

Modeling consumption-based CO₂-emissions and carbon leakage with the Global Resource Accounting Model GRAM

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1 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

2 Multi-regional Input-Output Theory

≤ 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

Austrian domestic production to satisfy domestic demand

Austrian domestic production to satisfy export demand

Imports to satisfy Austrian domestic demand

Domestic IO multiplier matrices

$$\begin{pmatrix} x_{11} & x_{12} & L & x_{1C} \\ x_{21} & x_{22} & L & x_{2C} \\ M & M & O & M \\ x_{C1} & x_{C2} & L & x_{CC} \end{pmatrix} = \begin{pmatrix} I - A_{11} & -A_{12} & L & -A_{1C} \\ -A_{21} & I - A_{22} & L & -A_{2C} \\ M & M & O & M \\ -A_{C1} & -A_{C2} & L & I - A_{CC} \end{pmatrix}^{-1} \begin{pmatrix} y_{11} & y_{12} & L & y_{1C} \\ y_{21} & y_{22} & L & y_{2C} \\ M & M & O & M \\ y_{C1} & y_{C2} & L & y_{CC} \end{pmatrix}$$

Imported IO multiplier matrices by exporting country

Domestic FD matrices in USD

Imported FD matrices in USD by exporting country

3 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)
CO₂ emissions associated with Austrian production to satisfy Austrian demand	$\begin{pmatrix} p_{11} & p_{12} & L & p_{1C} \\ p_{21} & p_{22} & L & p_{2C} \\ M & M & O & M \\ p_{C1} & p_{C2} & L & p_{CC} \end{pmatrix}$	$= \begin{pmatrix} E_1 & 0 & L & 0 \\ 0 & E_2 & L & 0 \\ M & M & O & M \\ 0 & 0 & L & E_C \end{pmatrix}$	$\begin{pmatrix} I - A_{11} & -A_{12} & L & -A_{1C} \\ -A_{21} & I - A_{22} & L & -A_{2C} \\ M & M & O & M \\ -A_{C1} & -A_{C2} & L & I - A_{CC} \end{pmatrix}^{-1}$	$\begin{pmatrix} y_{11} & y_{12} & L & y_{1C} \\ y_{21} & y_{22} & L & y_{2C} \\ M & M & O & M \\ y_{C1} & y_{C2} & L & y_{CC} \end{pmatrix}$

CO₂ emissions on Austrians exports

CO₂ intensity coefficients

CO₂ emissions on Austrian imports

4 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 CO₂ emission data
1995 - 2005
6 sectors

4 Data: Problems

Data problems

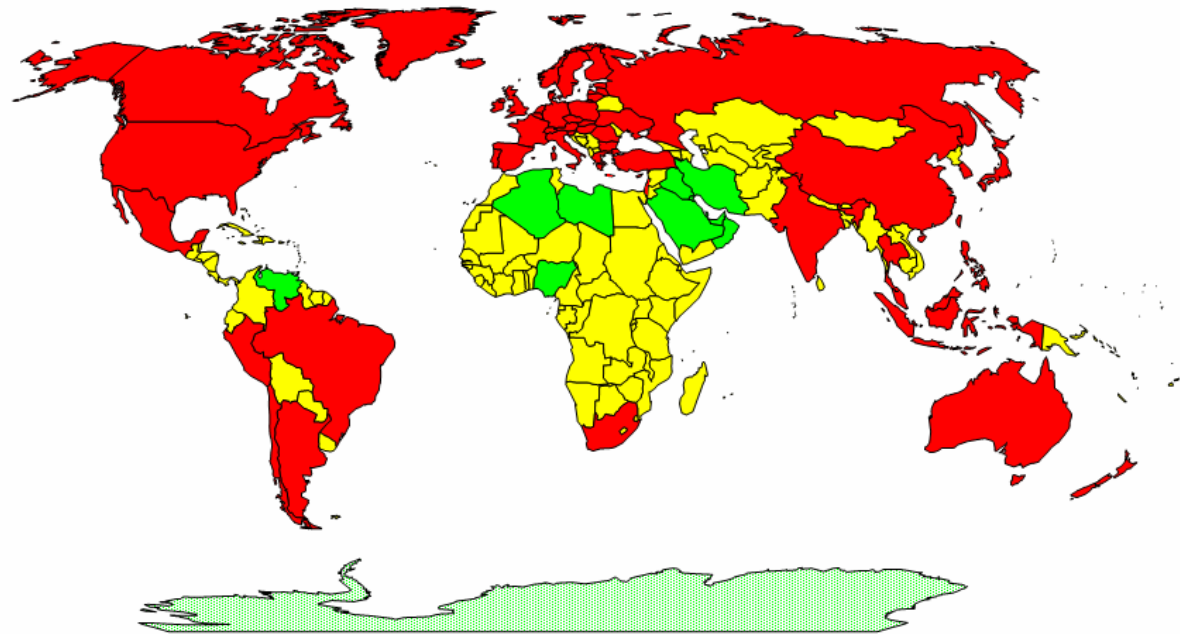
- ≤ Input-output tables (IOT)
 - available for at most three years
 - not available for all countries
- ≤ Bilateral trade data (BTD)
 - missing years for some countries, esp. before 1998
 - substantial gaps in service trade matrix
- ≤ Emission data
 - not available in IOT or BTD classification

