

Viewpoint

Adding apples and oranges: The monitoring of energy efficiency in the Dutch food industry

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Abstract

This article develops indicators to monitor energy efficiency developments in the food and tobacco industry based on physical production data at the firm level provided by the statistics office of the Netherlands in a confidential basis. We measure energy efficiency by using an energy efficiency indicator which is the aggregate specific energy consumption. Our results show that the food and tobacco industry has improved their energy efficiency indicator in primary terms by about 1% per year (uncertainty range between 0.9 and 1.3). In terms of final energy, there has been a decrease on the indicator for final demand of fuels of about 1.8% p.a. while there has been no improvement in the indicator for final demand of electricity. The development in energy efficiency is coherent with the reported implementation rate of energy conservation projects. We conclude that the type and the quality of the data compiled by Statistics Netherlands for the food sector is sufficient to develop indicators as required by energy and climate policy.

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1. Introduction

Decreasing CO₂ emissions is arguably a main goal on the global environmental agenda. The potential ecological damage that could result from a shift in our current climate regime due to the increase in CO₂ concentrations in the atmosphere has given rise to the necessity for policy making that could address the challenge of global warming. In this context, increasing energy efficiency has been pointed out as an important option for the abatement of greenhouse gases (i.e. two examples are the International Panel for Climate Change (IPCC) conclusion that technologies and practices for end use energy efficiency in buildings, transport and manufacturing industries account for more than half of the potential of greenhouse gas emission reduction in the 2010–2020 period (Metz et al., 2001) and the proposal from the European Commission (2004) for a directive in

energy use efficiency). There is however a question that arises when policies are designed to improve energy efficiency and that is how to monitor changes in energy efficiency.

The ratio of energy use to amount of activity, hereafter called energy intensity, has been accepted as the quantitative measure against which energy efficiency development can be measured.¹ Over the last decade, substantial research has been conducted on the problems and advantages related with the selection of activity measures (i.e. Freeman et al., 1997; Nanduri et al., 2002; Ross and Hwang, 1992; World Energy Council, 2001; Worrell et al., 1997). There is growing consensus that obtaining a clearer picture of energy efficiency improvements related to energy efficiency

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¹The main practical difference between the concept of energy intensity and energy efficiency is that while energy efficiency is inferred by looking at the technologies used in process and activities, energy intensity is inferred from data on activity and energy consumption (Schipper and Grubb, 2000).

policies requires the use of indicators which filter out the influence of structural changes and relate the energy consumed to the physical output. In the case where the analysis is done at a high level of aggregation, economic measures of output (i.e. value added or GDP) are the most used measures of activity. This is because of the daunting problem of representing output by a few well-defined products for which data on energy use and physical output are known (International Energy Agency (IEA), 2004).

Attempts to analyze energy efficiency trends in terms of energy per unit of physical output in the manufacturing sector at a lower level of disaggregation are found in an extensive body of literature, especially for energy intensive industries such as steel, pulp and paper or cement (i.e. Farla and Blok, 2000; Phylipsen et al., 1998; Ross and Feng, 1991). Non-energy intensive sectors, such as food or textiles, have drawn less attention and when studied, energy intensity trends are generally analyzed in terms of energy per unit of value added.

We are unaware of any study that has comprehensively examined the use of energy per unit of physical output in a heterogeneous, non-energy intensive manufacturing sector at a high level of aggregation. This article is a contribution to this deficiency. In it, we present findings from a detailed examination of the Dutch food and tobacco sector (NACE 15–16) for the period 1993–2001. Most important, we assess the feasibility of implementing the methodology and data sources used in this paper for monitoring future trends in energy intensity and the possibility of applying such methodology to other countries. It should be pointed out however, that in this paper we do not attempt to have an in-depth look at the factors that have affected the energy consumption in the food sector, leaving a formal treatment of the drivers behind the savings for another study. The structure of this paper is as follows. Section 2 briefly describes the food industry and its importance in the Dutch economy. A detailed description of the methodology and data used is given in Section 3 while main results are shown in Section 4. Finally, conclusions are drawn in Section 5.

2. The food and tobacco industry

In the European Union the food and tobacco sector (NACE 15–16) accounted for about 8% of the final energy demanded by the manufacturing sector in the year 2001² (International Energy Agency (IEA), 2003). In the same year, with a total of 4885 companies (from which only 630 have more than 20 employees), the food and tobacco sector accounted in the Netherlands for about 9% of the final industrial energy demand, 15% of

Table 1

Statistical classification of economic activities in the European Community (NACE) for the food and tobacco sector at the 2–3 digit level of aggregation

NACE code	Description
15	Manufacture of food products and beverage
151	Production, processing and preserving of meat and meat products
152	Processing and preserving of fish and fish products
153	Processing and preserving of fruit and vegetables
154	Manufacture of vegetable and animal oil and fats
155	Manufacture of dairy products
156	Manufacture of grain mill products, starches and starch products
157	Manufacture of prepared animal feeds
158	Manufacture of other food products
159	Manufacture of beverages
16	Manufacture of tobacco products

the industrial employment and 23% of the industrial value added. In terms of costs however, energy only amounts about 2% of the total production costs in the food sector (at the three and four digit level the range is 1–4%). The food and tobacco industry can be broken down into 10 three-digit NACE industry sectors (Table 1). Fig. 1 shows the primary energy demand of the food sector compared to the total Dutch manufacturing industry and its distribution by food sub-sector.³

3. Methodology and data issues

The analysis performed in this paper and the possibility to be implemented as a main source for analyzing energy efficiency developments in the food and tobacco industry depends greatly on the methodology used and the kind, availability and reliability of the data used. In this section we present an explanation of the method used to estimate energy efficiency improvement, the data used and the methodology applied to examine the effect of data uncertainty in the final results.

3.1. Development of energy efficiency indicator

The methodology used in this paper constructs on the work done by Phylipsen et al. (1997,1998) and Farla (2000). In this paper, we seek to develop trends for technical energy efficiency by comparing trends in realized energy demand (as reported by the statistical office) and a reference energy use. We have selected as reference energy use the amount of energy that the food and tobacco sector *would* have used if *no* improvements in energy efficiency have occurred with respect to a base

²It does not include mining and agriculture.

³Primary energy was calculated according to the methodology described in Section 3.1.

