Energy and CO_2 Efficiency in the European Manufacturing Sector: A Decomposition Analysis

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Abstract: *The industry sector is one of the largest consumers of energy and also one of the largest energy-related CO_2 emitters. This paper aims to gain insights into the mechanisms of change in industrial energy consumption as well as changes in CO_2 emissions for ten manufacturing industries in five European countries by using a time-series decomposition technique based on the Log Mean Divisia Index (LMDI) method. Results show that significant gains in energy productivity as well as fuel switch in power generation and final consumption can in most cases offset the effect of rising industrial activity and help to mitigate carbon dioxide emissions.*

1. Introduction and Literature Review

The industrial sector accounts for nearly one-third of global energy use. It is not only one of the largest consumers of energy, but also one of the largest energy-related carbon dioxide (CO_2) emitters. Energy efficiency efforts in the manufacturing sector help to cut corporate costs, reduce dependency on energy imports and mitigate Greenhouse Gas (GHG) emissions.

The first part of this empirical investigation looks into the mechanisms of change in industrial energy consumption for five European countries - France, Italy, Spain, Sweden and Belgium. One possibility to analyse the relationship between industrial energy demand and changes in underlying factors in this context is the use of decomposition analysis. This work provides a breakdown of the change in energy consumption between 1981 and 2005 for ten manufacturing sectors in the five countries mentioned above to the following effects: the overall industrial activity, activity mix and the sectoral energy intensity.

In the second part of this paper changes in energy-related CO_2 emissions are investigated for the same manufacturing industries, as this helps to gain deeper insights into the effects of fuel switch on carbon dioxide emissions in the industry sector. In addition to the decomposition of energy consumption changes, the two factors causing these changes are the sectoral energy mix and carbon dioxide emission factors.

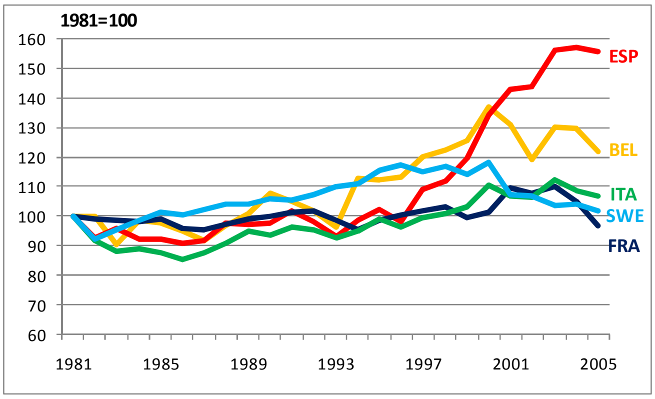

Fig. 1: Total final energy consumption of industries analysed[1]

As shown in figure 1 there has only been a moderate rise in industrial energy consumption in France, Italy and Sweden between 1981 and 2005, and there has even been a reduction in Swedish energy demand in the last ten years. In Belgium industrial energy use has been rising considerably within the period observed with a high volatility in the last years. Spain however experienced a boost in industrial energy consumption in the last decade. Looking at these developments and differences, the question arises whether the trend in industrial energy demand is primarily dependent on the impact of changes in energy intensity or structural, i.e. product-mix effects.

Figure 2 shows the development of carbon dioxide emissions for the time period observed. It becomes evident that the boost in energy demand in the Spanish manufacturing sector discussed above also had a significant impact on emissions. Nevertheless the increase in CO2 emissions has been lower than the increase in energy demand. For Sweden, Belgium and France emissions levels in 2005 were even remarkably lower than in 1981. Again it is useful to investigate why CO_2 emissions did not change according to the same pattern as industrial energy demand and why the five countries performed so differently within the time period observed.

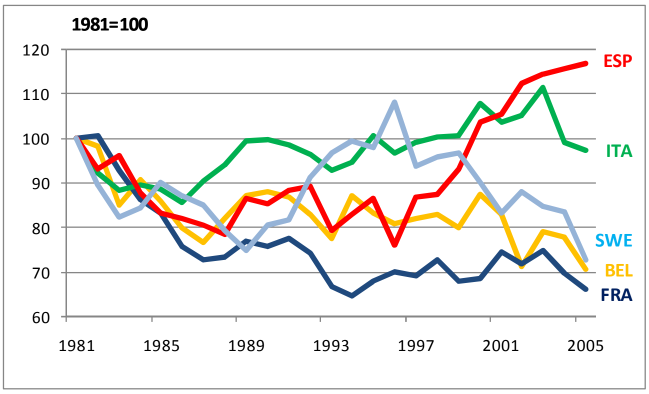

Fig. 2: Total CO_2 emissions of industries analysed[1]

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[1] Data source: IEA online database

In general, historical changes in economic, environmental or other socio-economic indicators can be analysed by assessing the underlying forces or determinants that are responsible for these changes. This can be done with two different methods, the structural decomposition analysis and the index decomposition analysis. The main difference between the structural and the index decomposition method is that the former uses input-output tables while the latter uses only aggregate sector information (Hoekstra and van der Bergh 2003). As index decomposition analysis requires less data which in addition is often available on an annual basis, it can be conducted to study different time periods and it allows cross-country comparisons. Due to the lack of time series data, usually information from two periods are used to examine which determinant changes have contributed most to a change in the indicator.

Furthermore, the index decomposition technique can be divided into methods linked to the Laspeyres index as well as methods linked to the Divisia index. Methods linked to the Laspeyres index are based on a percentage change and the impact of a determinant is computed through letting that determinant to change while holding all the others at their base year values. In contrast, the Divisia index methods use a weighted sum of logarithmic growth rates, where the weights are the determinants' shares in the total value. As exhibited in figure 2, decomposition can be performed multiplicatively, where the ratio change of an aggregate is decomposed, or additively, where the difference change is decomposed.

