlled by the reporting entity, electricity-related
activities (e.g. T&D losses) not covered in Scope 2,
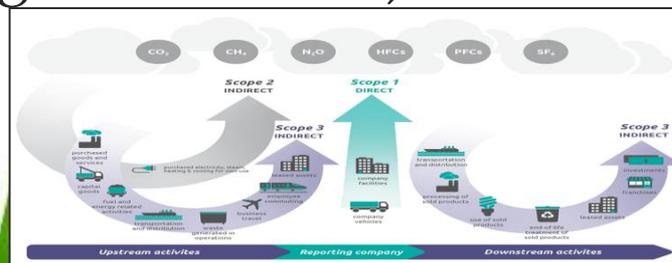
Scope of Carbon Emissions (or Impacts)
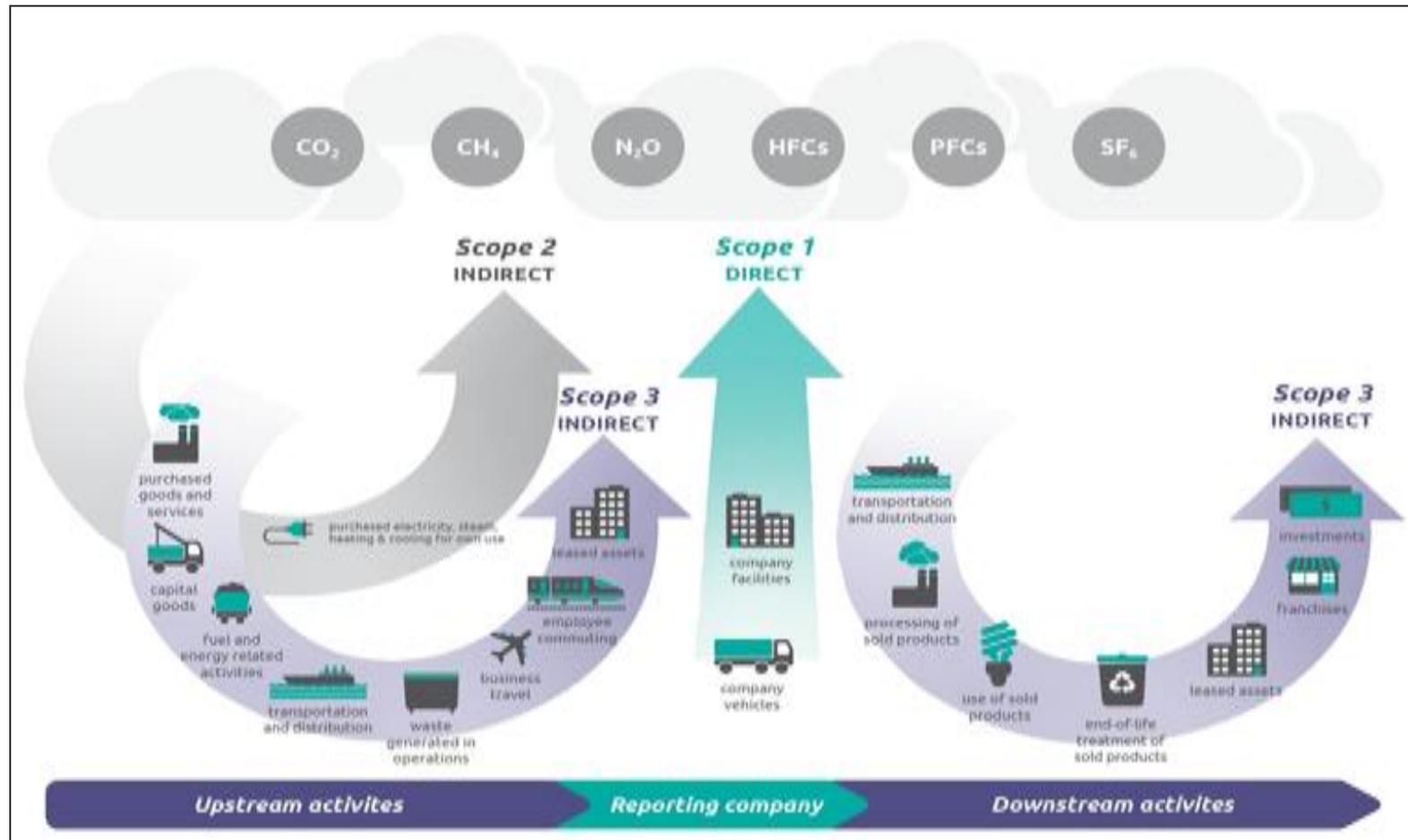
Types of LCA Methodologies

