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SCIENCE DIRECT®
Energy 31 (2006) 1984–2004
ENERGY
www.elsevier.com/locate/energy

From fluid milk to milk powder: Energy use and energy efficiency in the European dairy industry

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Received 1 November 2004

Abstract

In this paper, we conduct a cross-country analysis of energy consumption and energy efficiency for the dairy industry in four European countries. Changes in energy efficiency were monitored in two different ways. One way is to look at the energy use by tonne of milk processed by dairies (EEI_{p1}). Another way is by comparing the actual energy use with the energy that would have been used if no changes in energy efficiency would have taken place (EEI_{p2}). A characteristic of EEI_{p2} is that it corrects for differences in product mix among countries and in time. We found that changes in production mix are important in three of the four countries studied and that EEI_{p2} should be preferred when comparing levels of energy efficiency among countries or when there are significant changes in product mix. Once changes in product mix have been taken into account, our results show that France, Germany, the Netherlands and the United Kingdom have reduced their values in EEI_{p2}, respectively by −0.4%, −2.1%, −1.2% and −3.8% per annum. The results also show that the British, German and Dutch dairy industries have converged towards similar (lower) values in their energy efficiency indicators and that the French dairy industry would save 30% if were to converge to similar values of EEI_p as the ones obtained for Germany or the United Kingdom.

Keywords: Energy efficiency; Dairy industry; Specific energy consumption

1. Introduction

The dairy sector (NACE 155)[1] covers activities related to the treatment of milk for alimentary use and milk derived products and by-products. In most member states, and in Europe[2] as a whole, the dairy sector is the most important sector within the food industry with regard to turnover (67 billion Euros in 2002) [1]. A list of the most important dairy products is shown in Box 1 while Fig. 1 depicts a schematic overview of the main processes in the dairy sector. Interestingly, despite the strong role that energy plays (it is by heat treatment that

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[1]NACE stands for Classification of Economic Activities in the European Community.
[2]Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom.

0360-5442/$ - see front matter
doi:10.1016/j.energy.2005.10.014

Box 1
Dairy products

- *Liquid milk*: can either be pasteurized (72 °C for 15 s), sterilized (115 °C for 20 min) or long life milk (treated from 1 to 4 s to 138–150 °C in ultra high temperatures (UHT)). Milk can be further classified as
  - Whole: Milk with a minimum fat content of around 3.9%.
  - Semi-skimmed: Milk with a fat content of not less than 1.5% and not more than 1.8%.
  - Skimmed: Milk with a fat content of around 0.1%.
- *Fresh milk products:*
  - Milk drinks: product ready for consumption made from milk with additives such as cocoa or fruit, etc.
  - Butter.
  - Cream.
  - Fermented products: includes yoghurt, cultured cream and buttermilk.
- *Cheese*: is a milk concentrate, the basic solid of which consist mainly of protein and fat. Cheese can be categorized depending on the moisture content, the fat content or curing characteristics:
  - Rennet or natural cheese: manufactured straight from milk by using proteolytic enzymes (rennet) and acid.
  - Fresh cheese: it has a high degree of acidity and is not subjected to a proteolytic ripening process.
  - Processed cheese: it is made from rennet cheese and subjected to thermal treatment so it is made shelf stable.
- *Condensed milk:*
  - Unsweetened condensed milk: also called evaporated milk. It is a sterilized product, light in colour and with the appearance of cream.
  - Sweetened condensed milk: concentrated milk to which sugar has been added, yellowish in colour and highly viscous.
- *Dry milk products:*
  - Whole milk powder (WMP): typically contains 2–5% water content.
  - Non-fat milk powder (NFMP): contains 2% or less moisture and 1.5% or less milk fat.
  - Whey: it is the liquid residue of cheese and casein production:
    - whey powder (WP),
    - whey protein concentrate (WPC),
    - partially demineralized whey powder: WP which is 25–30% demineralized,
    - demineralized whey powder: WP which is 90–95% demineralized,
    - lactose.
  - Caseines: is the major protein in cow's milk and comprises about 80% of the total protein content.

bacterial growth is controlled and the shelf life of milk and milk by-products prolonged), energy only accounts for a limited share of the total production costs (1–3%) [2].

Several studies have examined energy consumption in the dairy industry [e.g., 3–6], individual dairy products [e.g., 7–9] and technologies [e.g., 10–13]. These studies are, however, restricted to one country and tend to focus on potential savings in a base year rather than analysing changes over time. Energy use is also addressed in benchmark and best available technologies reports (BAT) [e.g., 14,15]. BAT reports provide a detailed overview of processes and are useful for identifying potentials for emission reduction. However, they are not intended for studying the current situation of energy use/energy efficiency nor do they address sectors

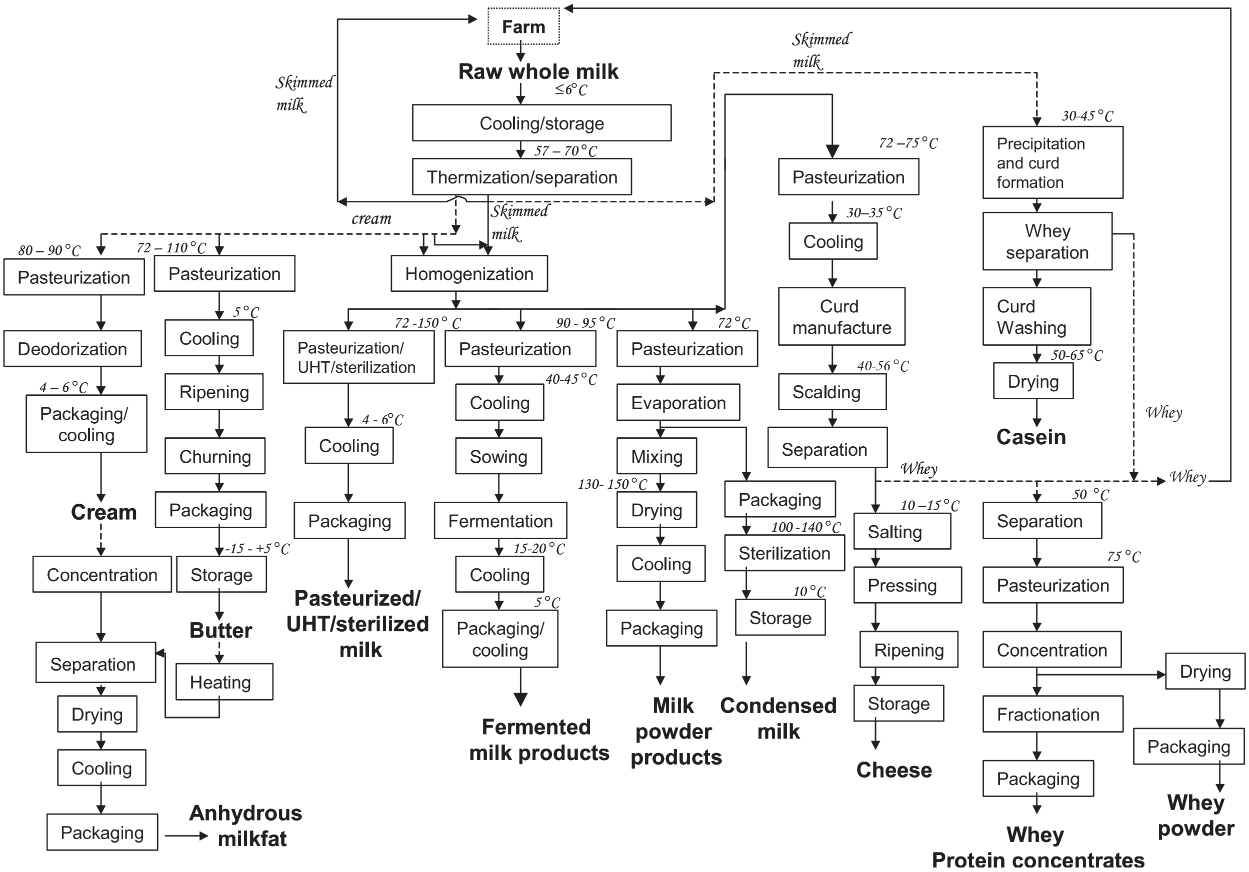

Fig. 1. The dairy industry.