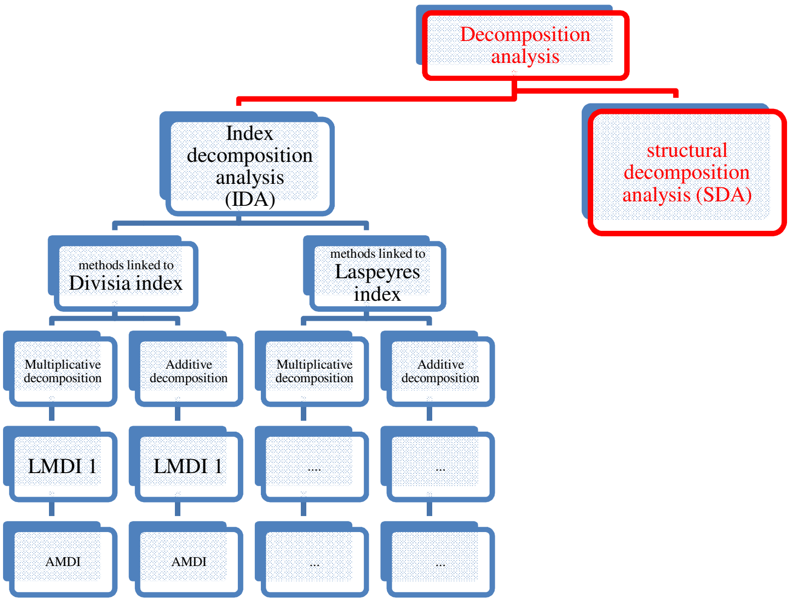


Fig. 2: Methods in decomposition analysis

Howarth et al. (1991) compared the results between the Laspeyres index and the Divisia index in an investigation of manufacturing energy use in eight OECD countries between 1973 and 1987 and found only minor differences between the two methods. Ang and Lee (1994) looked at five different methods and found that the adaptive weighting and the simple average Divisia index methods tended to yield smaller residuals in decomposition. A refined Divisia index method was introduced by Ang et al. (1998). This logarithmic mean Divisia index (LMDI) approach was able to get perfect decomposition, handle the zero values in the dataset and study the decomposition of a differential change. Sun (1998) presented a complete decomposition model to solve residual terms with a decomposition of the changes in world energy consumption. Ang and Liu (2001) then presented the log-mean Divisia method I (LMDI I), which had the desirable characteristics of perfect decomposition and consistency in aggregation. According to Ang (2004) the desirability of a decomposition method can be evaluated by four factors: (a) the theoretical foundation, (b) the adaptability, (c) the ease of use and (d) the ease of result interpretation. On this basis he recommends the log mean Divisia index methods LMDI 1 (additive or multiplicative) as the most preferred methods for empirical studies.

The most common application areas for the index decomposition analysis are energy demand and supply analysis as well as energy-related greenhouse gas (GHG) emissions.

In empirical papers covering energy demand and supply issues, the relative contributions of the impacts of structural change and energy intensity change are studied. Industrial energy demand is the most prominent area, but also demand analysis for the total economy and other sectors, such as transport or residential are conducted. These studies analyse the relative contribution of different factors affecting changes in energy use, and thus help to understand changing energy consumption patterns and to predict future energy demand.

One of the early contributions in this context was the paper of Jenne and Cattell (1983) who examined the change in the ratio of energy consumed to industrial production in the UK and concluded that first of all growth is the key to rising efficiency and after that structural change as a shift away from the heavy energy users within a sector. Howarth and et al. (1991) used the Laspeyres index method to look at trends in manufacturing energy use in eight OECD countries between 1973 and 1987 by decomposing the changes in energy consumption into an activity effect, a structure effect and an energy intensity effect. They compared the results to those obtained by using the Divisia index method and found minor differences between the Laspeyres index and the Divisia index calculations. Another study that assessed the influence of developments in energy efficiency and economic structure on the total primary energy consumption is that of Farla and Blok (2000). Park (1992) used structural change, energy intensity and output level, to decompose the industrial energy demand in Korea from 1973 to 1989.

In the field of energy-related GHG emissions, mostly carbon dioxide emission changes for the whole economy are analysed. In addition to structural and energy intensity changes, sectoral fuel shares and emission coefficients are relevant factors for changes in emissions on a national level. Ang and Zhang (1999) used a five factor decomposition for several groups of countries in 1993 to decompose the differences of emissions from fossil fuel use between the regions. The large disparities found between regions were mainly due to differences in GDP and energy intensity. Greening et al. (1998) applied the adaptive weighted Divisia index to analyse energy consumption and carbon intensity of the freight sector of 10 OECD countries. A four factor decomposition for Turkey for the period 1980-2003 was conducted by Lise (2006). This study identified a structural (composition) effect for the changing shares of sectors in GDP. The GDP effect, structure effect, and carbon intensity effect were all associated with substantial increases in emissions, while energy intensity lead to a small reduction in emissions. Lee and Oh (2006) produced a five factor decomposition for 15 APEC countries between 1980 and 1998. This group included high, middle and lower income countries. Although GDP and population were strong factors associated with an increase in emissions in all cases, in the high income countries falling energy intensity, the share of fossil fuels and a change in the fossil fuel mix all contributed to partially offsetting the impacts of the growth in the economies. The group of lower income countries was dominated by China which, in this period, experienced a large fall in energy intensity, offsetting nearly half the impacts of the increase in income and population.

This empirical study uses the LMDI 1 methodology to decompose the changes in total final energy consumption as well as the development of energy-related industrial carbon dioxide emissions in ten manufacturing sectors between 1981 and 2005 for five European countries.

2. Methodology

According to Ang (2005), changes in industrial energy consumption may be studied by quantifying the impacts of changes in the following three factors:

- The activity effect: Overall industrial activity
- The structure effect: Activity mix
- The intensity effect: Sectoral energy intensity

The index decomposition analysis (IDA) identity is:

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i \qquad (1)$$

where E is the total energy consumption in the industry,

$Q \ (= \sum_i Q_i)$ is the total activity level of all manufacturing industries covered,

$S_i (= \frac{Q_i}{Q})$ is the activity share of industry i,

$I_i (= \frac{E_i}{Q_i})$ is the energy intensity of industry i.

Since additive decomposition is used here the following difference is decomposed:

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \qquad (2)$$

The corresponding LMDI formulae for decomposing changes in industrial energy consumption are:

- $\Delta E_{act} = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} \ln \left(\frac{Q^T}{Q^0}\right)$ (3)
- $\Delta E_{str} = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} \ln \left(\frac{S_i^T}{S_i^0}\right)$ (4)
- $\Delta E_{int} = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} \ln \left(\frac{I_i^T}{I_i^0}\right)$ (5)

Changes in carbon dioxide emissions from industry can be analysed by quantifying the contributions from changes in activity, energy intensity and structure as well as two additional factors:

- The sectoral energy mix (energy-mix effect)
- CO_2 emission factors (emission-factor effect)

The sub-categories of the aggregate in this case are the industrial sector (*i*) and the fuel type (*j*); the IDA identity is:

$$C = \sum_{ij} C_{ij} \; = \; \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_i Q S_i I_i \, M_{ij} \, U_{ij} \qquad (6)$$

where C is the total CO_2 emission and C_{ij} is the CO_2 emission arising from fuel *j* in industry *i*.

E_{ij} is the consumption of fuel *j* in industrial sector *I* and $E_i\left(= \sum_j E_{ij}\right)$ is the total final energy consumption in industry *i* equal to the sum of the final consumption of fuels *j* in these sectors,

$M_{ij}(= \frac{E_{ij}}{E_j})$ is the fuel mix variable, and

$U_{ij}(= \frac{C_{ij}}{E_{ij}})$ is the CO_2 emission factor.

To analyse changes in energy related carbon dioxide emissions the following difference is decomposed additively:

$$\Delta C_{tot} = C^T - C^0 \; = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf}, \qquad (7)$$

and the LMDI formulae are:

- $\Delta C_{act} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{lnC_{ij}^T - lnC_{ij}^0} \ln \left(\frac{Q^T}{Q^0}\right)$ (8)

- $$\Delta C_{str} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{lnC_{ij}^T - lnC_{ij}^0} \ln\left(\frac{S_i^T}{S_i^0}\right) \tag{9}$$

- $$\Delta C_{int} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{lnC_{ij}^T - lnC_{ij}^0} \ln\left(\frac{I_i^T}{I_i^0}\right) \tag{10}$$

- $$\Delta C_{mix} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{lnC_{ij}^T - lnC_{ij}^0} \ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right) \tag{11}$$

- $$\Delta C_{emf} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{lnC_{ij}^T - lnC_{ij}^0} \ln\left(\frac{U_{ij}^T}{U_{ij}^0}\right) \tag{12}$$

In general decomposition analysis can be carried out in two ways: a) by simply using the data for the start year and the final year of a defined period (period-wise decomposition), or b) by applying time series analysis, where it can be analysed how the contributing effects have changed over time. Ang and Lee (1994) argued that if available, time series decomposition should be used because the decomposed results can better explain the underlying mechanisms of changes in industrial energy use or emissions and are less dependent on the methodology used. In the case of the countries and industry sectors investigated in this paper, time series data exists for the period between 1981 and 2005.