- ➤ Process/Traditional LCA

- ➤ Environmental Input-Output (EIO) ✔

- ➤ Hybrid LCA (combines Process and EIO)

Main issues related to LCA Methodology

- ❖ The ACCURACY of the Data

- ❖ ROBUSTNESS of the Methodology

- ❖ The COMPLETENESS of the System Boundary

Differences in the Methodologies

Process/Traditional LCA	Environmental Input-Output
➢ Bottom-Up approach	➢ Top-Down approach
➢ Subjective System Boundary	➢ Extended System Boundary
➢ More accurate (specific)	➢ Less accurate (generic)
➢ Data and Time Intensive	➢ Less Data and Time Intensive
➢ Physical Perspective	➢ Economic perspective
➢ Data confidentiality	➢ Freely available data
➢ Future product development	➢ Scenario Planning
➢ Lower uncertainty in data	➢ Higher uncertainty in data

Some Methodological Issues

1. **Lack of Consistent Methodologies:** No prescribed methodologies, just Guidelines as in the case of ISO standards for LCA.

2. **Incomplete System Boundary:** The result of subjectively setting the LCA system boundary due to truncation of data inputs.

3. **Aggregation of Data:** The whole economy with millions of products are modelled into limited number of industry sectors hence the aggregation.

4. **Links to Actual Supply Chains:** What are the relevance to practice?

5. **Selection of Indicators:** Which environmental indicators are relevant to study?

6. **Multi-Regional Supply Chains:** Brought about by the globalised nature of supply chains and the fact that countries depend on each other for goods and services used in production systems.

LCA System Boundary Issues and attempts at addressing it.
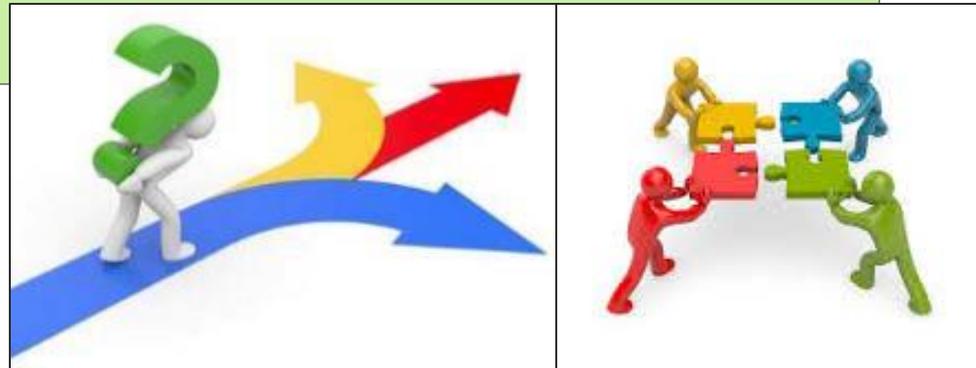
System Boundary Issue