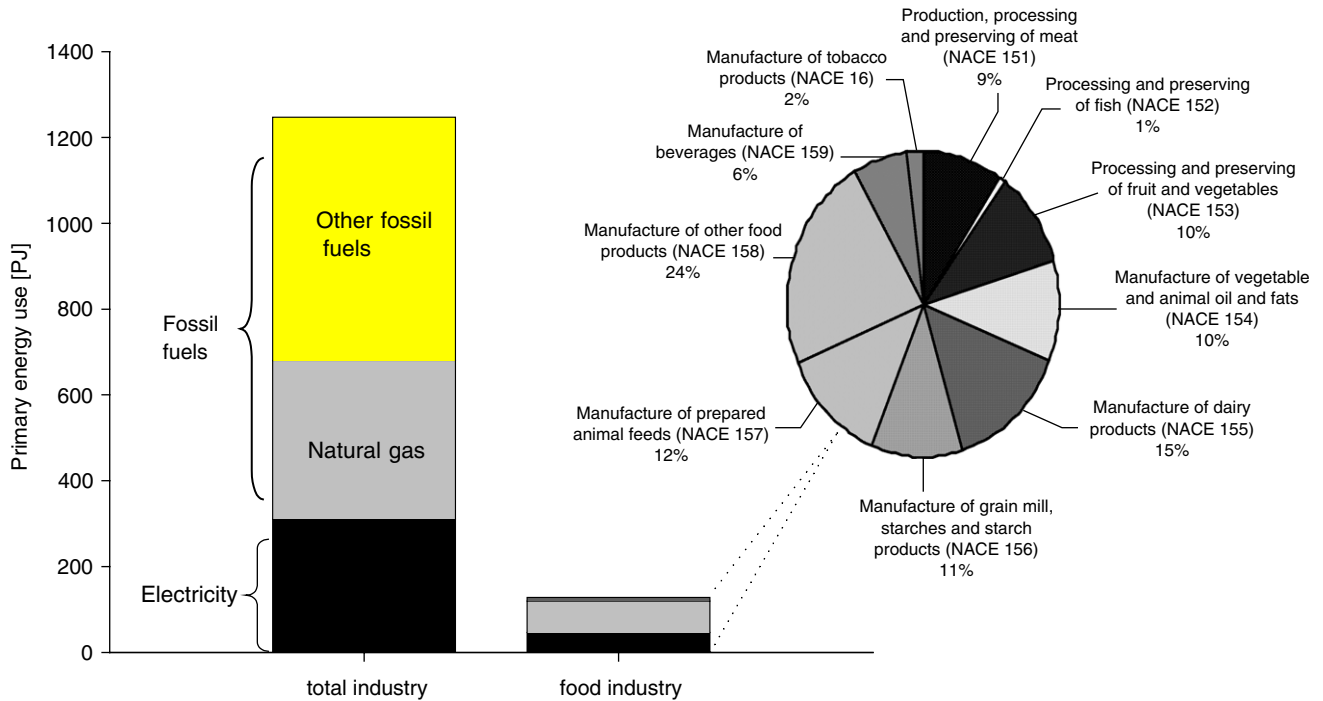


Fig. 1. Comparison of primary energy used by the Dutch food and tobacco industry, 2001.

year. We called this a frozen energy efficiency development. The frozen energy efficiency development is calculated based on two parameters: yearly physical production data and the amount of energy required in the base year to produce one physical unit of product. The latter parameter is generally referred to in the literature as specific energy consumption (SEC) or unit energy consumption. Note that the type of process, technology and efficiency level used to produce each product in the base year are reflected in the SEC value. Hence if for the base year, all products of a sector are accounted for and the SECs reflect their real energy requirements, the frozen energy demand equals the realized energy demand and thus the numeric value of the indicator would be one. Furthermore, because the frozen efficiency development is constructed by taking into account production developments in individual products, the resulting indicator already corrects for structural changes (e.g. shift of fluid milk to milk powder). This procedure is in essence the same used by the Dutch Energy and Environmental Agency (Novem) to monitor improvements in energy efficiency as a consequence of the Long-Term Agreements (LTA).⁴ Eq. (1) shows the energy efficiency indicator by type of fuel.

⁴LTA are voluntary agreements between sectors of the economy (e.g., an industrial sector) and the Dutch government. The main goal of the LTA is to increase the energy efficiency of the sector by a given percentage in an established period of time. The information provided by the companies is given in a confidential basis. For more information see: <http://www.mja.novem.nl>

The base year used in this paper is 1995.⁵

$$EEI_{j,k} \cong \frac{E_{j,k}}{\sum m_{i,k} \cdot SEC_{i,j,0}} \quad (1)$$

The energy efficiency indicator in primary energy (EEI_p) can then be calculated as:

$$EEI_{p,k} = \frac{E_{p,k}}{\sum m_{i,k} \cdot (SEC_{ref\ i,j,0} \cdot f_j)} = \frac{\sum E_{k,j} \cdot f_j}{\sum m_{i,k} \cdot (SEC_{ref\ i,j,0} \cdot f_j)} \quad (2)$$

In which k is the year of the analysis, with 0 denoting the base year, j the type of fuel (i.e. electricity, fossil fuels/heat), $EEI_{k,j}$ the energy efficiency indicator in year k for fuel j (dimensionless), $EEI_{p,k}$ the primary energy efficiency indicator in year k (dimensionless), $E_{j,k}$ the energy demand for fuel j , in year k (e.g., in Terajoule); from energy statistics, $E_{p,k}$ the primary energy demand in year k (in Terajoule), $m_{i,k}$ the physical production of product i in year k (e.g., in tonnes), $SEC_{i,j,0}$ the energy use to produce product i , for fuel j , in the base year (e.g., in Gigajoules per tonne of final product) and f_j the conversion factor from fuel j for final use to primary energy.

⁵Results from our analysis have been used as an input for the calculations of total energy savings in the Netherlands made by the Energy Research Center of the Netherlands (ECN). We use 1995 as the base year because that is the base year used by ECN to calculate total energy savings in the Netherlands.

3.2. Energy data

Energy data were taken from the annual energy balances for the food industry published in the energy–supply statistics part 1. Energy balances for the food sector are published at the two-digit level of aggregation (NACE 15–16) and they cover all food companies in the Netherlands. System boundaries for the energy balances are shown in Fig. 2. The energy balance data account for the final use of fuel (F_3),⁶ electricity (El_4), heat (H_4) and non-energy use (N). In this paper the analysis is based on data excluding non-energy use. Data on primary energy consumption ($E_{p,k}$) was calculated using final energy consumption values and tables for combine heat and power⁷ published in the energy–supply statistics part 2.⁸ These tables show values on CHP total energy input (F_1) and heat and electricity production (El_2 and H_2). Primary energy (E_p) is calculated according to Eq. (3). We use as conversion factors from final energy to primary (f_j) 1.05 for oil products, 1.01 for natural gas,⁹ 2.5 for electricity bought from the grid (reflecting a 40% conversion efficiency),¹⁰ and 1.11 for heat from boilers (reflecting a 90% conversion efficiency). For steam produced from a CHP unit steam has been valued at 83% of its energy content.¹¹

$$Ep_k = ((F_{1k} + F_{3k} + (H_{1k}/0.9))f_{\text{fuel}}) + (El_{1k}f_{\text{elect-grid}}). \quad (3)$$

To calculate the frozen efficiency development in terms of primary energy we take into account that already in 1995 (our base year), 32% of the final electricity (E_4) used in the food industry was produced by industrial cogeneration. We have estimated the

electric efficiency for CHP in 1995 as 43%. Thus, the average conversion factor for electricity_{CHP-powergrid} to primary is calculated as 2.41.

Finally, we have corrected the energy figures for climate influences using the Eurostat temperature correction method¹² (assuming an average heating share of 20% based on data published in European community, 2003 and RIVM, 1995).

