Accounting for global resource consumption and embodied CO_2 emissions using GRAM

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GRAM: **G**lobal **R**esource **A**ccounting **M**odel

- Multi-regional input-output model
- 53 countries and 2 regions
- 48 sectors per country/region
- Years covered: 1995 - 2005

- 1st version (2007/08)
  (petrE: resource productivity and environmental tax reform in Europe, Anglo-German Foundation)
  - 8 raw material categories
  - Linked single-region IO models

- 2nd version (2009/10)
  (Die Klimabilanz des österreichischen Außenhandels, Österreichischer Energie- und Klimafonds)
  - CO2 emissions
  - True multi-regional IO model

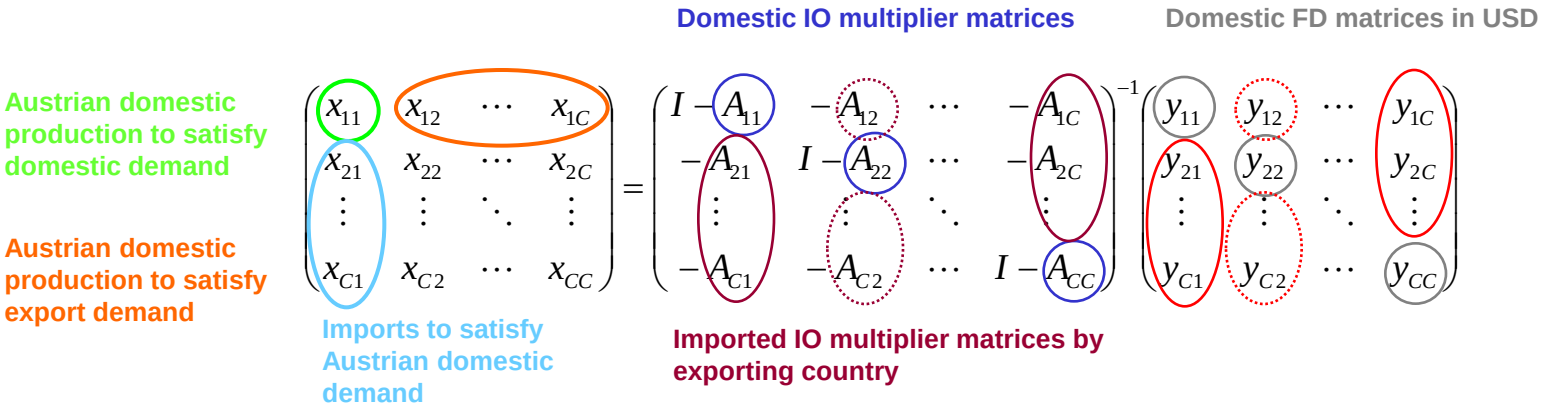
- 1-country case
  - A Interindustry requirements matrix
  - x Sectoral output vector
  - y Final demand vector
  - I Identity matrix

$$Ax + y = x$$

$$y = (I - A)x$$

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

- Multi-country case



Extension to emission/resource intensities

- Vector of emission/resource intensities, e
- Matrices E_i for each country i consisting of e_i
- Pollution matrix P consisting of vectors p_{ij}

$$P = E(I - A)^{-1} y$$

Size of matrices (2640 × 55) (2640 × 2640) (2640 × 2640) (2640 × 55)

CO_2 emissions associated with Austrian production to satisfy Austrian demand

$$\begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1C} \\ p_{21} & p_{22} & \cdots & p_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ p_{C1} & p_{C2} & \cdots & p_{CC} \end{pmatrix} = \begin{pmatrix} E_1 & 0 & \cdots & 0 \\ 0 & E_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & E_C \end{pmatrix} \begin{pmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1C} \\ -A_{21} & I - A_{22} & \cdots & -A_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{C1} & -A_{C2} & \cdots & I - A_{CC} \end{pmatrix}^{-1} \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1C} \\ y_{21} & y_{22} & \cdots & y_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ y_{C1} & y_{C2} & \cdots & y_{CC} \end{pmatrix}$$

CO_2 emissions on Austrians exports

CO_2 intensity coefficients

CO_2 emissions on Austrian imports

Data: Sources

- OECD input-output tables
  - ca 1995, ca 2000, ca 2005
  - 48 sectors
- OECD bilateral trade data
  - 1995 – 2005
  - 25 goods + 1 service sector
- IEA CO_2 emission data
  - 1995 - 2005
  - 6 sectors
- www.materialflows.net
  - 1995 – 2005
  - 4 material categories