❖ **Incomplete System Boundary:** due to truncation of data inputs

Different System Boundaries
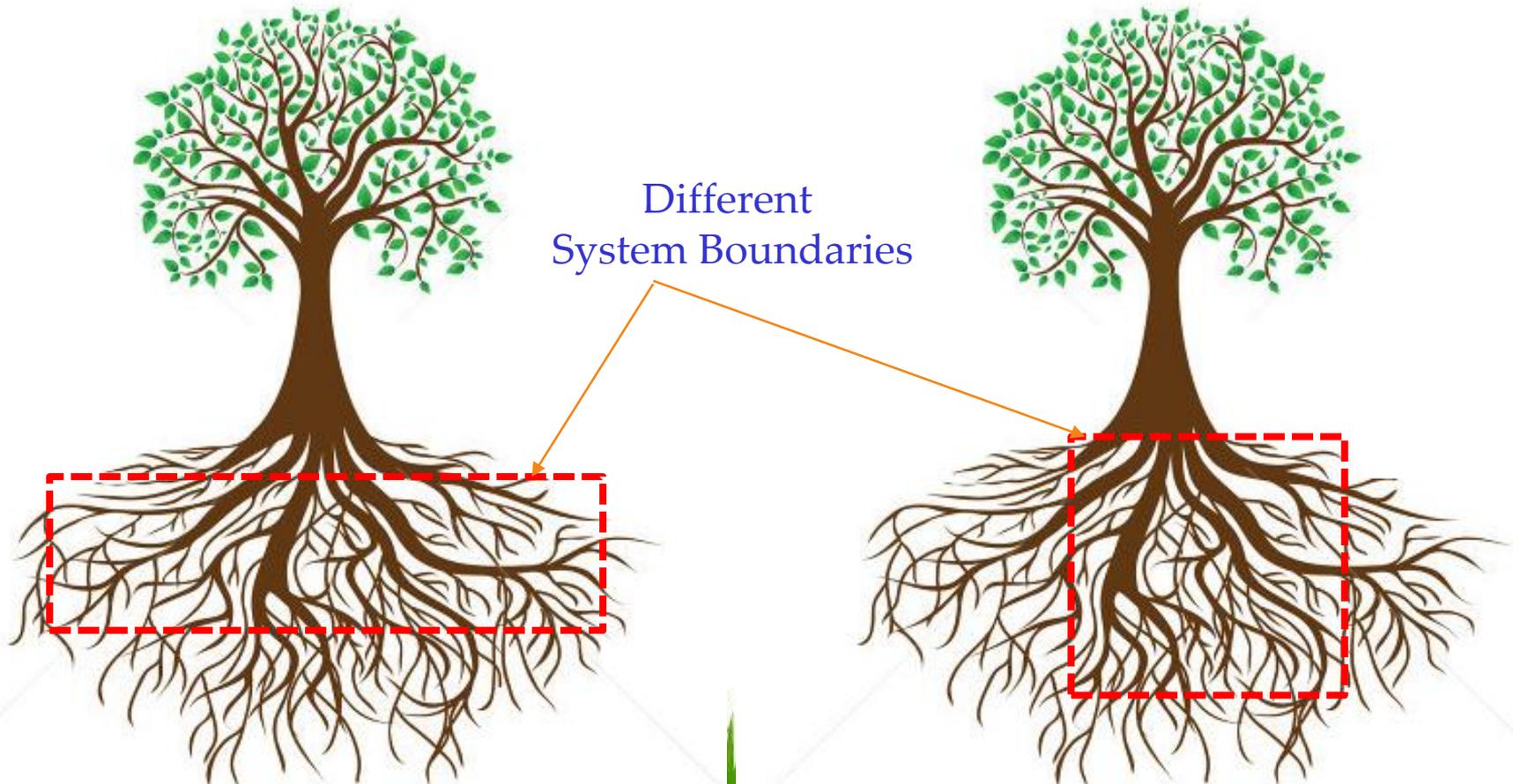
System Boundary Issue

❖ **Solution to Incomplete System Boundary:**
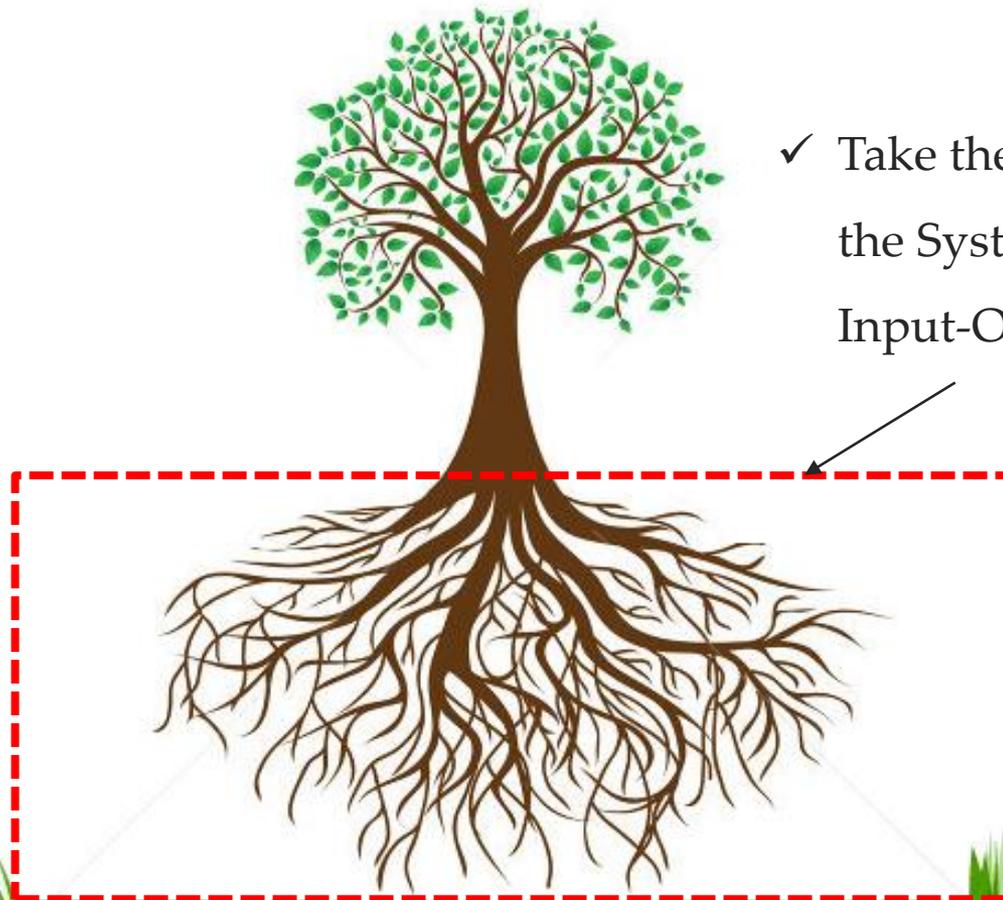
✓ Take the whole economy as the System Boundary using Input-Output Analysis