3. Data

The data used for this empirical investigation consists of the following indicators:

- Value Added at constant 2000 prices in national currencies by industry, denominated as *Q*
- Total Final Energy Consumption in kilotons of oil equivalent (ktoe) by industry and fuel, denominated as *E*.
- CO_2 emissions in kg by industry and fuel, denominated as *C*
- Emission factors by fuel type

The ten manufacturing industries analysed are

- Food and tobacco (FOD, ISIC Rev.3: 15-16)
- Textile and leather (TEX, ISIC Rev.3: 17-19)
- Wood and wood products (WOD, ISIC Rev.3: 20)
- Paper, pulp and printing (PAP, ISIC Rev.3: 21-22)
- Chemical and petrochemical (CHE, ISIC Rev.3: 24)
- Non-metallic minerals (NMM, ISIC Rev.3: 26)
- Iron and steel (IRS, ISIC Rev.3: 271+2731)

- Non-ferrous metals (MET, ISIC Rev.3: 272+2732)
- Machinery (MAC, ISIC Rev.3: 28-33)
- Transport equipment (TRA, ISIC Rev.3: 34-35)

The fuels covered are petroleum products, natural gas, coal and coal products as well as electricity. The annual data on energy consumption and CO_2 emissions used in this study is obtained from the International Energy Agency Online Data Services database as well as the emission factors for electricity consumption. Value added data for the manufacturing industries is taken from the OECD STAN structural database. The emission factors for the primary energy sources used are taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The time frame observed reaches from 1981 to 2005 for France, Italy, Spain, Sweden and Belgium.

Table 1: country indicators 1981 and 2005

	France		**Italy**		**Spain**		**Sweden**		**Belgium**	
VA in nat. cur.	1981	2005	1981	2005	1981	2005	1981	2005	1981	2005
Total	840.614	1.396.698	723.444	1.099.043	333.167	664.402	1.294.793	2.325.377	152.477	242.279
Industry	167.059	244.961	176.868	233.633	74.349	128.668	310.885	507.388	40.829	46.642
% of Total	19,9%	17,5%	24,4%	21,3%	22,3%	19,4%	24,0%	21,8%	26,8%	19,3%
∑ Sectors i	139.937	194.567	137.374	184.575	66.805	114.148	257.013	429.702	29.877	36.684
% of Industry	83,8%	79,4%	77,7%	79,0%	89,9%	88,7%	82,7%	84,7%	73,2%	78,6%
TFC in ktoe										
Total	137.456	176.395	100.221	145.223	47.255	105.192	33.746	35.169	30.579	40.621
Industry	35.635	32.881	33.737	37.536	18.666	30.481	11.077	11.999	10.032	12.180
% of Total	25,9%	18,6%	33,7%	25,8%	39,5%	29,0%	32,8%	34,1%	32,8%	30,0%
∑ Sectors i	29.975	29.078	32.162	34.409	17.172	26.728	10.344	10.525	9.193	11.182
% of Industry	84,1%	88,4%	95,3%	91,7%	92,0%	87,7%	93,4%	87,7%	91,6%	91,8%

Looking at the indicators in table 1 it becomes evident that the share of the industrial sector in relation to the total value added of the economy has fallen significantly between 1981 and 2005 in all the countries. With the exception of Sweden this is also the case for the share of industrial energy consumption. Nevertheless the industrial sector is still one of the biggest energy users and CO_2 emitters in the economy. The ten manufacturing industries analysed in this study account for approximately 80 to 95 % of all energy consumed in the industrial sector of the respective country.

4. Empirical Results

Decomposition of changes in energy consumption

The results summarized in table 2 show that in all five European countries, the activity effect between 1981 and 2005 was very large with values reaching from +19,5% in Belgium up to +57,4% in Spain.

This was only partly compensated by a significant negative energy intensity effect in Italy and almost fully compensated in Sweden due to a supporting negative structural effect. In the French manufacturing sector the activity effect and a positive structural effect could be overcompensated by large energy productivity gains (i.e. negative energy intensity effect). Spain has made the biggest leap in industrial energy consumption between 1981 and 2005 with an increase of 55,7% due to its enormous jump in industrial activity. In Belgium the structural and energy intensity effects were too small to influence overall energy consumption in industry.

Table 2: aggregated decomposition results

in ktoe	**France**	**Italy**	**Spain**	**Sweden**	**Belgium**
TFC 1981	**29.975**	**32.162**	**17.172**	**10.344**	**9.193**
e_{act} 1981-2005	+9.868	+8.404	+9.851	+5.754	+1.792
e_{str} 1981-2005	+3.976	1.727	-1.414	-1.047	-186
e_{int} 1981-2005	-14.740	-7.883	1.120	-4.527	382
ΔE	-897	2.247	9.557	181	1.989
TFC 2005	**29.078**	**34.409**	**26.728**	**10.525**	**11.182**
e_{act} 1981-2005	+32,9%	+26,1%	+57,4%	+55,6%	+19,5%
e_{str} 1981-2005	13,3%	5,4%	-8,2%	-10,1%	-2,0%
e_{int} 1981-2005	-49,2%	-24,5%	6,5%	-43,8%	4,2%
ΔE	-3,0%	+7,0%	+55,7%	+1,8%	+21,6%

In order to compare intensity and structural effects, a two-dimensional plot proposed by Liu and Ang (2007) is used (fig. 4). The X-axis is a measure of the intensity effect and the Y-axis represents the structure effect. Furthermore, the plot is divided into eight different zones (I to VIII). If a country is located in zone III for example, then it has a positive intensity and a positive structural effect, the latter being larger than the intensity effect.

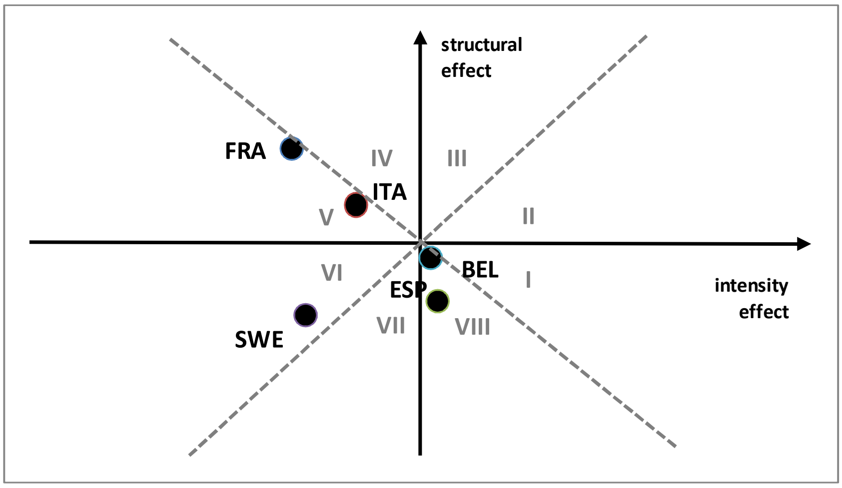


Fig. 4: Relative magnitude of intensity change and structure effect

For France, Sweden and Italy the energy intensity effect is negative, i.e. the change in output of the manufacturing industries analysed is larger than the change in energy consumption. In the case of France this negative intensity effect is partly neutralised by a positive structural effect, i.e. a shift to more energy consuming industries. This can also be observed in detail in figure 5 which exhibits the time series of cumulative activity, structure and intensity effects as well as the resulting change in energy consumption (Δe). The positive structural effect in the 1990's is caused by a shift towards the energy-intensive industries Iron and Steel and the Chemical sector.

