PEER-REVIEWED PAPER

Energy use in industrial processes: a method to transpose detailed data from France to Germany

Soumaya Kalouache
Arts et Métiers ParisTech
151 Boulevard de l'Hôpital
75013 Paris
France
soumaya.kalouache@ensam.eu

Mathieu Bordigoni
EDF R&D
Site des Renardières, Ecuelles
S77818 Moret-Sur-Loing Cedex
France
mathieu.bordigoni@edf.fr

Marc Berthou
EDF R&D
Site des Renardières, Ecuelles
S77818 Moret-Sur-Loing Cedex
France
marc.berthou@edf.fr

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Abstract

While energy efficiency in the manufacturing industry is a major objective of the European energy policy, it remains difficult to measure its potential. This paper examines to what extent detailed data from one European country can help to estimate energy use in industrial processes in other Member States. By this way, governments and industrial deciders may be able to identify the most relevant technologies to reduce energy consumption.

To this end, a comparison of energy use by process data between France (131 sectors, 46 process uses, and 14 energy carriers) and Germany (14 sectors, 13 process uses, and 12 energy carriers) is performed. The combination of two national databases enables the verification of the adequacy of a transposition method applied on detailed sectors in the manufacturing industry.

Our main result is that for about a half of industry sectors, processes and products are enough standardised so as to transpose energy use data according to energy consumption. In this aim, an indicator has been developed to determine when it is possible. For other sectors, transposition methods should include information on processes or on the products breakdown for the new country.

Introduction

European energy policy aims to ensure a sustainable, competitive and secure energy supply. Political initiatives are focused on encouraging countries to plan a diversified mix of energies and to boost energy efficiency. In 2011, Germany engaged in a radical energy transition "Energiewende" which goals are a total abandon of nuclear energy by 2022 and an 80 to 95 % reduction of greenhouse gases emissions by 2050 (European Commission, 2012). In France, the National Council for the Debate about energy transition has defined several energy challenges: reduce fuel poverty, reinforce energy independence, develop renewable energies and support industrial competitiveness (Conseil national du débat, 2013).

The manufacturing sector is a major stakeholder in energy efficiency, as this sector represents one quarter of total European final energy consumption (Enerdata, 2013). Understanding of energy use at the level of industrial processes is of critical importance for efficient energy policy. Indeed, technical improvements of energy performance are carried out at the scale of processes, not for a whole industrial sector. Moreover, common technical solutions could be applied to different industrial sectors with similar processing needs.

Unfortunately, there is a lack of detailed databases on energy consumption by process and by industry in Europe. Without robust information, it is not possible to provide effective guidance for best energy efficiency innovation and diffusion. Only some countries have developed insightful databases on this subject thanks to massive plant surveys. These surveys are however costly and long to be set up.

The objective of this paper is to compare energy use data by process between France and Germany in order to test the adequacy of a method transposing detailed data from one country to another one. In this paper, "*energy use*" describes the energy consumed by one production step in the industrial chain. For instance, most of electric energy is consumed to produce the

mechanical energy necessary for motors. In most cases, fuel energy is used in heat processes. Energy can also be consumed for utilities, which are outside the main production process of the plant, e.g. lighting or space heating.

Review of existing databases and previous analysis

ENERGY USE DATABASES IN FRANCE AND GERMANY

In France, the CEREN, an energy research centre, has developed a database on energy consumption per industrial use and by segment (Berthou, 2011). 131 sectors, 46 process uses and 14 energy carriers are included. Each segment includes a group of sector following the French nomenclature of activity NAF, equivalent to the European NACE R.2 classification. This database is based on a 4 years industrial survey with a large sample of industrial sites in France.

German data used for comparison are published by Fraunhofer ISI, a German organization of applied research (Rohde, 2011). This database has been developed by using a bottom-up model called "ISIndustry". For processes non-specific to an industry, the numbers of employees and of industrial facilities are used as a proxy for energy consumption. For industry-specific processes, the energy consumption is calculated by combining annual volume of production and the standard energy intensity of a process. In addition, data for energy-intensive processes are reviewed by industry experts. 14 sectors, 13 process uses and 12 energy carriers are included following the German WZ classification (equivalent to the NACE R.2 nomenclature).