3.3. Production data

Since the goal of this study is not only to study the development in energy efficiency for the last few years but also develop a methodology that can be applied in the future, data sources for physical production were selected according to three conditions: (a) the data must be published annually for the Netherlands, (b) the data must be easily available, and (c) the source should be reliable. The main data source used in this study is the industrial production statistics Prodcom. Prodcom stands for Products of the European Community. It records physical volume and value of production of self-manufactured goods by using a uniform methodology throughout Europe. Within Prodcom, products are classified using the same coding as for the NACE classification of economic activities. The statistical unit is defined as an independent unit producing goods or services for third parties (Eurostat, 2001). The Prodcom survey covers all industrial enterprises with 20 or more employees. Using Prodcom has two main advantages. On the one hand, it covers more than 4000 detail products of the manufacturing sector, hence decreasing the number of data sources that are generally required for this kind of analysis. On the other hand, the international character of the survey implies that similar studies can be conducted in other countries.¹³

Within Prodcom, information related to industrial companies exists at different levels. At company level (covering all production sites of the same company) and at an aggregate level: covering all production sites within the same industrial branch. Data are published only at the aggregate level. However, due to CBS policy concerning the protection of the privacy of individual respondents, not all production data is actually reported in the aggregate values. In order to overcome this problem, we work with Prodcom data at the company level. Company data has been provided by the National

⁶Distinguishing between oil, natural gas and cokes.

⁷A combined heat and power unit (CHP) is a unit that produces both heat and electricity. The efficiency of these kinds of units is higher than when electricity and heat are produced separately.

⁸In the Dutch statistics if a CHP unit is operated in a joint venture between industry and energy sector, it is considered as an enterprise with main activity to produce heat and electricity, and thus its outputs are allocated to the energy sector and not the industrial sector. The values for CHP shown in the food balance are thus incomplete. The CHP balances published in part 2 of the energy statistics show the input and output of all CHP units by sector.

⁹These conversion efficiencies reflect losses in transportation and fuel conversion which are considered to be relatively small (e.g. Philipsen et al., 1998). The Dutch Statistic Office has reported energy losses in transformation processes of about 7–10% for the oil sector and 1–5% in the gas sector. We took the upper limit.

¹⁰We maintain the electricity generation efficiency constant in order to determine purely the effect of efficiency improvement on the energy demand side; otherwise effects of efficiency improvements in power generation (energy supply side) would also be included.

¹¹We allocate fuel inputs of CHP plants on the basis of the exergy content of the products as described in (Philipsen et al., 1998). We use an exergy factor for steam of 0.36 (Blok, 1991). In the year 1995, steam is valued at 83% of its energy content and electric efficiency is allocated to be 43%.

¹²The temperature correction method of Eurostat is based on the share of fuels used for heating purposes. Hence the temperature corrected energy (E_{nt}) is given by: $E_{nt} = E_{ht}/d_t + E_{pt}$, where E_{ht} is the energy used for heating purposes, E_{pt} is the energy used for non-heating purposes, and $d_t = D_t/D$, where D_t and D are the actual and long-term degree days (Brook, 2001).

¹³For additional information on Prodcom see: http://forum.europa.eu.int/irc/dsis/bmethods/info/data/new/prodcom_questionnaire_en.pdf.

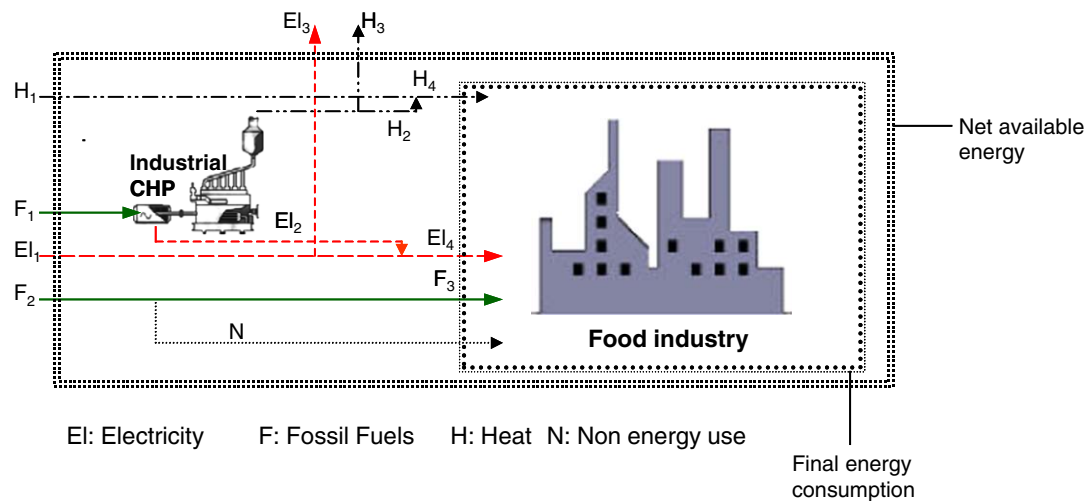


Fig. 2. System boundaries.

Statistical Office of the Netherlands (CBS) through their Center for Research of Economic Microdata (CEREM). There are however two main drawbacks. First, the data is only available from 1993 onwards and secondly, the data become available with a time lag. In the present set-up this means a time lag of two years. Hence, the time frame used in this study is 1993–2001. The list of products and the methodology used to select them are described in Section 3.4.

We use Prodcum data for most products with the following exceptions:

- Meat sector:** Because SEC data found in literature for the slaughtering of cattle, pig and poultry are based on dress carcass weight, we do not use Prodcum data which report production based on final weights but data provided by the Dutch Meat Board. Furthermore, since products produced during the processing of meat by-products (this is known as rendering) are not necessarily processed for sale (i.e. fallen stock or offal that are consider a danger to public health), we work with the amount of raw material processed (otherwise the influence of rendering in the energy consumption of the sector is underestimated). As there is a lack of statistical data on the total annual amount of raw material to be rendered, we assume that: (a) the total weight of raw material to be rendered per beast is typically: 198 kg (cattle), 21 kg (pig), 14 kg (sheep) and 0.7kg (poultry) (Meat and Livestock Commission (MLC), 1998) and (b) fallen stock represents 10% of the tonnage processed annually (idem).¹⁴ Using data on the total number of slaughtering published by the Product Board for Livestock, Meat and eggs (PVE), the total amount of raw material to be rendered is calculated.

- Dairy sector:** Prodcum values for dairy products show two problems: (a) strong fluctuations (it is the only sector studied which shows fluctuations of more than 100% from 1 year to another, for the other sectors typical fluctuations were at maximum of 30–40% from year to year) and (b) underestimation of the production of whole and semi-skimmed milk (this could be due to the fact that these products are not only sold as final products but are also used as intermediates and thus are not always reported within the sale statistics). Hence, we use production data reported by the Dutch Dairy Board (PZ).
- Cacao:** Since we did not find SEC reference values for cacao products, instead of using production data for cacao products, we use as measure of activity the raw material processed (for which SEC figures are available). Raw material in this case is the total amount of cacao beans processed by the Netherlands. This data is published annually by CBS.

3.4. Selection of products and specific energy consumption data (SEC)

The selection of key products and of their SEC is a critical point for the analysis of the food sector. Prodcum distinguishes 413 different food product categories, from which the Netherlands reports on 335. We look at each sub-sector of the food industry (i.e. dairy products, sugar, fruit and vegetables) and identified main processes and products which are important from an energy point of view. We made a literature survey to find SEC values. SECs were mainly gathered from open literature, however when data was unavailable from literature we calculated them based on energy and production data at the company level. For doing so, we select those companies that in our base year, 1995,

¹⁴In the Netherlands it is forbidden to bury fallen stock, all stock should be processed by rendering companies.

