JUST2CE
A Just Transition to Circular Economy

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Input-Output Analysis for Circular Economy research: what is to be done?

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Seminar - JUST2CE Project
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Outline

1. Personal introduction and background
2. What is an Input-Output table?
3. Calculating Technical Coefficients and the Leontief Inverse
4. Socio-economic and Environmental Extension
5. Multi-Regional Input-Output (MRIO) tables
6. Input-Output Analysis for Circular Economy
    - How Circular Economy has been incorporated in Input-Output models?
    - Limitations and Open challenges.
7. Research Agenda and plan within JUST2CE project

Personal introduction and research background

- BSc (2012) and MSc in Economics (2015) at the Institute of Economics of the Federal University of Rio de Janeiro (IE/UFRJ)
  - Research on structural change and Economic Development
  - Introduction to Input-Output Analysis with focus on premature deindustrialization debate in Brazil.
- Research Assistant (pre-doc) at the Institute of Applied Economic Research (IPEA)
  - Research assistant at the Macroeconomics division.
  - Specialized on National Accounts and developing nowcasting indicators to track economic activity.
- PhD at the Open University Business School (2021)
  - Research on International Trade, Exchange Rates and Income Distribution.
- Associate Lecturer at Institute of Management Studies Goldsmiths College.
  - Module leader in Foundations of Economics and Econometrics

What is an Input-Output table?

		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Govt. Purchases of Goods & Services	Net Exports of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
	Other Industry												
VALUE ADDED	Employees	Employee compensation								GROSS DOMESTIC PRODUCT			
	Business Owners and Capital	Profit-type income and capital consumption allowances											
	Government	Indirect business taxes											

Figure 1.1 Input–Output Transactions Table

Table 2.2 Expanded Flow Table for a Two-Sector Economy

		Processing Sectors 1	2	Final Demand (f)				Total Output ($\mathbf{x}$)
Processing Sectors	1	z_{11}	z_{12}	c_1	i_1	g_1	e_1	x_1
	2	z_{21}	z_{22}	c_2	i_2	g_2	e_2	x_2
Payments Sectors	Value Added ($\mathbf{v}'$)	l_1	l_2	l_C	l_I	l_G	l_E	L
		n_1	n_2	n_C	n_I	n_G	n_E	N
	Imports	m_1	m_2	m_C	m_I	m_G	m_E	M
Total Outlays ($\mathbf{x}'$)		x_1	x_2	C	I	G	E	X

$$Total\ Demand = Total\ Output = (domestic + imported)\ inputs + value\ added$$

$$z_{11} + z_{12} + c_1 + i_2 + g_1 + e_1 = x_1 = z_{11} + z_{21} + m_1 + l_1 + n_1$$

$$z_{21} + z_{22} + c_2 + i_2 + g_2 + e_2 = x_2 = z_{12} + z_{22} + m_2 + l_2 + n_2$$

$$Z + f_d = x$$

Table 2.3 Flows (z_{ij}) for the Hypothetical Example

		To Processing Sectors			
		1	2	Final Demand (f_i)	Total Output (x_i)
From	1	150	500	350	1000
Processing Sectors	2	200	100	1700	2000
Payments Sector		650	1400	1100	3150
Total Outlays (x_j)		1000	2000	3150	6150

$$Total\ Demand = Total\ Output\ = (domestic + imported)\ inputs + \ value\ added$$

Sum of 1st column = Sum of 1st row: $150 + 500 + 350 = 1000 = 150 + 200 + 650$

In matrix notation: $Z + f_d = x$

Technical Coefficients

- From information provided in Input-Output tables we can calculate the technical coefficients, that is:
  - How much of input i (e.g aluminium) is necessary to produce 1 unit of commodity j (e.g. aircraft).
- This is obtained by:

$$a_{ij} = \frac{z_{ij}}{x_j} = \frac{value\ of\ aluminium\ bought\ by\ aircraft\ producers\ in\ year\ t}{value\ of\ total\ production\ of\ aircrafts\ in\ year\ t}$$

- We can compile this for all intermediate input entries in the I-O table into a technical coefficient matrix (A), which in a 2-sector model can be expressed as:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} 0.15 & 0.25 \\ 0.2 & 0.05 \end{bmatrix}$$

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We can re-write, in matrix form, our accounting identity $(Z + f_d = x)$ as:

$$Ax^{-1} + f = x$$

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  - Allowing us to access changes in the technical coefficients (a_{ij}) that are in fact related to changes in technology, and not due to change in costs.
- In practice, sectors produce more than one good, and the assumption of one price for a sector's output is unrealistic. And, in any case, monetary tables are assembled on the basis of recorded values of transactions; price and quantity are generally not recorded separately.
  - So, there is an inevitable bias caused due to aggregation and change in the composition of output produced within each sector.