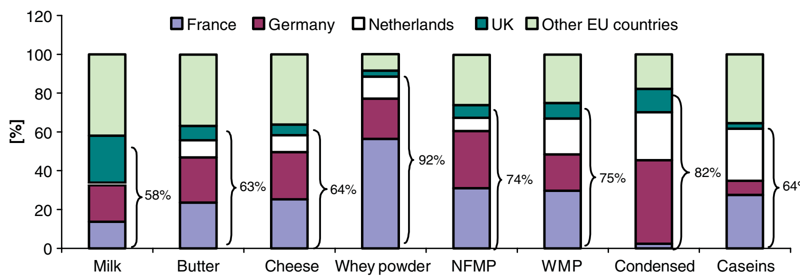

Fig. 2. Share of dairy production in the European Union by type of product, 2002.

at an aggregate level. Finally, energy is also one of the categories studied in life cycle analyses (LCA) of the dairy industry [e.g., 16,17], individual dairy products [18] and processes [19]. However, the role of energy during processing is rather small, and thus the results obtained from these kind of analyses do not provide enough information to allow one to understand the patterns of energy use among products and countries.

In the available body of literature on the food sector, hardly any attention is paid to developments of energy use and energy efficiency in the dairy industry, nor to cross-country analysis. Against this background, the main goals of this paper are twofold. *First*, to analyse the trends in energy use by the dairy industry in four European countries: France, Germany, the Netherlands and the United Kingdom. Depending on the kind of dairy product, these countries together produce between 58% and 92% of the total EU total production of dairy products (Fig. 2). *Secondly*, to develop and apply indicators that can be used to monitor trends in energy efficiency. We carry out the analysis for the time period 1986–2000.

2. Methodology

Changes in energy efficiency can be monitored by examining energy use by unit of activity. In this paper we develop two indicators of energy efficiency. The first indicator (EEI_1) is defined as the energy used to process one tonne of raw milk (Eq. (1)). EEI_1 is relatively simple to develop, especially in European countries, where as a consequence of the milk quota system, production and delivery of milk is quite well monitored.

Following the methodology developed by Phylipsen et al. [20] and Farla et al. [21], we examine changes in energy efficiency by comparing the actual energy use with the energy that would have been used if no changes in energy efficiency would have taken place (hereafter referred to as frozen efficiency development). The frozen efficiency development is calculated by using the time series of production (in physical terms, e.g., tonnes of cheese) and the reference values for the amount of energy needed to produce one physical unit of product in a base year (hereafter referred to as specific energy consumption SEC_{ref}). This second indicator (EEI_2) requires a larger amount of data than EEI_1 but it has the advantage of correcting the differences in product mix from various countries and years. Note that EEI_2 is dimensionless, which was not the case for EEI_1. The indicators can also be expressed in terms of primary energy as shown in Eqs. (3) and (4):

$$EEI_{1,j} = \frac{E_j}{MD}, \tag{1}$$

$$EEI_{2,j} = \frac{\textit{actual energy demand}}{\textit{frozen efficiency development}} \cong \frac{E_j}{\sum m_i \times SEC_{ref\ i,j}}, \tag{2}$$

$$EEI_{p_1} = \frac{\sum E_j \times f_j}{MD}, \tag{3}$$

$$EEI_{p_2} = \frac{\sum E_j \times f_j}{\sum m_i \times (SEC_{ref\ i,j} \times f_j)} \tag{4}$$

in which j is the type of fuel (i.e. electricity, fossil fuels/heat); EEI_1 the energy efficiency indicator for fuel j based on raw milk processed (MJ/tonne); E_j the energy consumption of the dairy sector for fuel j (megajoule); MD the raw milk delivered to dairies (in tonnes); EEI_2 the energy efficiency indicator for fuel j based on final product (dimensionless); m_i the physical production of key product i (tonnes); $SEC_{ref,i}$ the specific energy consumption of a certain key product i and fuel j (e.g., in gigajoules primary energy per tonne of product i); EEI_{p1} the primary energy efficiency indicator based on raw milk processed (MJ/tonne); EEI_{p2} the primary energy efficiency indicator based on final product (dimensionless); f_j the conversion factor from fuel j for final use to primary energy.

3. Data

The time period covered in this study was determined by the availability of *detailed* net available energy consumption data (Fig. 3). For France the analysis covers the period 1986–2000 [22], for the Netherlands 1989–2000 [23], for the United Kingdom 1990–2000 [24], and for Germany it is restricted to 1993–2000 [25].

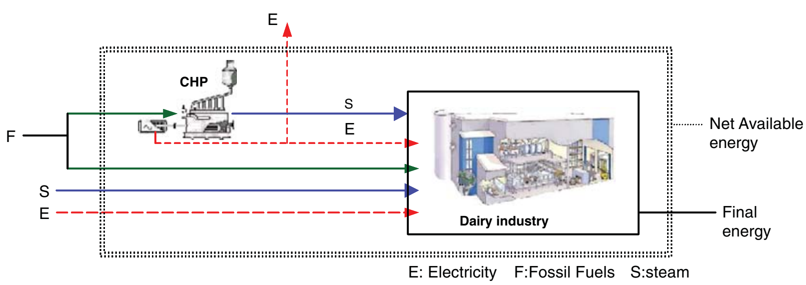

Fig. 3. System boundaries.

Data for earlier years would have been available for Germany but have been proven to be unreliable and inconsistent due to different reporting systems prior to reunification. For production data, we rely primarily on sources from industrial associations and statistical offices of the individual countries [26–33]. However, we use international data sources for closing data gaps and interviews for crosschecks [27,34,35].

The contribution of electricity to primary demand has been calculated by multiplying the net available electricity by 2.5 (corresponding to a 40% electricity generation efficiency).[3] Since in this paper we work with net calorific values,[4] we have corrected the British and German energy data [24,25] (which are based on gross calorific values) with the following net/gross ratios: 0.95 for coal and oil and 0.9 for natural gas.[5] Finally we have corrected energy consumption data for changes in climate using the Eurostat temperature correction method.[6]

4. Developments in the dairy sector

To provide a background for the discussion on energy use by the dairy industry, in this section we look at the economic context in which the industry works. One special feature of the European dairy sector is that milk production is subject to a quota system with relatively steep penalties for overproduction. The result of the quota system is that milk production tends to change little from year to year, rather, the mix of products varies depending on market prospects for each (Fig. 4). In the four countries studied production of bulk dairy products (butter and non-fat milk powder (NFMP)) has decreased in the last 15 years, while high-value added products (cheese, whey powder and ice cream) have increased. The United Kingdom stands out for the high proportion of raw milk which is directed towards bulk products (i.e., the liquid milk market is the single largest outlet for the UK produced milk) compared with the other countries (Table 1). We identify three major trends within the liquid milk market: (a) a trend towards low fat milk types: skimmed and semi-skimmed milk, (b) a trend towards ultra high temperatures (UHT) milk (Table 2), and (c) a trend towards milk drinks, fermented products and desserts.

Butter is a product which has shown a decrease followed by stagnation in production over the last 15 years (Fig. 4). The volume of butter production and the switch from butter to other products is determined by the relative price of butter (together with that of NFMP) in relation to the price of other major dairy products [39]. Since total milk input is controlled by the quota system, higher cheese prices have allowed an expanded cheese production, which consequently has meant less milk available for butter production. This trend has been reinforced by a declining demand of butter for household consumption (e.g., in France, the share of butter for table is estimated to have decreased from 85% in 1970 to 60% in 1995 [40]). The decrease in production has been controlled by EU programs which subsidized butter and helped to keep the market stable.[7] The developments for cheese are quite the opposite. The EU cheese sector has been characterized by a strong and steady growth. This increase has been related to two main driving forces: the growing variety of cheeses and the increasing use of cheese in fast food and catering services [42]. At the end of the 1990s growth seems to have slowed down. This could be related to two main causes: (a) a fall in cheese prices and (b) a decrease in cheese exports as a consequence of GATT[8] restrictions (i.e., since 1996, export subsidies for

[3]We maintain the electricity generation efficiency constant in order to exclude differences in generating efficiency between countries. Hence, we compare the efficiency in the dairy industry between countries, instead of a mixture of efficiency of the industry and of electricity generation.

