International Journal of Energy Economics and Policy
Vol. 4, No. 4, 2014, pp.516-530
ISSN: 2146-4553
www.econjournals.com

Changing Patterns of Electricity Usage in European Manufacturing: A Decomposition Analysis

Lars Wenzel
Hamburg Institute of International Economics (HWWI), Heimhuder Str. 71,
20148 Hamburg, Germany. Email: wenzel@hwwi.org

André Wolf
Hamburg Institute of International Economics (HWWI), Heimhuder Str. 71,
20148 Hamburg, Germany. Email: wolf@hwwi.org

ABSTRACT: This paper investigates the changing patterns of electricity intensity in Manufacturing in European countries since 2000. While GVA in Manufacturing has grown and electricity use has declined, it is not clear that this decrease in intensity is directly associated with improvements in technology. Decomposition of the effect suggests that a switch towards less energy intensive sectors accounts for roughly 10% of the total change in electricity intensity. A further level of disaggregation accounts for the factor mix and suggests substitution from labor to electricity. This does not appear to be driven by factor prices, as electricity prices grew significantly more than wage compensations within the sample. The adjusted intensity effect is consistently found to be negative and the average decrease in labor intensity has been more pronounced than the corresponding decrease in electricity intensity. Accordingly, aggregate changes cannot purely be attributed to less electricity-dependent modes of production, but are rather due to general improvements in productivity.

Keywords: decomposition analysis; electricity intensity; European manufacturing; Logarithmic Mean Divisia Index (LMDI)
JEL Classifications: L60, D24

1. Introduction

European Manufacturing is among the most advanced in the world. In order to maintain that position, continuous improvements in organization and process are necessary. This has led to the emergence of a number of concepts and future strategies such as “Smart Factories”, “Industry 4.0” or the “Internet of Things”. These are supposed to capture new trends in industrial production, which will be driven by novel automation technology and cyber-physical systems. This is expected to allow for highly flexible mass production or mass customization. It has been hailed as the next industrial revolution and can be expected to impact on the energy and labor intensity of production. As such, it may also play a significant role in the reduction of CO2-emissions as well as decreasing energy demand in Manufacturing, which are current hot topics for industrial European economies.

The rapid transformation of electricity generation that many European countries have initiated in recent years has also raised a lot of questions for the future. The principle goal of reducing CO2 (and related greenhouse gas) emissions is almost undisputed. The European commission has formalized this goal in its 20-20-20 targets, demanding a 20% reduction in CO2-emissions and 20 % increase in energy efficiency for the year 2020 compared to 1990 levels. In the period 2004-2011, all EU member states actually managed to increase the share of CO2-neutral renewable energies on final energy consumption, with Sweden (2011: 46.8 %), Latvia (33.1 %) and Finland (31.8 %) leading the way.[1]

However, changes on the demand side of electricity are also necessary. For example, shifts towards less CO2 intensive sectors as well as technological developments at the sector level can help attain these targets. Given the important role of the Manufacturing sector in many European economies, industrial electricity use will require special attention in this. In the EU28, Manufacturing accounted

---

[1] Source: Eurostat (2014)

for 36 % of total electricity consumption in 2012. The evolution of electricity intensity is thus one of the key factors in reaching energy savings goals and will be the focus of this analysis.

In order to empirically assess patterns of electricity use in Manufacturing, it is important to distinguish between at least two potentially divergent effects: shifts in the production structure (i.e. in output shares of subsectors) and intensity changes within sectors. The first one reflects phenomena like structural change and asymmetric responses of output to short-term shocks. The second one is supposed to address the various kinds of technological change: firms could switch to technologies which make more efficient use of electricity or which replace it by other energy sources like coal and oil. For forecasts and policy conclusions, it is essential to discriminate between these sources, since distinct explanatory factors are of different persistence and ask for different policy prescripts (Hankinson and Rhys, 1983).

Regarding total energy consumption, there is already a broad literature that applies this decomposition scheme to various countries and aggregation levels. In contrast, applications emphasizing electricity use are still relatively scarce (Al-Gandhoor et al., 2009; Hankinson and Rhys, 1983; Steenhof, 2006) and tend to focus on trends in the energy mix in production, excluding other factors. Hence, the evolution of electricity demand in relation to the demand for complementary factors like labor and capital is not analyzed. Undoubtedly, this would improve our understanding and provide grounds for discriminating between actual changes in production modes and pure scale effects, entailing distinct prospects for future trends.

In light of these considerations, the contributions of this paper are twofold. First, it decomposes electricity intensity results for manufacturing in 20 EU countries over the time span 2000-2011, updating earlier approaches (Howarth et al., 1991; Cornille & Fankhauser, 2004). Country results are assessed for the entire time horizon and on a year-to-year basis, covering both short- and longer term developments. Second, it introduces a further decomposition term by accounting for sectoral changes in the electricity-to-labor ratio. Its implications are assessed based on an application to our dataset.

The structure of the paper is as follows: Section 2 discusses trends at the national level. Section 3 describes our data sources for the decomposition analysis and introduces the basic methodology. Section 4 presents results of the two types of decomposition approaches. Section 5 discusses implications of the results. Section 6 presents the conclusions and identifies potential avenues for future research.

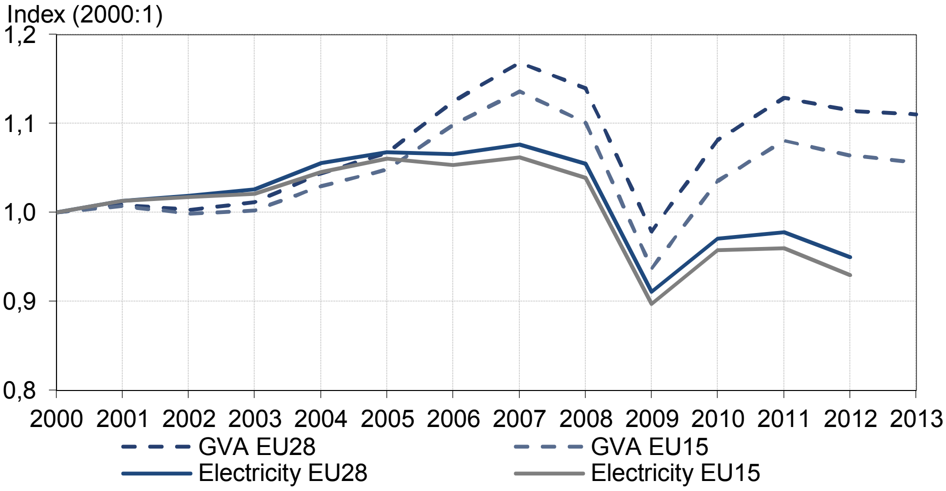
2. Electricity Intensity at the National Level

As a starting point, it is worthwhile to investigate the development of Gross Value Added (GVA) and electricity use in European Manufacturing. These are the two basic components of electricity intensity and their developments relative to the base year 2000 are shown in Figure 1. For both EU-classifications, GVA has increased since the year 2000. However, the economic crisis of 2008/9 created a significant drop and the pre-crisis level has still not been attained at the aggregate level. Manufacturing was one of the sectors most affected by the crisis, as GVA fell below the level of the year 2000. A difference between EU15 and EU28 is also apparent. The remnants of inefficient soviet Manufacturing and the economic slump associated with the collapse of the Soviet Union imply that the EU15 started from a higher base. Consequently, they have shown less dynamic than the EU28, which profit from the emerging markets in Eastern Europe and their growth potential. These catch-up effects can explain the gap between the two. However, even the 11 % growth of Manufacturing GVA in the EU28 is fairly limited, especially when taken over a 13-year time frame. This reflects the relative decline of Manufacturing in comparison to other sectors over this time span.