Data: Problems

Data problems

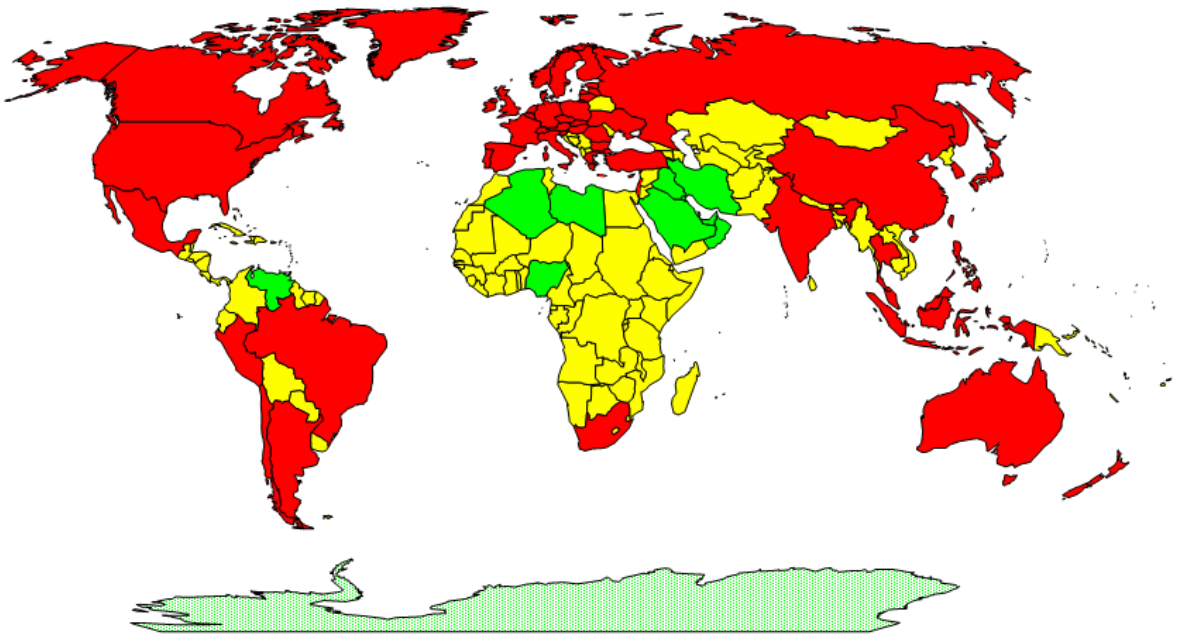
- Input-output tables (IOT)
  - available for at most three years
  - not available for all countries
- Bilateral trade data (BTD)
  - missing years for some countries, esp. before 1998
  - substantial gaps in service trade matrix
- Emission data
  - not available in IOT or BTD classification
- Material data
  - No sectoral data

Solutions

- Input-output tables
  - linear interpolation
  - example countries
- Bilateral trade data
  - structure of first available year
  - structure of 2000 for the years before
- Emission data
  - use of IEA Energy Balances
- Material data
  - use of respective IO sector

Data: country coverage

Country	Approximated by
Rest of the World	Argentina
Iceland	Norway
Bulgaria	Slovakia
Cyprus	Greece
Latvia	Poland
Lithuania	Poland
Malta	Greece
Romania	Slovakia
Honkong	Korea
Malaysia	Korea
Philippines	Korea
Singapore	Korea
Thailand	Korea
Chile	Brazil
OPEC	Indonesia



55 importing countries

55 exporting countries

OECD IOT data

OECD IOT data and OECD BTD data

$$\begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1C} \\ p_{21} & p_{22} & \cdots & p_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ p_{C1} & p_{C2} & \cdots & p_{CC} \end{pmatrix} = \begin{pmatrix} E_1 & 0 & \cdots & 0 \\ 0 & E_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & E_C \end{pmatrix} \begin{pmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1C} \\ -A_{21} & I - A_{22} & \cdots & -A_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{C1} & -A_{C2} & \cdots & I - A_{CC} \end{pmatrix}^{-1} \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1C} \\ y_{21} & y_{22} & \cdots & y_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ y_{C1} & y_{C2} & \cdots & y_{CC} \end{pmatrix}$$