Technical Coefficients & the Leontief Inverse

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- And manipulate the equation to isolate the total output vector (x):

$$x = \underbrace{(I - A)^{-1}}_{L} f$$

- $L = (I - A)^{-1}$ is known as the Leontief inverse or the total requirements matrix.
  - **Its computation is of paramount importance to enable one to conduct Input–output analysis.**

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- As it links the amount of ***total output required to be able to satisfy a given final demand***. For instance, it allows us to find some initial answers to questions such as:
  - If final demands (consumption, investment or exports) of all different commodities are forecasted to increase by some specific amounts next year, how much output from each sectors would be necessary to supply these final demands?

Input-Output Extensions

- The Leontief inverse (L) links the changes in final demand to changes in total output, for a given technology.

$$x = \underbrace{(I - A)^{-1}}_{L} f$$

- With minor modifications to the basic framework Input-Output analysis can provide insights regarding changes in trade flows, employment, pollution and waste treatment associated with changes in final demand (f_i) and in technology (a_{ij}).

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Socio-Economic factors- e.g. Employment

- If we know the employment level in each sector j in a given year, we can compute labour coefficients:

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- Computing labour coefficients for all sectors into a diagonal matrix (denoted by $\hat{l}$) and pre-multiplying the Leontief inverse matrix and final demand vector, we can obtain:

$$N = \hat{l}\, \underbrace{(I - A)^{-1}}_{L} f$$

- N will be a column vector with the total the total (direct and indirect) employment generated by final demand for output of each sector across the entire supply chain.

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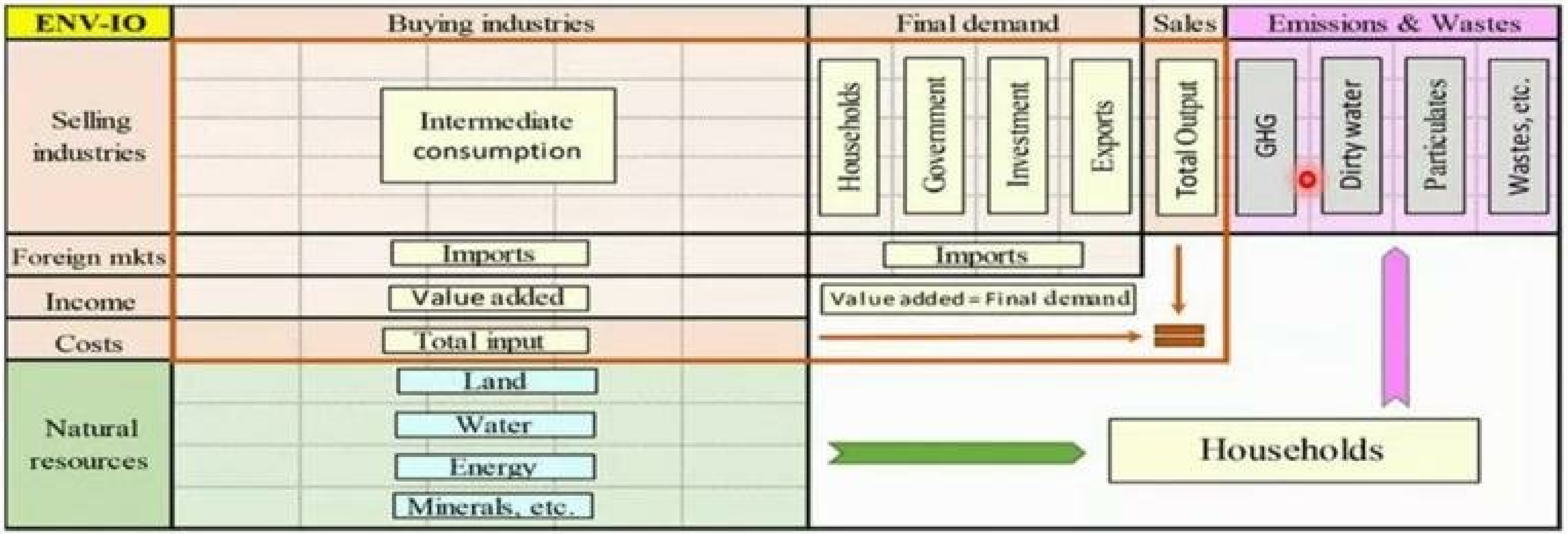
➢ **Hence, again, we can calculate the impact of changes in final demand and/or technical changes, but now on Employment.**