A similar picture can be seen when analyzing electricity use in european Manufacturing. Electricity consumption was actually lower in 2012 than it was in the year 2000. This is a first indication that electricity intensity has decreased in the new millenium as GVA increases, while electricity consumption decreases. A similar pattern to GVA can be observed, but at a lower level. Up to 2007, electricity consumption was actually increasing. The drop in electricity use during the crisis years can be explained by the reduction in production. Furthermore, the difference between the EU15 and EU28 is less pronounced than for GVA and shows that the EU15 have reduced their electricity consumption more strongly since the 2000 than the EU28. No clear trend is discernible.

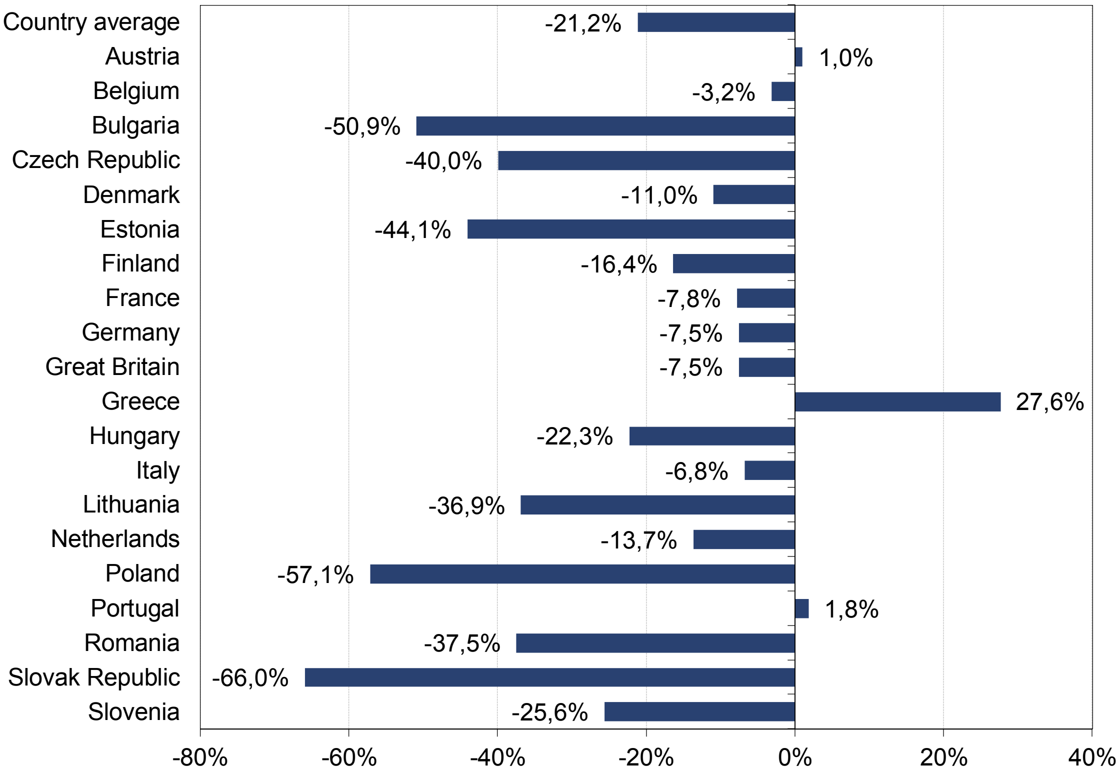
Having observed GVA and electricity usage, the next step is to assess the electricity intensity in Manufacturing. This is done for various EU countries in Figure 2. As expected from previous figures, Eastern European countries stand out in terms of their reduction in electricity intensity. On the other end of the spectrum, Greece stands out with an increase in electricity intensity of 27.6 % over the observed time span. The long-time EU member states range from modest decreases to slight increases. Decomposing this effect will be the subject of the ensuing analysis.

Figure 1. Gross Value Added and Electricity Use in Manufacturing



Source: Eurostat (2014)

Figure 2. Percentage change in electricity intensity of Manufacturing 2000-2011



Source: own calculations

3. Decomposition Approach

3.1. Methods

In a diversified economy, observed changes of factor intensities in production are not necessarily a sign of technological progress or factor substitution. They can also result from structural change, i.e. changes in the sectoral mix of aggregate production, as sectors differ in their relative factor use. This is important to consider in the case of electricity consumption. In general, industries like Paper and Metals are highly electricity-intensive, while others like Food exhibit considerably lower intensities. Following the literature, the effect of an altered sector mix on aggregate electricity intensity is referred to as **structure effect.** An additional effect is exercised by adjustments in electricity intensities at sector level, henceforth called the **intensity effect**. These definitions alone, however, do not provide a clear guide on how to distill these effects from observed data patterns.

In principle, there are infinite ways of decomposing a given time path of electricity intensity into structure and intensity effect. However, not all of these ways are equally intuitive and not all of them allow for a consistent economic interpretation. Surely the most intuitive approach is to compute the (counterfactual) change in aggregate intensity caused by changes in one potential source (shares of sectors in total production or sectoral factor intensities), while keeping the other source constant at its base year level. These counterfactual changes are then interpreted as structure and intensity effects. This procedure is equivalent to a Laspeyres price index and has represented the dominant approach in the energy decomposition literature until the mid-1980s (e.g. Hankinson and Rhys, 1983). Its intuitiveness comes at the cost of undesirable properties from an economic perspective. Foremost, as a consequence of imposing a fixed base year, intensity and structure effect do not add up to the actual change in aggregate electricity intensity. The resulting residual can potentially become fairly large and lacks economic meaning, which renders interpretation difficult.[2] In addition, the index does not fulfill the properties of time reversibility and factor reversibility required for an ideal index as defined by Fisher (1921) (for a theoretical discussion of these criteria see Fattore (2009)).