[4]The difference between NCV and GCV is the latent heat of vaporisation of the water produced during the combustion of the fuel. NCV excludes this heat.

[5]These are the factors used by the International Energy Agency [36], and the IPCC guidelines [37].

[6]The temperature correction method of Eurostat is based on a heating share. 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 with non-heating purposes, and $d_t = D_t/D$, where D_t and D are the actual and long-term degree days [38]. Based on data published by Arcadis [6] we have assumed a share of 20% of fossil fuel use for space heating.

[7]The EU butter disposal measures aim to limit surpluses by providing subsidies for the use of butter. The main measures are: granting aid for the use of butterfat in the manufacture of pastry products, ice cream and other foodstuffs (‘‘butter for pastry’’); granting a consumer subsidy for non-profit organizations and for welfare recipients (‘‘butter for non-profit organizations’’), and subsidizing the consumption of concentrate cooking butter (‘‘butter for direct consumption’’) [41].

[8]GATT stands for General Agreement on Tariffs and Trade.

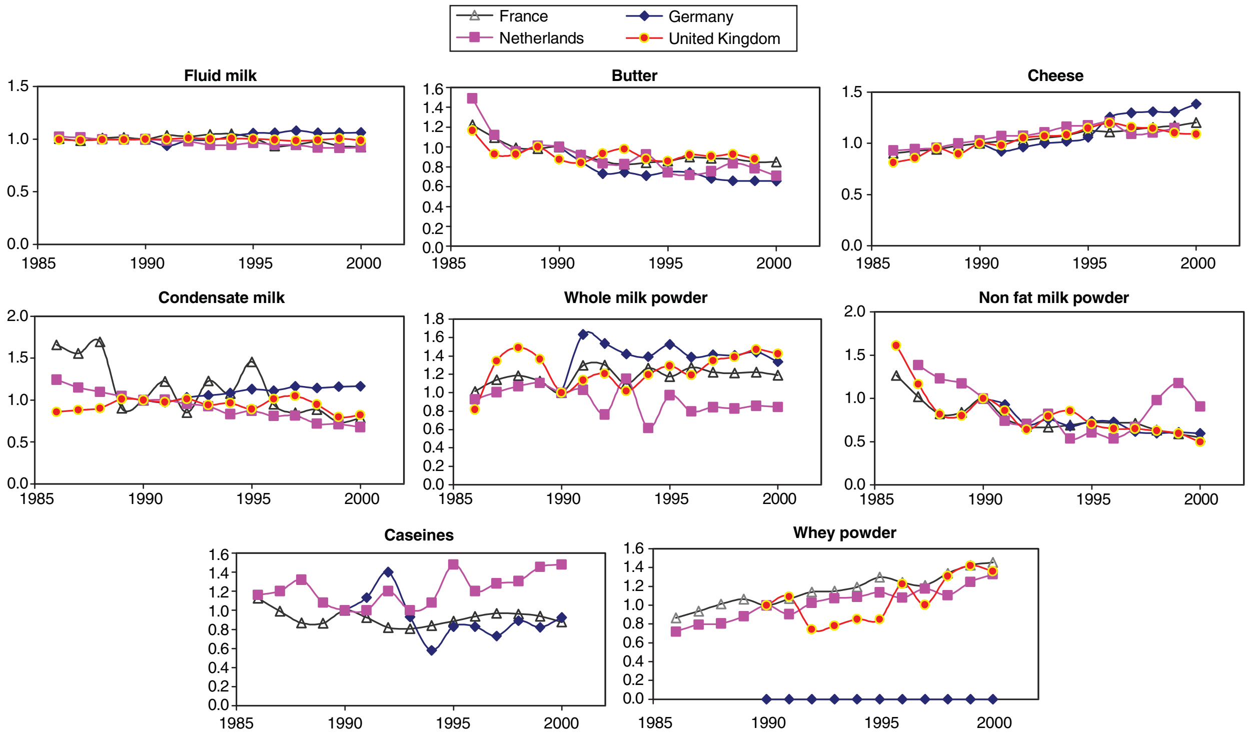

Fig. 4. Production trends for dairy products (values have been indexed to 1990).

Table 1
Percentage of utilization of raw milk in dairies by type of product and country, 2001

Milk product	France (%)	Germany (%)	The Netherlands (%)	United Kingdom (%)
Liquid milk & fresh milk products	19	28	16	56
Cheese	54	35	58	22
Milk powder	20	20	13	13
Condensed milk	4	5	6	4
Others	3	12	7	5

Note: Raw utilization for ice cream production was not available. *Source*: Own calculations based on data published by industrial associations.

Gouda, Edam and Maasdam have been reduced by 33%, 39% and 30%, respectively and it has been reported that the EU share in the world cheese market has decreased from 53% to 38% in the period 1995–2000 [43]).

The declining trend for NFMP has several causes. On the one hand, skimmed milk is increasingly being use for the manufacture of other dairy products (fresh products, cheese) and therefore, less feedstock is available for NFMP. On the other hand, and as of 1989, the European Union has discouraged the production of NFMP by limiting the delivery period for intervention, lowering the intervention prices and cutting subsidies for exports to third countries [39]. Besides, internal subsidies for the use of NFMP in calf milk replacers and other animal feed were either cut or discontinued. Another cause of the decline is a lower demand for NFMP in the animal feed sector due to lower veal production.[9] Furthermore, there has been a substitution of NFMP by other cheaper proteins sources.[10] One of these is whey. Production of dry whey as by-product of cheese

[9]NFMP is primarily used in animal feed, which can account for up to 70% of the total domestic use.

[10]Typically, whey powder prices are about 20% of those for NFMP. In the year 2000, for instance, price values for NFMP in the countries studied were in the range of 2.33–2.55 Euro/kg while prices for whey powder were of about 0.51 Euro/kg.

Table 2
Distribution of milk production by thermal treatment per country (in percent)

Milk type/country	1990			2000		
	UHT	Pasteurized	Sterilized	UHT	Pasteurized	Sterilized
Whole milk						
France	65.9[a]	19.8[a]	14.3[a]	77.8	13.5	8.7
Germany	36.6	63.1	0.3	47	52.9	0.1
Netherlands	4.3	88.6	7.1	3.1	3.3	93.6
Semi-skimmed milk						
France	89.1[a]	2.8[a]	8.1[a]	91.1	2.1	6.8
Germany	85.6	11.8	0.6	87.6	12.3	0.1
Netherlands	2.7	93.1	4.2	1.7	96.8	1.5
Skimmed milk						
France	90.3[a]	0.5[a]	9.2[a]	92.2	0.1	7.6
Germany	81.8	17.2	0.1	98.6	1.4	0
Netherlands	7.3	77.7	15	6.8	89.7	6.8
Total milk						
France	85.7[a]	5.2[a]	9.1[a]	89.6	3.3	7.1
Germany	52.4	47.0	0.6	63.4	36.5	0.1
Netherlands	3.3	91.5	5.2	2.1	96.0	1.9

[a]Data for 1993. *Source*: Own calculations based on data published by industrial associations.

production rapidly expanded over the last years. The increasing production (France, Germany and the Netherlands accounted for 53% of world dry whey production in 2000) has been driven by the increasing production of cheese,[11] the environmental concerns associated with disposing of whey into streams or sewage plants, and the acknowledgement of the nutritional benefits of whey proteins [43].

While the NFMP market is often determined by the residual skimmed milk which is available in dairies after covering the needs of other utilization, the market for whole milk powder (WMP) is driven by the demand from domestic and export markets.[12] In the Netherlands, for instance, production is almost entirely driven by export demand (domestic consumption is mainly limited to usage in the chocolate industry).[13]

Besides the change in consumption patterns, there have also been other changes in the milk supply chain. One of the most notable is the concentration process in the dairy industry during the last two decades. An indication of the present degree of concentration is the high share of processing by the four largest companies (France: 51%, Germany: 40%, the Netherlands: 96%, and the United Kingdom: 50%). Table 3 shows that there has been a reduction in the number of companies and that among those still in business a shift has taken place in favour of larger companies.