Environmentally Extended Input-Output (EEIO) Analysis



If we know the GHG emission occurring in the production process in each sector we can also calculate an emission coefficient for in each sector j in a given year:

$$e_j = \frac{j}{x_j} = \frac{Total\ GHG\ emissions\ in\ the\ aircraft\ producers\ sector\ in\ year\ t}{value\ of\ total\ production\ of\ aircrafts\ in\ year\ t}$$

$$GHG_{emissions} = \hat{e}\,\underbrace{(I - A)^{-1}}_{L} f$$

- Hence, again, we can calculate the **impact of changes in final demand** and/**or** of **technical changes** on **emissions** or in **raw material consumption**.

Multi-regional Extensions

Single region Input-Output tables can be extended to incorporate multiple regions (either subnational or multiple countries) by disaggregating imports (row) and exports column by sector of origin/destination of the trade flow.

- In the past decades several "global" databases have been compiled released such as WIOD, OECD-TiVA, EORA and EXIOBASE

		REGION 1		REGION 2		FINAL DEMAND		TOTAL OUTPUT
		INDUSTRY 1	INDUSTRY 2	INDUSTRY 1	INDUSTRY 2	REGION 1	REGION 2	
REGION 1	INDUSTRY 1	DOMESTIC INTERMEDIATE INPUTS OF REGION 1		INTERMEDIATE IMPORTS OF REGION 2 = INTERMEDIATE EXPORTS OF REGION REGION 1		DOMESTIC FINAL DEMAND OF REGION 1	EXPORTED FINAL DEMAND OF REGION 1 = IMPORTED FINAL DEMAND OF REGION 2	
	INDUSTRY 2							
REGION 2	INDUSTRY 1	INTERMEDIATE IMPORTS OF REGION 1 = INTERMEDIATE EXPORTS OF REGION REGION 2		DOMESTIC INTERMEDIATE INPUTS OF REGION 2		EXPORTED FINAL DEMAND OF REGION 2 = IMPORTED FINAL DEMAND OF REGION 1	DOMESTIC FINAL DEMAND OF REGION 2	
	INDUSTRY 2							
VALUE ADDED		VALUE ADDED OF REGION 1		VALUE ADDED OF REGION 2				
TOTAL INPUTS								

The transition towards a CE

- The transition to a circular economy involves economy-wide changes affecting a large variety of economic sectors and actors, across complex global supply chains.
- Environmentally extended Multiregional input–output (MRIO) analysis provides a useful building block for assessing this transition, tracking material flows across increasingly fragmented international supply chains.

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- The introduction of these practices affect consumption patterns and technology of production.
  - These can be introduced in our fundamental equation linking final demand, technical change, total out.

Circular Economy Strategies typology in I-O analysis

- Based on Aguilar-Hernandez et. al (2018)

CE Strategies	Description	Key interventions
Residual waste management (RWM)	Related to post-consumption activities where the materials are disposed	Landfill Energy recovery Waste treatment
Closing supply chains (CSC)	The re-integration of materials at different levels of the supply chain after being used, via for instance product reuse, component re-use, refurbishing, and recycling	Reuse Redistribution Refurbishment Remanufacture Recycle
Product lifetime extension (PLE)	Associated with slowing down the resource use as a consequence of extending lifetime of products, via for instance design for longevity and improved maintenance.	Delayed product replacement Maintenance Repair
Resource efficiency (RE)	Processes or mechanisms which optimise resource flows by using less resources per unit produced.	Resource efficiency Functional Economy

An example: Functional Economy- The case of Car Sharing 'Clubs'

zipcar → AVIS

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- To keep things simple, suppose we have an economy with 3 sectors- (1) Automobile Industry; (2) Rental and Leasing services; and (3) Repair and Maintenance.