In light of these shortcomings, the alternative method of the Divisia index has grown in influence over the years. Its origin dates back to an index formula developed by Divisia (1925), which was designed to isolate price and quantity changes underlying the evolution of expenditures over continuous time. It has been adapted by Törnqvist (1936) for applications to real-world discrete-time data. In this form, it has first been implemented by Boyd et al. (1987) to decompose the evolution of aggregate energy intensity into structure and intensity effect. By now, the Divisia method is regarded as a standard tool in decomposition analysis (see Ang & Zhang (2000) for a comprehensive survey). This is mainly the result of a number of refinements and attempts to generalize this concept. These include the integration of model types into a common parametric framework (Liu et al., 1992) and an extension towards multilevel decomposition (Ang, 1995). Most importantly, Ang and Choi (1997) have demonstrated that one particular adjustment of the Törnqvist formula can yield a perfect decomposition, i.e. a decomposition where no residual term is left. It is based on the logarithmic mean function introduced by Montgomery (1937) and therefore called the Logarithmic Mean Divisia Index (LMDI) method. In addition to the avoidance of unexplained residuals, it exhibits other advantages like a lack of path-dependence and the ability to deal with zero values (Ang, 2004). For the purpose of country comparisons, these features are helpful. Thus, this method forms the basis of the ensuing decomposition analysis, following Wang et al. (2010), who decomposed electricity use in Chinese Manufacturing by means of an LMDI approach.

There are two basic types of LMDI measures, an additive and a multiplicative one. The additive one serves to decompose absolute changes in electricity intensity, often measured in kWh per monetary unit. The multiplicative one serves to decompose relative changes and is therefore dimensionless. Choi and Ang (2003) have shown that the two measures can be transformed from one to another by means of simple algebra. They are thus essentially reflecting the same information, which renders the question of choosing one of the two a matter of convenience. For this analysis, the multiplicative version is implemented, mainly due to its lack of dimension. As a starting point, aggregate electricity intensity I in Manufacturing can be written as follows:

---

[2] Sun (1997) has proposed to circumvent this problem by distributing the residual term equally among structure and intensity effect. However, he does not provide any economic justification for his ad-hoc solution.

$$I = \frac{E}{Y} = \sum_{k=1}^{n} \frac{Y_k}{Y} \cdot \frac{E_k}{Y_k} = \sum_{k=1}^{n} S_k \cdot I_k. \qquad (1)$$

I is defined as the amount of annual electricity use in Manufacturing E (in kWh) divided by the amount of annual GVA generated in Manufacturing Y. It is interpreted as a weighted average of sectoral electricity intensities I_k, with sectoral output shares S_k as weights. Choi and Ang (2003) show that manipulating the above expression by means of calculus and discretization leads to the following equation for the relative change in aggregate electricity intensity from period $t = 0$ to $t = T$:

$$\frac{I_T}{I_0} = exp\left(\sum_{k=1}^{n} \alpha_k \cdot ln \frac{S_{k,T}}{S_{k,0}}\right) exp\left(\sum_{k=1}^{n} \alpha_k \cdot ln \frac{I_{k,T}}{I_{k,0}}\right) \qquad (2)$$

The problem is to determine parameters α_k such that the expression holds. Applying a logarithmic mean function, Ang and Choi came up with the following choice for α_k:

$$\alpha_k = \frac{L\left(I_{k,T} S_{k,T}.\ I_{k,0} S_{k,0}\right)}{L(I_t,\ I_o)} \qquad (3)$$

$$\text{with } L(x, y) = \begin{cases} (x - y)/(\ln x - \ln y), & x \neq y \\ x\,, & x = y \end{cases}$$

Adopting this measure allows us to carry out perfect decompositions, where the first term is interpreted as structure effect and the second term as intensity effect. Multiplying both delivers again the aggregate intensity change.

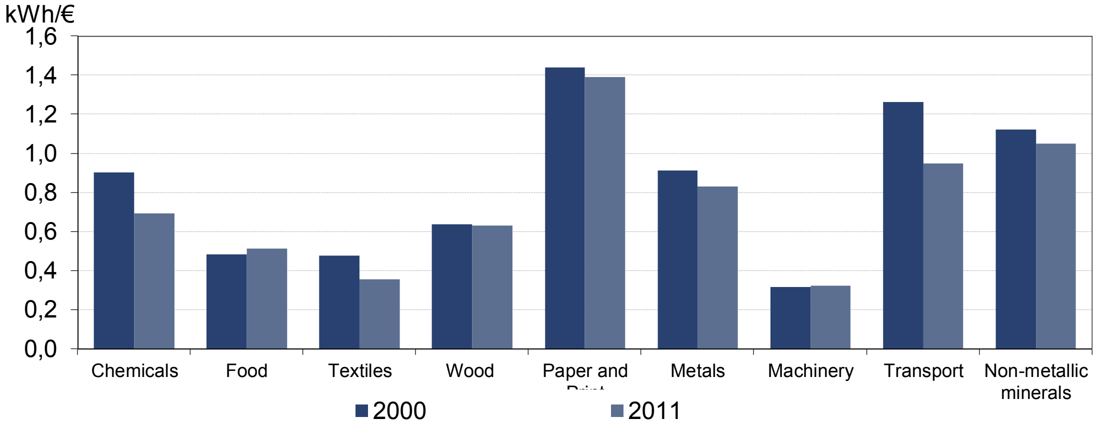
3.2. Data

The EU data service Eurostat provides data on sectoral Gross Value Added (GVA) for the EU countries at a maximum disaggregation of 64 sectors (as distinguished by NACE). At this level, Manufacturing is split into 19 subsectors. It also provides data on annual sectoral electricity consumption, albeit at a level of merely 10 industries. To a large part, these industries represent aggregations of the 64 classes available for GVA. Thus, aggregation of sectoral output data is required. In addition, there is one case where the GVA data is at a higher aggregation level. Manufacturing of Basic Metals / Fabricated Metal Products is split into Iron / Steel and Non-ferrous Metals, requiring us to aggregate electricity use in this case. After performing these steps, nine Manufacturing sectors are available for decomposition. The matching procedure and the resulting sector classifications are presented in the Appendix. There is some agreement in the literature that a minimum of 5-6 sectors is essential for identifying structural changes, including the most energy-intensive sectors Paper, Chemicals and Metals (Boyd et al., 1987; Howarth et al., 1991). Nonetheless, sectoral shifts at lower aggregation levels cannot be controlled for.

Concerning the country selection, decompositions for 20 EU countries are performed on the grounds of data availability. In the temporal dimension, the dataset principally offers annual data during the time period 1991 to 2011. However, for years earlier than 2000, there are some gaps in the data on electricity use for some sectors and some countries. Therefore, the period from 2000 to 2011 is chosen for this investigation.

Figure 3 provides a descriptive overview on sectoral electricity intensities for the EU as a whole, measured in kWh electricity consumption per 1 € of GVA. Paper and Print continues to be the most electricity-intensive sector in EU manufacturing. In comparison, the amount of electricity needed to generate 1 € of value added was much smaller (less than one third) in Machinery and Equipment. This demonstrates the potential importance of sector structure as a determinant of aggregate electricity intensity. It is also apparent that the evolution of intensities is far from uniform. Transport Equipment reduced its electricity-output ratio to the largest extent. Others only achieved merely modest declines. In the Food industry as well as in Machinery and Equipment the electricity intensity even went up slightly.