5. Energy use in the dairy sector

Having examined economic and structural developments in the dairy industry, we now take a look at the patterns of energy use in the dairy industry. In the year 2000, the dairy sector consumed about 52, 34, 16 and 14 PJ primary energy in France, Germany, the Netherlands and the United Kingdom, respectively. Fig. 5 shows the trends in the consumption *of final* energy by kind of fuel and country.[14] The fuel mix breakdown shows that fuel mix in the dairy industry has strongly shifted in the period studied: the share of natural gas

[11]In cheese production only 10–15% of the milk is actually converted into cheese, the remainder is whey.
[12]WMP is primarily used as a product for reconstitution into liquid milk products. The greatest use of WMP is in countries (typically developing) where local production is unable to meet the demand of increasing dairy consumption.
[13]The market share of the Netherlands decreased from about 8% of the world production in 1980 to about 3% by 2000 [44].
[14]In terms of primary energy, electricity accounts for over 40% of the energy used.

Table 3
Structure of dairies companies in four European countries

Country	1985		1991		2000	
	Number of dairies	Average milk input per dairy (000 t)	Number of dairies	Average milk input per dairy (000 t)	Number of dairies	Average milk input per dairy (000 t)
France	1332	19.5	966	24.6	710	31.9
Germany	515	60	379	90.9	250	134.1
Netherlands	38	321.9	22	478.9	15	555.6
UK	336	45.4	340	41.5	102	105

Source: Own calculations based on data published by statistical offices.

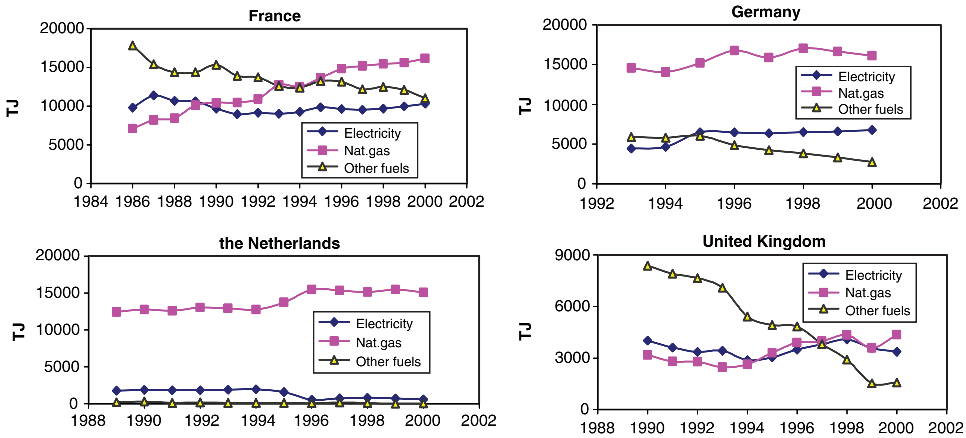

Fig. 5. Trends in final net energy consumption in the dairy industry by type of fuel/country.

consumed has increased at the expense of coal and petroleum products. The Netherlands is an exception since it had a high share of natural gas use already at the beginning of the period studied. This high share can be explained not only because the country has the second largest gas reserves in Europe after Norway, but also because natural gas penetration in the Netherlands has been characterized as "the highest in the world, virtually every home, office and factory is connected to the gas grid" [45]. Furthermore, our choice of system boundaries (Fig. 3) implies that electricity produced by combined heat and powder (CHP) is not taken into account as electricity but only as fuel. Hence, a higher auto production of electricity by the Dutch dairy industry[15] can also explain the higher demand of natural gas and the apparent lower consumption of electricity (in 2000, electricity accounted for only 4% of the total final net available energy used by the Dutch dairy industry while the percentages in France, Germany and the United Kingdom where of 28%, 26% and 17%, respectively). The replacement of coal and petroleum products such as heavy fuel oil by natural gas could be linked to some extent with (a) the increasingly stringent environmental regulation to which the industry has been submitted, and (b) increasing competitiveness of natural gas and in some cases, electricity.

Fig. 6 depicts trends in the use of fossil fuels in the British dairy industry. This figure shows a typical trend in fuel switching: at the beginning oil substituted coal and LPG and later, natural gas was used as a substitute of oil. The increasing share of natural gas and electricity after 1993 can be related to liberalization of the energy sector[16] which led to a fall in energy prices. The UK Department of Trade and Industry (DTI) reports that industrial gas prices (in real terms) between 1992 and 2000 fell by 35%, industrial electricity

[15]This point is further discussed in Section 7.

[16]Although the British gas industry was privatised in 1986, it was not before 1992 that competition started and prices dropped for most industrial consumers. The privatisation of electricity started in 1990 and it was extended in 1994.

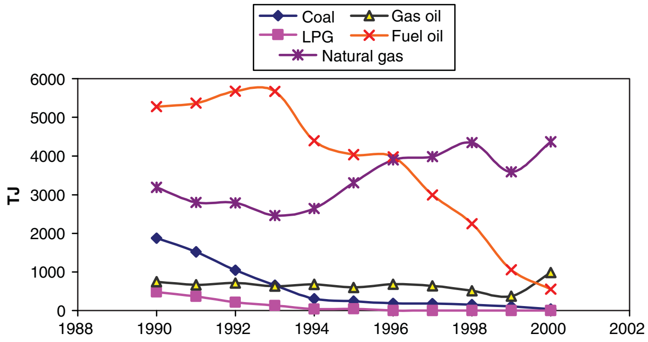

Fig. 6. Final energy consumptions of fossil fuels in the British dairy industry.

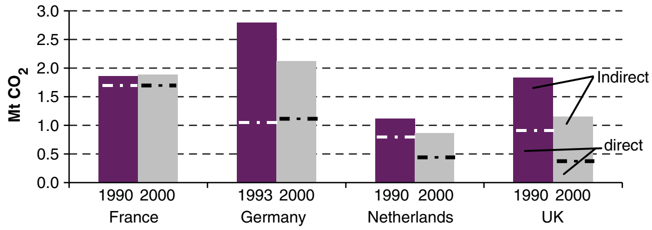

Fig. 7. CO_2 emissions of the dairy industry.

prices decreased 35.9%, industrial coal prices decreased by 40% while industrial fuel oil prices have increased by 23% [24]. Fuel switching has contributed substantially to the decrease of total CO_2 emissions in the British, German and Dutch dairy industries (Fig. 7). In France, the increase in energy consumption of the sector has offset the benefits obtained from fuel switching resulting in comparable CO_2 emissions in 1990 and 2000.[17]

As shown in Fig. 1, heating and cooling treatments are a fundamental part of dairy processing. Table 4 shows a distribution of energy by process. Next, we briefly address energy consumption in five main operations in the dairy industry since they account for about 50% (fluid milk) to 96% (dry products) of the energy consumption.

5.1. Heat treatment

The most common thermal process is pasteurization (thermal inactivation of microorganisms at temperatures below 100 °C). Other processes are sterilization (115–120 °C, 20–45 min), UHT treatment (165–140 °C, few seconds), radiation with UV, high-pressure process (40–60 °C, 2000–6000 bar) and microwave treatment. Of all, only sterilization and UHT treatment are widely applied. For the rest, low inactivation effects, legal barriers, high costs and changes in the organoleptic conditions of milk are considered the main barriers for their implementation [46]. UHT process is mainly used for pre-treatment of milk and production of UHT milk while sterilization is used for milk filled products that must be preserved for a period longer than 5 months. Nowadays, pasteurization consumes only a slight amount of energy (heat recovery between 90% and 94% is regarded as optimal). UHT and sterilization are far more energy consuming than pasteurization. In sterilization the temperature is much higher, and in general the temperature difference between the heat source and milk to be sterilized has to be much greater than in pasteurization [13]. The increasing tendency to produce UHT milk rather than pasteurized liquid milk (see Table 2) has meant that production of fluid milk demands more energy per litre of product.

