Energy Statistics and Indicators Training
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Energy Efficiency Indicators

Analyzing changes in energy and potential improvements in energy consumption

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Goal of this training session

Provide tools and best practice analysis to

1. Calculate the potential improvement in electricity generation from fossil-fuels

2. Calculate the factors underlying changes in energy consumption

Generation efficiency

- **Fossil fuels (coal, gas, oil)**
- **Main activity producer electricity plants and main activity producer CHP plants**
- **Efficiency E:**

$$E = \frac{energy\ output}{energy\ input}$$

  - Energy input: net calorific values (estimated using the lower heating value LHV)
  - Energy output: gross production of electricity and heat.

    auxiliary electricity consumption and losses in transformers are included

Generation efficiency: correction for CHP

- Efficiency
  - the extraction of heat reduces the electric efficiency
  - but increases the overall (electrical and thermal) efficiency
- Formula:

$$E = \frac{P + H * s}{I}$$

  - P: electricity production from public electricity plants and public CHP plants
  - H: heat output from public CHP plants
  - s: correction factor between heat and electricity, defined as the reduction in electricity per unit of heat extracted. S=0.15-0.2 (Phylipsen, 1998)
  - I: fuel input for public electricity plants and public CHP plants

Exercise: generation efficiency

- Calculate the energy efficiencies for 4 selected countries
- Compare the average efficiencies between 1990-1994 and 2004-2008
- Determine the potential fuel savings

Purpose of decomposition

- Quantify relative contributions of the pre-defined factors to the change in energy consumption
- Track down the origin in energy consumption variations
- Measure effectiveness of energy policy and technology

Main components of energy consumption

The changes in energy use within a sector are separated in various components:

$$E = \sum_{i}^{n} A \cdot \frac{A_i}{A} \cdot \frac{E_i}{A_i} = A \cdot \sum_{i}^{n} (S_i \cdot I_i)$$

i subsector or end-uses within a given sector

- **Aggregate activity A**

  value-added for manufacturing industry and services; population in the household sector; or as passenger-kilometres and tonne-kilometres, respectively, for the passenger and freight transport sectors

- **Sectoral structure S**

  mix of activities within a sector and further divides activity into industry sub-sectors, measures of residential end-use activity or transportation modes

- **Energy intensity I**

  energy use per unit of activity

Sector	Sub-sector	Activity (A)	Structure (S)	Intensity (I)
Households				
	Space Heating	Population	Floor Area/Population	Space Heating Energy[1] /Floor Area
	Water Heating	"	Population/ Occupied Dwellings	Water Heating Energy[2] /Occupied Dwellings
	Cooking	"	Population/ Occupied Dwellings	Cooking Energy[2] / Occupied Dwellings
	Lighting	"	Floor Area/Population	Lighting Energy /Floor Area
	Appliances	"	Appliances Ownership / Population	Appliances Energy / Appliances Ownership
Passenger Transport				
	Car	Passenger-kilometre	Share of Pass-kilometre	Energy/Pass-kilometre
	Bus	"	"	"
	Rail	"	"	"
	Domestic Air	"	"	"
Freight Transport				
	Truck	Tonne-kilometre	Share of Tonne-kilometre	Energy/Tonne-kilometre
	Rail	"	"	"
	Domestic Shipping	"	"	"
Manufacturing				
ISIC 15 – 16	Food, Beverages & Tobacco	Value-added	Share of Value-added	Energy/Value-added
ISIC 21 – 22	Paper, Pulp & Printing	"	"	"
ISIC 24	Chemicals	"	"	"
ISIC 26	Non-metallic Minerals	"	"	"
ISIC 27	Primary Metals	"	"	"
ISIC 28 – 32	Metal Products & Equipment	"	"	"
ISIC 17 – 20, 25, 33 – 37	Other Manufacturing	"	"	"
Services				
ISIC 50 – 99	Services	Value-added	Share of Value-added	Energy/Value-added
Other Industries[3]				
ISIC 1 – 5	Agriculture & Fishing	Value-added	Share of Value-added	Energy/Value-added
ISIC 45	Construction	"	"	"

[1] Adjusted for climate variations using heating degree-days.
[2] Adjusted for household occupancy.
[3] The following ISIC groups are not included in the analysis: 10 – 14 Mining & Quarrying; 23 Fuel Processing; and 40 – 41 Electricity, Gas & Water Supply. Industries in category "Other industries" are analysed only to a very limited extent in this study.

