Are We Moving Toward An Energy-Efficient Low-Carbon Economy?
An Input-Output LMDI Decomposition of CO2 Emissions for Spain and The EU28

Darío Serrano-Puente (2020)

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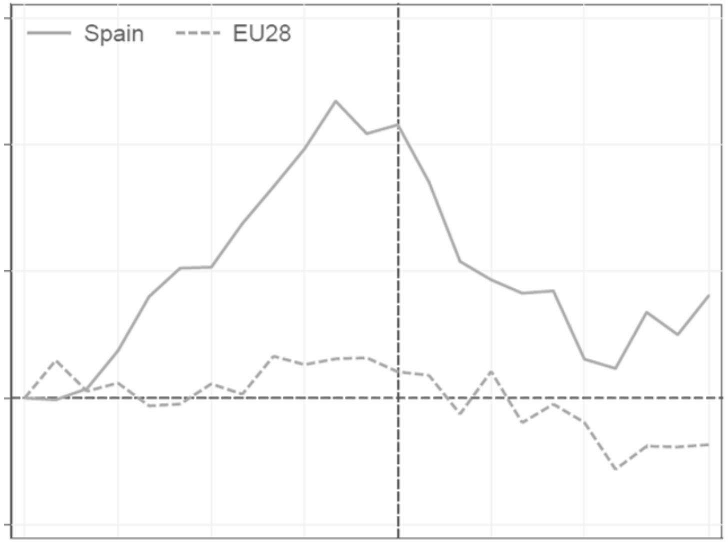

February 11th, 2021

Banco de España
DG of Economics, Statistics and Research

Research Question

- ☐ Are Spain and the EU28 moving toward an **energy-efficient low-carbon economy**?

- ☐ What are **main factors driving the evolution of the energy-related CO2 emissions**?

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- ❑ EEA (2015) → **>80% of total GHG emissions due to energy** (production and consumption)
- ❑ Eurostat (2020a) → **>95% of energy-related GHG emissions due to CO2**
- ❑ OWiD (2020) → **EU28 accounts for 10% of global energy-related CO2 emissions** (China, 29%; US, 15%; Rest of Asia and Pacific Ocean, 14%)
- ❑ Clear relationship between **energy consumption**, **share of low-carbon energy sources**, **energy efficiency**, and **GHG emissions**
  - UN (2015) → “*doubling the global rate of improvement in energy efficiency*“ or “*increasing substantially the share of renewable energy in the global energy-mix*"

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Energy and Climate Targets - EU28 and Spain

Target	EU28		Spain	
	2020	2030	2020	2030
Reduction in emissions (with respect to 1990 levels)	20%	40%	10%(*)	38% (**)
Energy efficiency improvement Reduction in primary energy consumption (with respect to 1990 levels)	20%	32,5%	20%	39,5%
Share of renewables in final energy-mix	20%	32%	20%	42%

- ☐ European Comission (2019) → **Climate neutrality by 2050** (reduction in emissions by 85-90% with respect to 1990 levels

(*) With respect to 2005 levels

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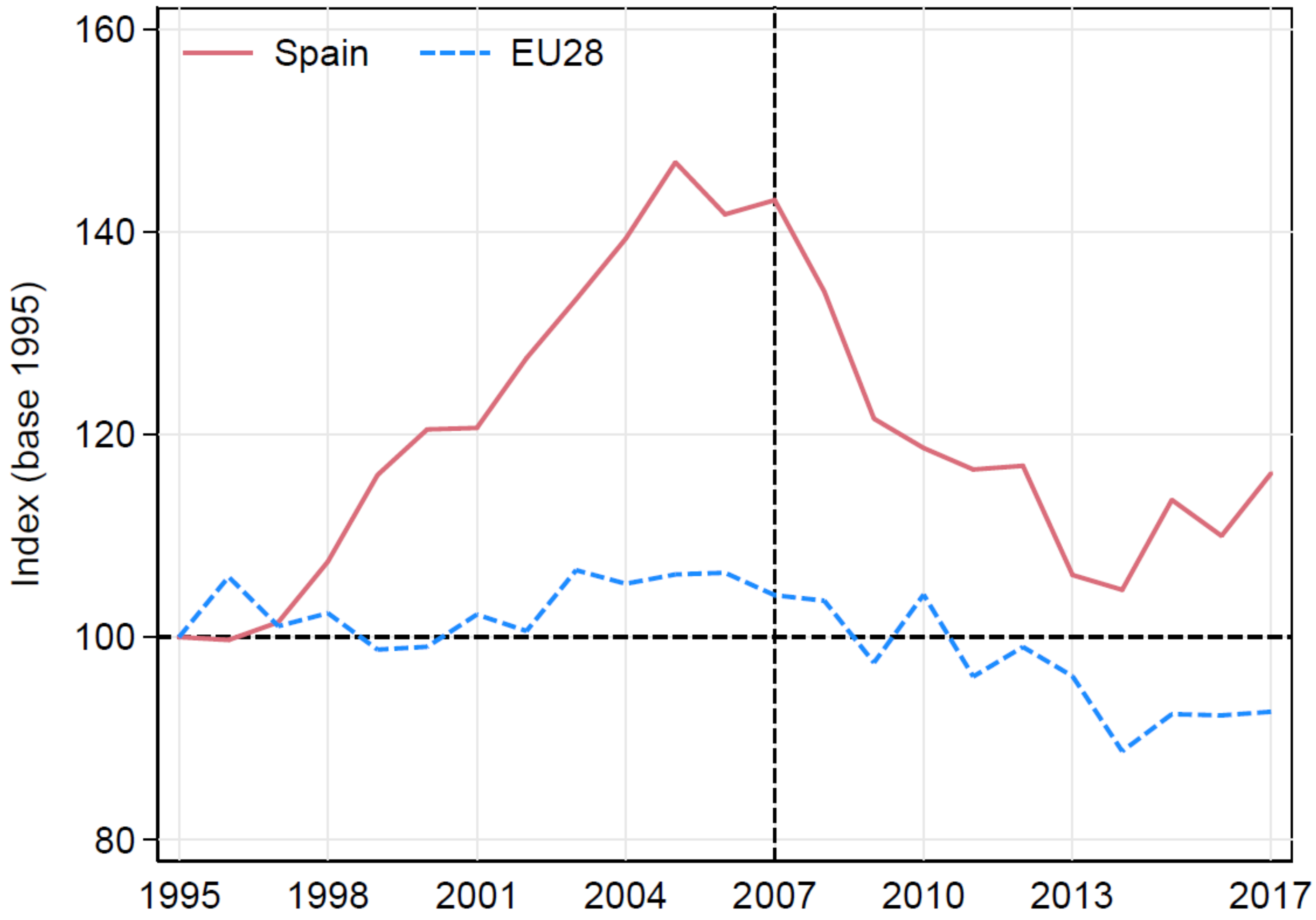
Energy-Related CO2 Emissions



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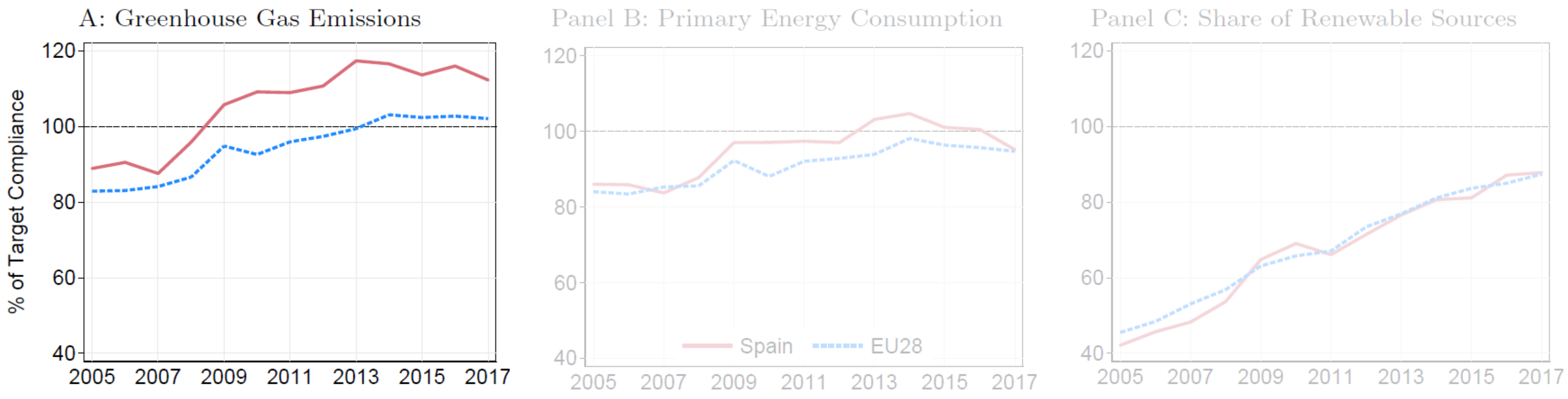

Note: Levels above 100 indicate target compliance.

- **Low-carbon energy** sources & **energy efficiency** → major areas to **effectively control emissions without hindering economic activity**
    - Drop in energy costs, in energy use, and in negative impacts like CO2 emissions.
- **Not all the increase in energy efficiency is translated into energy savings** → rebound effects, infra-utilization of equipment
- Also **other contributors to emissions** → economic activity, economic structure, efficiency of conversion sector, demography, lifestyle, weather, etc.

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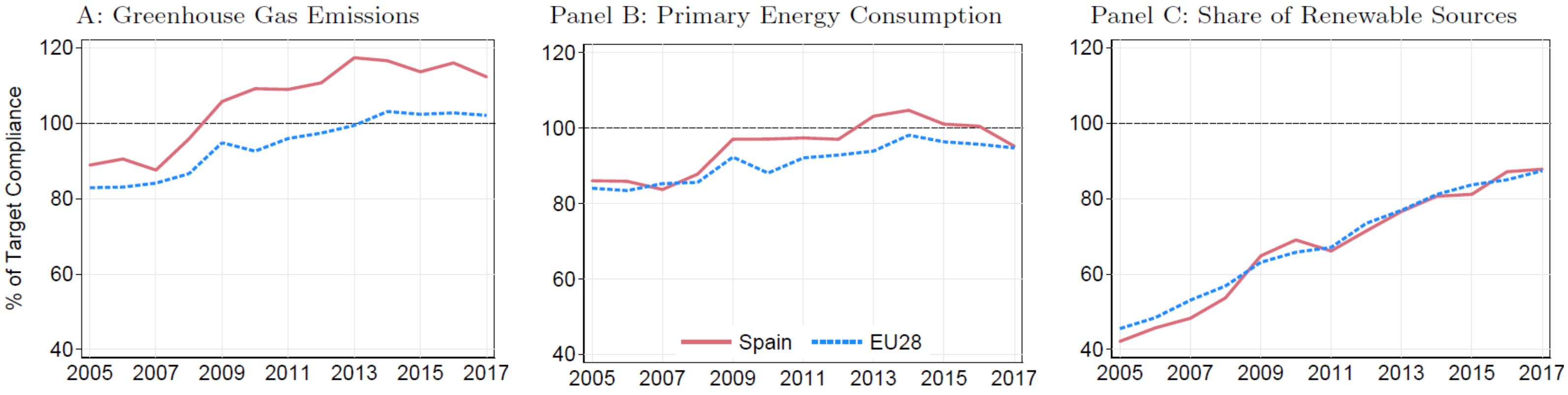

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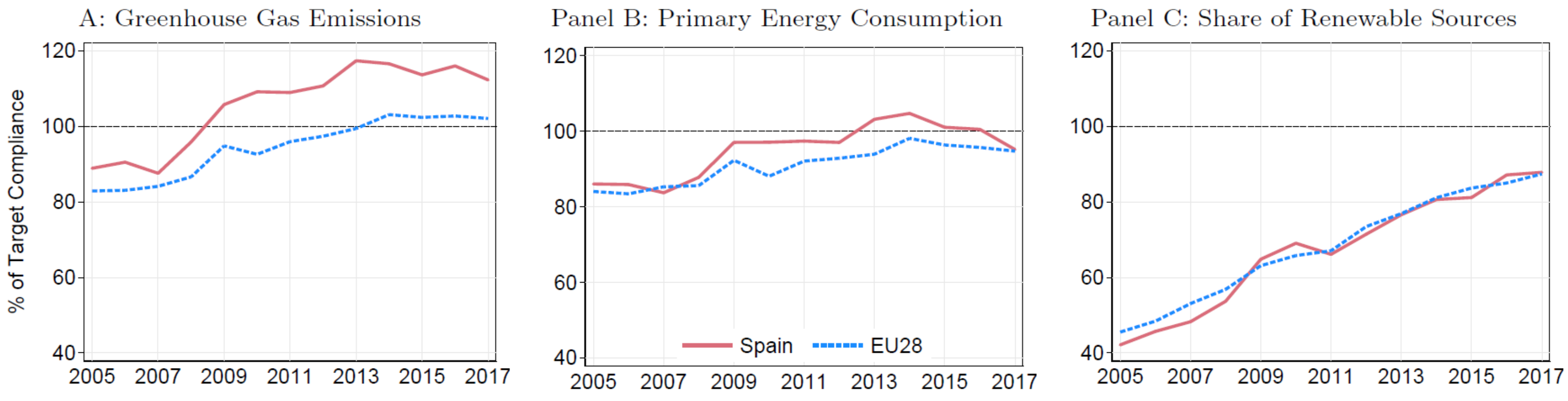

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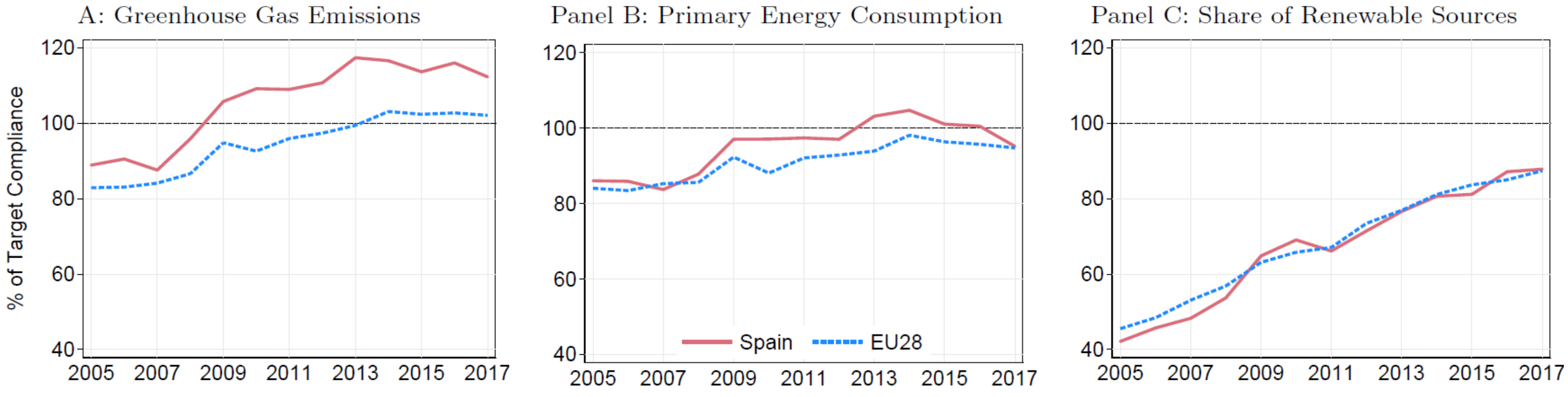