[17]Note that the small share of indirect CO_2 emissions is a reflection of the French nuclear power based energy generation.

Table 4
Average percentage of primary energy demand for selected products and processes in Dutch dairies in the year 2000

Product	Process	Energy consumption (%)
Fluid milk	Reception, thermization	2
	Storage	7
	Centrifugation/homogenization/pasteurization	38
	Packing	9
	Cooling	19
	Pressurized air	0.5
	Cleaning in place	9.5
	Water provision	6
	Building (lightening, space heating)	9
Cheese	Reception, thermization	19
	Cheese processing	14
	Cheese treatment/storage	24
	Cooling	19
	Pressurized air	5
	Cleaning in place	19
Butter	Cooling	66
	Pressurized air	8
	Cleaning in place	26
Milk powder	Thermization/pasteurization/centrifugation	2.5
	Thermal concentration/evaporation	45
	Drying	51
	Packing	1.5

Source: Own calculations base on data reported in Arcadis [6].

5.2. Concentration

Concentration can, together with drying, be considered as the most energy intensive operations of the dairy industry. Concentration can be done by evaporation or by membrane concentration. In the dairy industry, evaporation is mainly done in falling film evaporators.[18] In order to decrease energy demand during evaporation, multiple stage evaporators are employed. Evaporators can be equipped with either thermal vapour recompression (TVR) or mechanical vapour recompression (MVR).[19] Nowadays most new evaporators are equipped with MVR [15]. Typical final energy requirements per kilogram of water evaporated are shown in Fig. 8. Note that although MVR is more economical from an energy point of view, it requires high investments for the compressor. Hence, the choice between MVR and TVR depends on the local prices of different energy sources, the possibility of using condensate, the depreciation of the capital cost, and the cost of product losses during cleaning [47].

Compared with evaporation, concentration by membrane filtration demands significantly smaller amounts of energy[20] (0.014–0.036 MJ/kg water removed [13]). Nonetheless, restrictions in the pressure to which milk may be exerted imply that membrane concentration can only reach a maximum dry weight of 12–20%.[21] Nowadays, a combination of membrane filtration for pre-concentration and evaporation for final concentration is increasingly used, especially for whey products. For example, a survey of 70 factories in

[18]In this kind of evaporator, milk passes through steam-heated tubes under vacuum. Boiling takes place between 65 and 75 °C.

[19]TVR uses high pressure steam to increase the pressure of part of the vapour generated in an evaporator effect so it can be used again to drive the evaporation process, while MVR uses a turbo compressor or a high pressure fan to recompress all the vapour generated before returning it to the heating side of the evaporator.

[20]The main membrane processes are microfiltration, ultrafiltration, nanofiltration, reverse osmosis and electrodialisis.

[21]It is considered that pressures over 40 bar make the process economically not feasible.

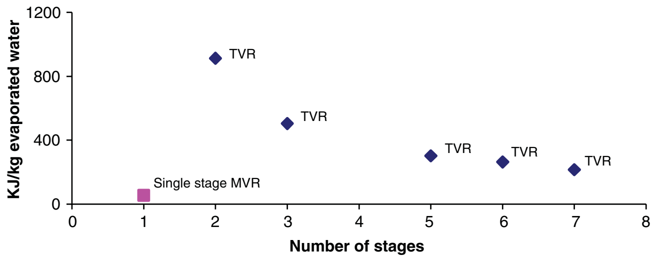

Fig. 8. Final energy consumption in stage evaporators.

the Dutch dairy sector shows that in 1995 there was already approx. 9000 m^2 of membrane installed and the potential for installation was around 50,000 m^2 [48].

5.3. *Drying*

Among the main possible drying technologies are: roller drying (at ambient pressure or under vacuum), spray drying (with jet or with a centrifugal nozzle), dough or paste drying (vacuum drying in cabinets or on continuous belt driers), foam drying (under ambient conditions or under vacuum). Nowadays, spray drying is the technique most used in the dairy sector. In Germany for instance, in the year 2000, 99.5% of all skim milk powder was produced by spray drying (compared to 95% in 1990). Unlike evaporators, no method exists for recovering the latent heat in the vapour produced during the evaporation. If compared to separation by evaporation, the energy consumed in spray drying is 10–20 times higher per kg of water removed. Hence it is common practice to pre-concentrate as much as possible in evaporators before drying. In practice a spray dryer can consist of one, two or three stages. The impact of the choice of the spray drier system on energy consumption can be seen in the following figures [13]: 1-stage: 4.9 MJ/kg water evaporated; 2-stage: 4.3 MJ/kg; 3-stage: 3.4 MJ/kg.

Table 5 shows a rough estimate of the amounts of water evaporated during concentration and drying. Assuming that the average evaporator use for milk concentration has 6 stages with TVR [6] and that for drying a 2-stage spray dryer is used [14], the amount of energy required for evaporating water during concentration and drying accounts for 28%, 25%, 20% and 30% of the total net fuel demand by the dairy industry of France, Germany, the Netherlands and the United Kingdom, respectively.

5.4. *Cleaning in place*

Cleaning in a dairy plant has two main goals: to keep hygiene standards and to avoid fouling (e.g., a study reports that in a fluid milk plant an increase of up to 8% in the energy consumption can be due to fouling and about 21% of the total energy consumption associated with operation and cleaning of milk pasteurization plants [12]). Cleaning in place causes a large part of the operating costs, especially in evaporators and dryers where it can account for up to 70% [49] and 10–26% [6] of the energy use for processing. Table 6 shows the energy consumption by cleaning cycle for different processes. Most of the energy required for cleaning uses temperatures of 65–75 °C. One of the consequences of the high-energy requirements of cleaning in place is that smaller volumes of production consume more energy per unit of output, since the equipment has to be cleaned and started up regularly regardless of the volume [16].

6. Understanding energy efficiency developments

We use Eqs. (1) and (2) as described in Section 2 to monitor changes in energy efficiency in the dairy industry. The first indicator, EEI_{p1}, is straightforward to calculate. Our results (Fig. 9) show an improvement in the indicator for the Netherlands and the United Kingdom (average annual changes of −0.4% and −3.1%, respectively) while France and Germany deteriorate their values: an increase of the EEI_p by about +0.7% and +1% per annum, respectively. EEI_{p1} does not take into account the differences in production mix among

Table 5
Amount of water evaporated and indicative energy demand by country for the year 2000

Product	France	Germany	Netherlands	United Kingdom
Pre-concentration before drying [ktonne of water evaporated]				
For NFMP[a]	2350	2547	364	630
For WMP[b]	1367	457	472	558
For whey[c]	7808	2935	3792	786
Concentration [ktonne of water evaporated]				
Condensed milk products[d]	124	1134	487	324
Drying of milk products [ktonne of water evaporated]				
NFMP[e]	309	335	48	82
WMP[f]	298	99	103	121
Whey powder[g]	441	166	214	44
Total water evaporated [ktonne of water evaporated]	*12697*	*7673*	*5480*	*2545*
Energy required[h] [TJ]	*7600*	*4400*	*2900*	*1800*

[a]It has been estimated that dry matter (DM) of skimmed milk is 10%, and DM after pre-concentration is 48%.
[b]DM of whole milk is 12%, DM after pre-concentration is 45%.
[c]DM of liquid whey is 6.5%, after pre-concentration is 40%.
[d]Initial DM is 11% and after pre-concentration is 30%.
[e]DM after drying is 96%.
[f]DM after drying is 97%.
[g]DM after drying is 95%.
[h]Assuming concentration with a 6-stage evaporator with TVR and drying with a 2-stage spray dryer.

Table 6
Energy requirements of cleaning in place

Equipment	Thermal energy requirement (MJ/cleaning cycle)
Cream separation	0.25–0.31
Milk pasteurization	0.14–0.3
Heat treatment of cream	0.1–0.5
Skim-milk evaporation	6.8–28.1
Skim milk drying	1.0–2.0

Source: [46].