Classifications for processes and energy carriers vary from one country to another. For instance, in its evaluation method, Fraunhofer ISI gathers all heat processes in one energy use (Rohde, 2011); while CEREN database defines 12 distinct heat processes. Therefore, all CEREN energy uses could be summed as in the German database classification. The same aggregation is performed with energy carriers. Conversely, Fraunhofer's classification includes distinct energy uses as "information and communication" or "air conditioning". However, energy consumption in the industry for these uses is not significant. These uses have not been considered further.

PREVIOUS COMPARISONS BETWEEN EUROPEAN DATA

Comparison of energy use at the process level among European countries has received scarce attention in the energy literature. V. Alcantara et al. (2004) have nevertheless demonstrated that energy intensity depends to a large extent to sectoral and national specificities, using an output-input structural decomposition analysis on European countries.

The French institute CEREN have realised a model of energy consumption in European industry in order to develop a European scale database on energy consumption. The methodology is based on the hypothesis that specific energy consumptions by industrial sector in neighbouring countries are equal. Results are given for 10 sectors in 13 European countries. France is considered as the baseline country. However, there is no analysis of energy use by process for each industrial sector (Ceren, 2003).

These studies highlight the difficulty of a consumption transposition: the industrial sector classification has to be sufficiently detailed to justify the common energy intensity hypothesis among countries. In this paper, the objective is to use a detailed sectoral database in order to use such a hypothesis.

An indicator to compare industry energy consumption between countries

GAP INDICATOR DEFINITION

The classification of industrial segments in the nomenclature depends more on economics aspects than on their energy consumption behaviour. Sub-sectors inside an aggregated industry may differ significantly in the way they use energy in processes. For example, the energy profile of an electric arc furnace in the steel industry differs widely from the one for oxygen blown converters. Similarly, some sectors manufacture very different products. The energy necessary for these different types of products may be quite different. As the distribution of these processes or of the manufactured products may differ between countries, the assumption of equivalent energy intensity cannot be used.

Conversely, at a detailed level, several industrial sectors may have very close energy and production profiles from one country to another. For these industries, it is relevant to suppose that energy consumption is the same in France and Germany, the two countries studied here. For instance, in the cement industry, processes and products are standardised. We can therefore suppose that energy use is the same in both countries for this sector.

With more than 100 industrial segments included in national energy consumption databases, CEREN for France (2012) and AGEB for Germany (2011), an indicator for segmenting industries with a common energy profile has been developed. This indicator is based on the electricity/fuel repartition in the energy consumption mix of sectors. An electricity-fuel repartition is relevant because these two kinds of energy are consumed for two different ranges of uses (apart from certain heat process uses). We assume that if a sector has an equivalent relative use of electricity compared to fuels in France and in Germany, this supposes a common energy profile.

This indicator is calculated both for electricity and fuel, as energy use in process depends on the energy carrier. In order to correct for particular cases of deviation, this indicator is defined in the following way, where G is the gap indicator, PF the part of electricity or fuel consumption in France (%) and PG the part of electricity or fuel consumption in Germany (%):

$$G = \frac{PF - PG}{PF + PG} \quad (1)$$

DIFFERENCES IN THE ENERGY MIX BETWEEN GERMANY AND FRANCE

Levels of the gap indicator for industrial sectors are presented in the following figures, in which each bubble represents a sector and its dimension is its average energy consumption of the two countries studied.

Energy consumption measures are more precise for high energy consuming sectors than for low consuming ones. Energy-intensive sectors have often a similar energy profile between France and Germany, except for specific case as plastics for fuels or steel and chemistry for electricity.