System Boundary Issue

❖ **Implications of Incomplete System Boundary:** due to truncation of data inputs:

  ➢ Incomplete system boundary usually results in upstream emissions which are difficult to directly measure to be excluded from the LCA analyses.

  ➢ Research have found out that **truncation error** in process analysis resulting in the omission of higher order energy contributions varies from study-to-study but can be up to 50% (Lenzen and Dey, 2000).
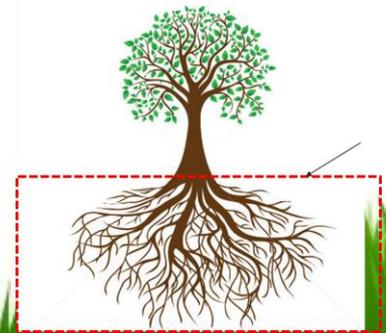
(Environmental) Input-Output Analysis

Input-Output Analyses is a framework based on the structure of the economy in which the flow of resources (products and services) recorded as monetary transaction in $ or £ in the economy are transforms into physical quantities and environmental externalities.

Environmental Input-Output LCA

- This is formulated from the principles of Input-Output analysis; a concept developed by Wassily Leontief (1936).

- The framework is based on the structure of the economy

- Flow of resources (products and services) are recorded as monetary transaction in $ or £

- Environmental Input-Output concept: Change economic flows into physical flows (Material, Water, Land, CO_2, etc)

- Used to measure supply chain impacts (such as Upstream and Indirect impacts)

Basic Input-Output Model

Numerical Example : A *3-by-3* I-O Model of an economy

m£	Agriculture	Electricity	Chemical	Government	Households	Exports	Total
Agriculture	100	20	60	25	70	15	290
Electricity	40	155	10	12	28	16	261
Chemical	75	30	140	4	55	60	364
Value Added	75	56	154				
Total	290	261	364				

Basic Input-Output Framework

Example: A *3-by-3* Input-Output Model of the economy

m£	Industry 1	Industry 2	Industry 3	Consumption/ Export	Total
Product 1					
Product 2	*Intermediate Consumption* Z			*Final Demand* y	*Total Demand* x
Product 3					
Value Added/	*Primary Inputs*				
Total	x				

Definition of Key Terms

- **Intermediate Consumption:** The use of resources (products and services) by an industry from its own and other industries in order to produce an output. Units: £ or $

- **Final Demand:** The demand for products and services by the final demand group namely: Government, Households, Exports, etc. Units: £ or $

- **Total Output:** The total production output by an industry. Units: £ or $. Given that the IO model is balanced;