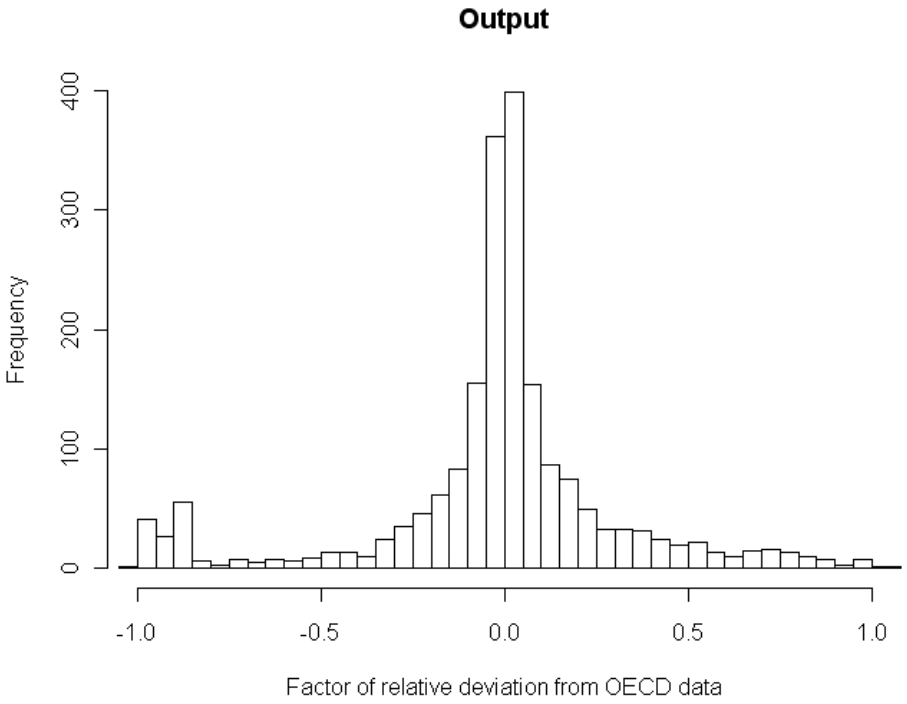
IEA emissions data → IEA EB structure → OECD IOT structure

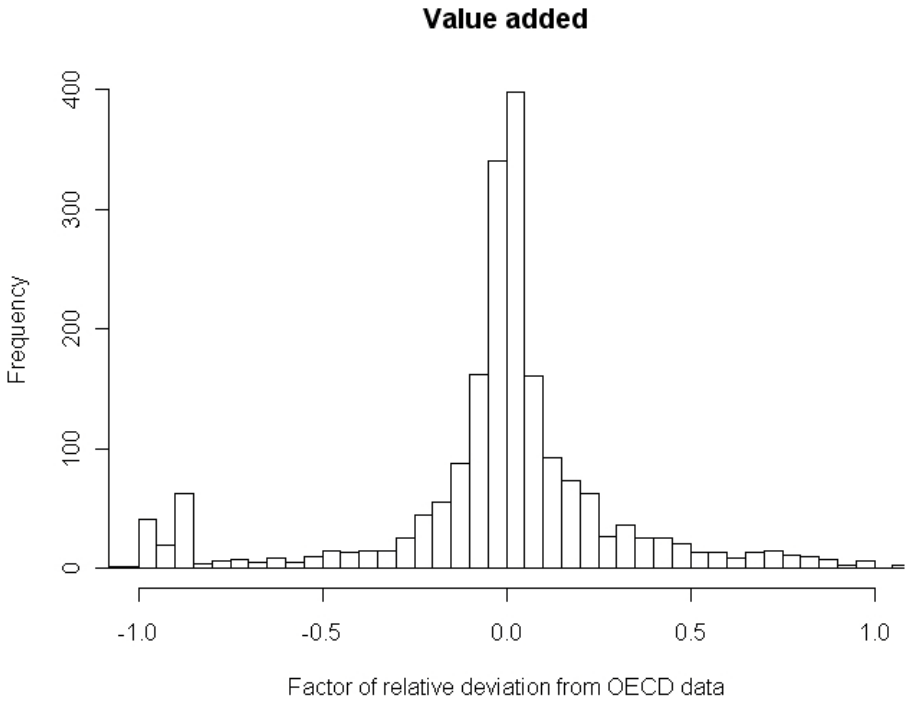
Size of matrices	(2640 × 55)	(2640 × 2640)	(2640 × 2640)	(2640 × 55)
	(55 × 55)	(55 × 2640)		

- Omitted data
  - Sectoral output
  - Sectoral export
  - Sectoral value added
- No RAS procedure

- Calculated data
  - $\hat{\mathbf{x}} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$
  - $\mathbf{ex}_{ij} = \mathbf{im}_{ji}$
  - $\mathbf{va}$ as residual