Figure 3. Electricity intensities of Manufacturing subsectors in the EU28



Source: Eurostat (2014); own calculations

4. Decomposing Electricity Intensity

4.1 Structure and intensity effects: empirical results

Decomposition results for the long-term changes in aggregate electricity intensities 2000-2011 in country comparison are presented in Table I. Direction and magnitude of the structure effects are highly heterogeneous. The large Central and Eastern European (CEE) countries Hungary, Poland and the Czech Republic all underwent a restructuring to less electricity-intensive Manufacturing. In Poland, the sector Machinery and Equipment exhibited particularly strong real GVA growth of 406.0 % from 2000 to 2011. In the Czech Republic and Hungary, Manufacture of Vehicles has been another less electricity-intensive sector with growth rates above average. Apart from this, no regional patterns are detectable. Greece represents an outlier with its strong shift towards electricity-intensive sectors. This turns out to be the sole explanation for its general intensity increase noted above. A massive output decline in the (less electricity-intensive) food industry was to a large part responsible for this. Finland is also an interesting case as the aggregate intensity effect is completely accounted for by the structure effect and is thus not due to reduced sectoral intensities. In comparison, the large economies have all experienced relatively modest structural change.

In contrast, the intensity effect delivers fairly uniform results. In the vast majority of countries, electricity intensity of production at a sub-sector level has decreased or stagnated during the time span 2000-2011. The only notable exceptions are Austria and Portugal. Hence, the impression created by aggregate intensity change above is confirmed when accounting for adjustments in sector weights. The strongest intensity declines can be observed for the CEE countries with Poland, Bulgaria and the Slovak Republic achieving more than 50 % improvements for the observed time span. Among West European countries, the Netherlands have been most successful in reducing electricity intensity within sectors at 16.3 %. In all, the magnitude of sectoral intensity effects dominates the outcome for all countries except Greece. Not accounting for the structure effect would on average overstate the drop in energy intensity by 2.7 percentage points in this sample. That is more than 10 % of the aggregate decline of 25.2 %.

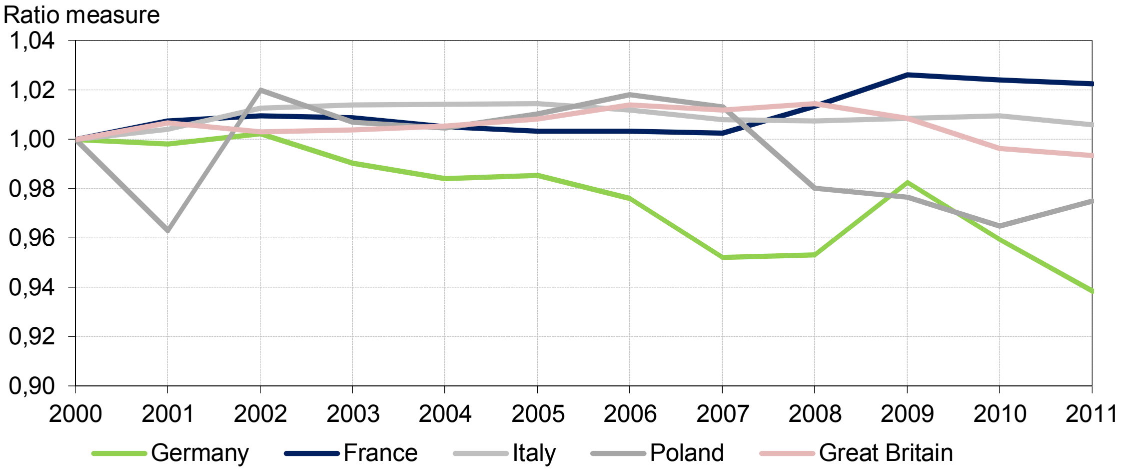
To reveal how these long-term responses emerged over time, the effect for 2000-2011 is further split into single year effects. This is achieved by applying the same decomposition technique to year-to-year changes in aggregate electricity intensity. Results for the five most populous countries in our dataset are plotted in Figure 4. The heterogeneity in the long-term structure effect is also observable for short-term fluctuations. This is particularly apparent for the crisis year 2009. Germany and France have shifted towards more, Great Britain and Poland towards less electricity-intensive sectors. A difference in export dependence among sectors is one of the likely factors contributing to this pattern. Concerning the evolution of the intensity effect in Figure 5, the Western European countries also show a high amount of volatility. Poland, in contrast, has, after a single peak in 2001, experienced a steady decline in average sectoral electricity intensity. Our calculations yield similar patterns for Hungary and Czech Republic, implicating that the long-term intensity decline in the CEE countries is the product of a continuous development.

Table I. Structure and intensity effect for the time span 2000-2011

Country	Structure effect	Intensity effect	Total change
Austria	0.949	1.065	1.010
Belgium	1.016	0.953	0.968
Bulgaria	1.020	0.481	0.491
Czech Republic	0.902	0.665	0.600
Denmark	0.914	0.974	0.890
Estonia	0.879	0.636	0.559
Finland	0.832	1.005	0.836
France	1.014	0.910	0.922
Germany	0.937	0.987	0.925
Great Britain	0.980	0.943	0.925
Greece	1.275	1.001	1.276
Hungary	0.860	0.904	0.777
Italy	1.005	0.927	0.932
Lithuania	1.095	0.576	0.631
Netherlands	1.031	0.837	0.863
Poland	0.975	0.439	0.429
Portugal	0.993	1.025	1.018
Romania	0.960	0.651	0.625
Slovak Republic	0.705	0.483	0.340
Slovenia	1.017	0.731	0.744
Country average	0.961	0.775	0.748