Decomposition components

- **Activity effect E_t^A**

  The activity effect can be calculated as the relative impact on energy use that would have occurred in year *t if the structure and energy intensities for a sector had remained* fixed at their base year values (t=0) while aggregate activity had followed its actual development.

- **Structure effect E_t^S**

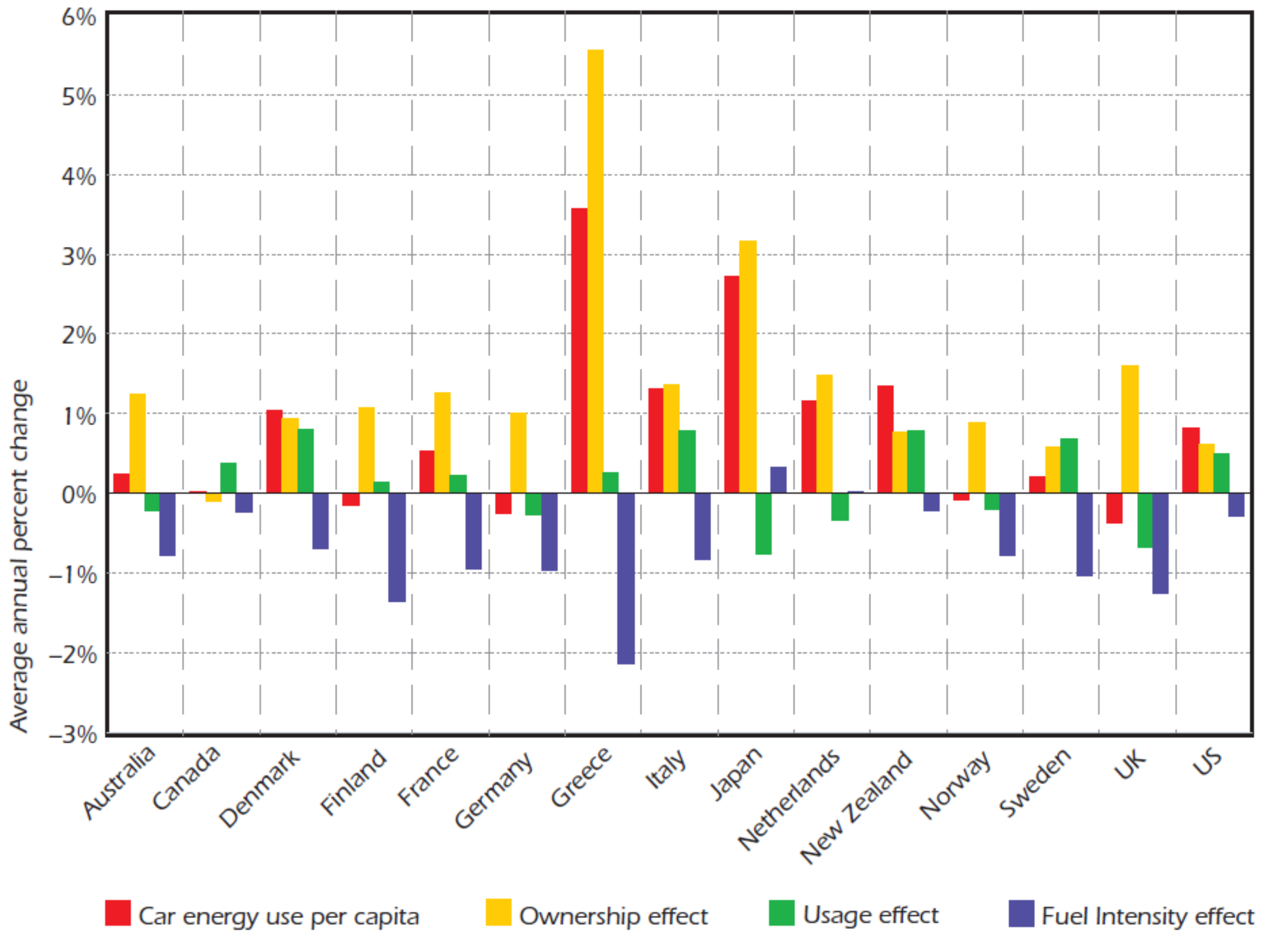
  The structure effect is determined by making the calculation using constant aggregate activity and energy intensities but varying the sectoral structure.