For the Italian manufacturing industries the negative energy intensity effect was larger than the effect coming from an increase in industrial activity in the 1980s. In the middle of the last decade the cumulated aggregate change in energy consumption turned positive as the productivity gains were neutralised by the activity effect. The structural effect over the whole period was slightly positive but hardly significant (fig. 6).

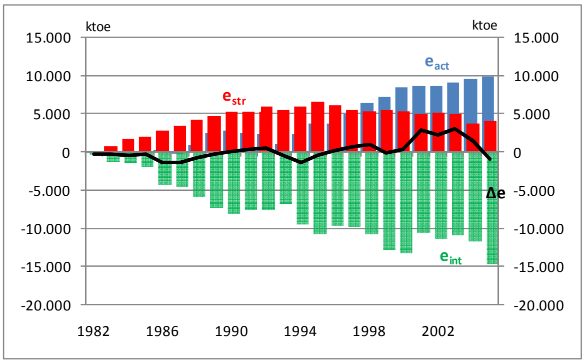


Fig. 5: energy decomposition results for France

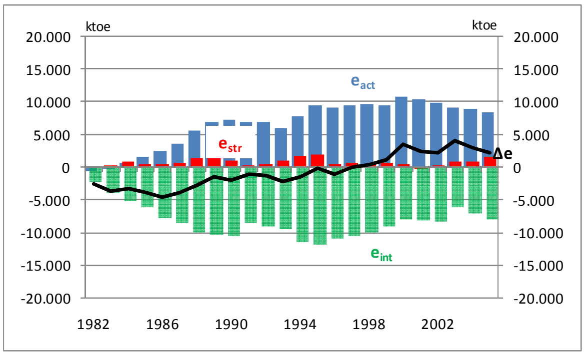
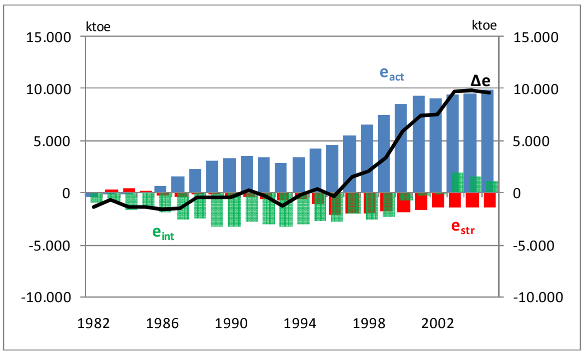


Fig. 6: energy decomposition results for Italy

In Spain the negative energy intensity effect made it possible to compensate for ascending industrial output until about 1995. After that energy productivity has been decreasing while the cumulative activity effect has continued to mount upwards. This has lead to a leap in industrial energy consumption in the last 10 years. The negative structural effect in the last ten years was not strong enough to stop this development (fig. 7).

Sweden's energy consumption in the manufacturing sector has been rising until the end of the 1990s. Since then the negative intensity effect has kept up with the growth rate of industrial activity. In addition a negative structural effect in the years 2003 to 2005 helped to reduce consumption almost to the level of 1981 (fig. 8).



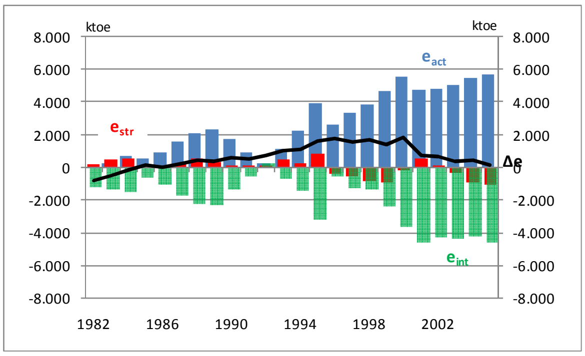


Fig. 7: energy decomposition results for Spain *Fig. 8: energy decomposition results for Sweden*

Even though there has been a shift to less energy-intensive industries in the second half of the 1990's, in Belgium it was not possible to offset the rise in industrial output through as energy intensity was increasing at the same time. Therefore aggregate industrial energy consumption is on a significantly higher level than at the beginning of the observation period (fig. 9).

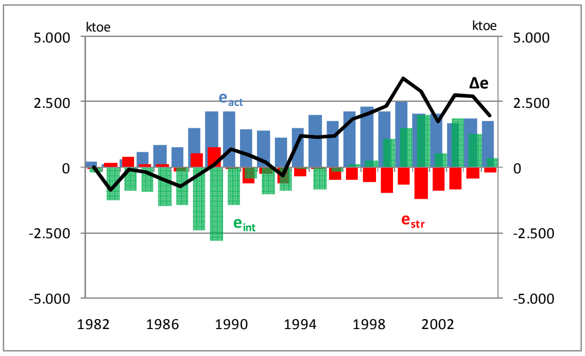


Fig. 9: energy decomposition results for Belgium

The performance of the individual manufacturing sectors can be derived from *table 3*. Huge energy productivity gains were achieved in the Chemical and Non-Ferrous Metals sectors in France and Italy as well as the Non-Ferrous Metals sector in Spain. In Sweden for the Food and Tobacco sector, the Chemical industry and above all for the Machinery sector a sharp reduction in energy intensity can be observed. Energy intensity has increased in the Transport sector in all countries except Spain.

Table 3: sectoral energy intensity performance 2005 / 1981

	FOD	TEX	WOD	PAP	CHE	NMM	IRS	MET	MAC	TRA	Total
France	-2,1%	-23,8%	-18,1%	-21,4%	-59,0%	-26,4%	-49,8%	-72,8%	-41,4%	35,6%	-30,2%
Italy	10,0%	43,8%	51,0%	-10,3%	-59,1%	-28,4%	-18,5%	-49,3%	-7,9%	61,6%	-20,4%
Spain	19,0%	11,3%	180,4%	8,3%	-11,9%	-6,6%	9,5%	-33,7%	30,4%	13,5%	-8,9%
Sweden	-52,7%	-40,4%	-21,0%	-18,7%	-54,9%	-45,9%	-14,6%	-24,9%	-78,5%	-36,1%	-39,1%
Belgium	24,6%	68,1%	591,9%	91,8%	25,5%	-48,1%	-25,2%	-16,9%	-44,8%	27,9%	-0,9%

Decomposition of changes in CO_2 emissions

As seen in figure 2 the development of carbon dioxide emissions has varied greatly between the five countries within the 25 years observed. Progress in the sense of successful mitigation efforts can be observed for Belgium, Sweden and France.