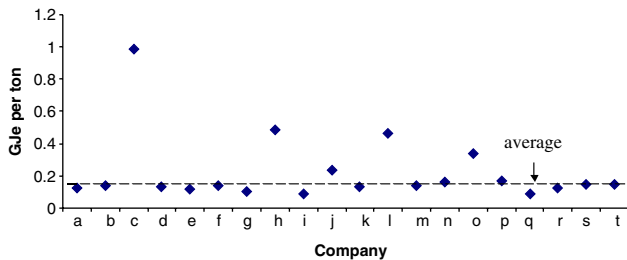


Fig. 3. Specific electricity consumption by Dutch companies that manufacture prepared food for farm animals in 1995.

only report one product in Prodcum (or use one main raw material) and using the energy data reported by the same company,¹⁵ we calculate their specific energy consumption as the ratio of the amount of energy use to the production (in physical terms). The SEC used in the analysis is determined as the average of the values found. As an example Fig. 3 shows the SEC for electricity for the manufacture of prepared food for farm animals. The products and SECs used in this study together with their sources are listed in Table 2. Due to confidentiality issues SECs that involve confidential information are only shown in terms of primary energy.

As explained in the methodology section, if all products were accounted for and their SEC were known, in the base year the frozen and realized energy use would be equal. We defined as coverage the proportion of the energy accounted for with the products selected respect to the total energy used by the sector in the base year. The coverage reached in this paper for the year 1995 is of about 81% for fuels/heat and 60% for electricity (we discuss the influence of these percentages in the results obtained in Section 4.3).

3.5. Uncertainty analysis

To *quantitatively* evaluate the uncertainty of our results we use what generally is referred to as a “Bayesian” or “subjective” characterization of probability. A Bayesian assessment of probability distributions can be interpreted as “the probability of an event is the degree of belief that the event will occur, given the observations, modeling results and theory currently available” (Moss and Scheiner, 2000). The procedure is as follows: first we identify the main sources of uncertainty, second we represent these uncertain elements as probability density functions PDFs¹⁶ (see Fig.

¹⁵Energy at the company level is also available from CEREM on a confidential basis. The energy panel contains information that makes it possible to calculate each company’s average electricity, fuel and heat demand.

¹⁶PDFs are a common way to present results. Unlike error bars, which only give a range in which the solution should fall, PDFs attach a likelihood to each possible value. A PDF represent the density of probability so that a parameter p takes a value $f(p_1)$ if the probability

4) and thirdly the inputs are combined to generate the PDF of the output. The program used to generate the PDF of the output is Crystal Ball 2000, the number of trials was set to 100,000 and the certainty range to 95%.

As sources of uncertainty we identified the following parameters: SECs for fuel and electricity, and the production and energy data provided by the statistical offices and industrial associations. For the parameters for which the range *and* the most likely value were known (from literature or national surveys) we use a triangular distribution.¹⁷ For those parameters for which there was only information available about the range of values but not about the most representative value for the Netherlands or the SEC data was not gathered in the base year, a uniform distribution is used.¹⁸ In this case, the range is made taken into account the most extreme values found in literature for European countries in the 1990s. When historical data was available we use Crystal Ball to fit the PDF to the data. In Appendix A we show the different PDFs used in this paper for the SECs values.

The method selected to encode the PDFs of the energy and production data is the fixed value method.¹⁹ Thus, for the energy data we use a triangular distribution with an uncertainty range of 5% (although uncertainty in the energy balances has been estimated as low as 1% (Boonekamp et al., 2001), we found that fluctuations in energy data oscillate about 5%). For production data from industrial associations we use a triangular distribution with an uncertainty of $\pm 5\%$.

For Prodcum data we consider that:

- There is a systematic error introduced by the fact that the answer response to the survey is not 100%;

(footnote continued)

of the parameter value lying between p_1 and $p_1 + \delta p$ is $f(p_1)\delta p$, where δp is a small increment of p . A PDF can take a number of standard forms i.e. uniform, normal, log normal, triangular, etc.

¹⁷In a bell shape or a triangular distribution we assume that the value is more likely to be near the mean than far away. We selected a triangular distribution because its “apparently arbitrary shape and sharp corners are a convenient way to telegraph the message that the detail of the shape of the distribution are not precisely known. This may help to prevent over interpretation of results or a false sense of confidence” (Morgan and Henrion, 1990, p. 96).

¹⁸In a uniform distribution we assume that there are equal probabilities that a value would be close to the mean than far away. This distribution is considered appropriate when it is possible to identify a range of possible values but is not possible to decide which value is more likely to occur.

¹⁹There are three main methods to encode distributions. Fixed values methods (the probability that the quantity lies in a specific range of values is assessed), fixed probability (values of the quantity that bound specified fractiles or confidence intervals are assessed; i.e. a typical question could be: give a value x such that the unknown quantity has a 25% chance of being less than x), bisection or intersection method (in it the median is assessed first, followed by the median of each quartile, the median of each octile and so on) (Morgan and Henrion, 1990).

therefore the survey tends to underestimate the production figures (as minimum the survey should report 90% of the production). Thus we assumed that the triangular PDF is skewed to the right (positively skewed) with ranges of -5 to $+10\%$.

- The survey only accounts for companies with more than 20 employees. This can increase the problem of underestimation for those products which are produced to a large extent in companies with less than 20 employees. In some cases it may not even possible to reach the 90% of the production. From the products selected in this paper the following products have been listed as problematic in a confidential evaluation made by the CBS on the Prodcom survey (Bontrider-de Steur and Stroeks, 2003): sausages not of liver (Prodcom 15.13.12.15), frozen vegetables and mixtures of vegetables (Prodcom 15.33.14.40), sweet biscuits (Prodcom 15.82.12.53), waffles and wafers (Prodcom 15.82.12.59), fodder for the feeding of pets (Prodcom 15.72.10.30 & 15.72.10.50). For these products we have used triangular PDFs with ranges of -5% to $+20\%$.
- There is a difference in the quality of the Prodcom data. It is estimated that data in 1993 and 1994 is less reliable than the data for the period 1995–2001 (1993 was the first year the survey was done; hence 1993 and 1994 have low response), we reflected this by doubling the uncertainty range of Prodcom data for the years 1993–1994.

4. Results

Fig. 5 shows the trends obtained for the primary energy efficiency indicator (EEI_p) and EEI by fuel (based on final energy use) for the food and tobacco industry as well as the frozen and realized energy use. Uncertainty ranges varies between 2% and 5% for EEI_p and between 3% and 6% for EEI for fuels and electricity (95% confidence). We found cumulative savings, in terms of primary energy, of about 11 PJ (uncertainty range 8–14 PJ) for the period 1993–2001. This savings have been mainly due to improvement efficiency of fossil fuels/heat per unit of product (EEI fuels has decreased by about 15% (range -8% ; $+19\%$) while no improvement in electricity efficiency has been observed. Furthermore, we calculate that in addition, increased penetration of CHP in the food and tobacco industry since 1993 has saved about $2.8 \text{ PJ} \pm 5\%$ primary energy in the Netherlands.

Next we explore our results in terms of projected savings, the sensitivity of the uncertainty ranges, the number of products analyzed and the fitness of SEC found in literature respect to the Dutch situation.

4.1. Confrontation of projected savings with total savings

To evaluate the plausibility of the savings shown by the EEI_p we have looked at (a) the penetration of CHP and (b) whether there has been new technologies or changes in process during the period that would demand lower fuel/heat consumption. An inventory of energy saving technologies was done using information published in the Long Term Agreements and data from three Dutch subsidy programs: TIEB (tenders industrial energy savings), BSET (subsidies for energy conservation techniques) and the Dutch subsidies program for project demonstration.