- **Intensity effect E_t^I**

  The intensity effect is calculated by assuming that the sectoral structure and aggregate activity for a sector had remained fixed at the base year values while energy intensities had followed their actual development.

Discussion of results: Passenger Transport

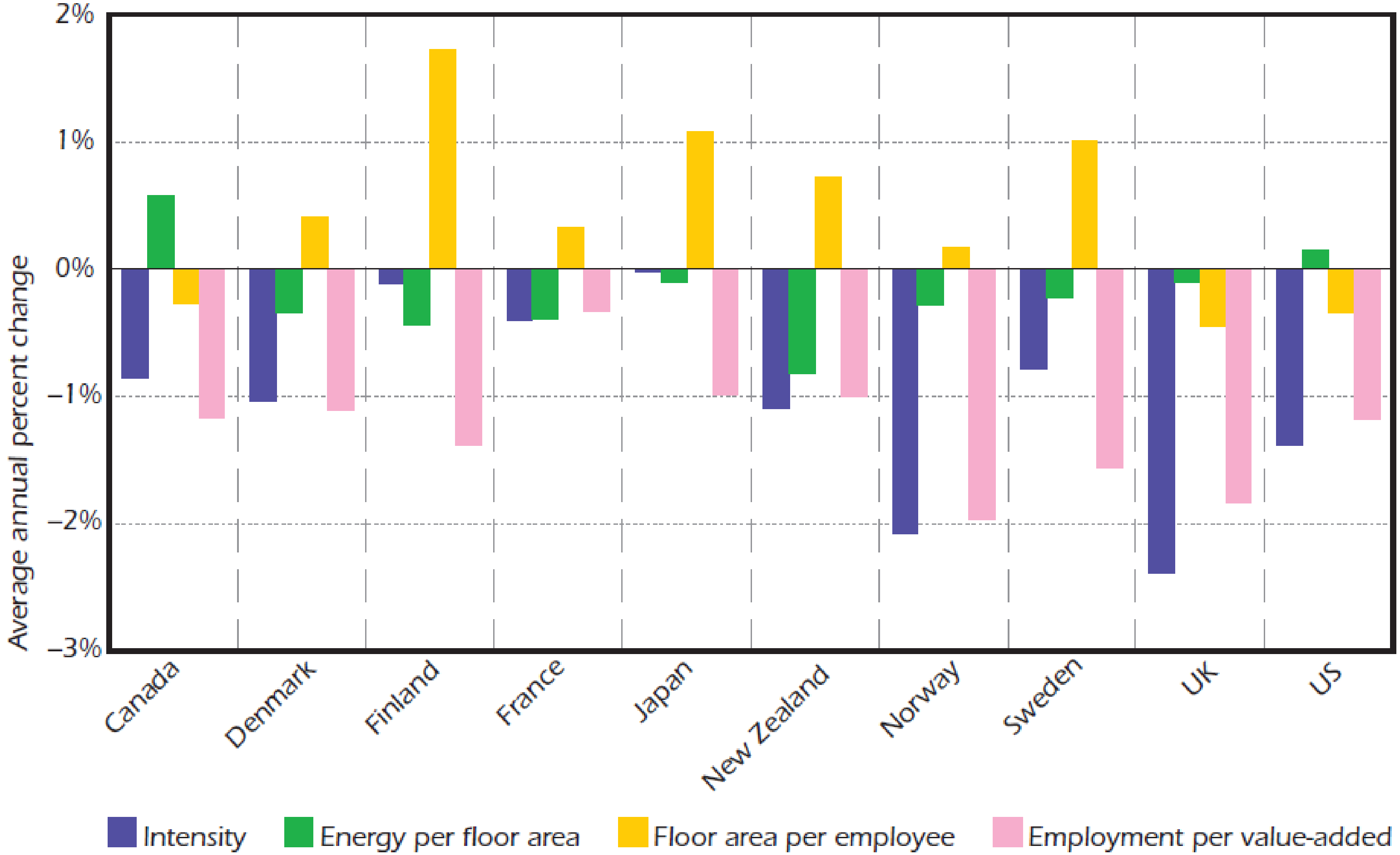
Figure 6.22 ▶ *Decomposition of Changes in Car Energy Use per Capita, 1990 – 2004*



