MONITORING ENERGY EFFICIENCY IN THE FOOD INDUSTRY

Monitoring Energy Efficiency in the Food Industry

Het monitoren van energie-efficiëntie in de voedingsmiddelensector
(met een samenvatting in het Nederlands)

Seguimiento de la eficiencia energética en la industria de alimentos
(con un resumen en español)

Proefschrift

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“A principle is a principle and in no case can it be watered down because of our incapacity to live it in practice. We have to strive to achieve it and the striving should be conscious, deliberate and hard”.

M. Gandhi

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"All energy conversions undertaken by humans are just means towards a multitude of ends. We convert energies not only to secure basic existential needs but also to satisfy assorted consumerist urges, to enrich our intellectual lives, and to make us more successful as a social and caring species or more brutal as an aggressive and belligerent one. And we have come to realize that, given the fundamental necessity to preserve the integrity of the biosphere we inhabit, all these conversions should be accomplished in ways that are the least disruptive to the maintenance of irreplaceable environmental services".

Vaclav Smil, Energy resources and uses: a global primer for the 21st century, 2002

CHAPTER 1

INTRODUCTION

1.1 Energy and climate change

Prior to the industrial revolution, people depended primarily on renewable sources of energy: animal power, human labor, flowing water, solar energy, wind and biomass combustion. With the development of the steam engine at the birth of the industrial revolution, the use of coal and eventually other fossil fuels contributed to profound changes in production processes, farming and domestic activities. The benefits of the fossil-fueled civilization have been dramatic: "No gain has been more fundamental than the substantial rise in global food production. No change has molded modern societies more than the process of industrialization. And no new developments have contributed more to the emergence of global civilization than the evolution of mass transportation and telecommunication" [Smil, 1994: 188]. However, these developments have not been achieved without cost. At the local and regional level, fossil fuel energy consumption has caused air and water pollution (e.g. emissions of particular matter, lead, sulphur, etc.), but it is the role of fossil fuel combustion in global climate change which has raised worldwide concern.

Fossil fuel combustion is the biggest source of anthropogenic greenhouse gas emissions[1] that are changing the composition of the atmosphere [UNDP, 2000][2]. In

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[1] Main greenhouse gases are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) and tropospheric ozone (O_3).

the year 2001, fossil fuels provided 81% of world energy use, releasing about 23.7 Gigatonnes of carbon dioxide (CO_2) into the atmosphere [IEA, 2004a]. The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) reported the atmospheric CO_2 concentration in 2000 at about 368 ppm. This is an increase of 31±4% with respect to the pre-industrial period (280 ppm for the period 1000-1750) [Prentice et al., 2001]. The increase of atmospheric CO_2 has been found to be interrelated with changes in sea level, snow cover, ice extent and precipitation. The changes have begun to affect physical and biological systems and are expected to have negative impacts both in social and economic systems in the medium to long term. The assessment also points out that stabilization of atmospheric CO_2 concentration at 450 ppm would require global anthropogenic emissions to drop below the 1990 level within a few decades.

In order to stabilize CO_2 concentrations in the atmosphere, three main strategies have been proposed [UNDP, 2000; Prentice et al., 2001]:

- To increase the efficiency of energy use,
- To increase reliance on renewable energy sources,
- To develop and deploy energy technologies that produce near-zero greenhouse gas emissions.

According to model-based analyses [e.g. Criqui et al., 2003; Vuuren and Vries, 2000; Metz et al., 2001] most reductions between 2005 and 2030 will come from energy efficiency improvements. By 2030 other options start to become important: biofuels instead of fossil fuels, and solar, wind and nuclear energy for power generation as well as CO_2 capture and sequestration.

Energy efficiency is an attractive option because it can assure an equal level of economic activity with less fuel; it enhances the reliability of energy supplies by reducing system loads and stresses; it can reduce the need for investment in energy infrastructure (i.e. plants and power lines); it often has short pay-back periods, and it reduces harmful emissions. Additional non-energy benefits can include: noise reduction, labor and time savings, improved process control, water savings and waste minimization [Worrell et al., 2003]. The last Communication of the European Commission to the European Parliament concerning climate change calls energy efficiency a ‘central pillar of any future energy strategy for the European Union’ and points out that ‘it could be economically feasible to realize energy savings of up to 15% in the coming decade while a technical potential of up to 40% exists’ [EC, 2005].

This thesis departs from the recognition that reducing the environmental effects of the energy cycle is a priority and that energy efficiency plays a crucial role in the transition towards a sustainable energy system.

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[2] The rise in CO_2 and other greenhouse gases has (very likely) increased global mean surface temperature by 0.6±0.2ºC within the 20th century [Prentice et al., 2001]. *Very likely* expresses a confidence level of 90-99%.

Measures of energy efficiency are central to designing and monitoring policies. They allow us to know how much energy is used, whether energy consumption has declined or not and how much is the potential for future savings. In the next section, we discuss the different measures of energy efficiency in more detail.

1.2 Measuring energy efficiency

In general, energy efficiency refers to using less energy for producing the same amount of services or useful output [Patterson, 1996]. The measurement of energy efficiency at the lowest level of aggregation, for instance a machine, is simple and straightforward. However, policy makers are generally interested in higher levels of aggregation, e.g. energy efficiency of an industrial sector or a country. In this case, energy efficiency cannot be directly measured and it therefore has to be analyzed by the use of surrogate measures (indicators).

Indicators have played an important role in scientific analysis and policy making. Indicators began to appear first in the field of economics in the 1930s (i.e. growth, employment, inflation), but the term itself became widespread only in the 1960s [Godin, 2002]. A comprehensive definition was given by the US Department of Health, Education and Welfare in 1970: “an indicator is a *statistics* of direct normative interests which *facilitates* concise, comprehensive and balanced judgements about the condition of major aspects of society. It is in all cases a *direct measure* of welfare and *is subject to the interpretation* that, if it changes in the “right” direction, while other things remain equal, things have got better, or people better off” [quoted in Godin, 2002] [3].

An energy efficiency indicator must be: i) easily observable with little or no lag, ii) close to the policy actions in the sense that is quickly affected by the policy undertaken, and iii) related to the target and goal variables. There is general consensus that an energy efficiency indicator should relate, by means of a ratio, the amount of energy use to the useful output or activity (equation 1.1)[4].

$$Energy \quad efficiency \quad indicator = \frac{energy \quad used}{amount \quad of \quad activity} \qquad \text{(Eq. 1.1)}$$

It is in the definition of activity that we distinguish two different approaches:

1. Activity is measured in economic terms: Gross Domestic Product, Value Added, Value of Production, etc.

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[3] Italics are from the author.

[4] Strictly speaking, the energy efficiency indicator and energy efficiency are inversely related. The first measures energy use per unit of activity while the latter refers to the output or activity delivered per unit of energy.

2. Activity is measured in physical terms: tonnes, kilometers, square meters, etc.

To differentiate between both approaches, we use the term *Economic Energy Intensity* for the ratio of energy use to unit of economic activity and *Physical Energy Intensity*[5] for the ratio of energy used to unit of physical activity.

In the literature, energy efficiency is often analyzed by examining changes in economic energy intensity. Energy per unit of gross domestic product (E/GDP) is the most common indicator of energy intensity. The value of the measure is in its simplicity and therefore relative ease of comparison among countries. However, it has been long recognized that E/GDP is a very aggregate measure, which provides little insights into the reasons for differences between countries and years. For instance, changes in E/GDP are due not only to changes in energy efficiency but also due to structural changes within the economy, changes in goods traded with other countries and changes in fuel mix. The fact that there is not a direct relationship between the economic output of an activity and the energy used constitutes the main drawback of economic energy intensity indicators.

Changes in physical energy intensity, on the other hand, can be directly associated to changes in energy efficiency because it relates energy to the unit of physical service provided. Comparisons of monetary-based and physical-based energy indicators recognize that physical energy intensity is a better indicator of energy efficiency than economic energy intensity. Freeman et al., [1997] for instance, examined different measures of industrial output for use in constructing estimates of industrial energy efficiency and found that economic energy intensities seem to be a poor source of information for policy makers. Farla [2000] concluded that physical indicators are preferable to value based indicators because the latter do not properly correct for the differences in output mix between different countries (structural differences). Similar results have been found by Nanduri et al., [2002]; Nyboer et al., [1996]; Ross and Hwang [1992], and Williams et al., [1987].

Physical energy intensity has become the preferred way of analyzing energy efficiency developments in energy intensive industries, such as iron and steel [e.g. Ozawa et al., 2002], pulp and paper [e.g. Farla et al., 1997] and ammonia [e.g. Rafiqul et al., 2005], the transport sector [e.g. He et al., 2005], and buildings/households [e.g. Haas, 1997]. The main objections to the development of physical based indicators are not seen in the lack of strength of the indicator to measure changes in energy efficiency but in the larger amount of data needed, the availability and reliability of the data, and in the case of heterogeneous sectors/processes the incommensurability of physical units (e.g. tonnes of potatoes versus liters of milk) [e.g. Golove and Schipper, 1997; Nanduri et al., 2002, Sinton and Levine, 1994].

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[5] Also referred to as specific energy consumption and unit consumption.

The methodological problem of incommensurability has already been dealt with by Worrell [1994], Phylipsen et al., [1998] and Farla [2000]. The methodology applied can be summarized as follows. The physical energy intensity indicator EEI_{agg} of a sector N which produces products ($i=1...n$) in the year j can be expressed as

$$EEI_{agg,N,j} = \frac{E_{N,j}}{\sum_i^n m_{i,j} \cdot SEC_{i,0}} = \frac{E_{N,j}}{\sum_i^n m_{i,j} \cdot \left(\frac{E_{i,0}}{m_{i,0}} \right)} \qquad \text{(Eq. 1.2)}$$

where E is the energy consumption, m is the production quantity, $SEC_{i,0}$ is a specific energy consumption of product i in a reference year. It is defined as the amount of energy needed in the reference year to produce one unit of physical product i (e.g. GJ/tonne product). $SEC_{i,0}$ reflects the type of process, technology and efficiency level used to produce each product i in the reference year. Equation 1.2 estimates energy efficiency as the ratio between the real energy use $E_{N,j}$ and a frozen energy efficiency development (the energy that would have been used if energy efficiency had remained equal to the reference year). The use of $SEC_{i,0}$ values as multiplier allows physical amounts of products to be transformed into energy amounts which can then be directly added. In international comparisons of energy efficiency one common set of references should be used for all countries. Depending on data availability this can be best practice, typical or reference values for one of the countries.

This methodology has already been successfully applied to the study of energy efficiency developments in energy- intensive sectors, which are characterized for having a limited number of key products, technologies and processes. *In this thesis we evaluate whether using this methodology provides a feasible way of analyzing energy efficiency changes in non-energy intensive manufacturing sectors at different levels of aggregation.*

1.3 Energy efficiency in non-energy intensive manufacturing sectors. The need for more research.

Until recently most in-depth energy efficiency analyses focused on the power generation sector, energy intensive industries (e.g. steel, aluminum, ammonia) and transport while largely disregarding non-energy intensive industries (e.g. food, textiles, machinery), the agricultural sector, and services (banking system, hospitals, etc). The low degree of attention paid to non-energy intensive sectors is a result of the lower individual contributions to total energy demand (or CO_2 emissions), the high heterogeneity of products, process and technologies and the lack of reliable data.

In the last years, however, the attention paid to non-energy intensive sectors has slowly increased since it has been realized that taken together they make up for a sizeable portion of energy demand (e.g. in 2002 the non-energy intensive part of the manufacturing sector together with agriculture and services accounted for about 30% of the primary energy demand in OECD countries[6]). The last IPCC assessment, for instance, stated that at the industrial level 'there are [in the non energy intensive industry] in relative terms probably more substantial savings possible than in heavy industry, but…options are not worked out in detail because of the diversity of the sectors and the lack of information" [Metz et al., 2001]. The final report of the first phase of the European Climate Change Programme (ECCP) [2001] estimated the economically feasible[7] saving potentials in the non-energy intensive industry of Europe-15 by 2010 at 419 PJ (about 40 Mt CO_2)[8]. This is a significant amount if it is considered that the same report identified the economically feasible saving potential for energy intensive industries at 670 PJ (about 60 Mt CO_2). A bottom-up analysis of technical potentials[9] for reducing energy-related CO_2 emissions in the European industry found similar proportions in the savings: 161 Mt CO_2 could be reduced in non-energy intensive industries by 2010 compared with 394 Mt CO_2 in energy-intensive industries [de Beer et al., 2001]. Another sign of the increasing attention paid to non-energy intensive sectors is the new European Commission initiatives such as the proposal for a Directive on energy end-use efficiency and energy services [EC, 2003].

However, if policy makers are to develop and implement strategies that effectively promote energy efficiency, a thorough understanding of the economic, technical and behavioral drivers underlying energy demand and energy efficiency in the non-energy intensive sectors is needed. Due to the low attention paid to non-energy intensive sectors in the past, this understanding is limited. *This thesis focuses on providing historical energy and energy efficiency data as well as understanding the key underlying drivers. We use the food sector as a case study of the non-energy intensive sector.*

1.4 The food industry

The food, drink and tobacco industry (hereafter food industry) transforms products originating from agriculture into both food and non-food commodities. Processes range from simple preservation (e.g. sun drying) and operations closely related to harvesting, to the production by modern, capital-intensive methods of products such as starch or milk powder. Table 1.1 shows an overview of three indicators for

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[6] To obtain primary energy values, electricity was transformed into primary fuel by using an average conversion efficiency of 40%.

[7] The economic potential is defined as the potential savings that can be achieved at a net positive economic effect, i.e. the energy savings resulting from the action are higher than the measure/investment cost (including investment, depreciation, and operation and maintenance costs).

[8] Compared with a business as usual scenario.

[9] The technical potential is defined as the total effect of all energy efficiency improvements measures that can be implemented. By definition the technical potential is larger than the economic potential.

several regions/countries: the share of food industry relative to manufacturing GDP, total manufacturing employment and total manufacturing final energy consumption. The food and tobacco industry plays a vital role in the economy of most countries. In 2001, the food and tobacco industry was the second largest manufacturing sector in the EU economy. It generated €143 billion of value added while employing 2.7 million persons [Eurostat, 2003].

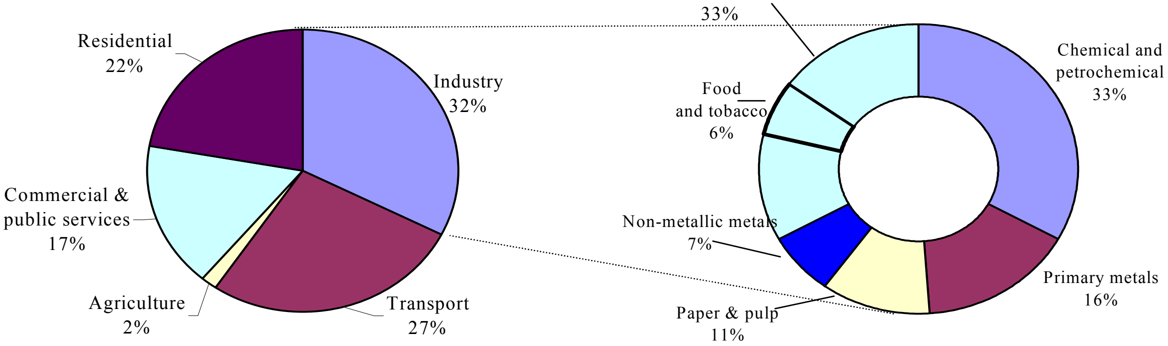
In energy terms, however, the food industry has a significantly lower share in total final consumption. Figure 1.1 plots the distribution of final energy demand by sector in OECD countries for the year 2002. 70% of the energy use in the industrial sector is accounted for by only four manufacturing sectors which explains the high level of attention they receive. The share of the food industry in 2002 was only 6% of the industrial energy demand, accounting for about 2% of the total demand. If agriculture is added the contribution of the food sector is 4% (this does not take into account the energy use for transportation and the indirect energy contained in agricultural inputs such as fertilizers). In Europe 15, the share of the food industry with respect to total energy demand is about 2.5%, and 5% if agriculture is taken into account.

Table 1.1 Overview of the importance of the food and tobacco industry in some regions and countries, in 2001.

Country/region	Percentage of manufacturing GDP	Percentage of manufacturing employment	Percentage of manufacturing total final energy consumption
Australia	18	16	13
Brazil	10	20	20
Europe 15	13	12	8
India	18	19	8
Philippines	45	50	11
United States	10	9	7

Data sources: Newcronos database and Energy balances of the International Energy Agency.

Figure 1.1 Distribution of primary energy demand in OECD countries, 2002.



Data source: International Energy Agency, 2004b.

Despite the low energy share, understanding the relationships between energy and food is a key element of global strategies to achieve sustainability, especially in the light of the need for growth in the sector to help meet the needs of the world's population and decrease the number of people with inadequate access to food. As stated by dr. Gustavo Best, Senior Coordinator of the Environment and Energy Programmes Centre of the Food and Agricultural Organization of the United Nations (FAO): "Most aspects controlling, guiding and ascertaining food security are energy dependent. It is impossible to envisage an effective food production system, or an efficient food processing and distribution chain without the necessary energy inputs which makes them operate. There is a close correlation between the quality and quantity of food produced, transformed and consumed and the quality and quantity of energy use to 'turn the wheels' of food security" [Best, 1996:1].

This thesis contains a historical analysis on how various factors such as level of activity, changes in production mix and efficiency have affected energy use. This is important information since it will provide modelers and policy makers with a good analytical basis from which to extrapolate baseline trends on energy use and energy efficiency in the food sector.

1.5 Scope and outline of this thesis

The overall aim of this thesis is to examine the role that energy efficiency and other factors have played in the development of energy use of non-energy intensive sectors, with special emphasis on the food industry. Specific goals are:

1. To study the developments in energy use, energy efficiency and sector structure in non-energy intensive industries of the Dutch manufacturing sector.
2. To develop physical energy efficiency indicators for monitoring changes in energy efficiency in the food and tobacco industry at different levels of aggregation.
3. To analyse the historical relations of fossil fuel demand and food production in the European food supply chain.

In each case, we identify and analyze the activity and structural drivers behind the development of energy use. This thesis is composed of three parts, one for each of the specific goals mentioned above. The first part (*Chapter 2*) takes a broad view. In it we examine the concept of non-energy intensive manufacturing sector and perform a historical analysis of energy demand and economic energy intensity for this sector in the Netherlands. The second part (*Chapter 3, 4 and 5*) focuses on the food industry. It examines whether it is possible to develop physical energy intensity indicators that provide a reliable estimation of changes in energy efficiency in the food industry. Chapters 3 and 4 contain the analysis of energy use and energy efficiency for the meat and dairy industry. Chapter 5 draws on the methodology and results found in Chapters 3 and 4 and expands the analysis to the whole food and tobacco sector. In Part three, we take a system approach. It looks at the relations between energy and physical flows in the fertilizer industry (*Chapter 6*) and the whole food supply chain (*Chapter* 7).

The contents of the various chapters are discussed in more detail below.

In *Chapter 2*, we analyse the non-energy intensive sector, using the Netherlands as a case study. First, we look at the criteria for distinguishing between the energy intensive part and the non-energy intensive part of the industrial sector. Then, using data at the 3-digit level of statistical aggregation we analyse the development of the non-energy intensive sector with respect to its energy consumption, energy intensity, value added, production value, and energy price. Finally, we apply a decomposition methodology to separate the influence of structural, production and intensity effects.

Using the definition of *Chapter 2*, we selected two non-energy intensive industrial sectors to perform a detailed analysis of historical changes in energy use and energy efficiency in four European countries. This is the object of study of *Chapters 3 and 4*.

Chapter 3 and *Chapter 4* provide analyses of energy use and energy efficiency for two food industries: dairy (*Chapter 3*) and meat (*Chapter 4*). The structure of both chapters is similar. Each chapter starts with an analysis of production and energy consumption in France, Germany, the Netherlands and the United Kingdom. We then assess changes in energy efficiency by developing and applying energy efficiency indicators, which are based on physical amounts of output. Finally, we analyse the reliability of the results and examine the possible causes for differences in the indicators among countries.

Chapters 3 and *4* deal with relatively homogeneous sectors. In *Chapter 5* we examine the energy use per unit of physical output in a heterogeneous, non-energy intensive sector at a high level of aggregation: the whole food and tobacco sector. The analysis is performed for the Netherlands and the time period 1993-2001. We also assess the feasibility of implementing the methodology and data sources for monitoring trends in energy efficiency in the future. In this chapter, we work with production data at the firm level provided by the Statistical Office of the Netherlands on a confidential basis. We explore the reliability of our results by i) analysing the uncertainty in the results; ii) examining how representative are our results of the behaviour displayed by the whole industry; and iii) comparing our results with data from the Long Term Agreements.

In *Chapter 6* we assess energy demand due to world fertilizer consumption in the time period 1961-2002. The chapter is composed of two parts. In the first one, we develop historical trends of specific energy consumption and gross energy requirements by kind of fertilizer and assess the energy embedded in world fertilizer consumption. These trends are later used in *Chapter 7* as part of the inputs needed to calculate total energy demand in the food supply chain. Furthermore, we examine the role of fertilizer consumption, fertilizer mix and changes in energy efficiency in the energy demand. In the second part, we explore whether technological development in the fertilizer industry can be analyzed using the concept of learning or experience curve.

Chapter 7 deals with the historical relationships of fossil fuel demand and food production in developed countries. The analysis is made for thirteen European countries in the time period 1970-2002. The system analyzed is composed of agriculture (including fertilizer), food processing and transport. In the first part of the paper, we examine the developments in energy use, physical production and economic output in the food supply chain. In the second part, we break down the trends by examining different factors that influence energy consumption in each step of the food chain. For agriculture we study the effect of population growth, increasing exports, feed production and changes in energy per calorie of output; for fertilizers we examine the effect of decreasing fertilizer consumption and increasing energy efficiency during their manufacture; for the food processing sector we study the effect of population growth, change in diet patterns and changes in energy per calorie output; finally, we analyze the effect of increasing transport, change in transport mode and the intensity of the transport system. The chapter finishes with a discussion of results around three main points: sensitivity of the results, the choice of the nutritional factor and the impact of the system boundaries.

This thesis finalizes with *Chapter 8* where the results are summarized and main conclusions are drawn.

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Part I

The non-energy intensive manufacturing sector

CHAPTER 2

The Non-energy Intensive Manufacturing Sector. An Energy Analysis Relating to the Netherlands[*]

Abstract

This chapter focuses on an area that has been neglected in energy analysis: the non-energy intensive industries. Using data at the 3-digit level for the Dutch manufacturing industry, we analyzed the performance of the sector with respect to its energy intensity, value added, value of production and energy costs. We found that energy consumption has increased by 30% between 1988-1999 while on average there has not been a decrease on energy intensity. A decomposition analysis was performed in order to separate structural, production and intensity effects. We found that structural changes played a minor role and that in fact, intensity effects added further energy requirements to those induced by output growth. The results of our study highlight the need for policy-makers and scientists to increase their attention to the non-energy intensive sector and encourage industries in these sectors to adopt energy-efficient technologies and management practices.

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[*] This chapter is a slightly adapted version of*: Ramirez C.A., Patel M., Blok K., 2005. The Non-energy Intensive Manufacturing Sector. An Energy Analysis Relating to the Netherlands. Energy 30, 749-767.* The only alteration to the published article is the addition of Appendix 1, which contains a list of industrial sectors at the 2-3 digit level.

2.1 Introduction

Energy efficiency has been and is still an important subject of discussion at the political and technological level. Two oil crises and the ongoing debate about how to reduce energy-related emissions of carbon dioxide have been the principal forces behind the discussion. However, despite the continuing policy interest in energy efficiency and the many reports and books written on the topic, little attention has been given to non-energy intensive sectors.

The demand for energy is normally broken down into four main sectors: industrial, residential, service and transport. According to the International Energy Agency, in the year 2000 the industrial sector alone accounted, in terms of total final energy consumption, for about 75% of world coal consumption, 20% of world oil consumption, and 44% of world natural gas consumption [IEA, 2002]. This substantial share explains the attention paid to this sector by energy and climate policies. So far, most policies, studies and measures focus on the energy intensive sector of industry but have neglected the non-energy intensive sector. To mention two examples (a) the World Energy Council (WEC) report comparing sectoral energy use [WEC, 1995], and (b) the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) [Metz et al., 2001]. The purpose of the WEC report was to provide a detailed assessment of past trends in energy use and future opportunities for utilizing energy more efficiently in the building and industrial sectors. Nevertheless, in the report there is no reference *at all* to non-energy intensive sectors. On the other hand, and despite the IPCC reports recognition that “there are [in the non-energy intensive sector] in relative terms probably more substantial savings possible on than in the intensive one”, the assessment *only* dealt with the energy intensive sector.

Against this background, the aim of this chapter is to study the non-energy intensive industrial sector (NEI), using the Netherlands as a case study. First of all, we look at the criteria for distinguishing between the energy intensive part and the non-energy intensive part of the industrial sector. This topic is addressed in Section 2.3 where energy demand studies are reviewed and some of the definitions are evaluated using empirical data for the Netherlands. Secondly, we consider whether it has been wise to pay so little attention to the NEI sector. To this end, we analyze aspects such as energy consumption, energy intensity, value added, production value, energy price and the influence of structural, intensity and production effects in energy consumption and present our results in Section 2.4. A discussion of results is shown in Section 2.5. Finally, conclusions are drawn in Section 2.6.

2.2 Data and methodology

2.2.1 Data

This chapter uses the Dutch manufacturing sector[1] as a case study. We have used data published by the Central Bureau of Statistics of the Netherlands (CBS). Data on energy consumption is published in “De nederlandse energiehuishouding, jaarcijfers” [CBS, annual publication-a]. Data on producer price index, energy costs, labor costs and capital stocks is published on “Samenvattend overzicht van de industrie” [CBS, annual publication-b]. We base our analyses on a 3-digit level of disaggregation of the Dutch standard economic classification (SBI)[2]. The advantage of using these highly disaggregate data is that we are closer to the industrial process itself. Note that data on industrial energy demand at the 3-digit level began to be published in 1988, however, in 1993 the Dutch statistics office adopted a new classification, and as a result data for the industrial sectors before and after 1993 are not completely compatible. Since the five-year period 1993-1998 seemed to be too short for us to draw conclusions, we decided –wherever possible- to develop longer time series. To this end, we conducted a branch-to-branch analysis for 1992 and 1993 in order to detect those sectors for which the change in classification would result in inconsistent time series. This was the case for the following groups: Manufacture of pharmaceuticals (SBI 244), Manufacture of other chemical products (SBI 246), Manufacture of man-made fibers (SBI 247), Manufacture of office machinery and computers (SBI 300), Recycling (SBI 371-2). These groups are therefore excluded from our analysis.

In this study, and unless otherwise specified, when we refer to energy we mean *primary energy.* We have assumed an efficiency of 40% for electricity production [Worell et al., 1994], which is representative for the Netherlands with its natural gas based power sector. For every MJ of oil products delivered we assumed a primary energy input of 1.05 MJ and for natural gas a primary energy equivalent of 1.01 MJ. The price of energy use is an average price calculated as the total costs of energy (including taxes) divided by the total energy content (J).

Finally, when referring to relative changes, we will use the term log percentage change (L%) instead of ordinary percentages because the latter have asymmetric and non-additive properties [Tornqvist et al., 1985]. The relative change of two numbers x_1 and x_2 is expressed as

$$L\% = \ln(x_2/x_1)\cdot 100 = [(x_2 - x_1)/L(x_2, x_1)]\cdot 100 \qquad \text{(Eq. 2.1)}$$

indicating that the log difference is literally a relative difference with respect to the logarithmic mean. L% is symmetric (it is independent of which point is taken as point of comparison), additive (successively relative changes can be added) and

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[1] The manufacturing sector in this paper excludes mining, agriculture and construction activities.

[2] From 1993, the SBI classification follows the NACE.

normed, all of which are desirable properties for measuring relative changes. For more information see [Tornqvist et al., 1985].

2.2.2 Energy intensity

Following most energy studies, we define energy intensity (EI) as the primary energy used per unit of economic output. Literature indicates that value of production (VP) should be used instead of value added (VA) since the latter tends to exaggerate year-to-year changes in efficiency [Freeman et al., 1997]. However, this conclusion has been made based on the analysis of energy intensive sectors. As no analysis has been performed for non-energy intensive sectors, we consider worthwhile to compare the results obtained using both measures of output, moreover when VA seems a preferred choice for many energy analysts.

2.2.3 Decomposition analysis

In order to single out the effect of changes of the structure of a sector on energy intensity and energy consumption, we apply an index decomposition methodology. There are several decomposition methods, Ang and Zhang [2000] shows a detailed survey of different methodologies. We chose to use a Multiplicative Log-Mean Divisia Method, which has been shown to be "perfect in decomposition but also consistent in aggregation" [Ang and Zhang, 2001].

Two approaches have been applied: an energy intensity approach and an energy consumption approach. In the energy intensity approach, the total change in aggregate energy intensity (I_{agg}) is decomposed into a structural effect (D_{str}), associated with the industrial composition of the sector, and an intensity effect (D_{int}), associated with changes in sectoral energy intensity. In the energy consumption approach a third component, production (D_{pdn}), is added in order to explain the change in energy use in absolute terms. The equations used are shown below [Ang and Zhang, 2000]:

- *Energy intensity approach:*

$$I_{agg} = \sum_i S_{i,t} \cdot I_{i,t} \qquad \text{(Eq. 2.2)}$$

$$D_{tot} = {I_t}/{I_0} = D_{str} \cdot D_{\text{int}} \qquad \text{(Eq. 2.3)}$$

$$D_{str} = \exp\left\{ \sum_i \frac{L(\omega_{i,t}, \omega_{i,0})}{\sum_i L(\omega_{i,t}, \omega_{i,0})} \ln({S_{i,t}}/{S_{i,0}}) \right\} \qquad \text{(Eq. 2.4)}$$

$$D_{\text{int}} = \exp\left\{ \sum_i \frac{L(\omega_{i,t}, \omega_{i,0})}{\sum_i L(\omega_{i,t}, \omega_{i,0})} \ln({I_{i,t}}/{I_{i,0}}) \right\} \qquad \text{(Eq. 2.5)}$$

Where

$$L(x,y)=(y-x)/\ln(y/x) \qquad \text{(Eq. 2.6)}$$

- *Energy consumption approach:*

$$E_t=\sum_i Y\cdot S_i\cdot I_i \qquad \text{(Eq. 2.7)}$$

$$D_{tot}={E_T}\big/{E_0}=D_{pdn}\cdot D_{str}\cdot D_{\text{int}} \qquad \text{(Eq. 2.8)}$$

$$D_{pdn}=\exp\left\{\sum_i \frac{L(\omega_{i,t,},\omega_{i,0})}{\sum_i L(\omega_{i,t,},\omega_{i,0})}\ln({Y_t}\big/{Y_0})\right\} \qquad \text{(Eq. 2.9)}$$

ω_i= Energy share of sector *i* in year *t* (=$E_{i,t}$/ E_t)
I_{agg}= Aggregate energy intensity
D_{tot}= Total change in aggregate energy intensity
D_{int}= Intensity effects
D_{str}= Structure effects
D_{pdn}= Production effects
E_t = Total primary energy consumption in year *t*
$E_{i,t}$ = Energy consumption in industrial sector *i* in year *t*
Y_t = Total industrial production in year *t*
$S_{i,t}$ = Production share of sector *i* in year *t* (=$Y_{i,t}/Y_t$)
I_{agg} = Aggregate energy intensity (=$E_t/Y_{i,t}$)
$I_{i,t}$ = Energy intensity of sector *i* in year *t* (=$E_{i,t}/Y_{i,t}$)

2.3 What is the non-energy intensive sector?

The first problem we came across in trying to find a definition of the non-energy intensive sector concerned the various names that were used to distinguish sectors depending on their energy intensity. In some studies, for instance, energy intensive industries were treated as being synonymous with heavy industries, whereas non-energy intensive industries were referred to as light industries [Blok et al., 1995; de Beer, 1998; Hirst et al., 1983; Jochem, 2000; Phylipsen et al., 1998; Schipper et al., 2001; Tang and La Croix, 1993; WEC, 1995]. Li et al., [1990] worked with the concepts of strategic and non-strategic high and low energy intensity sectors, defining strategic industries as those with lower energy intensity and higher value added. Williams et al., [1987] equated energy intensive industries with material-intensive industries, as did Capros and Mantzos [2000]. The Department of Energy of the United States [1995] defined three groups: high-energy consumer, high value added consumers and low energy consumers. The most energy-intensive industries were included into the “high energy consumer group” the exception being food and kindred products, which were said to be “high-energy consumer but not very energy intensive”. Other terms like non-major energy consuming sectors and the high technology sector are also widely used. However and despite the variety of terms, we could differentiate three approaches that have been commonly adopted when defining sectors according to their intensity[3]:

1. Single out a few major energy-intensive sectors and treat the remainder as a residual group.
2. Establish a limit that differentiates energy intensive from the non-energy intensive sectors. The limit between them is expressed in terms of energy intensity or total percentage of energy consumption.
3. Define the intensiveness or extensiveness of a sector via its process characteristics or via other 'known' definitions, such as light and heavy industry.

The problem with the two first approaches is that no arguments are given for the criteria chosen which therefore seem to be rather arbitrary. Worthy of special attention is the third approach, which distinguishes between energy intensive and non-intensive industries using other 'known' definitions. The definitions more widely used in this way are heavy and light industry. We have found that when referring to the heavy and light industry either one of the following concepts is generally used:

- Heavy and light industries are defined according to their position in the production chain. Hence, manufacturing sectors that produce intermediate products from raw materials are considered as heavy and those involved in the fabrication and assembling activities using basic materials created by other industries are considered as light sectors [e.g. Gardner and Elkhafif, 1998; Marlay, 1984; Schipper et al., 2001].
- Heavy and light industry concepts are related to the use of capital and labor [Hirst et al., 1998, Capros and Mantzos, 2000]. Industries that use capital intensively are considered as heavy, whereas labor-intensive industries are considered as light.

The first concept seems quite clear-cut. Indeed, at the industrial level, energy intensity in general decreases progressively with the shift away from material conversion to fabrication and processes. However, a valid definition when speaking of *processes* can prove to be difficult when applied to aggregate industrial sectors. Difficulties might particularly occur for industrial sectors which may comprise a variety of manufacturing sub-sectors that are heterogeneous with regard to their role in the production chain and their pattern of energy use (within a sector at the 2-digit level, it can be found industrial sub-sectors that differ from others by up to 20 times or more in their energy use per unit of economic value). Hence, at a low disaggregation level the energy intensive sectors *will* include both heavy and light industries.

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[3] This is made based on a survey of 60 energy demand studies dealing with the manufacturing sector.

The second concept relates energy intensity to the intensity of capital and labor. Figures 2.1 and 2.2 show the relationship between capital intensity and energy intensity, and labor intensity and energy intensity in 1998[4] for the Dutch manufacturing sector. Dutch industries are clustered around intermediate levels of capital and labor intensity[5]. To elucidate these relationships a correlation analysis was performed for several years. The correlation factors obtained are shown in Table 2.1. The relationship between capital and energy intensity is quite straightforward. The most capital-intensive sectors are also the most energy intensive. In fact, the analysis shows the expected positive and high correlation coefficients[6]. On the other hand, the relationship between labor and energy intensity is more complex. If light and non-energy intensive sectors are indeed the same group, sectors with high labor intensity are expected to be low energy intensive. The inverse correlation is reflected by the negative sign of the correlation factor for all the years. However, two points need to be highlighted: First, the correlation between energy and labor intensity for the manufacturing sector is only about half of the correlation found between capital and energy intensity. Secondly, the correlation between labor and energy intensity is decreasing over time. Figure 2.3 shows the relationship between change on energy intensity and labor intensity at the 2-digit level. The results indicate that there is a general trend towards lower energy *and* labor intensity[7]. Between 1993 and 1998 the decrease in labor intensity outpaced the decrease in energy intensity by a factor of 3[8]. Energy intensity decreased more slowly than labor intensity, which suggests that the consumption of energy per employee increased over time. However, higher growth rates of energy intensity do not necessarily mean higher or lower rates on labor intensity.

On the basis of the above mentioned considerations it can be concluded that as far as capital and labor are concerned, the concepts “heavy and light industries” should be approached with caution especially because an intensive use of labor in a manufacturing sector *does not* necessarily imply a low energy intensity. This probably explains why labor-intensive industries are sometimes considered to be high consumers of energy and therefore part of the energy intensive sector [Hirst et al., 1983] and sometimes low consumers of energy and therefore part of the non-energy intensive sector [Capros and Matzos, 2000].

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[4] Note that these graphs and the analysis are done for the whole manufacturing sector. In order to avoid problems with the change on the economic classification of 1993, the analysis is performed for the time period 1993-1999.

[5] Capital intensity was measured using the ratio of capital stocks to value added for each sector at 2-digit level. Labour intensity was measured as the ratio of the number of employees to value added of each sector at 2-digit level.

[6] The correlation was found to be equally strong if capital per employee was used as the measure for capital intensity.

[7] The average energy intensity for the whole manufacturing sector dropped from 18.8 in 1993 to 16.0 MJ/ Euro VA in 1998 while the average labour intensity dropped from 24.4 to 16.3 employees/mln Euro VA for the same years.

[8] Group 18 was excluded due to its high value; if this outlier were included the ratio would be 6:1.

Figure 2.1 Capital intensity and energy intensity in the Dutch manufacturing sector at 2-digit level, 1998

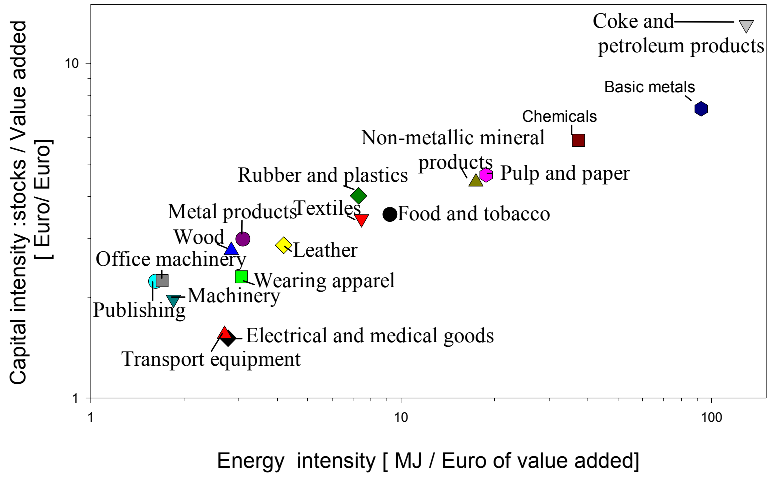


Figure 2.2 Labor intensity and energy intensity in the Dutch manufacturing sector at 2-digit level, 1998.

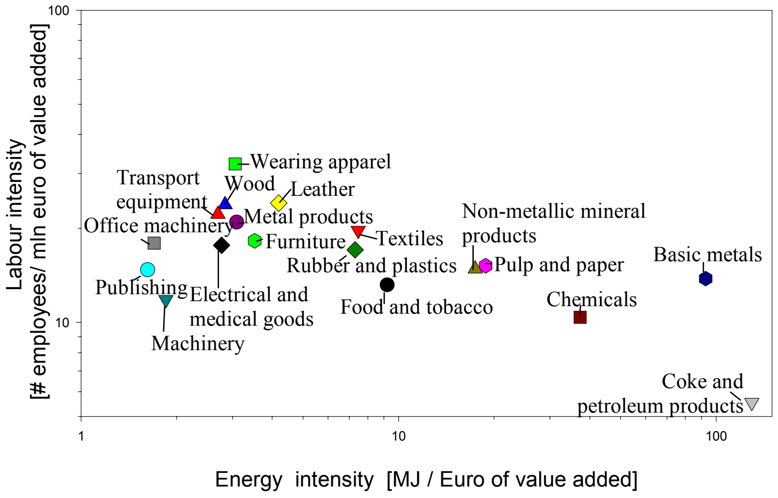
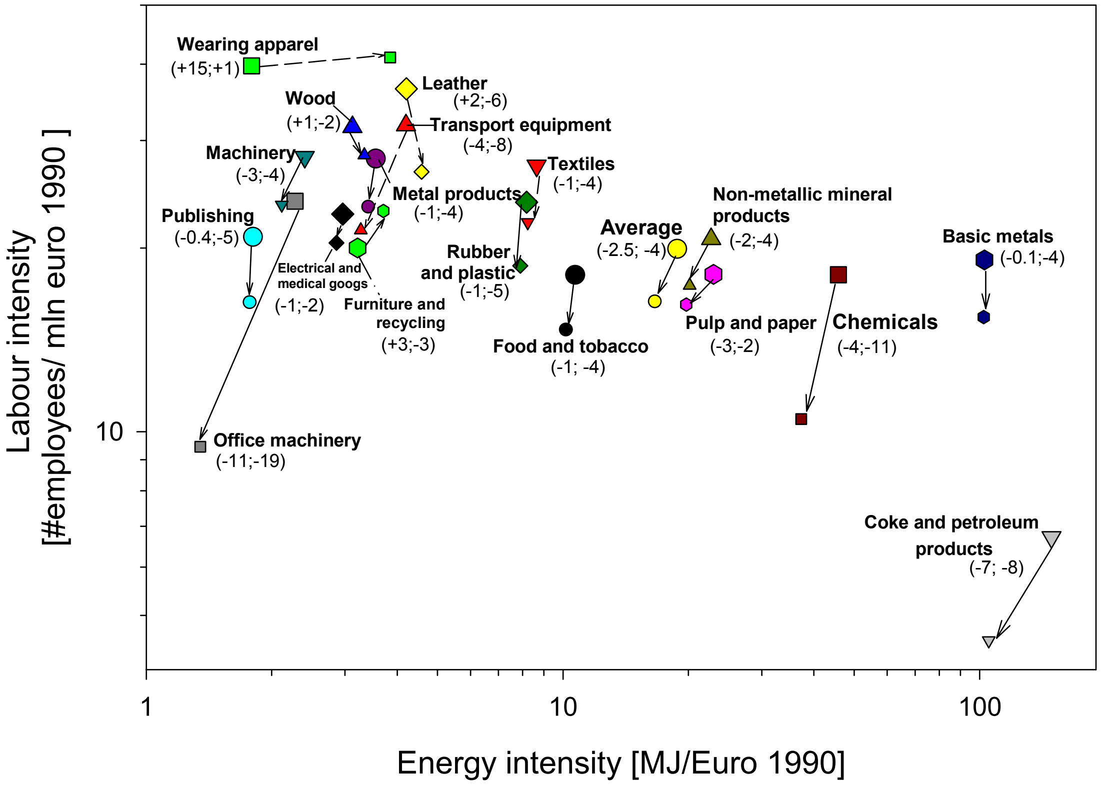


Table 2.1. Correlation coefficients between labor-energy intensity and capital - energy intensity in the Dutch manufacturing industry.

Correlation factor	1993	1994	1995	1996	1997	1998	1999
Capital - Energy intensity	0.93[a,b]	0.97[a,b]	0.97[a,b]	0.96 [a,b]	0.97 [a,b]	0.96 [a,b]	0.96[a,b]
Labor - Energy intensity	-0,69 [a,b]	-0,65 [a,b]	-0,58[a]	-0,55 [a]	-0,52 [a]	-0,49 [a]	-0.47[a]

a: significant at 0.05 level b: significant at 0.01 level

Figure 2.3 Annual Changes in labour and energy intensities for the Ducth manufacturing sector at 2-digit level, 1993-1998



Note: the larger symbols represent values for 1993 whereas the small ones represent values for 1998. The arrows indicate, in a schematic way,the change in each sector. Relative annual changes, as percentages, are indicated between brackets. The first number indicates the relative annual change on energy and the second number the annual change in labour intensity. The sign (+) indicates an increasing rate whereas the sign (-) indicates a decreasing one.

To summarize, the third approach has obvious flaws. We therefore revert to the first two approaches which we criticized as being arbitrary. Especially the second approach seems viable if good arguments can be found for setting the limit at a certain level. This seems possible with the help of the results of the studies reviewed. A limit is easy to understand and it allows comparisons to be made between studies, especially if the criteria used to establish such limit is clear.

In this chapter, we use two main criteria to establish this limit:

- The first criteria make use of the existing differences in magnitude of energy intensity across manufacturing sectors. Figure 2.4 depicts the differences in the Dutch manufacturing sub-sectors with respect to their energy intensity and production value in 1999[9]. Diagonal lines represent constant levels of total primary energy consumption. The spread of industrial branches in the graph with respect to energy intensity and production value is a typical characteristic of the manufacturing sector as is

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[9] A graph showing VA shows a similar picture.

the fact that most of the sub-sectors are located in the lower zone of the graph.

- The second criteria we want to use to characterize the non-energy intensive sector with is the share of energy costs in total costs[10]. Figure 2.5 plots the distribution of costs for Dutch manufacturing branches at the 3-digit level. The share of material costs dominates over the costs' shares in *all* industrial branches. Energy costs made up only a small proportion of the total costs, varying between 0.6% and 15% (the exception is the sector manufacture of coke oven products and nuclear fuel which has a share of 31%)

Figure 2.4 Energy intensity and value of production in Dutch manufacturing industries at 3-digit level, 1999. A list of the sectors is shown in Appendix 1.

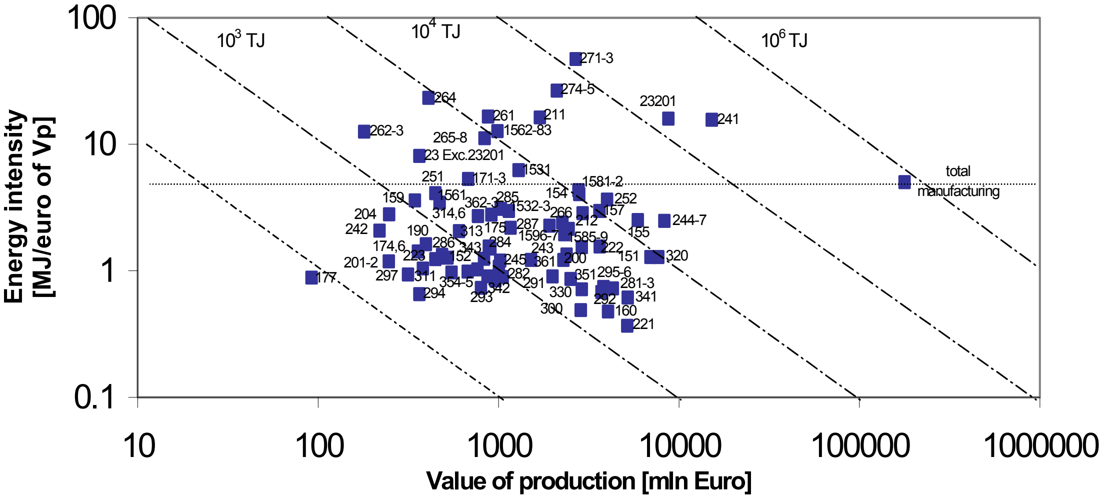
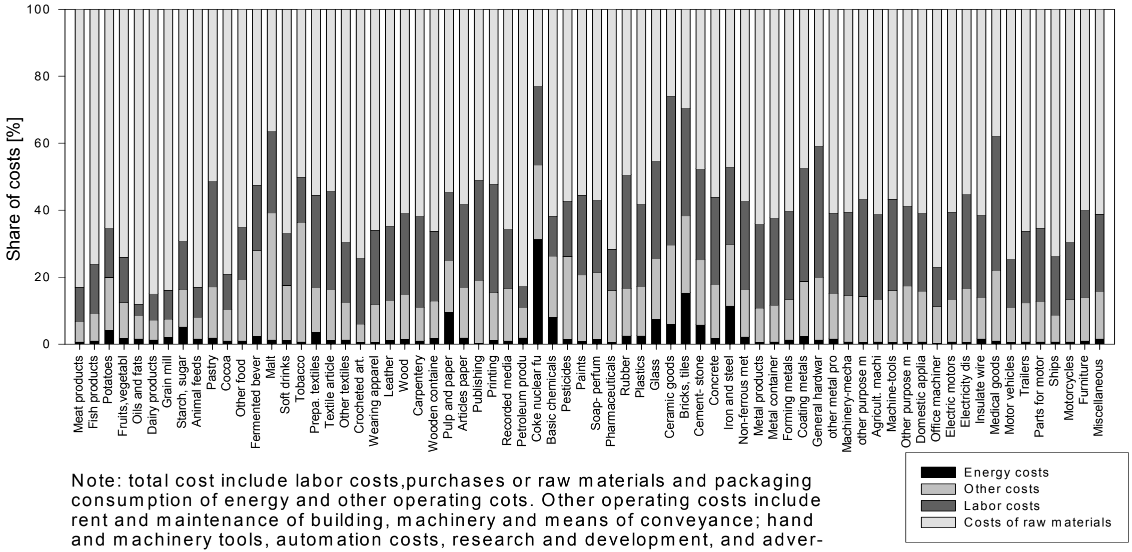


Figure 2.5 Share of costs in the Dutch manufacturing industry at 3-digit level, 1999.