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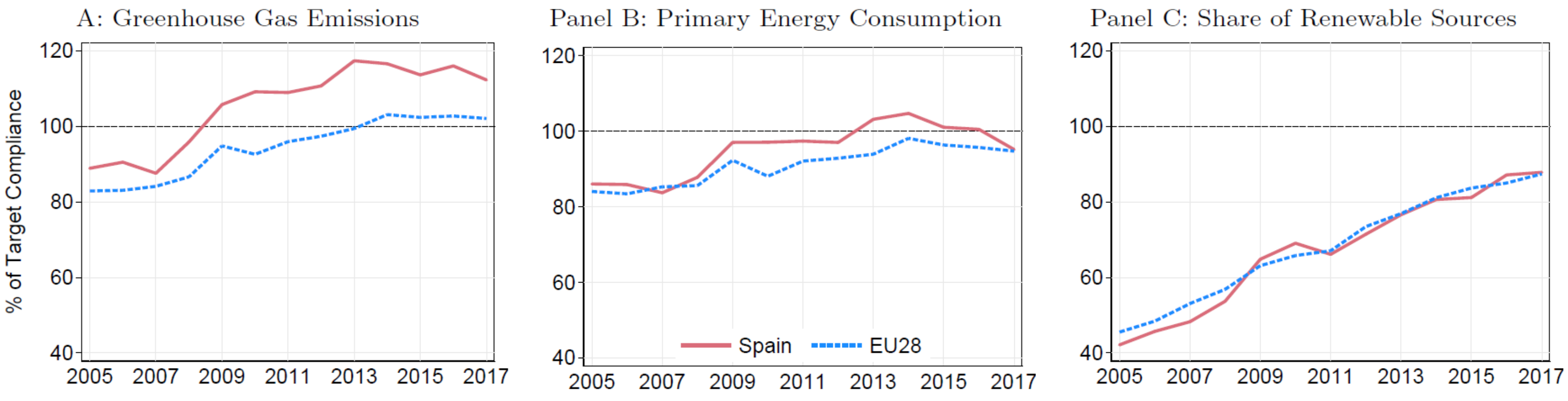

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- ☐ Use **very disaggregated data** from 1995 to 2017 for Spain and the EU28
- ☐ **Integrated analytical method** → study driving forces behind evolution of energy-related **CO2 emissions**, energy **consumption** & energy **efficiency**
- ☐ Through **input-output Structural Decomposition Analysis** (SDA)
  - **Efficiency of the energy conversion sector** → Leontief coefficients
  - **Primary energy consumption allocation diagram** for assigning the responsibility of primary energy requirements and CO2 emissions to the end-use sectors → primary energy conversion factor
  - **Renewable sources in the energy-mix** → carbon conversion factor
- ☐ Through **Index Decomposition Analysis** (IDA)
  - Contributions of **many potential influencing factors**
  - **Reconciliation between energy intensity and energy efficiency** metrics to study observed end-use energy efficiency
  - **Distinction between technical and observed end-use energy efficiency** → potential rebound effects and other factors

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Main Findings

- 1995-2007 → Spain ▲ 43% & EU28 ▲ 4%
  - **Population growth**, rising **per capita income**, and **social factors** → **contributors** to increase in emissions in Spain and EU28
  - But **very positive evolution of observed end-use energy efficiency in EU28**, and **very negative in Spain**.
  - **Transport** and **services** sectors → main **contributors** to increase in emissions in Spain and EU28. **HHs** and **industry** → **inhibitor in EU28**, but **contributor in Spain**.
- 2007-2017 → **Spain is on a path toward the decarbonization** of the economy, with **more accentuated trend**, Spain ▼ 19% & EU28 ▼ 11%
  - In **EU28** mainly by **efficiency of conversion** and **observed end-use energy efficiency**, **structural changes** toward less emission-generating sectors, **lower use of fossil fuels** in energy transformation.
  - **Same in Spain (+ social factors)**, but **no improvement in observed end-use energy efficiency at all**. Evolution of emissions in Spain is burdened by observed end-use energy efficiency → **Infra-utilization** (installation of end-use energy equipment above its potential)
  - **HHs** and **industry** → clear **inhibitors in Spain and EU28**. **Transport** → contribute to **fall in emissions**, **more in Spain** than in EU28.

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Methodology

Primary Energy & Carbon Conversion Factor - SDA

I. Energy Input-Output Table

Learn more…

- Find K_{PEQ} → **Total number of units of primary energy that must be consumed to produce one unit of final energy**
- Data → *Complete Energy Balances*, Eurostat (2020) Learn more…
  - 11 energy groups, 63 energy products (primary and secondary) Learn more…
- **Connection between final energy consumption** (sector by sector) **and primary energy consumption** (from extraction and imports) by using the Leontief inverse matrix → **Transformation or conversion sector** Learn more…

	1	2	3	$\dots$	j	$\dots$	63	$63+1$	$63+2$	$63+3$	$\dots$	$63+N_s$	Y	Q
1	$Q_{1,1}$	$Q_{1,2}$	$Q_{1,3}$	$\dots$	$Q_{1,j}$	$\dots$	$Q_{1,63}$	0	0	0	$\dots$	0	Y_1	Q_1
2	$Q_{2,1}$	$Q_{2,2}$	$Q_{2,3}$	$\dots$	$Q_{2,j}$	$\dots$	$Q_{2,63}$	0	0	0	$\dots$	0	Y_2	Q_2
3	$Q_{3,1}$	$Q_{3,2}$	$Q_{3,3}$	$\dots$	$Q_{3,j}$	$\dots$	$Q_{3,63}$	0	0	0	$\dots$	0	Y_3	Q_3
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
i	$Q_{i,1}$	$Q_{i,2}$	$Q_{i,3}$	$\dots$	$Q_{i,j}$	$\dots$	$Q_{i,63}$	0	0	0	$\dots$	0	Y_i	Q_i
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
63	$Q_{63,1}$	$Q_{63,2}$	$Q_{63,3}$	$\dots$	$Q_{63,j}$	$\dots$	$Q_{63,63}$	0	0	0	$\dots$	0	Y_{63}	Q_{63}
$63+1$	$Q_{63+1,1}$	$Q_{63+1,2}$	$Q_{63+1,3}$	$\dots$	$Q_{63+1,j}$	$\dots$	$Q_{63+1,63}$	0	0	0	$\dots$	0	0	Q_{63+1}
$63+2$	$Q_{63+2,1}$	$Q_{63+2,2}$	$Q_{63+2,3}$	$\dots$	$Q_{63+2,j}$	$\dots$	$Q_{63+2,63}$	0	0	0	$\dots$	0	0	Q_{63+2}
$63+3$	$Q_{63+3,1}$	$Q_{63+3,2}$	$Q_{63+3,3}$	$\dots$	$Q_{63+3,j}$	$\dots$	$Q_{63+3,63}$	0	0	0	$\dots$	0	0	Q_{63+3}
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
$63+N_s$	$Q_{63+N_s,1}$	$Q_{63+N_s,2}$	$Q_{63+N_s,3}$	$\dots$	$Q_{63+N_s,j}$	$\dots$	$Q_{63+N_s,63}$	0	0	0	$\dots$	0	0	Q_{63+N_s}

Primary Energy & Carbon Conversion Factor

II. Estimation of Energy-Related CO2 Emissions

- ☐ Find $\boldsymbol{K_{C,PEQ}}$ → **Total number of units of CO2 that are emitted when one unit of energy expressed in primary energy form is consumed**
- ☐ Data → *CO2 Emission Factors by Energy Source*, IPCC (2006)
- ☐ $\boldsymbol{K_{C,FEQ}}$ → **Total number of units of CO2 that are emitted when one unit of energy expressed in final energy form** (rather than in primary energy form) **is consumed** → $K_{C,FEQ} = K_{C,PEQ} \cdot K_{PEQ}$ Learn more…

Structural Decomposition of Energy-Related CO2 Emissions

$$C = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,FEQ,j}$$

C → total energy-related CO2 emissions

E_{FEQ} → the final energy consumption

j → energy product, $j \in \{1,2,3,\dots,63\}$

Primary Energy & Carbon Conversion Factor

II. Estimation of Energy-Related CO2 Emissions

- ☐ Find $\boldsymbol{K_{C,PEQ}}$ → **Total number of units of CO2 that are emitted when one unit of energy expressed in primary energy form is consumed**
- ☐ Data → *CO2 Emission Factors by Energy Source*, IPCC (2006)
- ☐ $\boldsymbol{K_{C,FEQ}}$ → **Total number of units of CO2 that are emitted when one unit of energy expressed in final energy form** (rather than in primary energy form) **is consumed** → $K_{C,FEQ} = K_{C,PEQ} \cdot K_{PEQ}$

Structural Decomposition of Energy-Related CO2 Emissions

$$C = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,FEQ,j}$$

C → total energy-related CO2 emissions

E_{FEQ} → the final energy consumption

j → energy product, $j \in \{1,2,3,\dots,63\}$

LMDI Decomposition – SDA + IDA

General

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{j=1}^{63} E_{FEQ,j} \cdot K_{C,FEQ,j}$$

- ❑ Energy-Related CO2 can be calculated **as a summation over sectors**

LMDI Decomposition – SDA + IDA

General

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{SERV} + C_{HH} + C_{TRNS} = \sum_{s} C_{TOT}$$

- ☐ Energy-Related CO2 can be calculated **as a summation over sectors**

LMDI Decomposition – SDA + IDA

General

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

- ❑ Energy-Related CO2 can be calculated **as a summation over sectors**

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m}\sum_{j=1}^{63} \boldsymbol{P} \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

☐ Population

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{\boldsymbol{VA}}{\boldsymbol{P}} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

☐ Income per capita

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{\boldsymbol{VA_{AGRI}}}{\boldsymbol{VA}} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

☐ Structural

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \boldsymbol{\frac{VA_{AGRI,m}}{VA_{AGRI}}} \cdot \frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

- ☐ Intra-Structural

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \boldsymbol{\frac{E_{FEQ,m,AGRI}}{VA_{AGRI,m}}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ End-Use Energy Intensity

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \boldsymbol{\frac{D_{m,AGRI}}{VA_{AGRI,m}}} \cdot \boldsymbol{\frac{E_{FEQ,m,AGRI}}{D_{m,AGRI}}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

- End-Use Energy Intensity
  - Physical to Monetary Output Relation
  - Observed End-Use Energy Efficiency

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{D_{m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI}}{D_{m,AGRI}} \cdot \boldsymbol{\frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ Final Energy-Mix

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{D_{m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI}}{D_{m,AGRI}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot \boldsymbol{K_{C,PEQ,j}} \cdot K_{PEQ,j}$$

☐ Primary Energy-Mix

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = \boldsymbol{C_{AGRI}} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Agriculture

$$C_{AGRI} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{AGRI}}{VA} \cdot \frac{VA_{AGRI,m}}{VA_{AGRI}} \cdot \frac{D_{m,AGRI}}{VA_{AGRI,m}} \cdot \frac{E_{FEQ,m,AGRI}}{D_{m,AGRI}} \cdot \frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}} \cdot K_{C,PEQ,j} \cdot \boldsymbol{K_{PEQ,j}}$$

☐ Efficiency of the Conversion Sector

LMDI Decomposition – SDA + IDA

I. Agriculture

Energy-Related CO2 Emissions

$$C_{TOT}=\sum_{s}\sum_{j=1}^{63}E_{FEQ,s,j}\cdot K_{C,PEQ,j}\cdot K_{PEQ,j}=\sum_{s}\sum_{j=1}^{63}E_{FEQ,s,j}\cdot K_{C,FEQ,j}$$

$$C_{TOT}=\boldsymbol{C_{AGRI}}+C_{IND}+C_{CPS}+C_{HH}+C_{TRA}=\sum_{s}C_{s}$$

Agriculture

$$C_{AGRI}=\sum_{m}\sum_{j=1}^{63}P\cdot\frac{VA}{P}\cdot\frac{VA_{AGRI}}{VA}\cdot\frac{VA_{AGRI,m}}{VA_{AGRI}}\cdot\frac{D_{m,AGRI}}{VA_{AGRI,m}}\cdot\frac{E_{FEQ,m,AGRI}}{D_{m,AGRI}}\cdot\frac{E_{FEQ,m,AGRI,j}}{E_{FEQ,m,AGRI}}\cdot K_{C,PEQ,j}\cdot K_{PEQ,j}$$

☐ Sub-Sectors

Agriculture & Forestry

Fishing

LMDI Decomposition – SDA + IDA

II. Industry

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + \boldsymbol{C_{IND}} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Industry

$$C_{IND} = \sum_{m} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{IND}}{VA} \cdot \frac{VA_{IND,m}}{VA_{IND}} \cdot \frac{D_{m,IND}}{VA_{IND,m}} \cdot \frac{E_{FEQ,m,IND}}{D_{m,IND}} \cdot \frac{E_{FEQ,m,IND,j}}{E_{FEQ,m,IND}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ Sub-Sectors

- Energy & Extractive
- Food & Tobacco
- Textile & Leather
- Wood
- Paper, Pulp & Print
- Chemical & Petrochem.
- Non-Metallic Minerals
- Basic Metals
- Machinery
- Transport Equipment
- Other
- Construction

LMDI Decomposition – SDA + IDA

III. Commercial and Public Services

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + \boldsymbol{C_{CPS}} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Commercial and Public Services

$$C_{CPS} = \sum_{\boldsymbol{u}} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{CPS}}{VA} \cdot \frac{D_{CPS}}{VA_{CPS}} \cdot \frac{E_{FEQ,CPS}}{D_{CPS}} \cdot \frac{\boldsymbol{E_{FEQ,u,CPS}}}{\boldsymbol{E_{FEQ,CPS}}} \cdot \boldsymbol{W_{u=\{SH,AC\}}} \cdot \frac{E_{FEQ,\boldsymbol{u},CPS,j}}{E_{FEQ,\boldsymbol{u},CPS}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

☐ Uses & Weather

Learn more…

LMDI Decomposition – SDA + IDA

III. Commercial and Public Services

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + \boldsymbol{C_{CPS}} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

Commercial and Public Services

$$C_{CPS} = \sum_{\boldsymbol{u}} \sum_{j=1}^{63} P \cdot \frac{VA}{P} \cdot \frac{VA_{CPS}}{VA} \cdot \frac{D_{CPS}}{VA_{CPS}} \cdot \frac{E_{FEQ,CPS}}{D_{CPS}} \cdot \frac{E_{FEQ,u,CPS}}{E_{FEQ,CPS}} \cdot W_{u=\{SH,AC\}} \cdot \frac{E_{FEQ,\boldsymbol{u},CPS,j}}{E_{FEQ,\boldsymbol{u},CPS}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ Uses

- Space Heating
- Hot Water
- Cooking
- Air Conditioning
- Electrics & Lighting

LMDI Decomposition – SDA + IDA

IV. Households

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + \boldsymbol{C_{HH}} + C_{TRA} = \sum_{s} C_{s}$$

Households

$$C_{CPS} = \sum_{u} \sum_{j=1}^{63} P \cdot \frac{\boldsymbol{H}}{\boldsymbol{P}} \cdot \frac{A}{H} \cdot \frac{E_{FEQ,u,HH}}{A} \cdot W_{u=\{SH,AC\}} \cdot \frac{E_{FEQ,u,HH,j}}{E_{FEQ,u,HH}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ Social

LMDI Decomposition – SDA + IDA

IV. Households

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + \boldsymbol{C_{HH}} + C_{TRA} = \sum_{s} C_{s}$$

Households

$$C_{CPS} = \sum_{u}\sum_{j=1}^{63} P \cdot \frac{H}{P} \cdot \frac{\boldsymbol{A}}{\boldsymbol{H}} \cdot \frac{E_{FEQ,u,HH}}{A} \cdot W_{u=\{SH,AC\}} \cdot \frac{E_{FEQ,u,HH,j}}{E_{FEQ,u,HH}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