Although total final energy consumption in the Belgian manufacturing industry rose considerably, there has been a remarkable reduction of CO_2 emissions within the observation period. *Table 4* shows how emissions by sector and fuel type have changed between 1981 and 2005. In the start year, emissions from coal and electricity were dominating[2] whereas in 2005 emissions from the use of natural gas especially in the Chemical sector were prevalent. The strongest reductions of emissions could be achieved in the Non Metallic Minerals (NMM) and the Iron and Steel (IRS) industries.

Table 4: emissions by industry and fuel for Belgium in 1981 and 2005

1981

t CO2	**FOD**	**TEX**	**WOD**	**PAP**	**CHE**	**NMM**	**IRS**	**MET**	**MAC**	**TRA**	**Total**
Coal	64.342	2.737	0	0	182.735	3.481.474	7.197.938	108.801	85.080	0	11.123.107
Gas	189.787	68.698	0	122.353	1.504.274	1.480.600	1.681.140	293.313	147.944	159.756	5.647.865
Oil	990.563	182.150	0	237.286	1.983.661	761.191	635.952	319.558	487.315	0	5.597.675
Electricity	1.107.793	638.450	188.687	755.341	4.587.226	995.649	2.897.945	916.733	983.782	396.954	13.468.560
Total	2.352.485	892.034	188.687	1.114.980	8.257.896	6.718.916	12.412.975	1.638.405	1.704.120	556.710	**35.837.208**

2005

t CO2	**FOD**	**TEX**	**WOD**	**PAP**	**CHE**	**NMM**	**IRS**	**MET**	**MAC**	**TRA**	**Total**
Coal	85.761	0	0	104.824	21.665	459.993	3.272.812	57.640	92.914	0	4.095.611
Gas	1.011.379	225.120	37.200	215.126	4.451.997	869.846	1.707.893	249.350	10.398	245.968	9.024.279
Oil	436.604	12.300	0	126.458	453.581	869.807	101.578	102.211	79.473	0	2.182.011
Electricity	1.081.752	333.660	503.878	734.539	3.731.515	630.186	1.625.474	468.642	587.903	269.421	9.966.969
Total	2.615.496	571.080	541.078	1.180.948	8.658.758	2.829.832	6.707.757	877.843	770.688	515.390	**25.268.870**

The advantage of time-series decomposition over period-wise decomposition is that the annual development of the five different effects on emission changes can be studied. *Fig. 10* illustrates that the cumulated effect of an early rise in industrial activity was offset by a significantly lower emission factor of electricity generation in the 1980s, i.e. a negative coefficient effect. In the 1990s the energy-mix effect and the effect of structural change were able to reduce CO_2 output while no more energy productivity gains could be achieved.

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[2] High emissions from electricity consumption in 1981 are also due to a higher share of coal in power generation, i.e. higher emission factor of electricity use.

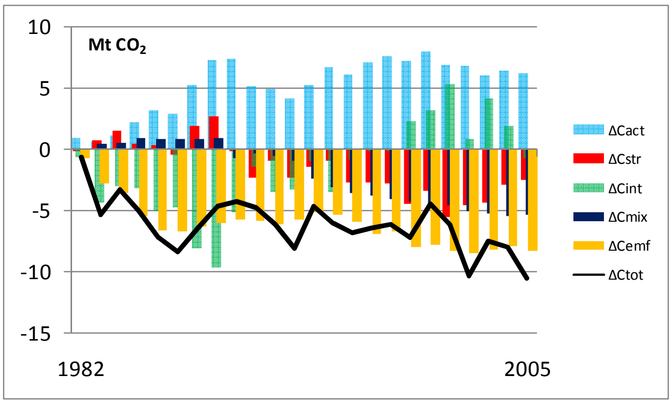

Fig. 10: overview of CO_2 decomposition results for Belgium

In the French manufacturing sector the accumulating activity effect was overcompensated by rising energy productivity (negative energy intensity effect). A positive structure effect – especially in the 1980s - was offset by an even larger negative emission factor effect due to the rising share of nuclear power in electricity generation in the first half of the 1980’s. The fuel-mix effect remained small but negative during the whole observation period (see *fig. 11*).

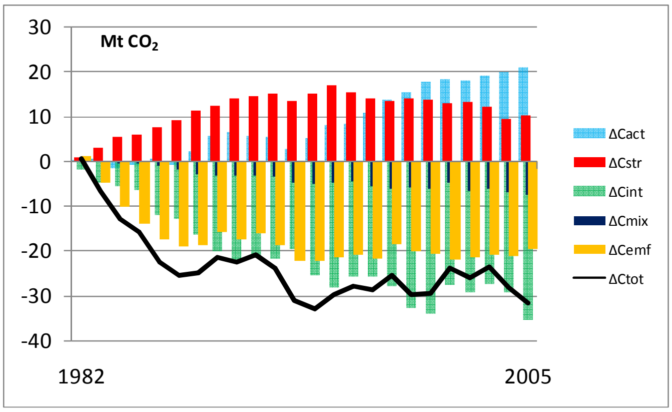

Fig. 11: overview of CO_2 decomposition results for France

The Swedish industry sector was also able to cut emissions, especially at the beginning of the time period analysed and in the last ten years, where a negative intensity and a supporting negative energy-mix effect overcompensated an almost continuous rise in industrial activity. The negative energy-mix effect was primarily caused by a shift away from oil towards the use of electricity. Neither a structural effect nor a change in the emission factor significantly influenced emissions (see *fig. 12*).

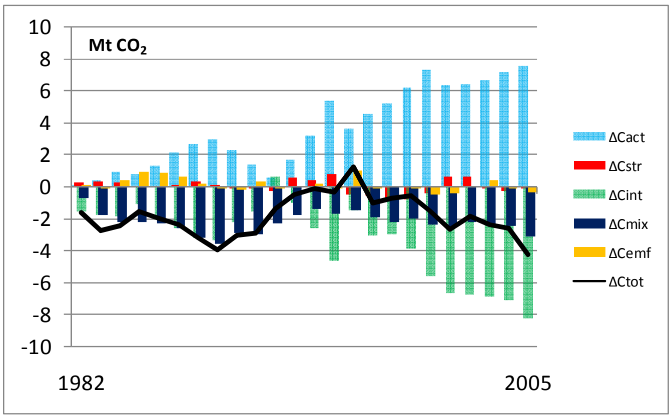

Fig. 12: overview of CO_2 decomposition results for Sweden

In Italy the cumulated activity effect is only slightly larger than the effect from increasing energy productivity. Due to a more favourable fuel-mix in power generation CO2 emissions could be reduced after 2003. The structure and fuel-mix effects have not played a mentionable role throughout the whole time frame (see *fig. 13*).

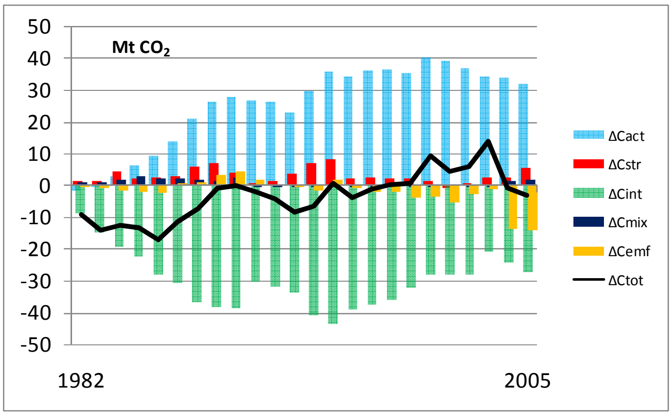

Fig. 13: overview of CO_2 decomposition results for Italy

Up to the mid 1990s the Spanish manufacturing industries analysed were able to reduce energy intensity and the emission factor at a higher rate than the increase of industrial activity. In the last ten years though, no more energy productivity efforts were made while the industrial sector experienced a sharp rise in activity. Even a negative fuel-mix and structural effect were not able to keep carbon dioxide emissions below 1981 levels (see *fig. 14*).