Note: total cost include labor costs,purchases or raw materials and packaging consumption of energy and other operating cots. Other operating costs include rent and maintenance of building, machinery and means of conveyance; hand and machinery tools, automation costs, research and development, and advertising expenses

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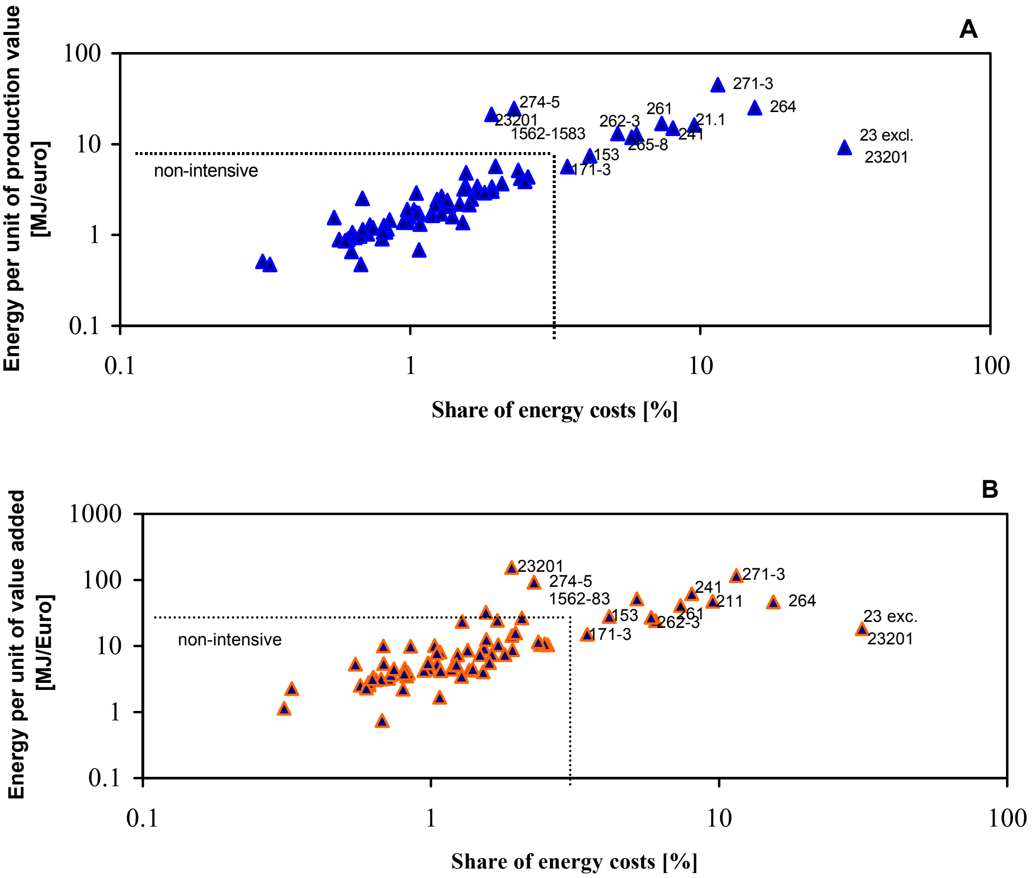
[10] Total costs include labor costs, purchases of raw materials and packaging, consumption of energy and other operating costs which include: rent and maintenance of buildings, machinery and

In Figure 2.6 we have plotted the share of energy costs against the energy intensity of the sub-sectors (both in terms of value of production and value added). In our analysis we consider that non-energy intensive sectors should have both low energy intensities and a low share of energy costs. In Figures 2.6A and 2.6B it is indicated within the frame what we would take as non-energy intensive branches at the 3-digit level. As low energy intensity we define those sectors which are located below the average for the whole manufacturing sector +50%, and for low share of energy costs those which have a share below 3%. As showed in the Figures, the selection of the non-energy intensive sectors is independent of the use of value added or value of production as the measure of economic output.

Figure 2.6 Energy intensity and share of costs in the Dutch manufacturing industry at 3-digit level. (A) Using production value as the measure of economic output. (B) Using value added as the measure of economic output. A list of the sectors is shown in Appendix 1.



2.4 The non-energy intensive industry (NEI); trends and developments in the Netherlands.

In 1999 the Dutch NEI consumed about 200 PJ which corresponds to 28% of the total primary energy used by the whole manufacturing sector. In economic terms,

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means of conveyance; hand and machinery tools, automation costs, research and development, and advertising expenses.

the Dutch NEI is clearly more important with large shares of value added (67%), value of production (70%) and employment (78%). Figure 2.7 shows the development of energy, production value, value added and employment in the non-energy intensive sector between 1988 and 1999. Energy consumption increased by 30% in this period, while production value and value added increased by 26% and 22% respectively. Employment, on the other hand, decreased by 12%. In absolute terms the non-intensive sector has been the sector driving the increase in total energy consumption for the whole manufacturing sector (although the energy intensive sector consumes more per unit of output, strong reductions in energy intensity have offset this effect and consequently the net increase on energy consumption by this sector has been minimal[11]).

Figure 2.7 Activity indicators for the Dutch non-energy intensive sector.

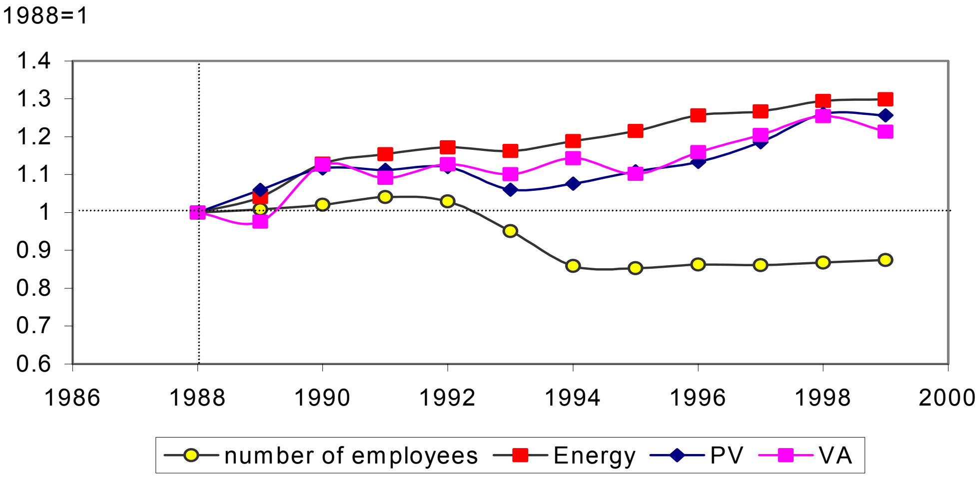
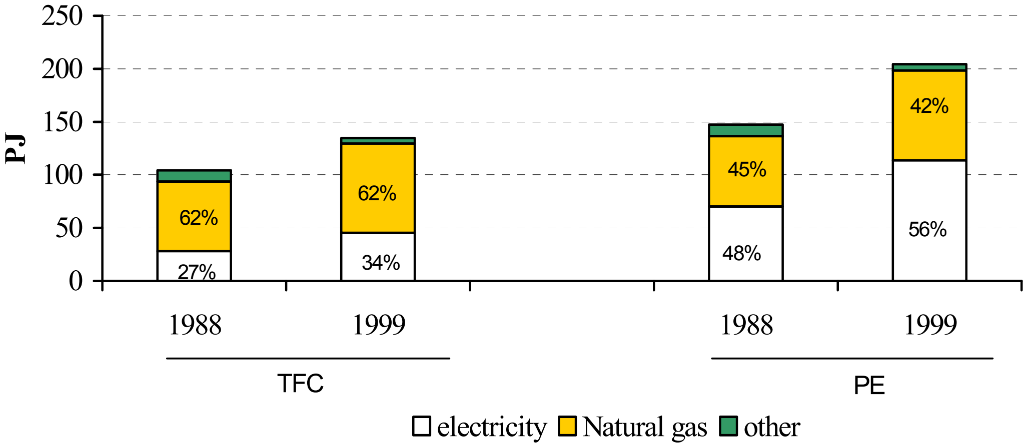


Figure 2.8 Shares of fuel in total final consumption (TFC) and primary energy (PE) in the Dutch non-energy intensive sector.



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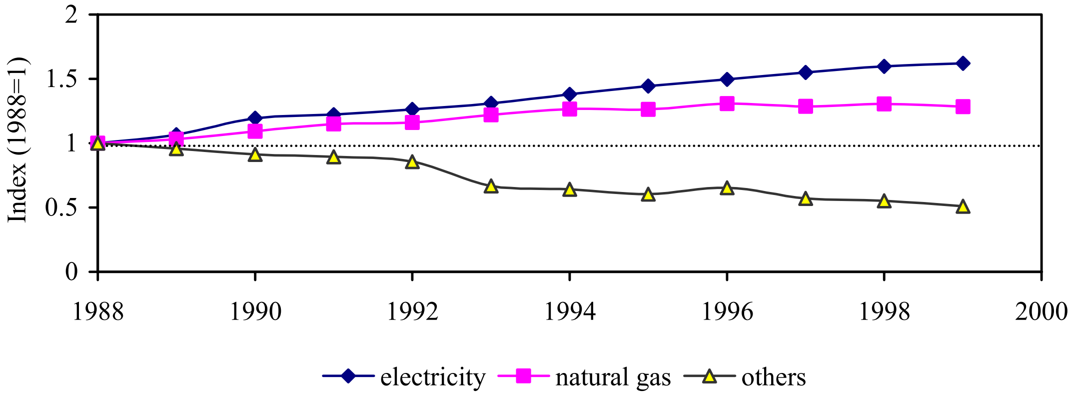
[11] Between 1993 and 1999 there has been a 4% increase in primary energy consumption by the whole manufacturing sector. Of this percentage 2% is due to an increase in energy consumption by the energy-intensive sector, while the NEI sector increased by 10% in the same period of time.

Finally, Figure 2.8 shows the average sectoral fuel shares for the non-energy intensive sector both in terms of total final consumption (TFC) and primary energy (PE). Note the importance of natural gas in terms of final consumption and of electricity in terms of primary energy. In fact, electricity has grown at a higher rate than natural gas, while ‘other fuels’ declined substantially during the last decade (Figure 2.9).

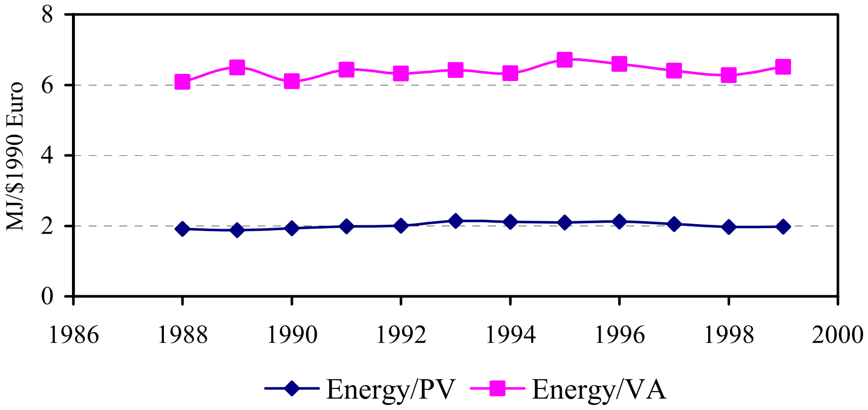
Figure 2.9 Developments of energy consumption for the Dutch non-energy intensive sector by kind of fuel.



2.4.1 Energy intensity

Figure 2.10 shows the developments in average energy intensity for the non-energy intensive sector between 1988 and 1999. A quick glance at the Figure indicates that energy intensity has increased (by 6% in the case of energy per value added, or by 2% for energy per unit of production value), a fact that is reflected in most of the sub-sectoral results (of the 55 NEI sectors studied as non-energy intensive, only 18 showed some decrease in their energy intensity).

Figure 2.10 Energy intensity developments for the Dutch non-energy intensive sector.



2.4.2 Decomposition analysis

From our definition of the non-energy intensive sector, we know that energy costs in the sector are minimal (<3%), so minimal that a deteriorating or static energy efficiency is perhaps possible although hard to rationalize. Could the lack of improvement on energy intensity be due to structural effects (industrial mix)? In order to single out the energy intensity from other effects we use the Multiplicative Log-Mean Divisia Method I described already in the methodology section. The changes in the observed energy consumption and aggregated energy intensity and the relative contribution of the structure, intensity and production effects are plotted in Figures 2.11 to 2.16. In these Figures a value of one means that the variable has no impact on aggregate energy intensity/consumption, a value over one indicates a contribution to higher aggregate energy intensity/consumption and a value below one indicates a decline. Note that a decrease in aggregate energy intensity is interpreted as an increase in energy efficiency.

- *Energy intensity approach:*

Figures 2.11 to 2.13 depict the results for the decomposition of aggregate energy intensity, electricity intensity and fuel intensity using value added and value of production as the economic measures of output.

There is a remarkable increase in the values between 1992 and 1993, especially when value of production is used as measure of economic output. The main explanation for this change can be attributed to the fact that CBS adopted a new classification in 1993. Although we checked the sub-sectors at the 3-digit level to minimize the impact of the change in classification, the effect is nevertheless evident at the sector level. However, it is worth pointing out that although the magnitude of the change is questionable, already in 1992, that is before the change in classification, there was evidence of an increase in both overall energy intensity and electricity intensity (independently of the use of value added or value of production as the measure of economic output).

The decomposition of energy intensity shows that:

- In general, intensity effects dominated over structural effects, and hence the increase of aggregate energy intensity was primarily caused by an *increase* in the intensity and not by changes in structure (although structural changes tended to reduce aggregate energy intensity, they had a negligible effect).
- Structural effects had only a major role for fuel intensity, and only if value added is used as the measure of economic output. In this case structural shifts caused aggregate energy intensity values to be lower than the sectoral energy intensity would suggest. In all the other cases, shifts in industrial structure had a minor role in limiting increases in energy intensity.

- The use of value added as economic measure of output tended to amplify structural effects.

    - *Energy consumption approach:*

Changes in primary energy consumption and the relative importance of aggregate energy intensity and production effects are plotted in Figures 2.14 to 2.16. In all cases both production effects (D_{pdn}) and intensity effects (I_{agg}) contributed to higher total primary energy consumption. However, the Figures illustrate quite clearly that growth in output was the main driving force that increased primary energy consumption in the Dutch non-energy intensive sector.

Figure 2.11 Decomposition of aggregate energy intensity for the Dutch non-energy intensity sector into structural (d_{str}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output.

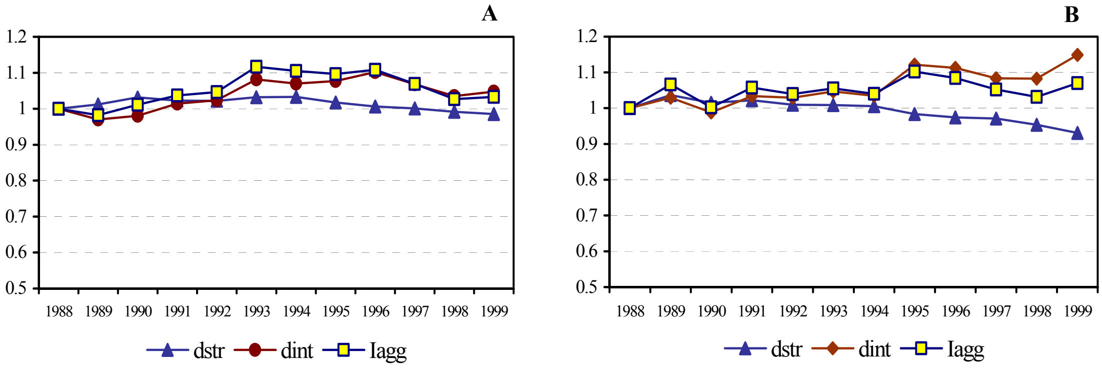


Figure 2.12. Decomposition of aggregate electricity intensity for the Dutch non-energy intensity sector into structural (d_{str}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output.

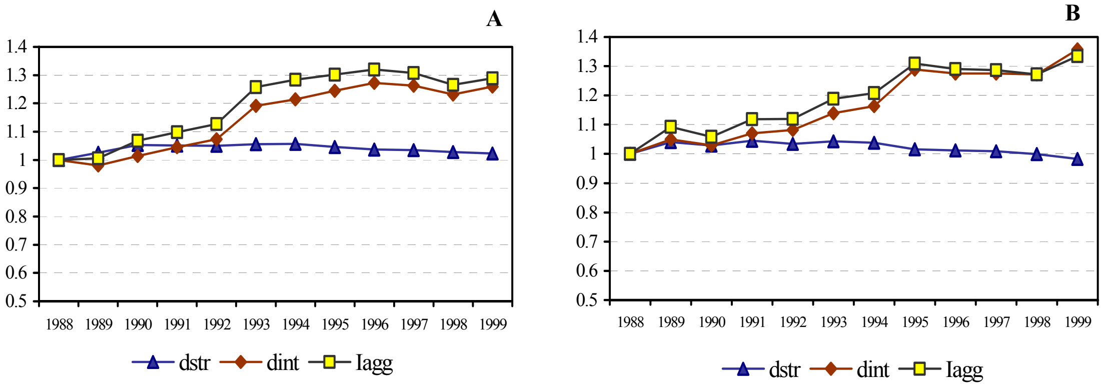


Figure 2.13 Decomposition of aggregate fuel intensity for the Dutch non-energy intensity sector into structural (d_{str}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output.

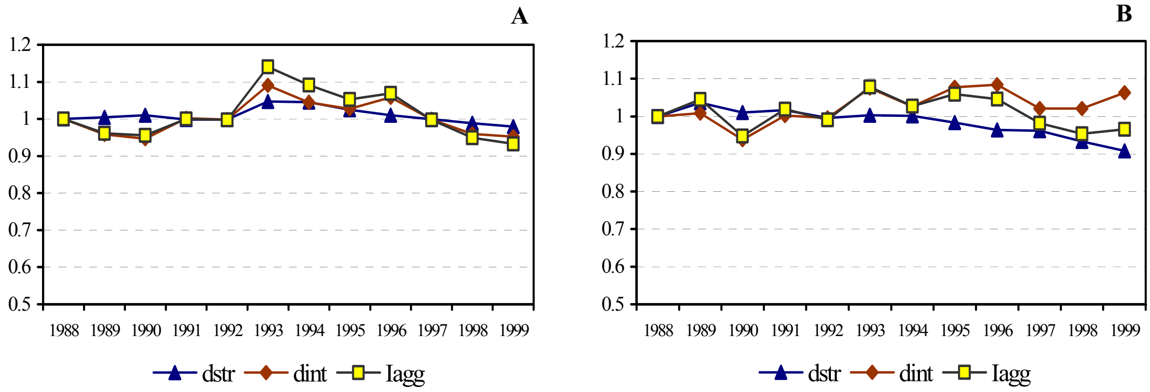


Figure 2.14 Decomposition of overall energy consumption for the Dutch non-energy intensity sector into production (d_{pnd}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output.

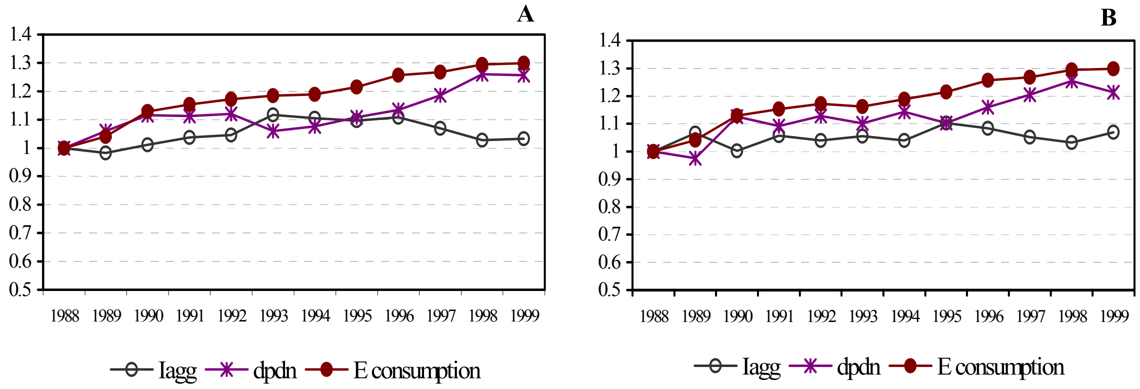


Figure 2.15 Decomposition of overall electricity consumption for the Dutch non-energy intensity sector into production (d_{pnd}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output .

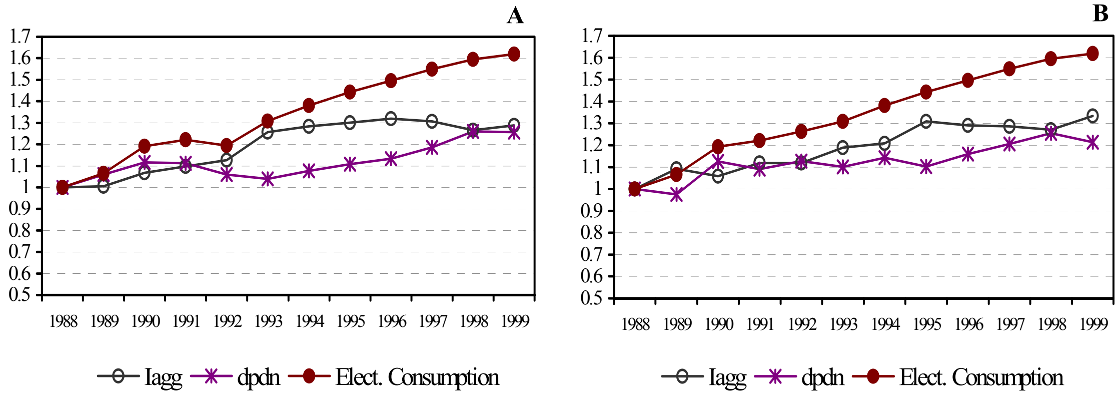
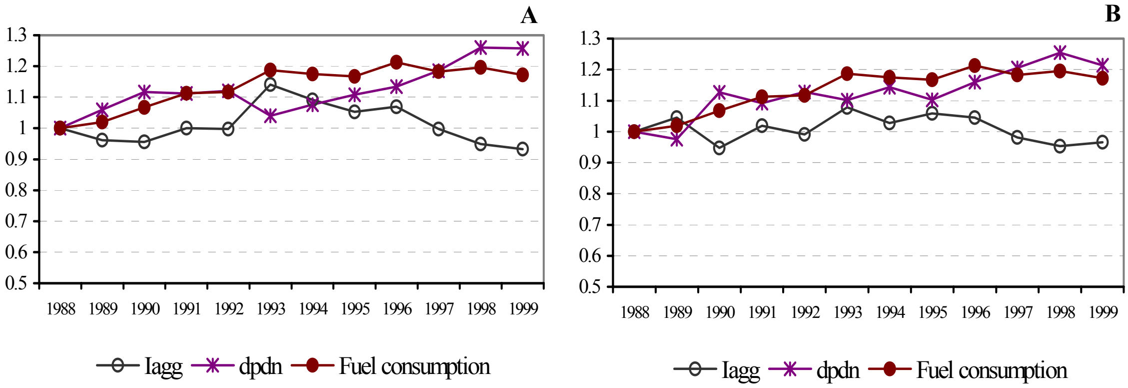


Figure 2.16 Decomposition of overall fuel consumption for the Dutch non-energy intensity sector into production (d_{pnd}) and intensity (d_{int}) effects. (A) Using PV as measure of economic output. (B) Using VA as measure of economic output.



2.5 Discussion of results

So far, our results show that the non-energy intensive sector has increased its energy consumption by 30% in a 12 year period (1988-1999), that output growth has added further energy requirements to those induced by energy intensity, and that the role of structural changes has been minor. The results are troublesome and we will use this section to discuss the plausibility of our results. In order to do so, we analyze the use of VA or VP as the measure of economic output, the relation between energy consumption and manufacturing output, the impact of fuel substitution and of energy prices.

- **Use of VA vs. VP.** As shown throughout this chapter, the value added based intensity indicators is somewhat more sensitive to changes in economic environment than the intensity based on production value (a way of measuring this sensibility is to calculate coefficient of variations. The average coefficients of variation for the energy intensity indicators between 1988 and 1999 found for the non-energy intensive sector were 13% for energy per unit of value of production and 18% for energy per unit of value added). Although the use of production value could be problematic because of double counting, its use helps to avoid short-term fluctuations and hence provides a better picture of energy intensity developments for the non-energy intensive sectors. Taking this into account, we can therefore conclude that between 1988-1999 the non-energy intensive sector has shown a slight increase in energy intensity (2%)[12].

- **Relation energy and manufacturing output**. NEIs are expected to play an important role in reducing the aggregate energy intensity of industry in the long term because of their economic importance and relatively high growth rate. One means of clarifying the relationship between manufacturing output and

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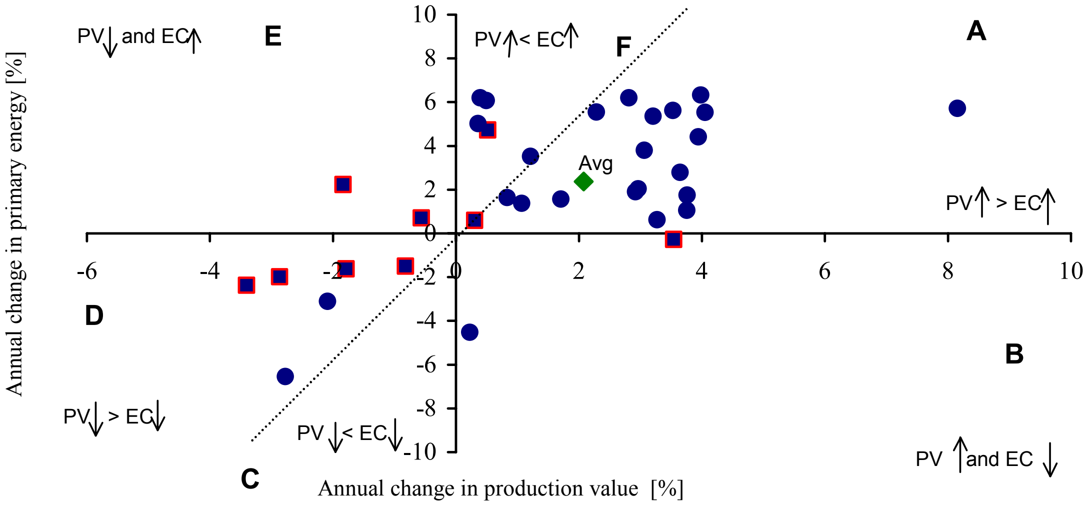
[12] If VA were used as the measure of economic output, the increase would be three times that of PV (6%).

energy consumption is to compare the growth rates of both variables, since this allow us to analyze the link between output and energy [Park et al., 1993]. Figure 2.17 plots this relationship. A 45° diagonal line divides the graph, each part showing different combinations of primary energy consumption and production value growth rates.

Although, non-energy intensive sectors can be found in five of the six zones, which can be explained from the heterogeneity of the group, the majority of the sectors as well as the sector's average are found in zone A, this mean that the production value grew faster than the primary energy consumption. In the figure, we have plotted with square dots those sectors that are relatively more energy intensive within the non-energy intensive sector. Calls the attention that most of these sectors are located on what can be called less efficient zones of energy use (value of production decreases at a faster rate than energy consumption). It should also be pointed out the low amount of sectors located in the zone showing a decoupling of energy and output (Zone B). Thus, we can conclude that due to the existing strong link between energy and output in the Dutch NEI, and if no changes in the trends occur, this sector will in the future help to increase, not decrease, energy consumption in the Netherlands.

Figure 2.17 Cross-sectoral comparison of growth rates on primary energy consumption and value of production for non-energy intensive sectors, 1988-1999.

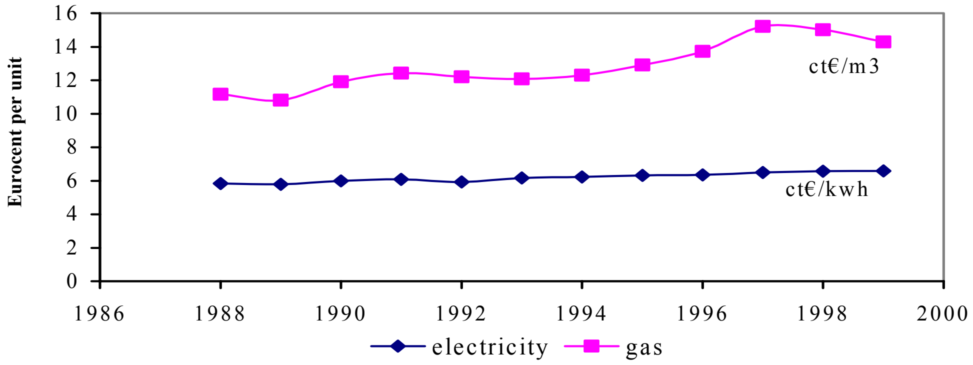


Note: Zones A, B, and C represent an efficient use of energy (note that zone B represents what is generally known as a decoupling of energy and manufacturing output). Zones D, E, and F suggest less efficient use of energy. Square dots show the most intensive sub-sectors.

- **Substitution of fuels**. In terms of TFC, natural gas kept a constant share in the 12 year period (62%), while there was an increase in electricity (7%) and 'other fuels' decreased its share by the same amount (Figure 2.9). The increasing growth of electricity and the decreasing trend showed by other fuels point towards a substitution effect that has resulted in an increase of PE use. However, since the share of 'other fuels' was already small in 1988 (11% of TFC, 7% of PE), and natural gas kept been the predominant fuel source (62% of TFC), the impact of the substitution of 'other fuels" by electricity in the aggregate energy intensity has been minor[13].

- **Energy prices**. Figure 2.18 shows the developments in average price of electricity and natural gas for the NEIs between 1988 and 1999. Natural gas prices have shown a relative increase of about 25% (12% for electricity). Have these increases of the prices of natural gas and in minor way in electricity, affected the energy consumption of the non-energy intensive sector? The general hypothesis is that an increase in energy price promotes a decrease on energy consumption, since they motivate improvements in process efficiency and contribute to shifts in output mix. Our results show that despite the increases on fuel prices, electricity has grown at a steady pace while consumption of natural has kept a constant share. Hence, the sector seems to remain relatively insensitive to changes in energy prices. This could be explained by the low share of energy costs and the fact that increases in energy prices, on what is already a small bill, seem not to promote per se changes in energy efficiency.

Figure 2.18 Energy price developments for the Dutch non-energy intensive sector.



2.6 Conclusions

In this chapter, we have focused our attention on a sector that has been often neglected from the analysis of energy consumption for the manufacturing sector, namely the non-energy intensive sector. One question behind this research was to analyze if the lack of attention paid to the energy extensive sector is justified. The answer is no. In the last decade, this sector has increased its energy consumption by 30% and shown a slight increase in aggregate energy intensity (2%). By decomposing the effects of changes in industrial production, structure and energy intensity, we found that a) the increase in aggregate energy intensity shown by the

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[13] A decomposition analysis was performed using TFC. The contribution of intensity and structure to the aggregate energy intensity was found to remain practically the same ($Dstr_{1988\text{-}1999}$: 0.99; $Dint_{1988\text{-}1999}$: 1.04)

sector is mainly the result of ‘real’ increases in energy intensity and not by structural changes, and b) output growth has added further energy requirements to those induced by energy intensity. An analysis of production value and energy consumption growth rates points out the strong existing link between manufacturing output and energy consumption in the non-energy intensive sector. All these points are of particular concern because they indicate that current energy policies have failed to improve energy efficiency in the non-energy intensive sector. Given these trends the non-energy intensive sector should be considered a key target area for reduction of carbon dioxide emissions.

Furthermore, the low energy costs within the non-energy intensive sector have important implications for energy policy instruments. Although little is known about the adoption of energy technologies and management practices in non-energy intensive sectors, it has already been underscored that cost-saving energy conservation proposals addressing a relatively small cost category and perceived as risky and capital intensive, may be uninteresting to managers and that, the size of energy bill may greatly influence investment decisions connected with energy conservation [Gillisen et al., 1995]. Further research is needed in this area. We need to identify and understand the barriers that are preventing the adoption of energy efficient technologies and management practices in the non-energy intensive sector.

Acknowledgements

The authors give special thanks to Mr. Wouter Tinbergen from CBS for his help on gathering and interpreting the data.

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Appendix 1. List of industrial sectors at the 2-3 digit level.

15	Manufacture of food products and beverages
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 oils 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
17	Manufacture of textiles
171	Preparation and spinning of textile fibres
172	Textile weaving
173	Finishing of textiles
174	Manufacture of made-up textile articles, except apparel
175	Manufacture of other textiles
176	Manufacture of knitted and crocheted fabrics
177	Manufacture of knitted and crocheted articles
18	Manufacture of wearing apparel; dressing and dyeing of fur
181	Manufacture of leather clothes
182	Manufacture of other wearing apparel and accessories
183	Dressing and dyeing of fur; manufacture of articles of fur
19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, and footwear
191	Tanning and dressing of leather
192	Manufacture of luggage, handbags and the like, saddlery and harness
193	Manufacture of footwear
20	Manufacture of wood and of products of wood and cork, except furniture
201	Sawmilling and planning of wood; impregnation of wood
202	Manufacture of veneer sheets; manufacture of plywood, laminboard, particle board, fibre board
203	Manufacture of builders' carpentry and joinery
204	Manufacture of wooden containers
205	Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting
21	Manufacture of pulp, paper and paper products
211	Manufacture of pulp, paper and paperboard
212	Manufacture of articles of paper and paperboard
22	Publishing, printing and reproduction of recorded media
221	Publishing
222	Printing and service activities related to printing
223	Reproduction of recorded media
23	Manufacture of coke, refined petroleum products and nuclear fuel
231	Manufacture of coke oven products
232	Manufacture of refined petroleum products
233	Processing of nuclear fuel
24	Manufacture of chemicals and chemical products
241	Manufacture of basic chemicals
242	Manufacture of pesticides and other agro-chemical products
243	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
244	Manufacture of pharmaceuticals, medicinal chemicals and botanical products
245	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes preparations
246	Manufacture of other chemical products
247	Manufacture of man-made fibres
25	Manufacture of rubber and plastic products
251	Manufacture of rubber products

252	Manufacture of plastic products
26	Manufacture of other non-metallic mineral products
261	Manufacture of glass and glass products
262	Manufacture of non-refractory ceramic goods other than for construction purposes
263	Manufacture of ceramic tiles and flags
264	Manufacture of bricks, tiles and construction products, in baked clay
265	Manufacture of cement, lime and plaster
266	Manufacture of articles of concrete, plaster and cement
267	Cutting, shaping and finishing of stone
268	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
271	Manufacture of basic iron and steel and of ferro-alloys (ECSC)
272	Manufacture of tubes
273	Other first processing of iron and steel and production of non-ECSC ferro-alloys
274	Manufacture of basic precious and non-ferrous metals
275	Casting of metals
28	Manufacture of fabricated metal products, except machinery and equipment
281	Manufacture of structural metal products
282	Manufacture of tanks, reservoirs and containers of metal; manufacture of central heating
283	Manufacture of steam generators, except central heating hot water boilers
284	Forging, pressing, stamping and roll forming of metal; powder metallurgy
285	Treatment and coating of metals; general mechanical engineering
286	Manufacture of cutlery, tools and general hardware
287	Manufacture of other fabricated metal products
29	Manufacture of machinery and equipment nec
291	Manufacture of machinery for the production and use of mechanical power, except aircraft,
292	Manufacture of other general purpose machinery
293	Manufacture of agricultural and forestry machinery
294	Manufacture of machine-tools
295	Manufacture of other special purpose machinery
296	Manufacture of weapons and ammunition
297	Manufacture of domestic appliances nec
31	Manufacture of electrical machinery and apparatus nec
311	Manufacture of electric motors, generators and transformers
312	Manufacture of electricity distribution and control apparatus
313	Manufacture of insulated wire and cable
314	Manufacture of accumulators, primary cells and primary batteries
315	Manufacture of lighting equipment and electric lamps
32	Manufacture of radio, television and communication equipment and apparatus
33	Manufacture of medical, precision and optical instruments, watches and clocks
331	Manufacture of medical and surgical equipment and orthopaedic appliances
332	Manufacture of instruments and appliances for measuring, checking, testing, navigating
333	Manufacture of industrial process control equipment
334	Manufacture of optical instruments and photographic equipment
335	Manufacture of watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment
36	Manufacture of furniture; manufacturing nec
361	Manufacture of furniture
362	Manufacture of jewellery and related articles
363	Manufacture of musical instruments
364	Manufacture of sports goods
365	Manufacture of games and toys
366	Miscellaneous manufacturing nec
37	Recycling

Part II

Developing physical energy efficiency indicators in the food industry

CHAPTER 3

From Fluid Milk to Milk Powder. Energy Use and Energy Efficiency in the European Dairy Industry[*]

Abstract

In this chapter we conduct a cross-country analysis of energy consumption and energy efficiency for the dairy industry of four European countries. Changes in energy efficiency were monitored in two different ways. First, by looking at the energy use by tonne of milk processed (EEI_{p1}). Secondly, 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}). The latter indicator 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 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 industry have converged towards similar (lower) values in their energy efficiency indicators and that the French dairy industry would save 30% if it were to converge to similar values of EEI_p as the ones reached by Germany or the United Kingdom.

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[*] *Co-authors: M. Patel and K. Blok.*

3.1 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) [European Commission, 2004]. A list of the most important dairy products is shown in Box 3.1 while Figure 3.1 depicts a schematic overview of the main processes in the dairy sector. Interestingly, and despite the strong role that energy plays (it is by heat treatment that bacterial growth is controlled and the shelf life of milk and milk by-products prolonged), energy only accounts for a limited share of total production costs (1-3%) [Ramírez et al., 2005].

Several studies have examined energy consumption in the dairy industry [e.g. SVEN, 1983; Miller, 1986; Kjaergaard-Jensen, 1999; Arcadis, 2000], in individual dairy products [e.g. Okoth, 1992; Zaher, 1997; NDC, 2001] and technologies [e.g. Molinari et al., 1995; Asly, 1999; Sandu and Singh, 1991; Hvid, 1992]. 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. Korsström and Lampi, 2002; European Commission, 2003]. 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 at an aggregate level. Finally, energy is also one of the categories studied in life cycle analyses (LCA) of the dairy industry [e.g. Høgaas, 2002; Sonesson and Belin, 2003], individual dairy products [e.g. Belin, 2002] and processes [e.g. Eide, 2003]. However, the role of energy during processing is rather small, and thus the results obtained from these kind of analysis do not provide enough information that allow to understand 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 study 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 production of dairy products (Figure 3.2). 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.

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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.

Box 3.1 Dairy products

- *Liquid milk*: can either be pasteurized (72ºC for 15 sec), sterilized (115ºC for 20 min) or long-life milk (treated from 1-4 sec to 138 to 150ºC 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: products 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: has a high degree of acidity and is not subjected to a proteolytic ripening process.
  - Processed cheese: 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: is the liquid residue of cheese and casein production.
    - Whey powder (WP)
    - Whey protein concentrate (WPC)
    - Partially demineralised whey powder: WP which is 25-30% demineralised.
    - Demineralised whey powder: WP which is 90-95% demineralised.
    - Lactose
  - Caseines: is the major protein in cow's milk and comprises about 80% of the total protein content.
  - Anhydrous milk fat: contains at least 99.8% of milk fat.

Figure 3.1 The dairy industry.

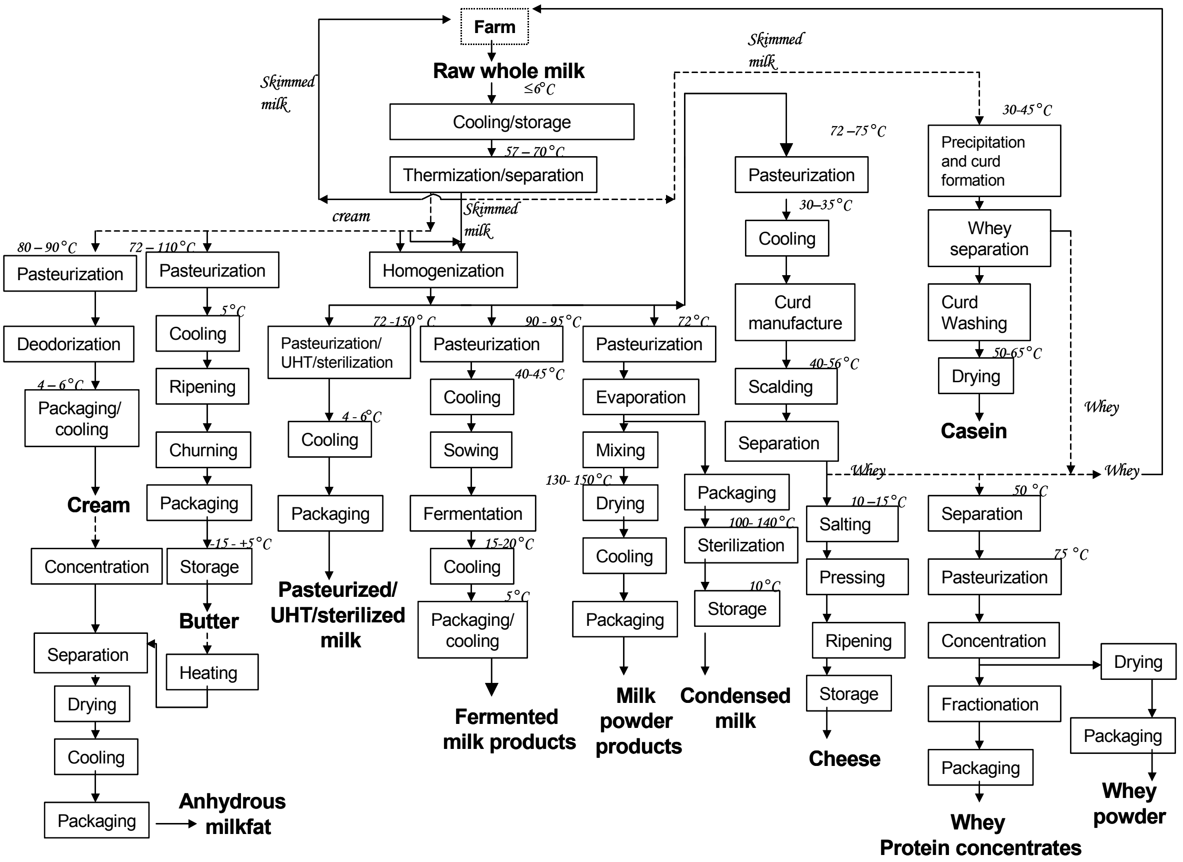
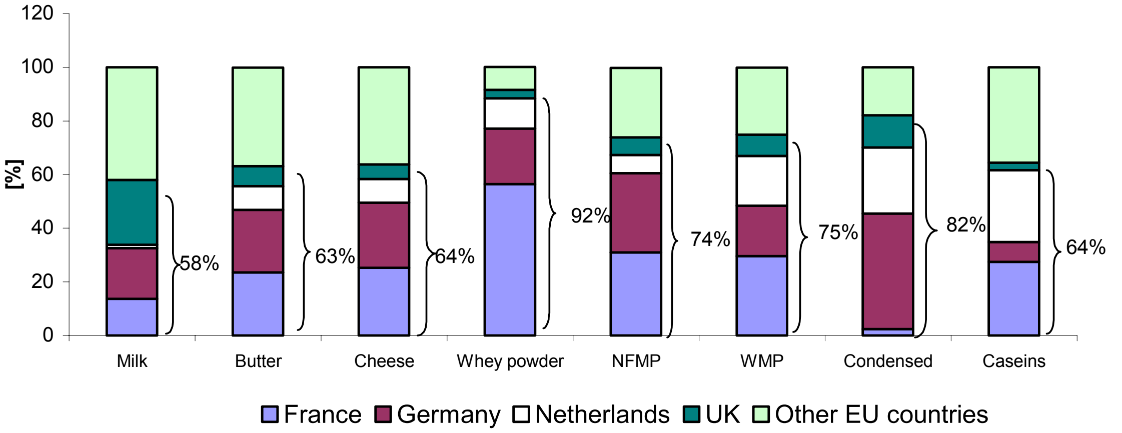


Figure 3.2 Share of dairy production in the European Union by type of product, 2002.



Note: Whey powder percentages are given for the year 2000; NFMP stands for non fat milk powder while WMP stands for whole milk powder.
Data source: Eurostat

3.2 Methodology

Changes in energy efficiency can be monitored by examining energy use by unit of activity. In this chapter 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 (equation 3.1). 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., [1998] and Farla [2000], 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 energy efficiency development). The frozen efficiency development is calculated by using time series of production (in physical terms, e.g. tonnes of cheese) and 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 that it corrects for differences in product mix in various countries and years (equation 3.2). 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 equations 3.3 and 3.4.

$$EEI_{1,j} = \frac{E_j}{MD} \qquad \text{(Eq. 3.1)}$$

$$EEI_{2,j} = \frac{E_j}{\sum m_i \times SEC_{ref\ i,j}} \qquad \text{(Eq. 3.2)}$$

$$EEI_{p_1} = \frac{\sum E_j \times f_j}{MD} \qquad \text{(Eq. 3.3)}$$

$$EEI_{p_2} = \frac{\sum E_j \times f_j}{\sum m_i \times (SEC_{ref\,i,j} \times f_j)} \qquad \text{(Eq. 3.4)}$$

In which:

j = Type of fuel (i.e. electricity, fossil fuels/heat).

EEI_1 = Energy efficiency indicator for fuel *j* based on raw milk processed (MJ/tonne).

E_j = Energy consumption of the dairy sector for fuel *j* (Megajoule).

MD = Raw milk delivered to dairies (in tonnes).

EEI_2 = Energy efficiency indicator for fuel *j* based on final product (dimensionless).

m_i = Physical production of key product *i* (tonnes).

$SEC_{ref,i}$=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} = Primary energy efficiency indicator based on raw milk processed (MJ/tonne).

EEI_{p2} = Primary energy efficiency indicator based on final product (dimensionless).

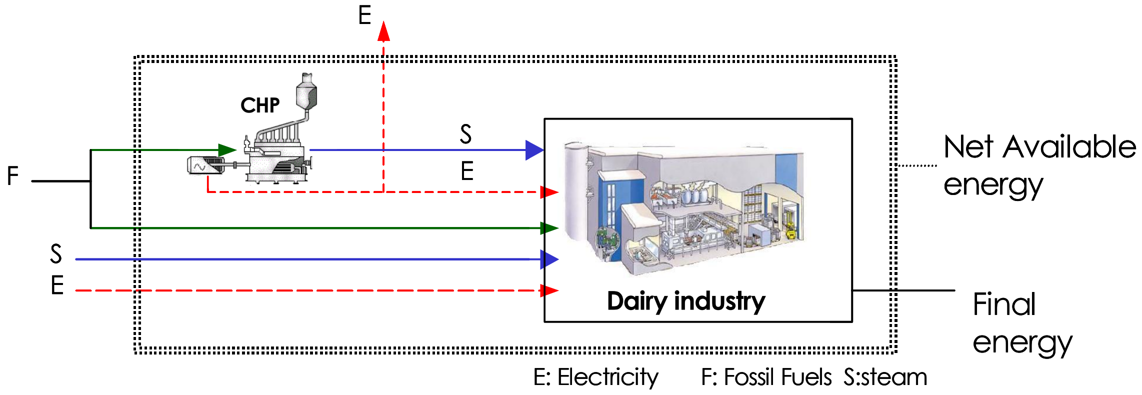
f_j= Conversion factor from fuel *j* for final use to primary energy.