- Comfort

LMDI Decomposition – SDA + IDA

IV. Households

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + \boldsymbol{C_{HH}} + C_{TRA} = \sum_{s} C_{s}$$

Households

$$C_{CPS} = \sum_{u} \sum_{j=1}^{63} P \cdot \frac{H}{P} \cdot \frac{A}{H} \cdot \frac{E_{FEQ,u,HH}}{A} \cdot W_{u=\{SH,AC\}} \cdot \frac{E_{FEQ,u,HH,j}}{E_{FEQ,u,HH}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

☐ Uses

- Space Heating
- Hot Water
- Cooking
- Air Conditioning
- Electrics & Lighting

LMDI Decomposition – SDA + IDA

V. Transport

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + C_{HH} + \boldsymbol{C_{TRA}} = \sum_{s} C_{s}$$

Transport

$$C_{CPS} = \sum_{p}\sum_{q}\sum_{j=1}^{63} P \cdot \frac{\boldsymbol{K_{p}}}{\boldsymbol{P}} \cdot \frac{\boldsymbol{K_{p,q}}}{\boldsymbol{K_{p}}} \cdot \frac{E_{FEQ,p,q,TRA}}{K_{p,q}} \cdot \frac{E_{FEQ,p,q,TRA,j}}{E_{FEQ,p,q,TRA}} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j}$$

❑ Social & Structural

LMDI Decomposition – SDA + IDA

V. Transport

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j}\cdot K_{C,PEQ,j}\cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j}\cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + C_{HH} + \boldsymbol{C_{TRA}} = \sum_{s} C_{s}$$

Transport

$$C_{CPS} = \sum_{p}\sum_{q}\sum_{j=1}^{63} P\cdot\frac{K_{p}}{P}\cdot\frac{K_{p,q}}{K_{p}}\cdot\frac{E_{FEQ,p,q,TRA}}{K_{p,q}}\cdot\frac{E_{FEQ,p,q,TRA,j}}{E_{FEQ,p,q,TRA}}\cdot K_{C,PEQ,j}\cdot K_{PEQ,j}$$

☐ Passenger transport

- Road
- Train
- Aviation

☐ Freight transport

- Road
- Train
- Navigation
- Pipeline

LMDI Decomposition – SDA + IDA

VI. LMDI Decomposition Calculation

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s} \sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_{s}$$

LMDI Decomposition of the Change from $t = 0$ to $t = T$

$$\Delta C_{TOT}^{T} = C_{TOT}^{T} - C_{TOT}^{0}$$

$$= \Delta C_{TOT,POP}^{T} + \Delta C_{TOT,INC}^{T} + \Delta C_{TOT,SOC}^{T} + \Delta C_{TOT,COM}^{T} + \Delta C_{TOT,STR}^{T} + \Delta C_{TOT,INTR}^{T}$$
$$+ \Delta C_{TOT,OUT}^{T} + \Delta C_{TOT,EFF}^{T} + \Delta C_{TOT,USE}^{T} + \Delta C_{TOT,WEA}^{T} + \Delta C_{TOT,MIX}^{T} + \Delta C_{TOT,CONV}^{T} + \Delta C_{TOT,EMI}^{T}$$

where, for instance,

$$\Delta C_{TOT,EFF}^{T} = L\left(C_{TOT}^{T}, C_{TOT}^{0}\right) \cdot \ln\left(\frac{EFF_{TOT}^{T}}{EFF_{TOT}^{0}}\right)$$

with $L(a,b) = (a-b)/(\ln(a) - \ln(b)) \rightarrow$ logarithmic mean of two positive real numbers

LMDI Decomposition – SDA + IDA

VI. LMDI Decomposition Calculation

Energy-Related CO2 Emissions

$$C_{TOT} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,PEQ,j} \cdot K_{PEQ,j} = \sum_{s}\sum_{j=1}^{63} E_{FEQ,s,j} \cdot K_{C,FEQ,j}$$

$$C_{TOT} = C_{AGRI} + C_{IND} + C_{CPS} + C_{HH} + C_{TRA} = \sum_{s} C_s$$

LMDI Decomposition of the Change from $t = 0$ to $t = T$

$$\begin{aligned}\Delta C_{TOT}^{T} &= C_{TOT}^{T} - C_{TOT}^{0} \\ &= \Delta C_{TOT,POP}^{T} + \Delta C_{TOT,INC}^{T} + \Delta C_{TOT,SOC}^{T} + \Delta C_{TOT,COM}^{T} + \Delta C_{TOT,STR}^{T} + \Delta C_{TOT,INTR}^{T} \\ &+ \Delta C_{TOT,OUT}^{T} + \Delta C_{TOT,EFF}^{T} + \Delta C_{TOT,USE}^{T} + \Delta C_{TOT,WEA}^{T} + \Delta C_{TOT,MIX}^{T} + \Delta C_{TOT,CONV}^{T} + \Delta C_{TOT,EMI}^{T}\end{aligned}$$

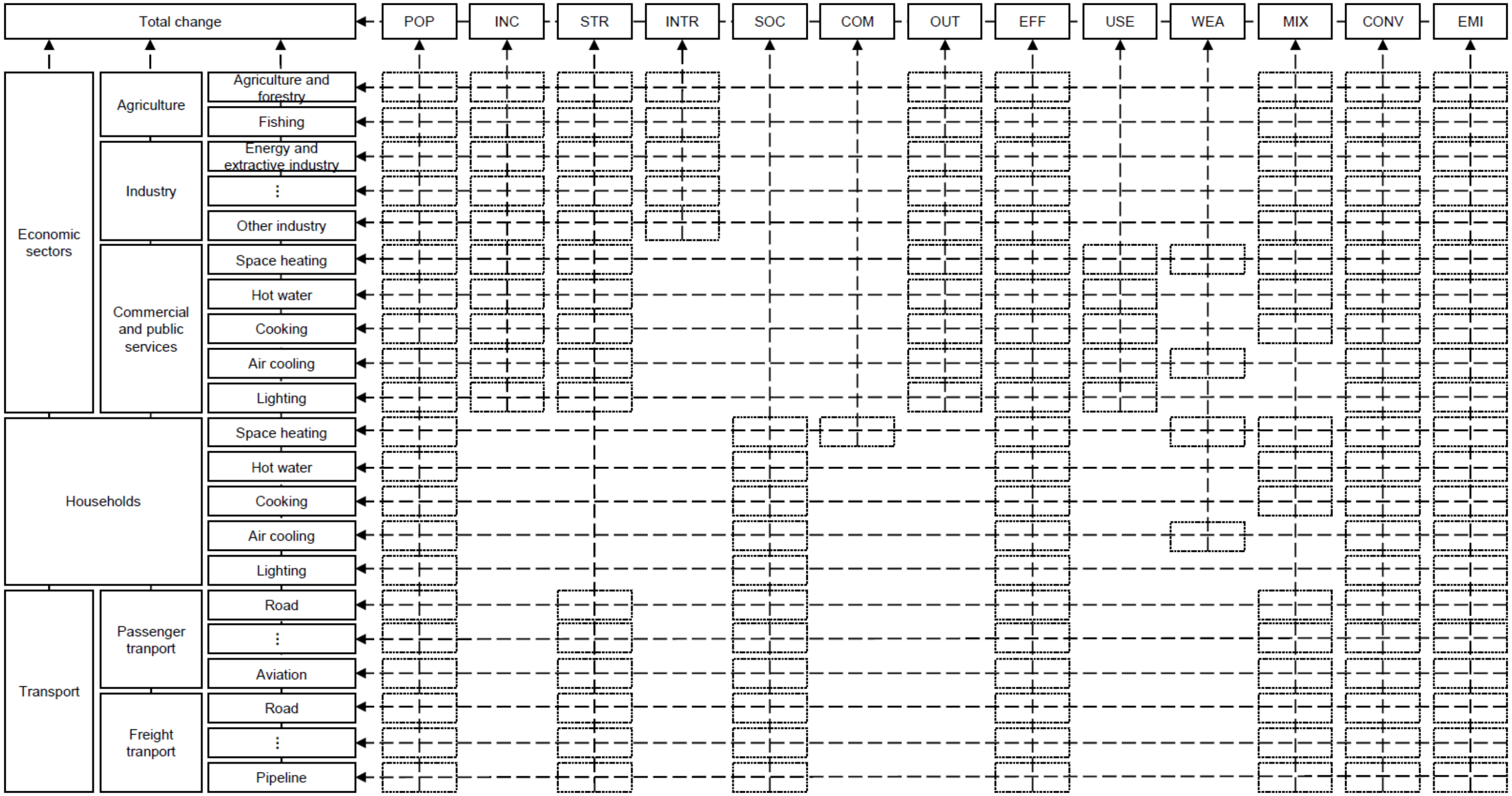
where, for instance,

$$\Delta C_{TOT,EFF}^{T} = L\left(C_{TOT}^{T}, C_{TOT}^{0}\right) \cdot \ln\left(\frac{EFF_{TOT}^{T}}{EFF_{TOT}^{0}}\right)$$

with $L(a,b) = (a-b)/(\ln(a) - \ln(b))$ → logarithmic mean of two positive real numbers

LMDI Decomposition – SDA + IDA

VII. Factor Aggregation Scheme



Total change

POP
INC
STR
INTR
SOC
COM
OUT
EFF
USE
WEA
MIX
CONV
EMI

Economic sectors

Agriculture
- Agriculture and forestry
- Fishing

Industry
- Energy and extractive industry
- ⋮
- Other industry

Commercial and public services
- Space heating
- Hot water
- Cooking
- Air cooling
- Lighting

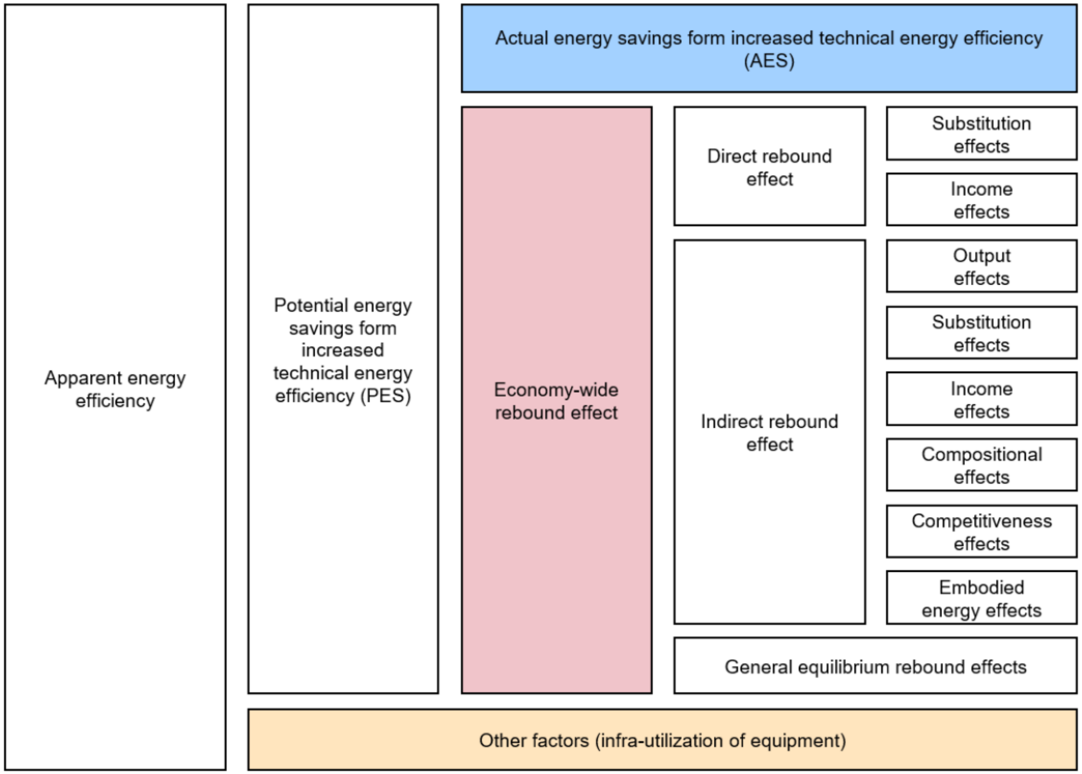
Households
- Space heating
- Hot water
- Cooking
- Air cooling
- Lighting

Transport

Passenger tranport
- Road
- ⋮
- Aviation

Freight tranport
- Road
- ⋮
- Pipeline

Further Decomposition of End-Use Energy Efficiency



Apparent energy efficiency

Potential energy savings form increased technical energy efficiency (PES)

Actual energy savings form increased technical energy efficiency (AES)

Economy-wide rebound effect

Direct rebound effect

Substitution effects

Income effects

Indirect rebound effect

Output effects

Substitution effects

Income effects

Compositional effects

Competitiveness effects

Embodied energy effects

General equilibrium rebound effects

Other factors (infra-utilization of equipment)

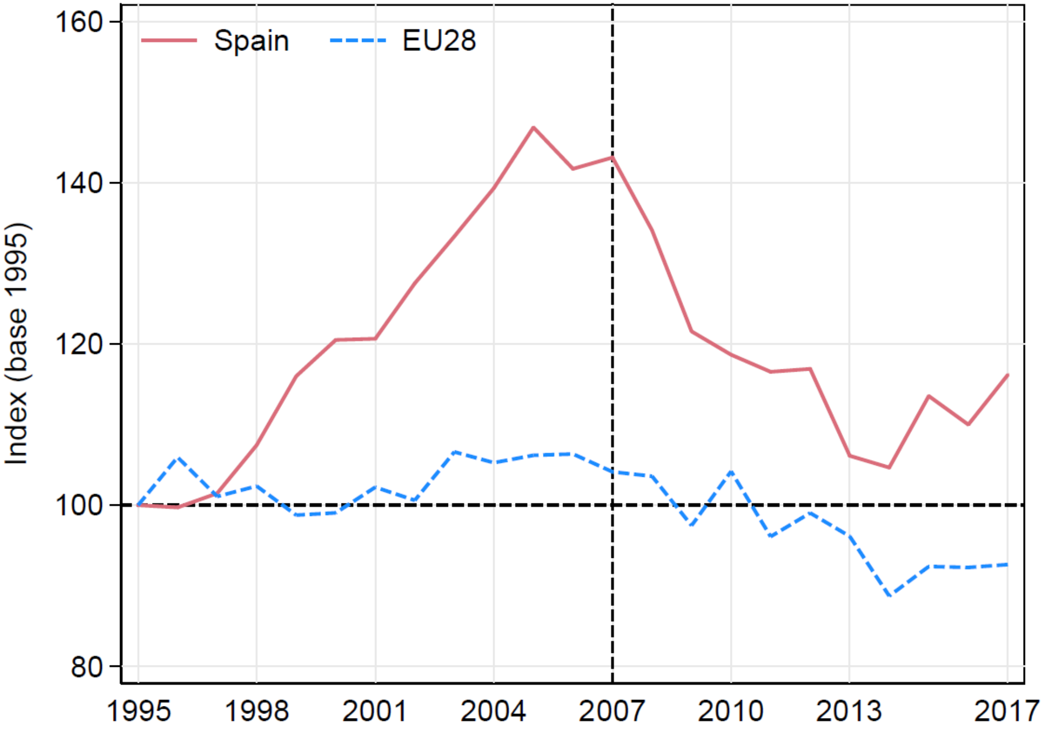
- **Technical energy efficiency** → Methodology from ODYSSEE-MURE (2020)
- **Rebound effect** → Peña-Vidondo et al. (2012) and Adetutu et al. (2016)
- What is **behind the observed/apparent end-use energy efficiency**