Source: own calculations

Figure 4. Structure effect relative to base year 2000

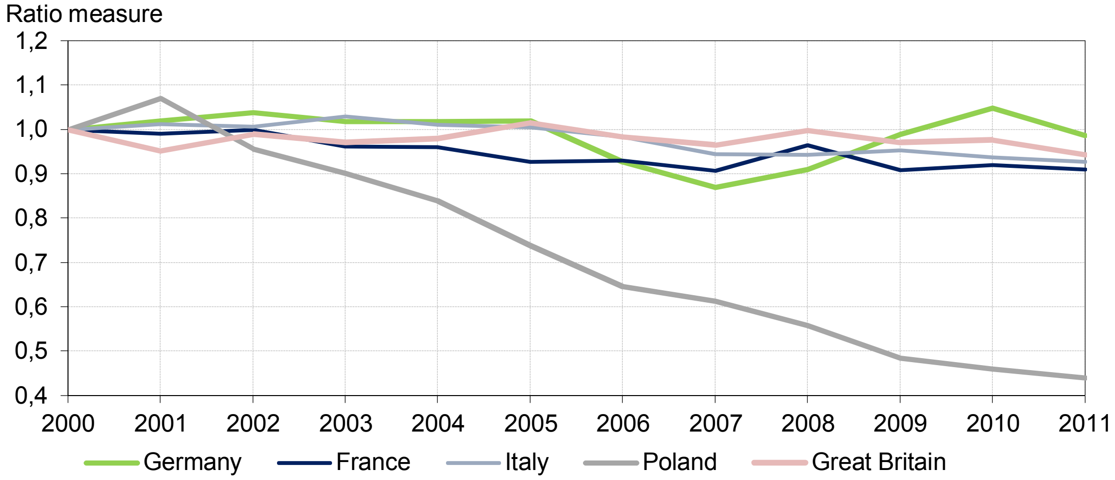


Source: own calculations

4.2 Electricity use and factor intensities: alternative decompositions

The central message of the results so far can be summarized as follows: while changes in sector structure do play a role, the observed decline in aggregate electricity intensities can at least partially be attributed to actual intensity reductions at sector level. If we defined efficiency of factor use on the grounds of factor intensities, this would let us conclude that the efficiency of electricity use at sector level has risen on average in the European countries. This descriptive evidence alone, however, neither points to the reasons for this decline nor how it is related to the factor mix. The technological change underlying changing factor intensities can operate in two directions: factors can be substituted for others in production and/or total factor productivity (defined as total output over aggregate use of inputs) can rise.

Figure 5. Intensity effect relative to base year 2000



Source: own calculations

Factor substitution could take the form of a replacement of processes reliant on thermal power by more electricity-intensive modes of production. Steenhof (2006) and Wang et al. (2010) analyze the relevance of this phenomenon for China. Alternatively, firms could aim at reducing the electricity intensity of a given mode of production through saving measures, such as the use of process heat for the heating of buildings or the installation of daylight sensors. This would not necessarily imply a fuel switch (i.e. a change in the energy mix for production), but the amount of electricity use per worker would be reduced, thereby adjusting relative factor employment. An increase in total factor productivity, on the other hand, could cause the electricity-intensity to decline even without affecting relative factor use. One example for such a factor-neutral productivity growth would be a general scale effect in production, where output growth is associated with a simultaneous productivity increase of all factors. An intuitive explanation for this is that some part of electricity consumption is fixed, i.e. irresponsive to adjustments of production levels. Examples include the power consumption of machines in standby mode and the electricity needed for air conditioning and lighting. The implications of this have not yet been explicitly accounted for by the energy decomposition literature.

In order to discriminate between the roles of factor substitution and general productivity effects, a further decomposition of electricity intensity is required. It is one of the advantages of the multiplicative LMDI approach that it allows for uncomplicated extensions. We extend our decomposition by incorporating labor use (measured in total working hours per year) as an additional factor of production in the following way:

$$I = \sum_{k=1}^{n} \frac{Y_k}{Y} \cdot \frac{E_k}{Y_k} = \sum_{k=1}^{n} \frac{Y_k}{Y} \cdot \frac{E_k}{L_k} \cdot \frac{L_k}{Y_k} = \sum_{k=1}^{n} S_k \cdot F_k \cdot \breve{I}_k \qquad (4)$$

where L_k stands for sectoral labor use measured in the total number of working hours. Given this representation, the effect of changing electricity intensity at sector level is split into a change in the electricity-to-labor ratio F_k and a change in labor intensity $\breve{I}_k$. This is achieved by applying the same calculations steps as in 3.1 to the above expression, yielding the following term:

$$\frac{I_T}{I_0} = exp\left(\sum_{k=1}^{n} \alpha_k \cdot ln \frac{S_{k,T}}{S_{k,0}}\right) exp\left(\sum_{k=1}^{n} \alpha_k \cdot ln \frac{F_{k,T}}{F_{k,0}}\right) exp\left(\sum_{k=1}^{n} \alpha_k \cdot ln \frac{\breve{I}_{k,T}}{\breve{I}_{k,0}}\right) \qquad (5)$$

with α_k defined as before.

To understand the intuition behind this strategy, one has to consider the interpretation of the single effects. Each effect informs about the potential change in aggregate electricity intensity induced by changes in the given factor when keeping all other factor constant at their base year levels. Hence, the effect caused by a changing electricity-to-labor ratio is based on constant labor intensity, i.e. cancels out any scale effect and focuses completely on factor substitution.[3] In the following, we refer to this as **factor mix effect**. The opposite holds for the other effect, which signals the impact of a simultaneous and equal change in labor and electricity intensity, i.e. keeping electricity use per hour worked constant. We refer to this as **adjusted intensity effect**, as it corrects for changes in the electricity-to-labor ratio.[4]

Data on working hours stems from the same Eurostat source, thereby guaranteeing internal consistency. However, some small adjustments to the data structure were made in order to cope with gaps in the working hour data. First, the countries Estonia, Hungary and Poland had to be dropped for this part of the analysis. Second, Manufacture of Chemicals and Manufacture of Non-metallic minerals had to be merged to one sector in order to achieve harmonization with the aggregation level of working hours.

Table presents the decomposition results for changes during the complete time span 2000-2011. The results confirm the need to distinguish these three effects. In all countries, they have worked in opposite directions during the time span considered. The factor mix effect has worked against a decline in electricity-intensity.

Table II. Structure, factor mix and adjusted intensity effect for the time span 2000-2011

Country	Structure effect	Factor mix effect	Adj. intensity effect	Total change
Austria	0.956	1.375	0.769	1.010
Belgium	1.016	1.114	0.855	0.968
Bulgaria	1.021	0.962	0.500	0.491
Czech Republic	0.903	1.303	0.510	0.600
Denmark	0.946	1.301	0.724	0.890
Finland	0.840	1.205	0.826	0.836
France	1.023	1.209	0.758	0.937
Germany	0.938	1.325	0.744	0.925
Great Britain	0.993	1.365	0.671	0.909
Greece	1.327	1.029	0.935	1.276
Italy	1.006	1.019	0.909	0.932
Lituania	1.100	1.276	0.450	0.631
Netherlands	1.024	1.182	0.712	0.863
Portugal	0.987	1.362	0.758	1.018
Romania	0.962	1.341	0.484	0.625
Slovak Republic	0.737	1.027	0.449	0.340
Slovania	1.037	1.305	0.550	0.744
Country average	0.975	1.247	0.628	0.772

Source: own calculations

In fact, the electricity-to-labor ratio has risen on an average basis. In other words, the average decrease in labor intensity has been more pronounced than the corresponding decrease in electricity intensity. Accordingly, aggregate changes cannot be attributed to less electricity-dependent modes of production, but are rather due to general improvements in productivity. This productivity improvement

---

[3] Note that this descriptive approach does not rely on any assumptions concerning the production technology.