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}; \qquad f = \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix}$$

- The introduction of Car Sharing ‘Clubs’ can be done in two forms:
  a) We can add a new specific sector increasing the system here from a 3×3 to 4×4 system. Or,
  b) Introduce the changes caused by the adoption of Car Sharing ‘clubs’ into an aggregated Rental and Leasing services sector.

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  - ↓ final demand for purchasing motor vehicles (f_1) and repair and maintenance (f_3) while increasing.
  - ↑ final demand for Rental and Leasing services (f_2).

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- However, if we assume that (zip)cars have a different usage, accident and breakdown risk than regular rental (Avis)cars, It also leads to changes in the technical coefficient matrix (A). E.g:
  - Higher breakdown risk of (zip)cars lead to higher intermediate demand from Rental and Leasing services for parts and components produced by the automobile industry (↑ a_{12}).
  - Higher accident risks lead to higher intermediate demand from Rental and Leasing services for Repair and Maintenance services (↑ a_{32}).

Literature Review on EEIO and Circular Economy

- Aguilar-Hernandez et. al (2018) systematic review of the literature which have used Environmentally extended I-O (EEIO) analysis to assess Circular Economy practices.
  - Total of 93 papers identified.

	CIRCULARITY INTERVENTION TYPE			
	PLE	CSC	RE	RWM
Number of Papers	17	54	13	68

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  - Among which 7 provide scenario analysis, other 4 focus on diagnosis, while 2 have a purely theoretical/methodological focus.

Towa et. al (2021) - I-O models for Waste Mgt

Acronym of the model	Name of the type of Model	Description
WEIO	Waste extended input-output model	• Denomination for an EEIO in which the environmental extension is for Waste. • Combines a conventional IOT (measured in monetary units) with information on waste generation by sector (compiled in physical units), added as satellite account (eventually next to other extensions) to a conventional IO model. • In a WEIO model, the only connection between product and waste flows is established by adding waste generation by sectors and by final demand to the monetary product flows in sectors and final demand. • The physical use of recycled material as a secondary material not explicitly considered.
WIO	Waste Input-Output model	• Also combines a conventional IOT (measured in monetary units) with information on waste generation by sector (compiled in physical units), added as satellite account (eventually next to other extensions) to a conventional IO model. • But total generation of waste per sector is net of waste recycled. • It shows the different types of waste generated by productive and waste treatment sectors (as positive entry) and additionally shows the use of waste by productive sectors, i.e. waste recycled (as negative entry).
PIO	Physical Input-Output	• Model that measures all flows in physical units: the flows of products, as well as the multiple flows which link the economy and the environment, namely natural resources, emissions and waste flows. • Such a model includes waste generated by sectors and final demand, and waste used by waste treatment sectors. PIO studies have often focused on a specific sector with one waste type.
HIO	Hybrid Input-Output	• Refer to models computed using a mixed-unit framework where the data in IOTs/SUTs are expressed in different units: tangible products in mass unit, energy flows in joules and services in monetary unit, regardless environmental accounts.

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All	WEIO	WIO	PIO	HIO	Total	%
Diagnosis	19	25	1	2	47	60%
Scenario Analysis	5	22	2	2	31	40%
Total	24	47	3	4	78	100%

Economic Analysis	WEIO	WIO	PIO	HIO	Total	%
Diagnosis	4	6	0	0	10	66%
Scenario Analysis	2	3	0	0	5	33%
Total	6	9	0	0	15	100%

I-O Economic Analysis for CE transition

- Our own systematic search for "Input-Output"& "Circular Economy" as well as "Input-Output" and other CE related terms in Scopus & Web-of-Science returned a grand total of 105 papers.
- Analysing these, together with papers identified from the reviews of Aguillar-Hernandez et.al (2018) and Towa et. al (2021), we arrived at:

I-O Economic Analysis for CE transition

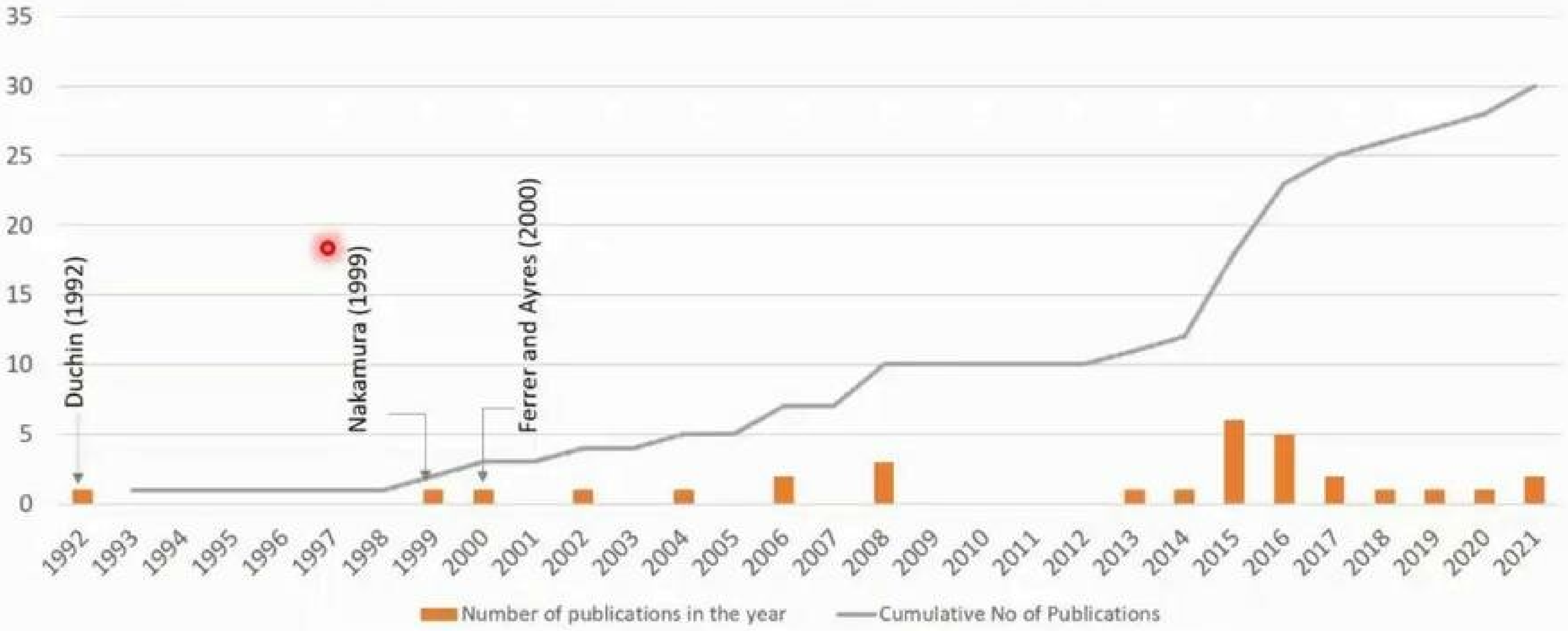
- Our own systematic search for "Input-Output"& "Circular Economy" as well as "Input-Output" and other CE related terms in Scopus & Web-of-Science returned a grand total of 105 papers.
- Analysing these, together with papers identified from the reviews of Aguillar-Hernandez et.al (2018) and Towa et. al (2021), we arrived at:
  - **30 papers** which develop an **analysis involving economic indicators** in relation to **Circular Economy practices**.

Total	Diagnosis	Scenario Analysis	Theoretical/ methodological
30	16	12	2

Where they have been published?

Journals	Papers published
Resources, Conservation and Recycling	5
Ecological Economics	4
Journal Of Industrial Ecology	4
International Journal of Life Cycle Assessment	2
Journal of Economic Structures	2
Journal of Material Cycles and Waste Management	2
Economic Systems Research	1
Central European Journal of Operations Research	1
Journal of Cleaner Production	1
Waste Management and Research	1
Agriculture (Switzerland)	1
Sustainability (Switzerland)	1
International Journal of Production Economics	1
Proceedings of the National Academy of Sciences of the United States of America	1
Energy & Environmental Science	1
Environmental science & technology	1
Sustainable Production and Consumption	1

When they have been published?