Results

Energy-Related CO2 Emissions

Estimated Energy-Related CO2 Emissions

- ❑ 1995-2007 → Spain ▲ 43% & EU28 ▲ 4%
- ❑ 2007-2017 → Spain ▼ 19% & EU28 ▼ 11%



Allocation of Primary Energy Needs and CO2 Emissions

I. By Energy Source

- Primary Energy Requirements

	Spain		EU28	
Energy	1995	2017	1995	2017
Total Energy Supply (MTOE)	101.22	124.39	1,648.43	1,621.40
Solid fossil fuels	1.47%	0.45%	3.79%	1.75%
Manufactured gases	1.32%	0.70%	2.53%	1.47%
Peat and peat products	0.00%	0.00%	0.06%	0.03%
Oil shale and oil sands	0.00%	0.00%	0.01%	0.00%
Oil and petroleum products	49.99%	38.34%	34.73%	31.85%
Natural gas	6.86%	13.79%	15.88%	16.84%
Renewables and biofuels	3.22%	5.25%	2.69%	6.37%
Non-renewable waste	0.08%	0.01%	0.10%	0.25%
Nuclear heat	0.00%	0.00%	0.00%	0.00%
Heat	0.00%	0.00%	5.32%	5.38%
Electricity	37.06%	41.46%	34.89%	36.06%

Allocation of Primary Energy Needs and CO2 Emissions

I. By Energy Source

- ❑ Energy-Related CO2 Emissions

	Spain		EU28	
Energy	1995	2017	1995	2017
Final energy consumption (Gg CO_2)	241.13	280.09	4005.41	3710.42
Solid fossil fuels	2.46%	0.71%	6.19%	2.84%
Manufactured gases	2.22%	1.11%	3.85%	2.29%
Peat and peat products	0.00%	0.00%	0.11%	0.05%
Oil shale and oil sands	0.00%	0.00%	0.01%	0.00%
Oil and petroleum products	54.72%	46.99%	36.87%	35.36%
Natural gas	6.22%	13.59%	14.46%	15.97%
Renewables and biofuels	5.25%	7.32%	4.61%	9.23%
Non-renewable waste	0.20%	0.01%	0.24%	0.59%
Nuclear heat	0.00%	0.00%	0.00%	0.00%
Heat	0.00%	0.00%	6.90%	6.95%
Electricity	28.93%	30.27%	26.74%	26.72%

Allocation of Primary Energy Needs and CO2 Emissions

II. By End-Use Sector

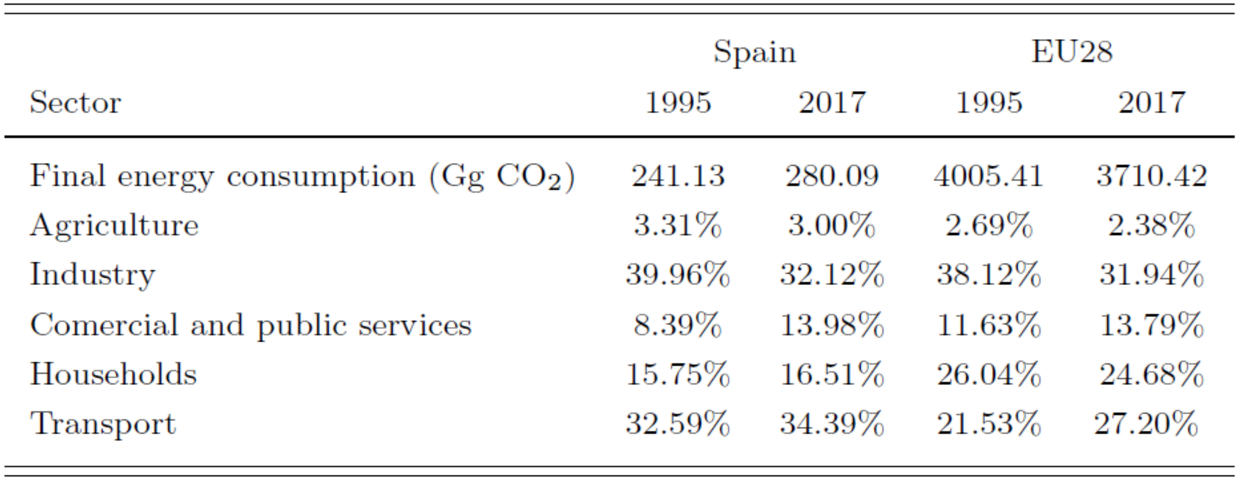
- ☐ Primary Energy Requirements

	Spain		EU28	
Sector	1995	2017	1995	2017
Total (MTOE)	88.36	116.3728	1,486.48	1,470.53
Agriculture	3.33%	2.77%	2.55%	2.27%
Industry	40.82%	33.63%	38.83%	32.85%
Commercial and public services	10.19%	18.18%	13.14%	16.99%
Households	16.37%	18.09%	26.27%	25.16%
Transport	29.29%	27.33%	19.20%	22.72%

Allocation of Primary Energy Needs and CO2 Emissions

II. By End-Use Sector

- Energy-Related CO2 Emissions

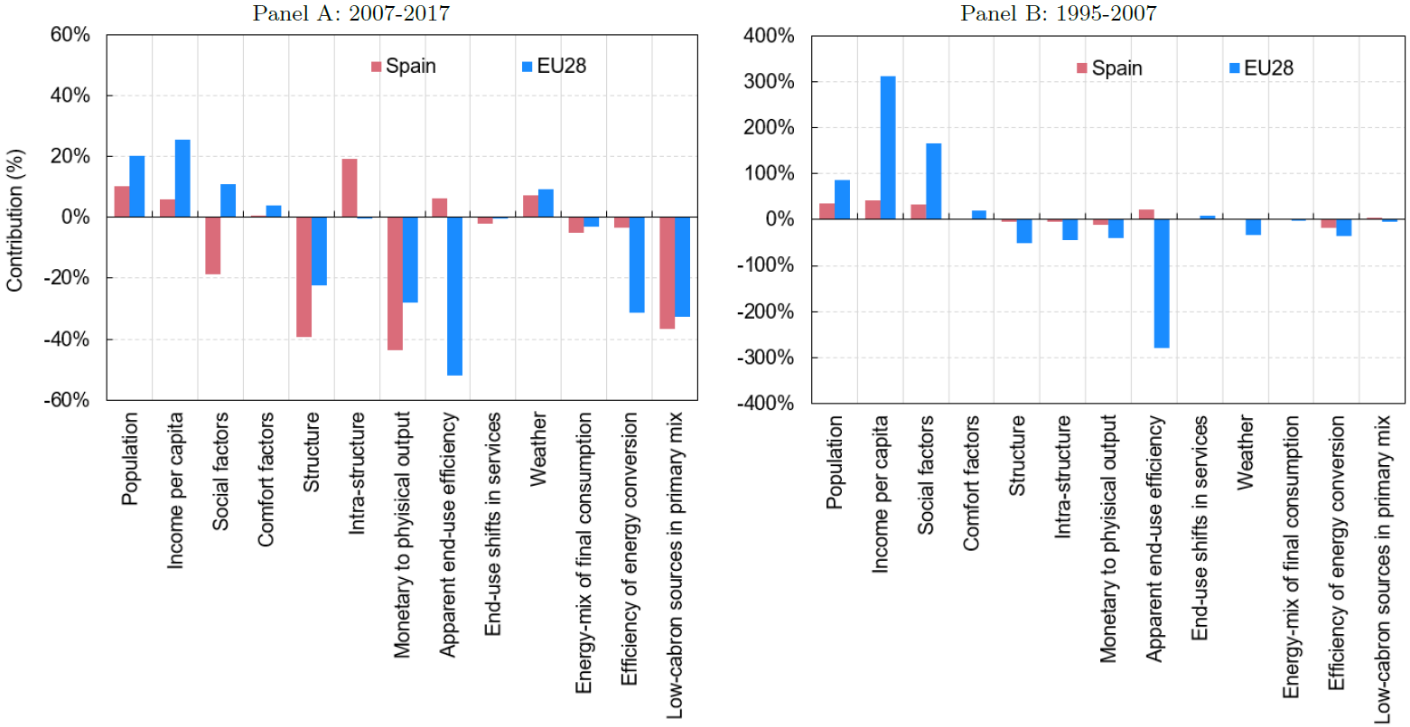


	Spain		EU28	
Sector	1995	2017	1995	2017
Final energy consumption (Gg CO_2)	241.13	280.09	4005.41	3710.42
Agriculture	3.31%	3.00%	2.69%	2.38%
Industry	39.96%	32.12%	38.12%	31.94%
Comercial and public services	8.39%	13.98%	11.63%	13.79%
Households	15.75%	16.51%	26.04%	24.68%
Transport	32.59%	34.39%	21.53%	27.20%

Decomposing Evolution of CO2 Emissions

I. By Influencing Factor

- ❑ Factor contributions to total change in energy-related CO2 emissions (Overview)

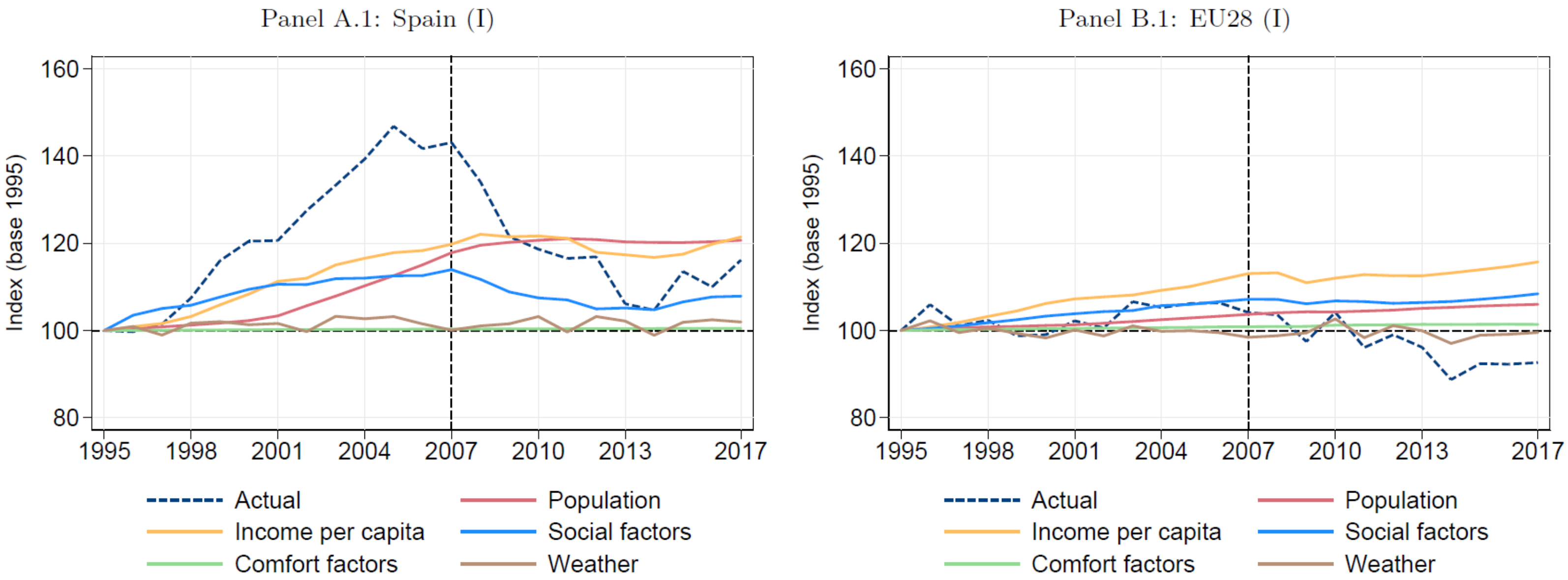


Note: Positive contributions refer to an increase of the energy-related CO_2 emissions associated to the evolution of the factor. Negative contributions refer to a decrease of the energy-related CO_2 emissions associated to the evolution of the factor.

Decomposing Evolution of CO2 Emissions

I. By Influencing Factor

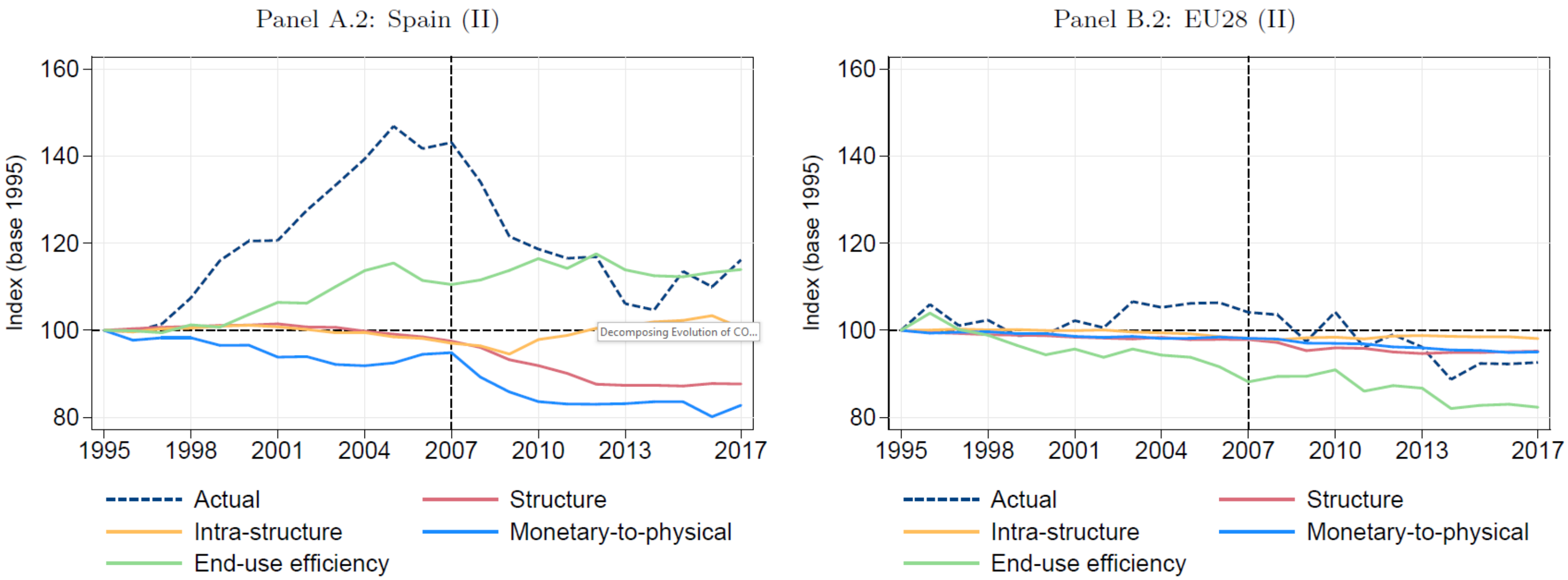
- ❑ Evolution of energy-related CO2 emissions and contributors (I) Learn more…