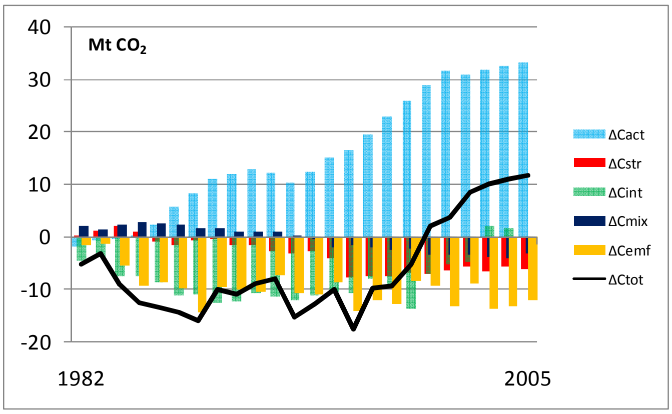

Fig. 14: overview of CO_2 decomposition results for Spain

5. Conclusion

The first part of this empirical investigation analysed the change in industrial energy consumption for 10 manufacturing sectors in five European countries using the LMDI1 method for the period 1981 to 2005. The results show that there have been considerable energy productivity gains in France, Italy and Sweden. Only in France it was possible to fully compensate for the rise of energy use due to higher industrial activity and despite a trend to more energy-intensive industries. A negative structural effect could be observed for Spain Sweden and Belgium.

The results of the decomposition of changes in CO_2 emissions for the manufacturing sector show that in addition to the energy productivity gains, changes in the fuel-mix and emission coefficients can support greenhouse gas mitigation efforts in the industry sector. The coefficient effect is fairly high in those countries which built up nuclear power capacity for electricity generation in the 1980s, namely France, Belgium and Spain and where oil was substituted by gas in power generation like Italy. In Sweden this effect is not very significant as the switch to nuclear power already began before the observation period. Negative fuel-mix effects were accomplished by a fuel switch from coal and petroleum products towards natural gas and electricity consumption in most of the cases. (see table 5).

From the results of this study it can be concluded that efforts to reduce energy consumption per unit of output in the manufacturing sectors in question have been successful over the last 25 years. Energy productivity gains are the most effective source for greenhouse gas mitigation, followed by a fuel-switch in power generation and supported by a fuel switch in final energy consumption. A negative structural effect, i.e. a shift to less energy- and carbon-intensive sectors within the manufacturing sector could only be observed for Spain and Belgium, but this was not the major contributor to emission reductions.

Table 5: CO2 decomposition results overview

in kt CO_2	France	Italy	Spain	Sweden	Belgium
C 1981	**92.077**	**118.856**	**71.498**	**15.425**	**35.837**
e_{act} 1981-2005	+20.817	+31.765	+33.185	+7.494	+6.214
e_{str} 1981-2005	+10.230	5.397	-6.168	-56	-2.472
e_{int} 1981-2005	-35.532	-27.501	-219	-8.186	-748
e_{mix} 1981-2005	-7.560	1.783	-3.206	-3.129	-5.309
e_{emf} 1981-2005	-19.580	-14.330	-11.909	-363	-8.253
ΔC	-31.625	-2.886	11.683	-4.240	-10.568
C 2005	**60.453**	**115.970**	**83.181**	**11.184**	**25.269**
e_{act} 1981-2005	+22,6%	+26,7%	+46,4%	+48,6%	+17,3%
e_{str} 1981-2005	+11,1%	+4,5%	-8,6%	-0,4%	-6,9%
e_{int} 1981-2005	-38,6%	-23,1%	-0,3%	-53,1%	-2,1%
e_{mix} 1981-2005	-8,2%	+1,5%	-4,5%	-20,3%	-14,8%
e_{emf} 1981-2005	-21,3%	-12,1%	-16,7%	-2,4%	-23,0%
ΔC	-34,3%	-2,4%	+16,3%	-27,5%	-29,5%

This work is only a fragment of the big picture concerning global greenhouse gas mitigation and energy efficiency efforts. In order to deepen the understanding of the change in intensity and structural trends it would also be necessary to take a closer look at additional underlying factors, such as the effects of energy prices or legal issues. A more comprehensive analysis including developing economies like China and India, the Eastern European transition countries and other developed countries (e.g. the United States, Japan and further European countries) could shed light on the question whether energy-intensive production is relocated to less developed countries. Moreover the investigation can be extended beyond the industrial sector to catch the effects from a shift towards the service sector or in the case of developing countries from agricultural to industrialized economies.

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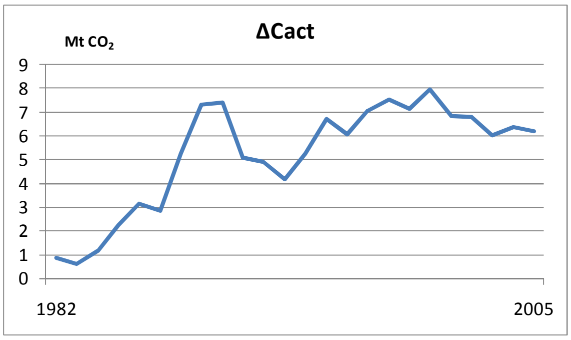
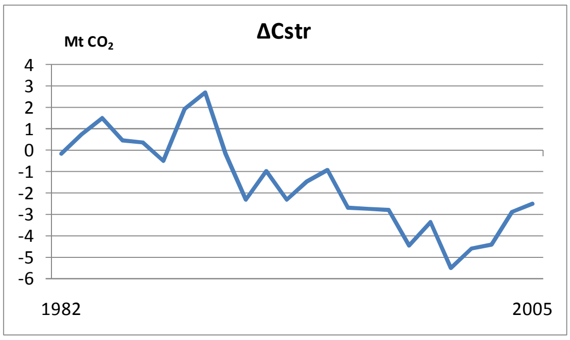
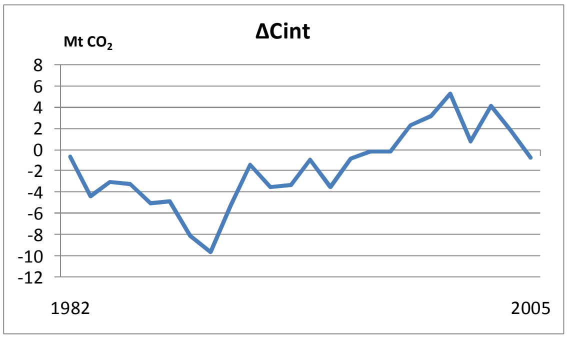
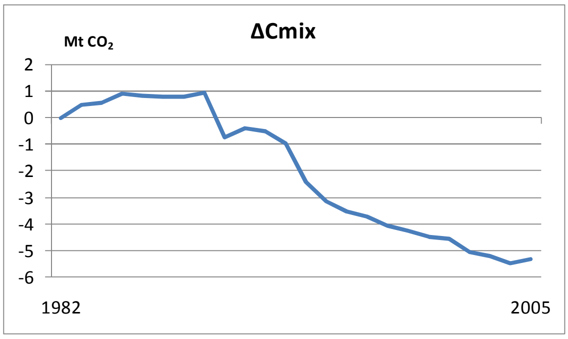
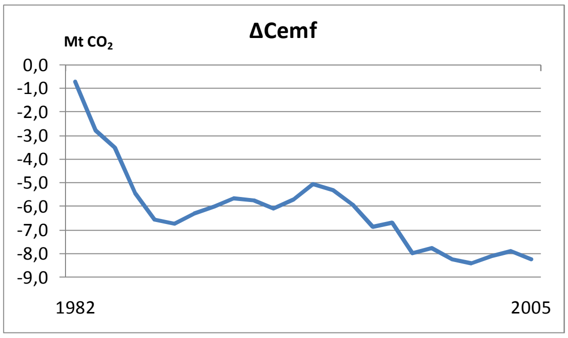
Appendix A: Time-series decomposition results of changes in CO2 emissions in Belgium