Note: Austria and Ireland are excluded due to the lack of complete time series data for vehicle-kilometres.

Discussion of results: Service sector

Figure 5.10 ▶ *Decomposition of Changes in Service Sector Energy Intensity, 1990 – 2004*



Mathematical derivation

- Goal: decompose energy consumption so that ε is minimal $\Delta E = E_t - E_0 = \Delta A + \Delta S + \Delta I + \varepsilon$
- Change in energy consumption:

$$E = \sum_i A_t S_{i,t} I_{i,t} \qquad \Big| \cdot \frac{d}{dt}$$

$$\Leftrightarrow \frac{\partial E_t}{\partial t} = \sum_i \frac{\partial A_t}{\partial t} S_{i,t} I_{i,t} + \sum_i \frac{\partial S_{i,t}}{\partial t} A_t I_{i,t} + \sum_i \frac{\partial I_{i,t}}{\partial t} A_t S_{i,t} \qquad \Big| \cdot \frac{1}{E_0} \int_0^t dt$$

$$\Leftrightarrow \ln\left(\frac{E_t}{E_0}\right) = \int_0^t \sum_i \frac{\partial A_t}{\partial t} \frac{S_{i,t} I_{i,t}}{E_0} dt + \int_0^t \sum_i \frac{\partial S_{i,t}}{\partial t} \frac{A_t I_{i,t}}{E_0} dt + \int_0^t \sum_i \frac{\partial I_{i,t}}{\partial t} \frac{A_t S_{i,t}}{E_0} dt$$

- Fortunately we do not need to solve this equation and various methods have been developed

Overview of existing methods

$$\Delta E = E_t - E_0 = \Delta A + \Delta S + \Delta I + \varepsilon$$

- ε is a residual whose magnitude depends on the decomposition method
- Common methods
  - Laspeyres method
  - Paasche index
  - Simple average divisia method (arithmetic mean or Törnqvist formulation)
  - Fischer Ideal
  - Parametric Divisia Method I (PMD I) and II (PMD II)
  - Log Mean Divisia I (LMD I) and II (LMD II)

Evaluation of existing methods

Index	Perfect decomposition	Time is reversible	Subsectors additive	Easy to understand
Paasche	no	no	YES	very easy
Simple Laspeyres	no	no	YES	very easy
Refined Laspeyres	YES	no	YES	moderately
Fischer Ideal	YES	YES	No	moderately
Simple average/ arithmetic mean/ divisia (Törnqvist)	no	YES	No	moderately
Adjusted PMD I and II	no	YES	YES	difficult
LMD I	YES	YES	YES	moderately
LMD II	YES	YES	no	moderately

- Laspeyres and LMDI are the preferred methods
  - Laspeyres for its ease of understanding, especially to non-experts, but the the existence of an interaction term is a drawback
  - LMDI for its theoretical soundness