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

4 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



country models

OPEC ex. Indonesia

RoW

5 Application

55 exporting countries

55 importing countries

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

OECD IOT data

OECD IOT data and OECD BTD data

IEA emissions data ‡ IEA EB structure ‡ OECD IOT structure

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

(55×55) (55×2640)

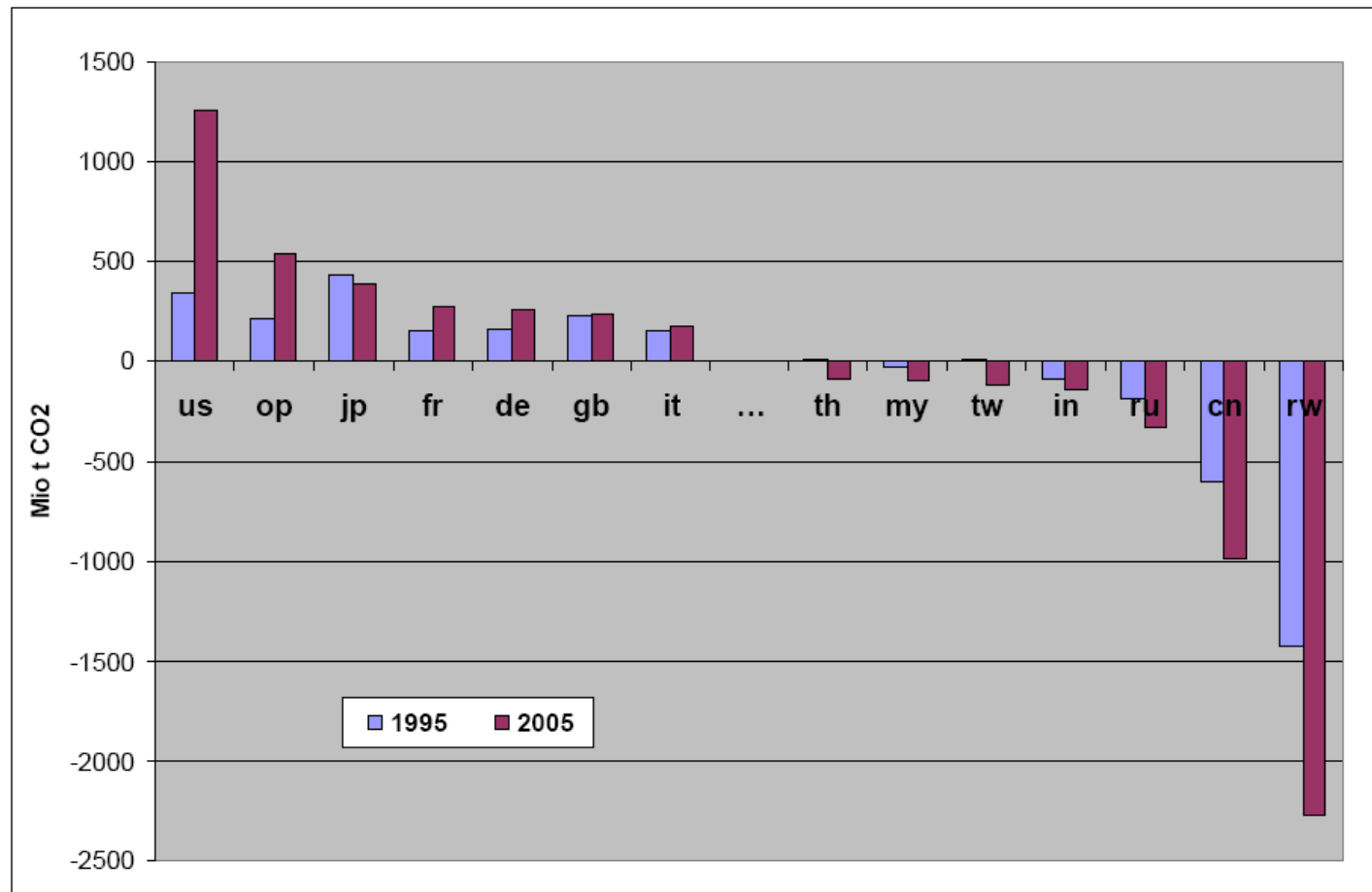
$\leq$ 2 possible handlings of e_i

E_i 's are diagonal matrices $\Rightarrow p_{ij}$'s are column vectors

E_i 's are row vectors $\Rightarrow p_{ij}$'s are scalars

6 Results

Largest CO₂ net importers and net exporters



6 Results

Carbon trade balances

<i>in mio t CO2</i>	US	Japan	France	Germany	UK	OECD	India	Russia	China	Non-OECD
1995										
Domestic Production & Consumption	3709	871	181	518	309	9009	588	680	2032	7511
Exports	460	107	78	176	102	292	131	221	727	2281
Imports	801	537	234	338	325	2281	42	35	120	292
Domestic Production	4170	978	258	694	411	9301	718	901	2759	9792
Domestic Consumption	4510	1409	415	856	633	11290	630	715	2152	7803
Imports - Exports	340	431	157	162	222	1989	-88	-186	-607	-1989
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	I	E	E	E	E
2005										
Domestic Production & Consumption	4295	859	183	414	329	10229	886	669	3092	10428.9