What aspects they tend to analyse?

- Typical aspects investigated are the impact of Circular Economy practices on indicators such as **employment** (9 studies), **value added** (6), **gross output** (6), **cost** (5)

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- No consideration of impact on public finances, or financial variables.
- Very few consider trade imbalances that may arise from transition towards circular economy practices.

Sectors and countries analysed

Sector	No of Studies
Air-Conditioning	1
Automotive	2
Electrical Home appliances	2
Aggregated Final Demand	2
Food	2
Household Demand	3
Manufacturing	1
Metal	1
Multi-sectoral	7
Packaging	2
Recycling	1
Remanufacturing	1
Steel	2
Tourism	1
Waste Management	3

Country/Region	No of Studies
Australia	2
Belgium	2
EU	2
France	3
Multi-regional	4
Japan	9
n.e.c.	3
Netherlands	1
New Zeeland	1
Portugal	2
United Kingdom	2
United States	2

Notable recent contributions

Wiebe et. al (2019) "Global Circular Economy Scenario in a Multiregional Input–Output Framework", *Environmental science & technology*, vol. 53, issue 11, pages 6362-6373.

- Projection of Exiobase (I-O database) until 2030.
- Multi-regional, individual countries results aggregate into 4 geographical regions: Europe; Asia and the Pacific; Americas; Africa and the Middle East.
- **Circular Economy Practices considered:** Resource efficiency, Product Life Extension, Closing Supply Chain (Recycling).
- **Environmental variables analysed:** Raw material extraction
- **Economic variables:** Employment and Value Added (Profits and Wages)
- **Main results:** Global material extraction is reduced by about 10% compared to the baseline scenario; Impact on employment is small but positive; in particular, the shift from resource extracting sectors to the service sector will provide more opportunities for high-skilled and female workers.

Notable recent contributions

Donati et. al (2020) "Modelling the circular economy in environmentally extended input-output tables: Methods, software and case study", *Resources, Conservation & Recycling*, vol. 152, issue 104508.

- 1-off exogenous changes to the Exiobase (I-O database).
- Multi-regional, individual countries results aggregate into 2 geographical regions (Europe, RoW)
- **Circular Economy Practices considered:** Resource efficiency, Product Life Extension
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- **Main results:** Environmental indicators are reduced by −10.1% Global Warming Potential 100-years (GWP) (IPCC, 2007), −12.5% Raw Material Extraction (RME), −4.3% Land Use (LU) and −14.6% Blue Water Withdrawal (BWW).Reduction of socio-economic indicators, -6.3% Value Added (VA) and -5.3% employment.

Limitations and open challenges

a) Technological change and demand changes assumptions

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  - Typically informed by targets set by public policy (e.g. recycling target for certain materials, emissions targets consistent with global warming targets).
  - But also derived from mixed-method approaches, including interviews from stakeholders (e.g. Cooper et. al, 2016).
  - However, there is still great discretionary power for researchers to choose the relative sizes of changes introduced, which may explain the divergent socio-economic outcomes of seemingly similar interventions in different studies.

Limitations and open challenges

a) Technological change and demand changes assumptions (cont.)

- The exogenous changes is a consequence of a lack of behavioural components in the model.
  - Consumers and firms make their consumption and investment decisions taking into consideration disposable income, relative prices, interest rates, expected demand, among other factors.
  - In a market economy, adoption rate of circular economy practices by consumers and firms are inevitably constrained by such considerations.

➢ This, however, can be addressed to some extent with the coupling of the Input-Output framework with macroeconomic models, such as Post-Keynesian Stock-Flow Consistent (SFC) models and/or Agent Based Models (ABM).

Limitations and open challenges

b) Modelling of the Rebound Effects

- Technological changes, such as increase in resource efficiency, and shifts in the composition of demand brought about the transitions to a Circular Economy ought to bring changes in relative prices and disposable income, which can lead to subsequent changes in demand for products, increasing material consumption, emissions, as well as affecting socio-economic variables further.