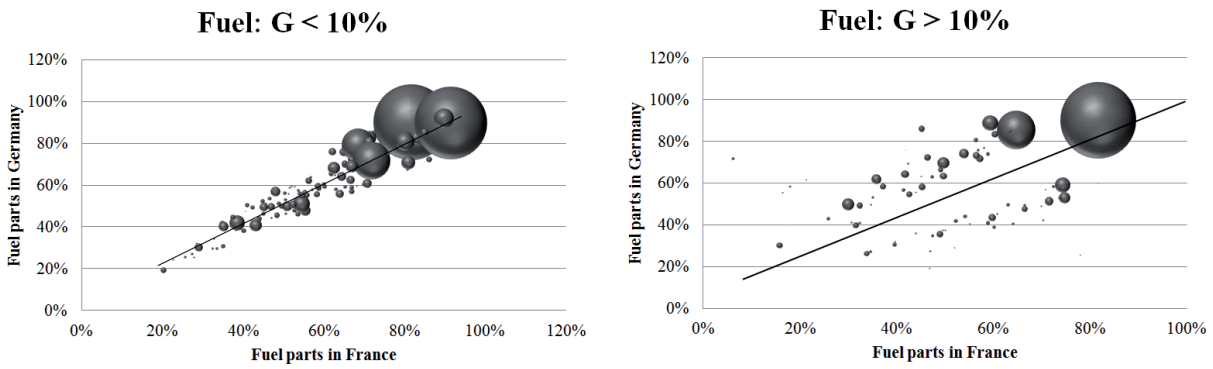

Figure 1. Part of fuel in total energy consumption in the German and French industries.

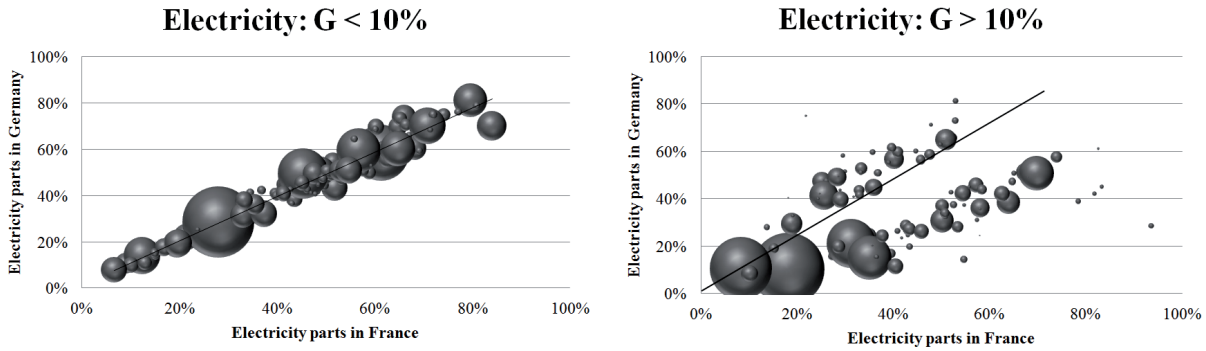

Figure 2. Part of electricity in total energy consumption in the German and French industries.

Conversely, most of sectors with a high gap indicator do not consume important part of energy (annual consumption inferior to 0.5 TWh). These sectors are often industries with non-standard processes and products. For example, there is an important gap in the energy consumption for bread production between France and Germany, more than 25 % both for electricity and fuels.

Comparison of energy use by process between Germany and France

METHOD

For most sectors, production processes are standardized and their energy consumption should be roughly equivalent in both countries. Previous general comparative analysis aims at identifying sectors for which a systematic and simple transposition method may be possible to determine German energy consumption by industrial use based on French data. Simultaneously, we want to identify which sectors are problematical and necessitate an additional expertise or, in worst case, need a survey on industrial sites.

To this end, a simple transposition method of energy use data by process in the French industry is used for Germany. However, there is no equivalent information by process for the German industry, only aggregated data. Therefore, we use precise data on energy consumption by sector both in Germany and France. We assume that the breakdown of energy use by process is the same in both countries for each detailed industrial sector. The following formula is used, where C is the energy consumption of one energy carrier e for a specific process use p in a industrial sector s, in Germany G or in France F.

$$C_{(p,e,G,s)} = \frac{C_{(p,e,F,s)} * C_{(e,G,s)}}{C_{(e,F,s)}} \quad (2)$$

Then, estimated data are aggregated and compared to public data available from Fraunhofer ISI on energy use by process. A sectoral relative gap in energy use between actual and estimated data is calculated by weighting the gap in each process by the energy consumption.