Decomposing Evolution of CO2 Emissions

I. By Influencing Factor

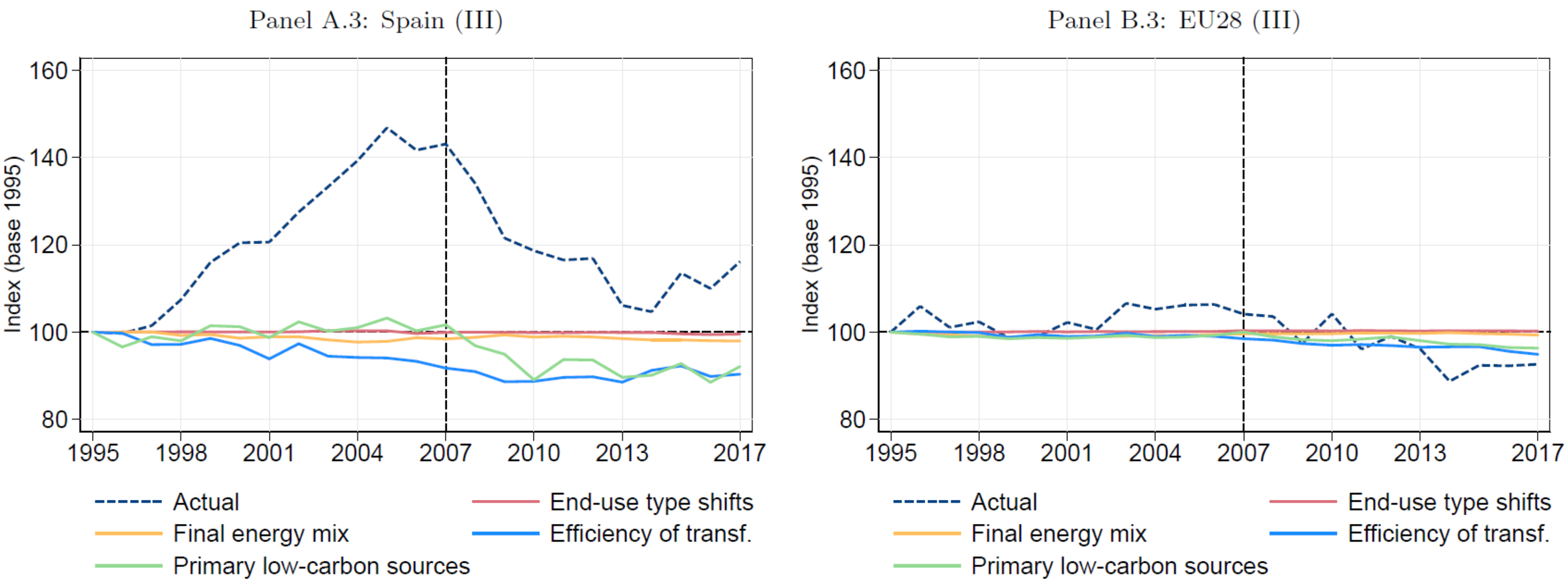
- ❑ Evolution of energy-related CO2 emissions and contributors (II)



Decomposing Evolution of CO2 Emissions

I. By Influencing Factor

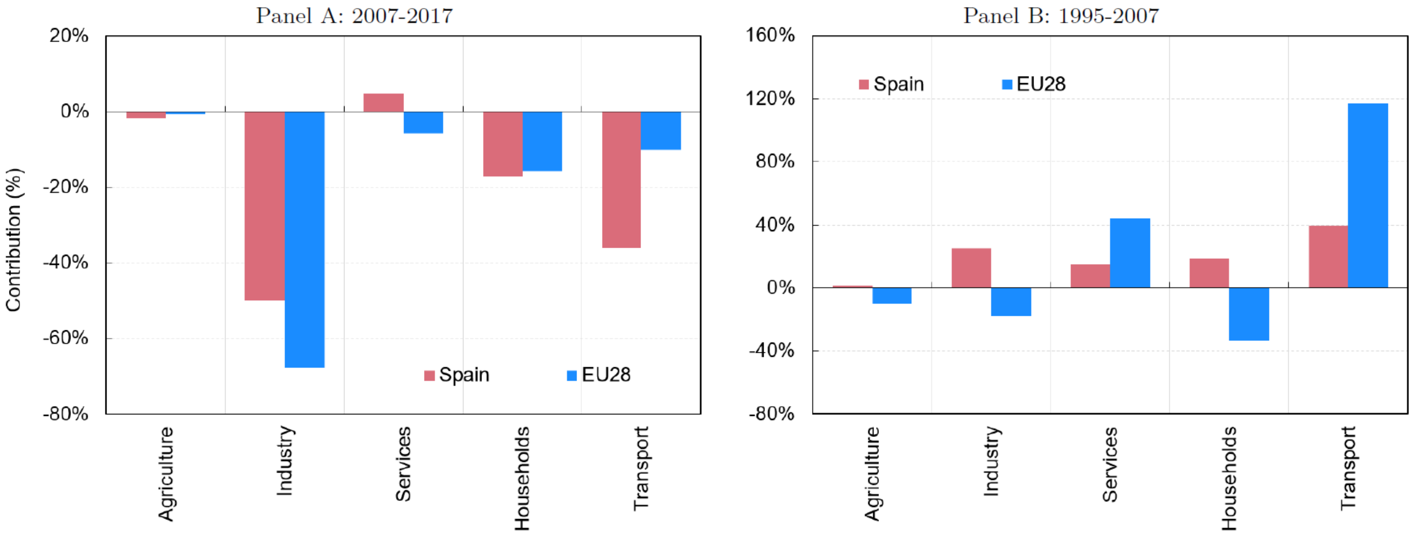
- ❑ Evolution of energy-related CO2 emissions and contributors (III)



Decomposing Evolution of CO2 Emissions

II. By Sector

- ❑ Sectoral contributions to total change in energy-related CO2 emissions (Overview)

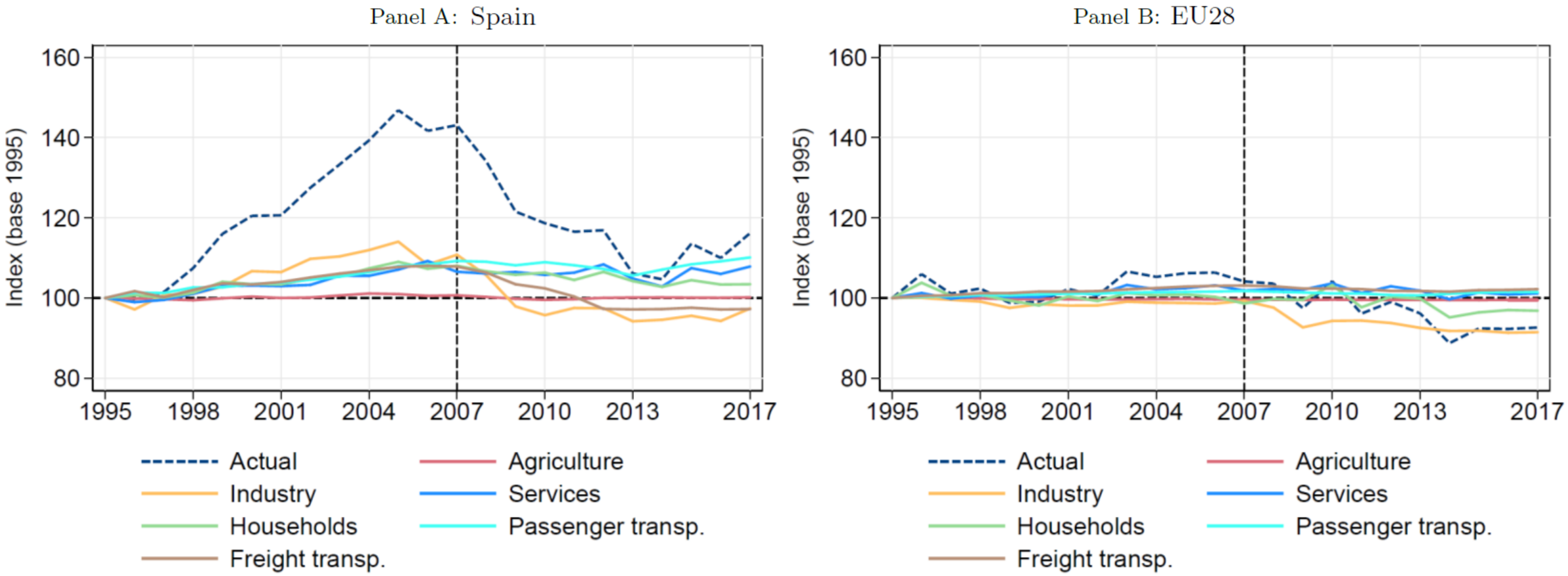


Note: Positive contributions refer to an increase of the energy-related CO_2 emissions associated to the evolution of the factor. Negative contributions refer to a decrease of the energy-related CO_2 emissions associated to the evolution of the factor.

Decomposing Evolution of CO2 Emissions

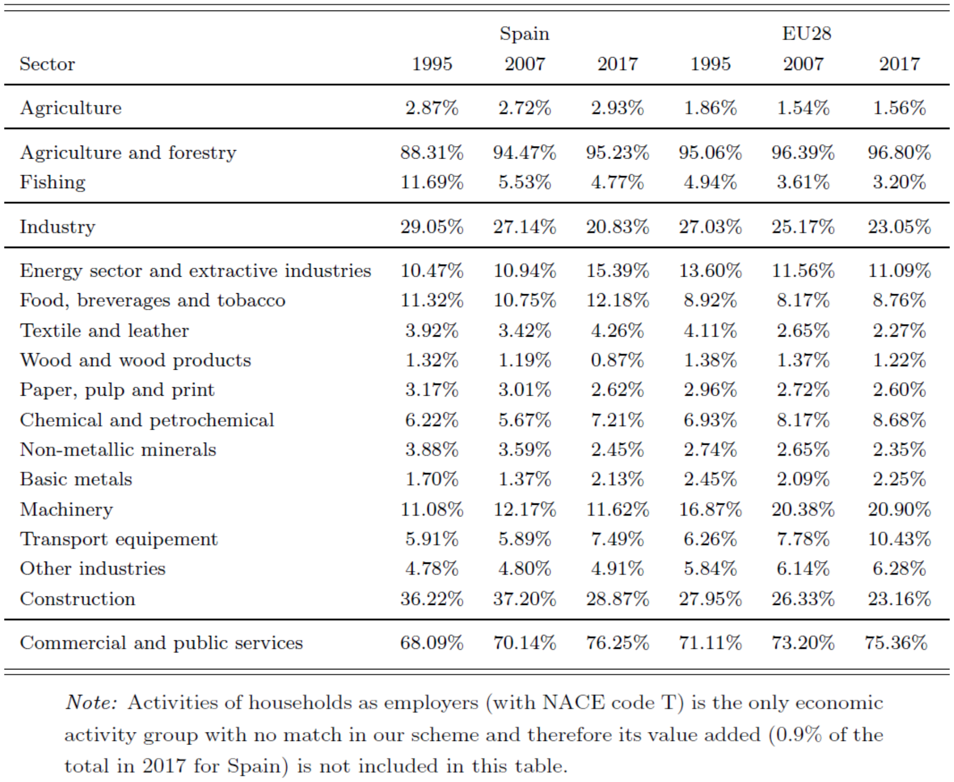
II. By Sector

- Evolution of energy-related CO2 emissions and sectoral contributions



Structural Change in Economy

- GVA sectoral and sub-sectoral shares



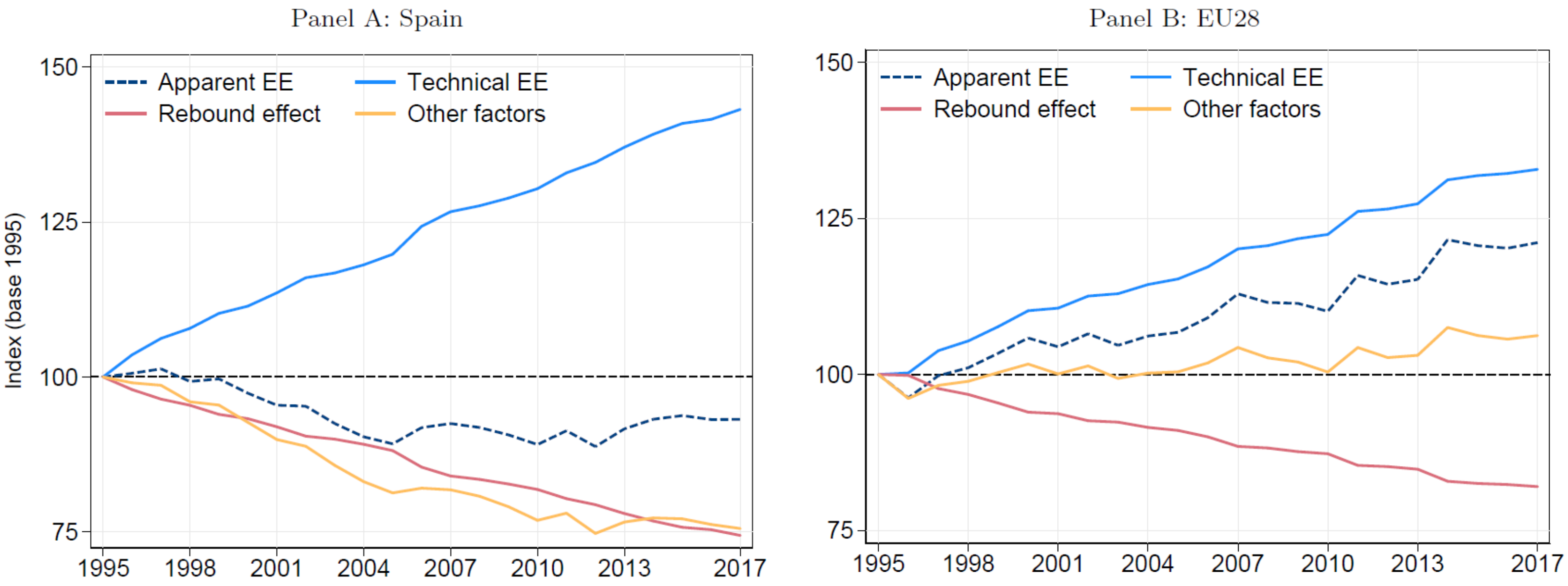
Sector	Spain 1995	2007	2017	EU28 1995	2007	2017
Agriculture	2.87%	2.72%	2.93%	1.86%	1.54%	1.56%
Agriculture and forestry	88.31%	94.47%	95.23%	95.06%	96.39%	96.80%
Fishing	11.69%	5.53%	4.77%	4.94%	3.61%	3.20%
Industry	29.05%	27.14%	20.83%	27.03%	25.17%	23.05%
Energy sector and extractive industries	10.47%	10.94%	15.39%	13.60%	11.56%	11.09%
Food, breverages and tobacco	11.32%	10.75%	12.18%	8.92%	8.17%	8.76%
Textile and leather	3.92%	3.42%	4.26%	4.11%	2.65%	2.27%
Wood and wood products	1.32%	1.19%	0.87%	1.38%	1.37%	1.22%
Paper, pulp and print	3.17%	3.01%	2.62%	2.96%	2.72%	2.60%
Chemical and petrochemical	6.22%	5.67%	7.21%	6.93%	8.17%	8.68%
Non-metallic minerals	3.88%	3.59%	2.45%	2.74%	2.65%	2.35%
Basic metals	1.70%	1.37%	2.13%	2.45%	2.09%	2.25%
Machinery	11.08%	12.17%	11.62%	16.87%	20.38%	20.90%
Transport equipement	5.91%	5.89%	7.49%	6.26%	7.78%	10.43%
Other industries	4.78%	4.80%	4.91%	5.84%	6.14%	6.28%
Construction	36.22%	37.20%	28.87%	27.95%	26.33%	23.16%
Commercial and public services	68.09%	70.14%	76.25%	71.11%	73.20%	75.36%

Note: Activities of households as employers (with NACE code T) is the only economic activity group with no match in our scheme and therefore its value added (0.9% of the total in 2017 for Spain) is not included in this table.