  Total Industry Output = Total Sector Products Consumed

Basic Input-Output Framework

Example: A *3-by-3* Input-Output Model of the economy

m£	Industry 1	Industry 2	Industry 3	Consumption/ Export	Total
Product 1					
Product 2	*Intermediate Consumption* *Z*			*Final Demand* *y*	*Total Demand* *x*
Product 3					
Value Added/	*Primary Inputs*				
Total	*x*				

$$x_i = x_j = \sum_j z_{ij} + \sum_j y_{ij}$$

In a generalised form: $\boldsymbol{x = Z + y}$ -------------------- *Eqn. 1*

Basic Input-Output Analysis

Numerical Example : A *3-by-3* I-O Model of the economy

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Agriculture	100	20	60	25	70	15	290
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Total	290	261	364				

Technical Coefficient Matrix

	Agriculture	Electricity	Chemical	Government	Households	Exports	Total
Agriculture	100/290	20/261	60/364				290/290
Electricity	40/290	155/261	10/364				261/261
Chemical	75/290	30/261	140/364				364/364
Value Added							
Total	290/290	261/261	364/364				

- **Technical Coefficient Matrix:** So called because it defines the 'technology' of all the individual industries. It is unit-less.

Technical Coefficient Matrix

	Agriculture	Electricity	Chemical
Agriculture	0.34483	0.07663	0.16484
Electricity	0.13793	0.59387	0.02747
Chemical	0.25862	0.11494	0.38462
Total	1	1	1

- **Interpretation: Eg-** For the Chemical Industry to produce £1 output of Chemicals, it requires £0.16484 from Agric; £0.02747 from Electricity and £0.38462 from the Chemical sectors.

Input-Output Analysis

From the Technical Coefficient Matrix:

$$A = [a_{ij}] = \frac{[Z_{ij}]}{[x_j]}$$

Hence:

$$[z_{ij}] = \boldsymbol{A} \cdot [\widehat{x}_j]$$

Where:

$[\widehat{x}_j]$ represents the diagonalised square matrix of $[x_j]$.

In a generalised form: $\boldsymbol{Z} = \boldsymbol{A} \cdot \boldsymbol{x}$ -------------------- *Eqn. 2*

Input-Output Analysis

$$x = Z + y \qquad \text{------------------} \quad \textit{Eqn. 1}$$

$$Z = A \cdot x \qquad \text{------------------} \quad \textit{Eqn. 2}$$

Substituting Equation 2 into 1:

$$x = A.\,x + y$$

Solving for x:

$$\underline{x} = (I - A)^{-1} \cdot \underline{y}$$

$(I - A)^{-1}$: is referred to as **Leontief Inverse Matrix**

Input-Output Analysis

$$\underline{x} = (I - A)^{-1} \cdot \underline{y}$$

$$\underline{x} = \left(A^0 * \underline{y}\right) + (A^1 * \underline{y}) + (A^2 * \underline{y}) + (A^3 * \underline{y}) + (A^4 * \underline{y}) + \cdots$$

$$\underline{x} = \underline{y} + A * \underline{y} + A^2 * \underline{y} + A^3 * \underline{y} + A^4 * \underline{y} + \cdots$$

$$\underline{x} = \left(I + A + A^2 + A^3 + A^4 + \cdots\right) * \underline{y}$$

✓ **This is the Total Indirect Upstream Supply Chain Requirements**

Environmental Extended IO Analysis

❖ IO analysis can be extended to an Environmental Input-Output (EIO) model

❖ Results generated can be used in the general assessment of supply chain impacts on the natural environment.

Let E be the direct environmental output from each Industry

Hence the direct intensity environmental impacts, E_{int} of each industry can be defined as: $E_{int} = \frac{E}{X}$. This is usually referred to as the **Direct Intensity Matrix** (DIM) and it can be diagonalised into a square matrix= $\widehat{E_{int}}$

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Environmental Extended IO Analysis

Direct Intensity Matrix (DIM) = $E_{int} = \dfrac{E}{X}$ **[Units:** unit/£]

Given that the total upstream supply chain requirements, **X** is given by:

$$\underline{x} = (I - A)^{-1} \cdot \underline{y}$$

It implies that the total upstream environmental impacts will be:

Impacts= DIMS $* \underline{x} =$ DIMS $* (I - A)^{-1} \cdot \underline{y} =$ TIM $* \underline{y}$

Total Intensity Matrix (TIM)