RESULTS

Quality of the estimation with a simple transposition method, using industrial sub-sectors data, relies heavily on the type of process analysed. In fact, estimation is more robust when the main consuming process for a specific energy carrier is considered: mechanical use for electricity and heat processes for fuel. The average relative error weighted by consumption is 32 % for electricity in mechanical processes and 39 % for fuel in heat processes. However, for other processes, the weighted average relative error is 121 % for electricity and more than 1,000 % for fuel. Consequently, the transposition method exposed previously can be applied only for the main consuming process for a specific energy carrier.

Different factors may explain this estimation issue. First, energy use database by process may be much more focused on most energy-consuming processes. Energy uses in other processes may often result from interpolations. For instance, according Fraunhofer ISI data, there is no use of electricity in heat processes in the glass and ceramic industry in Germany. Yet electricity is often used in melting or in heat treatment furnaces (i.e. electric boost). Secondly, data on energy consumption by sector differ between the German AGEB and Fraunhofer ISI databases. For example, electricity consumption is estimated to 45 TWh in the German basic chemistry sector by AGEB, but only to 36.4 TWh by Fraunhofer ISI. This gap can clearly be identified in the following figures. We have not been able to identify which database is the correct one. Thirdly, main energy-consuming processes may be more standardised across countries than low consuming processes or utilities. Finally, our data comparison is based on aggregated information. It may be more relevant to compare directly energy use by process for each sub-sector. Unfortunately, no detailed data are public for Germany.

Then, estimation error results are ordered according to the previous gap indicator *G* for electricity in mechanical processes and for fuel in heat processes. Low levels of the gap indicator, as defined previously, are related with lower relative errors between actual and aggregated estimated data from the simple transposition method on every sub-sector. According these results, we can suppose that the estimation error is lower than 30 % when the gap indicator *G* is below 10 % for a specific energy carrier.

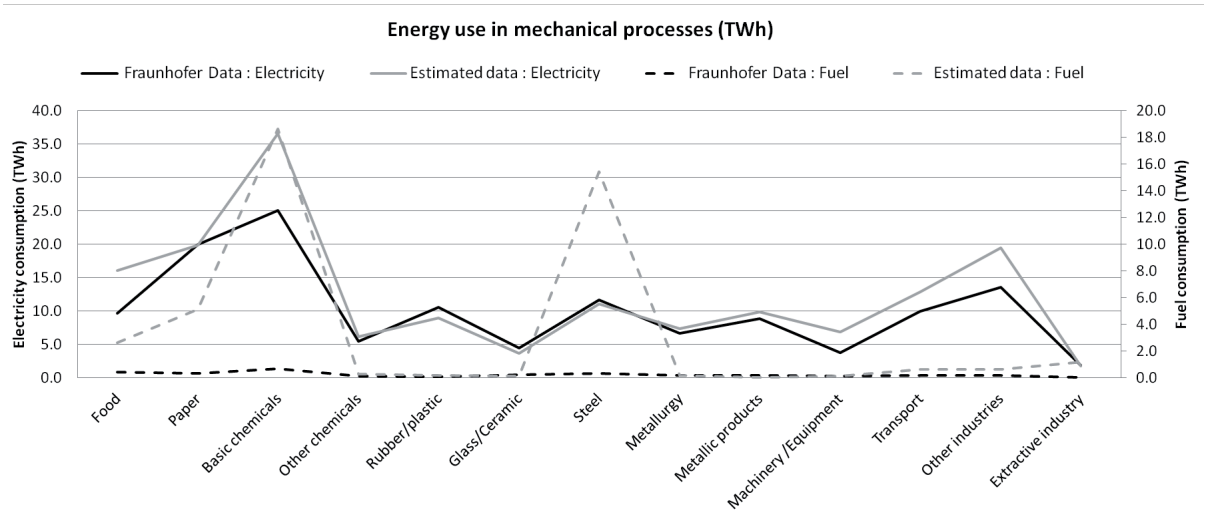

Figure 3. Comparison of energy consumption data in mechanical processes by sector and by energy between Fraunhofer ISI and the transposition estimation.