Exports	423	211	86	232	157	434	277	460	1357	3987
Imports	1678	592	361	488	389	3987	142	130	366	434
Domestic Production	4719	1070	269	645	486	10663	1163	1129	4449	14416
Domestic Consumption	5973	1450	544	902	718	14216	1028	799	3459	10863
Imports - Exports	1255	380	275	257	232	3553	-136	-330	-990	-3553
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	I	E	E	E	E

6 Results

Carbon trade between OECD, BRICSA and the rest of the world (RoW)

1995

<i>Mio t CO2</i>	OECD	BRICSA	RoW	Production
OECD	9009	154	138	9301
BRICSA	882	3930	239	5051
RoW	1399	164	3178	4741
Consumption	11290	4248	3555	

<i>% of consumption</i>	OECD	BRICSA	RoW	OECD Net-Imports <i>Mio t CO2</i>
OECD	80%	4%	4%	
BRICSA	8%	93%	7%	728
RoW	12%	4%	89%	1261

2005

<i>Mio t CO2</i>	OECD	BRICSA	RoW	Production
OECD	10229	251	183	10663
BRICSA	1906	5591	304	7800
RoW	2081	540	4204	6826
Consumption	14216	6381	4692	

<i>% of consumption</i>	OECD	BRICSA	RoW	OECD Net-Imports <i>Mio t CO2</i>
OECD	72%	4%	4%	
BRICSA	13%	88%	6%	1655
RoW	15%	8%	90%	1898

7 Possibilities and Discussion

- ≤ Origin and destination of embodied CO₂ emissions/material rucksacks
 - ø 1995 – 2005
 - ø 53 countries and 2 regions
 - ø 48 economic sectors
- ≤ Carbon leakage results
- ≤ Structural path analysis
- ≤ Resource dependency: 4/8 raw material categories

Thank you!