3.3 Data

The time period covered in this chapter was determined by the availability of *detailed* net available energy consumption data (see Figure 3.3). For France the analysis covers the period 1986-2000 [Agreste, annual publication-a], for the Netherlands 1989-2000 [Novem, 2001], for the United Kingdom 1990-2000 [DTI, 2000], and for Germany it is restricted to 1993-2000 [Statistisches Bundesamt, annual publication-a]. 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.

To obtain reliable time series of physical production was a time intensive task. We relied primarily on sources from industrial associations and statistical offices of the individual countries[3]. In order to ensure that fluctuations in the series were the result of real changes in the production patterns and not the result of errors in data reporting, we used international data sources for crosschecks (e.g. FAOSTAT database, United Nations) and conducted interviews with experts from the dairy industry, industrial associations and statistical offices.

Figure 3.3. System boundaries



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)[4]. Since in this chapter we work with net calorific values[5], we correct the British and German energy (which are based on gross calorific values)

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[3] Agreste, annual publication-b; CBS, annual publication-b; Productschap Zuivel, annual publication; Zentrale Markt- und Preisberichtstelle, annual publication; Onilait, 1997; UK National Statistical Office, annual publication; La Maison du lait, online database; Defra, online database; Statistisches Bundesamt, annual publication-b.

[4] We maintain the electricity generation efficiency constant in order to exclude differences in power generation 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.

[5] 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.

with the following net/gross ratios: 0.95 for coal and oil and 0.9 for natural gas[6]. We correct energy consumption data for changes in climate using the Eurostat temperature correction method[7].

3.4 Developments in the dairy industry

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 (Figure 3.4). In the four countries studied production of bulk dairy products (butter and non-fat milk powder) has decreased in the last fifteen years, while production of high-value added products (cheese, whey powder and ice cream) has increased. The United Kingdom stands out for the high proportion of raw milk which is directed towards bulk products compared with the other countries[8] (Table 3.1). We can 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 UHT milk (Table 3.2), and c) a trend towards milk drinks, fermented products and desserts.

Table 3.1 Percentage of utilization of raw milk in dairies by type of product and country, 2001.

Milk product	France [%]	Germany [%]	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.

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[6] These are the factors used by the International Energy Agency [2002], and the IPCC guidelines [2002].

[7] 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 [Brook, 2001]. Based on data published by Arcadis [2000] we have assumed a share of 20% of fossil fuel use for space heating. Strictly speaking, we should also apply a temperature correction method to the share of energy used for cooling and freezing. Nevertheless, since data to make such correction are not available (e.g. cooling degree days, share of electricity dependent on temperature, etc.), such correction is not made in this chapter.

[8] The liquid milk market is the single largest outlet for the UK produced milk.

Figure 3.4. Production trends for dairy products (values have been indexed to 1990).

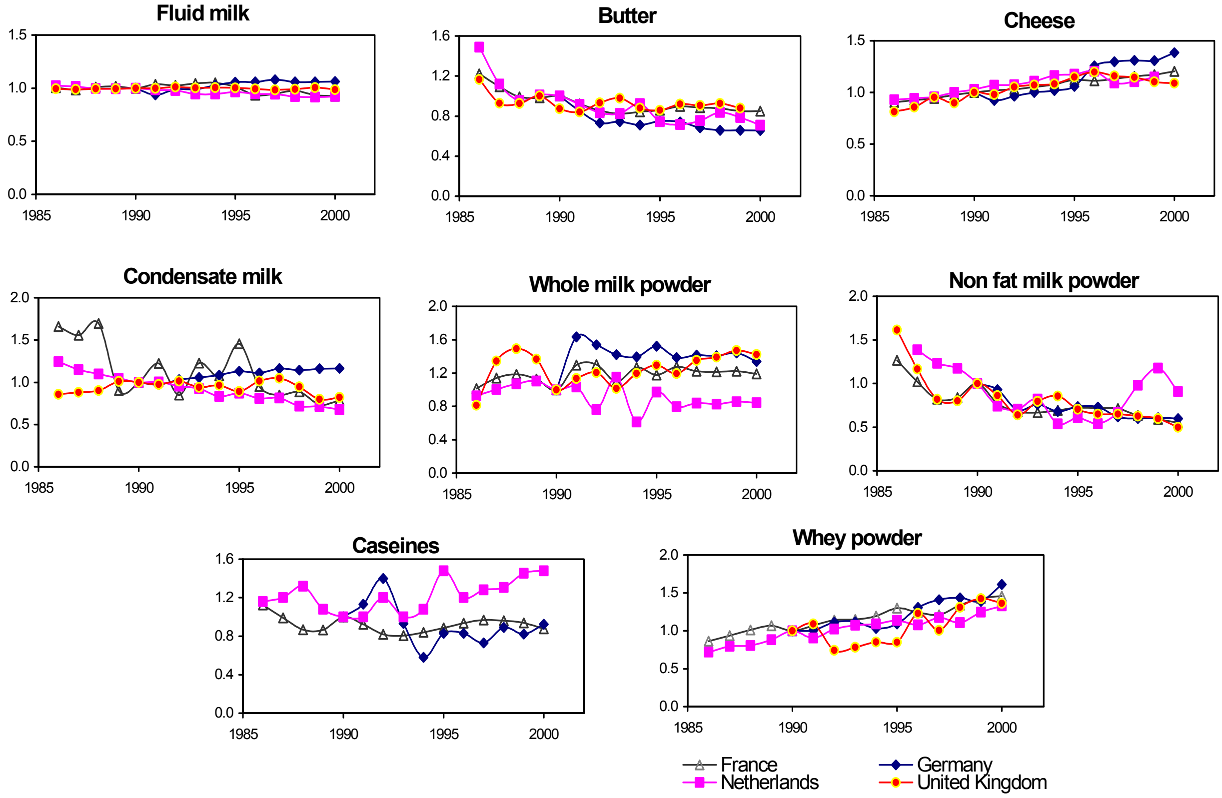

Table 3.2 Distribution of milk production by thermal treatment per country (in percent).

Milk	**1990**			**2000**		
Type/country	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
The 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
The 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
The 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
The 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.

Butter is a product which has shown a decrease followed by stagnation in production over the last fifteen years (Figure 3.4). 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 non-fat milk powder (NFMP)) in relation to the price of other major dairy products [Golman, 1995]. 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 [Onilait, 1997]). The decrease in production has been controlled by EU programs which subsidized butter and helped to keep the market stable[9]. 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 [Richards, 1997]. 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[10] restrictions (e.g. since 1996, export subsidies for 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 [Bessey et al., 2001]).

The declining trend for non-fat milk powder (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 [Golman, 1995]. 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[11]. Finally, there has been a substitution of NFMP by other cheaper proteins sources[12]. One of these is whey. Production of dry whey as by-product of cheese 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

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[9] 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) [European Court of Auditors, 2000].

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

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

[12] 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.

been driven by the increasing production of cheese[13], the environmental concerns associated with disposing of whey into streams or sewage plants, and the acknowledgement of the nutritional benefits of whey proteins [Bessey et al., 2001].

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[14]. In the Netherlands, for instance, production is almost entirely driven by export demand (domestic consumption is mainly limited to usage in the chocolate industry)[15].

Besides the change in consumption patterns, there has 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 3.3 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.

Table 3.3 Development of the structure of dairies companies in four European countries.

Country	**Number of dairies**	**Average milk input per dairy (1000t)**	**Number of dairies**	**Average per dairy (1000t)**	**Number of dairies**	**Average per dairy (1000t)**
	1985		**1991**		**2000**	
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
United Kingdom	336	45.4	340	41.5	102	105

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

3.5 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,

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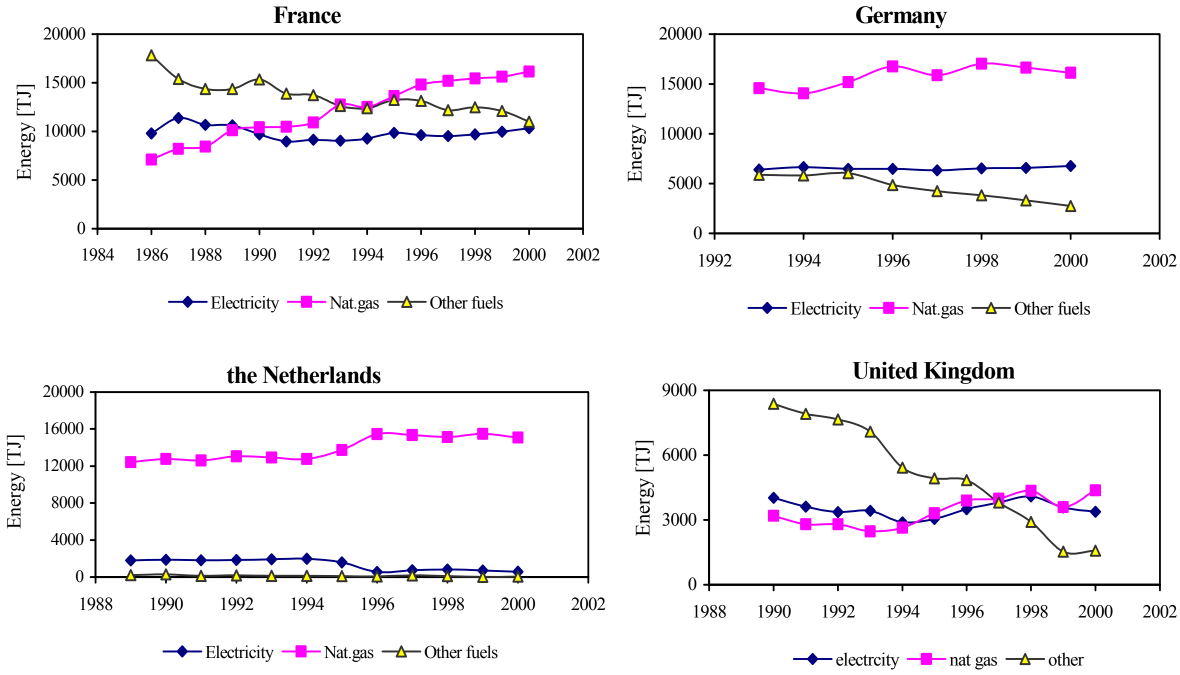
[13] In cheese production only 10 to 15% of the milk is actually converted into cheese, the remainder is whey.

[14] 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.

[15] The market share of the Netherlands decreased from about 8% of the world production in 1980 to about 3% by 2000 [Gould and Villareal, 2002].

Germany, the Netherlands and the United Kingdom respectively. Figure 3.5 shows the trends in the consumption of *final* energy by kind of fuel and country[16]. The fuel mix breakdown shows that fuel mix in the dairy industry has strongly shifted in the period studied: the share of natural gas 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" [IEA, 2000]. Furthermore, our choice of system boundaries (Figure 3.3) implies that electricity produced by cogeneration (CHP) is not taken into account as electricity but only as fuel. Hence, a higher auto production of electricity by the Dutch dairy industry[17] 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 were 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.

Figure 3.5 Trends in final net energy consumption in the dairy industry by type of fuel per country.



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[16] In terms of primary energy, electricity accounts for over 40% of the energy used.

[17] This point is further discussed in Section 3.7.

Figure 3.6 depicts trends in the use of fossil fuels in the British dairy industry. The 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[18] 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 prices decreased 36%, industrial coal prices decreased by 40% while industrial fuel oil prices have increased by 23% [DTI, 2000]. Fuel switching has contributed substantially to the decrease of total CO_2 emissions in the British, German and Dutch dairy industry (Figure 3.7). In France, the increased energy consumption of the sector has offset the benefits obtained from fuel switching resulting in comparable CO_2 emissions in 1990 and 2000[19].

Figure 3.6 Final energy consumptions of fossil fuels in the dairy industry of the United Kingdom.

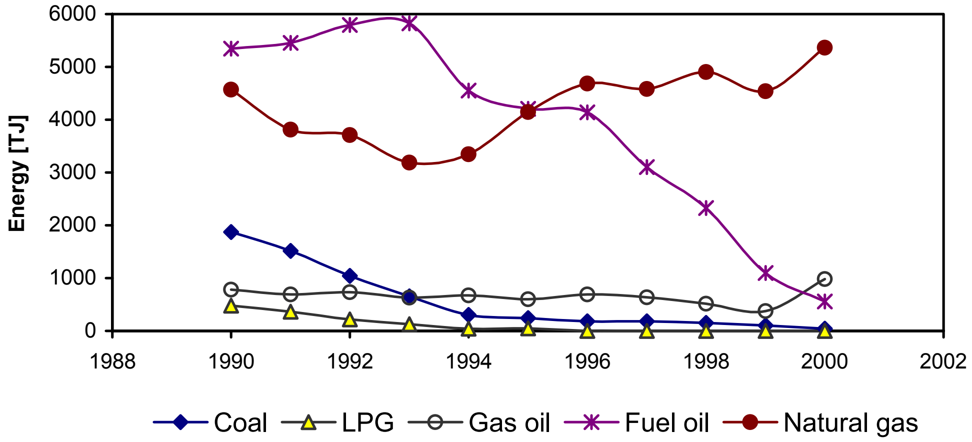
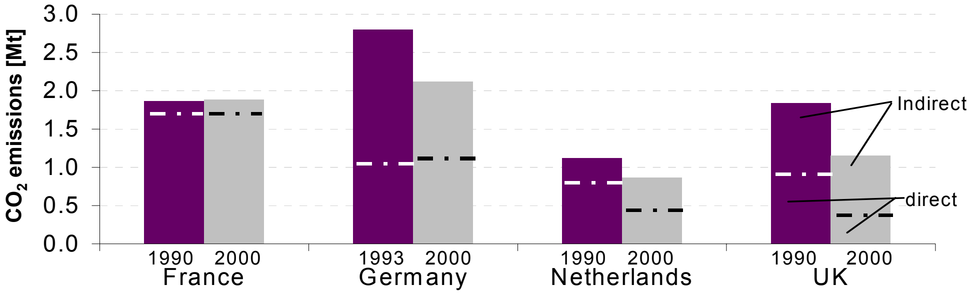


Figure 3.7 CO_2 emissions of the dairy industry.



Note: the dotted line divides the direct emissions of CO_2 as a consequence of fuel burning in the dairy industry from the indirect emissions caused by electricity consumption. CO_2 emmissions are calculated using the following IPCC carbon emmission factors: 25.8 tC/TJ final energy for coal and coal products, 20 tC/TJ for crude oil and petroleum products, 17.2 tC/TJ for natural gas liquids and petroleum products, 0 tC/TJ for biomass and, 15.3 tC/TJ for natural gas. Indirect CO_2 emmissions are calculated for each country and year using fuel mix inputs for electricity generation and electricity output published in the IEA energy balances.

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[18] 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.

- *Energy use in main dairy operations*

As shown in Figure 3.1, heating and cooling treatments are a fundamental part of dairy processing. Table 3.4 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.

Table 3.4 Average percentage of primary energy demand for selected products 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 [2000]

Heat treatment: The most common thermal process is pasteurization (thermal inactivation of microorganisms at temperatures below 100ºC). Other processes are sterilization (115-120ºC, 20-45 min), UHT treatment (165-140ºC, few seconds), radiation with UV, high-pressure process (40-60ºC, 2000-6000bar) 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

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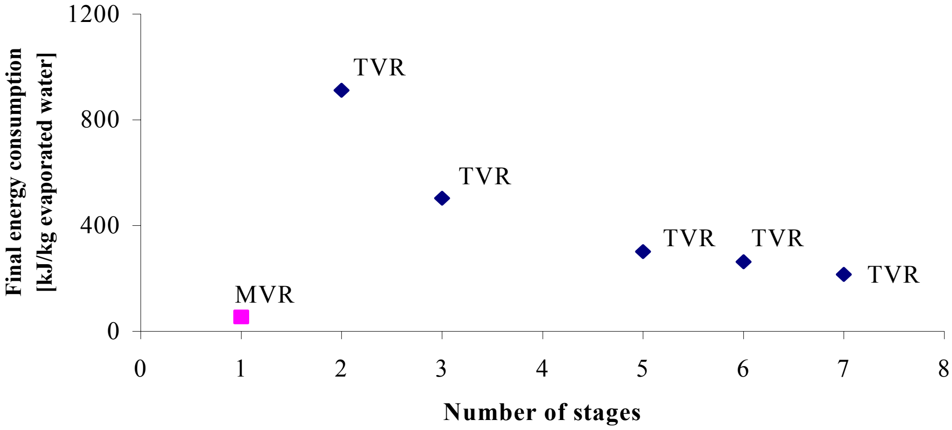
[19] The small share of indirect CO_2 emissions is a reflection of the French nuclear power based energy generation.

organoleptic conditions of milk are considered the main barriers for their implementation [Spreer, 1998]. 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 five months. Nowadays, pasteurization consumes only a slight amount of energy (heat recovery between 90-94% is regarded as optimal). UHT and sterilisation are far more energy consuming than pasteurisation. In sterilisation the temperature is much higher, and in general the temperature difference between the heat source and milk to be sterilised has to be much greater than in pasteurization [Hvid, 1992]. The increasing tendency to produce UHT milk rather than pasteurised liquid milk (see Table 3.2) has meant that production of fluid milk demands more energy per litre of product.

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[20]. 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)[21]. Nowadays, most new evaporators are equipped with MVR [European Commission, 2003]. Typical final energy requirements per kilogram of water evaporated are shown in Figure 3.8. 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 [GEA, 2003].

Figure 3.8 Final energy consumption in stage evaporators.



Note: data based on values reported by EC,2003

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[20] In this kind of evaporator, milk passes through steam-heated tubes under vacuum. Boiling takes place at temperatures between 65-75ºC.

[21] 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.

Compared with evaporation, concentration by membrane filtration demands significantly smaller amounts of energy[22] (0.014-0.036 MJ per kg water removed [Hvid, 1992]). 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%[23]. 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 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 50000 m^2 [Tholen, 1995].

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) and 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 [Hvid, 1992]: 1-stage 4.9 MJ /kg water evaporated; 2-stage: 4.3 MJ/kg; 3-stage 3.4 MJ/kg.

Table 3.5 shows a rough estimate of the amounts of water evaporated during concentration and drying for the year 2000. Assuming that the average evaporator used for milk concentration has 6 stages with TVR [Arcadis, 2000] and that for drying a 2-stage spray dryer is used [Korsström and Lampi, 2002], 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.

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 is associated with operation and cleaning of milk pasteurization plants [Sandu and Singh, 1991]). Cleaning in place causes a large part of the operating costs, especially in evaporators and dryers where it can account for up to 70% [de Jong and Verdumen, 2001], and 10% to 26% of the energy use for processing [Arcadis, 2000]. Table 3.6 shows the energy consumption by cleaning cycle for different processes. Most of the energy required for cleaning uses temperatures of 65-75ºC. One of the consequences of the high-energy

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

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

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 [Høgaas, 2002].

Table 3.5 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 assumed 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 3.6 Energy requirements of cleaning in place.

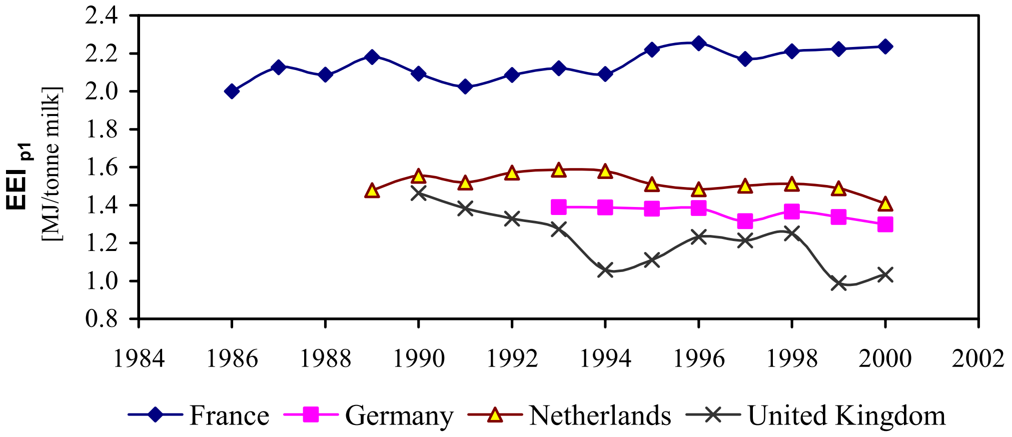
Equipment	**Thermal energy requirement to clean [MJ/cleaning cycle]**
Cream separation	0.25-0.31
Milk pasteurization	0.14-0.3
Heat treatment of cream	0.1-0.5
Skim-milk evaporation	6.8-28.1
Skim milk drying	1.0-2.0

Source: Spreer [1998].

3.6 Understanding energy efficiency developments

We use Equations 3.1 and 3.2 as described in Section 3.2 to monitor changes in energy efficiency in the dairy industry. The first indicator, EEI_{p1}, is straightforward to calculate. Our results (Figure 3.9) show that with exception of the British dairy industry (which declined the use of energy per tonne of milk processed at an average rate of 3.2% p.a.), improvements in the indicator have been either minor, as in the Dutch and German industry (< 1% p.a.), or not existing (the French dairy industry increased the values of the indicator by 0.7% p.a.). However, EEI_{p1} does not take into account the differences in production mix among countries and time; the changes showed in Figure 3.9 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).

Figure 3.9 Developments in EEI_{p1} by country.

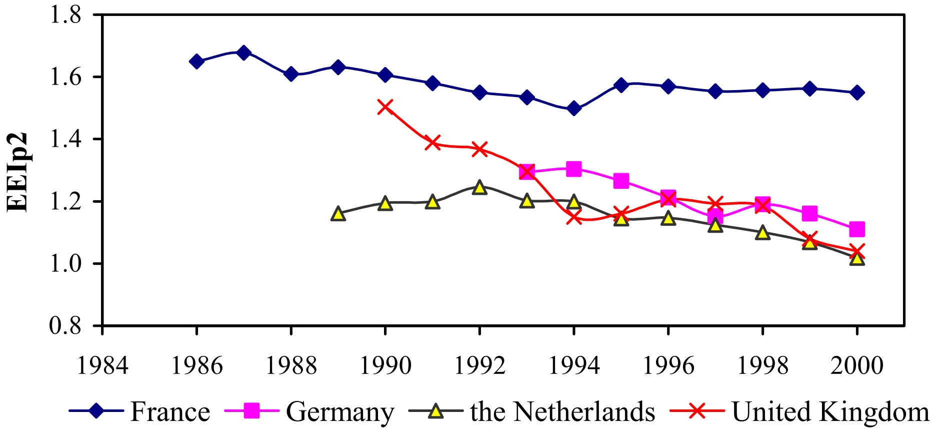


For calculating EEI_{p2} we selected as key products: fluid milk, fermented products (yoghurt, cream, desserts, buttermilk), cheese (fresh, processed cheese and quark), butter, milk powder (whole milk powder, non fat milk powder, semi-skimmed milk powder, buttermilk powder, cream powder), condensate 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 [Arcadis, 2000]. Table 3.7 shows the SEC_{ref} used in this chapter while Figure 3.10 depicts the results from applying Equation 3.4. 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.

Table 3.7. Chosen Reference Specific Energy Consumption values (SEC_{ref}) by sector in primary energy (Typical technologies for late 1990s).

Dairy Product	*Chosen SEC_{ref} [TJ/tonne product]*
Liquid milk & fermented products	1.1
Cheese	4.8
Butter	2.2
Milk Powder	12.1
Condensate milk	2.7
Whey products (powder)	11.7
Caseins & lactose	5.8

Figure 3.10 Developments in EEI_{p2} by country.



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 3.4 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 3.1). Since these products demand the least energy during processing (Table 3.7), 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 [Stace, 2003]. A study on the British dairy industry highlights the period 1993-1997 as a significant period of restructuring and investment in production capacity [MDC, 2003]. 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 1992-2000) are: a) the voluntary agreements between the dairy industry and the Dutch government[24], b) the rationalization process, and c) the increasing use of CHP[25]. 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.

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[24] In 1992, industrial sectors and the Dutch Ministry of Economic Affairs signed a covenant which aimed to improve 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.

[25] Combined heat and power (CHP) systems is the combine production of electrical (or mechanical) and useful thermal energy from the same primary energy source.

Indicators can also be developed by type of fuel (Equations 3.1 and 3.2). Table 3.8 shows the annual percentage change in EEI_2 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 (Figure 3.3). 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 communications 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 CHP [Stace, 2003; Gardiner, 2003]. 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 [Agreste, several years], the value for the Netherlands is 49%[26]. These data point towards a much higher penetration rate of CHP in the Netherlands than in France and the UK (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[27]). 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 physical 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 (i.e. more application of CHP units).

Table 3.8 Average annual changes in EEI_2 by fuel and country.

EEI	**France[a]**	**Germany[b]**	**Netherlands[c]**	**United Kingdom[d]**
	Average annual change (in percentage)			
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

The main unexpected result so far is that France has not only the higher values in the indicators and 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.

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[26] This value has been calculated based on data published in [Novem, 2001].

[27] 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.

3.7 Reliability of the results

In order to understand if 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 chapter (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 chapter are consistent in terms of system boundaries and product definition. Hence, we are confident that this factor 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 Table 3.9[28]). We found that the production mix in France and Germany is quite alike despite differences in their EEI_{p2} values 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[29]. If indirect UHT is applied, the SEC_{ref} value is almost the same as the SEC for pasteurization ($SEC_{ref,pasteurized}$: 782 MJ/tonne; $SEC_{ref,\ indirect\text{-}UHT}$: 784 MJ/tonne[30]) 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 ($SEC_{ref,direct\text{-}UHT}$: 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 [Arcadis, 2000; Hvid, 1992]. 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 3.9, 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 (Figure 3.13) by only 1%.

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[28] Categories such as caseins and lactose were not further decomposed due to lack of data.

[29] UHT milk can be processed using direct or indirect UHT treatments. In direct UHT, milk is heated from 75ºC to 135ºC by steam injection. Indirect UHT is basically the same process as pasteurization, but the operating temperature is higher. Indirect UHT is more 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 [European Commission, 2003]).

[30] We have used data published by Hvid [1992] to replace the pasteurization step used in Arcadis [2000] which is the source used to calculate EEI_{p2} in section 3.6.

We then turn our attention to the difference in cheese production found between Germany and France (Table 3.9). 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 not large enough to explain the higher EEI_{p2} values shown by France. They also confirm that the selection of products made in 3.6 does cover main differences in production mix among the countries.

Table 3.9 Detailed distribution of dairy products by type and percentage, year 2000.

Product	Germany	France	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*
Yoghurt & 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; [a]: e.g. Edam, Gouda; [b]: e.g. Camembert, Brie, etc.; Source: Own calculations based on data published by La Maison du Lait.

But if the results obtained are not the consequence of methodological flaws, then there are real differences in energy efficiency that places 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 to compare EEI_p at the subsectoral level (i.e. 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 (Arcadis, 2000)). The results of applying Equation 3.4 to each branch are shown in Table 3.10. The French dairy industry appears with higher values of EEI_p in each case. This gives us confidence that the higher EEI_{p2} for France is caused by real differences in energy efficiency. We further explore this point in the next section.

Table 3.10 EEI_p values at the subsectoral level for the French and Dutch dairy industry in 1998.

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

3.8 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, and differences in technologies (including the penetration of CHP, which we have already discussed).

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 3.4), it is important to look whether the pace of overall 'rationalisation' 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 (Figure 3.11). This is very likely to have important technology implications[31], and one cannot fail to notice that a) the ranking in values shown in Figure 3.11 for the year 2000 is in quite good harmony with size (Netherlands >Germany, United Kingdom> France) and b) the gap in the cumulative distributions

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[31] 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 are 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 [MDC, 2003].

of dairy companies between France and the other countries (Figure 3.11) 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 3.10). 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 specialisation. This is particularly valid for the production of specialised 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[32] 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 spend resources in energy management, and d) scale advantages would occur (e.g. less boundary losses).

Capacity Utilization. Another factor which can affect the amount of energy used per unit of output is the capacity utilization (e.g. data for a milk powder plant shows that its specific fuel consumption increased by 7% when production throughput decreased 12% [Cox, 1986]). Capacity utilisation (CU) provides an indication of how efficiently plant and equipment is utilised. While difficult to quantify accurately, and since there is a lack of official information, we have used monthly data to calculate a rough estimate (Equation 3.5). Results are shown in Table 3.11. 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.

$$CU_i = \frac{AP_i}{\left(MP_{\max,i} \times 12\right)} \times 100 \qquad \text{(Eq. 3.5)}$$

Where:

CU_i= Capacity utilization of sector i (in percentage).
AP_i= Annual production of product i (in tonnes).
$MP_{\max,i}$= Peak month production of product i (in tonnes).

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[32] A Canadian study on fluid milk plants shows that dairies producing between 20-50 million litres of milk per year consume 30% more energy (in final terms) than dairies producing between 50-100 million litres [NDC, 2001]. Similarly a Norwegian study on industrial milk production shows that small dairies consumed about 55% more energy (in final terms) than large dairies [Høgaas, 2002].

Figure 3.11 Cumulative distribution of dairy companies by country in the year 2000.

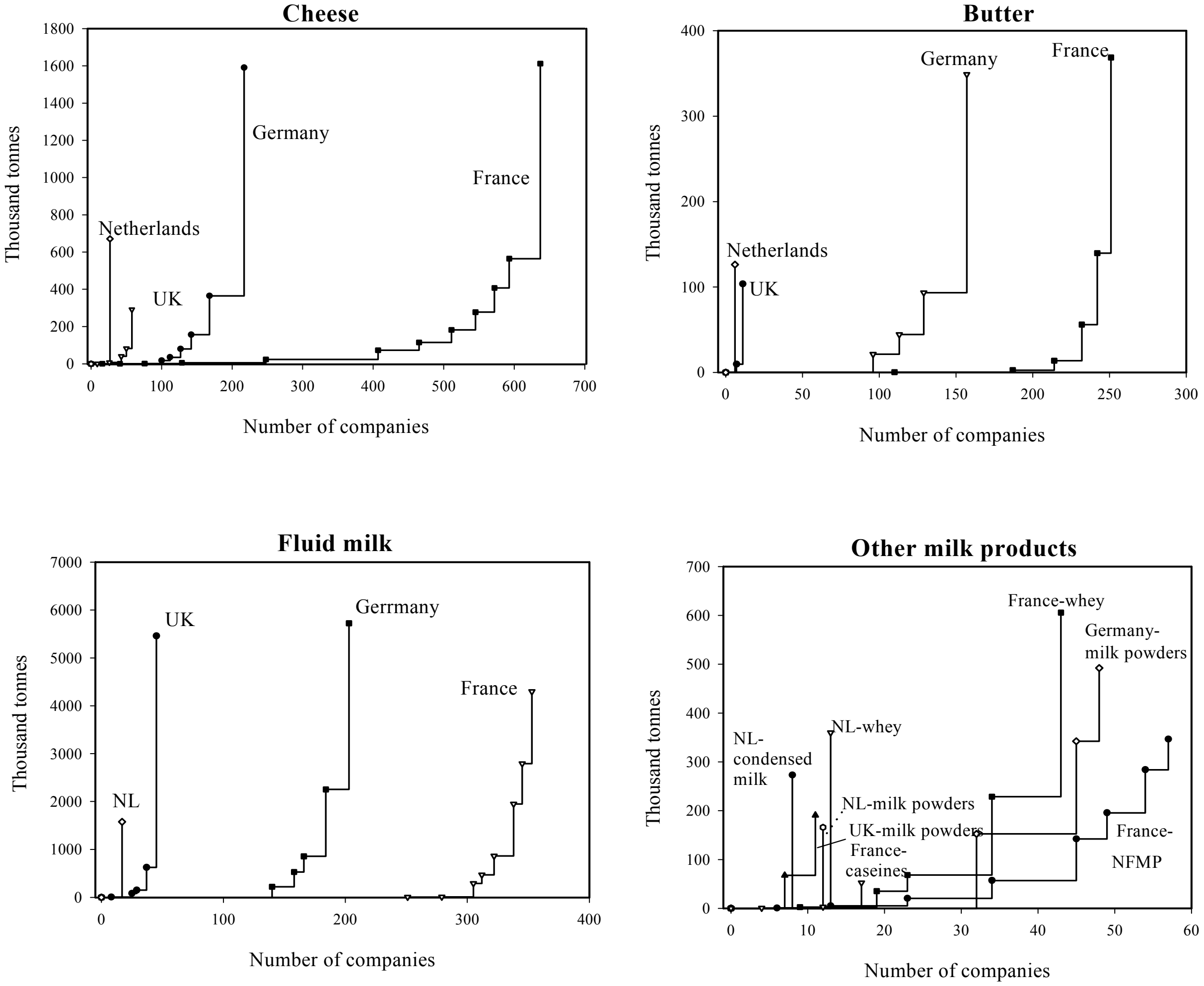


Table 3.11. Approximated capacity utilization by country and product for the year 2000, in percentage.

Product	France	Germany	Netherlands	United Kingdom
Liquid milk	90	92	95	96
Butter	84	86	86	89
Cheese	91	93	97	81
Condensed milk	71	95	95	84
NFMP	67	85	81	78
WMP	82	84		64
Whey powder	n.a	90	88	n.a

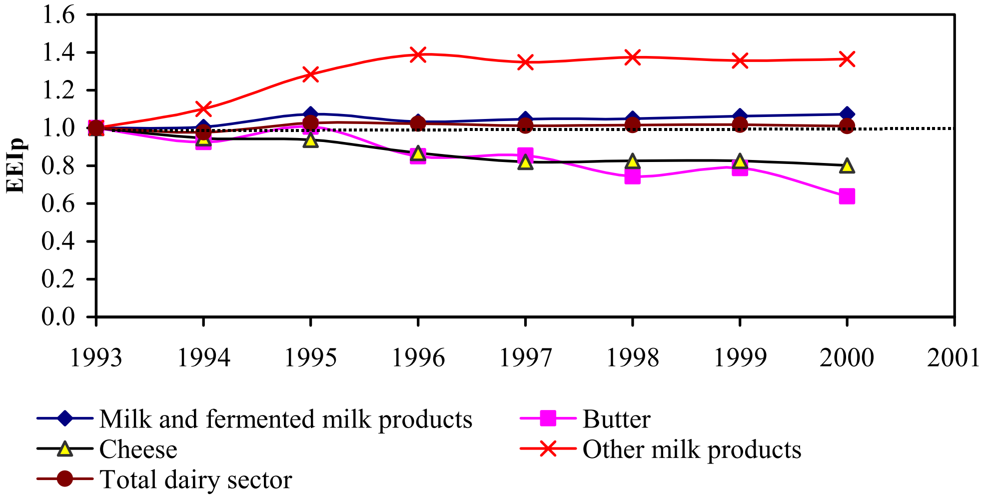
Source: Own calculations based on monthly production data published by industrial associations.

Differences in technologies. Another possibility to take into account is that France could be using more energy intensive processes. For example, in Table 3.5 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'[33] shown in Table 3.10. Unfortunately, we did not find information to explore the differences in technologies 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 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 subsector (e.g. cheese or milk powder) is responsible for the increase/decrease in the EEI_{p2} of the whole dairy industry. The results (Figure 3.12) indicate that the cheese and butter sectors have, in fact, decreased substantially 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 1993-1996. At the level of data presently available it is not possible to quantify the cause of the increases during this period.

Figure 3.12 Developments in EEI_p in the French dairy industry by branch.



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[33] "Other milk products" is composed of dairy products which are essentially the result of concentration and drying processes (Figure 3.1).

3.9 Conclusions

In this chapter 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 industry 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 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.

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CHAPTER 4

How Much Energy to Process One Pound of Meat? A Comparison of Energy Use and Physical Energy Intensity in the Meat Industry of Four European Countries*

Abstract

In this chapter we have used energy and physical production data to develop energy efficiency indicators for the meat industry of France, Germany, the Netherlands and the United Kingdom for the last 15 years. The meat industry comprises the production and preservation of meat plus the further processing of meat products. In the year 2001 the meat industry of these countries demanded about 116 PJ of primary energy. 40-60% of this amount was used in the further processing of meat products. We found a trend in all countries towards higher electricity use due to increasing demands for refrigeration and motor drive power generation. Furthermore, our results show a significant increase in primary energy use per tonne of product (France: 3.2% p.a., Germany: 3.4% p.a., the Netherlands: 1.4% p.a., and the United Kingdom: 1.6% p.a.). In order to understand the drivers behind the trends, factors such as the share of frozen products, the share of cut-up products and increasing food hygiene measures were analysed. We found that strong hygiene regulations can explain between one and two thirds of the increase while the role of increasing shares of frozen and cut fresh meat is found to be not significant.

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4.1 Introduction

The increasing importance of energy efficiency has been highlighted by the Intergovernmental Panel on Climate Change (IPCC) in its last report when stating that “almost all greenhouse mitigation and concentration stabilisation scenarios are characterized by the introduction of energy efficient technologies for both energy use and supply” and that “improvement of energy efficiency of industrial processes is the most significant option for lowering greenhouse gas emissions” [Metz et al., 2001: 8; 38]. However, developing and implementing policies that effectively promote energy efficiency require a thorough understanding of the economic, technical and behavioural drivers underlying energy consumption trends. Until recently most in-depth energy analyses for the manufacturing sector focussed on energy intensive branches (e.g. steel, petrochemical, aluminium) while disregarding non-energy intensive sectors (e.g. food, textiles, machinery). There are three main reasons for this. First of all, significant reductions in energy consumption (and CO_2 emissions) can be achieved by focussing on a few energy intensive sectors. Secondly, also due to their high energy consumption, detailed information on energy use is available and finally, the diversity of key products, technologies and processes in energy intensive sectors is fairly limited, which implies that meaningful analyses can be prepared without going into too much detail. Contrarily, a key feature of non-energy intensive sectors is their heterogeneity. It is therefore not a straightforward task to identify from an extensive list of products, processes and technologies, the ones that have enough explanatory power with regard to energy efficiency; and even when this is clear, there is often a lack of reliable data which would be required to develop consistent time series and cross-country comparisons.

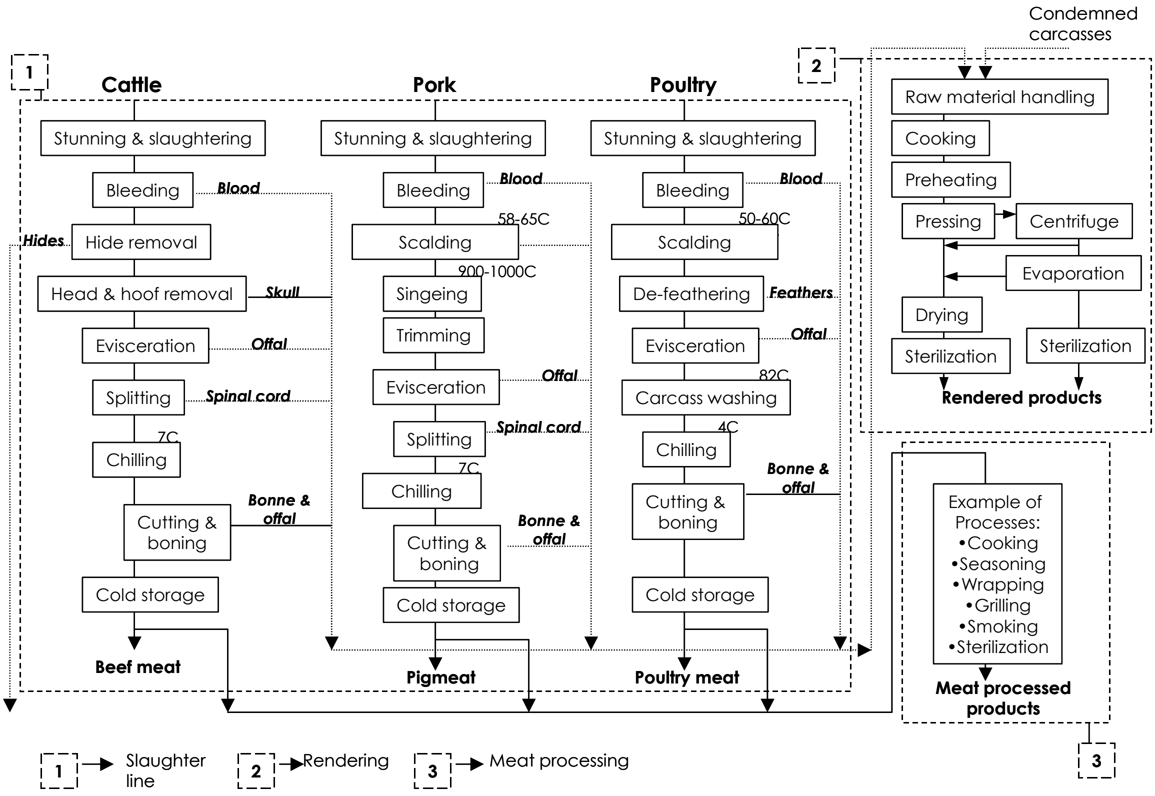
A related important issue is the choice of the indicator used when monitoring energy efficiency developments in the manufacturing sector. The use of energy per unit of output is the most common indicator for assessing trends and developments in energy efficiency. Given the large variety of products in the non-energy intensive sectors the simplest and therefore preferred approach when analysing non-energy intensive sectors, is to use economic values as the measure of output (i.e. energy per unit of production value or value added). It is, however, questionable whether economic-based energy efficiency indicators are a good measure for changes in technical energy efficiency [Freeman et al., 1997; Price et al., 1998]. Therefore, energy efficiency indicators based on physical amounts of output (i.e. energy per tonne) are often mentioned as the most reliable indicators to provide estimates of changes in energy efficiency [e.g. Freeman et al., 1997; Farla, 2000; Hyman and Reed, 1995; Nanduri et al., 2002; Phylipsen et al., 1998].

Against this background, and taking into account new developments such as the European Union draft directive on energy end-use efficiency and energy services which has as one of its main target groups non-energy intensive sectors [European Commission, 2003a], the main focus of this chapter is to conduct a comparatively assessment of energy efficiency indicators in a selected non-energy intensive sector:

the meat sector. The meat sector (NACE 151)[1] comprises the production and preservation of beef, sheep, goat and pork meat (NACE 1511), poultry meat (NACE 1512) plus the further processing of all types of meat, e.g. the production of sausages or ham and intermediate products like plasma and animal fat (NACE 1513). Production refers here to slaughtering; rendering and meat processing and storage (see Figure 4.1) while husbandry activities and retail are not included.

The goal of this chapter is twofold. First, we want to examine patterns of production and energy use in the meat sector of four European countries: France, Germany, the Netherlands and the United Kingdom. Secondly, we examine whether it is feasible to develop physical based energy efficiency indicators and we examine their strength.

Figure 4.1 Process flow diagram of the meat sector.



4.2 Data

One of the critical points, as well as the most time consuming, when constructing indicators is data gathering. This section provides an overview of the data sources used in this chapter. The time period covered in this study was determined by the availability of consistent and disaggregated *energy* data. Hence, for the Netherlands and France, the analysis covers the period 1986-2001 while it is restricted to 1990-

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[1] NACE is the classification of economic activities in the European community. Statistical data is generally reported according to this classification.

2001 for the United Kingdom, and 1993-2001 for Germany[2]. Data for earlier years would have been available for Germany but have been proven to be unreliable and inconsistent due to different reporting systems and economic systems prior to reunification.

Unless indicated otherwise, energy data in this chapter refers to primary energy. To this end, the contribution of electricity to primary energy demand has been calculated by multiplying the electricity end use by 2.5 (corresponding to a 40% electricity generation efficiency)[3]. In this chapter we work with net final energy data, hence, the electricity values used correspond to the electricity bought from the grid minus the electricity sold by the industry. Energy data reported by France and the Netherlands represent net calorific values (NCV), while the British and German data is based on gross calorific values (GCV)[4]. We have adjusted the British and German energy data to a NCV basis by using the net/gross ratios that are also applied by IPCC [2002] and the International Energy Agency [2002]: 0.95 for coal and oil and 0.9 for natural gas. We have also corrected the energy figures for climate influences using the Eurostat temperature correction method[5] (assuming a heating share of 20% based on data published in European Commission [2003b] and Infomil [1996]).

Time series for physical production data were developed using data provided by national statistical offices and by industrial associations. Amounts of slaughtered meat were calculated from information on slaughterings and average dress carcass weights. Amounts of further processed meat products were taken from national Prodcom statistics[6], which are based on industrial sales figures. Additionally, interviews with experts from industrial associations and statistical offices and international databases (e.g. the FAOSTAT data base and Industrial commodity statistics of the United Nations) were used for closing data gaps and for crosschecks.

4.3 Production developments in the meat sector

Meat production in the countries studied has increased between 5-13% in the last decade. The production structure, however, has changed substantially, with a shift

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[2] Data was taken from the statistical offices CBS (Netherlands), Agreste (France), Department of trade and industry (UK) and Statistiches Bundesamt (Germany).

[3] We 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.

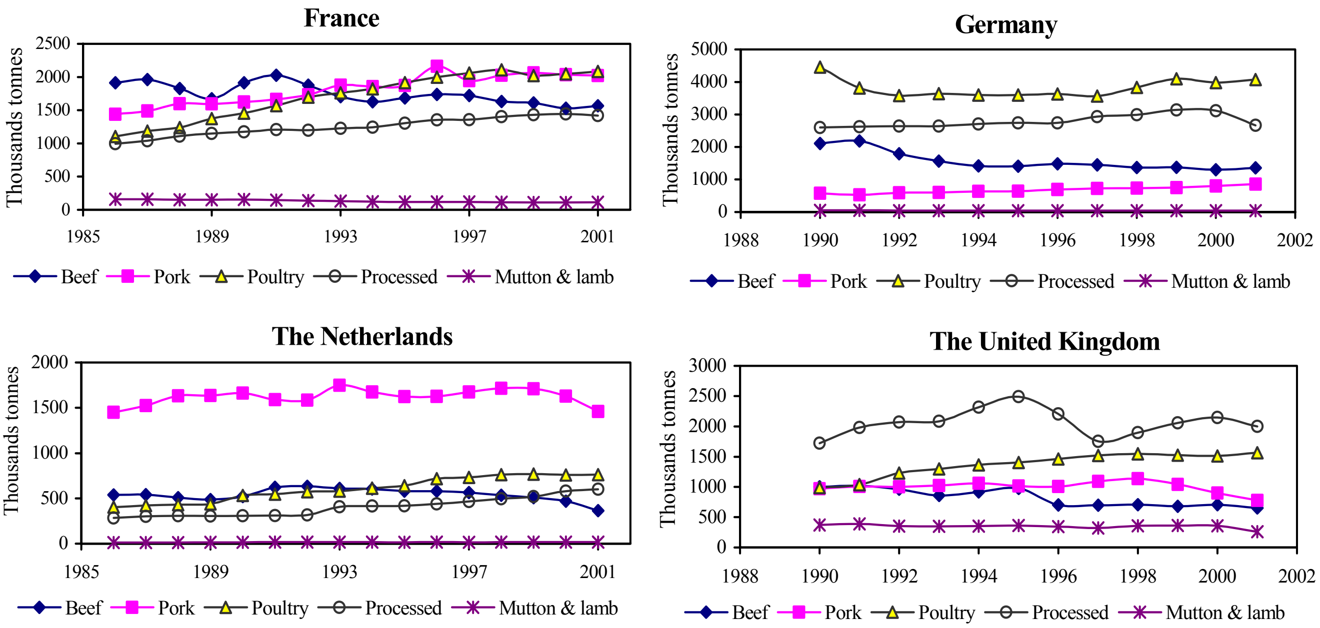
[4] The difference between NCV and GCV is the latent heat of vaporisation of the water produced during the combustion of the fuel. NCV excludes this heat.

[5] The 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]. Strictly speaking, we should also apply a temperature correction method to the share of energy used for cooling and freezing. Nevertheless, since data to make such correction are not available (e.g. cooling degree days, share of electricity dependent on temperature, etc.), such correction is not made in this chapter

[6] PRODCOM is the European community's classification for production statistics.

away from red meats towards white meats (especially poultry) and processed meat products (Figure 4.2). The declining trend in beef production has several causes. First of all, the decreasing status of meat and its declining nutritional significance together with the damage of public confidence in beef due to food scandals[7] have accelerated existing trends towards what is perceived as a healthier meat: poultry [Belker et al., 1998; European Union, 2001; European Commission, 1997]. Another cause of the decline is a side effect of the milk quota system established by the European Union. Since beef production is based for the greater part on the dairy industry[8] the decrease in cattle and increase of milk efficiency per cow, which allows farmers to fill their milk quota with fewer cows, have resulted in less available cattle for slaughter.