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- Apart from some preliminary attempts, an analysis of potential Rebound Effects is mainly absent in this stream of literature.
  - Wiebe et. al (2019) (relative price changes associated with changes in technical coefficient affecting demand).
  - Ferrao et. al (2014) (changes in disposable income due to changes in prices of products affected by CE.

Limitations and open challenges

c) Analysis of transitional paths

- Most studies develop an static analysis, where two or more 'end-states' are compared relative to a baseline scenario.
- The few studies which do simulate a transition towards a Circular Economy, such as Wiebe et. al. (2019) assume a linear change.
    - Important non-linear effects can occur during the transition period which might create economic, social and political challenges for arriving at the desired 'end-state'.
- Most studies lack assessment of the impacts of the investment required for the introduction of circular economy practices during the transition.
    - Can be achieved within dynamic input-output frameworks and/or SFC modelling.

Limitations and open challenges

d) **Limited coverage of socio-economic aspects**.

- So far literature has focused mainly in analysing impact of CE practices on economic growth and in employment, at an aggregate level.
- Broader social-economic aspects haven't been (much) explored:
  - Income distribution
  - Gender & Race employment impacts.
  - Trade imbalances
  - Public finances
  - On financial markets (e.g.: stranded assets impacts on balance sheets of banks, investment and pension funds).

Concluding Remarks

- Input-Output analysis is very powerful tool to track the interindustry flows originating from changes in technology of production and in final demand.
  - This characteristics makes I-O analysis a useful tool to simulate the environmental and economic impact of changes associated with Circular Economy practices.

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- Main limitation involves its relative **high degree of aggregation**, **exogenous** determination of changes in **technical coefficients**, lack of **modelling of transition path.**
  - While the former is a insurmountable, the latter two can be remediated with coupling the I-O framework with macroeconomic modelling for the demand side and technological adoption, such as **SFC models** as we **propose within WP5**.