Decomposing Observed End-Use Energy Efficiency

I. Spain & EU28

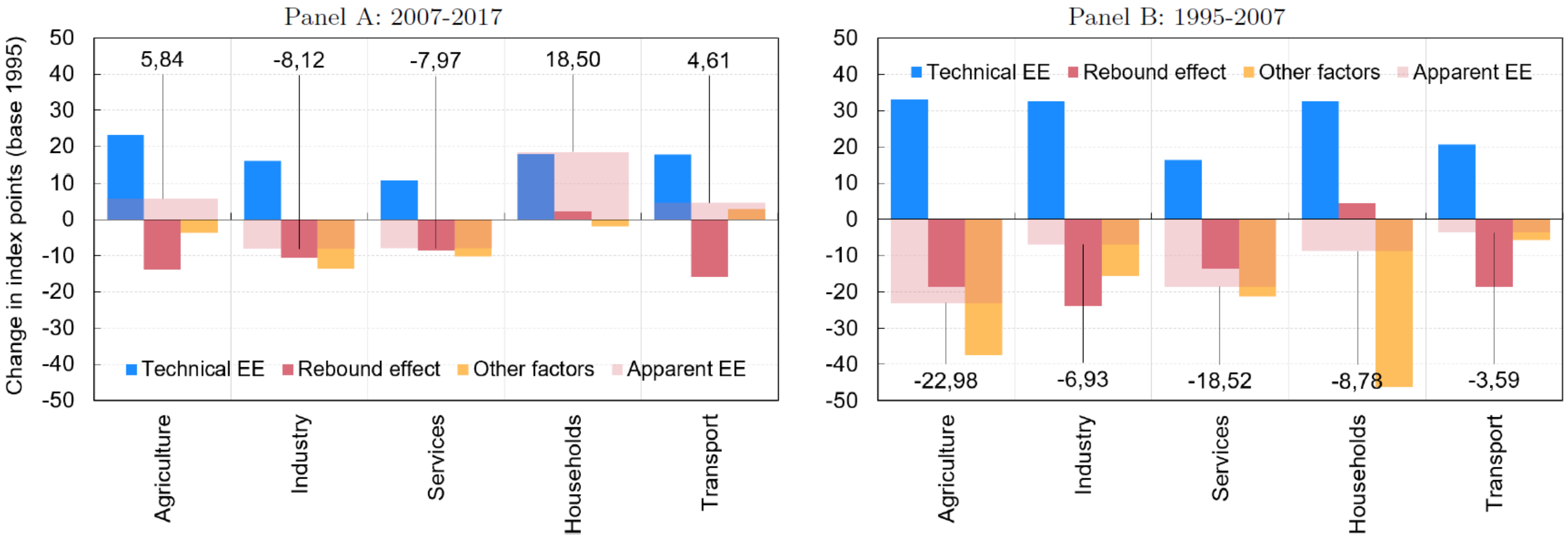
- ☐ Contributors to aggregate observed end-use energy efficiency



Decomposing Observed End-Use Energy Efficiency

II. Spain – By Sector

- ☐ Contributors to sectoral observed end-use energy efficiency in Spain Learn more…



Transformation Sector

I. Efficiency of the Conversion Sector

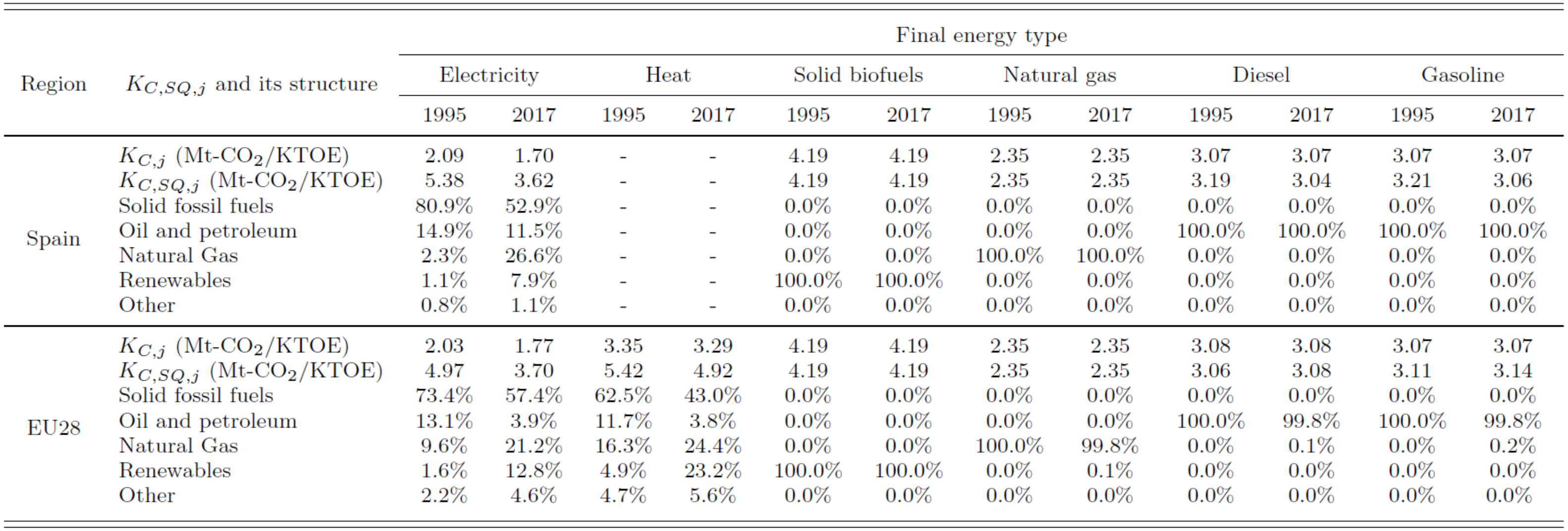
- ❑ K_{PEQ} of main energy products

Region	$K_{PEQ,j}$ and its structure	Final energy type											
		Electricity		Heat		Solid biofuels		Natural gas		Diesel		Gasoline	
		1995	2017	1995	2017	1995	2017	1995	2017	1995	2017	1995	2017
Spain	$K_{PEQ,j}$	2.57	2.13	-	-	1.00	1.00	1.00	1.00	1.04	1.00	1.04	1.00
	Solid fossil fuels	42.3%	22.6%	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil and petroleum	10.2%	6.3%	-	-	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%
	Natural Gas	2.0%	19.2%	-	-	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%
	Renewables	6.0%	20.5%	-	-	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Nuclear	38.1%	29.3%	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Other	1.4%	2.0%	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EU28	K_{PEQ}	2.46	2.09	1.62	1.49	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02
	Solid fossil fuels	36.7%	25.0%	51.8%	34.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil and petroleum	8.6%	2.2%	12.7%	4.1%	0.0%	0.0%	0.0%	0.0%	100.0%	99.8%	100.0%	99.7%
	Natural Gas	8.3%	16.0%	23.3%	34.1%	0.0%	0.0%	100.0%	99.8%	0.0%	0.2%	0.0%	0.2%
	Renewables	6.4%	19.0%	4.0%	20.7%	100.0%	100.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
	Nuclear	38.8%	35.7%	4.6%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Other	1.3%	2.1%	3.6%	4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Transformation Sector

II. Cleaner primary energy-mix

- ❑ $K_{c,PEQ}$ and $K_{c,FEQ}$ of main energy products



Region	$K_{C,SQ,j}$ and its structure	Final energy type											
		Electricity		Heat		Solid biofuels		Natural gas		Diesel		Gasoline	
		1995	2017	1995	2017	1995	2017	1995	2017	1995	2017	1995	2017
Spain	$K_{C,j}$ (Mt-CO_2/KTOE)	2.09	1.70	-	-	4.19	4.19	2.35	2.35	3.07	3.07	3.07	3.07
	$K_{C,SQ,j}$ (Mt-CO_2/KTOE)	5.38	3.62	-	-	4.19	4.19	2.35	2.35	3.19	3.04	3.21	3.06
	Solid fossil fuels	80.9%	52.9%	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil and petroleum	14.9%	11.5%	-	-	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%
	Natural Gas	2.3%	26.6%	-	-	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%
	Renewables	1.1%	7.9%	-	-	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Other	0.8%	1.1%	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EU28	$K_{C,j}$ (Mt-CO_2/KTOE)	2.03	1.77	3.35	3.29	4.19	4.19	2.35	2.35	3.08	3.08	3.07	3.07
	$K_{C,SQ,j}$ (Mt-CO_2/KTOE)	4.97	3.70	5.42	4.92	4.19	4.19	2.35	2.35	3.06	3.08	3.11	3.14
	Solid fossil fuels	73.4%	57.4%	62.5%	43.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Oil and petroleum	13.1%	3.9%	11.7%	3.8%	0.0%	0.0%	0.0%	0.0%	100.0%	99.8%	100.0%	99.8%
	Natural Gas	9.6%	21.2%	16.3%	24.4%	0.0%	0.0%	100.0%	99.8%	0.0%	0.1%	0.0%	0.2%
	Renewables	1.6%	12.8%	4.9%	23.2%	100.0%	100.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
	Other	2.2%	4.6%	4.7%	5.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Conclusions

Conclusions – Q&A

- 1995-2007 → Spain ▲ 43% & EU28 ▲ 4%
  - **Population growth**, rising **per capita income**, and **social factors** → **contributors** to increase in emissions in Spain and EU28
  - But **very positive evolution of observed end-use energy efficiency in EU28**, and **very negative in Spain**.
  - **Transport** and **services** sectors → main **contributors** to increase in emissions in Spain and EU28. **HHs** and **industry** → **inhibitor in EU28**, but **contributor in Spain**.
- 2007-2017 → **Spain is on a path toward the decarbonization** of the economy, with **more accentuated trend**, Spain ▼ 19% & EU28 ▼ 11%
  - In **EU28** mainly by **efficiency of conversion** and **observed end-use energy efficiency**, **structural changes** toward less emission-generating sectors, **lower use of fossil fuels** in energy transformation.
  - **Same in Spain (+ social factors)**, but **no improvement in observed end-use energy efficiency at all**. Evolution of emissions in Spain is burdened by observed end-use energy efficiency → **Infra-utilization** (installation of end-use energy equipment above its potential)
  - **HHs** and **industry** → clear **inhibitors in Spain and EU28**. **Transport** → contribute to **fall in emissions**, **more in Spain** than in EU28.

Conclusions – Q&A

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Conclusions – Q&A

Thank you!

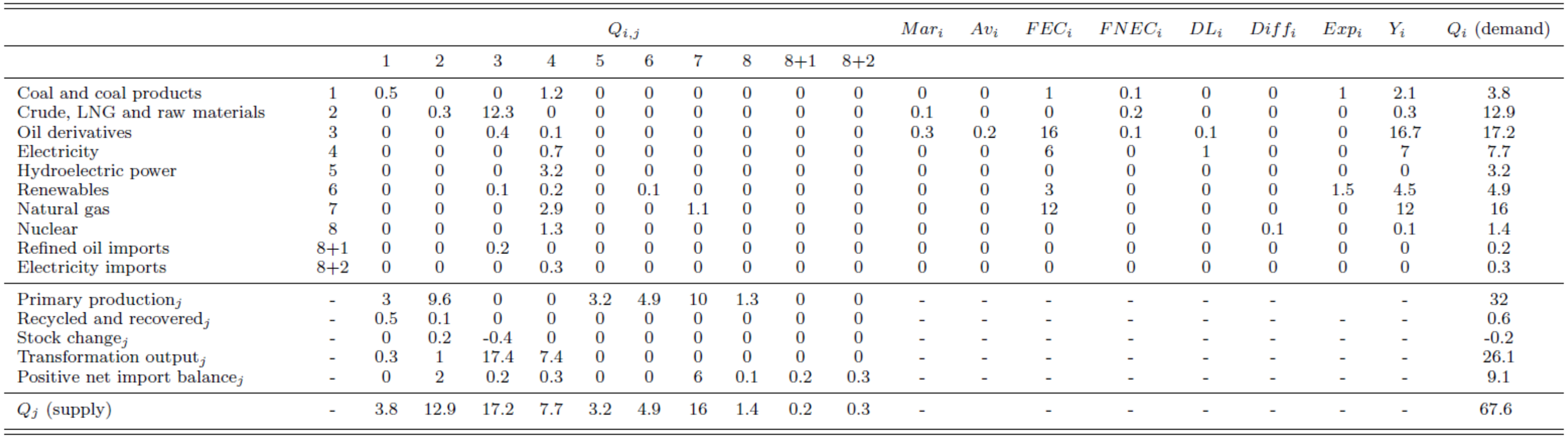
Darío Serrano-Puente
@darioserranopue

Appendix

Appendix

I. Example of Energy Input-Output Table

Return



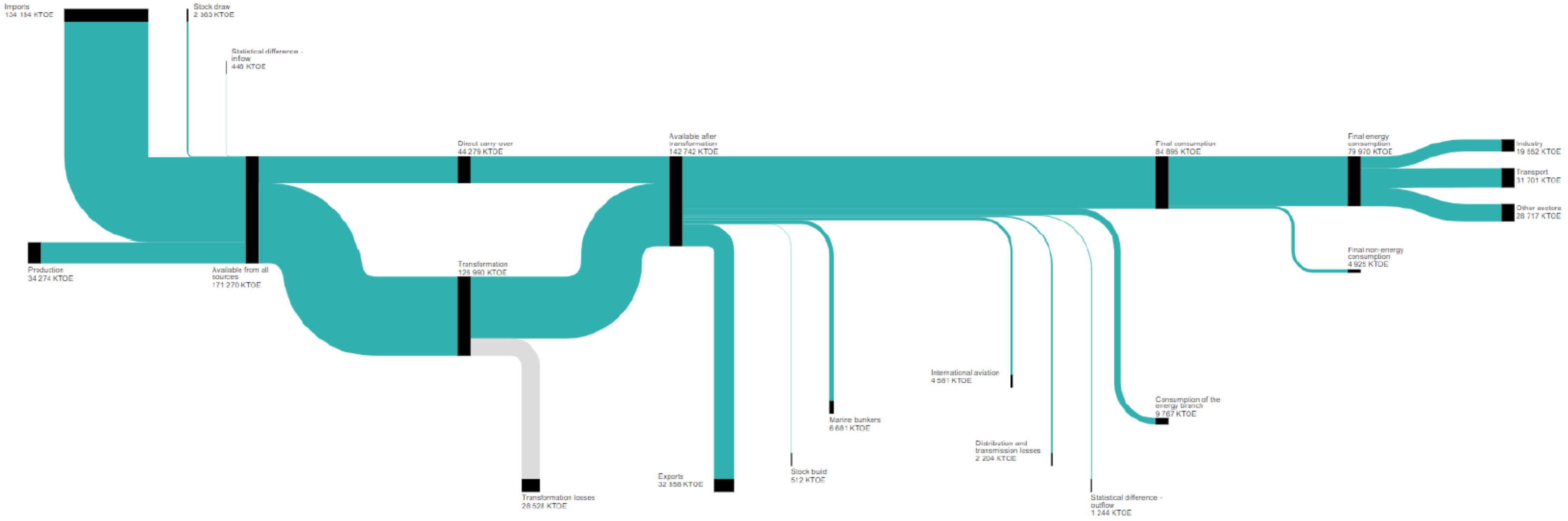
		$Q_{i,j}$										Mar_i	Av_i	FEC_i	$FNEC_i$	DL_i	$Diff_i$	Exp_i	Y_i	Q_i (demand)
		1	2	3	4	5	6	7	8	8+1	8+2									
Coal and coal products	1	0.5	0	0	1.2	0	0	0	0	0	0	0	0	1	0.1	0	0	1	2.1	3.8
Crude, LNG and raw materials	2	0	0.3	12.3	0	0	0	0	0	0	0	0.1	0	0	0.2	0	0	0	0.3	12.9
Oil derivatives	3	0	0	0.4	0.1	0	0	0	0	0	0	0.3	0.2	16	0.1	0.1	0	0	16.7	17.2
Electricity	4	0	0	0	0.7	0	0	0	0	0	0	0	0	6	0	1	0	0	7	7.7
Hydroelectric power	5	0	0	0	3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.2
Renewables	6	0	0	0.1	0.2	0	0.1	0	0	0	0	0	0	3	0	0	0	1.5	4.5	4.9
Natural gas	7	0	0	0	2.9	0	0	1.1	0	0	0	0	0	12	0	0	0	0	12	16
Nuclear	8	0	0	0	1.3	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.1	1.4
Refined oil imports	8+1	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
Electricity imports	8+2	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Primary production$_j$	-	3	9.6	0	0	3.2	4.9	10	1.3	0	0	-	-	-	-	-	-		-	32
Recycled and recovered$_j$	-	0.5	0.1	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	0.6
Stock change$_j$	-	0	0.2	-0.4	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-0.2
Transformation output$_j$	-	0.3	1	17.4	7.4	0	0	0	0	0	0	-	-	-	-	-	-	-	-	26.1
Positive net import balance$_j$	-	0	2	0.2	0.3	0	0	6	0.1	0.2	0.3	-	-	-	-	-	-	-	-	9.1
Q_j (supply)	-	3.8	12.9	17.2	7.7	3.2	4.9	16	1.4	0.2	0.3	-		-	-	-	-	-	-	67.6