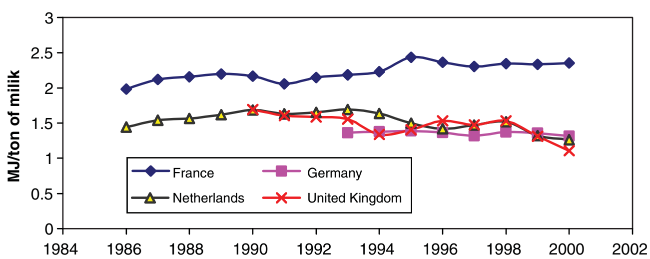

Fig. 9. Developments in EEI_{p1} by country.

countries and time; the changes showed in Fig. 9 can hence be caused by both, changes in energy efficiency and changes in product mix (i.e., production of more energy intensive dairy products such as milk powders).

For calculating EEI_{p2} we selected as key products: fluid milk, fermented products (yoghurt, cream, desserts, buttermilk), cheese (fresh, processed cheese and quark), butter, milk powder (WMP, NFMP, semi-skimmed milk powder, buttermilk powder, cream powder), condensate milk (sweetened and unsweetened condensed milk and coffee milk), whey products (whey powder, whey protein concentrates), caseines and lactose. As SEC_{ref} we use values provided by a detailed study of the Dutch dairy industry [6]. Table 7 shows the SEC_{ref}

Table 7
Chosen reference specific energy consumption values (SEC_{ref}) by sector in primary energy (typical technologies for late 1990s)

Dairy product	Chosen SEC_{ref} (GJ/tonne of product)
Liquid milk + fermented products	1.1
Cheese	4.3
Butter	2.2
Milk powder	11.1
Condensate milk	2.5
Whey products (powder)	8.2
Caseins + lactose	5.6

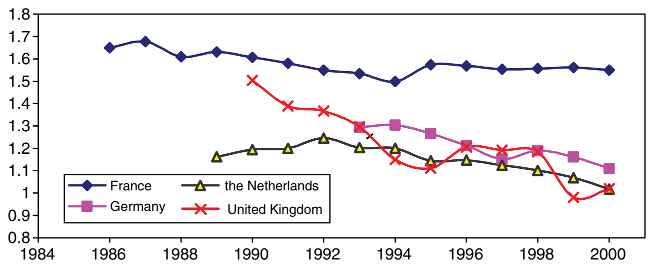

Fig. 10. Developments in EEI_{p2} by country.

used in this paper while Fig. 10 depicts the results from applying Eq. (4). We found that France, Germany, the Netherlands and the United Kingdom reduced their EEI_{p2} by −0.4%, −2.1%, −1.2% and −3.8% p.a., respectively.

A first point to take notice of is that when differences in product mix are not taken into account (EEI_{p1}), the British dairy industry appears as the least energy intensive, whilst accounting for product mix places the Dutch dairy industry as the one using the least energy per weighted product (EEI_{p2}). This is not an unexpected result. In Section 4, we pointed out that the United Kingdom stands out for processing over half of their raw milk for consumption as liquid milk and fresh milk products (Table 1). Since these products demand the least energy during processing (Table 7), it is a foreseeable consequence that the British dairy industry would show a lower demand of energy per unit of raw milk to be processed. Furthermore, the fact that average annual changes in EEI_{p1} and EEI_{p2} are almost equal for the British dairy industry indicates that the industry has not witnessed significant product mix changes during the period studied.

Two factors appear as the main driver forces for the decline in the British EEI_p: the concentration process and fuel switching [50]. A study on the British dairy industry highlights the period 1993–1997 as a significant period of restructuring and investment in production capacity [51]. It identifies three key drivers: the acquisition of brands, cost reduction through rationalization, and vertical integration by milk groups to develop processing capacity either through acquisition or greenfield site development.

In the case of the Netherlands, among the drivers for the decline (which has mainly occurred between 1992 and 2000) are: (a) the voluntary agreements between the dairy industry and the Dutch government,[22] (b) the rationalization process, and (c) the increasing use of CHP.[23] Drivers (a) and (c) are actually interconnected since CHP is considered by the dairy industry as a main option to achieve their energy efficiency goals.

[22]In 1992, industrial sectors and the Dutch Ministry of Economic Affairs signed a covenant which aimed to improved energy efficiency by a specific percentage within an agreed period. The dairy industry (excluding ice cream) signed this agreement in 1994 and the goal was to increase energy efficiency by 20% in the year 2000 respect to their 1989 values.

[23]A combined heat and power (CHP) system is the combined production of electrical (or mechanical) and useful thermal energy from the same primary energy source.

Table 8
Changes in EEI by fuel and country

EEI	Average annual change (in percentage)			
	France[a]	Germany[b]	The Netherlands[c]	United Kingdom[d]
Fuels	+0.5	−2.6	+0.4	−6.5
Electricity	−0.6	−1.7	−14	−2.1
Primary	−0.4	−2.1	−1.2	−3.8

[a]Time period 1986–2000.
[b]Time period 1993–2000.
[c]Time period 1989–2000.
[d]Time period 1990–2000.

Indicators can also be developed by type of fuel (Eqs. (1) and (2)). Table 8 shows the annual percentage change in EEI_{p2} by fuel and country. The Netherlands stands out for the high decrease in specific electricity consumption. This can be explained by our choice of system boundaries (Fig. 3). Net available energy implies that electricity produced by CHP is not taken into account as electricity (but the extra fuel that is needed is accounted for). The difference between net available and final energy for the dairy industry is not important in all countries. According to communication with the British Dairy Industry Association and with the statistical office of the United Kingdom, the role of CHP in the British dairy industry during the last decade is very small: they report that in 2000 only one medium-size site in the dairy sector has a CHP [50,52]. While there are no data available on the amount of heat produced by CHP, the French energy statistics reported that in 2000 only 4% of the electricity was auto produced [22], the value for the Netherlands is 49%.[24] These data point towards a much higher penetration rate of CHP in the Netherlands than in France and the United Kingdom (there is not data available for Germany) and can explain the relatively low use of energy per amount of product of the Dutch dairy industry (i.e., without CHP, in 2000 the value of the EEI_{p2} for the Dutch dairy industry increases from 1.02 to 1.12[25]). The higher penetration rate of CHP can also explain that in terms of net available energy, the Dutch industry increases fuel consumption while reducing substantially the amount of electricity bought. This does not mean that the industry uses less electricity by unit of product, only that it uses less electricity from the grid. Thus, while the indicators for the French and British dairy industry are essentially depicting energy intensity developments due to changes in processes, for the Dutch dairy industry they depict both, changes in processes and changes in industrial power generation (e.g., more application of CHP units).

The main unexpected result so far is that France has not only the higher values in the indicators but also shows the lowest rate of decrease in the indicators. There are two possible reasons that could explain this behaviour: (a) there are flaws in the methodology used or (b) there are real differences in energy efficiency. The next section takes a closer look at these two factors.

7. Reliability of the results

In order to understand whether the trends obtained are the result of methodological flaws we look whether (i) there are differences in system boundaries among countries, and (ii) there are important differences in product mix between France and the other countries that are hidden by the level of product aggregation used in this paper (e.g., condensed milk as the sum of sweetened and unsweetened condensed milk).

As far as we could check, the time series used in this paper are consistent in terms of system boundaries and product definition. Hence, we are confident that this is not the cause of the high EEI_p values shown by France. To explore the second factor requires a more detailed comparison of product shares among countries (see

[24]This value has been calculated based on data published in [23].
[25]This data was calculated assuming that the electricity produced by CHP was taken from the grid and that steam was produced by a boiler with an 85% efficiency.