Each of these programs publishes a description of the different projects by year and sector and it specifies energy savings by fuel. We only account for projects that have been implemented in the period 1995–2001 (when it was not specified in the description if and when the project has been implemented, we called the companies in charge). The kind of projects and savings are shown in Table 3. These projects alone have saved about 3780 TJ of primary energy. These savings together with increased CHP penetration are already able to explain about 80% of the change in the EEI_p between both years (Fig. 6). We also found that savings on electricity have not been very important. Furthermore, 60% of the savings due to energy saving technologies is due to technologies implemented after 1999. This corroborates the strong decrease shown by the indicator in Fig. 5 and thus it is a confirmation that the indicator is sensitive enough to reflect important changes.

4.2. Sensitivity of the uncertainty ranges

Fig. 5 shows the results of the uncertainty analysis as described in the methodology. In order to understand the uncertainty ranges, we first look at the influence of the uncertainties in each parameter (production, energy and SEC) by running calculations where only one of the parameters at the time contribute to the final uncertainty. Not surprisingly we found that in 1993 and 1994 uncertainties in production data had a higher influence than in 2001. This because as explained in Section 3.5, uncertainties ranges of Prodcom data were doubled (compared with the years 1995–2001) to account for a low response rate.²⁰ When this is not the case, uncertainties in SEC gain relevance.

We have then looked whether the results are dependent on the probability function assigned to the SECs. To this end, we have changed all SEC fuel and electricity PDFs to uniform distributions. We found that at the level of certainty we are working with (95%), changing the PDF only affect the uncertainty range

²⁰As a consequence of 1993 and 1994 being the first years where the survey was conducted.

Table 2
Specific energy consumption values (SEC) by product in the food and tobacco industry

Product	Origin production data (Prodom numbers)			SEC electricity	SEC fuels and heat	Unit	Source/comments
Meat							
Beef+Sheep	A	PVE statistics		341	537	MJ/ton dress carcass weight	Pontoppidan and Hansen (2001)
Pig	A	PVE statistics		465	932	MJ/ton dress carcass weight	
Poultry	A	PVE statistics		1008	576	MJ/ton dress carcass weight	Pontoppidan and Hansen (2000)
Processed meat	PC	15131110+15131130+5131150+15131170+15131190+15131213+5131215+15131225+15131233+15131235+5131243+15131245+15131253+15131259+5131260+15131263+15131269 Calculated based on PVE statistics	750		3950	MJ/ton product	Suijkerbuijk et al. (1995)
Rendering	A		234		1042	MJ/ton raw material	Schreurs (2003)
Fish							
Fresh (fillets)	PC	15201190	129		6	MJ/ton product	Nielsen et al. (2003)
Frozen fish	PC	15201210+15201230+15201270+15201290+15201530+15201553	608		6	MJ/ton product	
Prepared or preserved fish	PC	15201411+15201412+15201413+15201414+15201415+15201417+15201419+15201419+15201330+15201370+15201353+15201355+15201359+15201600	482		1062	MJ/ton product	
Smoked and dried fish	PC	15201353+15201355+15201359+15201370	12		2077	MJ/ton product	Own calculation
Fish meal	PC	15201700	684		6200	MJ/ton product	Nielsen et al. (2003)
Potatoes							
Potatoes products	PC	15311230+15311250+15311100+15311210+15311270+15311290	5722 ^a			MJ/ton product	Own calculation
Fruit and vegetables							
Unconcentrated juice	PC	15321013+15321015+15321021+15321022+15321023+15321025+15321026+15321029+15321030+15321040	250		900	MJ/ton product	Loretzon et al. (1997)
Tomato juice	PC	15321024	125		4789	MJ/ton product	Molinari et al. (1995)
Frozen vegetables and fruits	PC	15331100+15331440+15331500+15332100	738		1800	MJ/ton product	Average figure based on confidential data
Preserved mushrooms	PC	15331430				MJ/ton product	VITO
Vegetables preserved by vinegar	PC	15331500		2898 ^a		MJ/ton product	Own calculation
Tomato ketchup	PC	15871230	380	2178 ^a	1700	MJ/ton product	Own calculation
Jams and marmalade	PC	15332230+15332290+15881050	490		1500	MJ/ton product	Carlsson-Kanyama and Faist (2001)
Dried vegetables and fruits	PC	15331330+15331350+15331390+15332520	1500		4500	MJ/ton product	
Crude and refined oil							
Crude oil + Refined oil	PC	15411210+15411240+15411260+15411350+15421110+15421120+15421140+15421150+15421160+15421210+15421220+15421230	672 ^a			MJ/ton product	Own calculation
Dairies							
Milk and fermented products	A	Prodzuivel statistics	241		524	MJ/ton product	Hiddink (2004)
Butter	A	Prodzuivel statistics	457		1285	MJ/ton product	
Milk powder	A	Prodzuivel statistics	1051		9385	MJ/ton product	
Condensed milk	A	Prodzuivel statistics	295		1936	MJ/ton product	
Cheese	A	Prodzuivel statistics	1206		2113	MJ/ton product	

Table 2 (continued)

Product	Origin production data (Prodcod numbers)	SEC electricity	SEC fuels and heat	Unit	Source/comments
Casain and Lactose	A	918	4120	MJ/ton product	
Whey powder	A	1138	9870	MJ/ton product	
Starches and starch products	PC	2960	8800	MJ/ton product	European Commission, 2003 Average values
Wheat starch	PC	1000	2331	MJ/ton product	
Maize starch	PC	1425	3564	MJ/ton product	
Potato starch	PC				
Prepared animal feeds	PC				
For farm animals	PC	475 ^a		MJ/ton product	Own calculation
For pets	PC	2306 ^a		MJ/ton product	Own calculation
Sugar					
Refined sugar	PC	555	5320	MJ/ton product	Hulskotte et al. (1995) NL; best 1990
Beet pulp	PC	5	1820	MJ/ton product	
Cacao					
Cacao beans	CBS		6384 ^a	MJ/ton processed cacao beans	Own calculation
Coffee					
Non roasted	PC	141	1597	MJ/ton product	European Commission (2003)
Roasted	PC	518	1997	MJ/ton product	European Commission, 2003 (Assuming 20% shrinkage in roasting)
Extracts of coffee solid form	PC	15675		MJ/ton product	Own calculation
Beer and malt					
Beer	PC	19.5	153	MJ/hl product	Heineken (1999) (Europe; 1997)
Mineral waters and soft drinks					
Mineral water and soft drinks	PC	133	199	MJ/1000 l product	Department of Environment (1997)
Unsweetened water and soft drinks	PC	120	360	MJ/1000 l product	Gonsalves (1996)
Tobacco					
Cigar	PC	66		MJ/1000 sticks	Own calculation
Cigarettes	PC	16		MJ/1000 sticks	Own calculation
Others					
Sweet Biscuits	PC		4581 ^a	MJ/ton product	Own calculation
Waffles and wafers	PC		3195 ^a	MJ/ton product	Own calculation
Flours	PC	420	30	MJ/ton product	Carlsson-Kanyama and Faist (2001)
Soup and broths	PC		7659 ^a	MJ/ton product	Own calculation
Pasta	PC	648	2	MJ/ton product	European Commission (2003)

PC, Prodcod number; A, Industrial associations.