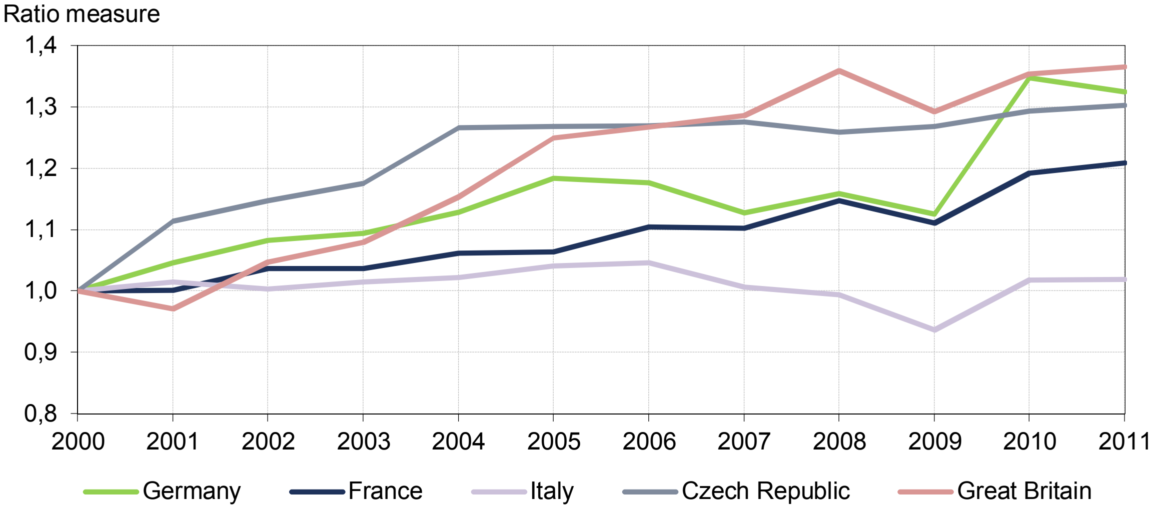
[4] However, one has to be aware that it also captures productivity changes in other unobserved factors like capital.

as reflected by the adjusted intensity effect outweighs the opposing factor mix effect in most of the countries.

In a country comparison, the adjusted intensity effect has been particularly pronounced in the CEE countries analyzed. At the same time, the factor mix effect is also very notable in all of these countries except for Bulgaria. Hence, technological change has in recent years led to both a substantial switch from labor to electricity and a strong increase in general productivity. In contrast, manufacturing in Italy and Greece has witnessed the smallest adjusted intensity effects according to our calculation. However, the trend towards factor substitution has also been less pronounced here, diluting the impact on sectoral electricity intensity. Among the Western European countries, Germany, Austria and Great Britain have experienced factor mix effects well above the European average, explaining the comparatively small declines in electricity intensity at sector level in these advanced industrial countries.

Once again, additional insights can be gained by splitting up the sample and decomposing changes for different end years within our time horizon. Figure 6 plots the evolution of factor mix and adjusted intensity effects for six large countries in our sample. All of these countries except for Italy have experienced a steady increase of the factor mix effect during the early 2000s. Hence, for the average sector, electricity use has played a growing role in the production process compared to the use of labor. Most interesting is the response to the crisis 2009. It has led to a rather sharp decline in the factor mix effect for all countries except for the Czech Republic. The decline in output was thus associated with a stronger reduction in electricity consumption than in the number of working hours. The following recovery of output (see Figure 7) has also triggered a rebound effect in the factor mix, whose magnitude differed between countries. It was particularly strong in Germany, causing electricity use per working hour to rise to a level not previously achieved. This suggests that the trend deviation in 2009 did not result from technological change, but rather represented a business cycle-driven temporary adjustment.

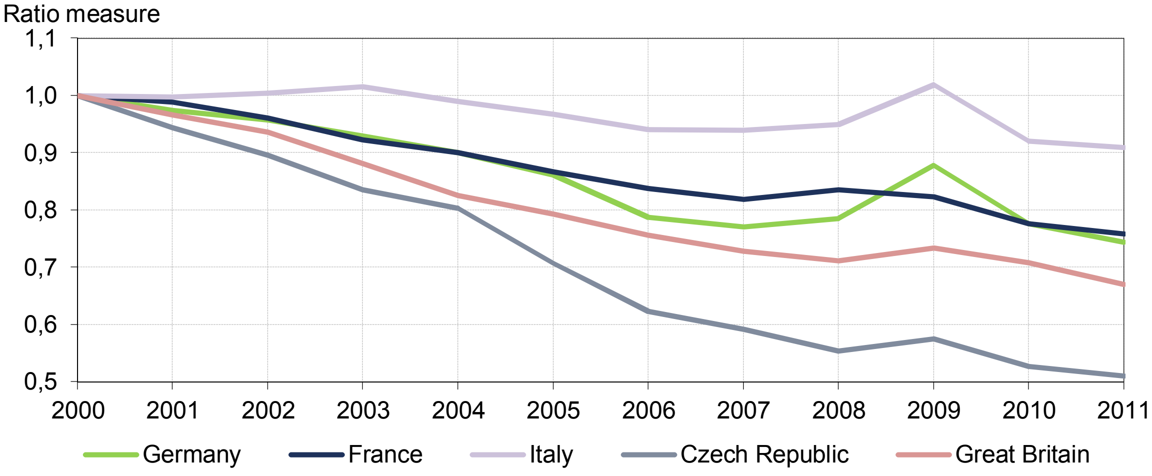
Figure 6. Factor mix effect relative to base year 2000



Source: own calculations

During the same time span, the adjusted intensity effects have shown patterns different from the factor mix in the countries under concern. The long-run decline in this effect is revealed to be the result of an almost permanent year-to-year reduction. Hence, controlling for changes in the factor mix tends to yield smoother paths for intensity changes at sector level. The exception is again the crisis year 2009 with a temporary upward drift in all countries except France. It opposes a downward movement of the factor mix effect. This year was thus largely characterized by an increase in factor intensity for both electricity and labor, with labor intensity however facing the stronger increase. Again, this is met by a rebound effect in the subsequent year.