Table 9
Detailed distribution of dairy products by type and country, year 2000 (in percentage)

Product	Germany	France	The Netherlands	United Kingdom
Milk and milk products				
Milk	63	64	54	93
Pasteurized	*37*	*3*	*96*	*90*
UHT	*63*	*90*	*2*	*n.a.*
Sterilized	*~0*	*7*	*2*	*n.a.*
Yogurt + other fresh milk products	32	31	44	3
Cream	5	5	2	4
Cheese				
Rennet cheese	47	59	96	83
Hard & semi hard[a]	*82*	50	100	97
Soft [b]	*18*	50	—	3
Processed cheese	8	8	3	8
Fresh and quark	45	33	2	9
Condensed milk				
Sweetened	27	48	24	25
Unsweetened	73	52	76	75
Milk powders				
NFMP	52	53	33	44
WMP	48	47	67	56

—: no produced; ~0: less than the unit; n.a: not available. *Source*: Own calculations based on data published by La Maison du Lait.
[a]e.g., Edam, Gouda.
[b]e.g., Camembert, Brie.

Table 9[26]). We found that the production mix in France and Germany is quite alike despite differences in their EEI_{p2} values are of about 33%. The main differences in product mix between both countries are the shares of UHT milk, sterilized milk, sweetened condensed milk and within cheese production, the share of soft and hard cheese. We check whether further detailing the product mix would lead to different results. To correct the EEI_{p2} indicator for these differences we need SEC_{ref} for the products and thus several assumptions have to be made. First of all, the energy demand of processing UHT milk depends greatly on the type of process employed.[27] If indirect UHT is applied, the *SEC* value is almost the same as the *SEC* for pasteurization ($SEC_{ref,\ pasteurized}$: 782 MJ/tonne; $SEC_{ref,\ indirect\ UHT}$: 784 MJ/tonne[28]) and therefore, the difference in shares between pasteurized, UHT and sterilized milk do not help to explain the differences in the final EEI_{p2} obtained. Hence, we assume that UHT milk is processed by direct application of steam ($SEC_{ref,\ direct\ UHT}$: 1116 MJ/tonne[30]). For sterilized milk we assume that $SEC_{ref,\ sterilized}$: 1153 MJ/tonne[30]. Secondly, since the production of sweetened condensed milk is less energy intensive than that of unsweetened (the latter requires higher temperatures and a sterilization step that increases the demand for energy) and, as we could not find SEC_{ref} that differentiate between both products, we assume that the sterilization step accounts for 15% of the primary energy used per tonne of product [6,13]. These assumptions lead to a $SEC_{ref,\ sweetened}$ of 2125 MJ/tonne and a $SEC_{ref,\ unsweetened}$ of 2500 MJ/tonne. Combining these SEC_{ref} values with the product distribution shown in Table 9, we found that including specifications for UHT, sterilized milk and sweetened condensed milk in the French dairy industry lower the gap in EEI_{p2} values between France and Germany (Fig. 13) by only 1%.

[26]Categories such as caseins and lactose were not further decomposed due to lack of data.
[27]UHT milk can be processed using direct or indirect UHT treatments. In direct UHT, milk is heated from 75 to 135 °C by steam injection. Indirect UHT is basically the same process as pasteurization, but the operating temperature is higher. Indirect UHT is most energy efficient since internal heat recovery is possible (part of the heat could be recovered from the direct UHT treatment by the use of vapour recompression but this is seldom done [15]).
[28]We have used data published by Hvid [13] to replace the pasteurization step used in Arcadis [6] which is the source used to calculate EEI_{p2} in Section 6.

Table 10
EEI_p values at the subsectoral level for the French and Dutch dairy industry in 1998

Branch	EEI_p	
	France	The Netherlands
Milk and fermented products	2.16	1.06
Butter	4.78	2.15
Cheese	10.9	3.23
Other milk products (milk powders, condensed milk, whey products, caseines and lactose)	1.06	0.83

We then turn our attention to the difference in cheese production found between Germany and France (Table 9). Although there is not enough information to estimate SEC_{ref} by kind of cheese, after comparing temperature requirements during cheese making, we found that soft cheese and fresh cheese seems to demand less severe conditions than hard cheese processing and hence we expect that the share distribution in France would imply a lower demand of energy per tonne of product instead of a higher one (as would be the case if this could explain the difference in EEI_p values). Concluding, the results show that differences in production mix are no large enough to explain the higher EEI_{p2} shown by France. They also confirm that the selection of products made in Section 6 does cover main differences in production mix among the countries.

But if the results obtained are not the consequence of methodological flaws, then there are real differences in energy efficiency that place the French dairy industry as the most energy intensive among the four countries. The first point we look at is whether the gap in EEI_{p2} values between France and the other countries occur across all dairy branches. One way of exploring this is by comparing EEI_p at the subsectoral level (e.g., fluid milk plants, cheesemakers, etc.). Net available energy consumption data at this level of aggregation is only available for France (published by Agreste since 1993–2000) and for the Netherlands (only for 1998 using data reported in [6]). The results of applying Eq. (4) to each branch are shown in Table 10. The French dairy industry appears with higher values of EEI_p in each case. This gives us confidence that the higher EEI_{p2} of France is caused by real differences in energy efficiency.

8. Possible causes for differences

Differences in efficiency can be explained by several factors, for instance differences in the size of the companies, the capacity at which plants are used, differences in technologies (including the penetration of CHP, which we have already discussed).

8.1. Average size

Although we have already noted that overall the number of companies has decreased while the output of the remnant companies has increased (Section 4), it is important to look whether the pace of overall 'rationalization' in France has differed from the other countries and whether French individual processors are of a smaller scale. We found that, while the dairy French industry has indeed concentrated at a slower rate than the British and Dutch industry, the concentration rates of the French and German industries are again quite similar. However more important, the average size of the French dairy industry is much smaller (Fig. 11). This is very likely to have important technology implications,[29] and one cannot fail to notice that

[29]To obtain the benefits of an economy of scale requires significant capital investment, which includes investing in modern technologies that could increase production levels. These new technologies generally are able to produce largest quantities of product with improved energy efficiencies and lower costs. A study on the British dairy industry shows that, in 2000, actual production costs for smaller plants of about 100 million litre capacity were about £0.05 a litre. This reduces to about £0.03 for plants around 200 million litres, and to about £0.02 for plants with a production rate over 300 million litres a year [51].

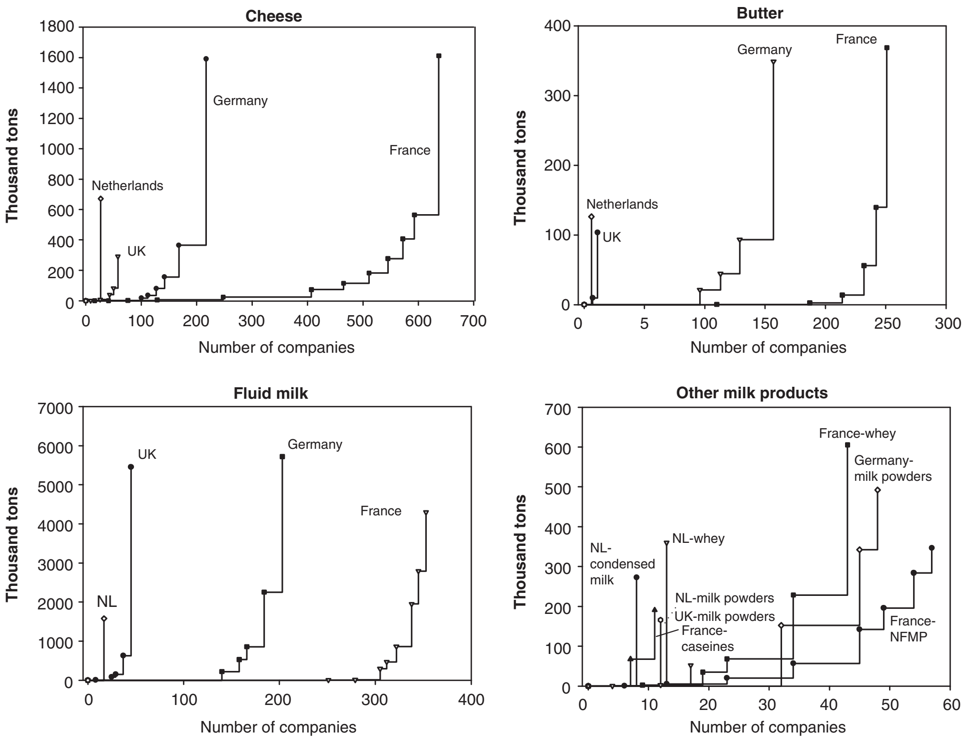

Fig. 11. Cumulative distribution of dairy companies by country in the year 2000.