^aDue to confidentiality restrictions data is only shown as primary energy.

when the PDF of the original outcome distribution is highly asymmetrical. This shows that the results are dependent on uncertainties in the shape of the SEC distributions.

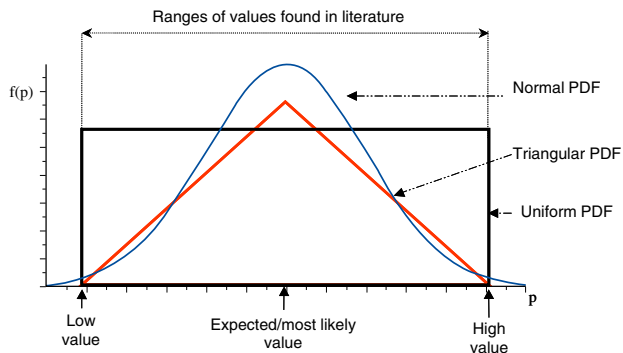


Fig. 4. Schematic illustration of probability density functions for parameter p .

Finally, we have taken into consideration that SECs values for fuel and electricity are not always independent. Crystal Ball generates random numbers for each input parameter without regard to how random numbers are generated for other assumptions. This procedure does not affect our results for individual fuels but it does for primary energy. Since there is a lack of data to evaluate the dependence between SECs for fuel and electricity, we have assumed three cases: (i) there is a 'negative strong' dependence between electricity and fuel use, (ii) there is a 'negative weak' correlation and, (iii) there is no correlation. The first case applies especially to products where most of the energy is used for concentration/evaporation (i.e. powder products). Here high use of fuels/heat is generally accompanied by a lower demand of electricity (i.e. evaporation with thermal vapor recompression demands larger amounts of heat and almost no electricity, while evaporation with mechanical vapor recompression demands the opposite). No correlation applies to products that are for instance frozen (since the amounts of heat used during

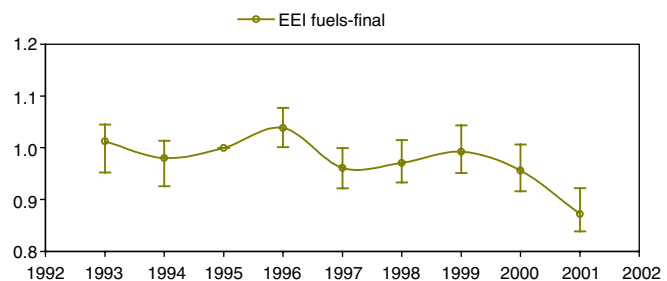
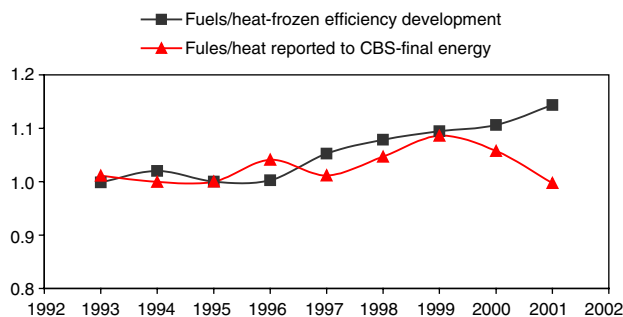
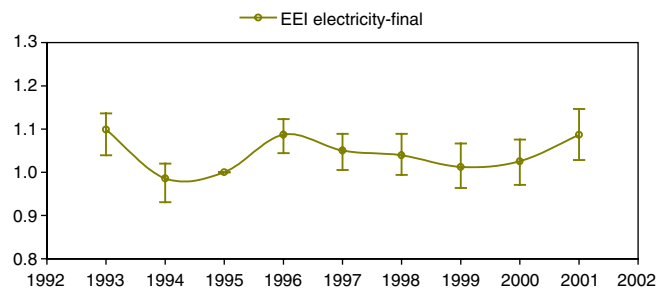
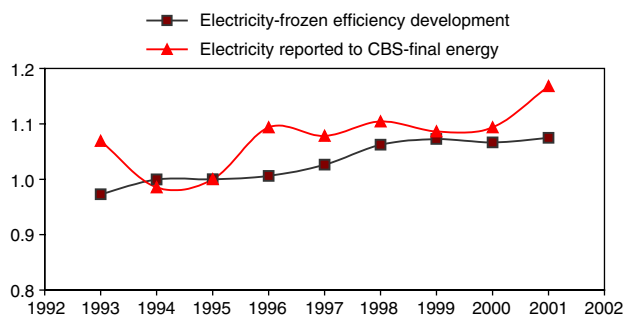
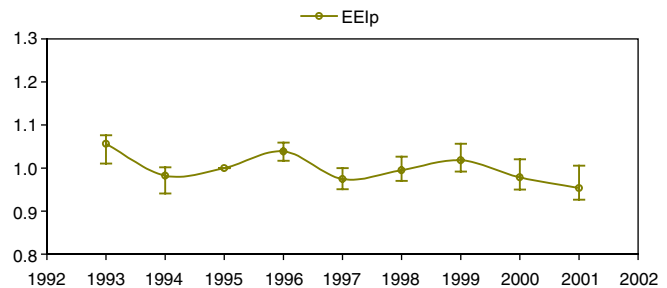
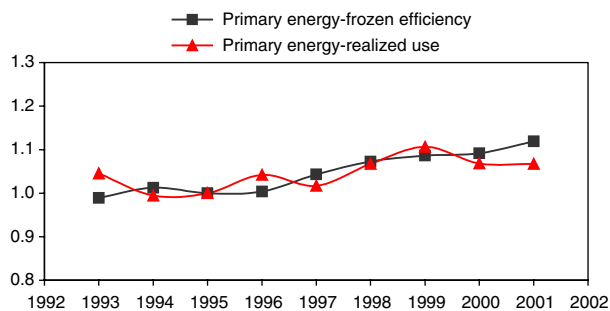


Fig. 5. Reference energy use, realized energy use and energy efficiency indicator for primary energy, final fuels/heat, electricity in the Dutch food industry.

Table 3

New energy saving processes/technologies in the food and tobacco industry for the period 1995/2001

Kind of saving technique/project	Number of projects	Primary energy savings (TJ)
Membrane filtration	3	16
Heat recovery/reuse	62	527
Batch to continuous process	3	52
Retrofit/installation cleaning in place	17	43
Retrofit/optimization of drying	11	43
Regenerative thermic oxidation	2	278
Retrofit/optimization of evaporators (includes installation of MVR)	18	175
Increase capacity/higher load factors	9	206
Installation/optimization isolation	17	11
Implementation biogas/solar energy	22	80
Use of less water/recirculation water/water at less temperature	19	67
Automation/knowledge system	13	119
Increase efficiency boilers/rational use boilers	18	59
Optimization steam use	2	4
Optimization cooling	51	41
Optimization compress air	22	13
Change in pasteurization conditions	6	5
Optimization/retrofit electric motors, pumps ventilators, lightning	40	21
Increase efficiency of vacuum pumps/system	6	131
Installation/retrofit/optimization condensers	8	48
Installation/retrofit economizers after boiler	7	8
Optimization fuel use/change on fuel	5	37
Optimization production process	23	282
Energy management and good housekeeping	179	264
Introduction new production lines/closing energy inefficient lines	8	11
Other (i.e. installation of sector specific techniques or processes such as butter deodorization (packed column), use of less energy intensive packaging, etc.)	195	1239
Total	766	3780