Figure 7. Adjusted intensity effect relative to base year 2000



Source: own calclulations

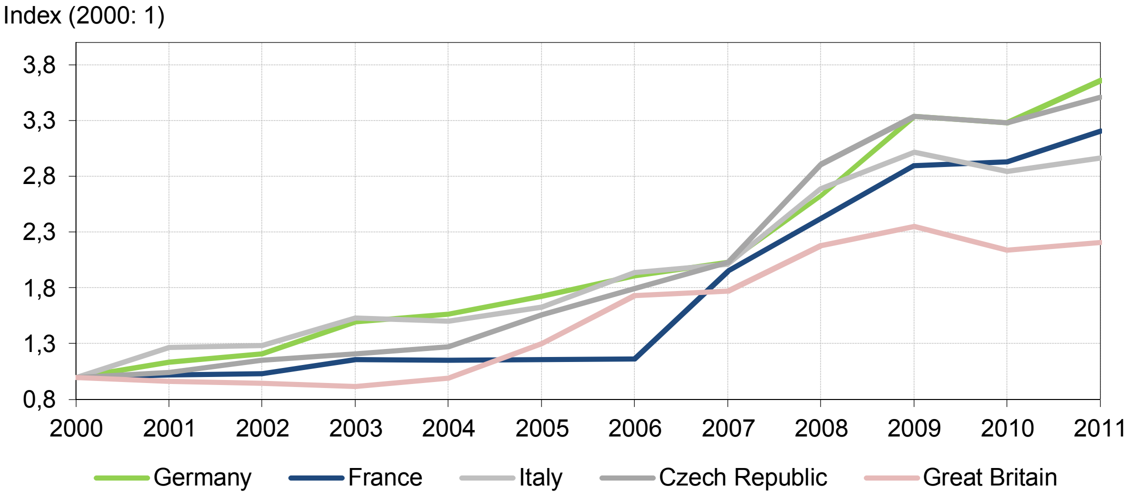
The short-run nature of these responses definitely does not point to technological change as a primary source. Besides, the fact that the ratio of electricity use to working hours overtly decreased during the crisis suggests that a simultaneous increase in electricity intensity was not driven by factor price adjustments. Rather, results seem to indicate the presence of business cycle dependent scale effects. This would imply that some part of both electricity and labor use is indeed fixed, i.e. irresponsive to short-run output fluctuations. Given the observed changes in the factor mix, this part would inferred to be larger for labor, implying that firms rather adjust electricity consumption than employment or working time in response to sudden external demand shocks. Working hours thus appear to be sticky relative to electricity.

5. Discussion

To underpin this point, it is helpful to consider the evolution of the corresponding factor prices in the individual countries. Figures 8 and 9 depict the changes in average gross earnings per hour and electricity prices (including taxes) per kWh in national Manufacturing. It demonstrates a striking divergence in relative factor costs during the time span considered. At least from the mid-2000s onwards, electricity prices have been subject to considerably higher growth than worker compensation in all of these countries. Manufacturing in Germany represents a particularly striking case. It has experienced the smallest increase in earnings and simultaneously the strongest rise in electricity prices, exceeding the earnings increase more than tenfold. The crisis year 2009 itself shows no significant departure from the general trend. One can observe a delayed response in the form of a price consolidation (or even a price decline as in Great Britain) for the following year, but in 2011 electricity prices were again on the rise.

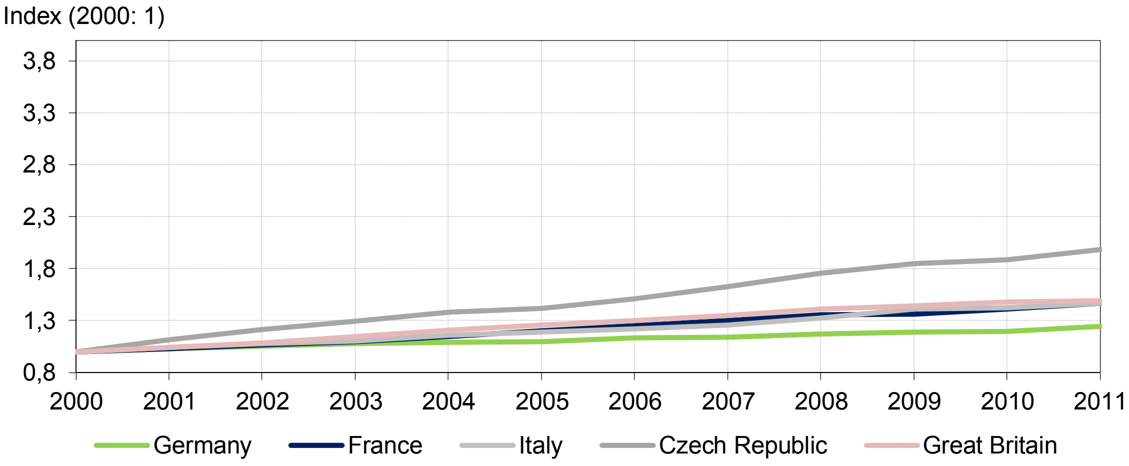
This proposes that the shift in the factor mix from labor to electricity is not the outcome of factor price changes, as they would suggest a contrary development. Moreover, price changes are also unlikely to be the source of the observed intensity effects. For instance, when comparing Germany and Great Britain, British Manufacturing has experienced the stronger decline in sectoral energy intensities, even though German Manufacturing had to cope with a much steeper price path.

Figure 8. Electricity prices in Manufacturing



Source: IEA (2014)

Figure 9. Labor costs in Manufacturing

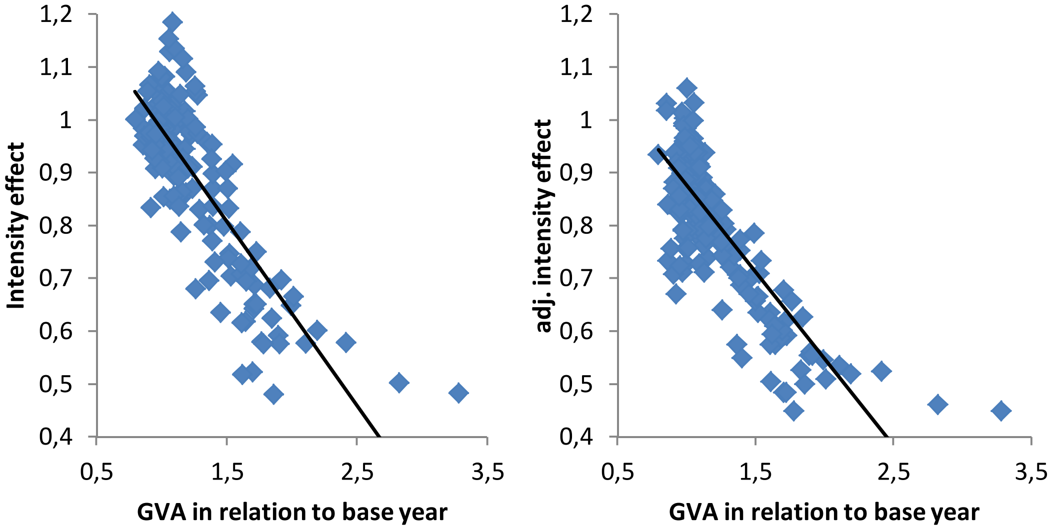


Source: Eurostat (2014)

Consequently, the answer has to lie in technology. As argued above, this does not need to involve technological change in the sense of innovations to production modes. Patterns like these can also emerge from static scale economies, given that some proportion of electricity consumption represents a fixed rather than a variable cost component. In this way, demand-driven fluctuations in output can influence electricity intensities without actually exercising any longer-term organizational change in production. Figure 10 is suited to further support this view. It documents a clearly negative correlation between national Manufacturing output (relative to base year levels) and intensity as well as adjusted intensity effects. Hence, stronger increases in manufacturing production during this time span tended to indicate stronger declines in sectoral electricity intensities, even when accounting for changes in relative factor use.