Deviation of calculated sectoral data

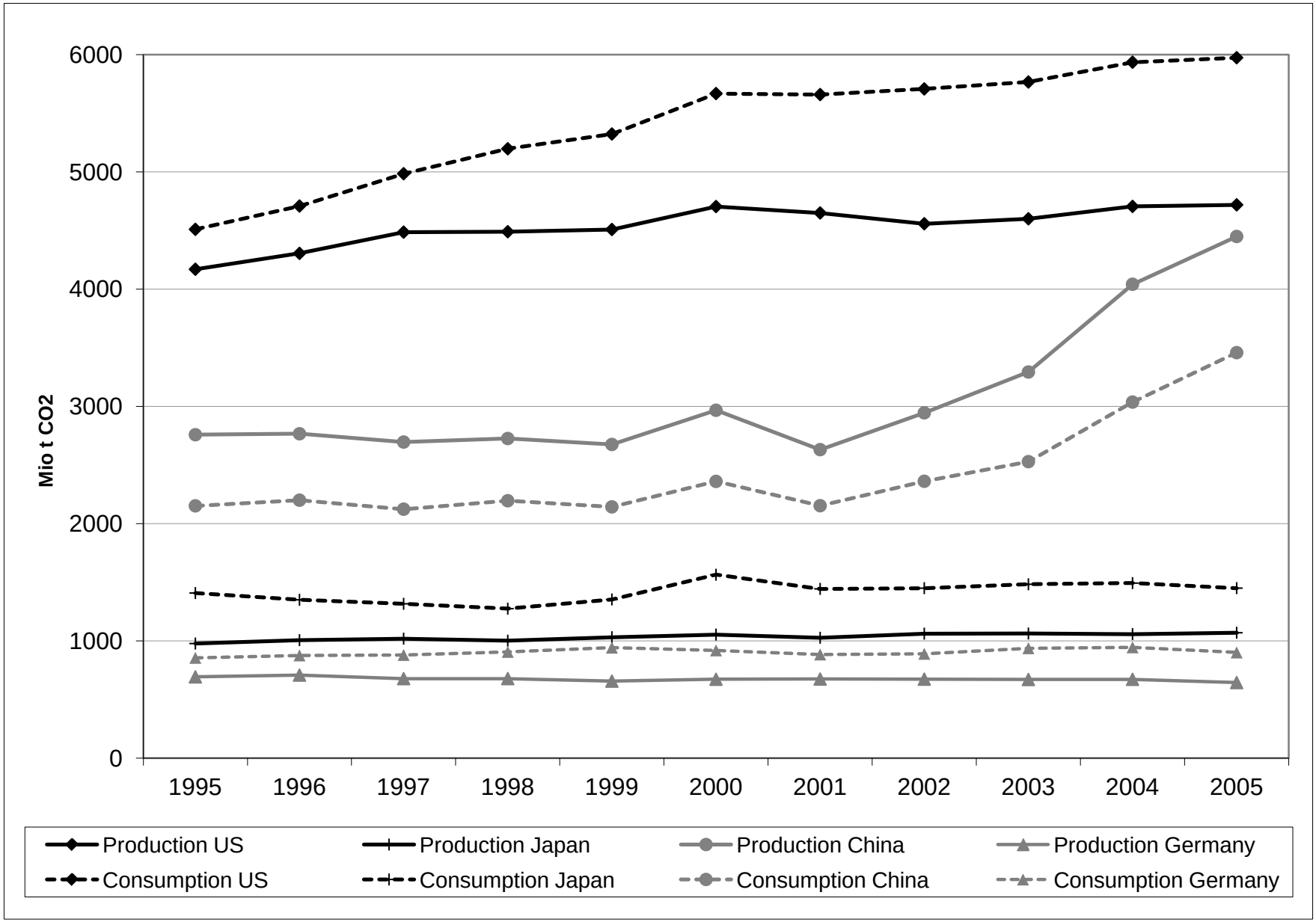




- Deviation of total output (2005)
  - US 0.5%
  - Japan -0.7%
  - Germany 2%

- Highest sectoral deviations
  - 17 Office, accounting & computing machinery
    Greece 2000/2005, Luxembourg 1995/2000
  - 19 Radio, television & communication equipment
    Luxembourg 1995/2000/2005