Note: Q_i denotes the total energy needs of energy i, $Q_{i,j}$ denotes the intermediate consumption of each energy i to produce energy j, Mar_i denotes the consumption of energy i for international maritime bunkers, Av_i denotes the consumption of energy i for international aviation, FEC_i denotes the final consumption of energy i (including final consumption of the energy branch), $FNEC_i$ denotes the final non-energy consumption of energy i, DL_i denotes the distribution losses of energy i, $Diff_i$ denotes the statistical difference between Q_i calculated from the supply side and Q_i calculated from the demand side, Exp_i denotes the positive net export balance of energy i, and Y_i denotes the final demand of energy i.

Appendix

II. Sankey Diagram of Energy Flow – Spain (2017)

Return

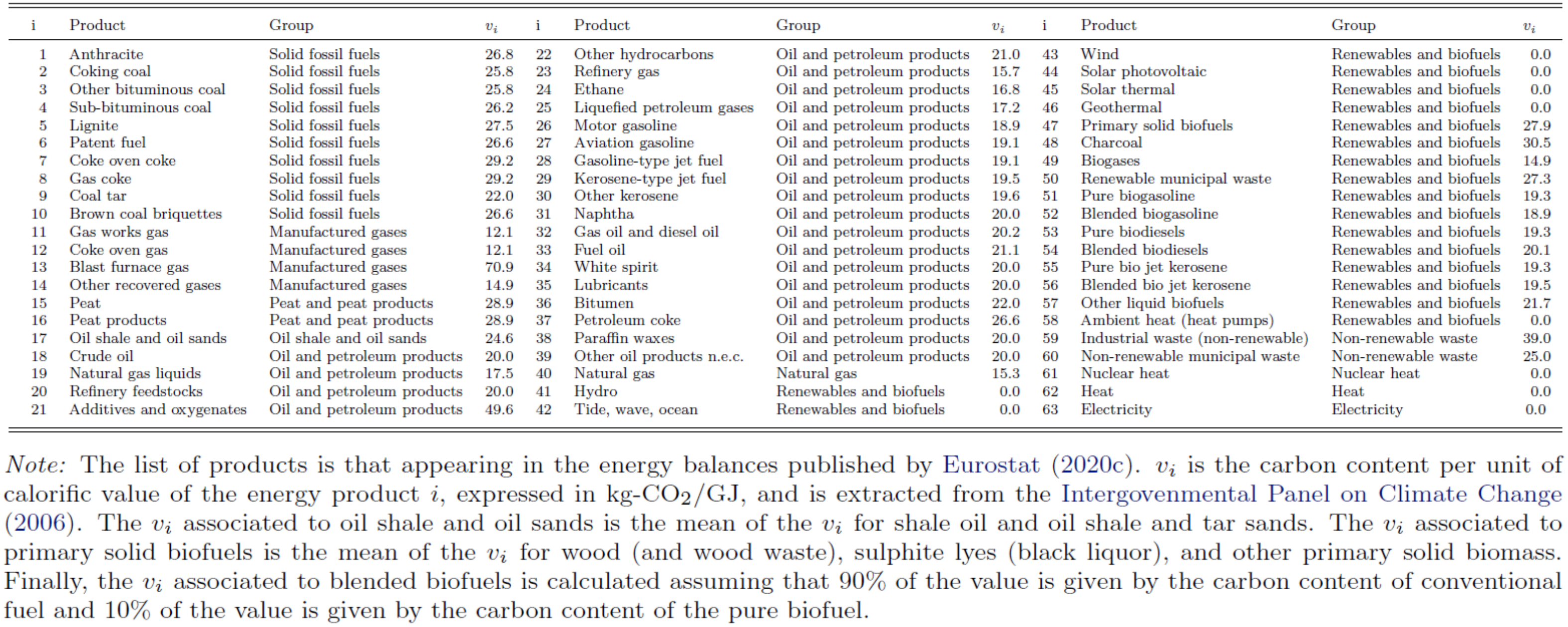


Source: Picture directly taken from the Eurostat Sankey drawing tool.

Appendix

III. List of Energy Products and Carbon Content

Return



i	Product	Group	v_i	i	Product	Group	v_i	i	Product	Group	v_i
1	Anthracite	Solid fossil fuels	26.8	22	Other hydrocarbons	Oil and petroleum products	21.0	43	Wind	Renewables and biofuels	0.0
2	Coking coal	Solid fossil fuels	25.8	23	Refinery gas	Oil and petroleum products	15.7	44	Solar photovoltaic	Renewables and biofuels	0.0
3	Other bituminous coal	Solid fossil fuels	25.8	24	Ethane	Oil and petroleum products	16.8	45	Solar thermal	Renewables and biofuels	0.0
4	Sub-bituminous coal	Solid fossil fuels	26.2	25	Liquefied petroleum gases	Oil and petroleum products	17.2	46	Geothermal	Renewables and biofuels	0.0
5	Lignite	Solid fossil fuels	27.5	26	Motor gasoline	Oil and petroleum products	18.9	47	Primary solid biofuels	Renewables and biofuels	27.9
6	Patent fuel	Solid fossil fuels	26.6	27	Aviation gasoline	Oil and petroleum products	19.1	48	Charcoal	Renewables and biofuels	30.5
7	Coke oven coke	Solid fossil fuels	29.2	28	Gasoline-type jet fuel	Oil and petroleum products	19.1	49	Biogases	Renewables and biofuels	14.9
8	Gas coke	Solid fossil fuels	29.2	29	Kerosene-type jet fuel	Oil and petroleum products	19.5	50	Renewable municipal waste	Renewables and biofuels	27.3
9	Coal tar	Solid fossil fuels	22.0	30	Other kerosene	Oil and petroleum products	19.6	51	Pure biogasoline	Renewables and biofuels	19.3
10	Brown coal briquettes	Solid fossil fuels	26.6	31	Naphtha	Oil and petroleum products	20.0	52	Blended biogasoline	Renewables and biofuels	18.9
11	Gas works gas	Manufactured gases	12.1	32	Gas oil and diesel oil	Oil and petroleum products	20.2	53	Pure biodiesels	Renewables and biofuels	19.3
12	Coke oven gas	Manufactured gases	12.1	33	Fuel oil	Oil and petroleum products	21.1	54	Blended biodiesels	Renewables and biofuels	20.1
13	Blast furnace gas	Manufactured gases	70.9	34	White spirit	Oil and petroleum products	20.0	55	Pure bio jet kerosene	Renewables and biofuels	19.3
14	Other recovered gases	Manufactured gases	14.9	35	Lubricants	Oil and petroleum products	20.0	56	Blended bio jet kerosene	Renewables and biofuels	19.5
15	Peat	Peat and peat products	28.9	36	Bitumen	Oil and petroleum products	22.0	57	Other liquid biofuels	Renewables and biofuels	21.7
16	Peat products	Peat and peat products	28.9	37	Petroleum coke	Oil and petroleum products	26.6	58	Ambient heat (heat pumps)	Renewables and biofuels	0.0
17	Oil shale and oil sands	Oil shale and oil sands	24.6	38	Paraffin waxes	Oil and petroleum products	20.0	59	Industrial waste (non-renewable)	Non-renewable waste	39.0
18	Crude oil	Oil and petroleum products	20.0	39	Other oil products n.e.c.	Oil and petroleum products	20.0	60	Non-renewable municipal waste	Non-renewable waste	25.0
19	Natural gas liquids	Oil and petroleum products	17.5	40	Natural gas	Natural gas	15.3	61	Nuclear heat	Nuclear heat	0.0
20	Refinery feedstocks	Oil and petroleum products	20.0	41	Hydro	Renewables and biofuels	0.0	62	Heat	Heat	0.0
21	Additives and oxygenates	Oil and petroleum products	49.6	42	Tide, wave, ocean	Renewables and biofuels	0.0	63	Electricity	Electricity	0.0

Note: The list of products is that appearing in the energy balances published by Eurostat (2020c). v_i is the carbon content per unit of calorific value of the energy product i, expressed in kg-CO_2/GJ, and is extracted from the Intergovenmental Panel on Climate Change (2006). The v_i associated to oil shale and oil sands is the mean of the v_i for shale oil and oil shale and tar sands. The v_i associated to primary solid biofuels is the mean of the v_i for wood (and wood waste), sulphite lyes (black liquor), and other primary solid biomass. Finally, the v_i associated to blended biofuels is calculated assuming that 90% of the value is given by the carbon content of conventional fuel and 10% of the value is given by the carbon content of the pure biofuel.

Appendix

IV. Acquirement of K_{PEQ}

Return

$$\sum_{j}^{63+N_s} Q_{i,j} + Y_i = Q_i \tag{2}$$

$$ID + Y = Q, \tag{3}$$

where $Q_{i,j}$ is the i, j-element of the matrix of intermediate demand, ID, Q is the column vector of total output, and Y is the column vector of final demand.

We define the direct consumption efficiency (or transformation coefficient) $a_{i,j}$ as the energy i consumed to produce one unit of energy j, which is shown in Equation (4).

$$a_{i,j} = \frac{Q_{i,j}}{Q_j} \tag{4}$$

Hence, Equation (3) can be further expressed as Equation (5).

$$AQ + Y = Q, \tag{5}$$

where $a_{i,j}$ is the i, j-element of the matrix A.

Appendix

IV. Acquirement of K_{PEQ}

Return

Further, Equation (5) can be rewritten as Equation (6), where $(I-A)^{-1}$ is the Leontief inverse matrix, which is denoted with symbol L', as shown in Equation (7).

$$Q = (I-A)^{-1}Y \tag{6}$$

$$Q = L'Y \tag{7}$$

$$K_{PEQ,j} = \sum_{i=1}^{63+N_s} L'_{i,j} \cdot \mathbb{1}_{i \notin \mathcal{S}} \tag{8}$$

where $\mathcal{S}$ is the subset of secondary energy products, $\mathbb{1}_{i \notin \mathcal{S}}$ is an indicator variable that takes value 1 when the energy product i is not part of the subset of secondary products and 0 otherwise, and $K_{PEQ,j}$ is the primary energy quantity conversion factor of energy j. In other words, $K_{PEQ,j}$ would represent the direct and indirect primary energy requirements needed to obtain a unit of energy j for consumption of the end-use sectors. Therefore, this elevation factor allows us to transform energy quantities in standard (or final energy) quantity (SQ) form into primary energy quantity (PEQ) form.

Appendix

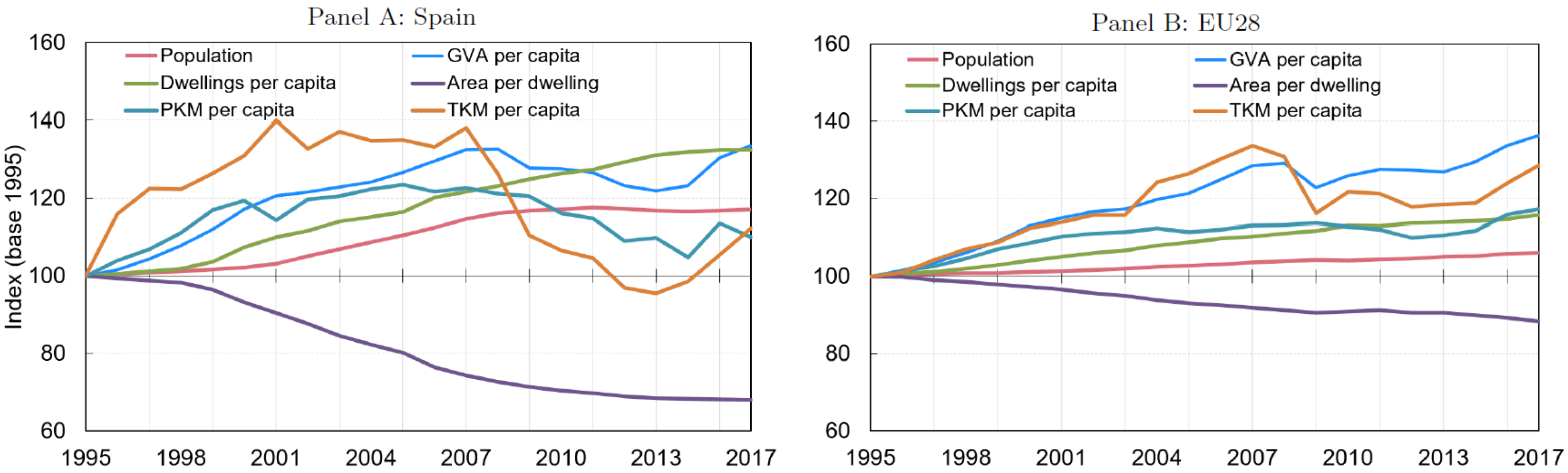
V. Intermediate Conversion Sector in Energy I-O Table

Return

Transformation sector	Description
Electricity & heat generation (10 sub-sectors)	Production of electricity and/or heat, including renewable energies, like hydro power, wind power and solar photovoltaic, which are transformed into electricity, or the energy transformed in nuclear or thermal power plants (e.g. burning of oil, coal, gas and biofuels) to produce electricity and/or heat, or district heating plants, which are central locations used to produce district heat that is distributed through a network and may be used for processing or space heating purposes.
Coke ovens	Transformation of coal into coke oven coke, which is the most important raw material for blast furnaces.
Blast furnaces	Transformation of coke oven coke into blast furnace gas.
Gas works	Transformation of fuels into gas works gas, which is a flammable gas.
Refineries & petrochemical industry (6 sub-sectors)	Transformation of crude oil and other intermediary products into refined petroleum products (like gasoline, diesel oil, fuel oil, lubricants, etc.). Input to refineries consists of crude oil and intermediary products (feedstocks) treated in the refineries, including treatment on behalf of foreign countries. The quantities of oil products re-treated in the refineries (recycling) are also included. It also covers the petrochemical industry, which is the transformation of energy carriers during the production of petrochemicals (chemical products derived from petroleum) in the petrochemical industry. The backflows are considered as an input as well, i.e. all energy commodities obtained as outputs from transformation processes but used as an input to other transformation processes, for example, fuels returned from the petrochemical sector to refineries for further processing/blending. Although the real backflow is not known from the energy balance, a minimal backflow can be inferred by consistency: any amount of a given product that is present at the transformation input node, but not provided by energy available from all sources, must be a backflow.
Patent fuel plants	A composition fuel manufactured from hard coal fines with the addition of a binding agent. The amount of patent fuel produced may, therefore, be slightly higher than the actual amount of coal consumed in the transformation process.
BKB & PB plants	Plants used to produce brown coal briquettes and peat briquettes. These are bricks composed of shredded peat or brown coal, compressed to form a slow-burning, easily stored and transported fuel.
Coal liquefaction plants	Quantities of coal, oil shale and tar sands used to produce synthetic oil.
Blended in natural gas	Quantities of coal gases or petroleum gas products blended with natural gas.
Liquid biofuels blended	Quantities of conventional and pure biofuels to produce blended biofuels.
Charcoal production plants	Charcoal is a manufactured fuel from solid biofuels, i.e. the solid residue of the destructive distillation and pyrolysis of wood and other vegetal material.
Gas-to-liquids plants	Quantities of natural gas used as feedstock for the conversion to liquids e.g. the quantities of fuel entering the methanol production process for transformation into methanol.
Not elsewhere specified	Transformation input/output is reported under Non-specified only as a last resort, if a final breakdown into the above sub-sectors is not available.