Laspeyres

- + easy to communicate
  - interaction term

	Additive	Multiplicative
Activity Effect	$E_t^A = A_t \sum_i S_0^i I_0^i - E_0$	$E_t^A = \frac{A_t \sum_i S_0^i I_0^i}{E_0}$
Structural Effect	$E_t^S = A_0 \sum_i S_t^i I_0^i - E_0$	$E_t^S = \frac{A_0 \sum_i S_t^i I_0^i}{E_0}$
Intensity Effect	$E_t^I = A_0 \sum_i S_0^i I_t^i - E_0$	$E_t^I = \frac{A_0 \sum_i S_0^i I_t^i}{E_0}$

LMDI

- + no interaction term

  - more difficult to communicate to non-experts

  - Method not defined for zeros or negative numbers in data

	Additive	Multiplicative
Activity Effect	$E_t^A = \sum_i L(E_i^T, E_i^0) \ln\left(\frac{A^T}{A^0}\right)$	$E_t^A = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \ln\left(\frac{A^T}{A^0}\right)\right)$
Structure Effect	$E_t^S = \sum_i L(E_i^T, E_i^0) \ln\left(\frac{S_i^T}{S_i^0}\right)$	$E_t^S = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \ln\left(\frac{S_i^T}{S_i^0}\right)\right)$
Intensity Effect	$E_t^I = \sum_i L(E_i^T, E_i^0) \ln\left(\frac{I_i^T}{I_i^0}\right)$	$E_t^I = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \ln\left(\frac{I_i^T}{I_i^0}\right)\right)$
$L(a,b) = \frac{a-b}{\ln a - \ln b}$ *with* $a,b > 0$ *and* $a \neq b$		

Exercise session: end-use

- Perform complete decomposition using Laspeyres and LMDI
- Calculate the activity, structure and intensity effect of the given dataset for the manufacturing sector
- Compare results from LMDI and Laspeyres

Fixed vs. rolling base year decomposition

For every method, two decomposition schemes exist:

- Fixed base year or non-chained decomposition
  - change in energy consumption between base year 0 and final year T
  - + data for all intermediate years not required
- Rolling base year or chained decomposition
  - yearly change in energy consumption between base year 0 and 1, year 1 and 2, … year T-1 and T and finally chaining of results
  - + more precise

Commodity correction

- In the industrial sector, the best measure of activity is physical units of production (e.g. tones of pulp, liters of beer).
- These units are difficult to compare, but they are a better indicator of activity
- No constant relation between value added (GDP) and physical units exist, as changes in price influence the relationship. The activity can be corrected as follows:

$$A_i = P_i^0 * \frac{V_i^t}{V_i^0}$$

P: GDP output; V: physical unit; i:subsector; t: current year; 0: base year

- IEA collects commodity data for cement, steel, pulp and paper

currently: no correction performed, but recommended

Weather correction

The impact of weather should be considered in household heating and cooling:

- Correction for weather for space heating energy

$$E_{-SH} = \frac{E_{SpaceHeating}}{1-\sigma_{heat}(1-\tau_{heat,i})}$$

- Correction for weather for space cooling

$$E_{-SC} = \frac{E_{SpaceCooling}}{1-\sigma_{cool}(1-\tau_{cool,i})}$$

- Correction for weather

$$E_{-W} = E_{-SH} + E_{-SC}$$

$\sigma_{heat/cool}$ heating/cooling elasticity for adjusting heating requirements

$\tau_{heat,\, i/\, cool,\, i}$ heating/cooling index of variance from average requirements by year i (e.g. heating/cooling degree days in current year compared to average from 30 past years)

IEA assumptions

- only heating considered
- σ_{heat} assumed 1 (probably around 0.75)
- $HDD_{30\ past\ years}$ =2700 (global average)

Take-away messages

- Decomposition analysis is essential to analyze energy end-use
- Energy consumption can be decomposed in Activity (A), Structure (S) and Intensity (I)

$$E = A \cdot \sum_{i}^{n} (S_i \cdot I_i)$$

- LMD I preferred method
- Fixed base-year vs. rolling base year (depending on available data)
- Correction for cooling should be considered in warm regions