These results encourage a skeptical view on the usefulness of macroeconomic productivity accounts as indicators of technological progress. If demand-driven effects do play a significant role, energy intensities are not good indicators of long-term developments. This sheds doubt on the appropriateness of these measures as target indicators for energy and climate policy goals, for instance as postulated in the 20-20-20 strategy of the EU. Moreover, it also puts the general usefulness of the decomposition literature for deriving policy implications into question. Given the observation of notable intensity effects, many studies conclude that technological progress has created significant societal benefits in terms of energy efficiency and thus deserves public support. This can be seen as a more or less explicit call for subsidizing research into efficient technologies, hence drawing taxpayers' money to subsidies to industries or investments in public research (e.g. Al-Gandhoor et al., 2009; Zhao et al., 2010). The compelling logic of these arguments is challenged by these results.

Figure 10. Intensity and adj. Intensity effect in relation to GVA change



Source: own calculations

6. Conclusion

This paper set out to investigate the patterns of electricity use in European manufacturing. In light of developments in automation, global connectedness and the need for reducing emissions, an improved understanding of electricity intensities is paramount. While GVA in Manufacturing has grown since 2000 and electricity use has declined, it is not clear that this decrease in intensity is directly associated with improvements in technology. Decomposition of the effect suggests that for several countries a switch towards less energy intensive sectors accounted for part of the observed effects. Only in Greece could a significant switch in the other direction be observed. Overall, accounting for the sector structure reduces the drop in electricity intensity by 2.7 percentage points. Generally, it was found that CEE countries reported significant decreases in electricity intensity, likely due to catch-up effects.

A further level of disaggregation was added in order to account for the factor mix in the form of potential substitution between labor and electricity. For both factors, signs for the role of scale economies were found, which are especially pronounced for labor. The factor mix effect was positive for all countries except Bulgaria, implying that substitution from labor to electricity has been the norm within the sample. Interestingly, this does not appear to be driven by factor prices, as electricity prices grew significantly more than wage compensations within the period at hand. The adjusted intensity effect was consistently found to be negative and the average decrease in labor intensity has been more pronounced than the corresponding decrease in electricity intensity. Accordingly, aggregate changes cannot purely be attributed to less electricity-dependent modes of production, but are rather due to general improvements in productivity. Furthermore, the sensitivity towards the crisis underlines the impact of temporary shocks on measures of electricity intensity.

There are a number of ways in which the results could be extended. Capital could be included as a factor to more fully reflect the means of production. This could be easily handled with the given disaggregation method, but acquiring the necessary data has prevented the inclusion here. Furthermore, investigating the determinants of electricity intensity might prove insightful and improve our understanding of the underlying processes.

References

Al-Ghandoor, A.; Jaber, J.; Samhouri, M., Al-Hinti, I. (2009). Analysis of aggregate electricity intensity change of the Jordanian industrial sector using decomposition technique. International Journal of Energy Research, 33(3), 255-266.

Ang, B. (1995). Multilevel decomposition of industrial energy consumption. Energy Economics, 17(1), 39–51.

Ang, B. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy, 32(9), 1131-1139.

Ang, B., Choi, K. (1997). Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. The Energy Journal, 18(3), 59–73.

Ang, B., Zhang, F. (2000). A survey of index decomposition analysis in enrgy and environmental studies. Energy, 25(12), 1149-1176.

Boyd, G.; McDonald, J.; Ross, M., Hanson, D. (1987). Separating the changing composition of US manufacturing production from energy efficiency improvements: a Divisia index approach. The Energy Journal, 8(2), 77–96.

Choi, K., Ang, B. (2003). Decomposition of aggregate energy intensity changes in two measures: ratio and difference. Energy Economics, 25(6), 615-624.

Cornillie, J., Fankhauser, S. (2004). The energy intensity of transition countries. Energy Economics, 26(3), 283-295.

Divisia, F. (1925). L'indice monetaire et al theorie de la monnaie. Revue d'économie politique, 39, 980-1008.

Fattore, M. (2009): Axiomatic properties of geo-logarithmic price indexes. Journal of Econometrics, 156(2), 344-353.

Fisher, I. (1921). The Best Form of Index Number. American Statistical Association Quarterly. 17(133), 533-537.

Hankinson, G. & Rhys, J. (1983). Electricity consumption, electricity intensity and industrial structure. Energy Economics, 5(2), 146–152.

Howarth, R.; Schipper, L.; Duerr, P., Strom, S. (1991). Manufacturing energy use in eight OECD countries – Decomposing the impacts of changes in output, industry structure and energy intensity. Energy Economics, 13(2), 135-142.

Liu, X.; Ang, B., Ong, H. (1992). The application of the Divisia index to the decomposition of changes in industrial energy consumption. The Energy Journal, 13(4), 161–77.

Montgomery, J. (1937). The mathematical problem of the price index. London: P.S. King & Son.

Steenhof, P. (2006). Decomposition of electricity demand in China's industrial sector. Energy Economics, 28, 370-384.

Törnqvist, L. (1935). A memorandum concerning the calculation of Bank of Finland consumption price index. Unpublished memo, Bank of Finland, Helsinki.

Wang, W.; Mu, H.; Kang, X.; Song, R.; Ning, Y. (2010). Changes in industrial electricity consumption in china from 1998 to 2007. Energy Policy, 38(7), 3684–3690.

Zhao, X.; Ma, C., Hong, D. (2010). Why did China's energy intensity increase during 1998-2006: Decomposition and policy analysis. Energy Policy, 38(3), 1379-1388.

Appendix

Matching of sector classifications

NACE classification	Paper two-part decomposition	Paper three-part decomposition
Manufacture of food products beverages and tobacco products	Food	Food
Manufacture of textiles, wearing apparel, leather and related products	Textiles	Textiles
Manufacture of wood and of products of wood and cork *Manufacture of furniture*	Wood	Wood
Manufacture of paper and paper products	Paper and print	Paper and print
Printing and reproduction of recorded media		
Manufacture of chemicals and chemical products	Chemicals	Chemicals and non-metallic minerals
Manufacture of basic pharmaceutical products and pharmaceutical preparations		
Manufacture of coke and refined petroleum products		
Manufacture of rubber and plastic products		
Manufacture of non-metallic mineral products	Non-metallic minerals	
Manufacture of basic metals	Metals	Metals
Manufacture of fabricated metal products		
Manufacture of computer, electronic and optical products *Manufacture of electrical equipment*	Machinery	Machinery
Manufacture of machinery and equipment		
Manufacture of motor vehicles, trailers and semi-trailers	Transport equipment	Transport equipment
Manufacture of other transport equipment		