Figure 4.2 Trends in meat production by country.



France **Germany** **The Netherlands** **The United Kingdom**

Contrary to the developments observed for beef production, and despite the food scandals, poultry and pork production have increased in the last decade. Nevertheless, the growth rate of pork production has fallen behind the increase showed by the poultry sector. In the Netherlands, for instance, two main reasons can be identified: a) low producer prices (for poultry) and, b) the new legislation for animal husbandry (environmental measures) which has mainly consequences for pork production. These measures (e.g. restrictions on the number of pigs held per farm) are an attempt of the Dutch government to respond to public concerns for animal welfare, intensive livestock farming and the current manure surplus problem

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[7] For instance: E.coli in beef trimmings, the use of hormones in cattle, the Bovine Spongiform Encephalopathy (BSE) crisis in the UK, the Creutzfeld-Jakob disease (vCjd) and the mouth & foot disease.

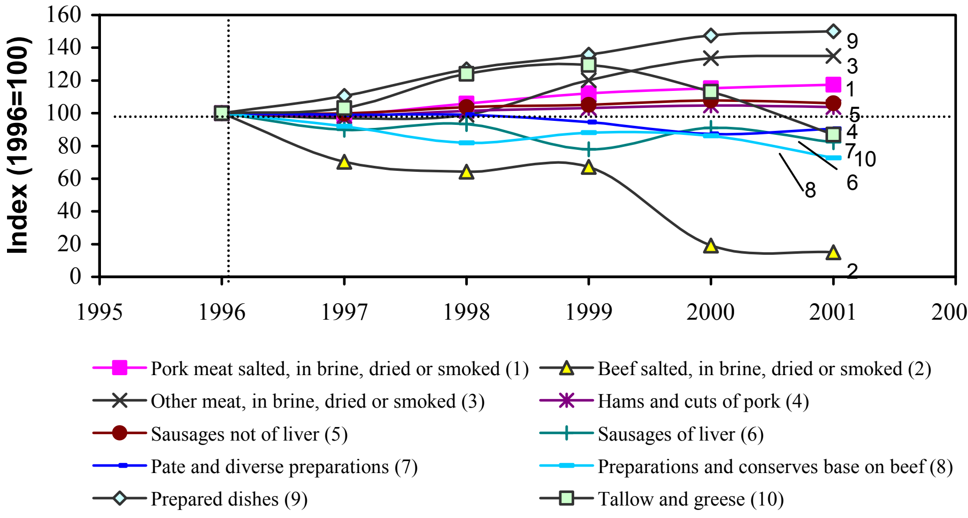
[8] In 1995, 43% of Dutch beef and veal production came from culled dairy cows [Langezaal and Grolman, 1995]. In the UK the percentage was about 60%: 41% from the dairy herd and 22% from culled cows [BSE enquire, 2000].

and have led to the reduction of the pig stock. Furthermore, outbreaks of swine vesicular disease in 1994 and 1997 further diminished the Dutch pig stocks.

Poultry production, on the other hand, has in fact benefited from the red-meat crisis. As noted above, people perceive poultry as healthier than beef or pork: poultry meat is considered by consumers as being lighter and having a lower fat content. Besides, the increase in poultry is in part due to the fact that poultry production allows responding to changes in the sector more promptly than other types of meat. Compared to other sectors, the poultry sector of the European community is facing a very liberal market organization, where there are no guaranteed prices or intervention systems [European Commission, 1997]. Another factor which has favoured the increase of poultry production is the evolution in consumer prices. Compared with other meats, poultry is an inexpensive meat which has remained cheaper resulting in an increased market share at the expense of other types of meat, particularly beef [European Commission, 2000]. In addition to the factors just outlined, the increase in poultry production can also be related to animal efficiency. It has been reported that in Europe, to produce 1 kg of broiler meat, it takes 3.1 kg of dry matter feed, whereas pigs require 6.2 kg of feed and non-dairy cattle 24 kg of feed [Alcamo, 1994]. These ratios make poultry an attractive option for farmers.

Figure 4.2 also shows an increasing trend in the production of processed meat products. This increase has been driven by efforts to add value and improve margins and in response to end-user demand. At a first sight, and with the exception of the United Kingdom, the crisis in the meat sector in the mid 1990’s seems not to have affected substantially the further processing of meat products. However, an analysis of production trends for France indicates that production of processed products based on beef have declined while those based on poultry or pork have increased (Figure 4.3). Hence, it seems that developments found for slaughtering activities (especially cattle) can be found back in the processed meat sector, albeit to a lesser extent.

Figure 4.3 Physical production of meat products in France. Values have been indexed to 1996.



Other interesting developments in the meat sector are the shift from slaughtering by many small facilities to a handful of large facilities which control the market[9] (Table 4.1), and the increase in the size of the largest facilities (e.g. it is reported that in 1992/3 abattoirs numbers in the United Kingdom were 40% of those operating in 1972/3, but the average slaughterhouse had a throughput that was 2.5 times higher than twenty years before [Northen et al., 1997]). Industry concentration in the meat sector could be explained by the need to comply with higher environmental and health standards. This has prompted companies to undertake new investments. A study made by the OECD pointed out that the implementation cost of the EU hygiene standards (Directive 91/497/EEC) in the United Kingdom was potentially high and hence the burden on small operators was likely to be particularly great since it is difficult for small plants to generate sufficient turnover to absorb the costs of upgrading to meet the standards [OECD, 1997]. Furthermore, there are significant economies of scale associated with the cost of upgrading plants. Consequently, the Directive has most likely supported the process of concentration.

Table 4.1 Number of slaughterhouses by kind of animal and country.

Animal type	**France[a]**		**Germany[b]**		**United Kingdom[b]**		**Netherlands[c]**	
	1988	2001	1990	1997	1987	1997	1985	1996
Cattle	580	343	178	210	835	395	331[d]	267
Pigs			221	210	703	308	55	25
Poultry	1 392	186	157	115	n.a	n.a	91	52

[a]: data provided by Agreste; [b]: Northen et al, 1997; [c]: Langeveld, 2000; [d]: data for 1991.

4.4 Energy use

In the year 2001, the meat sector consumed about 39, 35, 10 and 32 PJ of primary energy in France, Germany, the Netherlands and the United Kingdom respectively. Of this amount between 40 and 60% was used by the further processing of meat sector (NACE 1513). Figure 4.4 shows the increasing trend in energy consumption by the whole meat sector. Natural gas is the fuel used most in the Netherlands, Germany and the United Kingdom, while in France, it is electricity. One important reason for the high share of electricity in the French meat industry are the efforts promoted by the French government to use electricity for process heat, a trend not existing in the other countries [IEA, 2000; Bossebeouf, 2003].

There has been a trend in all countries towards higher electricity use due to increasing demands for refrigeration and motor drive power generation. Table 4.2 shows the annual growth of both final and primary energy consumption. The effect of electricity growth in terms of primary energy is substantial.

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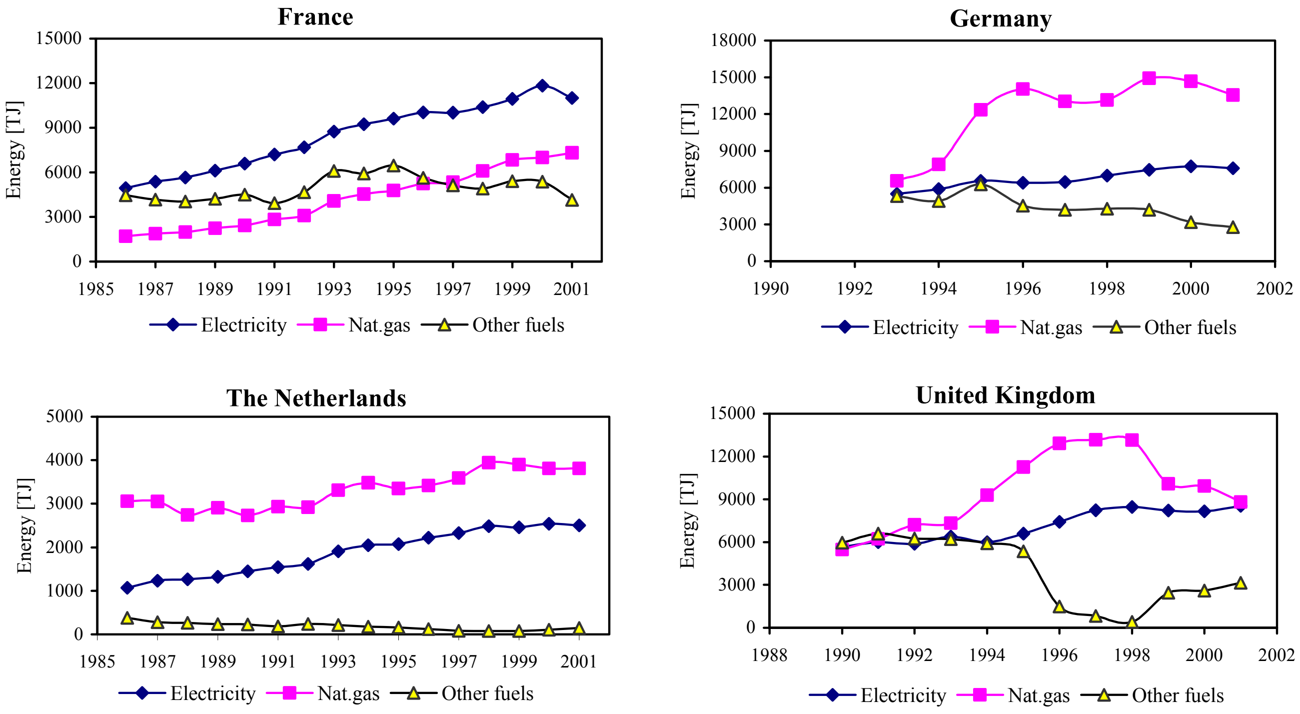
[9] In the United Kingdom 30 pig abattoirs accounted in 1997 for 81.4% of throughput, while 15 cattle abattoirs accounted for 40% of throughput; in Germany 27 poultry slaughterhouses accounted for about 92% of total throughput.

Table 4.3 shows the distribution of final energy in the meat sector by energy function, subsector and fuel[10]. Fossil fuels are mainly used for process heat while the main use of electricity is cooling. Refrigeration constitutes between 45-90% of total final electricity use during working day and almost 100% during non-production periods [European Commission, 2003b].

Figure 4.4 Developments in final energy consumption by fuel and industry.



France

Germany

The Netherlands

United Kingdom

Table 4.2. Increase of annual total final and primary energy in the meat sector by country.

Country	Growth of Total Final Energy Consumption (TFC) [% p.a.]		Growth of Primary Energy (PE) [% p.a.]
	Fuels	Electricity	
France[a]	3.8	5.0	4.6
Germany[b]	3.4	3.6	6.3
The Netherlands[a]	0.9	5.3	3.2
The United Kingdom[c]	0.4	3.7	2.9

[a]: 1986-2001; [b]: 1993-2001; [c]: 1990-2001

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[10] Not all activities are reported, therefore values do not necessarily add to 100%.

Table 4.3 Energy consumption in the meat industry.

SECTOR	ELECTRICITY		FUELS	
	Activity	**%**	**Activity**	**%**
Pork slaughtering	Cooling	49[a]-70[b]	Gas oven	60[a]-65[b]
	Slaughtering	5[b]-30[a]	Cleaning and disinfecting	18[a]-20[b]
	Water cleaning	5[b]-7[a]	Singeing	15[a,b]
	Lighting	2[a]-8[b]		
	Evisceration	3[a]	Space heating	7[a]
Cattle slaughtering	Slaughtering	26[a]	Cleaning and disinfecting	80[b,c]-90[a]
	Evisceration	3[a]		
	Cooling	45[a],[b]-70[c]		
	Compressed air, lighting and machines	30[c]	Space heating	10[a],[b]-20[b]
Poultry slaughtering	Cooling	52[c]-60[b]	Singeing	60[b]
	Machines and compressed air	30[b]	Cleaning and disinfecting	30[b]
	Lighting and ventilation	4[b]	Space heating	10[b]
Meat processing	Cutting and mixing	40[b]	Cleaning and disinfecting	25[b]
	Cooling	40[b]	Space heating	15[b]
	Packing	10[b]		
	Lighting	10[b]		
Rendering	Compressed air, lighting and machines[c]	12	Vacuum evaporation[c]	2
	Grinding and pressing[c]	17	Drying[c]	61
	Drying[c]	23	Grinding and pressing[c]	17
	Vacuum evaporation[c]	6	Space heating[c]	1
	Milling plant[c]	8	Fat treatment[c]	3
	Meal sterilization[c]	2	Meal sterilization[c]	8

[a]: Pontoppidan and Hansen, 2001 [b]: Infomil, 1996; [c]: European Commission, 2003.

4.5 Understanding energy efficiency developments

In this section we study the developments in energy efficiency made in the meat industry by examining the use of energy per unit of physical output (hereafter referred to as specific energy consumption). In general, equation 4.1 can be used to calculate the specific energy consumption. This equation can be applied not only to an industry but also to an industrial sector. In the meat sector, for instance, the specific energy consumption of the sector could be calculated as the energy use per tonne of slaughtered meat (see Figure 4.5). However, if products differ significantly in terms of energy requirements, changes in the results provided by equation 4.1

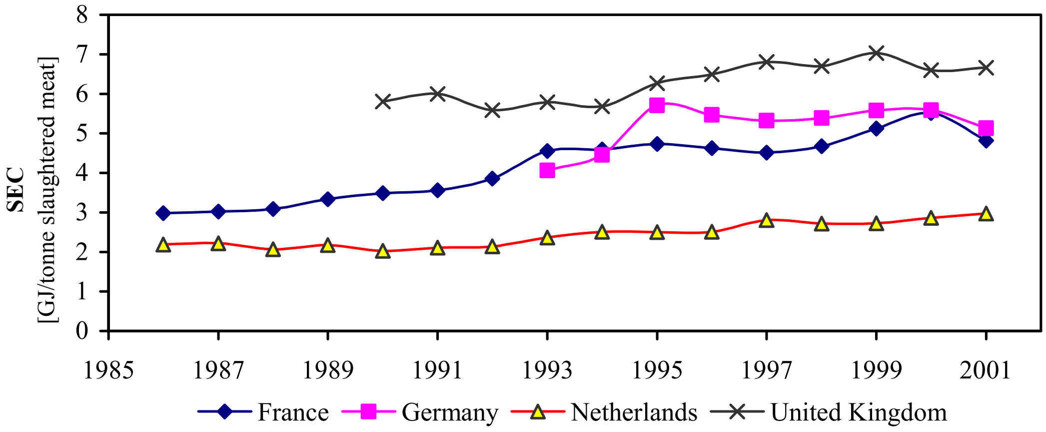
would be partly due to changes in efficiency and partly due to changes in production mix.

$$SEC_i = \frac{E_i}{m_i} \qquad \text{(Eq. 4.1)}$$

In which:

SEC_i= Specific energy consumption for product i (e.g. in Megajoule per tonne).
E_i = Primary energy consumption of product i (e.g. in Megajoule).
m_i = Physical production of product i (e.g. in tonnes of dress carcass weight).

Figure 4.5 Trend in specific energy consumption by country.



Following the methodology developed by Phylipsen et al., [1998] and Farla and Blok [2000], we correct equation 4.1 for differences in product mix. This is done by comparing the realised energy use (published by statistical offices) with a scenario where there are not improvements in energy efficiency (hereafter referred to as a frozen energy efficiency development). We call this an Energy Efficiency Indicator EEI (Equation 4.2). The frozen efficiency scenario is developed by taking into account the differences in energy requirements *between* products by using the specific energy consumption of the products (SEC_{ref}) in a base year. In this chapter we use SEC_{ref} values which reflect typical technologies in use in the late 1990s.

$$EEI_j = \frac{E_j}{\sum_i m_{i,j} \times SEC_{ref_{i,j}}} \qquad \text{(Eq. 4.2)}$$

In which:

EEI_j= Energy efficiency indicator of sector j (dimensionless).
$E_{i,j}$ = Primary energy consumption of product i in sector j (e.g. in Megajoules).
E_j= Primary energy consumption of sector j as given in the statistics (e.g. in Megajoules).
$m_{i,j}$= Physical production of product i in sector j (e.g. in tonnes of dress carcass weight).

$SEC_{ref,i}$ = Reference value for the specific energy consumption of product *i* (e.g. in Megajoule per tonne).

We identified as key products: beef/veal meat, goat meat, sheep and lamb meat, poultry meat, pig meat, rendered products and processed products[11]. We use for the cattle, pig and poultry processing typical SEC_{ref} values reported in two studies [Pontopiddan and Hansen 2000, 2001] and for the further processed meat industry, values reported by Suijkerbuijk et al., [1995] (despite efforts made for gathering information on SEC_{ref} for processed meat products, only aggregate figures were obtained). The meat sector also includes the processing of meat by-products (e.g. bones, blood, feathers, fat). Since some of the by-product submitted to rendering process are not processed for sale (i.e. fallen stock or offals that are considered a danger to public health), it is important to work with the annual amount of raw material to be rendered and not with production data based on sales figures (this underestimates the influence of rendering in the energy consumption of the sector). As there is a lack of statistical data on the total annual amount of raw material to be rendered, we make the following assumptions. First, we assume that the total weight of raw material to be rendered per beast is typically[12]: 198 kg (cattle), 21 kg (pig), 14 kg (sheep) and 0.7 kg (poultry) [MLC, 1998a]. Secondly contrary to the United Kingdom, in Germany, France and the Netherlands it is forbidden to bury fallen stock on farm, these amounts are included in our calculations. Hence, it is assumed that fallen stock represents 10% (for the Netherlands) and 15% (for Germany and France) of the tonnage processed annually[13]. Finally, we assume that rendering is done in a continuous system with cooking and multiple-effect evaporation in added fat[14]. The SEC_{ref} used for rendering is based on data provided by Nielsen [2004] and Schreurs [2004]. Table 4.4 shows an overview of the SEC_{ref} used in this chapter.

Table 4.4 Specific energy consumption values in the meat industry (in primary energy, typical technologies for the late 1990s).

Product	**Unit**	**SEC_{ref}**
Beef, veal and sheep	MJ/tonne dress carcass weight	1390
Poultry	MJ/ tonne dress carcass weight	3096
Pork	MJ/ tonne dress carcass weight	2097
Meat products	MJ/tonne final product	5500
Rendering	MJ/tonne of raw material processed	1625

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[11] Within the processed products, we include the following products: Ham; bellies and cuts of swine salted, in brine, dried or smoked; pig meat salted, in brine, dried or smoked (including bacon); sausages; prepared pork meat (including mixtures); preparations of beef and veal.

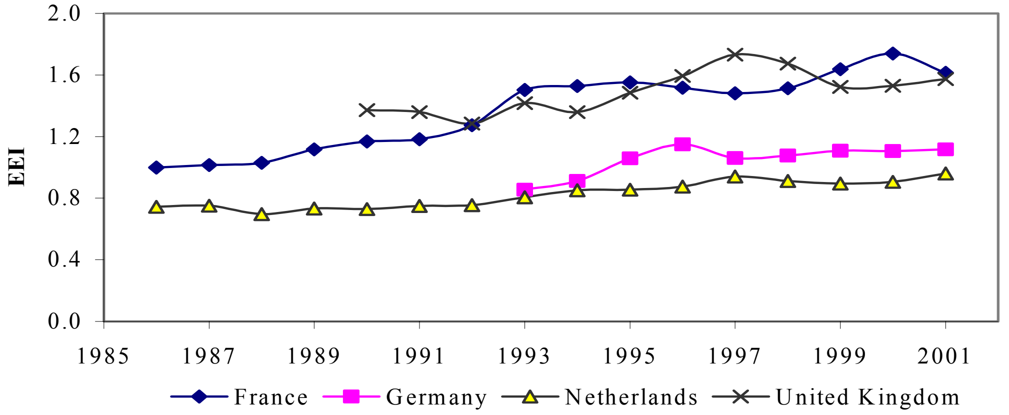
[12] These amounts exclude treatment of hides and skins because this is generally done in tanneries.

[13] Based on survey data published by MLC [1998b].

[14] In this kind of process, the material is minced, heated, pressed and separated in a twin screw press, thereafter the fat is separately sterilized. The wet protein fraction is then dried and sterilized without fat present [MLC, 1998a]. This process provides a high-quality fat and meat -and bone meal low in fat content, of an upgraded quality, of a light colour and highly digestible.

The results of applying Equation 4.2 to the meat sector (NACE 151) are shown in Figure 4.6. The results point towards an increasing primary energy consumption per unit of output during the last decade (3.2% p.a. in France, 3.4% p.a in Germany, 1.4% p.a in the United Kingdom and 1.6% p.a. in the Netherlands[15]). The general increase in EEI by the meat industry is troublesome since one could expect that even in the absence of energy saving policies, there would be autonomous energy efficient developments. In the next section we explore some factors that could explain the general deterioration in energy efficiency for the meat sector.

Figure 4.6 Energy efficiency indicators of the meat industry by country.



4.6 Discussion of results

The increasing energy demanded by the meat sector can be explained by two main factors. On one hand, increasing demand is caused by the change in consumer preferences from beef towards pigmeat and poultry (see section 4.4) since poultry and pork slaughtering are more energy intensive than cattle slaughtering[16] (see Table 4.4). On the other hand, the meat industry has progressed from the sales of carcasses, complete with fat and bone, to large bone-in or boneless cuts that are vacuum packaged, fully trimmed products and pre-cooked and ready-to-eat products which increase the demand in electricity and fuel. To understand the deterioration in energy efficiency is, however, more complicate. Thus, we explore two main trends in the meat industry and their influence on the EEI: a) shifts in meat products towards fast food and cut-up and debonned products and, b) the increasing demand for food security.

4.6.1 Structural changes: increasing demand of fast food, cut and frozen products

In a sector such as the meat industry, growth is heavily influenced by changing consumer preferences. In order to understand changes in production mix that have

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[15] For the periods: 1986-2001 (France and the Netherlands), 1993-2001 (Germany), 1990-2001 (UK).

[16] This is due mainly to the energy consumed in dehairing, defeathering and singeing operations as illustrated in Figure 4.1.

not yet been captured by our indicator, we differentiate between factors affecting slaughtering houses and those affecting the further processing of meat.

- *Slaughterhouses*

Two main factors that could explain changes in the demand of energy per unit of product are: a) changes in the share of frozen products, and b) changes in the share of cut and deboned products. From an energy point of view the increase or decrease of frozen products is important because freezing increases the electricity demand. Likewise, the trends towards cut-up and deboned products imply an increase of electricity and fuel demand. Higher electricity consumption is a consequence of the increasing use of automated equipment to cut-up and the temperature conditions in which cutting and debonning can take place[17], while increased heat consumption is a consequence of an increasing demand for hot cleaning water. Figure 4.7 shows the importance of freezing, cutting and debonning by type of meat and country[18]. Note that while the share of frozen products is only significant in the poultry sector, and with exception of pigmeat production, the general trend is towards a decrease on the production of frozen fresh meat. On the contrary, the share of cut-up and deboned products is significant for all meat and has increased in the last decade. We estimate the influence of the shares and their change on the EEI of the meat sector as follows.

Since the SEC_{ref} values we have used for cattle, poultry and pig meat slaughtering (Table 4.4) refer to fresh chilled products, not frozen ones, we correct these figures for the additional energy demand. Data from the Danish meat industry indicates that freezing would add between 120–260 kWh for tonne of poultry product[19] [Pontopiddan and Hansen, 2000], 115 kWh per tonne of pigmeat and 80 kWh per tonne of beef [Pontopiddan and Hansen, 2001]. Note that frozen *poultry* products demand more energy not only because of higher refrigeration requirements but also because the meat is submitted to higher temperatures during scalding. Frozen poultry (and poultry for frying) undergoes what is called hard-scalding, with water temperatures in the range of 58 to 60°C, while poultry for fresh sale is submitted to soft-scalding (50-53°C). Assuming 1.4 litre of water for the scalding tank per kg poultry[20], and an efficiency of 70% of the steam system (boiler and distribution lines)[21], we calculate an additional fuel demand of about 83.8 MJ/tonne. To calculate the increase in energy demand as a consequence of cutting and debonning we used data published in a report on best available technologies for Finnish slaughterhouses which indicates that cutting up and deboning consume 60 kWh/tonne of finished product (electricity) and 216 MJ/tonne of finished product

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[17] According to European legislation temperature of the cutting room should not exceed 10°C.

[18] Information was not available for all years and countries.

[19] The range given depends on packaging type.

[20] This value is an average figure. It has been calculated based on data provided by Pontopiddan and Hansen [2000]; Derden et al., [2003] and the Environmental Agency of the UK [2001].

[21] Although for some food industries boiler efficiencies of 80 to 90% are common, we have considered that boilers in slaughterhouses are older and the level of maintenance is not the same than in other industries, hence 70% efficiency was considered appropriated.

(fuel) for cattle, poultry and pig [FEI, 2000]. As data is given in kg of finished product, we use the following carcass cutting yields to convert kg of boneless cut meat to dress carcass weight: 1.53 for cattle, 1.37 for pork and 1.8 for poultry. Table 4.5 shows the SEC$_{ref}$ for products which are frozen, cut-up and debonned.

Figure 4.7 Share of frozen products and cut products in meat production by country. (A) Beef and veal production; (B) Pigmeat production; (C) poultry production.

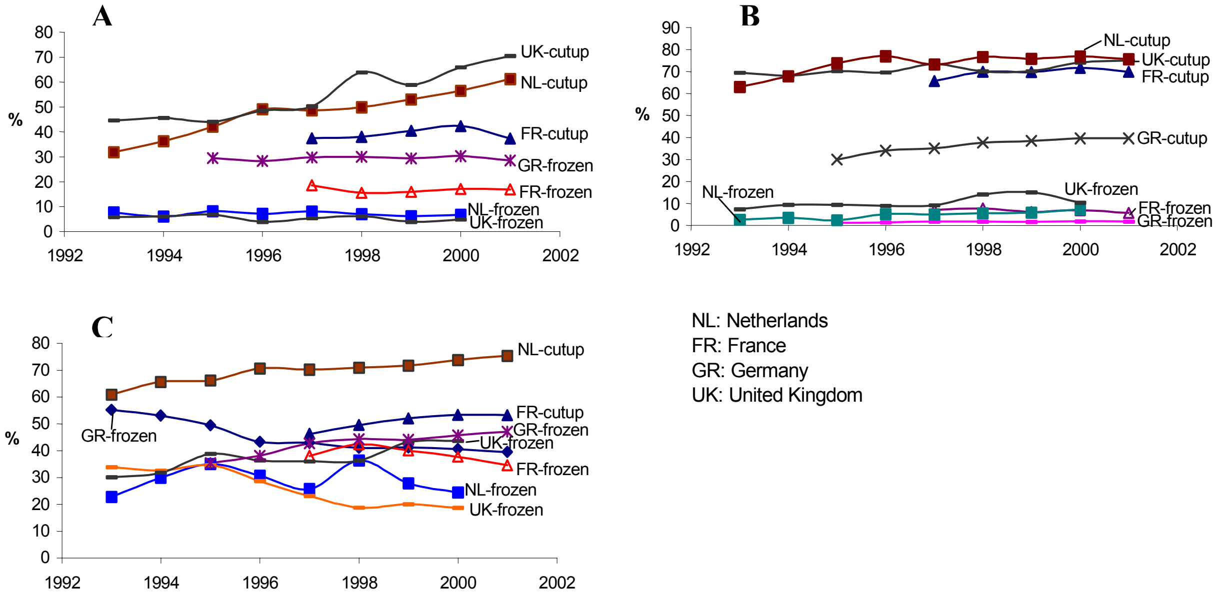
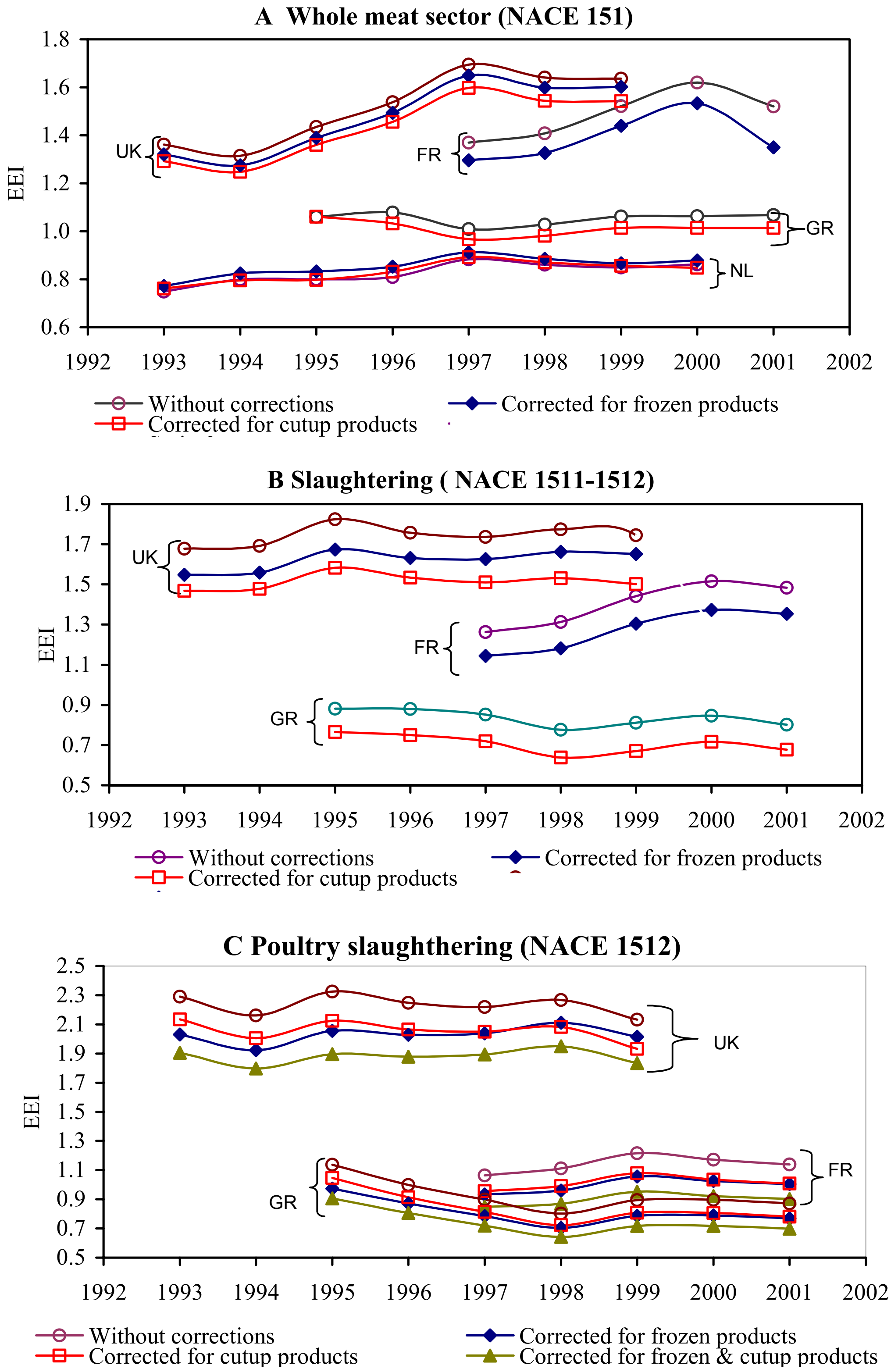


Table 4.5 Comparison of SEC$_{ref}$ values (in primary energy): the effect of freezing, cutting and deboning meat.

Product	**SEC$_{ref}$** Whole & chilled	**SEC$_{ref}$** Whole & Frozen	**SEC$_{ref}$** Cut-up, deboned & chilled	**SEC$^{*}_{ref}$** Cut-up, deboned & frozen
	MJ/tonne dress carcass weight			
Beef, veal and sheep	1390	2110	2146	2866
Pork	2093	3128	2849	3884
Poultry	3096	4258-5518	3852	5014-6274

Figures 4.8A and 4.8B depicts the effects of correcting the EEI by including frozen products *or* by cut-up products for the whole meat and for the slaughtering sector. A more accurate picture is achieved if we correct for products that are cut-up, deboned *and* frozen. However, this demands a high level of disaggregate data that at the moment is only available for the poultry sector. The effect on the trend is shown in Figure 4.7C. Correcting for cutting and freezing a) decreases the absolute value of the indicator, b) tends to decrease the gap between countries and, c) can explain some of the fluctuations showed by the trends at a disaggregate level but it does *not* explain the increase on EEI showed by the whole meat sector.

Figure 4.8 Influence of different corrections in the energy efficiency index of the meat sector at different levels of aggregation by country: France (FR), Germany (GR) and the United Kingdom (UK).



- *Further processing of meat-fast food*

Another possible reason for the increase in the EEI of the meat sector shown in Figure 4.6 could be the use of more energy intensive processes in the processed meat sector (NACE 1513). The central problem we face is that not enough information is available to distinguish among different types of processed meat products and the related energy consumption, thus the EEI trends shown do not correct for changes in the production mix between further processed meat products. We therefore point out some developments that could explain the increasing energy demand per product: a) increasing number of new products, b) structural changes in the production from less energy intensive products towards more energy intensive ones, c) increasing packaging and automation (which increases the amount of electricity demand), and d) increasing food hygiene standards (see section 4.6.2).

An increasing number of products could increase energy demand because if processed in small amounts, production lines would be used for different products which increase the amount of energy used during cleaning and star-ups. However, at the moment it is not possible to test this hypothesis since statistical data does not allow monitoring the entrance and amount of new products. The only information we found comes from a report from the Dutch Ministry of Economic Affairs recognizing that "new products were introduced (in the meat sector), leading to extra process stages (including frying) and to higher energy consumption" [Minez, 1999]). Furthermore, the Dutch Long Term Agreements[22] for the meat sector stated that in the year 2000 about 8% of the total energy used by the companies that signed the covenant was due to the introduction of new products [Novem, 2001].

As an attempt to obtain a better insight into the contribution of new products to overall energy use Figure 4.9 compares the increasing energy demand in France with production trends. According to Figure 4.9A prepared dished and conserves may have contributed decisively to the increased primary energy demand in the last five years. Figure 4.9B provides some support for this hypothesis since a) increasing packaging is accompanied by the increasing demand of energy of the sector, and b) the role of frozen products is quite limited. However, due to lack of data, a detailed analysis that allows calculating the effect of the different categories on the increasing energy demand is not possible.

4.6.2 Increasing demand for food security

A different impact on energy consumption does not come from changes in production mix but from changes in process conditions. During the last decade, the food scandals which have shaken the sector have generated a strong focus on food safety. As a reaction to public concern, stringent hygiene requirements in meat companies (and pressure to accomplish such requirements) have been established.

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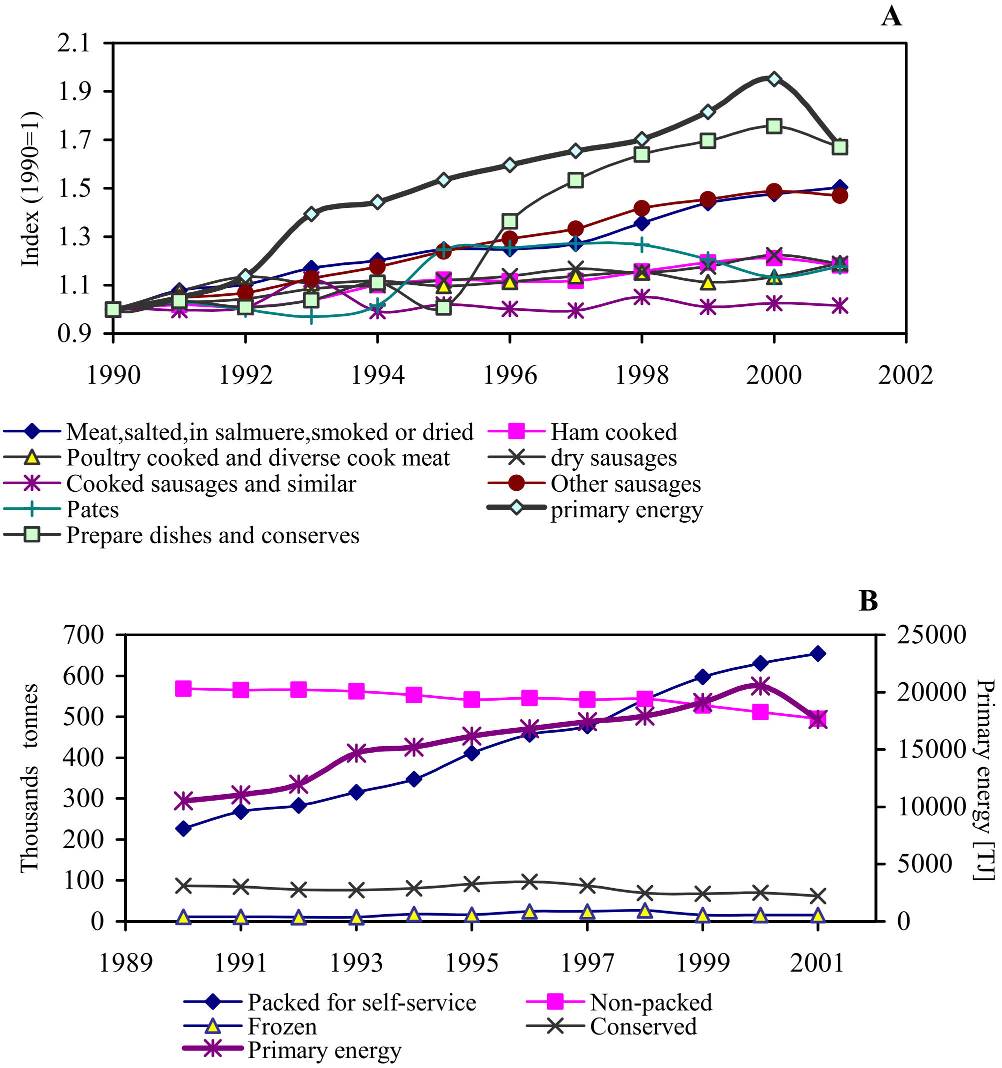
[22] The LTA's are voluntary agreements between a specific sector and the minister of economic affairs. It involves a commitment by a sector to make efforts to improve energy efficiency by a percentage in a pre-arrange term. LTA's are based on physical measures of output.

Temperature has been a fundamental factor in increasing food safety (cold and hot treatments are effective ways of controlling microbiological growth and eliminating pathogens). A report made for the Dutch meat sector in the context of Long Term Agreements (LTA) pointed out that "the introduction of the Hazard Analysis Critical Control Points method for food health, safety and quality led to an increase in energy consumption which eliminated the effect of conservation measures" [Minez, 1999]. Part of the increased amount of gas originates from the higher demand for hot water which is related to more stringent hygiene requirements (e.g., hot water is used for the sterilisation of tools and bacterial decontamination of carcasses). Furthermore, and as noted before, refrigeration is the biggest consumer of electricity. In fact, some studies have already shown that EC slaughterhouses complying with EC temperature legislation use more electricity than those that do not [European Commission, 2003b].

Figure 4.9 Comparison by type of product and primary energy use for the French processed meat sector. (A) Processed meat product development by type of products. (B) Processed meat product by type of distribution.



We have made an estimate for the increased fuel demand as a consequence of implementing EU legislation. Since there is not enough data to establish at which penetration rate EU slaughterhouses are implementing EU legislation[23], we have assumed that[24]:

- In the year 1990, slaughterhouses were using water for cleaning and sterilization at 60ºC and that in the year 2001 the temperature is 82ºC.
- In the year 1990, poultry slaughterhouses were not using hot pre-wash before evisceration, while this was the case for the year 2001.
- In the year 1990, slaughterhouses did not chill the blood recollected and in the year 2001 all blood was chilled to 5ºC.

The result of implementing these three measures leads to an increase of energy demand of about 335 TJ in France, 316 TJ in Germany, 142 TJ in the Netherlands and 369 TJ in the United Kingdom. Because there is not enough information to calculate the additional demands on electricity for cooling as a consequence of stringent food security in a bottom-up way, we have proceeded as follows. Since Germany, France and the United Kingdom publish detailed energy figures for slaughtering houses and meat processing factories and the shares of electricity used for cooling are known (Table 4.3) we conduct a sensitivity analysis using assumptions for the share of additional electricity used to comply with EC regulations (Table 4.6). The results shown in Figure 4.10 depict what would have been the EEI of the meat sector in the year 2001 if the regulations had not been implemented. The influence of increasing electricity use in the EEI is higher than the influence of increasing fuel demand. Increase use of electricity could explain between 3% and 8% of the increase in the value of the EEI of the meat sector in the UK, 3 and 9% in France and 2 and 4% in Germany in the period 1990-2001.

Table 4.6 Scenarios used to estimate the influence of increased electricity use as a consequence of more stringent EC hygiene regulations.

Scenario	**Share of the electricity that has been used to accomplish with EC regulations [%]**	
	Slaughterhouses	**Meat processing facilities**
1	10	10
2	25	10
3	25	25

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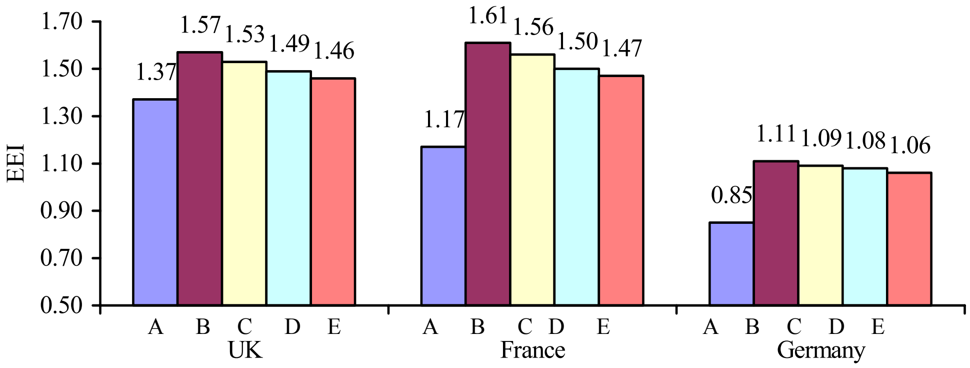
[23] We found partial information for EC approved slaughterhouses in the United Kingdom. The report states that in 1992 only 12% of slaughterhouses were approved while the number in 1996 increased to 62% [Shaoul, 1996]. These figures support our assumptions.

[24] The values were calculated assuming that: water use at 82ºC is about 30 l per pig, 105 l per cattle, 4.3 per chicken [Pontoppidan and Hansen, 2000, 2001]; the amount of water use for hot washing before chilling in poultry, according to EU legislation, is 1.5-3.5 l per carcass [European Commission, 1996]; average amount of blood that can be collected per animal is 3.6 kg per pig, 13.6 kg per cattle, 2.5 kg/lamb and 0.06 kg per chicken [Gracey, 1998] and requirements for blood refrigeration is 30.5 kWh/tonne of blood [European Commission, 2003b].

Figure 4.10 Influence on increased energy demand as a consequence of hygiene regulations in the EEI of the meat sector.



A: EEI 1990- Without corrections

B: EEI 2001- Without corrections

C: Scenario 1; EEI 2001- electricity share used to accomplish food hygiene standars: 10% in slaughterhouses; 10% in meat processing factories

D: Scenario 2; EEI 2001-electricity share used to accomplish food hygiene standars:25% in slaughterhouses; 10% in meat processing factories

E: Scenario 3; EEI-2001 electricity share used to accomplish food hygiene standars: 25% in slaughterhouses; 25% in meat processing factories

Another consequence of the implementation of the new EU measures has been felt in the rendering sector. In the late 1980s the trend in the rendering industry was to move from a batch process towards a continuous process [Coopers & Lybrands, 1996]. The continuous process is considered a more reliable process, which generates less water and air pollution, involves less manual work and no organic solvents. Furthermore, it consumes around 30-40% less heat per tonne of product than the batch process [Krenk, 19991; Prosper de Mulder, 1991][25]. However, as a consequence of Council Directives 90/667[26] and 96/449[27] processing conditions have changed. In the UK for instance, specified bovine material (sbm) [28] has to be rendered in separated plants or dedicated lines within the plants, generally in *batch* units; the same development has occurred in France [Coopers & Lybrands, 1996]. In the Netherlands, the introduction of the new legislation and the opinion of the steering committee of the EC[29] caused a reintroduction of batch sterilization in *all* Dutch rendering plants in 1996. Hence, the EC directives have contributed to an increasing energy demand in the rendering industry (with exception of Germany, where the Directive 90/667/EEC is essentially German law and has been applied by rendering houses since the beginning of the 1980s [Fodgen, 1991]). To estimate

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[25] The reason for this is that in the continuous process there is reutilization of heat.

[26] It establishes that high risk material must be heated to a core temperature of at least 133ºC for 20 minutes at a pressure of 3 bar.

[27] It establishes the approval of alternative heat treatment systems for processing animal waste [European Commission, 1996].

[28] Specified meat offal comprises the skull, including the brain and the eyes, tonsils, intestines, thymus and spinal cord of bovine, ovine and caprine animals.

[29] When the batch system was changed to continuous it was overlooked that the heat treatment in some of the systems were less than in conventional batch systems. Continuous systems are indeed able to get rid of salmonella and vesicular disease, however their effectiveness to eliminate BSE is doubted.

this increase we assume that in the year 2001, sbm[30], meat-and-bonemeal for animal feed and fallen stock was pressure treated in batch vats. The specific energy consumption of such a process is reported to be 1960 MJ of primary energy/tonne raw material [Schreurs, 2004]. Under these assumptions, we calculated for the year 2001 an increase of about 476 TJ, 308 TJ and 362 TJ in the energy demand of the rendering process for France, the United Kingdom and the Netherlands respectively.

Concluding, stringent hygiene regulations can explain a significant share of the increasing EEI. For instance, in the United Kingdom, and depending on the impact on the electricity demand, it can explain between 42% and 78% of the 32% increase shown by the EEI between 1990-2001. While in France it explains between 18 and 37% and in Germany between 14% and 32%. Because of the aggregate nature of the Dutch data we could not estimate the influence of hygiene in electricity demand, however if the effect were of a 3% (minimum of French and UK and average Germany), hygiene regulations could explain already one third of the 35% increase on the EEI shown by the Dutch meat sector.

4.7 Conclusions

The purpose of this chapter has been to analyse energy use and energy efficiency developments for the meat industry of four European countries in the last decade. Our results show that during the last decade there has been an increase in both energy demand and the energy efficiency indicator in the meat industry of the four countries analysed (between 1.4% and 3.4% per annum). In exploring the causes for such trends we found that strong hygiene regulations can explain up to two thirds of the increase on EEI and that the role of increasing shares on freezing and cutting fresh meat are quite limited in all countries. There is however a significant share of the increase on the EEI that could not be explained. A possible cause is an increase on energy intensive process in the further processed meat sector, however further analysis was halted by the lack of current available data. Understandably, when looking at the meat sector, studies on processes and hygiene have focused their attention on slaughterhouses, since not only they are considered an important source of epidemics but also have a limited number of processes. On the other hand, only very little attention has been paid to the further processed meat sector, with more than 40 different product categories. Despite a couple of studies which deals with sausage-making there is not information available on SEC by products which implies that changes in structure within the further processed meat sector remain in the energy efficiency indicator.

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[30] In the UK, sbm is calculated to be 46.5 kg per cattle and 2 kg per sheep and goats, while for France and the Netherlands it is 17 kg per cattle and 2 kg per sheep and goats [MLC, 1998b]. The higher amount per cattle in the UK reflects the fact that British law (Specified risk material order, 1997) considers as sbm the head and spleen of the animals.

This chapter thus shows that from a methodological point of view it is viable to develop energy efficiency indicators using available statistical data in a heterogeneous non-energy intensive sector. However, we found that data availability is indeed a constrain when exploring the drivers behind changes in energy efficiency. Hence, to understand the drivers increase data on energy consumption by process and product is necessary and this can only be achieved in active cooperation with the industry. Gathering such data will certainly come at a cost, but the research towards this direction is both promising and challenging.