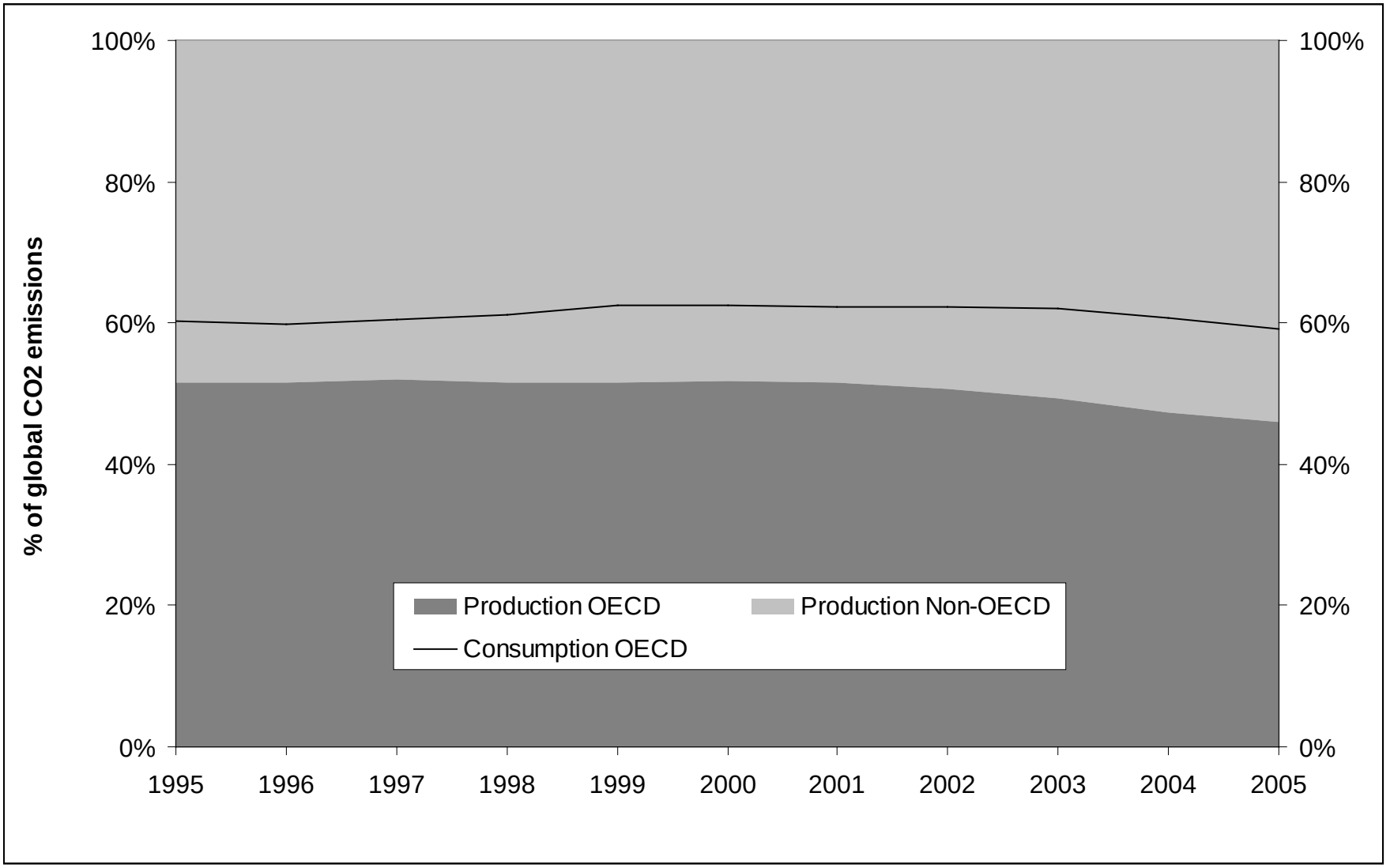
Results: Carbon imports and exports



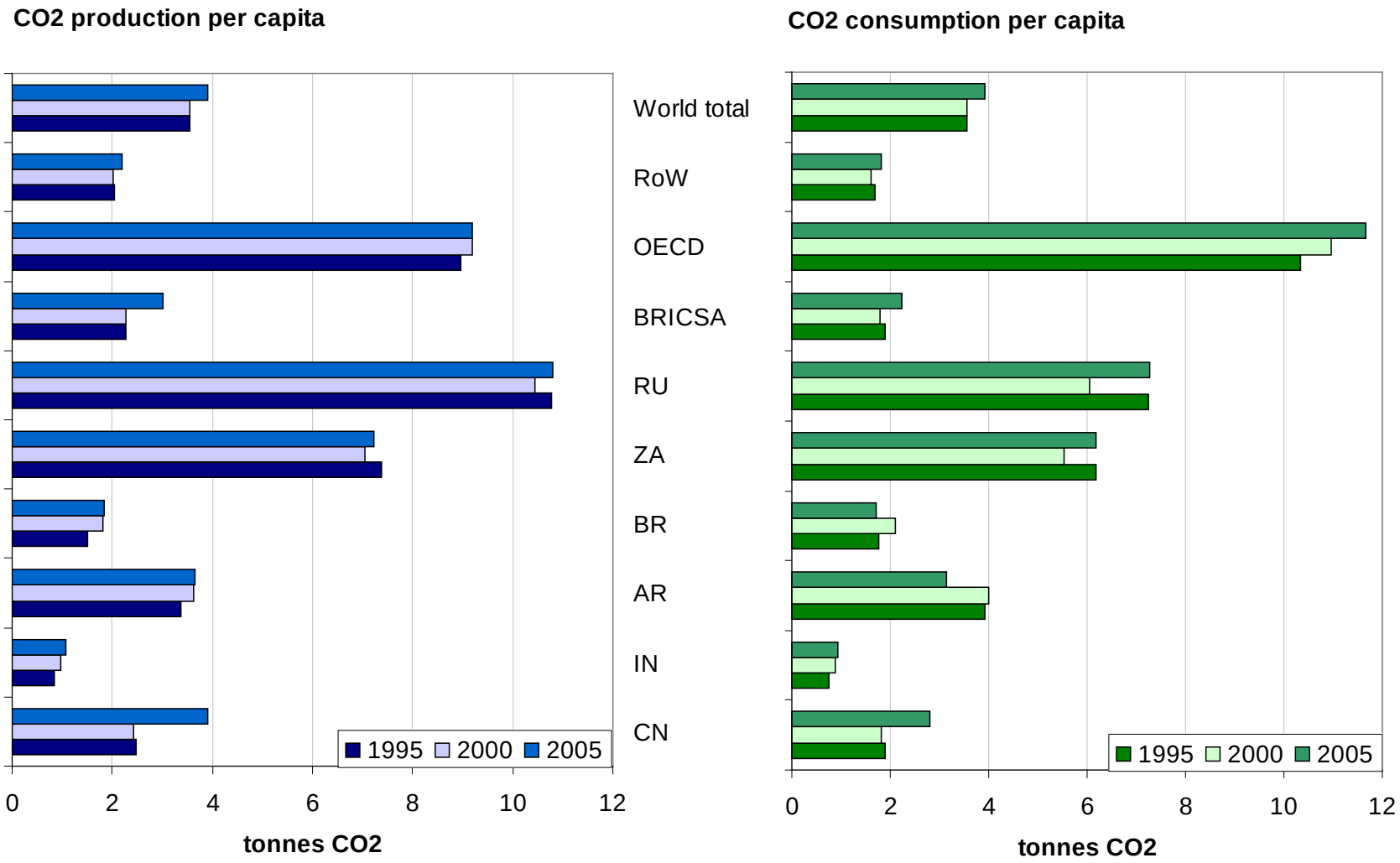
Results: Carbon trade balances

in million t CO2	US	Japan	Germany	France	UK	**OECD**	India	Russia	China	Non-OECD
1995										
Domestic CO2 Production	5266	1191	890	373	546	**9695**	789	1595	2993	**9067**
Domestic CO2 Consumption	5518	1632	1039	497	724	**11322**	703	1072	2285	**7440**
Exports	480	111	179	80	107	**368**	125	615	829	**1995**
Imports	732	552	328	204	284	**1995**	39	92	121	**368**
Imports - Exports	252	440	149	124	178	**1627**	-86	-523	-708	**-1627**
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	**I**	E	E	E	**E**
2000										
Domestic CO2 Production	5837	1229	854	400	561	**10540**	984	1526	3052	**9798**
Domestic CO2 Consumption	6442	1614	1052	577	774	**12709**	890	886	2305	**7629**
Exports	549	166	200	86	129	**446**	174	736	915	**2615**
Imports	1154	551	399	263	342	**2615**	80	96	168	**446**
Imports - Exports	605	385	198	177	212	**2169**	-94	-640	-747	**-2169**
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	**I**	E	E	E	**E**
2005										
Domestic CO2 Production	5916	1269	839	411	575	**10908**	1171	1546	5090	**12811**
Domestic CO2 Consumption	6773	1588	1058	616	786	**14011**	1037	1041	3665	**9708**
Exports	525	214	228	91	141	**519**	245	675	1734	**3622**
Imports	1383	533	447	296	351	**3622**	111	171	309	**519**
Imports - Exports	857	320	219	205	210	**3103**	-134	-504	-1425	**-3103**
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	**I**	E	E	E	**E**