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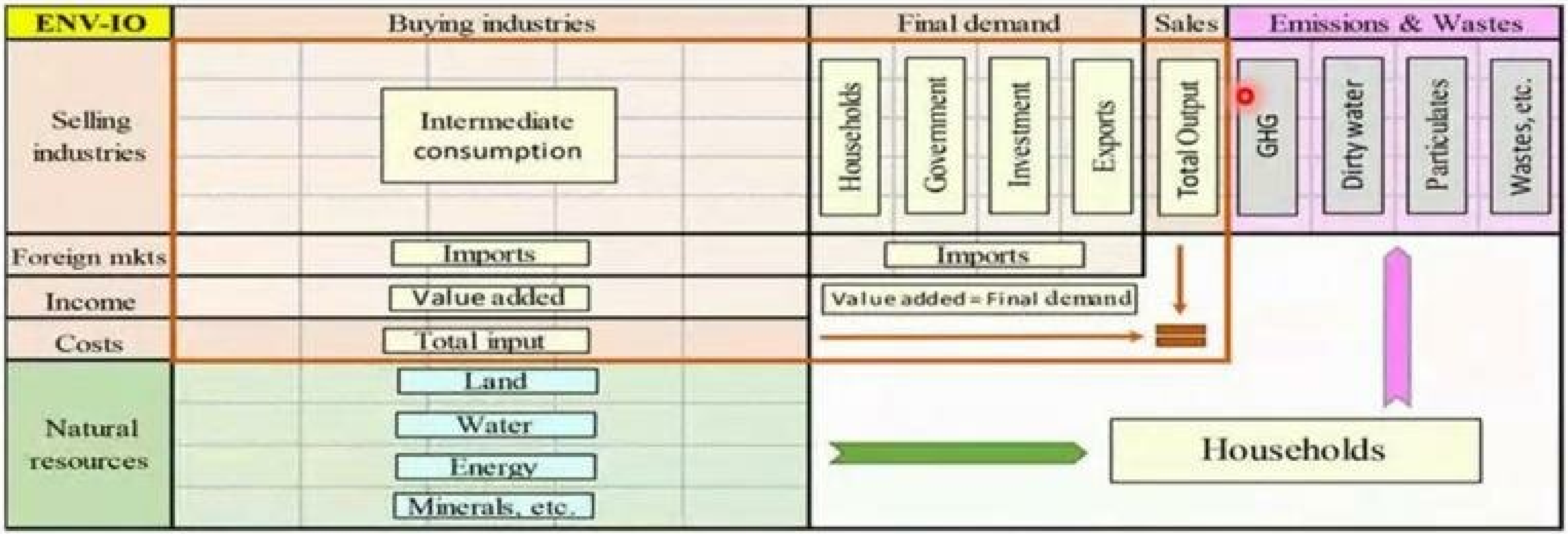
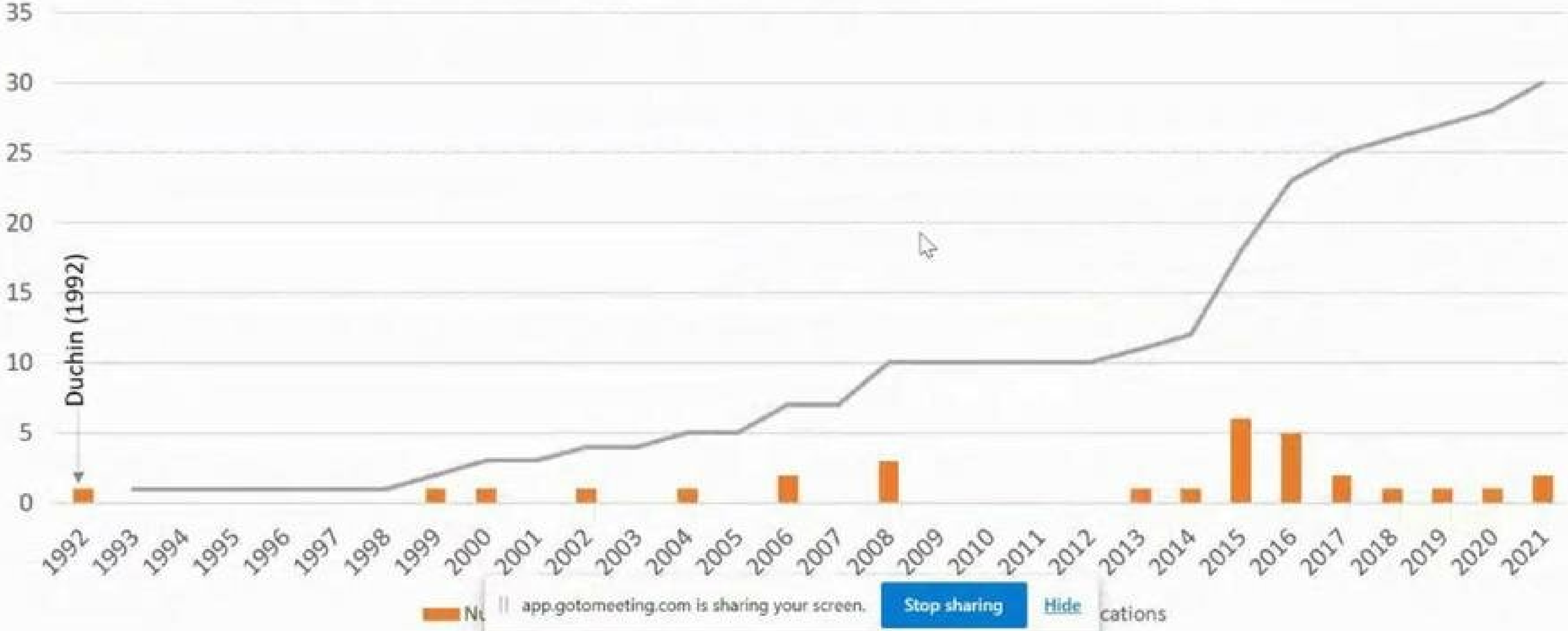
  - While the former is a insurmountable, the latter two can be remediated with coupling the I-O framework with macroeconomic modelling for the demand side and technological adoption, such as **SFC models** as we **propose within WP5**.
- Literature has advanced considerably in recent years, but there is still gaps in the literature that need to, and can, be addressed.
  - Broadening of socio-economic factors analysed.
  - Modelling of rebound effects.
  - Implications for international trade and developing countries specialized in raw material extraction.

Environmentally Extended Input-Output (EEIO) Analysis



If we know the GHG emission occurring in the production process in each sector we can also calculate an emission coefficient for in each sector *j* in a given year:

When they have been published?



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