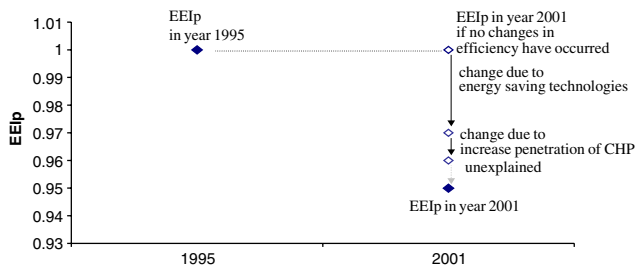


Fig. 6. Causes of changes in the EEIp for the period 1995–2001.

processing is not affected by the amount of electricity used for refrigeration). When computing uncertainties for the EEI_p , the correlations limit the way as the random numbers for each parameter are selected (i.e. in a negative correlation, if the computer selects a high SEC for fuel, it will then select a low SEC for electricity). The correlation factors are: -0.7 , -0.3 and 0 , respectively. Note that the correlation factors used only reflect our qualitative understanding of the relations. We found that as expected including the correlations in the simulation decreases the skewness of the distributions of the outcome (i.e. in 2001 the PDF for the EEI_p show an skewness of 1.465 without the correlations and with the correlations is 1.038) and decreases their range of

uncertainty, although only marginally (by about 0.5%). Since for the purpose of the paper the shape of the outcome PDF is not important, the overall impact of introducing the correlations is weak and we consider our results as robust on this point.

4.3. Coverage

One question we have not tackled yet is how representative our results are for the behavior displayed by the whole food industry. As pointed out in Section 3, we do not take into account all products when developing EEIs (the 49 product categories shown in Table 2 account for 51% of the Prodcom food categories and, the coverage obtained in the base year is of 81% for fuels and 60% for electricity). There are two main reasons for it. First of all, specific energy consumption data is not available for every individual product. Secondly, if the methodology is to be used in a regular and consistent basis, the burden of data gathering and evaluation of data quality should be minimized. Therefore, there must be some kind of trade-off between the number and the representativity of characteristics accounted for.

In order to assess whether or not the product mix studied in this paper is representative, we have

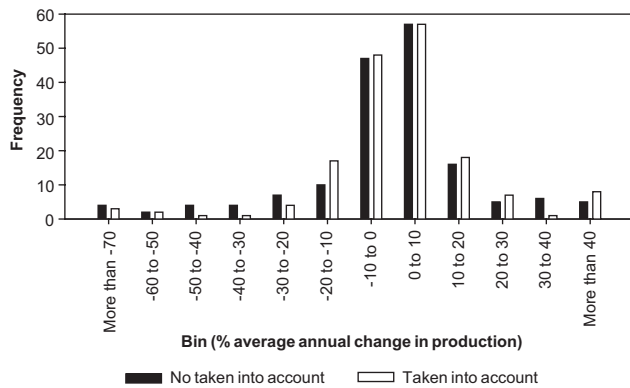


Fig. 7. Histograms for annual change in production when developing energy efficiency indicators.

calculated the average annual change in physical production for the 335 Prodcom products reported for the period 1993–2001. We compare the distribution of the products taken into account in this study against those left out. Fig. 7 depicts the frequency distribution of both groups. As shown, both groups exhibit similar behaviors. Thus, we are confident that the products selected reflect important structural changes in the food industry (i.e. decrease in energy consumption as a consequence of decreasing production of relatively more energy intensive products).

4.4. Comparison with data from the LTAs

So far we have analyzed the uncertainty level generated by data, and the representativity of the products selected, there is however an additional issue: the indicators depicted in Fig. 5 have been calculated based on 49 SEC values (Table 2) which were gathered from open literature and own calculations. The question then arises whether the trends based on such SECs reflect the “real” frozen efficiency behavior of the Dutch food and tobacco industry. One way to verify this is to compare the frozen efficiency energy use developed in this study with that reported by Novem (which is based on the LTA). Since the LTA data are based on confidential data provided by the industries, the frozen efficiency energy demand of the LTA should reflect the real production mix of the Dutch industry and will allow us to assess how well our indicators fit the Dutch situation. Note that the comparison can only be done for primary energy because it is the only information published by the Dutch Energy and Environmental Agency (Novem) (2001a–j).

Fig. 8 shows the trends reported by Novem and two trends developed in this study for the food sector: (a) if only the LTA industries which signed the covenant were taken into account and (b) if LTA industries and three

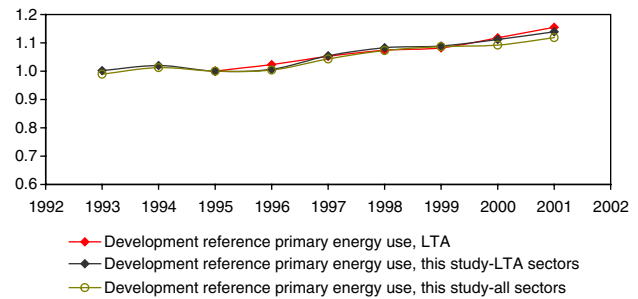


Fig. 8. Primary frozen energy efficiency in the food and tobacco industry according to this study and according to the LTA.

additional sectors plus some food products are included (this is the result shown in Fig. 5). Note that since not all sectors had LTAs before 1995, the LTA for the whole food and tobacco sector is only given for 1995 onwards. We found that our values differ from LTA values by a maximum of 4%. For comparison, Fig. 9 shows the indexes for those industries with a LTA. From Figs. 8 and 9, we conclude that the indexes developed in this study accurately reflect the frozen energy efficiency behavior of the Dutch food and tobacco industry.

5. Conclusion

Much energy and environmental policy is based on prediction, prediction relies on modeling which in turn relies on indicators that accurately reflect “real” developments. In the energy debate it seems to be accepted that wherever possible, energy efficiency indicators should be used which are based on physical measures of output. In the past this kind of analysis has been mainly done for energy intensive sectors such as steel or aluminum and was in fact the basis of the first generation of the Long Term Agreements applied in the Netherlands. In this paper we have shown that it is indeed feasible to monitor energy efficiency developments in the food industry based on physical production data at the company level and according to our uncertainty analysis and comparison with other data the results obtained are reliable. This is an important finding since it means that energy efficiency in the food sector can be monitored by an energy agency without needing to implement a task force that depends on company reporting which is done with the sole purpose of monitoring developments in energy efficiency. This is a very promising outcome not only because it is rather likely that similar analysis can also be conducted for other non-energy intensive industries in the Netherlands, it also gives rise to hopes that similar analysis for non-energy intensive sectors can be conducted for other