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CHAPTER 5

Adding Apples and Oranges. The Monitoring of Energy Efficiency in the Dutch Food Industry[*]

Abstract

In this chapter we develop 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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[*] Article in press in *Energy Policy.* Co-authors: K. Blok, M. Neelis and M. Patel.

5.1 Introduction

Decreasing CO_2 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 CO_2 concentration 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 (e.g. 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 to 2020 period [Metz et al., 2001] and the proposal from the European Commission [2003] for a directive on 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 [e.g. 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 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 were the analysis is done at a high level of aggregation, economic measures of output (i.e. value added or GDP) are the most use measures of activity. This 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 [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 aggregation are found in an extensive body of literature, especially for energy intensive industries such as steel, pulp and paper or cement [e.g. 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 chapter is a contribution to this deficiency. In it, we present findings from a detailed examination of the Dutch food

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[1] The 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].

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 chapter for monitoring trends in energy intensity in the future and the possibility of applying such methodology to other countries. It should be pointed out, however, that in this chapter 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 chapter is as follows. Section 5.2 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 5.3 while main results are shown in section 5.4. Finally, conclusions are drawn in section 5.5.

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 2001[2] [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 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% to 4%). The food and tobacco industry can be broken down into 10 three-digit NACE industry sectors (Table 5.1). Figure 5.1 shows the primary energy demand of the food sector compared to the total Dutch manufacturing industry and its distribution by food sub-sector[3].

Table 5.1 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 beverages
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

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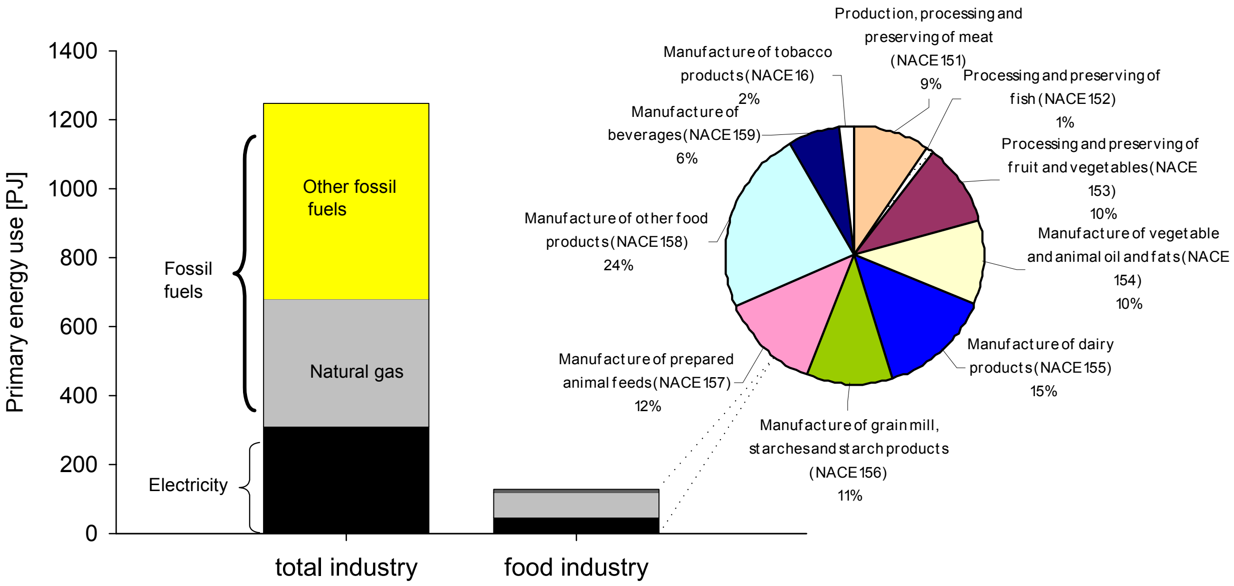
[2] It does not include mining and agriculture.

[3] Primary energy was calculated according to the methodology described in section 5.4.1

Figure 5.1 Comparison of primary energy used by the Dutch food and tobacco industry, 2001.



5.3 Methodology and data issues

The analysis performed in this chapter 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.

5.3.1 Development of energy efficiency indicator

The methodology used in this chapter constructs on the work done by Phylipsen et al., [1997; 1998] and Farla [2000]. In this chapter, 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 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 SEC's 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 power). 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]. Equation 5.1 shows the energy efficiency indicator by type of fuel. The base year used in this chapter is 1995[5].

$$EEI_{j,k} = \frac{E_{j,k}}{\sum m_{i,k} \times SEC_{i,j,0}} \qquad \text{(Eq. 5.1)}$$

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

$$EEI_{p,k} = \frac{E_{p,k}}{\sum m_{i,k} \times (SEC_{ref,i,j,0} \times f_j)} = \frac{\sum E_{k,j} \times f_j}{\sum m_{i,k} \times (SEC_{refi,j,0} \times f_j)} \qquad \text{(Eq. 5.2)}$$

In which:

k = Year of the analysis, with 0 denoting the base year;
j= Type of fuel (i.e. electricity, fossil fuels/heat);
$EEI_{k,j}$ = Energy efficiency indicator in year *k* for fuel *j* (dimensionless);
$EEI_{p,k}$ = Primary energy efficiency indicator in year *k* (dimensionless);
$E_{j,k}$ = Energy demand for fuel *j*, in year *k* (e.g., in Terajoule); from energy statistics;
$E_{p,k}$= Primary energy demand in year *k* (in Terajoule);
$m_{i,k}$= Physical production of product *i* in year *k* (e.g., in tonnes);
$SEC_{i,j,0}$ = Energy use to produce product *i*, for fuel *j*, in the base year (e.g., in Gigajoules per tonne of final product);
f_j= Conversion factor from fuel *j* for final use to primary energy.

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[4] The Long Term Agreements (LTA) 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: htpp:// www.mja.novem.nl

[5] Results 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.

5.3.2 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 Figure 5.2. 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 chapter 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 power[7] 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 equation 5.3. 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].

$$Ep_k = \left(\left(F_{1k} + F_{3k} + \left({H_{1k}}/{0.9} \right) \right) \times f_{fuel} \right) + \left(El_{1k} \times f_{elect-grid} \right)$$

(Eq. 5.3)

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 $\text{electricity}_{\text{CHP-powergrid}}$ to primary is calculated as 2.41

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[6] Distinguishing between oil, natural gas and cokes.

[7] A 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.

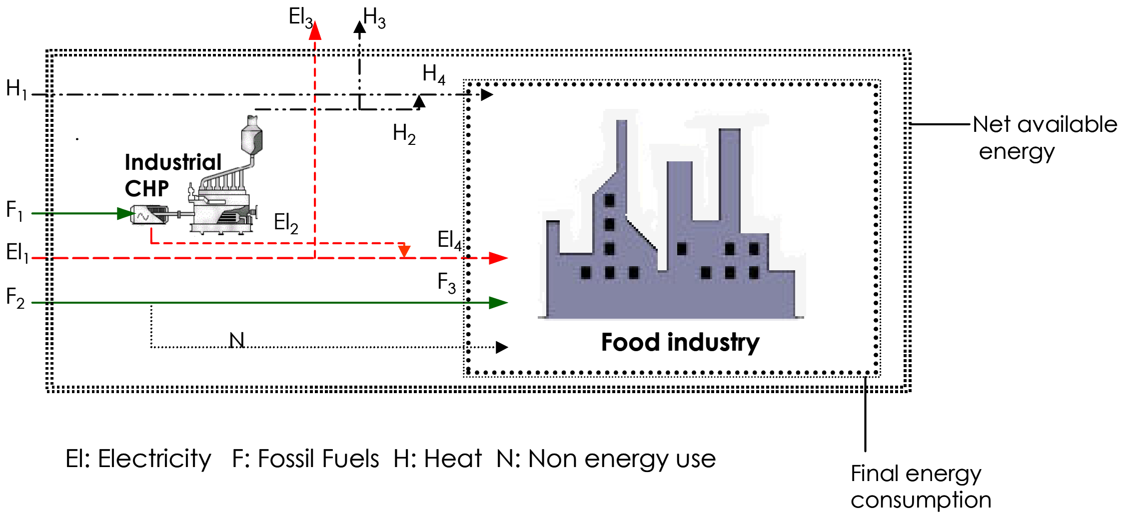
[8] In the Dutch statistics if a CHP unit is operated in a joint venture between industry and energy sector, it is considered as an enterprise with main activity to produce heat and electricity, and thus its outputs are allocated to the energy sector and not the industrial sector. The values for CHP 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.

[9] These conversion efficiencies reflect losses in transportation and fuel conversion which are considered to be relatively small [e.g. Phylipsen 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.

[10] We 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.

[11] We allocate fuel inputs of CHP plants on the basis of the exergy content of the products as described in Phylipsen 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%.

Figure 5.2 System boundaries.



Finally, we have corrected the energy figures for climate influences using the Eurostat temperature correction method[12] (assuming an average heating share of 20% based on data published in European Commission [2003] and RIVM [1995]).

5.3.3 Production data

Since the goal of this chapter 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].

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[12] The 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].

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

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 Statistical Office of the Netherlands (CBS) trough 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 5.3.4.

We use Prodcom 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 Prodcom 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 (e.g. 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 0.7 kg (poultry) [Meat Livestock Commission, 1998], and b) fallen stock represents 10% of the tonnage processed annually [idem][14]. Using data on the total number of slaughterings published by the Product Board for Livestock, Meat and eggs (PVE), the total amount of raw material to be rendered is calculated.

- *Dairy sector*. Prodcom values for dairy products show two problems: a) strong fluctuations (it is the only sector studied which shows fluctuations of more than 100% from one 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).

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

- *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.

5.3.4 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. Prodcom 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, etc.) and identified main processes and products which are important from an energy point of view. We made a literature survey to find SEC values. SEC's 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, only report one product in Prodcom (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 Figure 5.3 shows the SEC for electricity for the manufacture of prepared food for farm animals. The products and SEC's used in this study together with their sources are listed in Table 5.2. Due to confidentiality issues, SEC's 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's 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 chapter 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 5.4.3).

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[15] Energy at the company level is also available form 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.

Table 5.2 Specific energy consumption values (SEC) by product in the Dutch food and tobacco industry.

Product		Origin production data (Prodcom numbers)	SEC Electricity	SEC Fuels and heat	Unit	Source/ Comments
Meat						
Beef+ Sheep	A	PVE statistics	341	537	MJ/t dress carcass weight	Pontoppidan and Hansen, 2001
Pig	A	PVE statistics	465	932	MJ/t dress carcass weight	
Poultry	A	PVE statistics	1008	576	MJ/t 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	754	3950	MJ/t product	Suijkerbuijk et al., 1995
Rendering	A	Calculated based on PVE statistics	234	1042	MJ/t raw material	Schreurs, 2003
Fish						
Fresh (fillets)	PC	15201190	129	6	MJ/t product	Nielsen et al., 2003
Frozen fish	PC	15201210+15201230+15201270+15201290+15201530+15201553	696	6	MJ/t product	
Prepared or preserved fish	PC	15201411+15201412+15201413+15201414+15201415+15201417+15201419+15201419+15201330+15201370+15201353+15201355+15201359+15201600	482	1062	MJ/mt product	
Smoked and dried fish	PC	15201353+15201355+15201359+15201370	1200	2077	MJ/t product	Own calculation
Fish meal	PC	15201700	684	6200	MJ/t product	Nielsen et al., 2003

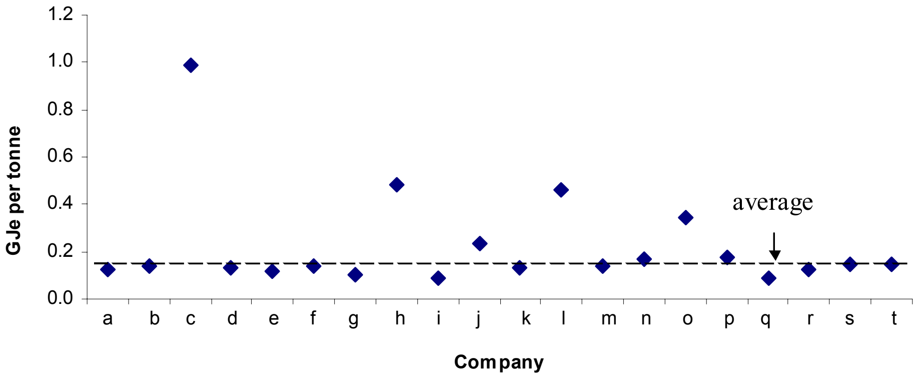
Product		Origin production data	SEC Electricity	SEC Fuels and heat	Unit	Source
Potatoes						
Potatoes products	PC	15311230+15311250+15311100+15311210+15311270+15311290	5722^a		MJ/t product	Own calculation
Fruit and vegetables						
Unconcentrated juice	PC	15321013+15321015+15321021+15321022+15321023+15321025+15321026+15321029+15321030+15321040	250	900	MJ/t product	Lorentzon et al., 1997
Tomato juice	PC	15321024	125	4789	MJ/t product	Molinary et al., 1995
Frozen vegetables and fruits	PC	15331100+15331440+15331500+15332100	738	1800	MJ/t product	Average figure based on confidential data VITO
Preserved mushrooms	PC	15331430	2898^a		MJ/t product	Own calculation
Vegetables preserved by vinegar	PC	15331500	2178^a		MJ/t product	Own calculation
Tomato ketchup	PC	15871230	380	1700	MJ/t product	Carlsson-Kanyama and Faist, 2001
Jams and marmalade	PC	15332230+15332290+15881050	490	1500	MJ/t product	
Dried vegetables and fruits	PC	15331330+15331350+15331390+15332520	1500	4500	MJ/t 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/t product	Own calculation
Dairies						
Milk and fermented products	A	Prodzuivel statistics	241	524	MJ/t product	Hiddink, 2004
Butter	A	Prodzuivel statistics	457	1285	MJ/t product	
Milk powder	A	Prodzuivel statistics	1051	9385	MJ/t product	
Condensed milk	A	Prodzuivel statistics	295	1936	MJ/t product	

Product		Origin production data	SEC Electricity	SEC Fuels and heat	Unit	Source
Cheese	A	Prodzuivel statistics	1206	2113	MJ/t product	Hiddink, 2004
Casein and Lactose	A	Prodzuivel statistics	918	4119	MJ/t product	
Whey powder	A	Prodzuivel statistics	1138	9870	MJ/t product	
Starches and starch products						
Wheat starch	PC	15622211	2960	8800	MJ/t product	European Commission, 2003 Average values
Maize starch	PC	15622213	1000	2331	MJ/t product	
Potato starch	PC	15622215	1425	3564	MJ/t product	
Prepared animal feeds						
For farm animals	PC	15711003+15711005+15711007+15711009	475[a]		MJ/t product	Own calculation
For pets	PC	15721030+15721033+15721035	2306[a]		MJ/t product	Own calculation
Sugar						
Refined sugar	PC	15831230+15831290	556	5320	MJ/t product	Hulskotte et al., 1995 NL; best 1990
Beet pulp	PC	15832000	5	1820	MJ/t product	
Cacao						
Cacao beans	CBS	CBS data	6384[a]		MJ/t processed cacao beans	Own calculation
Coffee						
Non roasted	PC	15861130	141	160	MJ/t product	European Commission, 2003
Roasted	PC	15861150+15861150	518	1997	MJ/t product	European Commission, 2003 (Assuming 20% shrinkage in roasting)
Extracts of coffee solid form	PC		15675		MJ/t product	Own calculation

Product		Origin production data	SEC Electricity	SEC Fuels and heat	Unit	Source
Beer and malt						
Beer	PC	15961000	20	153	MJ/hl product	Heineken, 1999 (Europe; 1997)
Mineral waters and soft drinks						
Mineral water and soft drinks	PC	15981130	133	199	MJ/1000 l product	Department of Environment, 1997
Unsweetened water and soft drinks	PC	15981150+15981230+15981255	120	360	MJ/1000 l product	Gonsalvez, 1996
Tobacco and Others						
Cigar	PC	160011130	66		MJ/1000 stucks	Own calculation
Cigarettes	PC	160011150	16		MJ/1000 stucks	Own calculation
Sweet Biscuits	PC	15811255	4581[a]		MJ/t product	Own calculation
Waffles and wafers	PC	15821259	3195[a]		MJ/t product	Own calculation
Flours	PC	156112100+15612200+15612400	420	30	MJ/t product	Carlsson-Kanyama and Faist, 2001
Soup and broths	PC	15891100	7659[a]		MJ/t product	Own calculation
Pasta	PC	156113133+156113135+15613230	648	2	MJ/t product	European Commission, 2003

mt: tonne; a: due to confidentiality restrictions data is only shown as primary energy; PC: Prodcom number; A: Industrial associations

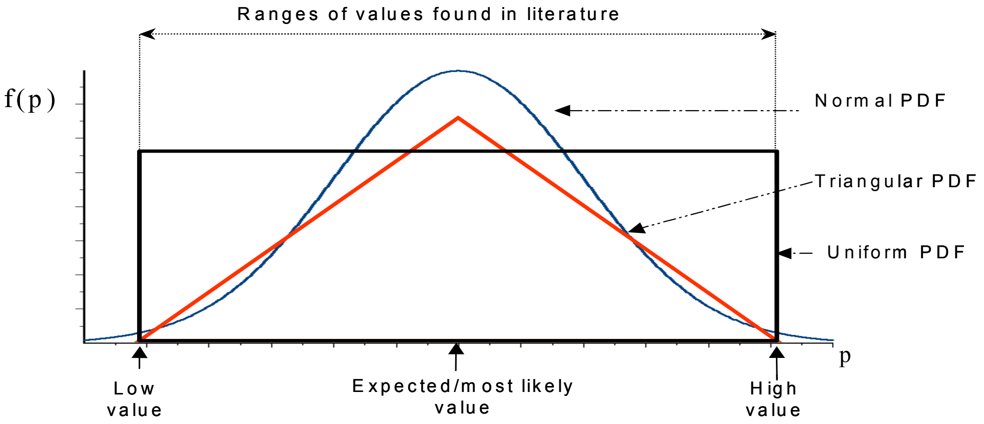
Figure 5.3 Specific electricity consumption of Dutch companies that manufacture prepared food for farm animals in 1995.



5.3.5 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 PDF’s[16] (see Figure 5.4) 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%.

Figure 5.4 Schematic illustration of probability density functions for parameter p.



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[16] Probability density functions (PDF’s) are a common way to present results. Unlike error bars, which only give a range in which the solution should fall, PDF’s 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 of the parameter value lying between p_1 *a*nd $p_1+\delta p$ 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.

As sources of uncertainty we identified the following parameters: SEC's 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 were available we use Crystal Ball to fit the PDF to the data. In Appendix 1 we show the different PDF's used in this chapter for the SEC's values.

The method selected to encode the PDF's 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 ±5%.

For Prodcom data we consider that:

- There is a systematic error introduced by the fact that the answer response to the survey is not 100%; 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 chapter the following products have been listed as problematic in a confidential evaluation made by the CBS on the Prodcom survey [Bontrider and Stroeks, 2003]: sausages not of liver

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[17] In 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, 1990:96].

[18] In 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.

[19] There 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; e.g. 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].

(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 PDF's 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.

5.4 Results

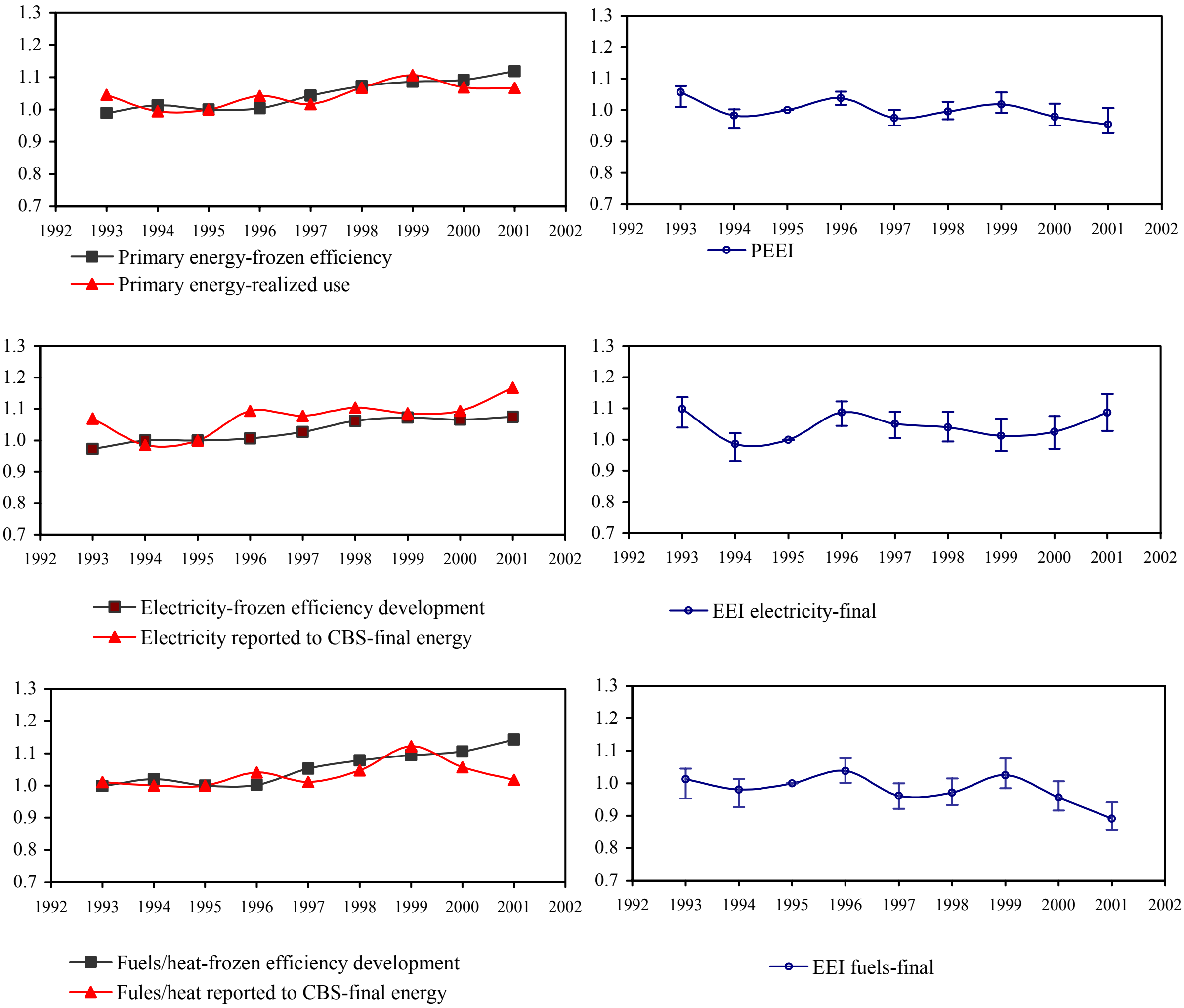
Figure 5.5 shows the trends obtained for the primary energy efficiency indicator (EEI_p) and EEI by fuel (based on final energy use) for the food and tobacco industry as well as the frozen and realized energy use. Uncertainty ranges varies between 2 and 5% for EEI_p and between 3 and 6% for EEI for fuels 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 PJ ± 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.

5.4.1 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.

Figure 5.5 Reference energy use, realized energy use and energy efficiency indicator for primary energy, final fuels/heat and electricity in the Dutch food industry.

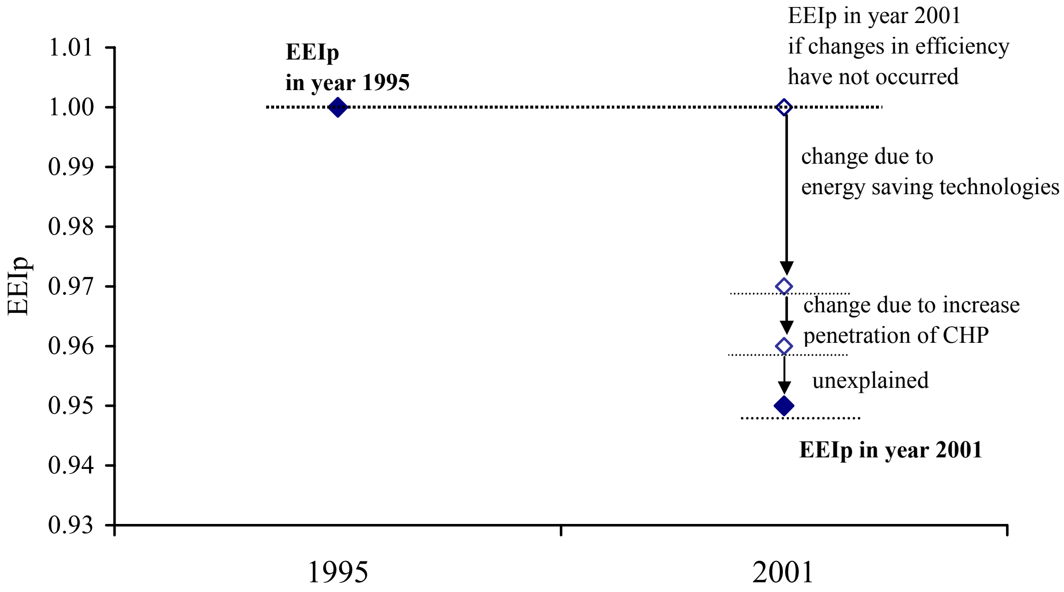


Each of these programs publishes a description of the different projects by year and sector and it specifies energy savings by fuel. We only account for projects that have been implemented in the period 1995-2001 (when it was not specified in the description if and when the project has been implemented, we called the companies in charge). The kind of projects and savings are shown in Table 5.3. 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 (Figure 5.6). 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 Figure 5.5 and thus it is a confirmation that the indicator is sensitive enough to reflect important changes.

Table 5.3 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

Figure 5.6 Causes of changes in the EEIp for period 1995-2001.



5.4.2 Sensitivity of the uncertainty ranges

Figure 5.5 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 5.3.5, 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 SEC's. 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 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.

Finally, we have taken into consideration that SEC's 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 SEC's for fuel and electricity, we have assumed 3 cases: i) there is a 'negative strong' dependence between electricity and fuel use, ii) there is a

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

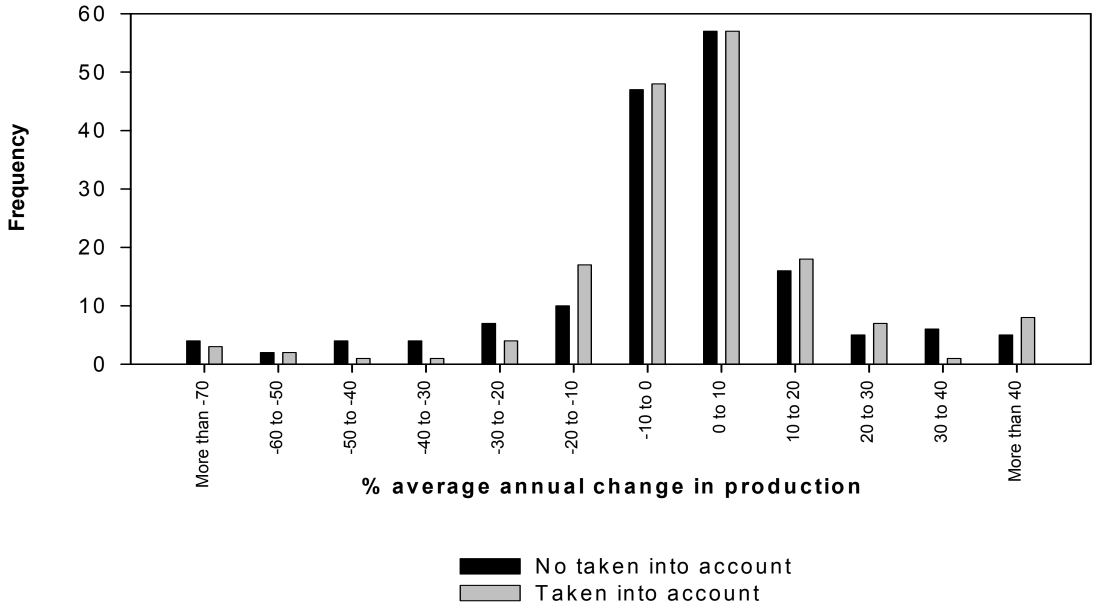
'negative weak' correlation and, iii) there is no correlation. The first case applies especially to products where most of the energy is used for concentration/evaporation (i.e. powder products). Here high use of fuels/heat is generally accompanied by a lower demand of electricity (e.g. evaporation with 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 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 (e.g. 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 this chapter 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.

5.4.3 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 5.3.4, we do not take into account all products when developing EEIs (the 49 product categories shown in table 5.2 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 chapter is representative, we have 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. Figure 5.7 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).

Figure 5.7 Histograms for annual change in production when developing energy efficiency indicators.



5.4.4 Comparison with data from the Long Term Agreements

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 Figure 5.5 have been calculated based on 49 SEC values (Table 5.2) 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 chapter 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 to 2001j].

Figure 5.8 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 additional sectors plus some food products are included (this is the result shown in Figure 5.5). 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, Figure 5.9 shows the indexes for those industries with a LTA. From Figures 5.8 and 5.9 we conclude that the indexes developed in this study accurately reflect the frozen energy efficiency behavior of the Dutch food and tobacco industry.

Figure 5.8 Primary frozen energy efficiency in the food and tobacco industry according to this study and according to the LTA.

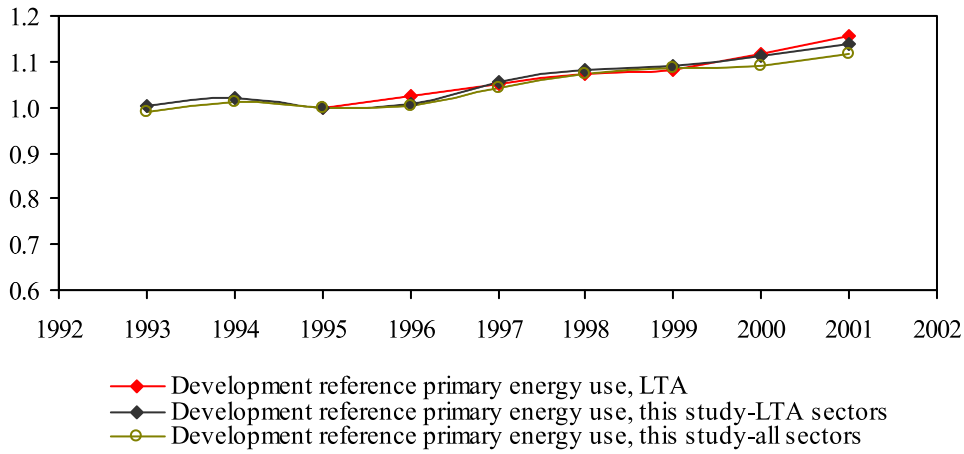
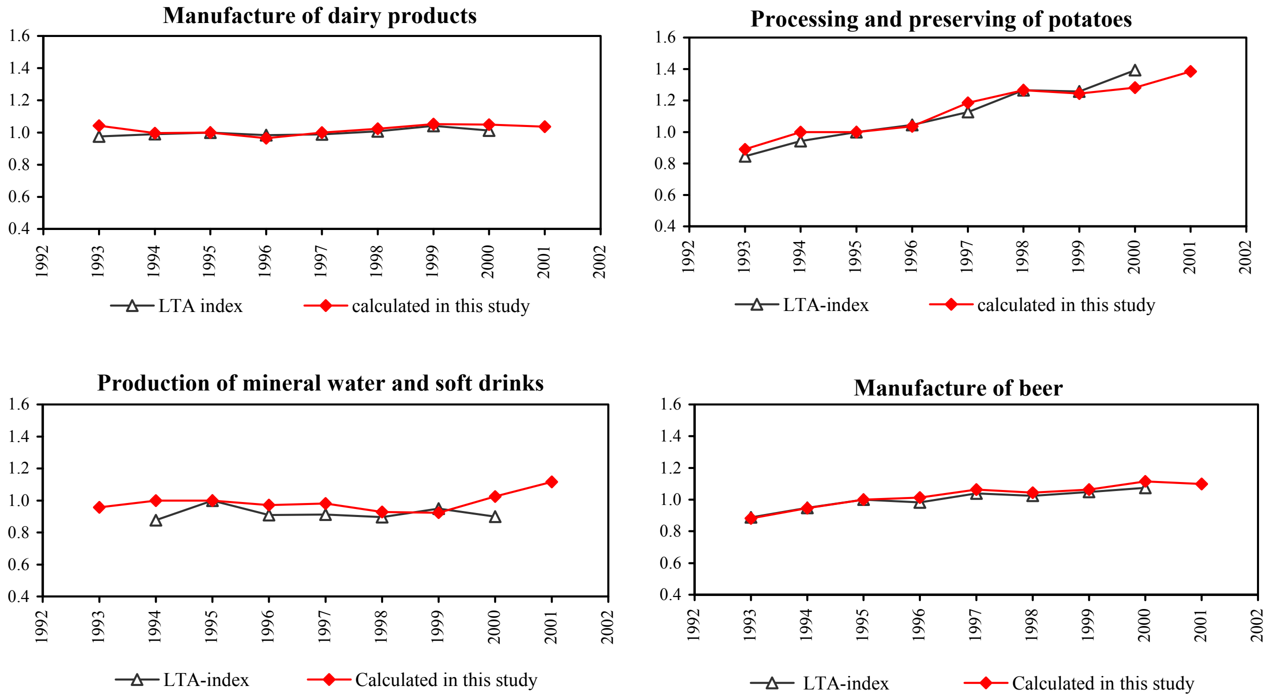
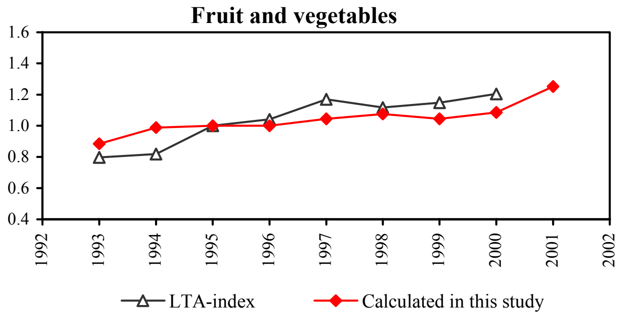
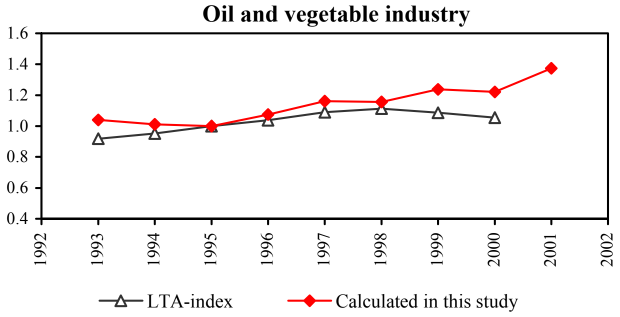
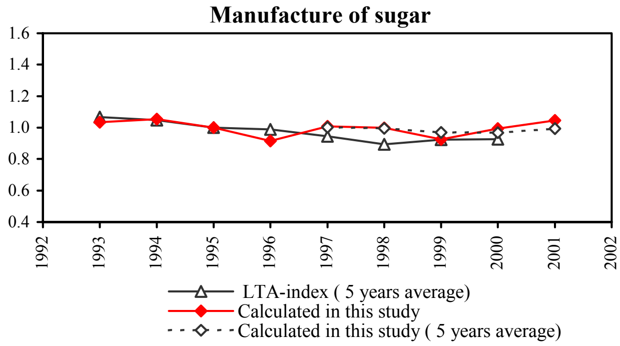


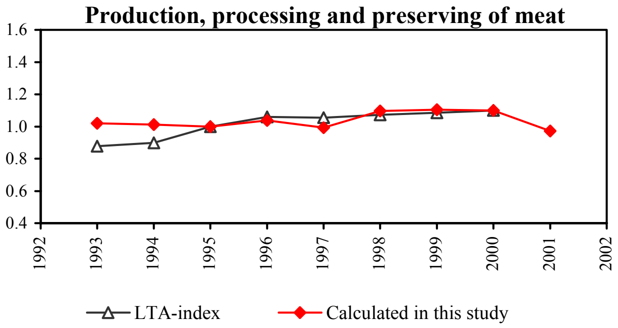
Figure 5.9 Primary frozen energy efficiency development by branch in the food industry according to this study and the LTA (indexed to 1995).

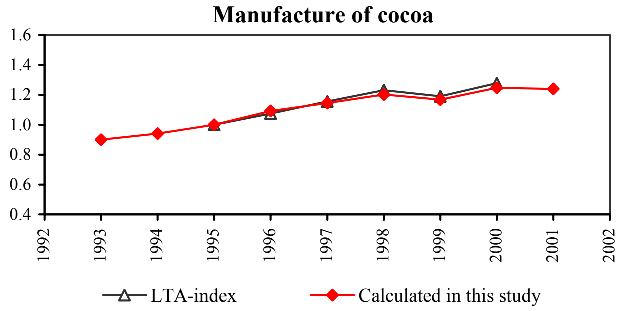


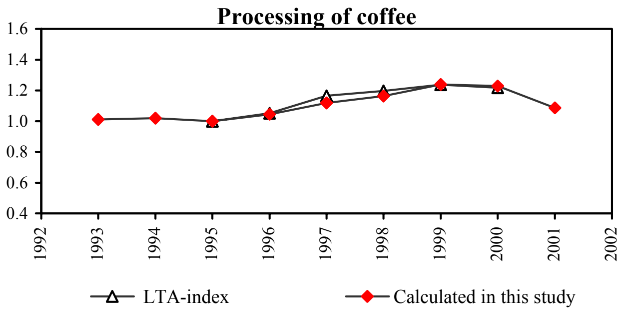












5.5 Conclusions

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

Acknowledgements

The authors are grateful to Mr. Wouter Tinbergen and Mr. Theo Klinkers (†) from the National Statistical Office of the Netherlands (CBS) for their help on gathering and interpreting the data used in this chapter; to prof. Dr. Bert Balk and the people from CEREM that made possible the access to firm level data and to Dr. Jeroen van der Sluijs (Utrecht University) for his help on the development of the uncertainty analysis.

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Appendix. Probability distribution functions used in this paper.

	PDF attributes	
Parameter/product	**SEC fuels**	**SEC electricity**
Beef+ Sheep	Triangular [483-591]	Triangular [100-500]
Pig	Log normal σ = 157	Log normal σ = 65
Poultry	Log normal σ = 218	Log normal σ = 237
Processed	Triangular [2555-4345]	Triangular [490-1017]
Rendering	Triangular [984-3000]	Triangular [100-350]
Fresh (fillets)	Triangular [6-7]	Triangular [90-168]
Frozen	Triangular [6-7]	Triangular [520-810]
Prepared or preserved fish	Triangular [906-1268]	Triangular [337-627]
Smoked and dried	Triangular [1869-2285]	Triangular [840-1560]
Fish meal	Triangular [5580-6820]	Triangular [547-821]
Potatoes products	Triangular [3220-3935]	Triangular [621-932]
Unconcentrate Juice	Uniform [610-1100]	Uniform [200-400]
Tomato juice	Triangular [3500-5268]	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 [1400-1900]	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 [3008-5332]	Triangular [73-135]
Milk and fermented products	Log normal σ = 63	Log normal σ = 63
Butter	Triangular [1157-1414]	Triangular [411-563]
Milk powder	Log normal σ = 224	Log normal σ = 224
Condensed milk	Triangular [1742-2130]	Triangular [266-325]
Cheese	Log normal σ = 1820	Log normal σ = 1820
Casein and Lactose	Log normal σ = 412	Log normal σ = 91.8
Whey powder	Triangular [6910-12831]	Triangular [800-1552]
Wheat starch	Uniform [6768-10998]	Uniform [1692-4230]
Maize starch	Uniform [1332-3330]	Uniform [666-1332]
Potato starch	Uniform [1188-5940]	Uniform [950-1901]
Food for farm animals	Log normal σ =608	Log normal σ = 140
Food for pets	Triangular [1144-2900]	Triangular [31-65]
Refined sugar	Triangular [5024-6699]	Triangular [202-824]
Cacao	Triangular [3391-4152]	Triangular [947-1157]
Non roasted coffee	Triangular [130-193]	Triangular [112-169]
Roasted coffee	Triangular [1600-2416]	Triangular [415-622]
Extracts of coffee solid form	Triangular [8910-14000]	Triangular [1071-1301]

	PDF attributes	
Parameter/product	**SEC fuels**	**SEC electricity**
Beer	Triangular [138-169]	Triangular [18-22]
Mineral water	Triangular [179-219]	Triangular [106-160]
Unsweetened water and soft drinks	Triangular [290-436]	Triangular [97-144]
Cigar	Triangular [19-61]	Normal σ =15
Cigarettes	Triangular [5-6]	Triangular [4-5]
Sweet Biscuits	Triangular [2700-5300]	Triangular [660-760]
Waffles and wafers	Triangular [2700-3300]	Triangular [63-84]
Flours	Triangular [200-430]	Triangular [240-540]
Soup and broths	Uniform [2700-5300]	Uniform [1296- 2037]
Pasta	Triangular [2-3]	Triangular [504-940]

Part III

Energy use in the food supply chain

CHAPTER 6

Feeding Fossil Fuels to the Soil. An Analysis of Energy Embedded and Technological Learning in the Fertilizer Industry[*]

Abstract

In this chapter we assess energy demand due to fertilizer consumption in the period 1961-2001. Based on historical trends of gross energy requirements, we calculate that in 2001 global energy embedded in fertilizer consumption amounted to 3660 PJ, which represents about 1% of the global energy demand. Total energy demand has increased at an average rate of 3.8 % p.a. Drivers behind the trend are rising fertilizer consumption and a shift towards more energy intensive fertilizers. Our results show that despite significant energy efficiency improvements in fertilizer manufacture (with exception of phosphate fertilizer in the last 20 years) improvements in energy efficiency have not been sufficient to offset growing energy demand due to rising fertilizer consumption. Furthermore, we found that specific energy consumption of ammonia and urea developed in close concordance with the learning curve model, showing progress ratios of 71% for ammonia production and 88% for urea. This suggests an alternative approach for including technological change in energy intensive industries in middle and long-term models dealing with energy consumption and CO_2 emissions.

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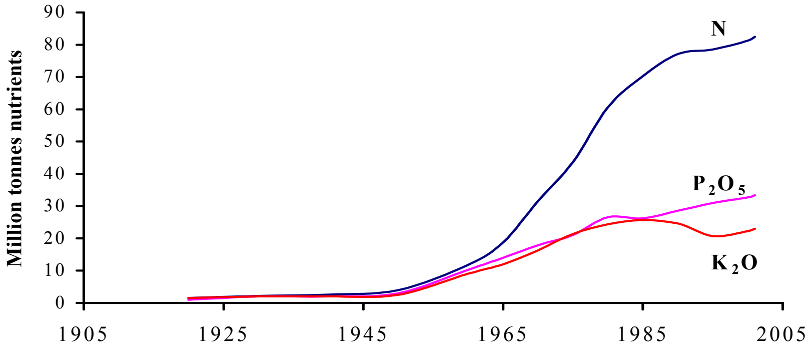
[*] Article in Press in *Resources, Conservation and Recycling.* Co-author: E. Worrell.

6.1 Introduction

The growth of fertilizer use is an integral part of the technological revolution in agriculture that has generated major changes in production techniques, shifts in inputs and growth in output and productivity. Although several fertilizers have been known for over a century (e.g. superphosphate production by treatment of ground bones with sulfuric acid was patented in 1842), it is only in the last 50 years that growth in fertilizer consumption has really taken place (Figure 6.1). In the year 2001, about 137 million tonnes of fertilizer nutrients were applied around the world. The growth in agricultural production has been enabled by the growth of yields that has been accompanied by an increasingly intensive use of land [FAO, 2003]. With higher yields normally demanding higher fertilizer application rates, and with this trend expecting to continue for the next 30 years, debate is also intensifying over the interactions between increasing fertilizer application and the effects on ecosystem stability, biodiversity and processes of climate change.

Figure 6.1. Historical trends of world fertilizer consumption.



Source: IFA , 2004

Several analyses of the energy embedded in fertilizers can be found in literature, especially in the late 1970s and early 1980s [e.g. Achorn and Salladay, 1982; Disney and Aragan, 1977; Hignett and Mudahar, 1982; Honti, 1976; Lockeretz, 1980] when higher energy prices affected the price and supply of fertilizers. Interest in the topic seemed, however, to have decreased with the fall in energy prices. Only, from the beginning of the 1990s concern for climate change (related with the high use of fossil fuels needed to produce fertilizers) increased again the attention to energy consumption and energy efficiency in fertilizer production [e.g. Worrell and Blok, 1994]. For instance, the indirect energy use due to increase fertilization has proven to be a determining factor on calculating the net available energy benefits of biofuels [e.g. Pimentel, 2001; Patzek, 2004; Worrell et al., 1995].

If the interactions between fertilizer application and climate change are to be better understood, there is a need for studies that analyze the role that different factors (e.g. energy efficiency, increasing fertilizer consumption) have played in the development of energy use. There is, however, a remarkable lack of this kind of studies. In this context, the purpose of this chapter is twofold. First, to analyze the impact of improvements in energy efficiency during the manufacture of fertilizers in world energy demand (due to increased fertilizer consumption), and second, to examine technological learning in the fertilizer industry. This chapter is composed of two parts. In the first, we develop historical trends of gross energy requirements by kind of fertilizer and assess the energy demand embedded in fertilizer consumption for the time period 1961-2001. Furthermore, we examine the role of fertilizer consumption, fertilizer mix and changes in energy efficiency in total energy demand. In the latter part, we explore whether technological development in the fertilizer industry can be analyzed using the concept of learning or experience curve to study energy efficiency development in the fertilizer industry.

6.2 Methodology

In this chapter, energy and mass balances are made for the following fertilizers (see also Table 6.1): Ammonia, ammonium nitrate (AN), calcium Ammonium nitrate (CAN), urea, single superphosphate (SSP), triple superphosphate (TSP), mono- and di-ammonium phosphate (MAP & DAP), muriat of potash (Potassium Chloride), PK 22-22 and complex fertilizers (NPK). In 2001, these fertilizers accounted for 83% of total nitrogen[1], 91% of total phosphates, and 96% of total potash consumed in the world.

Table 6.1. Composition of important fertilizers, as percentage of final product.

Product	Nitrogen [N]	Phosphorus [P_2O_5]	Potassium [K_2O]
Nitrogen fertilizers			
Ammonia	82	0	0
Ammonium sulphate	21	0	0
Ammonium nitrate	33-35	0	0
Calcium ammonium nitrate	25	0	0
Urea	46	0	0
Phosphate fertilizers			
Single superphosphate	0	16-20	0
Tripple superphosphate	0	46	0
Monoammonium phosphate	11	52	0
Diammonium phosphate	18	46	0
Potash fertilizers			
Muriat of potash (potassium chloride)	0	0	60
Sulfate of potash	0	0	50
Complex fertilizers			
NP fertilizers	15-25	15-25	0
NK fertilizers	13-25	0	15-46
NPK fertilizers	5-25	5-25	5-25

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[1] The other 17% is made up by nitrogen solutions, calcium nitrate, sodium nitrate, ammonium chloride, calcium cyanamid and ammonium bicarbonate.

We distinguish between specific energy consumption (SEC) and gross energy requirement (GER). SEC is defined as the amount of energy used (as fuel, heat, electrical or mechanical energy) to produce one unit of product. GER is defined as the amount of energy which is sequestered by the process, including energy to produce the raw materials in the course of the production of a specific process [Worrell and Blok, 1994]. For instance, we define the SEC of ammonium nitrate (AN) as the amount of electricity, heat and fuels used to covert ammonia and nitric acid to one tonne of AN, while the GER also includes the energy (electricity, heat and fuels) used to produce ammonia and nitric acid. In our analysis, we do not include the energy use for transportation of raw materials and distribution of fertilizers. The analysis of GER can be understood as a simplified LCA of the fertilizer industry focusing on energy use. Historical developments of SEC by product were calculated in this chapter using fossil fuel and electricity data gathered from literature. GER were calculated using the SEC trends and literature data on input efficiencies by process. All energy data is expressed in lower heating value (LHV). We use metric units throughout this study.