Appendix

VI. Population, Income & Other Social/Comfort Factors Return



Appendix

VII. Acquirement of K_{CQ}

Return

$$K_{C,j} = \sum_{m=1}^{63+N_s} \frac{L'_{m,j} \cdot \mathbb{1}_{m \notin \mathcal{S}}}{K_{PEQ,j}} \cdot f_m \tag{9}$$

Further, if we would like to compute the total number of units of CO_2 that are emitted when one unit of end-use energy j expressed in SQ form (rather than in PEQ form) is consumed, we would have to calculate the elevation factor $K_{C,SQ,j}$, which is given by Equation (10).

$$K_{C,SQ,j} = K_{C,j} \cdot K_{PEQ,j} = \sum_{m=1}^{63+N_s} \frac{L'_{m,j} \cdot \mathbb{1}_{m \notin \mathcal{S}}}{K_{PEQ,j}} \cdot f_m \cdot K_{PEQ,j} = \sum_{m=1}^{63+N_s} L'_{m,j} \cdot \mathbb{1}_{m \notin \mathcal{S}} \cdot f_m \tag{10}$$

Here, f_m denotes the CO_2 emission factor of the primary energy m.

Appendix

VII. Acquirement of K_{CQ}

Return

$$f_m = NCV_m \cdot v_m \cdot o_m \cdot \frac{44}{12} \tag{11}$$

where NCV_m is a factor to convert the net calorific value of the energy m into TJ units. In our case, the energy quantities in the energy balances are expressed in KTOE. Hence, we have to multiply the KTOE quantity of each energy product m by $NCV_m = 41.868$ to convert it into TJ. v_m is the carbon content per unit of calorific value of the energy product m, expressed in kg-CO_2/TJ. It can be shown in Table 13 of the Appendix. o_m denotes the oxidation rate of the energy product m when it is used. The value of o_m is usually 1, reflecting complete oxidation of the energy product m. Lower values are used only to account for carbon retained indefinitely in ash or soot. Finally, $\frac{44}{12}$ denotes the molecular weight ratio of carbon dioxide (CO_2) to carbon (C). We should mention that the CO_2 emission factors of the different primary energies are the same for every region.

Appendix

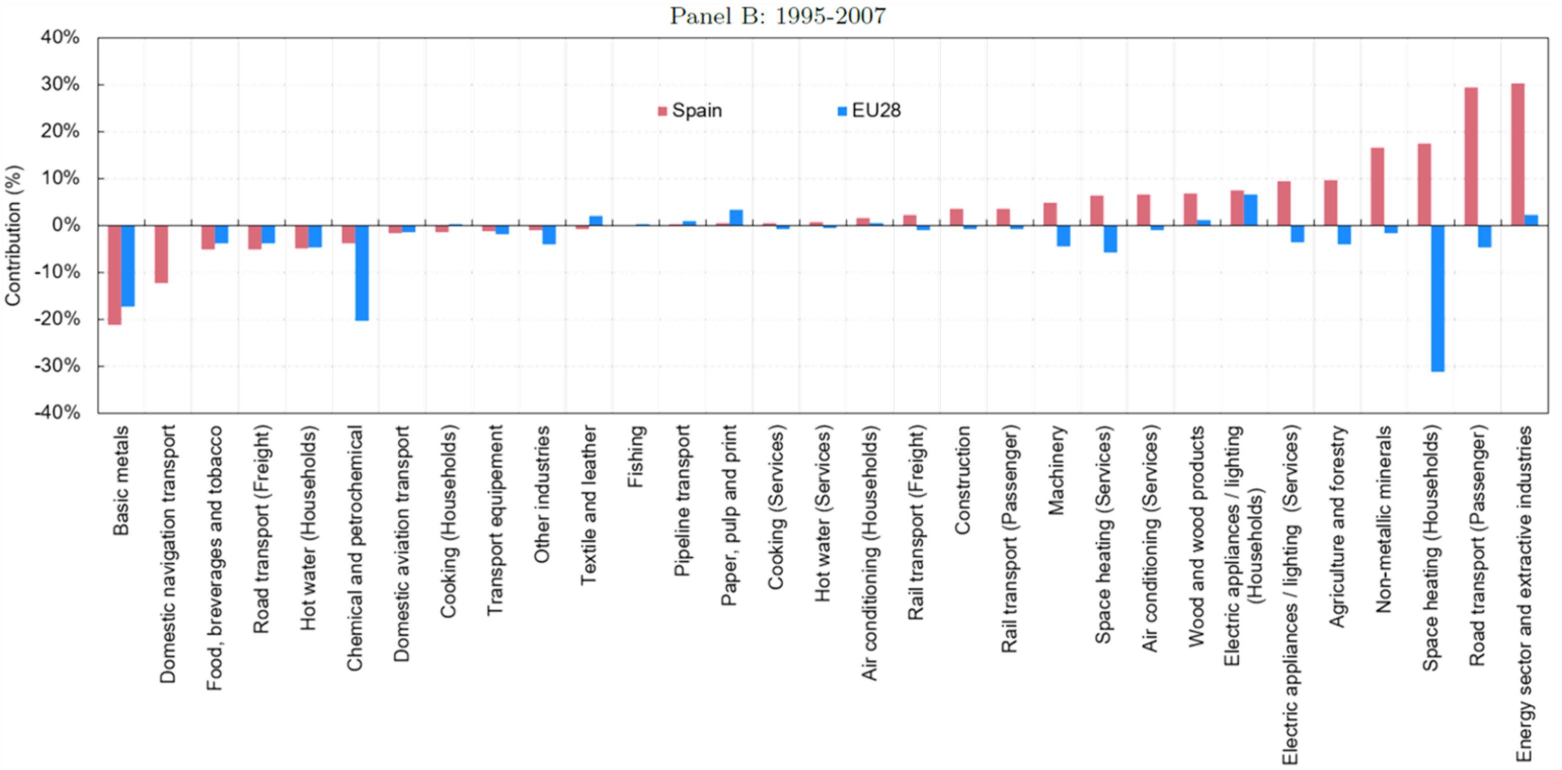
VIII. Transport Mode Composition

	Spain			EU28		
Mode	1995	2007	2017	1995	2007	2017
Passenger transport (% of total PKM)						
Road	90.17%	88.57%	87.37%	90.41%	89.84%	89.04%
Rail	6.37%	6.14%	8.05%	8.52%	8.62%	9.49%
Aviation	3.46%	5.29%	4.58%	1.06%	1.55%	1.46%
Freight transport (% of total TKM)						
Road	80.66%	84.26%	80.76%	67.34%	72.61%	73.54%
Rail	3.95%	2.68%	3.03%	20.28%	17.05%	16.11%
Navigation	13.16%	10.92%	13.42%	6.38%	5.49%	5.64%
Pipeline	2.23%	2.14%	2.80%	6.00%	4.85%	4.71%

Appendix

IX. Sub-Sectoral Contributions to End-Use Efficiency

Return



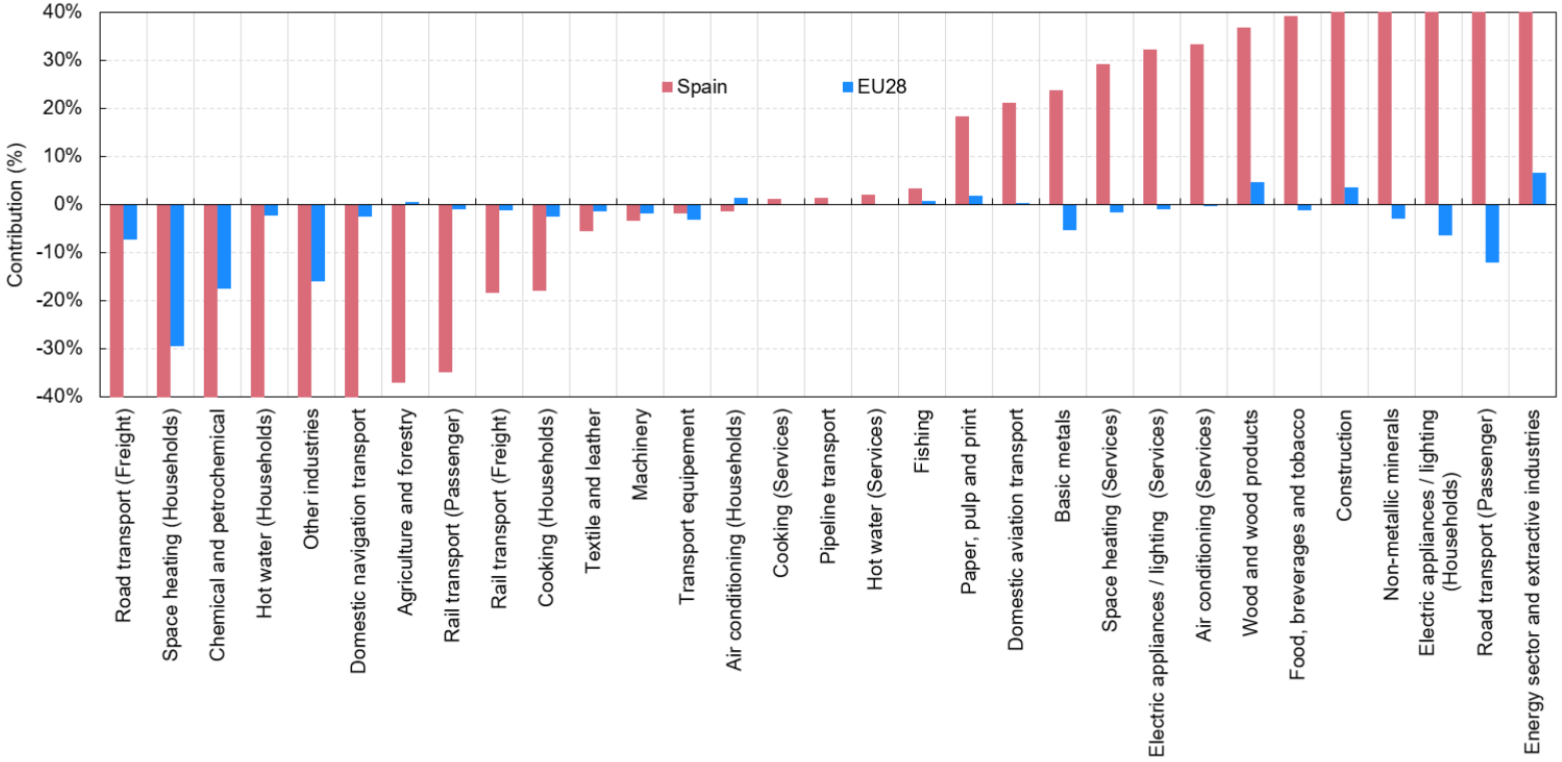
Note: Positive contributions refer to an upward pressure of the apparent end-use energy efficiency on the energy-related CO_2 emissions. Negative contributions refer to a downward pressure of the apparent end-use energy efficiency on the energy-related CO_2 emissions. Factors are sorted by contribution to the Spanish apparent energy efficiency contributing factor.

Appendix

IX. Sub-Sectoral Contributions to End-Use Efficiency

Return

Panel A: 2007-2017

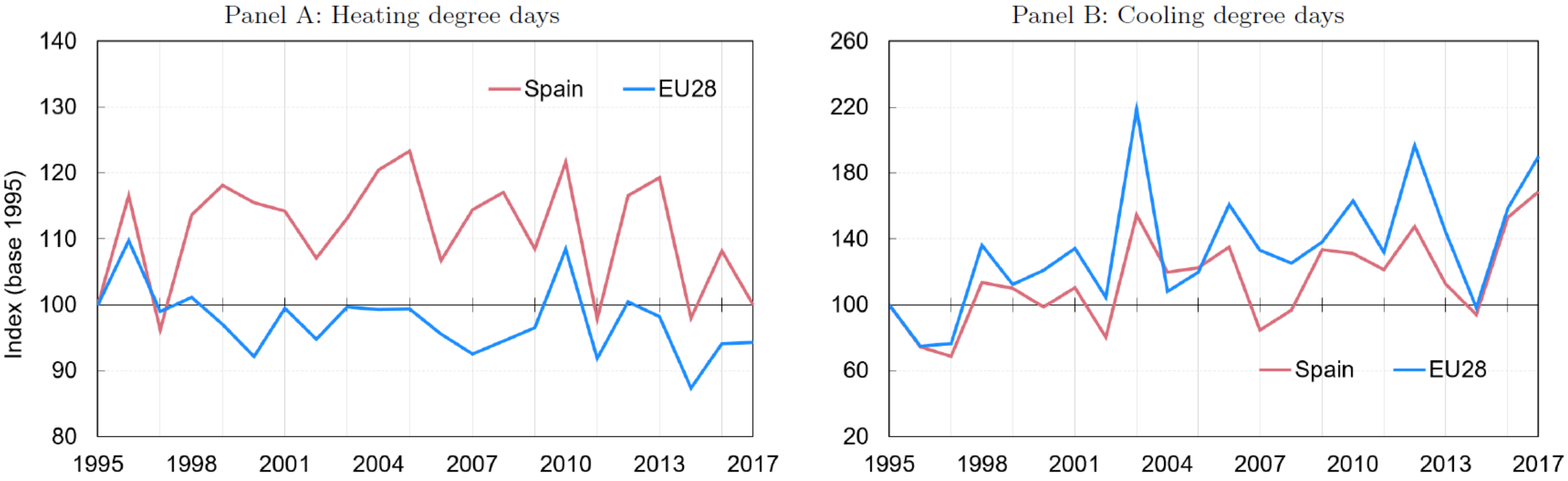


Note: Positive contributions refer to an upward pressure of the apparent end-use energy efficiency on the energy-related CO_2 emissions. Negative contributions refer to a downward pressure of the apparent end-use energy efficiency on the energy-related CO_2 emissions. Factors are sorted by contribution to the Spanish apparent energy efficiency contributing factor. There are some contributions in the period 2007-2017 that are greater than 40% (indeed, they are of the order of 200-300%) but the Panel A graph is limited to this region for a better visualization.

Appendix

X. Heating and Cooling Degree Days

Return



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