(a) the ranking in values shown in Fig. 11 for the year 2000 is in quite good harmony with size (Netherlands > Germany, United Kingdom > France) and (b) the gap in the cumulative distributions of dairy companies between France and the other countries (Fig. 11) is the largest for cheese and the smallest for 'other milk products'. This is in agreement with the differences in EEI_p found at the sectoral level (Table 10). The large differences in size for cheese, and small differences for other milk products can be explained by the fact that there are certain product types where scale of production is not the critical factor to increase price margins, but rather product innovation and specialization. This is particularly valid for the production of specialized cheese, which is significant in France. In the area of the production of commodity type products such as milk powder and condensed milk, the trend is for larger scale plants to achieve economies of scale. Even though there is not much information available, it is plausible that largest dairies would have a better energy efficiency than smaller ones[30] since (a) technologies have cost advantages of scale (plus efficiency advantages, (b) they tend to have continuous process lines that can be more energy efficient than batch lines which are the common way of processing among small specialized industries, (c) large companies can afford to expend resources in energy management, and (d) scale advantages would occur (e.g., less boundary losses).

8.2. Capacity utilization

Another factor which can affect the amount of energy used per unit of output is the capacity utilization (CU) (e.g., data for a milk powder plant shows that its specific fuel consumption increased by 7% when production throughput decreased 12% [53]). CU provides an indication of how efficiently plant and equipment are utilized. While difficult to quantify accurately, and since there is a lack of official information,

[30]A Canadian study on fluid milk plants shows that dairies producing between 20 and 50 million litres of milk per year consume 30% more energy (in final terms) than dairies producing between 50 and 100 million litres [9]. Similarly, a Norwegian study on industrial milk production shows that that small diaries consumed about 55% more energy (in final terms) than large diaries [16].

Table 11
Approximated capacity utilization by country and product for the year 2000 (%)

<table>
<tr><th>Product</th><th>France</th><th>Germany</th><th>The Netherlands</th><th>United Kingdom</th></tr>
<tr><td>Liquid milk</td><td>90</td><td>92</td><td>95</td><td>96</td></tr>
<tr><td>Butter</td><td>84</td><td>86</td><td>86</td><td>89</td></tr>
<tr><td>Cheese</td><td>91</td><td>93</td><td>97</td><td>81</td></tr>
<tr><td>Condensed milk</td><td>71</td><td>95</td><td>95</td><td>84</td></tr>
<tr><td>NFMP</td><td>67</td><td>85</td><td rowspan="2">81</td><td>78</td></tr>
<tr><td>WMP</td><td>82</td><td>84</td><td>64</td></tr>
<tr><td>Whey powder</td><td>n.a.</td><td>90</td><td>88</td><td>n.a.</td></tr>
</table>

Source: Own calculations based on monthly production data published by industrial associations.

we have used monthly data to calculate a rough estimate (Eq. (5)). Results are shown in Table 11. Germany and the Netherlands show almost identical patterns, with the United Kingdom and France slightly falling behind. However, and with exception of NFMP and condensed milk, the differences are not significant and hence we do not find enough evidence to support the fact that a lower CU could explain the higher EEI_p shown by France.

$$CU_i = \frac{AP_i}{(MP_{\max,i} \times 12)} \times 100, \tag{5}$$

where CU_i is the CU of sector i (in percentage); AP_i the annual production of product i; $MP_{max},_i$ the peak month production of product i.

8.3. Differences in technologies

Another possibility to take into account is that France could be using more energy intensive processes. For example, in Table 5 we assumed that concentration and drying were typically done with a 6-stage film evaporator with TVR and a 2-stage spray drier. If instead, the typical technology used by the French dairy industry were a 3-stage evaporator with TVR, this factor alone could account for a 30% increase in the fuel demand and explain 83% of the gap in the EEI_{p2} for the ‘other milk products’[31] shown in Table 10. Unfortunately, we did not find information to explore the differences in technologies used in the processes used in the dairy industry between the countries studied.

In conclusion, and although there is a lack of detailed data, the higher EEI_{p2} values showed by the French dairy industry can be related to the fact that the French dairy industry works at a small scale, it is highly fragmented, and it has shown a relatively slow pace of concentration. Furthermore, it could also be using different technologies (which are more energy intensive) to produce dairy products. The factors named above can also be the cause of the lowest decrease in EEI_p shown by France.

A better understanding of why France shows a slower rate of decrease on its EEI_{p2} values has proven to be more difficult. A better insight is gained by quantifying the level at which each sub sector (i.e. cheese or milk powder) is responsible for the increase/decrease on the EEI_{p2} of the whole dairy industry. The results (Fig. 12) indicate that the cheese and butter sector have, in fact, decreased substantially in their EEI_{p2} values but this decrease has been offset by an increment of the EEI_{p2} in ‘other milk products’ and we found it not to be the result of structural effects. Consequently, values for the whole French dairy sector appears to remain constant. The results also indicate that a great share of the increase occurred between 1993 and 1996. At the level of data presently available it is not possible to quantify the cause of the increases during this period, and hence further research is necessary to understand the energy consumption behaviour within these branches of the dairy industry.

[31] “Other milk products” is composed of dairy products which are essentially the result of concentration and drying processes (Fig. 1).

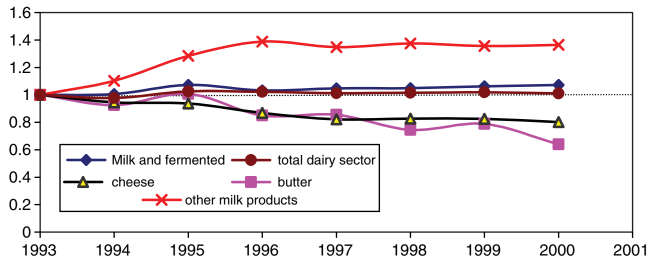

Fig. 12. Developments in EEI_p in the French dairy industry by branch.

9. Conclusions

In this paper, we have presented an analysis of the dairy industry of four European countries in terms of energy consumption and energy efficiency. Changes in energy efficiency have been monitored by the development of two different indicators. The first indicator, EEI_{p1}, has several appealing characteristics. It is easy to calculate, requires few data, can be understood by non-specialists audiences and easily communicated. It has however a main drawback. EEI_{p1} is not sensitive enough to reflect important changes in product mix. EEI_{p2}, on the other hand, is a much more complex indicator to calculate and data burden is higher. However, it accounts for differences in structures among countries and changes in product mix (which have proven to be significant in three of the four countries studied). It also allows for refinement as better information, and data, becomes available. Thus, we conclude that EEI_{p2} should be the preferred indicator when comparing levels of energy efficiency among countries or when there are significant changes in product mix.

Our results also show that the German, British and Dutch dairy industries have achieved considerable improvements in energy efficiency, contrary to the developments showed by the French industry. Furthermore, by the end of the 1990s Germany, the Netherlands and the United Kingdom are converging in their EEI_p values. This can be a sign of technology diffusion among companies. There is a need for research on this point. How important is technology transfer among dairy firms? What are the factors that influence it? Why is the French dairy sector not catching up? These are some questions that deserve especial attention since our results point out savings potentials of over 30% for the French dairy industry if it were to converge to similar values of energy use per unit of output as the ones obtained for Germany or the United Kingdom.

Acknowledgments

We wish to thank the following people for their help on data collection and comments on early drafts of this paper: Ernst Worrell (Lawrence Berkeley National Laboratory, USA), Martin Valstar and Jurgen Jansen (Prodzuivel, the Netherlands), Fons Pennartz (KWA, the Netherlands), Gareth Stace (Dairy Industry Association, UK), Peter de Jong (NIZO, the Netherlands), Reinhard Schoch (ZMP, Germany), and Barbara Schlomann (ISI-Fraunhofer, Germany).

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