Energy consumption is analyzed at the process boundary, and adjusted to a primary fuel equivalent basis. The primary fuel equivalent energy requirement of electricity was calculated based on historical efficiency development of power plants. Where steam data is given, energy values are converted into primary fuel assuming 85% boiler efficiency.

In order to single out the influence of increasing fertilizer consumption, changes in the mix of fertilizers use and changes in energy efficiency during fertilizer manufacturing on the total energy embedded in fertilizer consumption, we apply a statistical decomposition methodology. Statistical decomposition allows us to "give quantitative measures of the relative contributions of a set of pre-defined factors leading to the change in the aggregate indicator" [Ang and Liu, 2001:537] (for a detailed overview of existing methodologies see [Ang and Zhang, 2000]). The method used in this chapter is known as the Log-mean Divisia Index Method I (see equations 6.1-6.6).

$$D_{tot} = E_t / E_0 = D_{cons} \cdot D_{str} \cdot D_{\text{int}} \qquad \text{(Eq. 6.1)}$$

$$D_{cons} = \exp\left\{ \sum_i \omega_i(t^*) \ln(Y_t / Y_0) \right\} \qquad \text{(Eq. 6.2)}$$

$$D_{str} = \exp\left\{ \sum_i \omega_i(t^*) \ln(S_{i,t} / S_{i,0}) \right\} \qquad \text{(Eq. 6.3)}$$

$$D_{\text{int}} = \exp\left\{ \sum_i \omega_i(t^*) \ln(I_{i,t} / I_{i,0}) \right\} \qquad \text{(Eq. 6.4)}$$

$$\omega_i(t^*) = \frac{L(E_{i,0}, E_{i,t})}{L(E_0, E_t)} \qquad \text{(Eq. 6.5)}$$

Where $L(x, y) = (y - x) / \ln(y / x)$ (Eq. 6.6)

D_{tot}= Total change in energy embedded due to fertilizer consumption.
D_{int}= Effect of changes in energy efficiency during fertilizer manufacture.
D_{str}= Effect of changes in fertilizer mix .
D_{cons}= Effect of increasing consumption of fertilizers.
E_t = Total primary energy consumption of fertilizer industry in year *t*, in Gigajoules.
$E_{i,t}$ = Energy consumption due to fertilizer *i* in year *t*, in Gigajoules.
Y_t = Total fertilizer consumption in year *t* ($=\Sigma Y_{i,t}$), in tonnes.
$Y_{i,t}$= Consumption of fertilizer *i* in year *t*, in tonnes.
$S_{i,t}$ = Consumption share of fertilizer *i* in year *t* ($=Y_{i,t}/Y_t$).
$I_{i,t}$ = Energy efficiency of manufacturing fertilizer *i* ($=E_{I,t}/Y_{i,t}$), in Gigajoules per tonne.

To analyze technological development in energy efficiency we make use of the learning or experience curve concept. A learning curve provides a simple quantitative way of understanding technological progress. It is in essence “a relation between one of several, substitutable inputs and cumulative output” [IEA, 2000:26]. It most often is described by an exponential relationship between an input A and the cumulative output Z (Equation 6.7). The parameter b defines the slope of the curve and is generally referred to as the experience index. The progress ratio (PR) and the learning rates (LR) are calculated according to Equations 6.8 and 6.9. PR is the level at which input falls each time the cumulative output doubles. For instance, a PR of 85% (LR=15%) implies that the input falls to 85% of its previous level for each doubling of cumulative output. Most published material on learning or experience curves relates costs to the cumulative production or use of a technology [e.g. Spence, 1981; Lieberman, 1989; Gruber, 1992; Junginger et al., 2005]. However, in this chapter we relate specific energy consumption values to the cumulative production of the fertilizer. By analogy our experience curve can be expressed as Equation 6.10.

$$A = c \cdot Z^b; \qquad \text{(Eq. 6.7)}$$
$$PR=2^b; \qquad \text{(Eq. 6.8)}$$
$$LR=1-2^b; \qquad \text{(Eq. 6.9)}$$
$$SEC_i = SEC_{i,0} * CP^b; \qquad \text{(Eq. 6.10)}$$

Where SEC is the specific energy consumption of product *i*; $SEC_{i,0}$ is the specific energy consumption of the first unit produced; CP is the cumulative unit production; b is the experience index.

6.3 The fertilizer sector

The fertilizer sector is defined here as the chemical or physical transformation of raw materials into mineral fertilizers. Table 6.1 shows typical compositions of main fertilizer products in terms of three major nutrients: nitrogen, phosphorus and potassium[2]. Departing from world fertilizer consumption figures published by the International Fertilizer Association [2004] and input efficiencies by process, we have calculated nutrients flows for the year 2001 (Figure 6.2). This figure illustrates the importance of ammonia in the fertilizer industry. A brief description of the processes named in Figure 6.2 is given in Table 6.2. For a more extended description of each process we refer to Kirk-Othmer [1993]; European Commission [2004] and Wiesenberger [2002].

Table 6.2 Brief descriptions of production processes by kind of fertilizer.

Product	***Description***	***Main reactions***
Ammonia NH_3	Produced by the reaction between hydrogen and nitrogen at high pressure (Haber process). There are two main stages: the reforming stages (first and second reformer) and the converting stage (ammonia synthesis). Between these two stages, carbon monoxide is converted into carbon dioxide and removed from the process.	$\left.\begin{array}{l} CH_4 + H_20 \rightarrow CO + 3H_2 \\ CH_4 + 2H_20 \rightarrow CO_2 + 4H_2 \end{array}\right\}$ primary reformer $\left.\begin{array}{l} 2CH_4 + O_2 \rightarrow 2CO + 4H_2 \\ CH_4 + O_2 \rightarrow CO_2 + 2H_2 \end{array}\right\}$ secondary reformer $\left. CO + H_20 \rightarrow CO_2 + H_2 \right\}$ Water-Gas- shift $\left. N_2 + 3H_2 \rightarrow 2NH_3 \right\}$ Ammonia synthesis
Urea NH_2CONH_2	Produced by reacting ammonia and carbon dioxide.	$2NH_3 + CO \rightarrow NH_4COONH_2$ $NH_4COONH_2 \rightarrow NH_2CONH_2 + H_20$
Nitric acid HNO_3	Produced by the oxidation of ammonia.	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_20$ $2NO + O_2 \rightarrow 2NO_2$ $3NO_2 + H_20 \rightarrow 2HNO_3 + NO$
Ammonium nitrate NH_4NO_3	Produced by reacting ammonia with nitric acid.	$NH_3 + HNO_3 \rightarrow NH_4NO_3$
Calcium ammonium nitrate $Ca(NO_3)_2$	Produced by mixing slurry of ammonium nitrate with a filler containing ground dolomite, ground limestone or with byproduct calcium carbonate.	$2NH_4NO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + 2NH_3 + CO_2 + H_20$
Sulfuric acid H_2S0_4	Produced by the oxidation of sulfur	$S + O_2 \rightarrow SO_2$ $SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$ $SO_3 + H_20 \rightarrow H_2S0_4$
Ammonium sulfate $(NH_4)_2SO_4$	It is mainly a byproduct from manufacture of caprolactam and acrylonitrile, scrubbing coke oven gas or from other processes. It can also be produced directly by neutralizing ammonia with sulfuric acid or from a solution which is obtained.	$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

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[2] Nitrogen is essential for growth and development in plants. Phosphorous is vital for adequate root development while potassium is central to the translocation of photosynthesis and for high yielding crops.

Product	*Description*	*Main reactions*
Phosphoric acid[a],[b] H_3PO_4	Produced from the reaction of phosphate rock and sulfuric acid.	$3Ca_3(PO_4)_2.CaF_2 + 10H_2SO_4 + 20H_20 \rightarrow 10CaSO_4.2H_20 + 2HF + 6H_3PO_4$
Superphosphates	Produced by reacting phosphate rock and sulfuric acid (single superphosphate) or phosphoric acid (triple superphosphate).	$Ca_{10}F_2(PO_4)_6 + 7H_2SO_4 + H_20 \rightarrow 2HF + 3Ca(H_2PO_4)_2.H_20 + 7CaSO_4$ } SSP $Ca_{10}F_2(PO_4)_6 + 7H_3PO_4 + 10H_20 \rightarrow 2HF + 10Ca(H_2PO_4)_2.H_20$ } TSP
Ammonium phosphate	Produced by neutralizing phosphoric acid with ammonia.	$2NH_3 + H_3PO_4 \rightarrow (NH_4)HPO_4$ } DAP $NH_3 + H_3PO_4 \rightarrow NH_4H_2PO_4$ } MAP
Potassium chloride (potash)[c]	Occurs naturally in association with sodium or magnesium chloride	
Compound fertilizers	They are produced either by chemical or physical blending.	

[a]: Pure phosphoric acid has the chemical form H_3PO_4 but is customary in the phosphate industry to express quantities of phosphate fertilizer in terms of the equivalent P_2O_5 content. Thus 1 tonne of phosphoric acid (100%) is equivalent to 0.724 tonne P_2O_5; [b]: The process described is generally known as the classical or dehydratate process (DH). Two variations which reduce the energy use are the hemihidratate and the hemidratate dehydrate process. The main difference between these two process and DH is that higher strength H_2SO_4 is used which results in direct production of H_3PO_4 at a strength of 50% P_2O_5, obviating the need for evaporative concentration; [c]: Strictly, potash has the chemical form of K_2O, but in the fertilizer industry potassium chloride (KCl) is referred to as potash and is normally recorded in by its K_2O equivalent: 1 tonne of KCl is equivalent to 0.632 tonne K_2O.

6.4 Energy embedded in fertilizer consumption

The first step to calculate the energy embedded in fertilizer consumption is to obtain historical trends in SEC for each fertilizer. The trends are then use to calculate GER using input efficiencies by process. In order to illustrate the procedure used, Figure 6.3 shows how the GER trend for ammonium nitrate (AN) was obtained: from SEC trends for the production of ammonia, nitric acid and AN. Each point in the graphs represents typical SEC values for the average of plants in a given year. The points were obtained from a literature review (about 50 sources, which include state of the art analyses; reports and books on chemical processes and technologies; companies brochures; scientific articles, etc.)[3], and included data for different geographical regions. In this way, the trends characterize the average developments of SEC in the world. Feedstocks requirements needed to calculate GER are shown on top of the arrows. The values represent stoichiometric requirements and are constant during the period studied[4]. Negative values of the SEC for nitric acid appear because a) all chemical reactions in the production of nitric acid are exothermic and b) plants have improved heat utilization and consequently, modern

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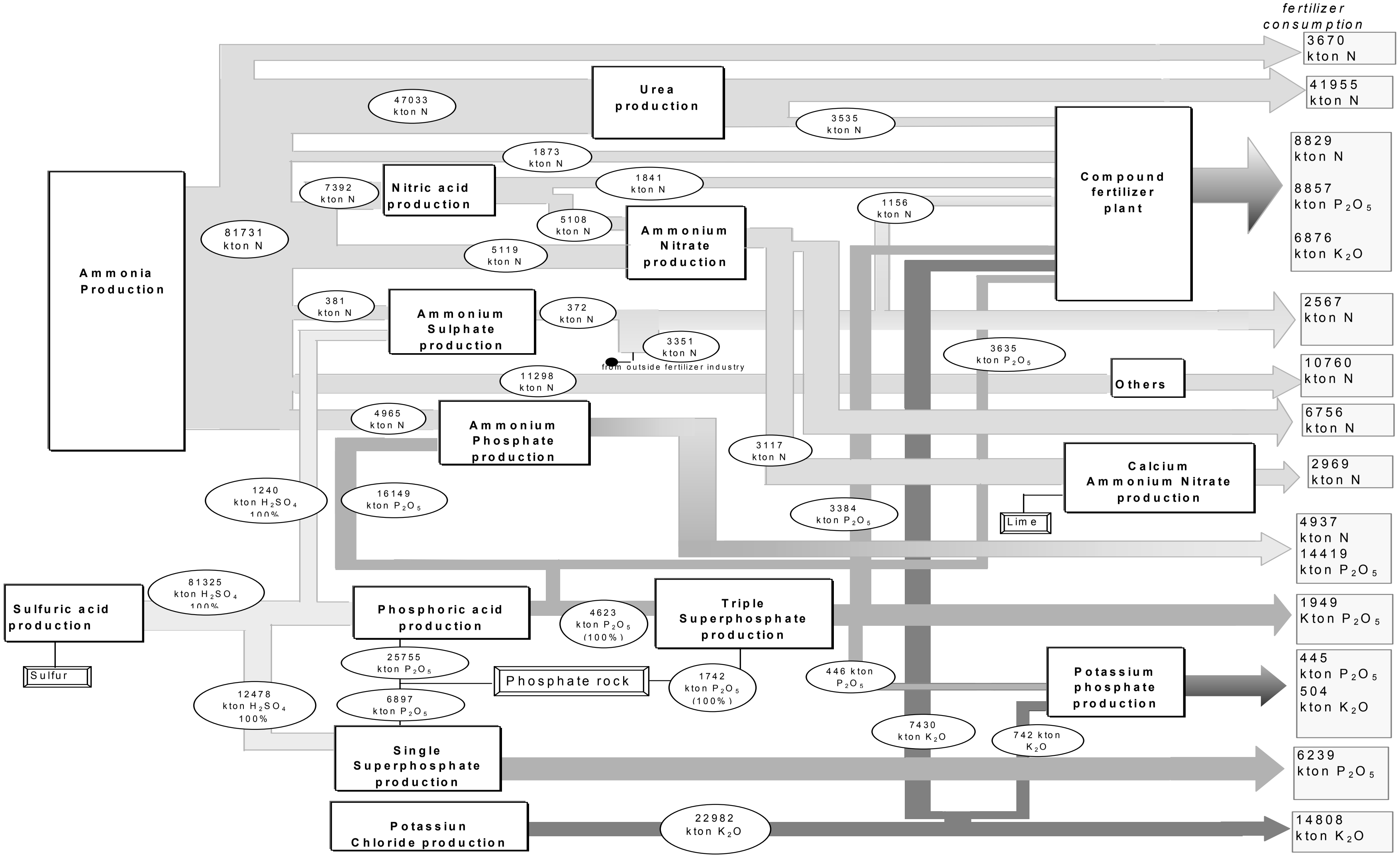
[3] Data gathered in the literature is available by contacting the author.

[4] Deviations on from the stoichiometric requirements reported in the literature were found to be of less than 10%, which justifies to use stoichiometric values in this analysis.

Figure 6.2. Global nutrient flows, 2001.



Note: This balance does not include the following fertilizer categories: basic slag, ground phosphate rock, Fused magnesium phosphate, dicalcium phosphate, phosphoric acid (applied direct), potassium magnesium sulphat and crude potash salts. They account for about 2% of the total nutrient consumed in the year 2001. The category named "other" include: nitrogen solutions, calcium nitrate, sodium nitrate, ammonium chloride, calcium cyanamide, ammonium bicarbonate.

We have assumed the following routes for the processing of compound fertilizers: 40% based on ammonium nitrate, phosphoric acid and potassoim chloride, 40% from urea, triplesuperphosphate and potassium chloride and 20% is based on Amonium sulphate, diamonnium phsophate and potassium chloride.We also asummed that only 10% of the Ammonium sulfate is produced in the fertilizer industry, the rest is a by-product of caprolactam production and gas scrubbing.

plants export heat. Note that the technological development in ammonia production is the most important factor in the GER of AN and in fact, of all nitrogen fertilizers.

Figure 6.3 SEC and GER involved in the production of Ammonium Nitrate (AN).

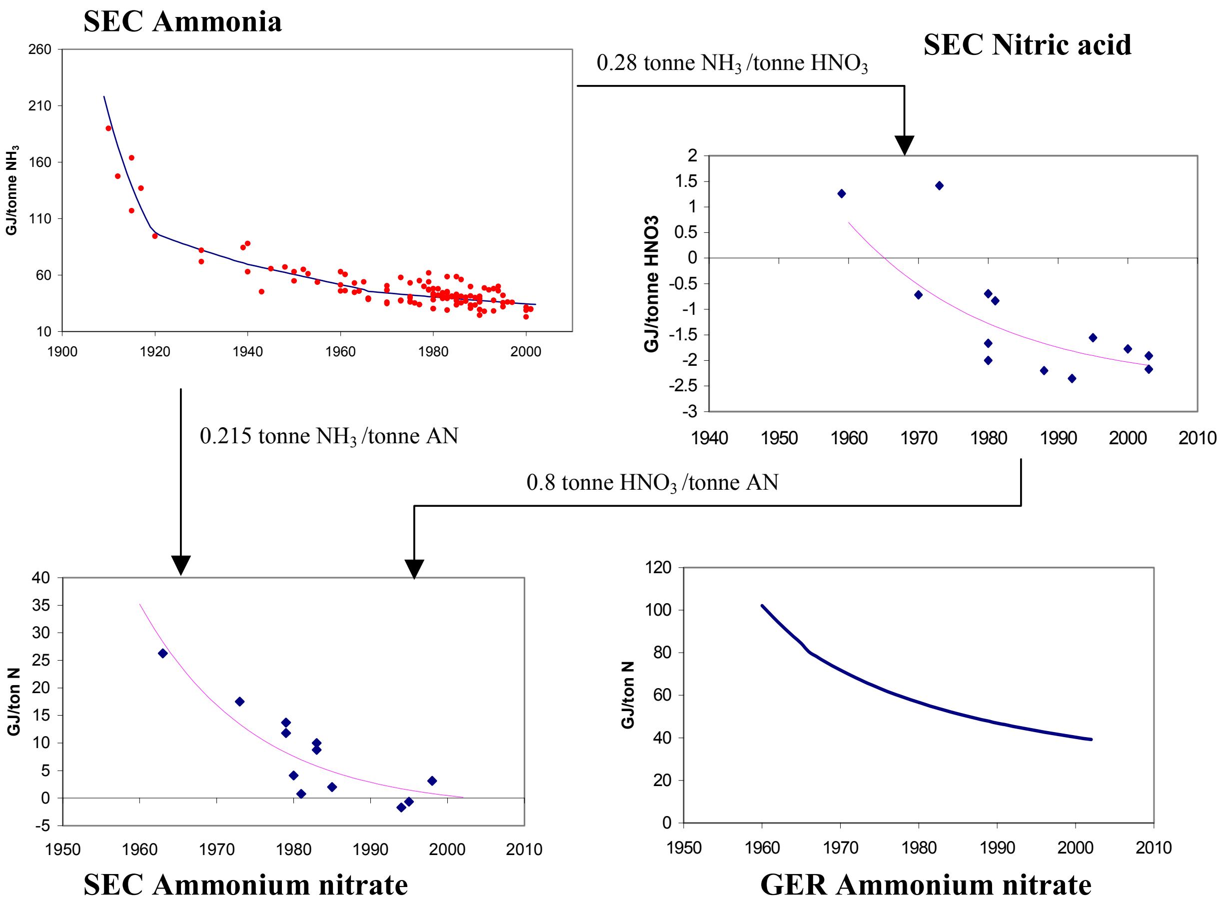
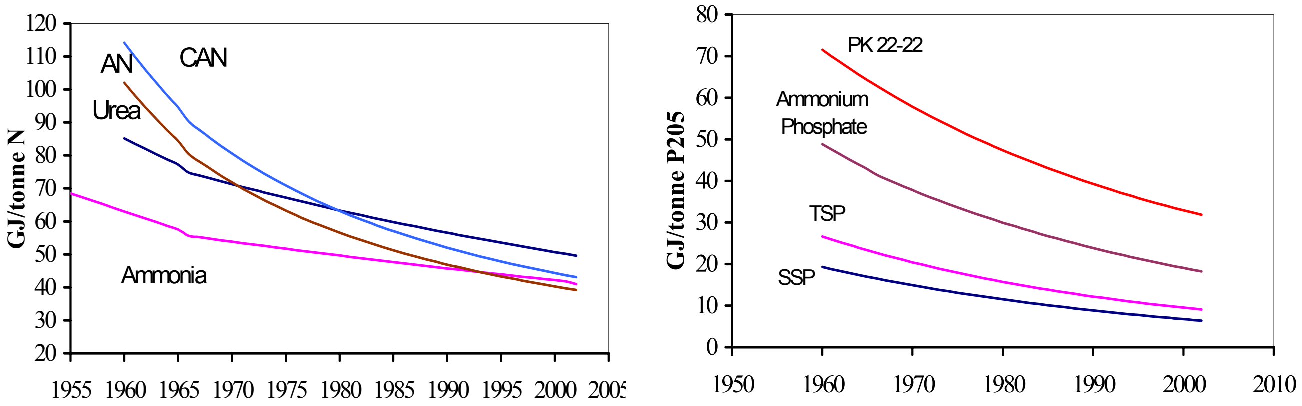


Figure 6.4 shows the historical developments in GER obtained by kind of fertilizer. By using the GER per tonne of nutrient and the world consumption as reported by the International Fertilizer Association [IFA, 2004], we calculate world energy use by the fertilizer sector (Figure 6.5). According to our analysis, in the year 2001 energy embedded in world fertilizer consumption was about 3660 PJ, of which 72% was for the production of nitrogen fertilizers, 10% for phosphate fertilizers, 16% for complex fertilizers and only 2% for potassium fertilizers. The highest average annual rate of energy demand was shown by nitrogen fertilizers followed by compound fertilizers (4.5% p.a. and 3.9% p.a., respectively). Energy for phosphate fertilizer increased at a rate of 2.1% p.a., while the rate for potassium fertilizers was 1.7% p.a. Total energy demand increased by about 3.8% p.a. in the period 1961-2001 (this rate is the result of an increase of about 6% p.a. between 1961-1988 and a decrease of 0.3% p.a. between 1989-2001). The fall in energy demand shown between 1990 and 1994 is due to a steep decrease in fertilizer consumption (and production) in Central and Eastern Europe and Central Asia. The fall in consumption by 70% is directly linked to the changes of the economic and political systems in the region [Malinowski, 2000], and although since 1995 the agricultural

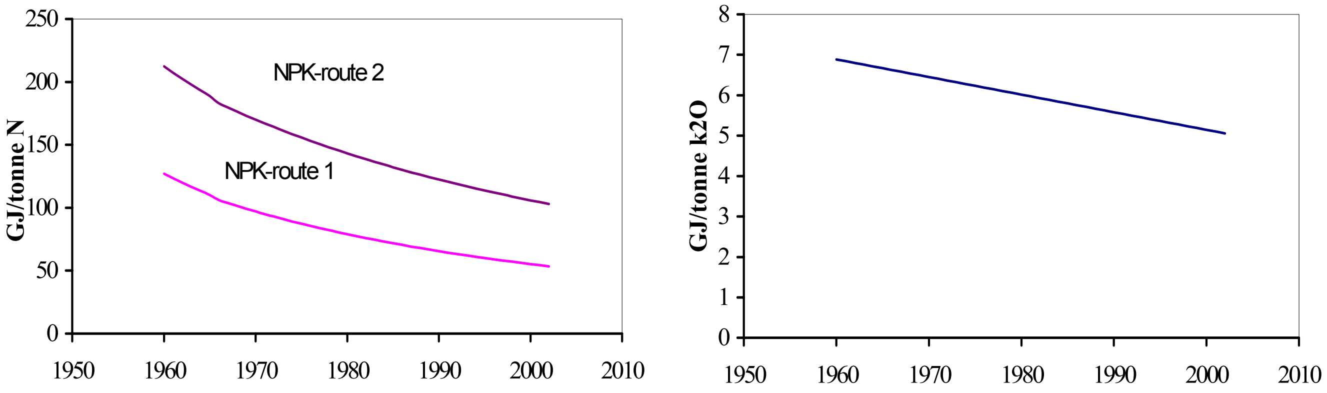
systems began to recuperate from the crisis (and fertilizer consumption began to increase), fertilizer consumption has not yet reached the peak levels of 1989.

Figure 6.4. Historical Gross Energy Requirements by type of fertilizer.

Nitrogen fertilizers **Phosphate fertilizers**

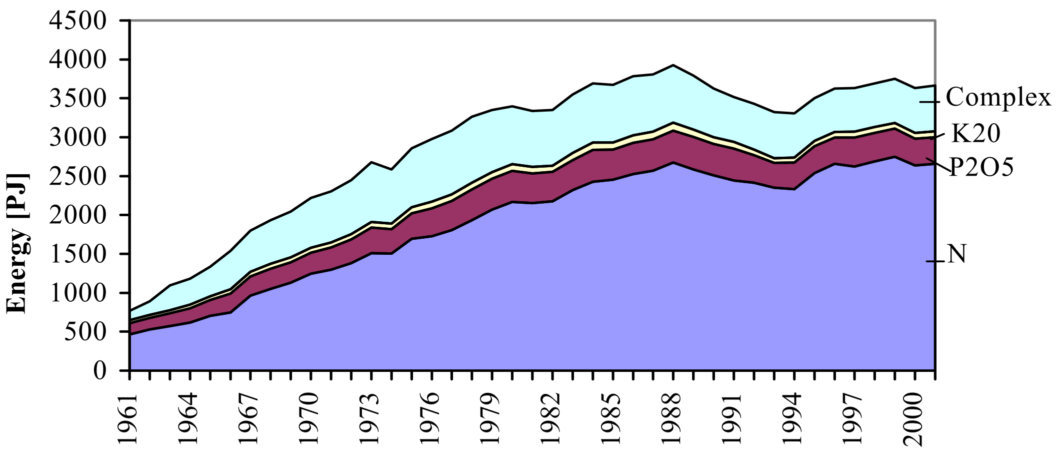


Complex fertilizers **Potash**



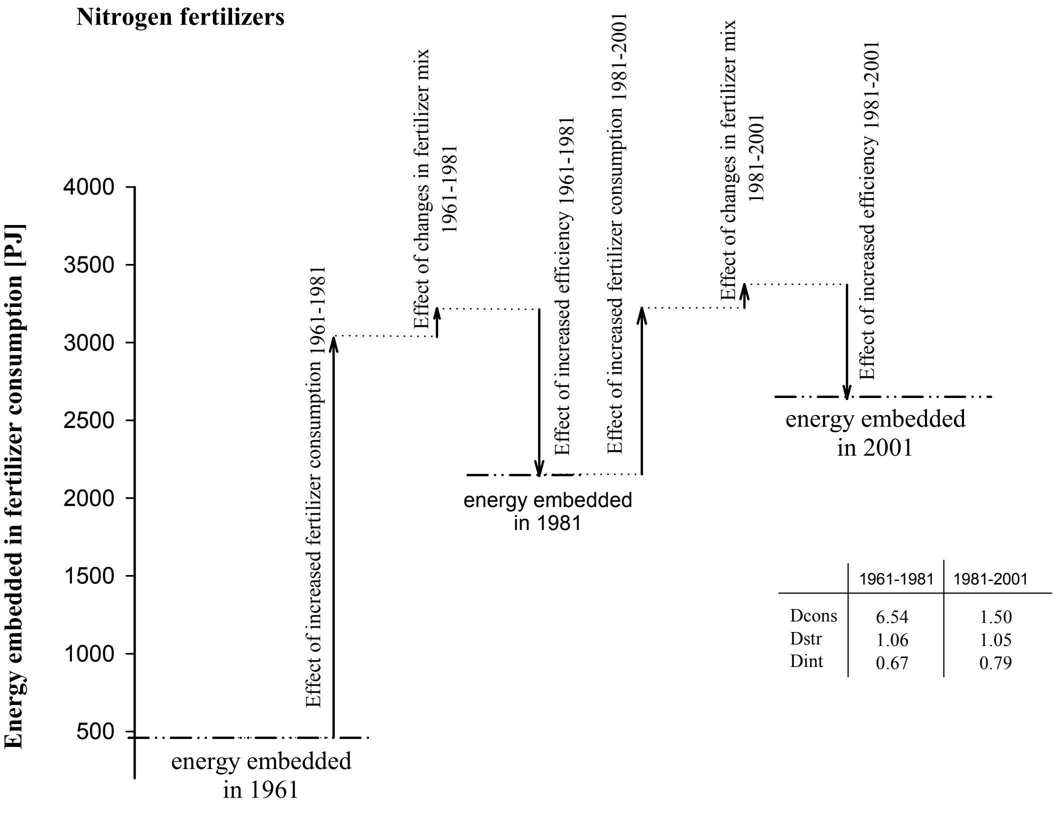
Note: The GER includes the heat content of feedstock (i.e. the heat content of natural gas in the production of ammonia and of sulfur in the production of sulfuric acid). Trends for NPK refer to a fertilizer 17-17-17. Route 1 stands for a fertilizer based on AN, Phosphoric acid and Potash while route 2 stands for a fertilizer based on Urea, TSP and Potash. In both cases all energy has been allocated to the Nitrogen content. In the case of ammonium phosphate and PK 22-22 energy has been allocated to the P_2O_5 content.

Figure 6.5 World Historical consumption of primary energy for fertilizer production.

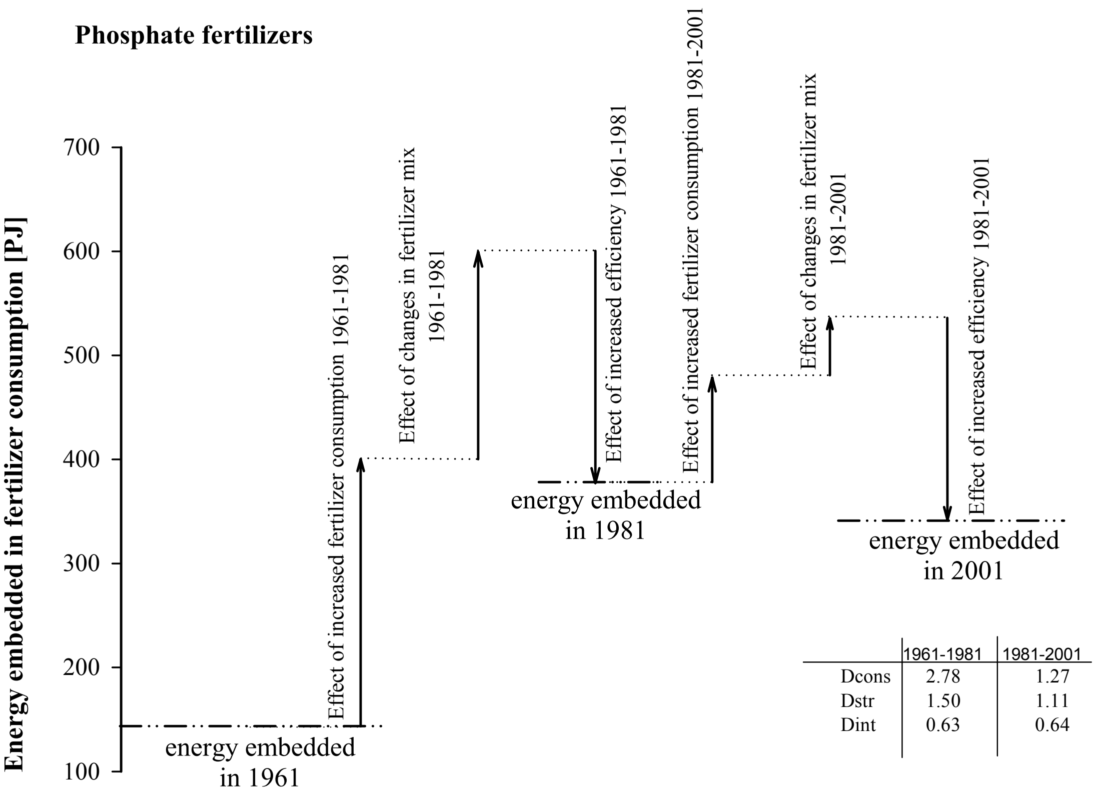


In order to understand the development in embedded energy due to fertilizer consumption between 1961 and 2001 (Figure 6.5), we have applied a decomposition methodology to each nutrient for the time period 1961-1981 and 1981-2001. The results allow us to assess the effect of improved energy efficiency in fertilizer manufacture (D_{int}), increasing consumption of fertilizers (D_{cons}) and changes in the fertilizer mix used (D_{str}) in the change in total energy embedded (D_{tot}). For nitrogen, the fertilizers (i) taken into account are: direct application of ammonia, ammonium nitrate, calcium ammonium nitrate and urea. Phosphate fertilizers are: single superphosphate, triple superphosphate, ammonium phosphate, and PK 22-22. The results for the world are depicted in Figure 6.6. There are three major findings from these results. The first is not surprising: growth in fertilizer consumption has been the main driver of increasing energy consumption. The second finding is that the fertilizer mix has moved towards more energy-intensive fertilizers per tonne of nutrient which has led to an increasing energy demand. This trend is especially significant for phosphate fertilizers (i.e. from superphosphates towards ammonium phosphates). The third implication is that although significant improvements in energy efficiency have been able to offset the increased energy consumption as a result of changes in the fertilizer mix (with exception of phosphate fertilizers in the period 1981-2001) they were not sufficient to offset the impact of increased fertilizer consumption. In the case of nitrogen fertilizers, the impact of changes in energy efficiency was higher in the period 1961-1981 than in 1981-2001.

Figure 6.6 Effect of increasing consumption, fertilizer mix and energy efficiency on the world energy use due to fertilizer consumption between 1961 and 2001.



	1961-1981	1981-2001
Dcons	6.54	1.50
Dstr	1.06	1.05
Dint	0.67	0.79



	1961-1981	1981-2001
Dcons	2.78	1.27
Dstr	1.50	1.11
Dint	0.63	0.64

6.5 Technological improvement in the nitrogen fertilizer industry: learning curves.

The results shown so far point out significant improvements in energy efficiency. In this section we further examine the nitrogen fertilizer industry, since it accounts for over 70% of the total energy demand. As mentioned earlier, the decrease in GER values of nitrogen fertilizers has been driven by the decreasing SEC of ammonia production. It is not our intention to assess all process changes that have contributed to a reduction of the specific energy consumption in the nitrogen fertilizer industry, since this has already been well documented [e.g. Appl, 1997; Quartulli and Buividas, 1976]. Instead we look at technological development as a learning process. Most published material on experience or learning curves relates prices to the cumulative production or use of a technology[5]. The mathematical equations behind the experience curve were described in Section 6.2. In this chapter, we relate the historical trends in specific energy consumption (SEC) of various nitrogen fertilizers to cumulative production. Natural gas costs represent around 70 to 90% of the ammonia production costs and (including the gas cost in ammonia production and the additional process gas costs needed for the production of urea) natural gas represents around 70-75% of urea production costs [Hydro company, 2003; Appl, 1997; UNIDO, 1967]. Hence, it is reasonable to assume that decreasing total energy consumption per unit of product has been a main driver of technological change in

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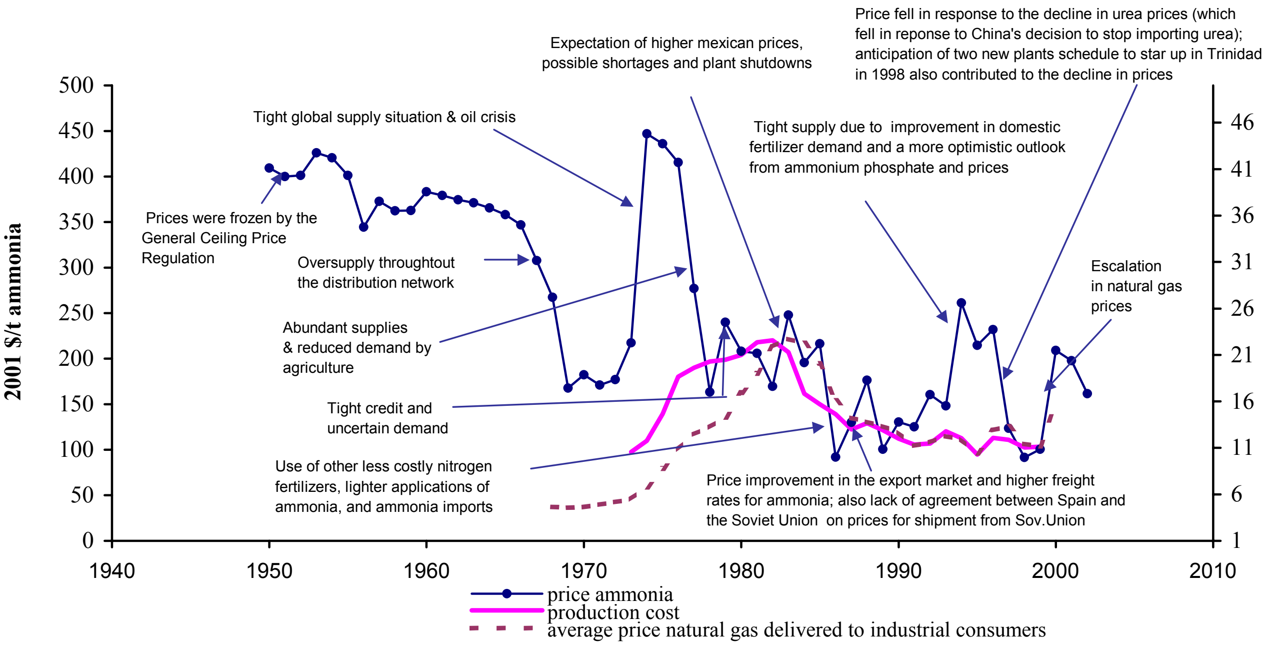
[5] Strictly speaking, learning curves apply to production cost rather that price. However, given than production costs are generally not publicly available, price data tend to be used as a surrogate measure of cost.

the nitrogen fertilizer industry. Several reports confirm this point [e.g. Swaminathan and Sukalac, 2004; Mudahar and Hignett, 1987a; Marsal, 1986; Slack and James, 1973]. Furthermore, by working with SECs instead of prices per unit of product we avoid problems associated with fluctuations of fertilizer prices that reflect market conditions, and not necessarily are related to technology productivity changes. As an example, in Figure 6.7 we plot historical trends for the US price of ammonia, production costs of ammonia and natural gas prices (all deflated to 2001 values). The figure shows the strong influence of market forces and price of natural gas on the prices and production costs of ammonia. As a consequence, the correlation factor between costs or prices and cumulative output is too weak ($R^2<0.4$) to make any strong conclusion about learning rates in US ammonia production.

Figure 6.7 Historical trends in the price of ammonia, production cost of ammonia and natural gas in the United States of America, with explanatory notes for changes in ammonia prices.



Data sources: ammonia prices: US Mineral yearbooks (several years) ; natural gas prices: Energy Information Administration (2001); production costs of ammonia: Vroomen (2004) and Midahar and Hignett (1987b).

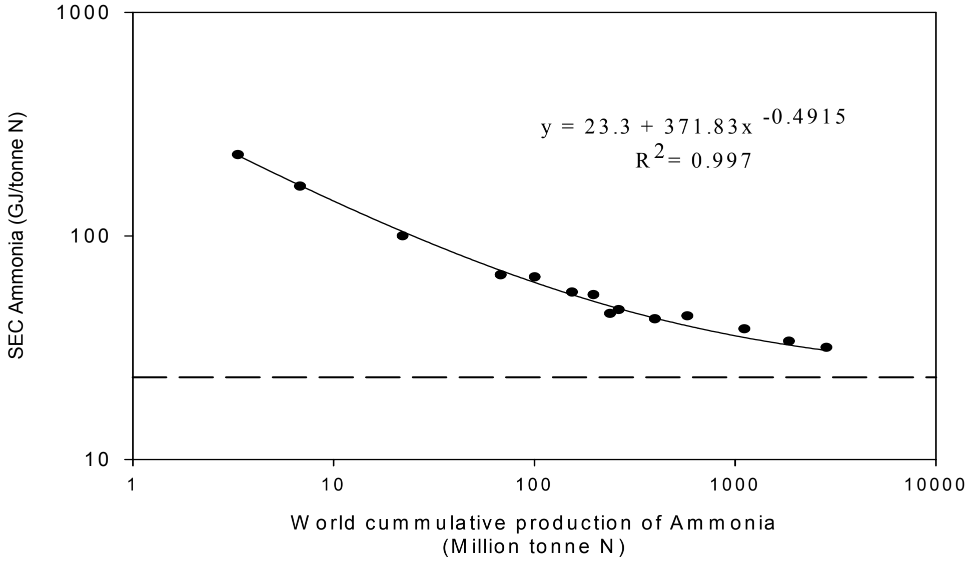
A main difference with experience curves based on prices is the existence of a physical limit: specific energy consumption figures cannot go below theoretical minimum energy requirements, for instance, in the case of ammonia 23.3 GJ/ton N (LHV). Therefore, the equation for the experience curve (equation 6.10) can be rewritten as follows:

$$SEC_i = SEC_{\min} + SEC_{i,0} * CP^b \tag{Eq 6.11}$$

where, SEC_{min} is the thermodynamically minimum energy requirement, SEC is the specific energy consumption of product i; $SEC_{i,0}$ is the specific energy consumption of the first unit produced; CP is the cumulative unit production; b is the experience index.

Figure 6.8 plots the experience curve for specific energy consumption obtained for world ammonia production between 1913 and 2001. The experience curve in Figure 6.8 is based on Best Available Technologies values (BAT). The progress ratio found for ammonia production is 71% (R^2=0.997)[6]. We compare the learning curve plotted in Figure 6.8 with a learning curve obtained by using average SEC values. Results are depicted in Figure 6.9. The progress ratio found for the average development in SEC in the period 1913-2001 is 77% (R^2=0.925). The potential for energy savings in ammonia production is still significant. Based on the current progress ratios, it will take a 3.3 doubling of the 2001 cumulative production (3066 million tons) for the world's SEC average to reach BAT performance levels of 2001 (≈ 32 GJ/tonne N). We estimate that at the current rate of annual production growth, a cumulative production of 12000 million tonnes will be reached in the year 2045. Calculations on fertilizer requirements until the year 2030, made by FAO [2000], assume, however, a slowdown in the growth of world population and crop production and an improvement in fertilizer use efficiency, which would result in growth rates of nitrogen fertilizers between 0.7% and 1.3% p.a. (compared with an average annual rate of 3% over the last 40 years). With these assumptions, a cumulative production of 12000 millions tons would be reached in the years 2065 or 2055 respectively.

Figure 6.8 Changes in SEC values for Ammonia. Best available technologies.



We performed a similar analysis for urea. Figure 6.10 shows the learning curves for BAT and average SEC development. The progress ratios found were for SEC_{BAT} 88% (R^2=0.856) and for $SEC_{average}$ 91% (R^2=0.724). Contrary to the ammonia

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[6] If the SEC_{min} is not taken into account (equation 6.10) the progress ratio is 81% (R^2=0.951).

curves were the gap between BAT and average SECs seems to be closing up, there is no indication of this happening for urea production.

Figure 6.9 Trends in SEC and cumulative production of ammonia, BAT and average technologies. Data in LHV.

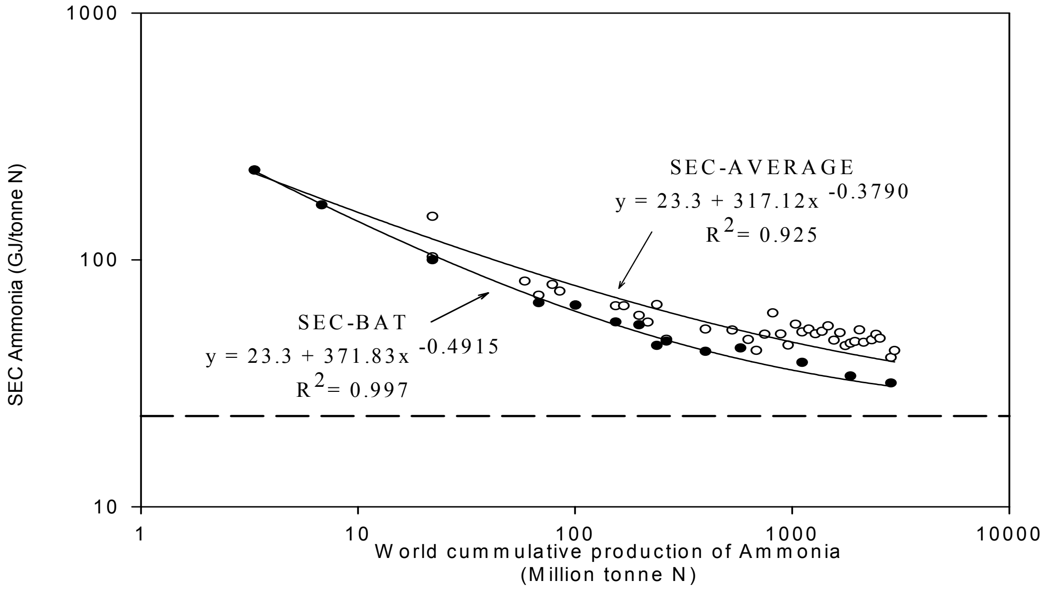
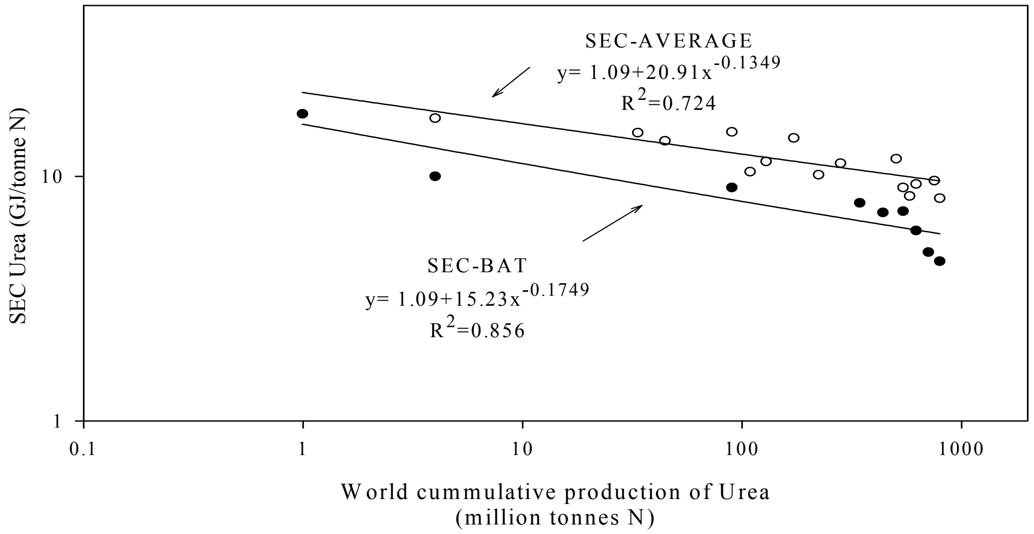


Figure 6.10 Trends in SEC and cumulative production of urea, for BAT and average developments in technologies.



We attempted to perform the same kind of analysis for other fertilizers (AN, CAN, SSP, TSP, DAP, MAP). We found that despite a decline in SEC throughout the years (Figure 6.4), correlation factors between SEC and cumulative production are too low ($R^2 < 0.65$) pointing out weak dependences among the variables. This result is not totally unexpected. Firstly, most of the processes for the manufacture of these fertilizers are relatively simple (e.g. mixing and blending) and thus the space for improvement may be more limited. Secondly, because energy plays a minor role in production costs for these processes, increased energy efficiency may not be a main driver of technological development.

6.6 Discussion and conclusions

This chapter departed from two main goals: to assess world energy demand due to fertilizer consumption and the impacts of increasing energy efficiency on total energy demand, and examining technological development using the learning curve concept. We calculate that primary energy demand for the year 2001 was about 3660 PJ which represents about 1% of the world total energy demand in 2001. Recent data on energy consumption related to fertilizers has been published by Kongshaug [1998][7], estimating the global energy consumption due to fertilizer consumption in 1998 at 3832 PJ, compared to 3629 PJ in 1998 in this study. This is a difference of 5%. Kongshaug does not publish global energy consumption figures for earlier years so it is not possible to compare trends in the development of energy consumption.

When analyzing the drivers of increasing energy demand for fertilizer production (about 3.8% p.a. for the period 1961-2001), we found that although improvements in energy efficiency have been able to counterbalance the effect of changes in fertilizer mix towards more energy intensive fertilizers, they have not been able to offset the impact of increased fertilizer consumption. A comparison with BAT developments (Figure 6.11) reveals a saving potential for the year 2001 of about 19% (687 PJ of energy). This potential is found mainly in the nitrogen fertilizer industry (Figure 6.11). For instance, we calculate the energy embedded due to nitrogen fertilizer consumption in 2001 at 2660 PJ. However, if BAT would have been used, the energy embedded in 2001 would have been 2140 PJ, which would place the energy demand due to nitrogen fertilizers in 2001 below the level seen in 1980 (2160 PJ). In other words, the implementation of BAT would have counterbalanced the effects of raising fertilizer consumption and changes in fertilizer mix in the last two decades (Figure 6.6).