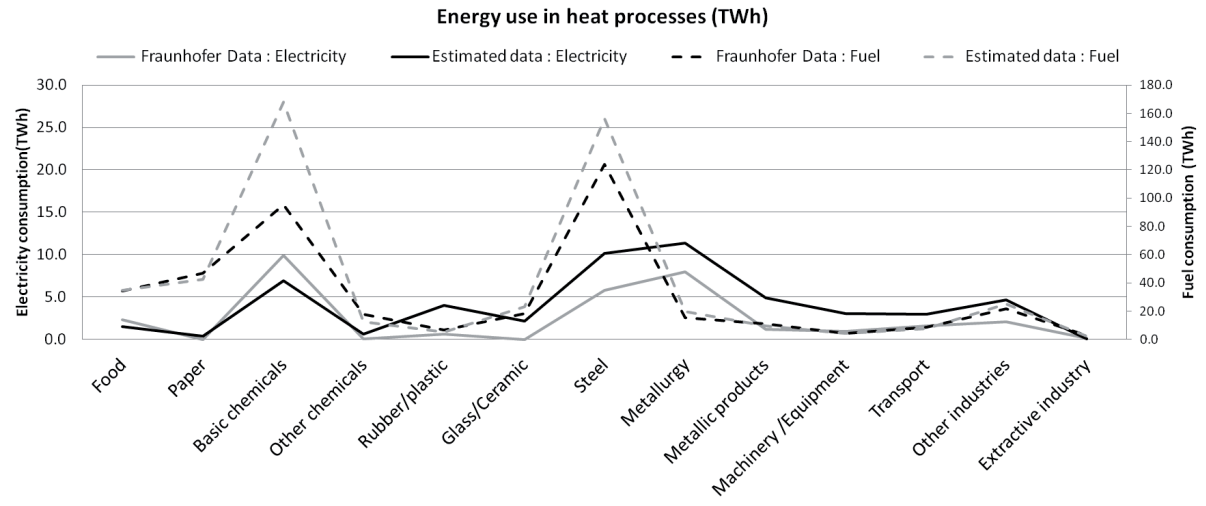

Figure 4. Comparison of energy consumption data in heat processes by sector and by energy between Fraunhofer ISI and the transposition estimation.