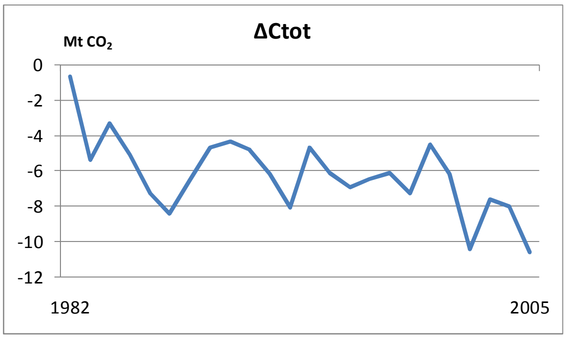




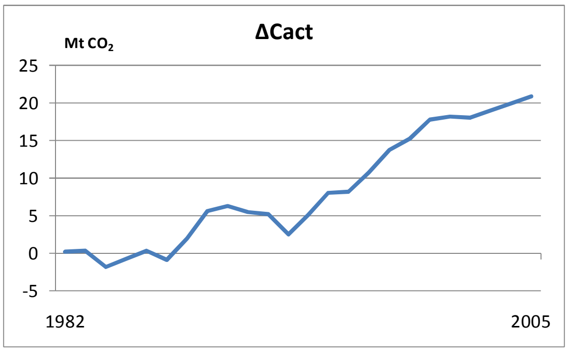


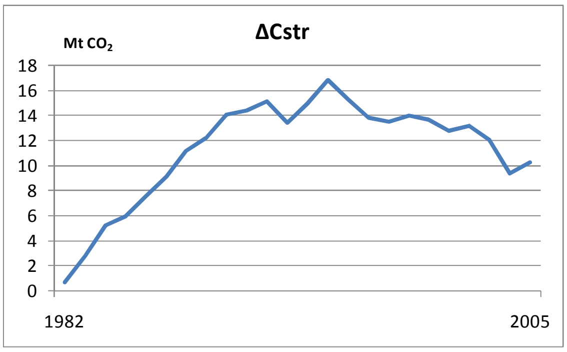


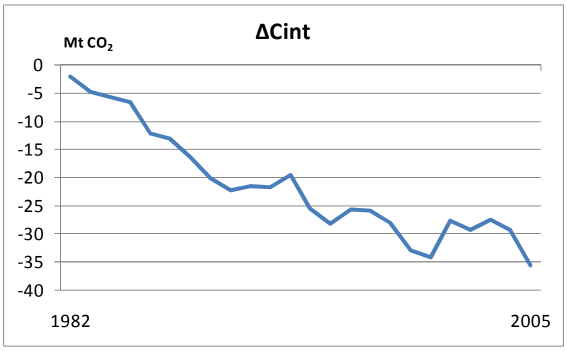


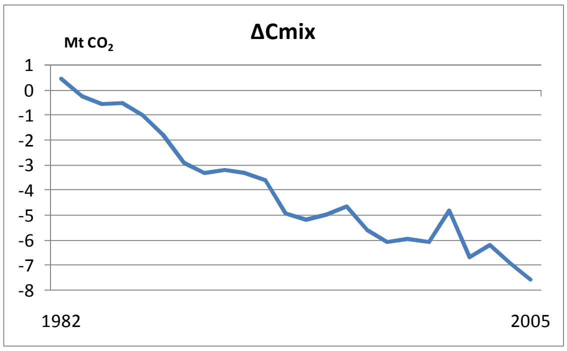


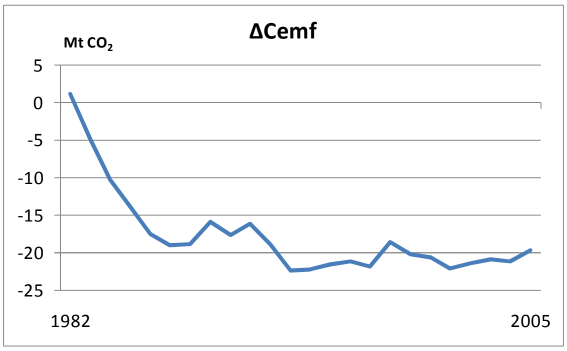
Appendix B: Time-series decomposition results of changes in CO2 emissions in France