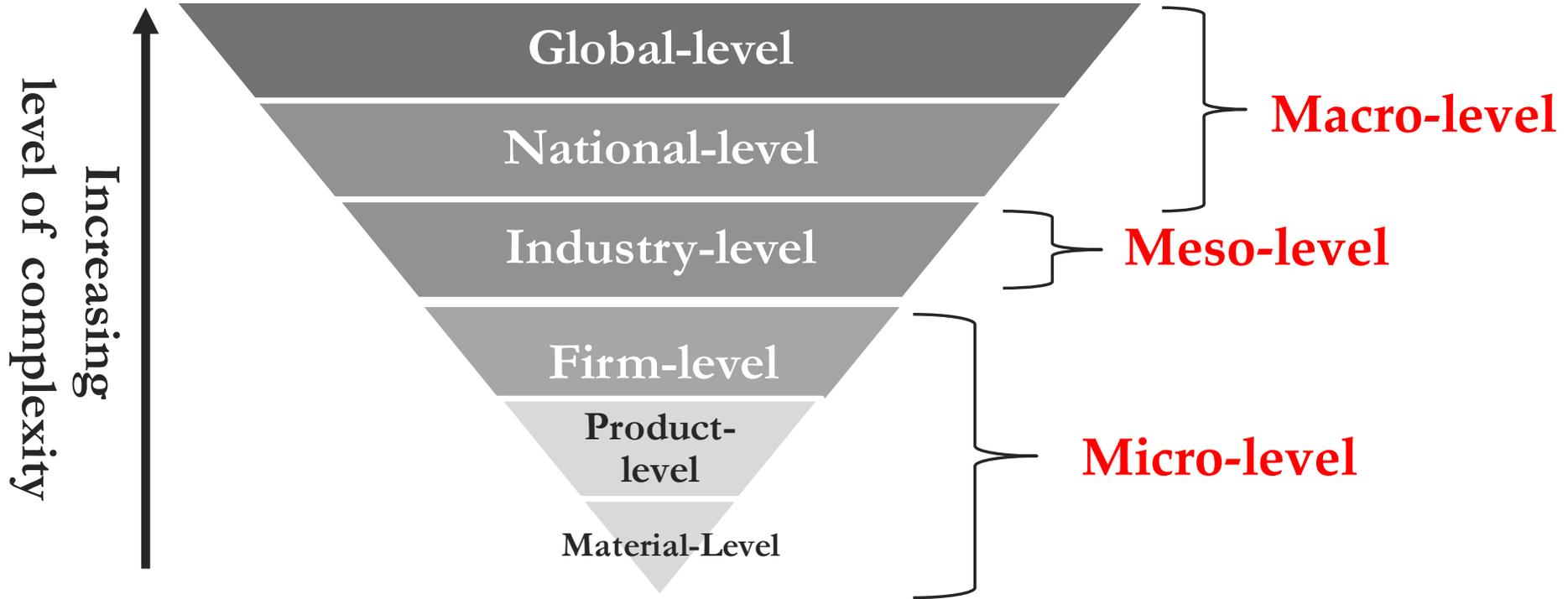# Consumption and Production-based View

❖ **Production-based Accounting:**

➢ This is based on the direct intensity of environmental impacts, E_{int} and it is defined as: $DIM * \underline{y} = E_{int} * \underline{y}$

❖ **Consumption-based Accounting:**

➢ This is based on the total intensity of environmental impacts and it is defined as: $TIM * \underline{y} = DIM * (I - A)^{-1}\underline{y}$.

Environmental Assessment across the Value Chain

Limitations of Environmental Input-Output LCA

❖ It **assumes linearity** in production and consumption of supply chain goods and services; but economies of scale shows that is not always the case.

❖ It makes use of **homogeneity assumption**; that is two or more products and services aggregated together in the same sector are produced using the same technology

Sample Reading Materials

PRODUCT-level ANALYSES

❖ Smith, L., Ibn-Mohammed, T., Yang, F., Reaney, I. M., Sinclair, D. C., & Koh, S. L. (2019). Comparative environmental profile assessments of commercial and novel material structures for solid oxide fuel cells. Applied Energy, 235, 1300-1313.

FIRM-level ANALYSES

❖ Martinez, S., Delgado, M. D. M., Martinez Marin, R., & Alvarez, S. Organization Environmental Footprint through Input-Output Analysis: A Case Study in the Construction Sector. Journal of Industrial Ecology.

INDUSTRY-level ANALYSES

❖ Acquaye, A., Genovese, A., Barrett, J., & Lenny Koh, S. C. (2014). Benchmarking carbon emissions performance in supply chains. Supply Chain Management: An International Journal, 19(3), 306-321.

Thank You.

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