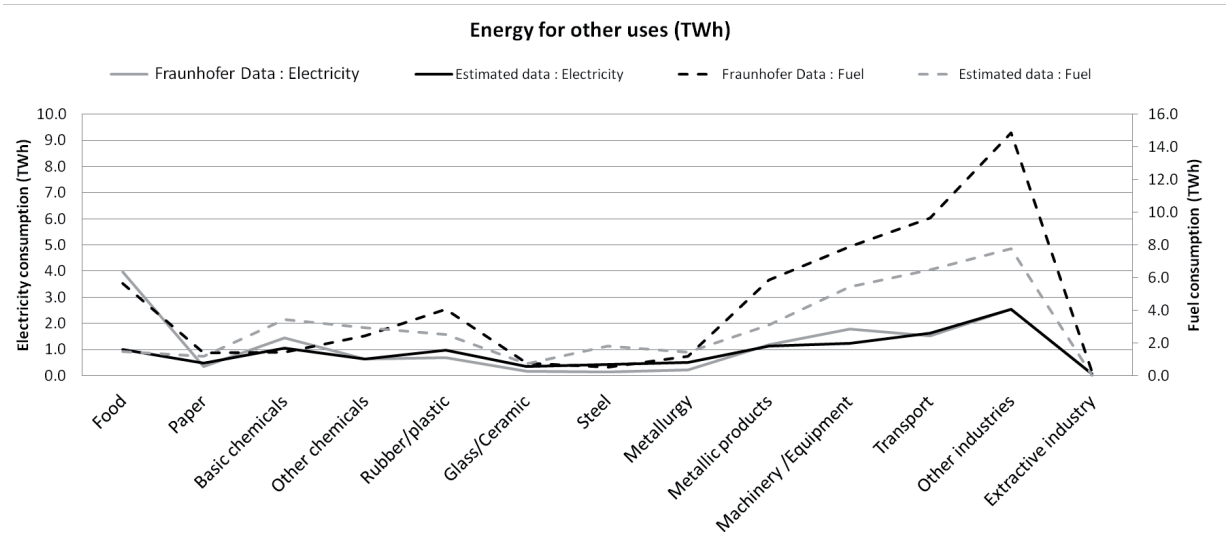

Figure 5. Comparison of energy consumption data in other processes by sector and by energy between Fraunhofer ISI and the transposition estimation.

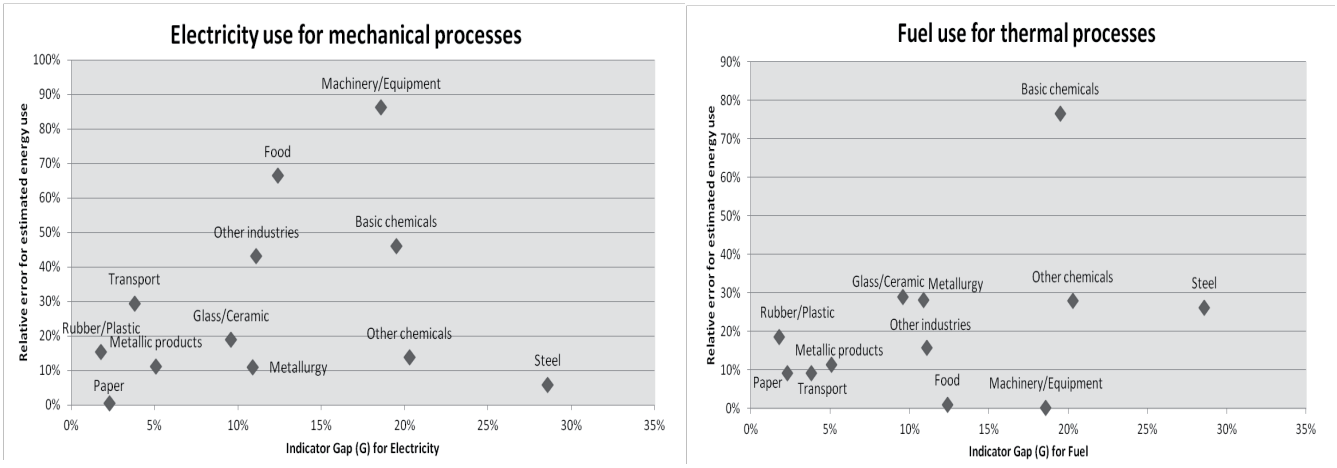

Figure 6. Estimation error relative to the indicator gap (G) level.

However, higher gap indicator levels do not imply larger estimation errors. When the gap indicator *G* is higher than 10 %, it is not possible to evaluate the relative error induced by using a simple transposition method from French data on subsectors. For instance, for the food and machinery industries, the breakdown of fuel consumption among processes is very close between Germany and France, although the gap indicator is higher than 10 %. Conversely, for basic chemicals, the process breakdown is very different. These deviations for basic chemistry may be explained by different production processes or products between the two countries, but only by various energy intensities in food or machinery industries.

Conclusion

Information on energy use by process in the manufacturing industry is crucial for developing an effective energy efficiency policy. However, databases combining statistics by process, sector and energy carrier are long and costly to set up using plant surveys. This study compares energy use between Germany and France so as to analyse when a simple transposition method of the energy use breakdown by process, using a detailed sector classification, is relevant.

For half of industrial sectors examined in this study, the estimation error using this methodology is below 30 % for the main energy-consuming processes for a specific energy carrier: mechanical use for electricity and heat processes for fuel. These sectors can be identified with a simple quantitative indicator calculated on the relative use of electricity and fuels within a sector. However, for most of secondary processes, it is not possible to use this transposition method between two countries.

Further improvements including the impact of a different processes or products distribution are necessary. In addition, it would be useful to set up a European cooperation to develop robust databases on energy use by process.

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