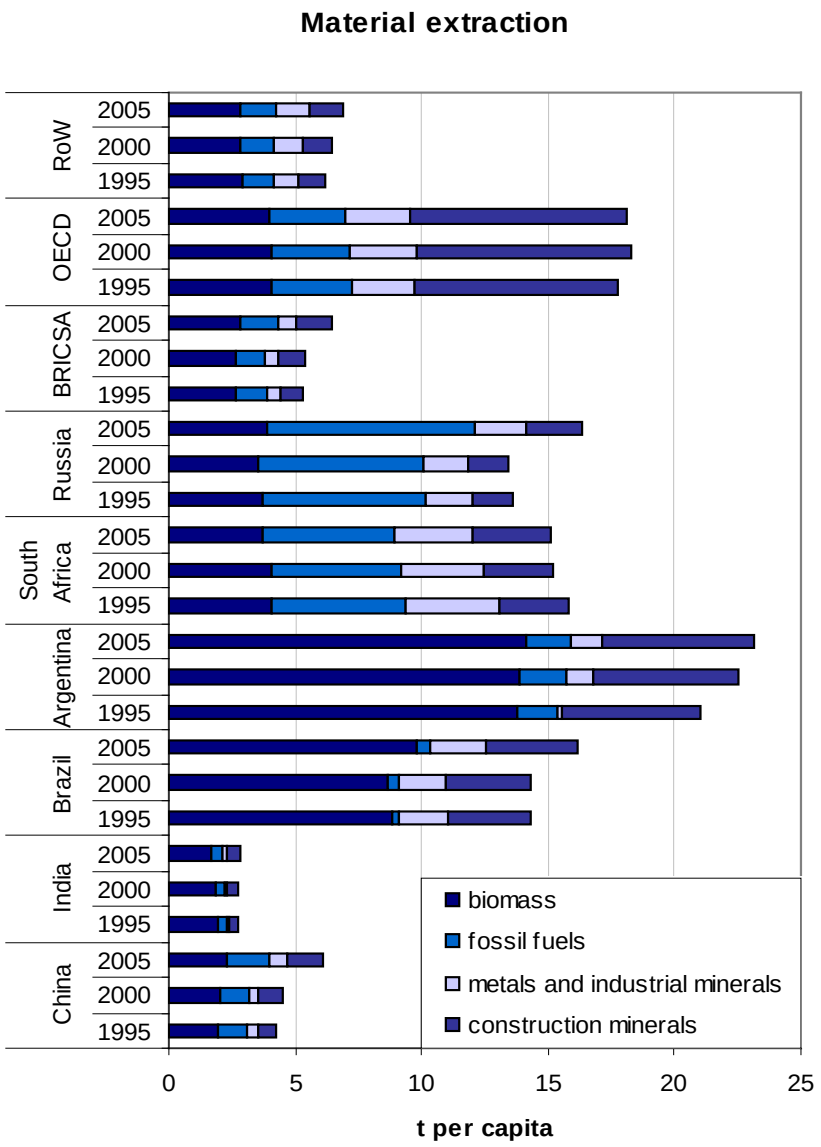
Results: OECD vs Non-OECD

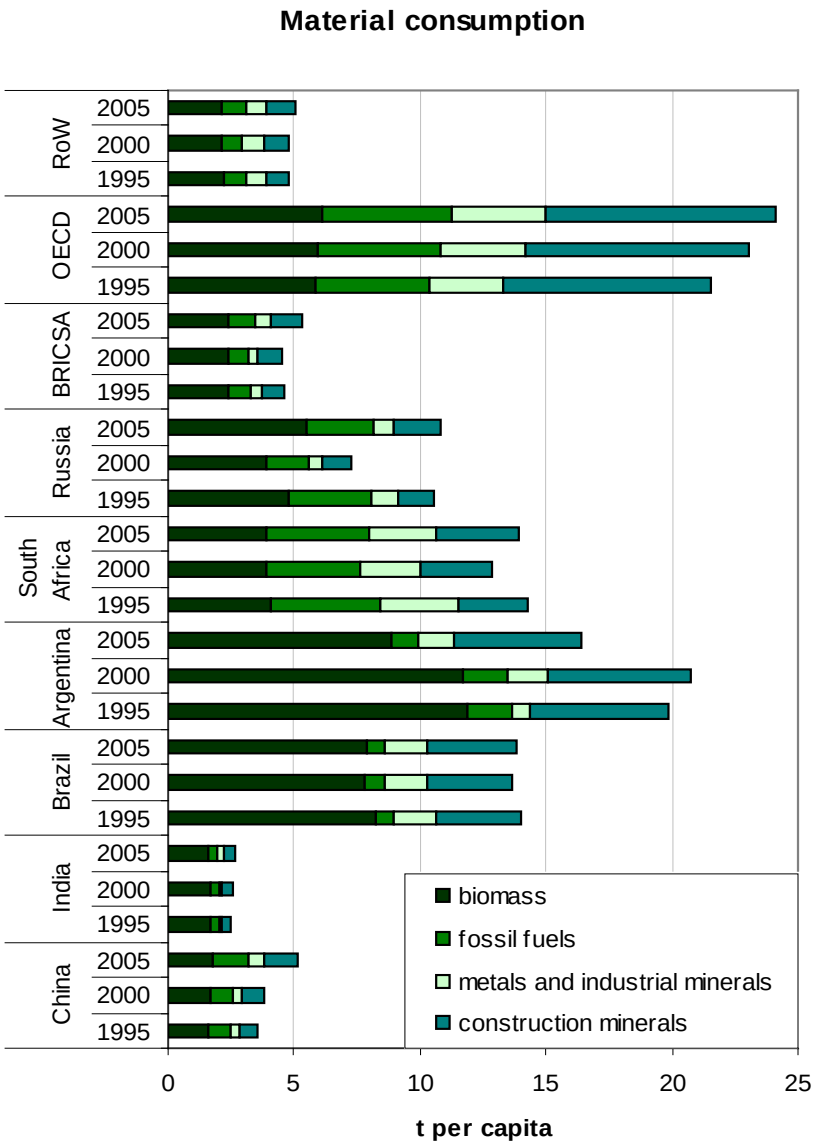


Results: CO2 per capita



Results: Material per capita





Results: CO2 embodied in Austrian trade

Sektor	Importe		Exporte		Handelsbilanz	
	kt CO_2	*Anteil an Gesamt-importen*	*kt CO_2*	*Anteil an Gesamt-exporten*	*kt CO_2*	*Anteil an Gesamt-bilanz*
Elektrizität	23.880	33,1%	4.839	17,6%	19.041	42,6%
Landtransport	7.305	10,1%	3.486	12,7%	3.819	8,6%
Eisen und Stahl	6.724	9,3%	2.326	8,4%	4.397	9,8%
Lufttransport	5.001	6,9%	1.001	3,6%	4.000	9,0%
Koks und Raffinerieprodukte	4.205	5,8%	6.706	24,3%	-2.501	-5,6%
Wassertransport	3.935	5,4%	199	0,7%	3.736	8,4%
Chemikalien (ohne Pharmazeutika)	3.377	4,7%	1.371	5,0%	2.006	4,5%
Verarbeitete Metallprodukte (o. Maschinen)	2.924	4,0%	45	0,2%	2.879	6,4%
Gummi und Plastik	1.991	2,8%	561	2,0%	1.430	3,2%
Land- und Forstwirtschaft	1.216	1,7%	482	1,8%	734	1,6%
Bergbau (Energie)	1.209	1,7%	240	0,9%	968	2,2%
Andere nicht-metallische Produkte	1.095	1,5%	505	1,8%	590	1,3%
Möbel und Recycling	1.072	1,5%	31	0,1%	1.041	2,3%
Pharmazeutika	877	1,2%	514	1,9%	363	0,8%
Textilien	784	1,1%	234	0,8%	550	1,2%
Medizinische Instrumente	761	1,1%	12	0,0%	749	1,7%
Papier	693	1,0%	1.430	5,2%	-737	-1,7%