References

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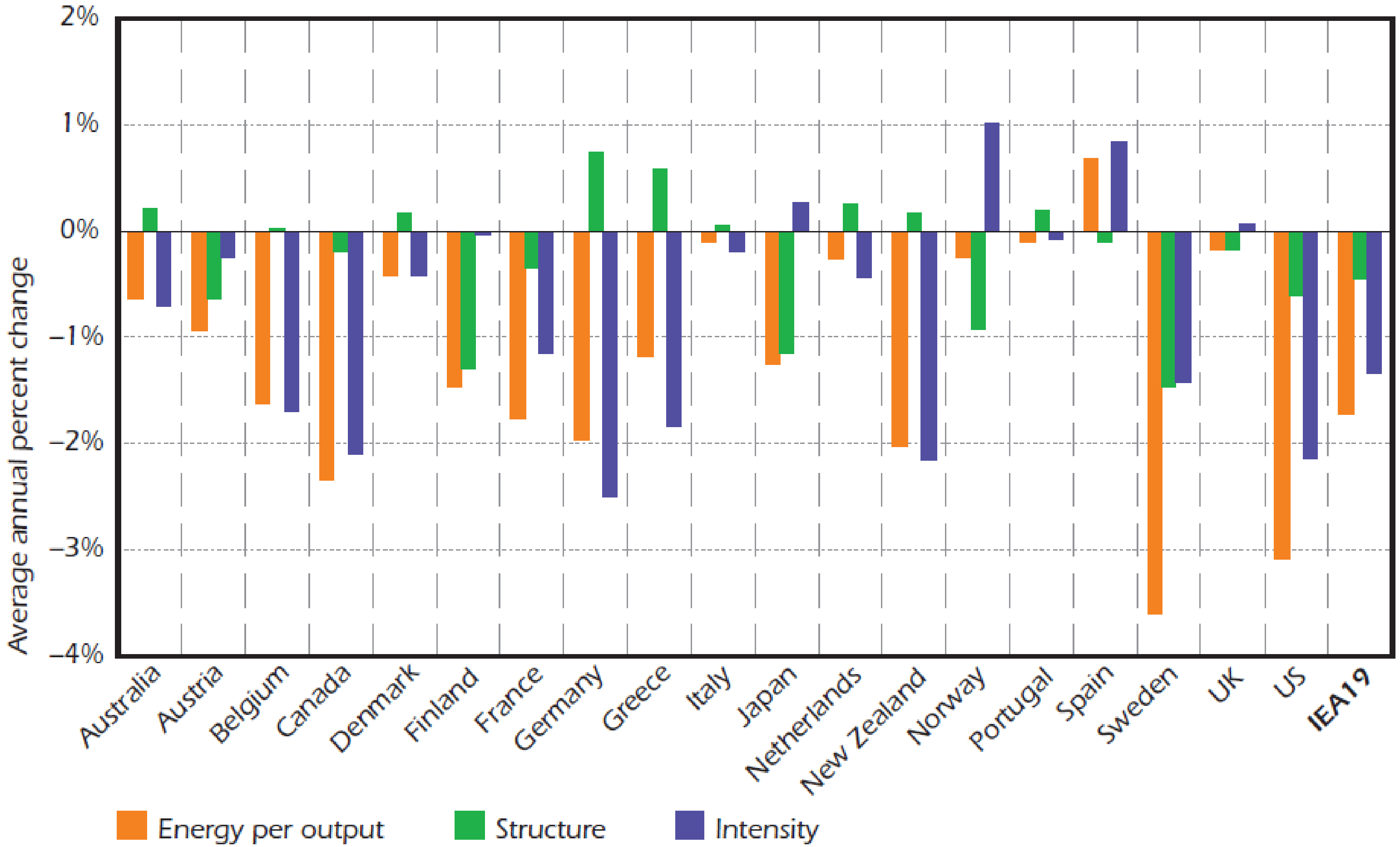
Discussion of results: Manufacturing

Figure 3.16 ▶ *Decomposition of Changes in Manufacturing Energy Intensity, 1990 – 2004*



Discussion of results: Household heating

Figure 4.16 ▶ *Decomposition of Changes in Space Heating per Capita, 1990 – 2004*