For more information please visit

www.gws-os.com ‡ GWS-Modelle ‡ GRAM

www.seri.at ‡ Ongoing projects ‡ GRAM CO2



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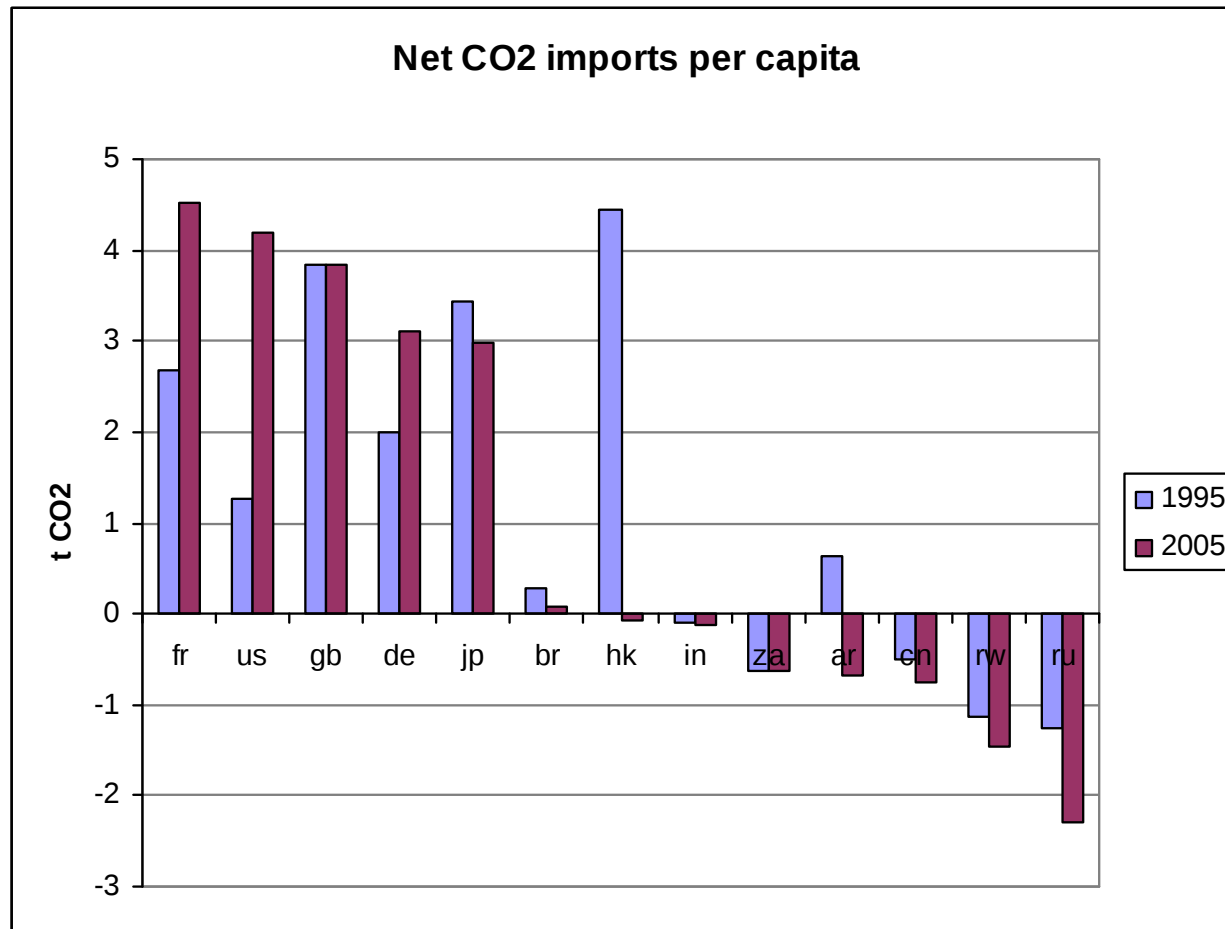
5 Application: Final demand data

≤ Final demand vector: domestic vs import

c1Total intermediate	c2 HHFC	c3 NPISH	c4 GGFC	c5 GFCF	c6 Changes in Inventories	c7 Valuables	c8 Exports	c9 Imports	c10 Discrepancy
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≤ Imported exports / transit exports

6 Results



6 Results

More carbon trade balances

in mio t CO2	US	Japan	France	Germany	UK	Italy	OECD	Thailand	Malaysia	Taiwan	India	Russia	China	Non-OECD
1995														
Domestic Production & Consumption	3709	871	181	518	309	231	9009	82	44	85	588	680	2032	7511
Exports	460	107	78	176	102	70	292	39	51	65	131	221	727	2281
Imports	801	537	234	338	325	223	2281	49	23	75	42	35	120	292
Domestic Production	4170	978	258	694	411	301	9301	121	95	150	718	901	2759	9792
Domestic Consumption	4510	1409	415	856	633	453	11290	131	67	160	630	715	2152	7803
Residential	357	65	52	127	76	53	1015	4	3	4	52	147	296	818
Private Road	315	56	29	40	27	26	645	11	5	7	25	24	24	275
Total Domestic CO2 Production	4841	1099	340	861	514	379	12951	136	104	161	795	1071	3079	8896
Total Domestic CO2 Consumption	5181	1530	496	1023	737	532	24886	145	75	171	707	885	2473	16974
Imports - Exports	340	431	157	162	222	153	1989	10	-28	10	-88	-186	-607	-1989
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	I	I	I	E	I	E	E	E	E
2005														
Domestic Production & Consumption	4295	859	183	414	329	251	10229	128	85	136	886	669	3092	10428.9
Exports	423	211	86	232	157	88	434	136	129	180	277	460	1357	3987
Imports	1678	592	361	488	389	268	3987	43	27	67	142	130	366	434
Domestic Production	4719	1070	269	645	486	340	10663	264	214	316	1163	1129	4449	14416
Domestic Consumption	5973	1450	544	902	718	520	14216	171	113	203	1028	799	3459	10863
Residential	347	67	65	122	80	61	1034	5	2	5	71	118	243	847
Private Road	381	56	31	37	29	29	764	14	10	9	23	28	56	391
Total Domestic CO2 Production	5447	1193	366	805	596	430	16014	283	226	330	1256	1274	4748	12101
Total Domestic CO2 Consumption	6702	1573	641	1061	827	610	30994	190	124	217	1121	945	3757	23355
Imports - Exports	1255	380	275	257	232	180	3553	-93	-102	-113	-136	-330	-990	-3553
Net-importer (I) / Net-exporter (E)	I	I	I	I	I	I	I	E	E	E	E	E	E	E