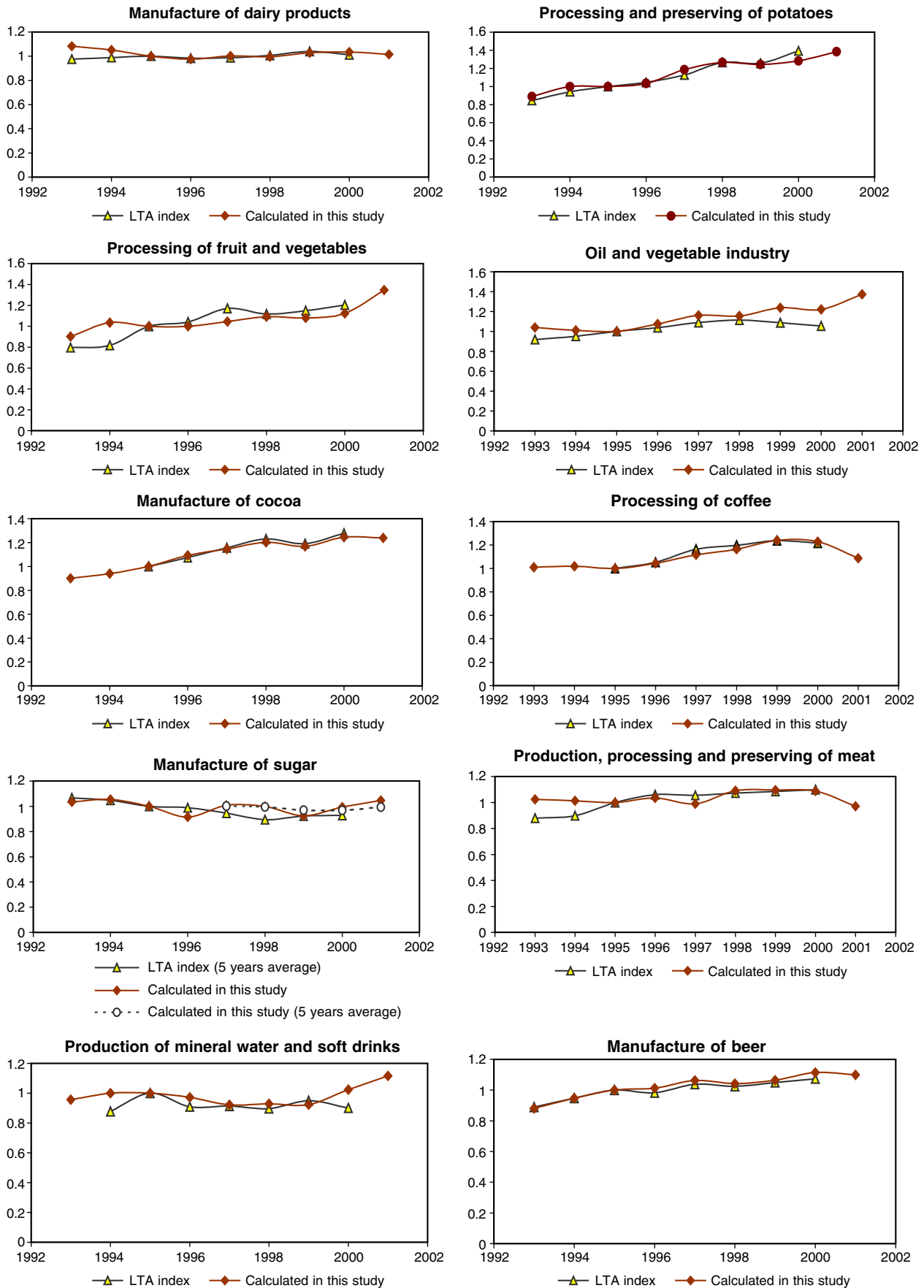


Fig. 9. Primary frozen energy efficiency development by branch in the food industry according to this study and the LTA (indexed to 1995).

countries. The sole condition is that production data can be made available (for example in a confidential basis as in the Netherlands).

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Appendix A

The different PDFs used in this paper for the SECs values (Table 4).

Table 4
Probability distribution functions used in this paper

Parameter/product	PDF attributes	
	SEC fuels	SEC electricity
Beef+ Sheep	Triangular (4833–5907)	Triangular (150–500)
Pig	Log normal $\sigma = 0.157$	Log normal $\sigma = 0.65$
Poultry	Log normal $\sigma = 2.77$	Log normal $\sigma = 2.37$
Processed	Triangular (2555–4340)	Triangular (490–1017)
Rendering	Triangular (1674–3000)	Triangular (100–350)
Fresh (fillets)	Triangular (6–7)	Triangular (90–170)
Frozen	Triangular (6–7]	Triangular (520–810)
Prepared or preserved fish	Triangular (900–1260)	Triangular (337–627)
Smoked and dried	Triangular (1869–2280)	Triangular (840–1560)
Fish meal	Triangular (5580–6820)	Triangular (547–821)
Potatoes products	Triangular (3220–3930)	Triangular (621–932)
Unconcentrate Juice	Uniform (610–1100)	Uniform (200–400)
Tomato juice	Triangular (3500–5200)	Triangular (100–450)
Frozen vegetables and fruits	Triangular (1500–2000)	Triangular (371–1325)
Preserved mushrooms	Uniform (2198–3155)	Uniform (314–707)
Vegetables preserved by vinegar	Uniform (900–1503)	Uniform (275–590)
Tomato ketchup	Triangular (1400–1500)	Triangular (267–497)
Jams and marmalade	Uniform (750–2550)	Uniform (343–637)
Dried vegetables and fruits	Uniform (4050–6990)	Uniform (1350–1950)
Crude oil + Refined oil	Triangular (3008–5530)	Triangular (73–135)
Milk and fermented products	Log normal $\sigma = 0.63$	Log normal $\sigma = 0.63$
Butter	Triangular (1156–1414)	Triangular (411–563)
Milk powder	Log normal $\sigma = 2.44$	Log normal $\sigma = 2.24$
Condensed milk	Triangular (1742–2130)	Triangular (265–325)
Cheese	Log normal $\sigma = 1.62$	Log normal $\sigma = 1.82$
Casein and Lactose	Log normal ($\sigma = 1.76$)	Log normal ($\sigma = 1.94$)
Whey powder	Triangular (6910–12831)	Triangular (8080–15000)
Wheat starch	Uniform (6768–10998)	Uniform (1692–4230)
Maize starch	Uniform (1332–3330)	Uniform (666–1332)
Potato starch	Uniform (1188–5940)	Uniform (950–1901)
Farm animal	Log normal $\sigma = 0.608$	Log normal $\sigma = 0.1428$
Pets	Triangular (1144–2900)	Triangular (31–65)
Refined sugar	Triangular (5024–6699)	Triangular (202–824)
Cacao beans	Triangular (3391–4150)	Triangular (947–1150)
Non roasted coffee	Triangular (130–190)	Triangular (112–169)
Roasted coffee	Triangular (1600–2410)	Triangular (415–622)
Extracts of coffee solid form	Triangular (8910–14000)	Triangular (10710–13000)
Beer	Triangular (1379–1680)	Triangular (176–210)
Mineral water and soft drinks	Triangular (1800–2190)	Triangular (106–160)
Unsweetened water and soft drinks	Triangular (290–435)	Triangular (97–140)
Cigar	Triangular (0.019–0.061)	Normal $\sigma = 0.0148$

Table 4 (continued)

Parameter/product	PDF attributes	
	SEC fuels	SEC electricity
Cigarettes	Triangular (5–7)	Triangular (4–5)
Sweet biscuits	Triangular (2700–5300)	Triangular (660–760)
Waffles and wafers	Triangular (2710–3300)	Triangular (630–840)
Flours	Triangular (200–400)	Triangular (240–540)
Soup and broths	Uniform (2700–5300)	Uniform (1296–2037)
Pasta	Triangular (2–3)	Triangular (504–940)

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