As far as we know no attempts have previously been done to use the concept of learning curves to development of industrial energy efficiency. The results presented in Figures 6.7 to 6.9 reveal that over the long term, developments in specific energy consumption for ammonia and urea decline in close concordance with the learning curve concept. This is an important result since middle and long-term models of energy consumption and CO_2 emissions face the difficulty of how to consider technological changes. The use of progress ratios can provide an alternative to include technological change into scenario developments. Another consequence of our findings is that for energy intensive industries for which classical learning curves (i.e. based on prices or costs) cannot be developed due to

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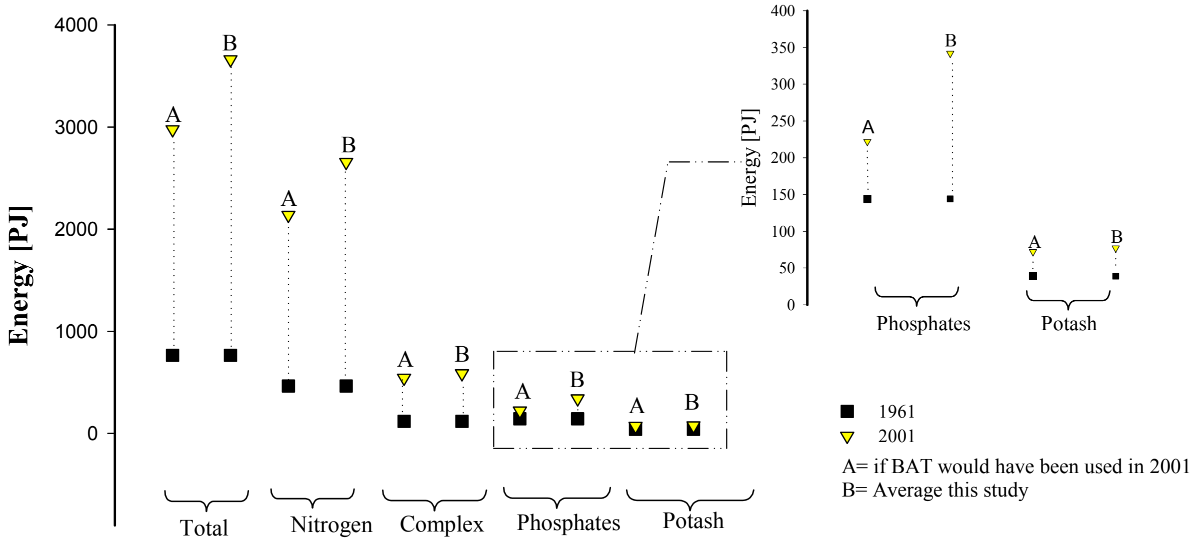
[7] We have adjusted the data provided in Kongshaugh [1998] to the number of fertilizers used in this study.

high dependences on market prices and strong fluctuations of raw material prices (e.g. ammonia, see Figure 6.7), the analysis of SEC as a main indicator of technological development can provide a way out to analyze rates of technological change for energy intensive processes (i.e. those processes for which energy is a major cost factor).

Figure 6.11 Comparison of the effect of best available technologies in global energy embedded in fertilizer consumption by kind of fertilizer, with a zoom for phosphate and potash fertilizers.



Scenario A shows the increase in energy between 1961 and 2001 if best available technologies would have been implemented in 2001. Scenario B shows the increase in energy consumpion calculated in this study.
The differences between both scenarios correspond to the savings potentials respect to BAT available in 2001.

The results in this chapter are only the first step into understanding learning in energy efficiency development. It would be interesting to test if the results found in this study for urea and ammonia apply as well to other industrial energy intensive processes. Furthermore, if the results are going to be used for more than developing business-as-usual scenarios, for instance, if progress ratios are to be changed by policy measures, the dynamics behind the learning curve need to be better understood.

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"The great conceit of industrial man imagined that his progress in agricultural yields was due to new know-how in the use of the sun….and that higher efficiencies in using the energy of the sun had arrived. This is a sad hoax, for industrial man no longer eats potatoes made from solar energy; now he eats potatoes partly made of oil".
Howard T. Odum - Environment, Power and Society.

CHAPTER 7

Energy Use in the European Food Supply Chain. Interaction between Energy and Physical Flows[*]

Abstract

The purpose of this chapter is to analyze the historical relationships of fossil fuel demand and the food production system in European countries for the time period 1970-2002. Our results show that primary energy demand has grown at an annual rate of 1.6% p.a. We found that the only part of the system showing decreasing energy demand (about 2% p.a.) is the energy needed for the manufacture of fertilizers. Agriculture, food processing and transport have increased their energy consumption at a rate of 1.6%, 1.8% and 2.3% p.a. respectively. In this chapter, we choose as functional unit the output of food and fodder expressed in value added and calorie content. We estimated that the physical output of the total food supply chain in the year 2002 was about 924 petacalories (or 3868 PJ), while the economic output of agriculture and food processing was about €342 billion of value added (5% of total GDP). Physical output of the total system has grown at a rate of 1.8% p.a. while economic output has grown at a rate of 3.6% p.a. This means that economic energy intensity decreased at a significantly higher rate (2.7% p.a.) than physical energy intensity (0.2% p.a.). If animal feed is excluded from the system, the rate at which the physical energy intensity of the system decreased is significantly lower (0.2% versus 0.04% per annum). Furthermore, we found that between 1970 and 2002 output growth (especially increased demand for feed production, calorie intake per capita and tonne-kilometer transported) increased primary energy demand by 1.8% p.a. while changes in physical energy intensity offset this demand by only 0.2% p.a. Thus, with exception of fertilizer manufacture, changes in physical energy intensity -which is a proxy for energy efficiency- have not played a significant role in decreasing total energy demand in the European food supply chain.

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[*] *Co-author: K. Blok.*

7.1 Introduction

Nowadays, energy of fossil origin is applied to the food supply chain in a variety of forms, such as mechanical power to replace human and animal labor, for irrigation and fertilization to increase production, energy for transportation, processing and conservation. The importance of balancing food supplies and energy use against a growing food demand has been acknowledged as one of the main challenges on the path towards sustainable development. For instance, Dr. Gustavo Best, Senior Coordinator of the Environment and Energy Programmes Centre of the Food and Agricultural Organization of the United Nations (FAO) stated "[the energizing of the food production chain]…is a topic which requires increasing attention from policy makers and scientists as a key element of national and global responses to the need for fossil fuel substitution, enhancing environmental awareness, achieving emission targets and, more importantly, eliminating poverty and hunger from the rural areas of many developing countries" [Best, 2001:1].

If policy makers want to influence the way food production systems develop, it is important to have an understanding of the mechanisms that govern these developments. In general, the development of production systems is described in economic terms and measured in monetary quantities. However, it is unmistakable that the long-term resource and environmental issues relevant for sustainability are determined by physical processes. The development of physical inputs and outputs of production systems to a large extent determines their environmental impacts. Next to this, also changes in physical efficiency play a role. For an adequate understanding of the development of such systems it is therefore necessary to analyze the development in terms of physical inputs and outputs [see also Haberl et al., 2002; Daniels and Moore, 2004]. But also, it is important to analyze how the food production system contributes to economic development. Therefore, in this chapter, we analyze development both in physical and monetary terms.

Exploring the relationships between physical flows and energy flows that drive agricultural production has been a goal behind several energy studies, e.g. assessing fossil energy use [Hirst, 1974; Cleveland, 1995], comparing organic and conventional farming [Dalgaard et al., 2001; Refsgaard et al., 1998], assessing non-conventional food production [Slesser et al., 1977] or evaluating the differences in energy terms between processed and fresh food [Rawitscher and Mayer, 1981]. However, these studies focused on detailed aspects instead of the whole food supply system and therefore, current understanding of the relationships between physical and energy flows for the whole food supply chain is much more limited (older examples are Green, 1978; Leach, 1976; Pimentel et al., 1973).

In this chapter, we will analyze the development of the food production system in a historical perspective, using time series analysis for a period of about three decades. We will focus on an input that is an indicator for a variety of environmental impacts: the use of fossil energy. The purpose of this chapter is to analyze the historical relationships of fossil fuel demand and food production in developed countries. The research questions that guide this chapter are:

- What is the share in the total energy demand of the different steps of the food supply chain (e.g. agriculture, transport, food processing) and how do they change over time?
- What is the relation between energy use on one hand and the physical and economic flows on the other hand?
- How can the development of energy use be understood from the development of activity, structure and energy efficiency?
- Can we explain why these factors developed this way?

To answer these questions we examine the food supply chain of 13 European countries in the time period 1970-2002. The chapter is structured as follows. In section 7.2 a description of the methodology used to calculate each of the flows is presented. Section 7.3 examines the energy use and output in the food supply chain while in Section 7.4 we analyze the main drivers behind the changes observed. A discussion of results is made in Section 7.5 and main conclusions are drawn in Section 7.6.

7.2 Data and methodology

In this chapter, all data are gathered at the country level and then aggregated to obtain values for what we have defined as Europe-13 (Austria, Belgium, France, Germany, Greece, Italy, Luxemburg, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom). These countries are representative of Western Europe[1]. The system boundaries are shown in Figure 7.1. In comparison with a life cycle assessment where a cradle-to-grave approach is taken, in this chapter the analysis is conducted for the food supply chain as far as it takes place in Europe-13. Retail and households are not included. This approach has been driven by the need to keep the system manageable (e.g. limiting the amount of data needed, keeping the system relatively homogeneous). The impact of the system boundaries on the results turn out to be small. This aspect is further discussed in section 7.5. A detailed description of how each of the flows shown in Figure 7.1 was estimated follows.

7.2.1 Energy inputs into the system

Energy data used by the *agriculture* (E_A) and the *food processing sector* (E_{FP}) are taken from country energy balances published by the International Energy Agency [IEA, 2004] for the time period 1970-2002 (values before 1970 are not available or consistent for all years and countries). Electricity values are transformed into primary energy using the trend in electricity generation efficiency shown in Figure

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[1] Data availability determined the countries taken into account in this chapter. Additional to the countries named, Western Europe traditionally also includes Iceland, Ireland, Denmark and Switzerland.

7.2. This trend reflects the average development of Europe-13 and it has been calculated using IEA data for power generation. Heat has been converted to primary fuel energy by assuming 85% boiler efficiency.

Figure 7.1 System boundaries and flows used in the analysis of the food supply chain.

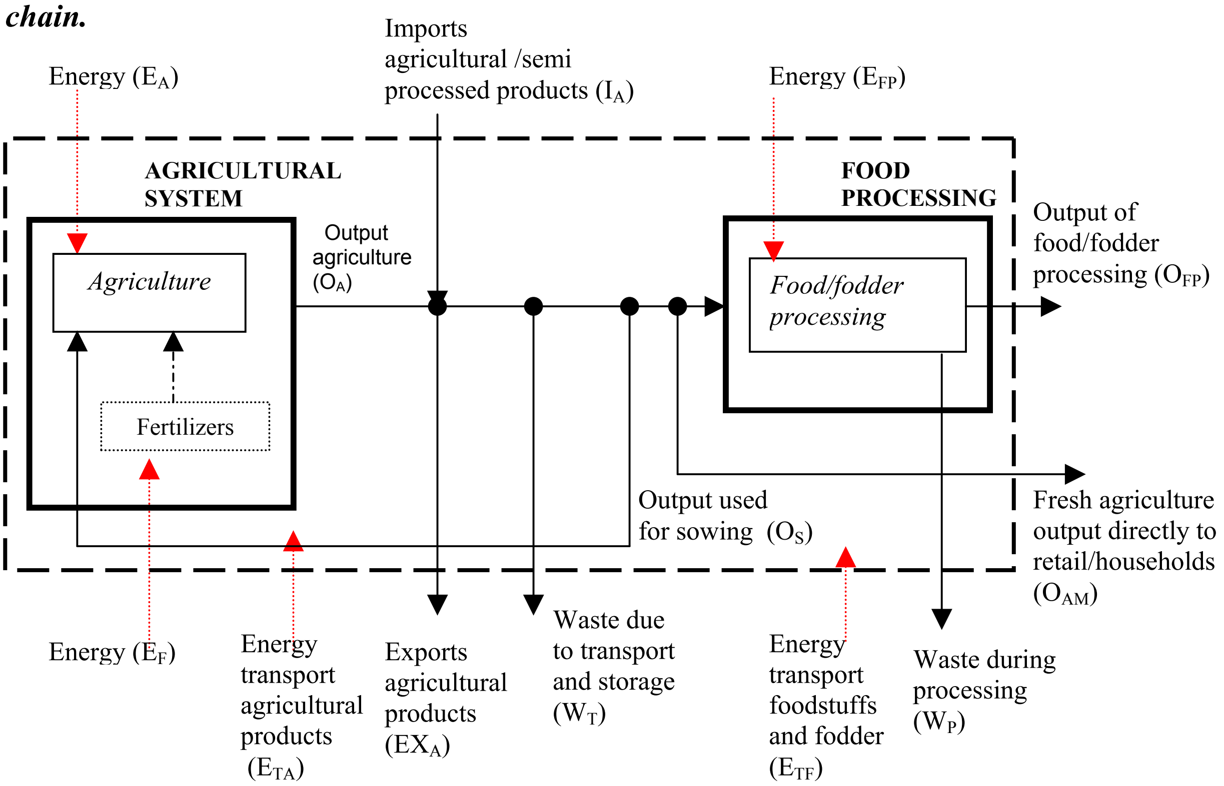
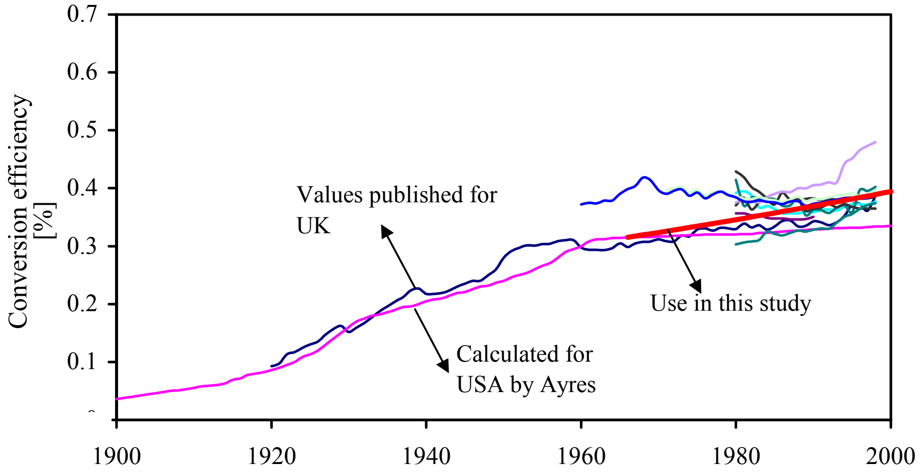


Figure 7.2 Historical developments in power generation efficiency in USA and European countries.



Sources: Ayres et al., 2003; DTI, 2004; International Energy Agency

Energy consumption due to *transport of agricultural products and foodstuffs/fodder (E_T)* is not published in national nor in IEA statistics. To calculate it we use the following procedure. First, we break down energy use in each mode of the transport sector (e.g. road) into passenger and freight by using country data provided in the

Odyssee database[2] (time period 1980-2002). We then calculate the share of the energy use for the transportation of agricultural products and foodstuffs in each mode of freight transport by using as allocation factor the ratio of agricultural and food products transported to the total amount of tonne-kilometers (tkm) transported in each year. Information on the amount of tkm by product groups for each country and mode is published by Eurostat's reference database NewCronos at the chapter level of NST/R classification[3] [Eurostat, 2005]. In this analysis, we focus on the following groups: Cereals (01); potatoes, other fresh or frozen fruits and vegetables (02); live animals and sugar beet (03); oil seeds and oleaginous fruits and fats (07), and foodstuff and animal fodder (06).

Since both the Odyssee and NewCronos databases do not publish data before 1980, we have extrapolated, on the one hand, the trends of the shares of goods transported and, on the other hand, the shares in energy use by mode of freight transport published by Odyssee. The resulting shares have then been applied to energy data for the transport sector at the country level published by the IEA.

Energy demand due to *fertilizer consumption* (E_F) was calculated by multiplying annual consumption data of each fertilizer (in tonnes) published by the International Fertilizer Association [IFA, 2004] with historical developments in the cumulative energy required to produce one tonne of fertilizer (generally referred to as gross energy requirement GER[4]). The fertilizers taken into account are: ammonia, urea, ammonium nitrate, calcium ammonium nitrate, ammonium phosphate, single superphosphate, triple superphosphate, potassium chloride (potash), and complex fertilizers. A discussion on the methodology used to obtain the GER trends can be found in Chapter 6.

Another flow that could be included in the analysis is the energy consumption due to the manufacture of pesticides. The most complete list of energy used per tonne of active ingredient by fuel was published by Green in 1987 (24 different kinds of herbicides, 4 fungicides and 10 insecticides). Since then only scattered data has been published, and in fact, Green's values are at the moment a recurrent source in life-cycle analysis and energy analysis for the agricultural sector. We use Green's data to calculate average values in primary energy terms. Following the procedure used to calculate energy inputs due to fertilizer manufacture, by multiplying averages energy use per tonne of active ingredient (herbicides: 320 MJ/kg active ingredient; fungicides: 93 MJ/kg active ingredient; insecticides: 239 MJ/kg active ingredient) with 2002 consumption figures of pesticides (in tonnes active ingredient) provided by the European Crop Protection Association (ECPA), we obtain a total energy input due to pesticides for Europe-13 of 43 PJ. Despite using

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[2] The Odyssee database is a European database on energy consumption and energy efficiency by sector, supported by the SAVE programme of the European Commission [Enerdata, 2002]. For more information see: http://odyssee-indicators.org

[3] NST/R stands for Standard Goods Nomenclature for Transport Statistics/Revised. It consists of 24 goods groups.

[4] GER is defined as the sum of energy input to the process, including the energy content of the feedstocks.

average values of 1987, which can overestimate energy used (one could assume that increases in energy efficiency in pesticides processing have occurred in the last 15 years), the share of pesticide manufacture in the total energy use is only 1% (we calculate that the total primary energy demand in the food supply system is about 3960 PJ, see section 7.3). This small share together with the lack of historical data for GER makes us to decide not to include the energy due to pesticide manufacture in our analysis.

Other flows that could be included are those related with the energy used during the manufacture of capital goods (e.g. buildings, tractors, machines, etc). A main problem is that time series which allow us to construct trends in GER for each capital good are not available and hence, studies which includes some of these flows (mainly tractors) use values in trend analysis over time based on data for one single year [e.g. Leach, 1976; Pimentel and Dazhong, 1990; Steinhart en Steinhart, 1974]. The percentage of energy use for the manufacture of capital goods with respect to total energy used has been found to be between 6-11% [e.g. Dalgaard et al., 2001; Gezer et al., 2003; Uhlin, 1999]. These values, however, do not account for the energy use for the transport of food and agricultural products. Since we calculate that transport accounts for 27% of total energy use (see section 7.3), the share of energy allocated to manufacture of capital good can be expected to be lower than the 6-11% range reported in literature. Due to the lack of time series data and the expected low contribution to the total energy, we do not include these flows into the analysis.

7.2.2. Outputs

In this chapter we choose as functional unit the output of food and fodder expressed in a) economic value (Euros) and b) energy values (calories). In the latter case, amounts are gathered in physical terms (e.g. tonnes) and transformed into energy values by using nutritional factors (i.e. kilocalories per 100 g product) from the Food and Agriculture Organization of the United Nations [FAO, 2005]. Note that though nutritional values can also be expressed in SI units (i.e. joules[5]) we decided to keep the values in calories since this will avoid confusion when referring to energy from fossil fuels and nutritional energy of food. Output in physical terms is calculated for the time period 1961-2002.

To measure output of the processed food and agricultural sector in economic terms, we have taken value added (GDP) series. Value added is the net economic output of a sector, measured by the price differential between the price of output and the cost of input. The price differential comprises compensation to employees, operating surplus, the consumption of fixed capital and the excess of indirect taxes over subsidies. The value added data were taken from the OECD Structural Analysis Database (STAN) and have been converted to constant 1995 Euro's, using 1995 expenditure purchasing power parities (PPP) as given by the OECD. Because of

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[5] 1 kilocalorie is equivalent to 4.187 kilojoules.

data availability across the 13 OECD countries, time series are restricted to the period 1978-2001.

The amount of agricultural output (O_A), in physical terms, was calculated using time series for crop production and livestock (in tonnes) published by FAO for each country (excluding harvesting losses) [FAO, 2004]. Appendix 1 shows the list of crops, vegetables, fruits and animal products taken into account. Production figures published by FAO under 'meat production' relate to animals slaughtered within national boundaries regardless of their origin. In order to obtain the gross indigenous meat production from the agricultural sector, we have added to the 'meat production' figures the meat equivalents of live animal exported minus the imported published also by FAO.

Output of the food-processing sector (O_{FP}), in physical terms, has proven more difficult to quantify than agricultural output. One could, for instance, choose all foodstuffs produced in the food industry (in tonnes) and using a similar methodology to the one applied to the agricultural sector, transform them into calories. The main problem with this method is the huge amount of data needed. Since the number of products in the food processing sector is much higher than for the agricultural sector and time series for the period selected are not available, we have opted for a more simplified approach. The output of the total system O_{TS} can be estimated as the calories that enter into the system minus the calories lost in the waste streams (Equations 7.1 and 7.2). Below we describe how each of the components of the equations has been calculated (see also Figure 7.1).

$$O_{TS} = O_{FP} + O_{AM} \qquad \text{(Eq. 7.1)}$$

$$O_{FP} = O_A + I_A - EX_A - W_T - O_S - O_{AM} - W_P \qquad \text{(Eq. 7.2)}$$

In which:

O_{TS}= Output of the total system
O_{FP}= Output of the food/fodder processing sector
O_A= Output of agriculture
I_A= Imports agricultural/semi processed products
EX_A= Export agricultural products
W_T = Waste due to transport and storage
O_S = Output used for sowing
O_{AM} = Fresh agricultural output going directly to retail/households
W_P= Waste during processing

Imports (I_A) and *expor*t flows (EX_A) from and to Europe-13 were calculated for the years 1962, 1980 and 2002. Data were taken from the United Nations trade statistics database UN Comtrade for each country [UN, 2005]. The number of commodities was 165 for imports and 103 for exports. The difference is due to semi-processed products (e.g. strawberries, provisionally preserved but unsuitable in that state for immediate consumption). Semi-processed products are accounted for in the import flow I_A, since they go into the food processing industry for further treatment, but not in the export flow EX_A. Semi-processed products originated in Europe-13 are part of the output flow of the food processing sector O_{FP}. They are exported once they are outside the system boundaries. We use the results to calculate the values for the years in between by assuming a linear trend.

The amount of *agricultural products used for sowing* purposes (O_s) were calculated using time series of seed by crop and country published by the FAO [FAO, 2004]. *Waste due to transport and storage* (W_T) was calculated for each agricultural product and country by using average percentages of supply that are wasted. These percentages are used by the FAO when developing food balance sheets for each country. We found values for the period 1993-1997 in FAO [2000]. When a value was not available for a specific crop/country we used average values of the countries studied. Although the percentages of waste can change over time we have kept the shares constant for the whole period studied since there is no information available for the rest of the time series.

Waste generated during food/fodder processing (W_P) is quite difficult to estimate. For instance, fresh potatoes lose about half of their real weight when being processed into frozen French fries. Although this appears to represent a “loss” of edible fresh potatoes, most of the “loss” is actually recovered and used by processors for other potato products, such as potato starch, and potato skins are often sold to renderers for animal feed which are also part of the food processing sector studied in this chapter [Kantor and Lipton, 1997]. This may be the reason why most studies which deal with losses in the food system focus on post-harvesting losses and losses in retail and households, thereby neglecting the losses that occur during food processing untreated (e.g. Kantor and Lipton, 1997; Hellen and Keoleian, 2003). A possible data source for food losses are the food balances published by FAO [2004]. Food balances provide the amounts of waste by product and country. The waste values published there are a combination of waste generated during transportation and storage and technical losses occurring during the transformation of primary commodities into processed ones (by use of extraction rates). The balances, however, disregard all by-products which are not suitable for direct human consumption. For instance, in the example given above, the balances use extraction rates of fresh to frozen potatoes of about 48-52% while the remainder is accounted for as waste. Thus, total waste figures provided by the food balances overestimates the amount of waste which is produced by the whole food processing sector. Due to lack of other data on the percentage of calories wasted during food/fodder processing, we use nevertheless the percentages of waste in total food supply as published in the food balances and we deduct the waste during storage estimated previously to calculate average food lost during processing.

To estimate the amount of *fresh agriculture products which go directly to the market* (O_{AM}), we depart from several assumptions. First, that all cereals, pulses, oilseeds, sugar, coffee, cocoa beans and meat goes into the food processing sector. Secondly, according to USDA [2004] the share of fresh to processed food products (e.g. dried, frozen, preserved, juice) in industrialized countries was about 58% for vegetables and 42% for fruits in 1960[6] and 50% for vegetables and 46% for fruits in 2002. From the share of fresh fruit and vegetables we assumed that in 1960 80% was going directly into the market, while in 2002 90% is sorted, cleaned and packaged in food processing establishments (this assumptions are supported by data found on Bergmann, 1983; Heller and Keoleian, 2003; Mackintosh, 1997). Furthermore, we assumed that the decline was exponential. The influence of the different assumptions made in this section is discussed in Section 7.5.

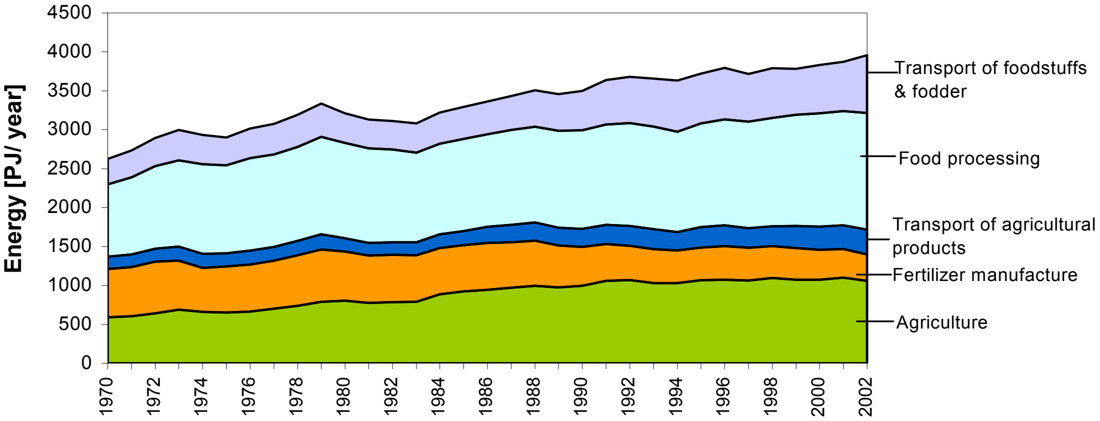
7.3 Developments in energy use, physical production and economic output in the food supply chain

In this section, we show the developments in energy demand and output (in physical and economic terms) for Europe-13. The trends were obtained by applying the methodology explained above.

7.3.1 Energy

We estimate that in 2002 the food supply chain in Europe-13 used about 3960 PJ of primary energy (2620 PJ in 1970). This corresponds to about 7% of the total final energy use by Europe-13 in the same year (shares in the individual countries are in the range of 4 to 11%). Trends for the time period 1970-2002 are depicted in Figure 7.3. We found that total energy demand has increased at an annual rate of 1.6%. The only part of the system showing a decrease (about 2% p.a.) is the indirect energy allocated to the manufacture of fertilizers. While in 1970 energy for fertilizer manufacture accounted for 26% of the total energy requirements, the share has decreased to 9% in 2002. The highest rate of increase is shown by transport, with about 2.1% p.a. for transportation of agricultural goods and 2.5% p.a. for the transportation of foodstuffs and fodder. A more disaggregate picture of the energy allocated to transport by good groups is shown in Figure 7.4.

Figure 7.3 Energy use in the food supply chain, Europe 13.



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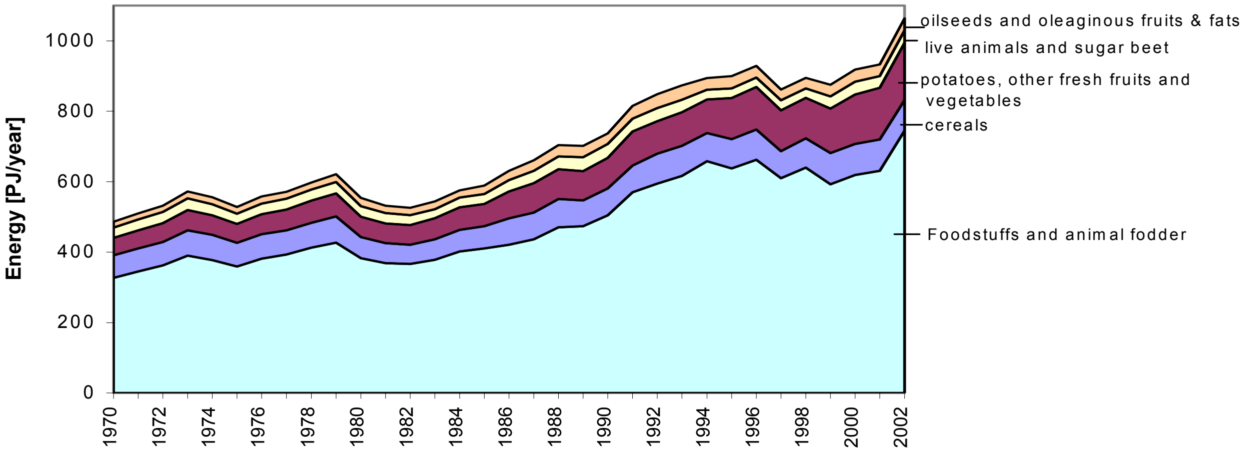
[6] A report for European countries showed similar values for 1959 (EPA, 1959).

Figure 7.4 Energy demand of freight transport by type of food and feed products.

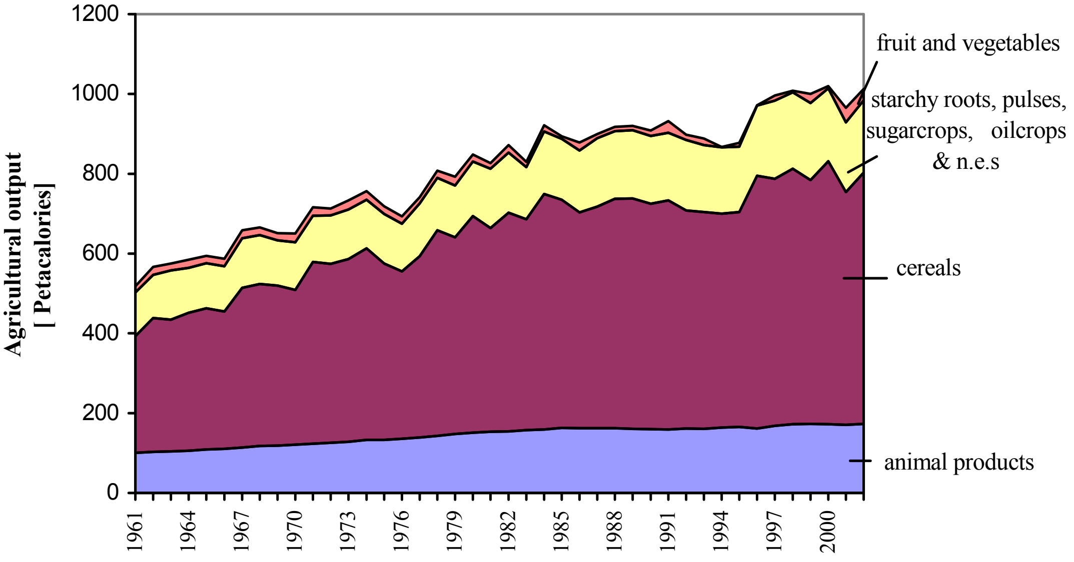


7.3.2 Output

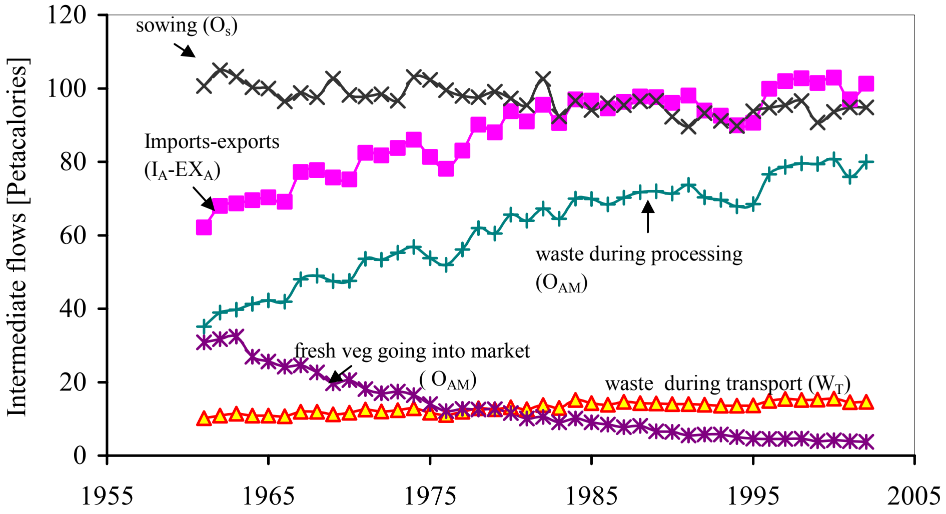
In the year 2002, the physical output of the total food system (O_{TS}) was about 924 Petacalories (or 3868 PJ). Figure 7.5 shows the trends obtained for each of the output flows drawn in Figure 7.1 (see also equations 7.1 and 7.2). In Figure 7.5A we have further disaggregated agricultural output by kind of products. Note that the biggest share of calories since 1961 is allocated to cereals. In the period 1961-2002, agricultural output increased at an annual rate of 1.5 % p.a. while the total output of the system increased at a slightly higher rate: 1.8% p.a.

Figure 7.5 Output flows in calories for Europe-13. Note differences in vertical axis.

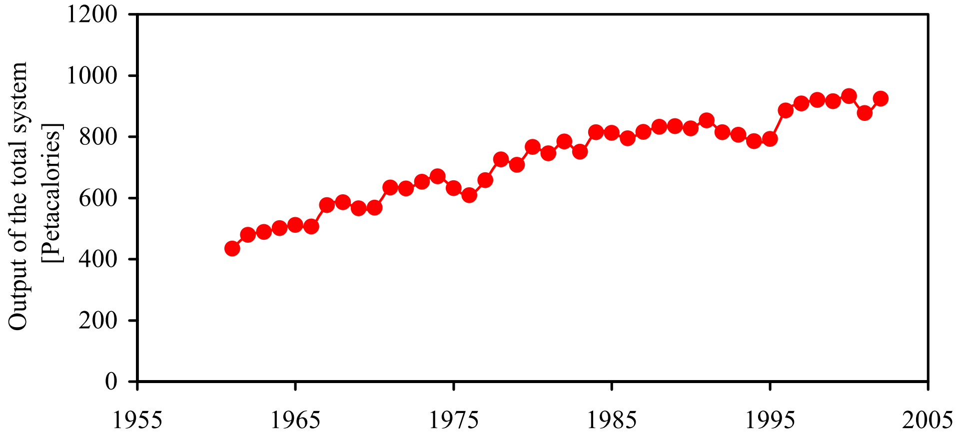
(A) Total agricultural output of the system by kind of product.



(B) Intermediate flows.



(6C) Total output of the system (O_{TS}).



The output in economic terms (million Euros) for agriculture and food processing is plotted in Figure 7.6 for the time period 1978-2001. The food-processing sector shows a significant faster rate of growth than the agricultural sector: 4.7 % p.a. versus 2.6 % p.a. In the same period, euro per calorie output of the total food processing sector increased 3.9% p.a. while euro per calorie output of agricultural system increased 1.5% p.a. The differences in the rates are a reflection of the food processing manufacturers success to add value through product innovation or new products such as convenience food, nutritional products (e.g. fortified multiple vitamins) and light products (e.g. products low in calories, salt, cholesterol, etc.).

To place the values obtained into context, we plot in Figure 7.7 the developments in energy and output of the food supply chain together with the trends in Gross Domestic Product (GDP), total population and agricultural land in Europe-13. Energy use and output produced by the food supply chain have grown at a much faster rate than population growth. Value added of the food processing shows the highest rate of increase of all indicators plotted. With a contribution of about 14%

of the manufacturing GDP in 2002, the food-processing sector is the second largest manufacturing sector in the European Union[7]. Together, agriculture and the food industry accounted in 2002 for about 5% (range 3%-9% varying by country) of the total GDP and 7% (range 3%-16%) of the total labor force[8] (in 1978, agriculture and the food industry accounted for about 7% of total GDP and 16% of the labor force).

Figure 7.6 Value added of the agriculture and food process sector in Europe-13, values have been deflated to 1995.

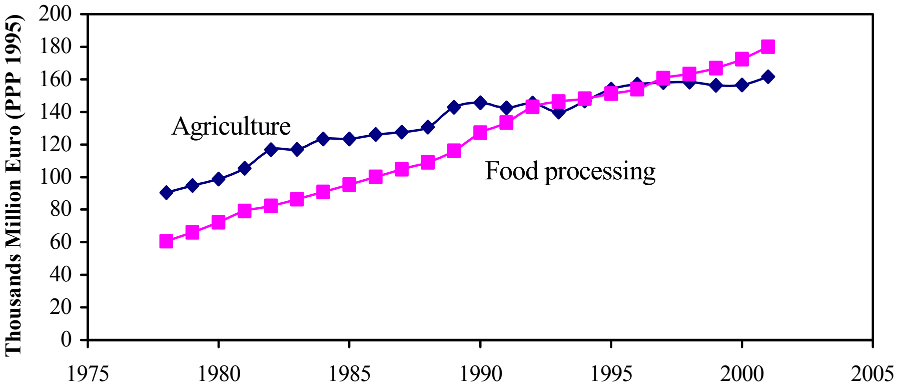
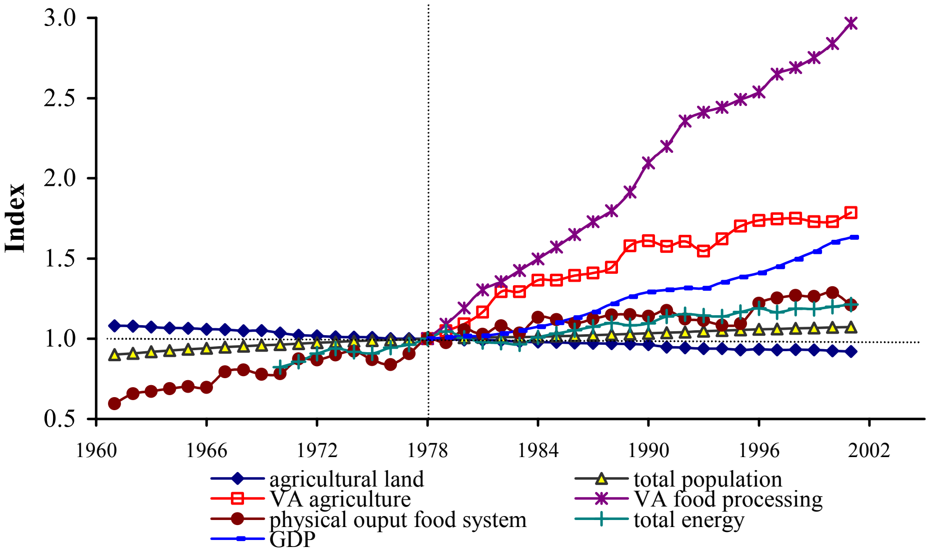


Figure 7.7 Development of several indicators in Europe-13, values have been indexed to the year 1978.



7.3.3 Energy intensities

Two ways of analyzing if the whole system has become more or less efficient is by looking at two indicators: the ratio of energy to unit of economic output (economic

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[7] Europe 15.

[8] The shares of GNP and total labor are based on data for agriculture and food processing; they exclude the contribution of fertilizers.

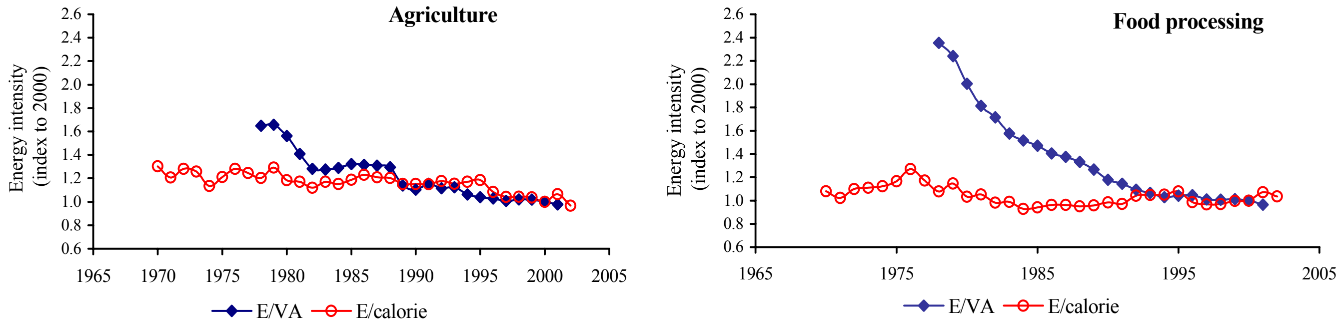
energy intensity, E/VA) and the ratio of energy to unit of physical output (physical energy intensity, E/calorie). The two indicators are plotted in Figure 7.8 (to facilitate comparison, all values have been indexed to the year 2000). We found that in comparison to the economic energy intensity, physical energy intensity has decreased at a significantly slower rate (Table 7.1). Contrary to the 'physical indicator' based on output measured in energy values (calories), the 'economic indicator', based on output measured in value added, does not measure a direct relationship between the volume of production and energy consumption. The reason is that changes in value added are not only the result of changes in production volume but also, for example, of changes in the mix and characteristics of products or changes in the market prices of the product. As a result, reductions in energy intensities with output measured in terms of value added cannot directly be interpreted as improving energy efficiency. It does, however, give a good impression of the amount of energy required to produce a unit of GDP – still the most important indicator of the value of economic activity.

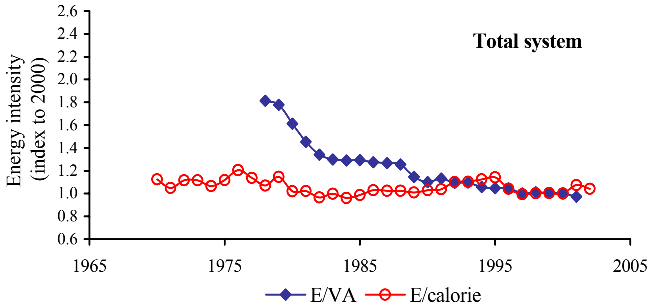
Table 7.1 Annual percentage change in the energy intensity indicators.

	Agriculture [% p.a.]	Food processing [% p.a.]	Total system [% p.a.]
Economic energy intensity[1]	-2.3	-3.7	-2.7
Physical energy intensity [2]	-0.9	-0.1	-0.2
Physical energy intensity[1]	-0.5	<0.1	<0.1

[1]: time period 1978-2001; [2]: time period 1970-2002.

Figure 7.8 Comparison of energy intensities for Europe 13. Values have been indexed to the year 2000





Absolute values of the indicator for the year 2000

Sector	E/calorie [J/cal]	E/VA [MJ/euro]
Agriculture	1.5	9.3
Food processing	1.7	8.5
Total (agriculture+food proc+ transport)	4.4	11.7

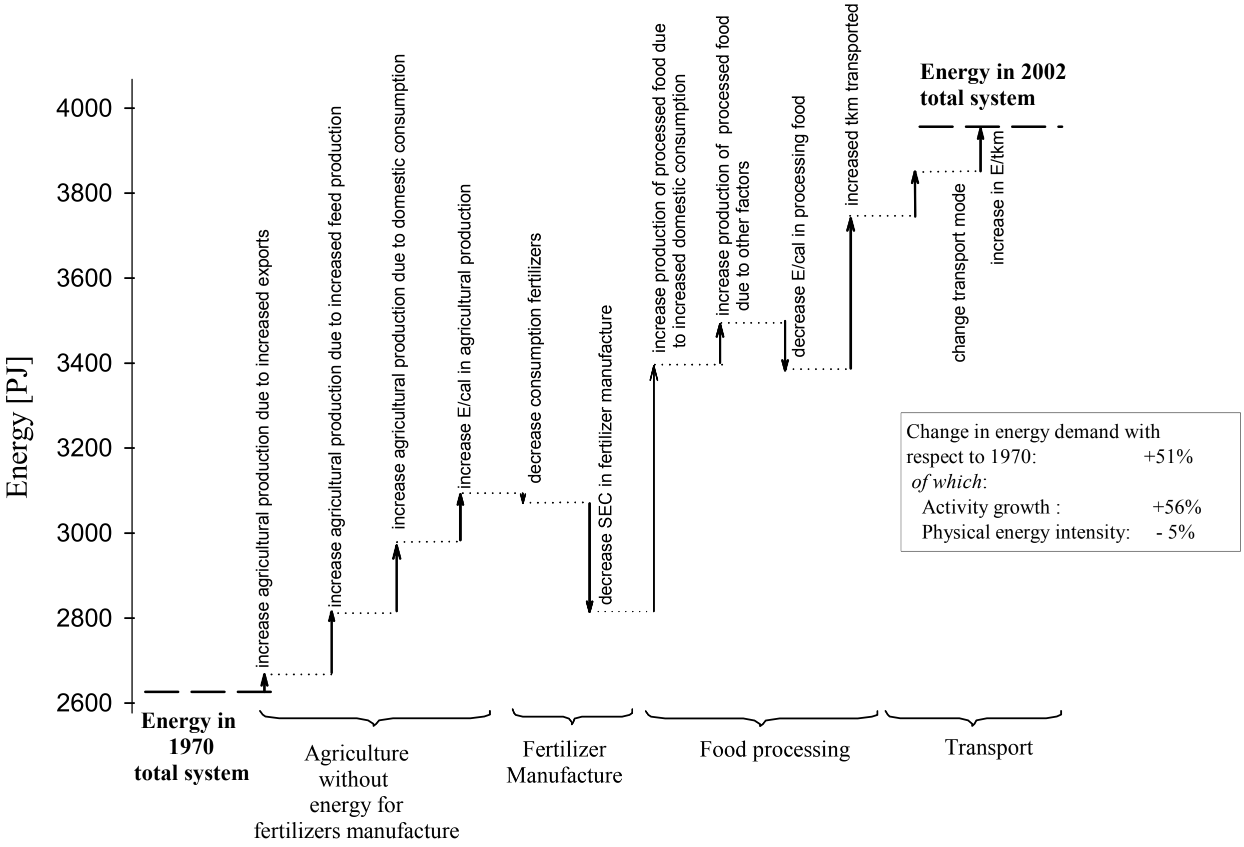
7.4 Breaking down the trends

Our results have shown that both economic and physical energy intensity have decreased in the last three decades, and that economic energy intensity has decreased at a significantly faster rate than physical energy intensity. To better understand the increasing energy demand of the whole system and the impact of energy efficiency developments, we examined different factors that influence energy consumption in each step of the food supply chain. For agriculture we looked at the effect of population growth, changes in exports/import rates, feed production and changes in energy per calorie of output; for fertilizers we examined the effect of decreasing fertilizer consumption and increasing energy efficiency during their manufacture (decreasing GER); for the food processing sector we looked at the effect of population growth, change in diet patterns and changes in energy per calorie. Finally, we analyze the effect of increasing transport; change in transport mode and in the energy intensity of the transport system (energy per tonne-kilometer).

To estimate the influence of each factor we have used a stepwise approach: first, one of the factors (e.g. population growth) is changed while the others are kept constant. The difference between the new energy value and the original reference value (i.e. energy use of the whole system in 1970) represents the influence of the factor studied. The new energy value is now taken as the new reference value and another factor is changed (e.g. increase agricultural exports) while all the other factors are kept constant. Once again the difference between the reference value and the new estimated value shows the influence of the factor. In this way every parameter can be studied, thus breaking down the total difference in energy use between 1970 and 2002 into its components. Results for the period 1970-2002 are shown in Figure 7.9.