Nahrungsmittel und Getränke	571	0,8%	410	1,5%	161	0,4%
Bergbau (Metalle und Mineralien)	360	0,5%	777	2,8%	-417	-0,9%
Motorisierte Fahrzeuge	203	0,3%	537	1,9%	-334	-0,7%
Rest	4.032	5,6%	1.845	6,7%	2.187	4,9%
Gesamt	**72.212**	**100,0%**	**27.550**	**100,0%**	**44.662**	**100,0%**

Possibilities and discussion

- Origin and destination of embodied CO_2 emissions/ material rucksacks
  - 1995 – 2005
  - 53 countries & 2 regions
  - 48 sectors
- Possibilities
  - Carbon leakage
  - Resource dependency
  - Structural path analysis
- Future research
  - Use of additional data for final demand
  - Improve export modelling
  - Projections into the future

Thank you!

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Results: Carbon trade

	1995				2005			
Mio t CO2	**OECD**	**BRICSA**	**RoW**	Production	**OECD**	**BRICSA**	**RoW**	Production
OECD	9327	213	155	9695	10389	316	203	10908
BRICSA	1078	4104	290	5472	2323	5448	394	8165
RoW	917	193	2484	3595	1300	239	3108	4646
Consumption	11322	4510	2929		14011	6003	3705	

% of consumption	**OECD**	**BRICSA**	**RoW**	OECD Net-Imports *Mio t CO2*	**OECD**	**BRICSA**	**RoW**	OECD Net-Imports *Mio t CO2*
OECD	82%	5%	5%		74%	5%	5%	
BRICSA	10%	91%	10%	865	17%	91%	11%	2006
RoW	8%	4%	85%	762	9%	4%	84%	1097