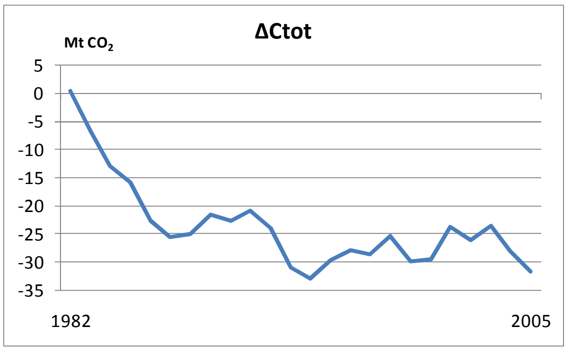




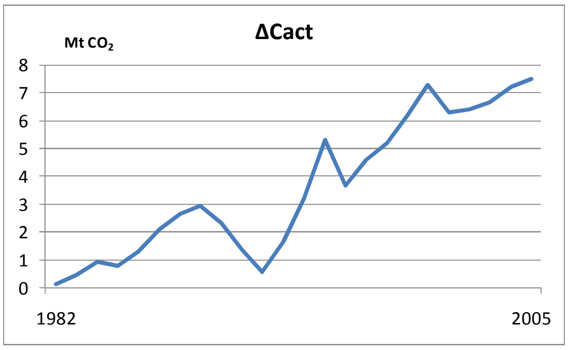


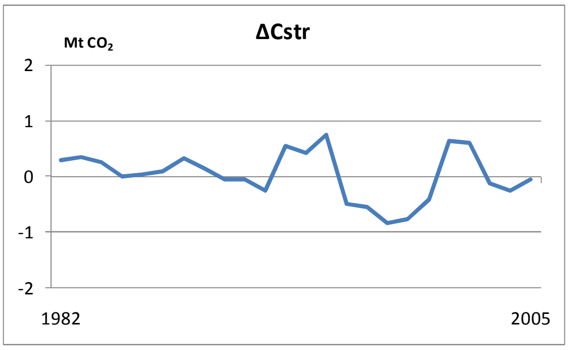


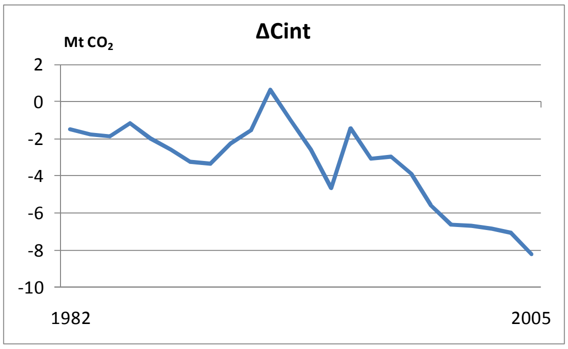


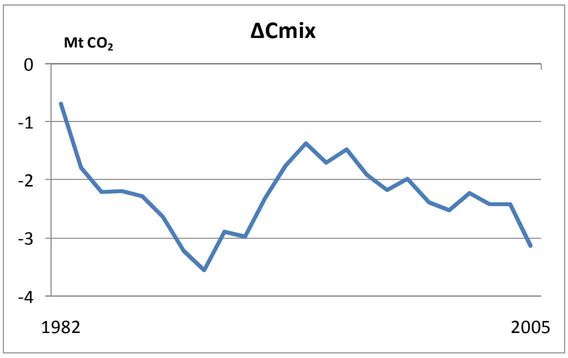


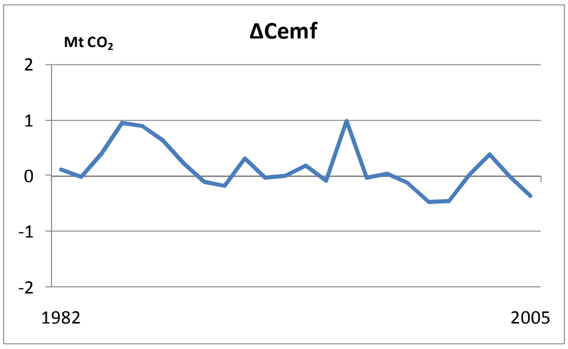
Appendix C: Time-series decomposition results of changes in CO2 emissions in Sweden

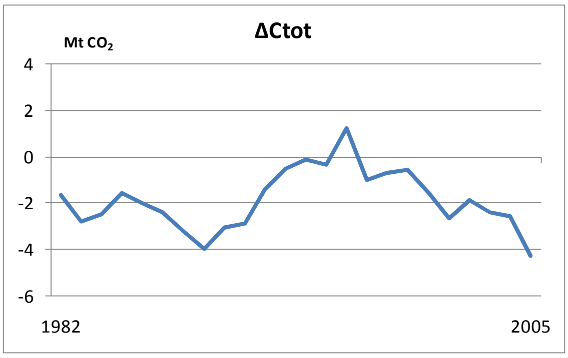




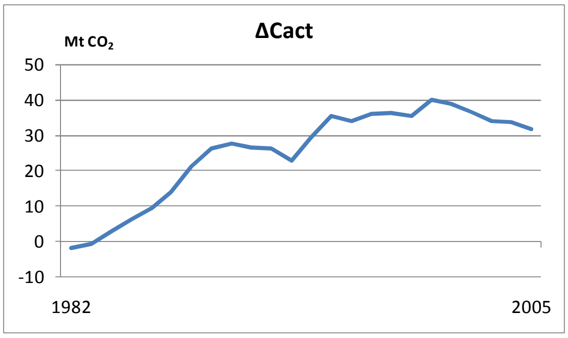


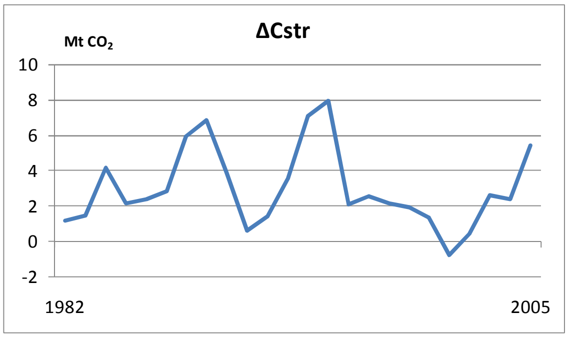


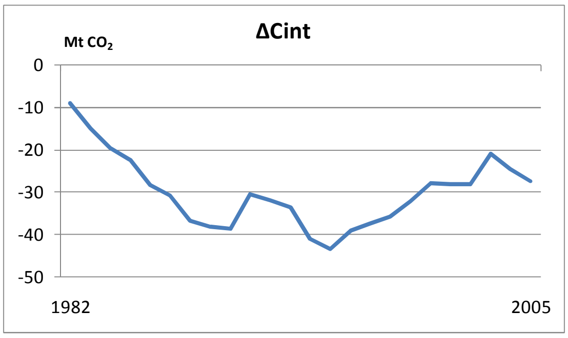


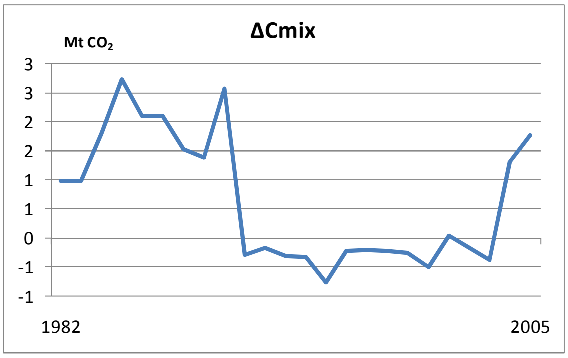


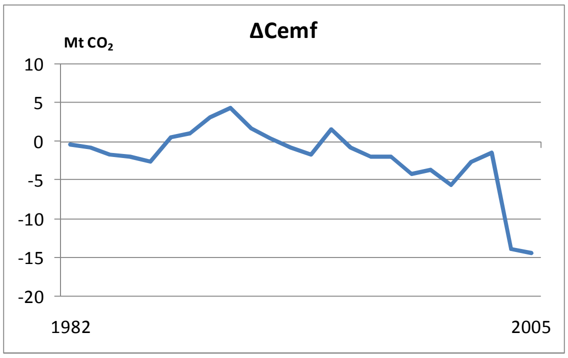
Appendix D: Time-series decomposition results of changes in CO2 emissions in Italy

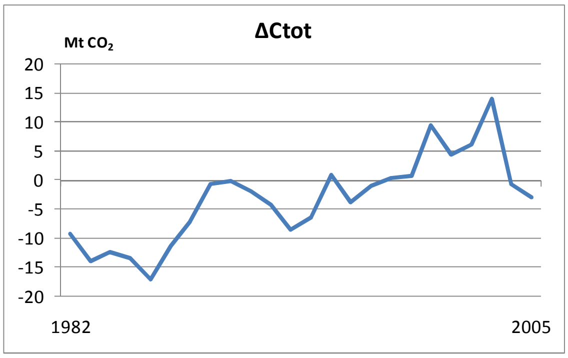












Appendix E: Time-series decomposition results of changes in CO2 emissions in Spain