At a first glance two main conclusions can be drawn from Figure 7.9. First, increased activity (i.e. agricultural output, food processing output and amounts of tonne-kilometer transported) has been the main driver for the rising energy demand shown by the food supply chain. Secondly, changes in energy efficiency (measured as E/cal output) have not been able to offset the increasing demand due to activity growth; on the contrary, some of the developments in physical energy intensities have even boosted energy demand. A more detailed analysis of each of the factors plotted in Figure 7.9 follows.

Figure 7.9 Influence of diverse factors in the energy demanded by the food supply chain, 1970-2002. Production measured in physical terms



7.4.1 Agriculture (without energy for fertilizers manufacture).

- *Activity:*

About 90% of the increased energy demand of the agricultural sector between 1970 and 2002 can be explained by activity growth (increased production of agricultural products O_A). Increased production has been driven by three main factors. Domestic consumption (i.e. population growth and increased demand from the food processing sector) is responsible for about 48% of the activity growth; about 12% is due to increasing exports, while 40% is explained by the increase in feed production. Figure 7.10 shows the development of livestock populations in Europe-13 since 1961[9]. These developments influenced agricultural production, due to the linkages of livestock production to the crop sector (crops used for feed in Europe-13 accounted for 53% of crop production, in 2002 the share increased to 60%). In fact, the growth of cereals for feed use has been a main driver in total crop production: in

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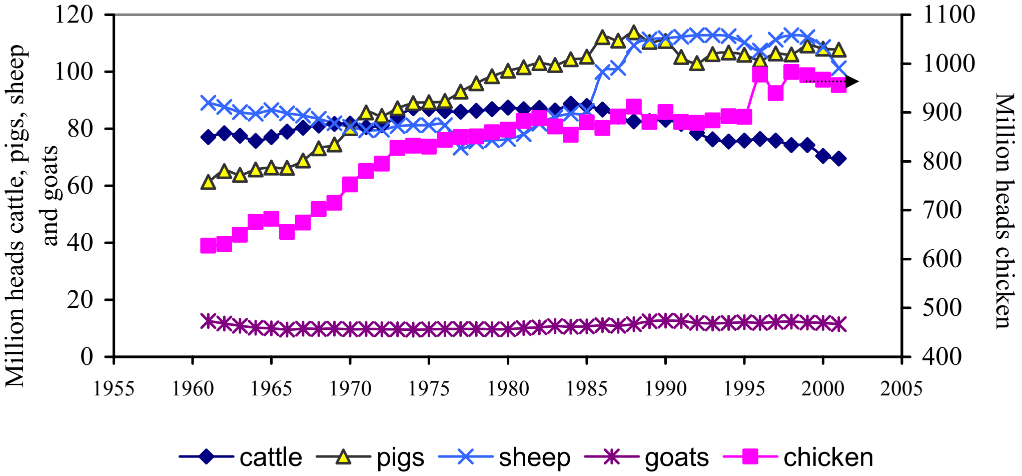
[9] The number of cattle has been declining since the mid-1980s, thus exhibiting a different trend than other livestock species in the Figure. This trend is linked to increasing yields, both in terms of milk produced and carcass weight, restrictions imposed by milk quotas (since 1984) and changes in consumer preferences.

the period 1970-2002, production of crops used for feed increased in average by 1.8% p.a.[10], while crops for other uses only increased by 1.1%.

Figure 7.10 Livestock population in Europe-13, 1961-2002.



- *Physical energy intensity:*

The change in energy used per agricultural output produced (E/cal) explains about 10% of the increase in energy demand of agriculture. This result seems to be contradictory with the trends shown in Figure 7.9, which shows a decrease in the value of energy per calorie in the agricultural system of about 30% between 1970 and 2002. Energy per calorie for the agricultural system in Figure 7.8 includes energy use for fertilizer manufacture, which in Figure 7.9 has been treated separately. In Figure 7.11, we plot energy use for the agricultural sector both with and without energy use for fertilizer manufacture. For the latter, agriculture shows an 11% increase in energy per calorie between 1970 and 2002.

The increasing use of energy per calorie of output is a consequence of the intensification of the factors of production which is reflected in the rise of inputs used in production. This is a phenomenon that has been well documented: production increases have historically been achieved through use of fertilizers and pesticides; drainage, irrigation and water abstraction; mechanization and physical practices (old studies such as Chancellor and Goss, 1976; Leach, 1976; and Pimentel et al., 1973 confirmed these trends up to 1970; recent studies validate the same developments using time series up to 1990, e.g. Cleveland 1995; Swanton et al., 1996). Figure 7.12 shows some trends that point out these developments for Europe-13.

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[10] Crops taken into account are wheat, rice, barley, maize, rye, oats and potatoes.

Figure 7.11 Influence of energy for fertilizer manufacturing in the physical energy intensity of the agricultural system, Europe 13 (values have been indexed to the year 2000).

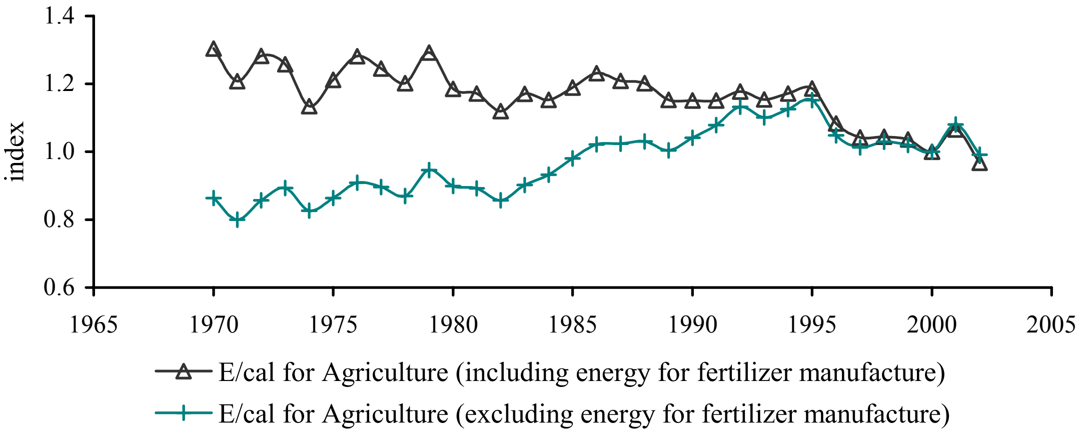
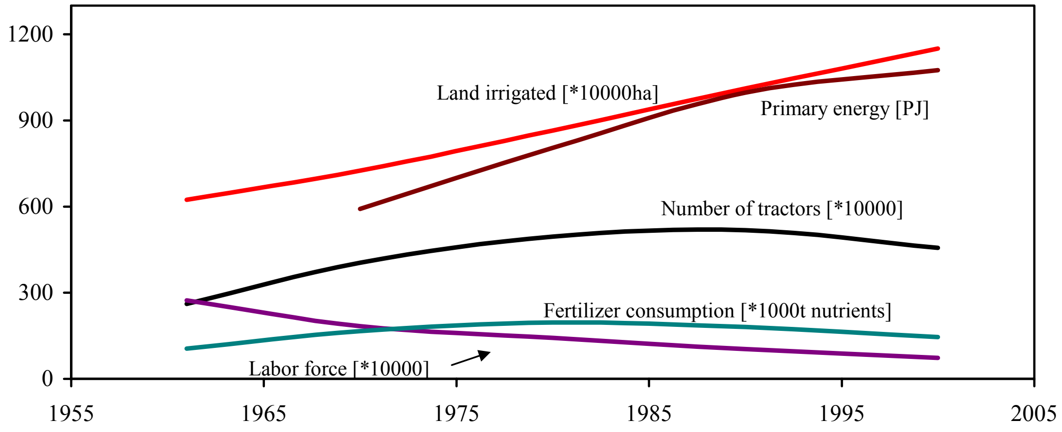


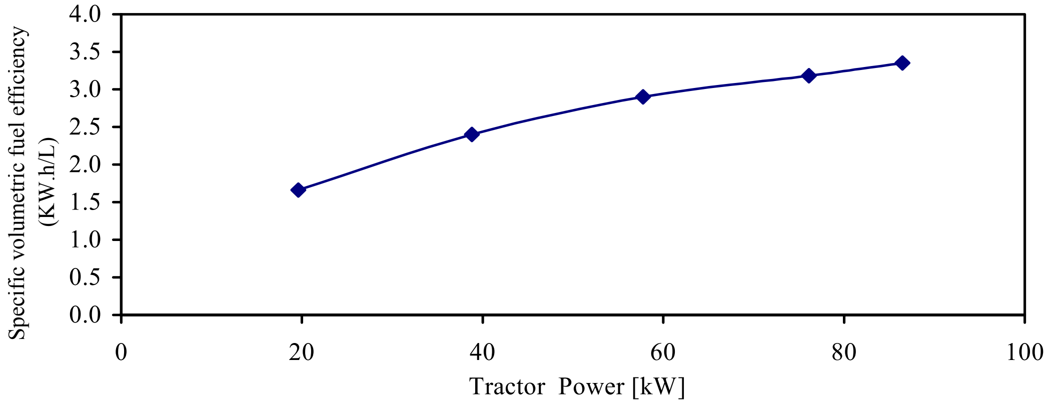
Figure 7.12 Developments of several inputs in the agricultural system, Europe-13.



Note: the trends were constructed based on data for the years 1960, 1970, 1980, 1990 and 2000.

To assess the impact of mechanization in the agricultural energy consumption of Europe-13 in the last three decades is not a straightforward task. For instance, on the one hand, the growth in the total number of tractors slowed after 1975 and began to decrease since the end of the 1980s. On the other hand, there has been a shift towards equipment with higher capacity (which increases energy demand, see Figure 7.13). An analysis of technical trends of tractors and combines based on Italian data [Biondi et al., 1996] found that between 1961 and 1989 the average power of combines rose from 44 to 130 kW and the average power for tractors rose from 28 to 51 kW. A study of the European Commission [1999] reported that the number of tractors with a power force higher than 60 kW (80.4 hp) has more than doubled in most European countries in the period 1975-2000.

Figure 7.13. Relation between tractor power and specific volumetric fuel efficiency[11].



Source: Grisso et al., 2004. Data is the result of a John Deere tractor test report.

The trend towards equipment with higher capacity has been driven by increases in the area to be worked (fewer holdings which are using more agricultural area). The increase in the average area of the holdings has had an effect of the production practices, which has promoted specialization and increase the scale of production. For instance, in crop farming cash crops have taken over and permanent crops have moved towards a single specific line of production (e.g. vines or fruit trees). A study of the European Commission [1999] reports that in the period 1975-1995 while specialized farms (holding earning a main source of revenue from a single type of products such as field crops, horticulture, permanent crops, grazing livestock, poultry) decreased slightly in number and increased in area, the number of non-specialized farms (i.e. mixed cropping, mixed livestock, crops-livestock) decreased significantly: 50 % decrease in number, 60% decrease in area.

Another factor that influences energy consumption in the agricultural sector is irrigation. For instance, a study of energy use in three crop types in Norway found that irrigation increased energy consumption per kilogram yield by 8 to 20% [Refsgaard et al., 1998]. In the period studied the share of irrigated land in Europe-13 increased significantly: it accounted for about 7% of the total agricultural area in 1961 and 18% in 2000. Irrigation depends on several factors such as climate, soil characteristics, cultivation practices and crop types (e.g. in Spain, irrigation of maize and sorghum uses about 50% more water per hectare than leguminous plants [European Commission 1999]). Changes in crop types have been significant in the last 20 years. For example, in 1975 42% of the irrigated French land was used for market gardening and horticulture. This figure has fallen to 27% by 1995. 47% of the irrigated land is now used for growing maize, followed by soya beans and

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[11] Specific volumetric fuel efficiency is defined as the rate of power production to fuel consumption during a specific period of time. This indicator is not affected by the engine size and can be used to compare the energy efficiency of tractors having different sizes and under different operating conditions [Grisso et al., 2004].

sunflowers [IEEP, 2000]. The expansion of the irrigated area in several European countries has been also influenced by policy measures supporting the provision of irrigation infrastructure and providing subsidies to farmers installing irrigation equipment as well as guaranteeing low water prices for agriculture [IEEP, 2000; Poux, 2000].

7.4.2 Fertilizers manufacture

Significant improvements in energy efficiency in the manufacture of fertilizers (see Chapter 6) and falling fertilize consumption (Figure 7.13) have decreased energy demand in the total system (Figure 7.9). A study made by IFA on the fertilizer industry in Western Europe names the following as main drivers of the declining trend in fertilizer consumption [Bethke, 2000]: a) Western Europe has become a mature market; b) the reform in the European Union common Agricultural Policy (CAP) has resulted in a set-aside program and drastically reduced grain intervention prices; both measures had a direct impact on farming and fertilizer consumption; c) the continuing and increasing use of farm yard manure; and d) increasing environmental concerns which resulted on better on-farm nutrient management and improved fertilizer efficiency.

7.4.3 Food processing

- *Activity:*

Activity growth in the food processing industry raised energy demand by 25%. 86% of this change is due to increased domestic consumption (population growth, calorie intake) while 14% is due to other factors (e.g. exports). When looking at the domestic consumption, the most explanatory factor is the change in calorie intake (it accounts for 70% of the 86%). On average, calorie intake[12] in Europe-13 increased from 3110 kcal/cap/day in 1970 to 3607 kcal/cap/day in 2002[13]. A study on long- term changes in food consumption identifies a common pattern that characterizes the increasing consumption per capita: first, an *expansion effect*, where at low income levels there is change towards higher energy supplies whereby additional calories come largely from foodstuffs of vegetal origin (this trend has been shown by Portugal, Spain and Greece in the last 40 years). Secondly, there is a *substitution effect* from calories of staples (cereals, roots and tubers) to calories from animal sources, vegetable oils and sugar [Schmidhuber, 2003]. Factors contributing to the increased energy intake include: consumption of food away from home (food eating out provides a higher proportion of energy from fat than

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[12] This number has been calculated using FAO data derived from food balances for each crop and livestock. The number, therefore, corresponds to the 'average apparent food consumption' which may not be equal to average food intake (i.e. it does not account for waste at the household level) [FAO, 2004].

[13] In 1970, about 2177 kcal/cap/day were of vegetal origin and 933 were of animal origin. In 2002, about 2436 kcal/cap/day were of vegetal origin while 1094 were of animal origin. Although in relative terms calorie intake of animal has increased at a faster rate than of vegetable origin, the shares in the total consumption are relatively stable.

household food [Defra, 2004]); increased energy consumption of salty snacks, soft drinks and pizza [Nielsen et al., 2002], and increased portion sizes [Nielsen and Popkin, 2003].

- *Physical energy intensity:*

Changes in physical energy intensity in the food processing sector (E/cal) have helped to decrease energy consumption in the food supply chain by 0.1% p.a. At the level of aggregation used in this chapter it is not possible to assess the impact that different factors have had in the rate of decline of physical energy intensity. In Chapters 3 and 4 we analyzed changes in physical energy intensity for the dairy and meat industry. Although these chapters only cover two of the food processing branches for four European countries, and the system boundaries differ to the one used in this chapter, they provide information that help to understand the main drivers of physical energy intensity. We point out three main findings that we consider relevant for the food processing sector. First, during the last decades, the elimination of smaller, least efficient plants (concentration process) has played an import role in the reduction of specific energy demand. Second, consumers have shifted to higher quality and more convenient and fast food, which increases the energy demand per unit of product. Typical examples are: increased production of preserved food products (e.g. canned, frozen) and light products (more energy input to obtain less energy content in the output); most fresh fruits and vegetables go trough a minimum level of processing (e.g. sorting, cleaning, packaging); products need to guarantee high levels of hygiene (e.g. aseptic processing and packaging); increased demand for process control, which in turn increases automation; etc. Third, the rate at which physical energy intensity decreased is small (like in chapter 3 and 5) or does not occur (e.g. the meat sector increased the energy use per unit of physical product). These results are in close concordance with the results found in this chapter and suggest that despite improvements in energy efficiency in individual processes/equipment (e.g. implementation of evaporators with mechanical vapor recompression instead of thermal vapor recompression, increasing use of membrane technology), improvements in energy efficiency at the *system* level have not been significant.

7.4.4 Transport

Finally, we have broken down the energy use of transport of agricultural products and foodstuffs into three components: a) activity growth (movement of goods measured in tonne-kilometer), b) the change in transport mode (i.e. rail into road transport), and c) changes in the energy intensity of transport (energy use per tonne-kilometer).

- *Activity:*

Activity growth has been the main driver in increasing energy consumption in the energy allocated to transport (Figure 7.9). Agricultural products and foodstuffs are traveling further to reach the consumer (see table 7.2). In the period 1970-2002, average freight activity, measured in tkm, increased by about 1.8% p.a. (1.2% p.a. for agricultural products and 2.1% p.a. for foodstuffs and fodder). Among the main factors that influence freight transport growth are: expansion of market areas, geographical concentration of production, geographical concentration of inventory, wider sourcing of supplies, relocation of production/warehousing, subcontracting of non-core process and just in time delivery [McKinnon and Foster, 2000].

- *Transport mode:*

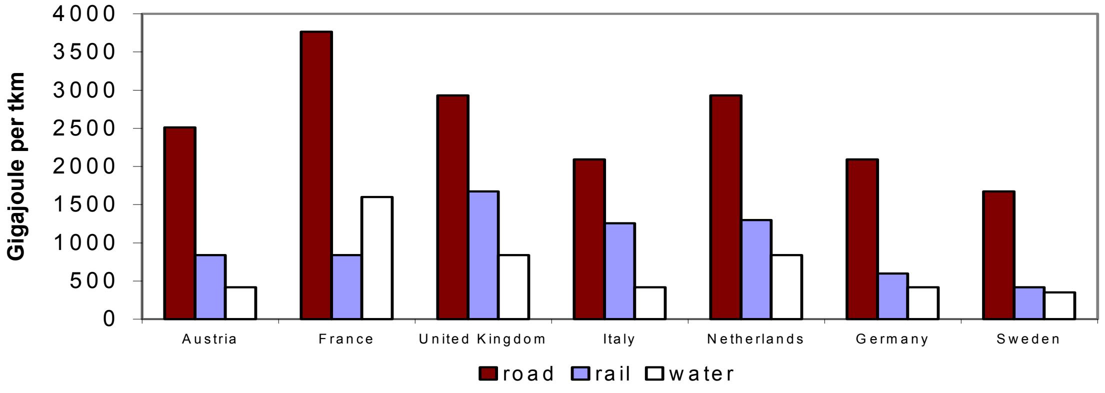
Changes in the shares of transport mode have also increased energy demand. During the period studied there was a significant shift towards road transport (especially trucks) and away from rail and water-borne transport. For example, while in 1970 about 71% of all agricultural and foodstuff goods were moved by road, in 2002 the share increased to 95%. This trend has implied higher demands of energy per tonne kilometer (see Figure 7.14). Among the reasons for the shift are that trucks offers greater flexibility, the growing use of just in time delivery and logistical advantages such as lot size, short term delivery and distance [Schipper et al., 1997; Landwehr and Lilliuh, 2002].

Table 7.2 Percentage of agricultural and foodstuffs transported by road according to distance class for several European countries in 1982 and 2002.

Distance [km]	**Belgium**		**France**		**Netherlands**		**United Kingdom**	
	1982	2002	1982	2002	1982	2002	1982	2002
0<50	62%	38%	50%	39%	51%	39%	50%	25%
50<150	33%	38%	30%	26%	36%	40%	32%	34%
≥150	4%	24%	20%	35%	13%	20%	18%	41%

Note: only includes national transport. Data source: Eurostat

Figure 7.14 Comparison of modal energy use for freight per tkm in some European countries, 1999.



Source: Odyssee database

- *Intensity:*

The final factor, changes in energy use per tkm, has also contributed to higher energy requirements of the total system. Changes in energy per tkm are determined by several factors, for instance, technology (e.g. engine efficiency), the mix of vehicles (e.g. a small rigid vehicle of 2 axes (< 7.5 tonnes) consumes about 4 km/l while a 4 axes (38-44 tonnes) articulated vehicule consumes 2,8 km/l [McKinnon et al., 2003]), average load, usage (speed, driving behavior), auxiliary energy needs (i.e. need for temperature control) and external factors such as infrastructure, congestion, geography, environmental regulation, etc. Of all these factors, it has been reported that in the case of trucking the overall energy intensity is far more dependent on the composition of fleet and its utilization than on the vehicles' energy intensities [Schipper et al., 1997; McKinnon et al., 2003]. Thus, it is not contradictory that while there have been significant increases in energy technological energy efficiency of vehicles in the last 30 years, the transport system of food products demanded more energy per tkm in 2002 than it did in 1970.

7.5 Discussion

The results obtained in this chapter are the result of combining large amount of data, data sources and assumptions. It remains a question the degree at which the results are affected by the data and assumptions used. This section is organized around three main points: i) the sensitivity of the results; ii) the choice of calories as the measure to represent output, and iii) the consequences of the chosen system boundaries on the results.

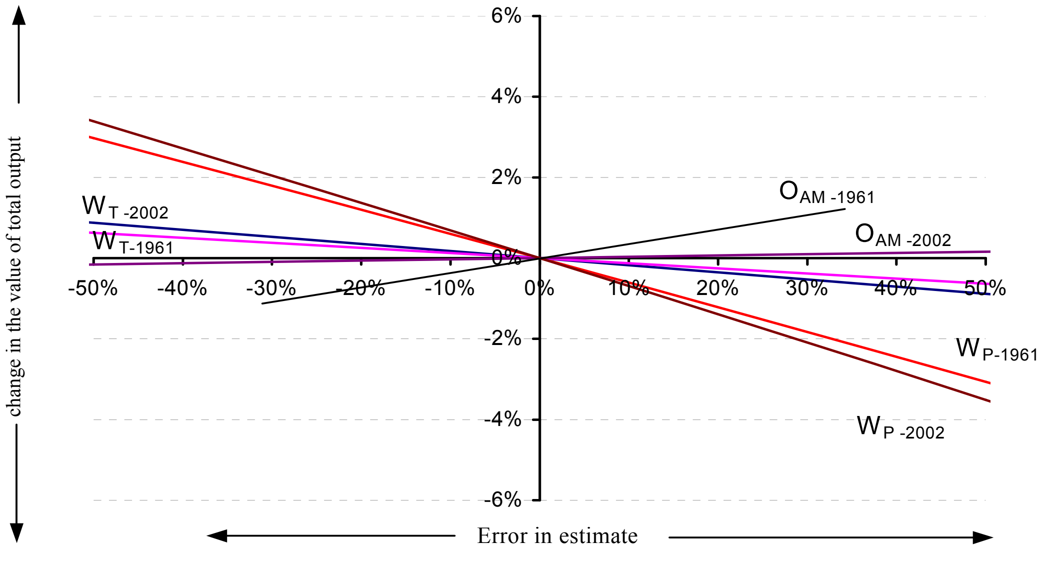
7.5.1 Sensitivity

The different flows used in this chapter can be divided into two categories: i) flows that were calculated based on literature information and educated guesses (i.e. waste due to transport and storage W_T; waste due to processing W_P; and fresh agricultural output going directly to households O_{AM}) and ii) flows for which primary data was taken directly from databases (IEA, FAO, NewCronos, Comtrade).

We have performed a sensitivity analysis to assess whether the results are robust in view of the assumptions made to calculate the first type of flows (W_T, W_P, O_{AM}),. The results are plotted in Figure 7.15. We found that errors of up to 50% in the estimates for the different parameters would only result in changes in the final values of output by a maximum of 4% and in the physical energy intensity of the total system by a maximum of 3%. Thus, we conclude that our results are robust to possible errors made in these assumptions.

The accuracy of the international databases is more difficult to evaluate quantitatively. Data on agricultural production reported by FAO is governed by established accounting practices and considered to be reliable especially concerning crop and livestock data for developed countries. Differences between data reported by FAO and national statistical offices for four countries (France, Germany, the Netherlands and the United Kingdom) show average differences of less than 3% per crop. Following a similar procedure, we compared net trade figures for Europe-13 obtained by using the Comtrade and NewCronos (Eurostat). We found a difference of only 5% for the year 2002. Energy data is taken from the IEA energy balances. Electricity is transformed to primary energy using a historical trend in power generation efficiency (Figure 7.2). We calculate the difference in the primary energy demand for agriculture and the food sector for the year 2002 if power efficiency would have been 37% and 43% (this range takes into account the differences in energy efficiency of fossil fired power production of the countries studied). We found that our estimate of total energy demand (3960 PJ[14]) would have decreased by 1% if a 43% efficiency would have used and increased by 3% in the case of the 37% efficiency. The limited influence of power efficiency on the estimation of primary energy is a reflection of the low share of electricity in total final consumption. We conclude that our results hold despite the uncertainty that inevitably comes from using large amounts of data and different data sources.

Figure 7.15 Sensitivity analysis. Influence of possible errors in the assumptions for waste due to transport and storage (W_T), waste due to processing (W_P) and fresh agricultural output going directly to households (O_{AM}) on the calculated value of output for the total food supply chain for the years 1961 and 2002.



7.5.2 Selection of nutritional factor

Throughout this chapter we have expressed the mass flows of food and fodder into nutritional calories. There are two arguments against its use. First, it has been pointed out that the calorific content of food products does not represent the whole function of food. For instance, light or diet products and alcoholic beverages are not consumed because of their nutritional value. We should, however stress that the use

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[14] The efficiency used for the year 2002 in our calculation was 41%.

of nutritional calories on this chapter is not based on the understanding that they comprise all food services but that using the calorific content is a methodologically straightforward way of representing mass flows in the food supply chain.

Second, some studies argue that flows from the food system should be followed not in calories but in terms of protein content [e.g. Slesser et al., 1977]. The basis of the argument is the 'protein-calorie' tradeoff: if the human body faces a calorie deficit it will convert proteins into calories but not the reverse [Pimentel et al., 1975]. To assess if the choice of calories influences the developments in physical output, we compare the trends for the output of the agricultural sector both in terms of calories and protein content. We found no significant differences (less than 2% variation per year) and hence we feel confident that the trends in physical output are not affected by the selection of the nutritional factor selected.

7.5.3 Influence of system boundaries

A final factor to be discussed is the consequences of the chosen system boundaries on the results. For instance, households and retail are not included in the system (see Figure 7.1). To assess the relative importance of the energy used by the food supply chain with respect to the energy used by the food system (including households and retail), we made a rough estimation of the energy used for food-related activities in households and the commercial sector[15]. We estimated that, for the year 2002, the energy used by food-related activities in Europe-13 was 935 PJ in the residential sector and 301 PJ in the commercial sector. Thus, corroborating that the system chosen in this chapter accounts for a major share of total energy demand (about 76%).

Another consequence of the chosen system boundaries is that the system is not closed. Even though imported products are taken into account in the material balance (Equation 7.2), the energy used for their production is not. In Table 7.2 we compare the different flows for the years 1962 and 2001. In order to include the energy needed to produce the 158 Petacalories of agricultural products imported from the world to Europe-13 in 2001, and following the methodology used in this chapter, we would need to assess the direct fuel used in agriculture in each exporting country, the energy embedded in fertilizer consumption as well as the fuel used during transport. To include all this information would make the present analysis unfeasible.

However, a rough approximation of the impact that energy embedded in imported products can have on the total system energy demand can be done by multiplying

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[15] To calculate the energy use in households and the commercial sector related to food activities we made the following assumptions: i) for households we assume that 5% of the final energy was used for cooking and 12 % for lightening and appliances (55% of final electricity used, of which 23% is due to refrigerators and freezers); ii) for the commercial sector, we assume that retail accounted for 20% of the electricity use and 15% of the fuel used, and within these shares, 10% of the fossil fuel was used for cooking while 30% of the electricity was used for refrigeration and freezing. The assumptions are based on: Kersemeeckers [2001], Odyssee [2004], Geiger et al., [1999].

the physical flow with physical energy intensity values. For instance, we can multiply the 158 Petacalories imported in 2001[16] with physical energy intensity values for the years 1970 and 2001 of the agricultural sector (agriculture and fertilizers) calculated earlier in this chapter[17]. In the first case, we assume that all imports come from countries which have an energy demand per unit of product in 2001 comparable to the European situation 30 years ago. In the second case, we assume that all imports come from countries with a similar situation to Europe nowadays. In the first case, the energy demand of the total system would be 4164 PJ, compared with 3871 PJ when the energy embedded in imported products is not taken into account (our original calculation). With a physical energy intensity value of 2001, the total energy demand is calculated at 4110 PJ. This is equivalent to an increase of 6-7% over our original value. A point to take into account is that the amount of imported products has grown at the same rate as indigenous production (Table 7.3). We can therefore conclude, although the absolute amount of energy that goes into the system is indeed underestimated, the impact on the energy demand trend (Figure 7.5) should be negligible.

Table 7.3 Comparison of indigenous production, imports and exports of agricultural products in Europe 13-for the years 1962-2001.

Flow	Physical flow [Petacalories]		% annual change
	1962	2001	
Total agricultural indigenous production (O_A)	567	966	1.4
Of which:			
Meat	103	171	1.3
Other products	464	795	1.4
Total imports (I_A)	91	158	1.4
Of which:			
Meat	1	4	4.3
Other products	90	154	1.4
Total exports (EX_A)	9	59	4.8
Of which:			
Meat	0.4	4	6.5
Other products	9	55	4.8
Net apparent indigenous consumption	649	1065	1.3
Of which:			
Meat	104	171	1.3
Other products	545	894	1.3

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[16] Strictly speaking the amount of imported products should be higher than 158 Petacalories because the feed needed to produce meat is not taken into account. However, since imports of meat only account for 2% of the total imports, the indirect amount of product needed can be disregarded.

[17] There is not enough information to asses the impact of the transport of imported products in the total energy demand.

Another consequence of the system boundaries chosen in this chapter is that we consider both food and fodder as outputs of the system. An important remaining question is what is the efficiency of the system with respect to human consumable output. Let's first examine the agricultural system (agriculture plus fertilizers). We calculate that in 2002 the physical energy intensity for agriculture was 1.4 J/cal. However, if we take into account that about 401 Pcal (1679 PJ) is allocated to crops destined for animal feed and exclude this from the system, the physical energy intensity value would be 2.3 J/cal. That is an increase of 64%. This increase in the ratio of energy input to output points out the inefficiency introduced in the system by raising animals. Animals are very poor converters of the food energy they consume into edible human foodstuffs such as meat, milk and eggs (typical conversion efficiencies for Europe are 3.1 kg of dry matter feed for 1 kg of broiler meat, 6.2 kg of feed for 1 kg of pigmeat and 24 kg of feed for 1 kg of beef [Alcamo, 1994]).

Our results also show that the physical energy intensity for the total supply chain in 2002 was 4.3 J/cal. The first point to take notice is that the proportion of the energy which is used to process and transport food is three times higher greater than that which is used to grow or produced it. Furthermore, when only human consumable food is taken into account, the physical energy intensity changes to 7.6 J/cal which is equivalent to a 76% increase.

In Table 7.4 we compare the results obtained in this chapter (section 7.3) with those resulting from excluding animal feed of the system. The rate at which the total system decreases its specific consumption in the last three decades is six times lower if the output used for animal feed is excluded. The influence on the results as a consequence of examining the system only in terms of food for human consumption is significant and provides a more pessimistic view of energy efficiency improvements in the food supply chain.

Table 7.4 Impact of feed production in the system, average annual change for the period 1970-2002.

	Agriculture [% p.a.]	**Total system [% p.a.]**
Output, including animal feed	+1.4	+1.6
Output, excluding animal feed	+1.1	+1.3
Physical energy intensity, including animal feed	-0.9	-0.2
Physical energy intensity, excluding animal feed	-0.7	-0.04

7.6 Conclusions

In this chapter we have analyzed the historical relationships of fossil fuel demand and food production for Europe-13 in the time period 1970-2002. Our results show that the food supply chain (agriculture, fertilizers, transport and food processing) has increased primary energy demand at a rate of 1.6% p.a. In 2002, food processing had the highest share in the total primary energy demand (37%). The analysis also shows that during the last three decades, there has been a shift of the shares of transport and fertilizers in primary energy demand. The manufacture of fertilizers decreased from 26% to 9%, while the transport's share increased from 19% to 28%. Furthermore, in relative terms, transport has shown the highest rate of increase in energy demand (1.8% p.a.). The results point out transport and food processing as critical sectors in the energy consumption of the food supply chain.

To assess changes in the energy efficiency of the system we have used two indicators: energy per unit of value added (economic energy intensity) and energy per calorie (physical energy intensity). Our results shows that economic energy intensity decreased at a rate of 2.7% p.a. while physical energy intensity decreased 0.2% p.a. An analysis of the different factors that influence energy consumption in each step of the supply chain has shown that output growth has been the main driver of energy demand. Between 1970 and 2002 output growth (especially increased demand for feed production, calorie intake per capita and tkm transported) increased primary energy demand by 1.8% p.a. while physical energy intensity offset this demand by only 0.2% p.a. Thus, with exception of fertilizer manufacture, changes in physical energy intensity – which is a proxy for energy efficiency- have not played a significant role in decreasing total energy demand.

The limited role that physical energy intensity has played so far is an important result. In the ongoing debate on dealing with greenhouse emissions, expectations are high that improvements in energy efficiency can help to significantly decrease total energy consumption without hampering the future economic growth of the nations. Because of the increasing demand for processed food, the increasing amount of tonne-kilometers of food transported and given the findings of this study, unless there is a significant change in the rates at which physical energy intensities decrease, we are far away from being curbing the energy demand in the European food processing chain.

We conclude by pointing out that the use of material flows in energy analysis is helpful in understanding the changes and drivers behind the increased energy consumption shown by the food supply chain. This kind of analysis requires large amount of data, which can appear to be a daunting task. However, it provides additional insights into the development of energy consumption in a given sector of society compared to just focusing on the relations between energy demand and economic output of a certain section of the process chain. A next step is to dive further into the relation between material flows and economic flows (e.g. a detailed analysis of how value added and physical production flows develop in time). A focused examination of the actors and drivers behind this relation can provide a better understanding of the cause and effect relationships that determine energy demand. This is an area where further work can make an important contribution to ensuring that energy efficiency and CO_2 emission reduction strategies are not based on oversimplified scenarios which are mainly derived from monetary indicators without explicit links to the physical world.

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Appendix 1.

Commodity	Au	Be/lux	Fr	Ge	Gr	It	Nl	No	Po	Sp	Sw	UK
Almonds		■				■			■	■		
Apples	■	■	■	■	■	■	■	■	■	■	■	■
Apricots	■		■	■	■	■			■	■		
Artichokes			■		■	■						
Bananas									■	■		
Barley	■	■	■	■	■	■	■	■	■	■	■	■
Beans dry		■	■	■	■	■	■		■	■		
Beans green	■	■	■	■	■	■	■		■	■		■
Beef and buffalo meat	■	■	■	■	■	■	■	■	■	■	■	■
Broad beans dry		■	■	■	■	■	■		■	■		
Cabbages	■	■	■	■	■	■	■	■	■	■	■	■
Cauliflower		■	■	■	■	■	■			■	■	■
Cherries	■	■	■	■	■	■	■	■	■	■		■
Chestnuts			■									
Cow milk whole fresh	■	■	■	■	■	■	■	■	■	■	■	■
Cotton seed					■	■						
Currants							■	■				■
Figs					■	■			■	■		
Goat milk	■		■	■	■	■		■	■	■		
Grapes	■	■	■	■		■			■	■		
Hen eggs	■	■	■	■	■	■	■	■	■	■	■	■
Lemons and limes					■	■			■	■		
Lentils			■	■	■	■				■		
Lettuce	■		■	■			■					
Linseed		■	■	■		■	■					
Lupins				■		■						
Maize	■	■	■	■	■	■	■		■	■		
Mixed grain	■	■	■	■	■		■	■			■	■
Oats	■	■	■	■	■	■	■	■	■	■	■	■
Olives			■		■	■			■	■		
Onions dry	■	■	■	■	■	■	■		■	■	■	■
Oranges					■	■			■	■		
Peaches and nectarines		■	■	■	■	■			■	■		
Peas green		■	■	■	■	■	■				■	■
Peas dry	■	■	■		■	■					■	
Pears	■	■	■	■	■	■	■	■	■	■	■	■
Pigmeat	■	■	■	■	■	■	■	■	■	■	■	■
Plums	■		■	■	■	■	■	■	■	■		■
Potatoes	■	■	■	■	■	■	■	■	■	■	■	■
Poultry meat	■	■	■	■	■	■	■	■	■	■	■	■
Pulses n.e.s	■	■	■	■	■	■	■		■	■	■	■
Rapeseed		■	■	■			■				■	
Raisins				■								
Rice paddy			■			■			■	■		
Rye	■	■	■	■	■	■	■	■	■	■	■	■
Sheep and goat meat	■		■		■	■	■	■	■	■		■

Commodity	**Au**	**Be**	**Fr**	**Ge**	**Gr**	**It**	**Nl**	**No**	**Po**	**Sp**	**Sw**	**UK**
Sheep milk			■	■	■	■			■	■	■	
Sugar beet	■	■	■	■	■	■	■		■	■	■	■
Sunflower seed			■		■	■				■		
Strawberries		■	■	■			■	■				■
Tomatoes	■	■	■	■	■	■	■	■	■	■	■	■
Wheat	■	■	■	■	■	■	■	■	■	■	■	■
Watermelons					■	■				■		

Au: Austria; Be: Belgium; Fr: France; Ge: Germany; GR: Greece; It: Italy; Nl: Netherlands; No: Norway; Po: Portugal; Sp: Spain; Sw: Sweden; UK: United Kingdom

CHAPTER 8

Summary and Conclusions

8.1 Introduction

Prior to the industrial revolution, people depended primarily on renewable sources of energy: animal power, human labor, flowing water, solar energy, wind and biomass combustion. With the development of the steam engine at the birth of the industrial revolution, the use of coal and eventually other fossil fuels contributed to profound changes in production processes, farming and domestic activities. The use of fossil fuels has, however, originated environmental problems. At the local and regional level, fossil fuel energy consumption has caused air and water pollution, but it is the role of fossil fuel combustion in global climate change which has raised worldwide concern. Fossil fuel combustion is the biggest source of anthropogenic greenhouse gas emissions that are changing the composition of the atmosphere and increasing the global mean surface temperature. This thesis departs from the recognition that reducing the environmental effects of the energy cycle is a priority and that energy efficiency plays a crucial role in the transition towards a sustainable energy system.

Defining energy efficiency, measuring it, and devising specific programs to encourage it are challenging tasks. In this thesis, energy efficiency improvement refers to using less energy for producing the same amount of services or useful output. We analyse changes in energy efficiency by using the ratio of energy used to useful output. Output can be measured in economic (e.g. value added) or physical terms (e.g. tonnes of product). In the first case, the indicator is referred to as economic energy intensity, in the second case as physical energy intensity. For processes that generate one single product, the physical energy intensity indicator is defined as the ratio of the energy used to the physical amount of the product. When more than one product is generated (e.g. by an industrial sector), the physical energy intensity indicator is calculated as the ratio of the energy used to a weighted summation of the different products. The weights are based on the amount of energy needed to produce one physical unit of each product (e.g. Megajoule per tonne of product). By keeping the weights constant to a reference year, the weighted summation provides the amount of energy that would have been used if energy efficiency in the period studied would have remained equal to a reference year (frozen energy efficiency development). Hence, the physical energy intensity indicator is indeed a comparison of the realized energy use and a frozen energy efficiency development. The frozen efficiency development does account for yearly changes in the structure of production. Physical energy intensity is hence an indicator that is corrected for structural changes.

The use of physical energy intensity, although recognized as a better indicator of changes in energy efficiency than economic energy intensity, has been generally limited to energy intensive sectors which are characterized by having a limited number of key products, technologies and processes. A key feature of non-energy intensive sectors is their heterogeneity. It is, therefore, not a straightforward task to identify from an extensive list of products, processes and technologies, the ones that have enough explanatory power with regard to energy efficiency. In this thesis, we evaluate whether physical energy intensity indicators provide a feasible way of analyzing changes in energy efficiency in non-energy intensive sectors at different levels of aggregation.

Historically, non-energy intensive sectors have received a low degree of attention from policy-makers and the scientific community. Attention has, however, slowly begun to increase since it has been realized that *i*) taken together they make up for a sizeable portion of energy demand and *ii*) the saving potentials are significant. However, if policy makers are to develop and implement strategies that effectively promote energy efficiency, a thorough understanding of the economic, technical and behavioral drivers underlying energy demand and energy efficiency in non-energy intensive sectors is needed. Due to the low attention paid to these sectors, this understanding is limited. This thesis focuses on analyzing historical developments of energy use and energy efficiency as well as understanding the key underlying drivers in the non-energy intensive sector. This information is important because it will provide modelers and policy makers with a good analytical basis from which to extrapolate trends in energy use and energy efficiency as well as a historical analysis on how various factors such as level of activity, changes in production mix and efficiency affect energy use. We use the food sector as a case study of the non-energy intensive sector.

8.2 Scope of this thesis

The overall aim of this thesis is to examine the role that energy efficiency and other factors have played in the development of energy use of non-energy intensive sectors, with special emphasis on the food industry. Specific goals are:

1. To study the developments in energy use, energy efficiency and sector structure in non-energy intensive industries of the Dutch manufacturing sector.

2. To develop physical energy efficiency indicators for monitoring changes in energy efficiency in the food and tobacco industry at different levels of aggregation.
3. To analyse the historical relations of fossil fuel demand and food production in the European food supply chain.

In each case, we identify and analyze the activity and structural drivers behind the development of energy use. This thesis is composed of three parts, one for each of the specific goals mentioned above. The results of the various parts and chapters are summarized below.

8.3 Summary of results

Part I of this thesis (***Chapter 2***) focuses on examining patterns of energy consumption and economic energy intensity in the non-energy intensive part of the manufacturing sector. The study is conducted using empirical data for the Netherlands for the time period 1988-1999.

A main question behind the research in *Chapter 2* was to analyze if the lack of attention paid to the non-energy intensive sector is justified. The answer is no. On the one hand, we found that between 1988-1999, energy consumption in the non-energy intensive sectors increased by 3% per year on average. Furthermore, in absolute terms, the non-energy intensive sector has been the sector driving the increase in total energy consumption of the Dutch manufacturing sector. On the other hand, aggregate economic energy intensity of the non-energy intensive sector increased between 1988 and 1999 (6% in the case of energy use per unit of value added, or by 2% for energy use per unit of production value).

A decomposition methodology (the Multiplicative Log-Mean Divisa Method) was applied to single out the effect of changes of structure (industrial mix) and increased production from changes in economic energy intensity of the 55 individual sectors. The results show that: *i*) the increase of aggregate economic energy intensity was primarily caused by an increase in the economic energy intensity and not by changes in structure; *ii*) structural effects had only a major role for fuel intensity, and only if value added is used as the measure of economic output. In all the other cases (electricity and primary energy for value added and all types of energy for production value), shifts in industrial structure had a minor role in limiting increases in energy intensity; *iii*) output growth has added further energy requirements to those induced by energy intensity, and *iv)* the use of value added as economic measure of output tended to amplify structural effects.

Finally, an analysis of production value and energy consumption growth rates pointed out no signs of decoupling of energy and output. Due to the observed strong link between manufacturing output and energy consumption, and if no changes occur in the current trends, it is expected that without additional policies, the non-energy intensive sector will in the future contribute to an increase of energy consumption in the Netherlands. Given the trends found in this chapter, the non-energy intensive sector should be considered a key target area for energy efficiency improvement and the reduction of carbon dioxide emissions.

Based on the results found in *Chapter 2*, a closer look to the non-energy intensive manufacturing sectors was taken. Using as a case study the food industry, we analyze historical patterns of energy use and energy efficiency at different levels of aggregation. **Part II** (*Chapters 3, 4 and 5*) examines whether it is possible to develop physical energy intensity indicators that provide a reliable estimate of changes in energy efficiency in the food industry.

The first chapter of Part II, ***Chapter 3***, has as subject of research the dairy industry. The main goals of this chapter are twofold. First, to analyze the trends in energy use by the dairy industry in four European countries: France, Germany, the Netherlands and the United Kingdom. Second, 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.

In the year 2000, the dairy industry consumed about 52, 34, 16 and 14 PJ of primary energy in France, Germany, the Netherlands and the United Kingdom respectively. The dairy industry of these four countries was responsible for the emission of about 6 Mt CO_2 (39% of which are related to the indirect emissions caused by electricity consumption). Changes in energy efficiency were monitored in two different ways. First, by looking at the energy use per tonne of milk processed by dairies (EEI_{p1}). Secondly, by comparing the actual energy use with a frozen energy efficiency development (EEI_{p2}). The latter indicator corrects for differences in product mix among countries and in time. 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: it does not reflect important changes in product mix which were found to be substantial. EEI_{p2}, on the other hand, is a much more complex indicator to calculate and the data burden is higher. However, it accounts for differences in structures among countries and changes in product mix. It also allows for refinement as better information and data becomes available. We found that changes in production mix are important in three of the four countries and therefore EEI_{p2} should be preferred when comparing levels of energy efficiency in the dairy industry.

Once changes in product mix have been taken into account, our results show that while in Germany, the Netherlands and the United Kingdom the dairy industry has reduced their EEI_{p2} values by more than 1% p.a. (2.1%, 1.2%, and 3.8% respectively), EEI_{p2} values for the French dairy industry have declined at a significantly lower rate (0.4% p.a.). We found that throughout the period studied, EEI_{P2} values for the French dairy industry were larger than for the other countries (e.g. in 2000, the EEI_{p2} values were 30-40% larger).

An analysis of the possible causes behind the differences between countries, especially between France and the other three countries, shows that higher EEI_{p2} values calculated for the French dairy industry can be related to the fact that the French dairy industry works at a smaller scale, is highly fragmented and has shown a relatively slow pace of concentration. Although there is a lack of detailed information, our results suggest that the French dairy industry is using different technologies (which are more energy intensive) to produce dairy products. A more detailed analysis of the French dairy industry revealed that while the cheese and butter making sub-sectors have decreased substantially in their EEI_{p2} values, the decrease has been offset by an increase of the EEI_{p2} in the 'other milk products' category (milk powders and condensate products). Consequently, values for the whole French dairy sector appears to remain nearly constant. Finally, our results also show that the British, German and Dutch dairy industry have converged towards similar (lower) values in their energy efficiency indicators and that the French dairy industry would save about 30% if it were to converge to similar values of EEI_{p2} as the ones reached by Germany or the United Kingdom.

Following a similar structure to *Chapter 3*, ***Chapter 4*** examines patterns of production, energy use and energy efficiency in the meat sector (production and preservation of meat plus the further processing of meat products) of France, Germany, the Netherlands and the United Kingdom. The analysis is carried out for the time period 1986-2001. In the year 2001, the meat industry demanded about 39, 35, 10 and 32 PJ of primary energy in France, Germany, the Netherlands and the United Kingdom respectively. 40-60% of this amount was used in the further processing of meat products. The meat industry of the four countries studied was responsible for the emission of 4.5 Mt CO_2 (58% of which are related to the indirect emissions caused by electricity consumption). Our results also show significant increases in primary energy use per tonne of product: France (3.2% p.a.), Germany (3.4% p.a.), Netherlands (1.4% p.a.), and the United Kingdom (1.6% p.a.). We found a trend in all countries towards higher electricity use due to increasing demands for refrigeration and motor drive power generation.

In order to understand the drivers behind the trends, factors such as the share of frozen products, the share of cut-up products and increasing food hygiene measures were analysed. We found that correcting the indicator for changes in the shares of frozen, cut-up and deboned meat products *i*) decreased the absolute values of the energy efficiency indicator, *ii*) decreased the gap between countries, and *iii*) explained some of the fluctuations showed by the trends at a disaggregate level. Nevertheless, these changes in product mix cannot explain the increase of the energy efficiency indicator displayed by the whole meat sector. The impact of stringent hygiene regulations on energy demand was stronger. It explains between one and two thirds of the increase in the energy efficiency indicator.

Chapters 3 and *4* show that patterns of energy consumption and energy efficiency can be monitored and analysed at lower levels of aggregation. ***Chapter 5*** builds on the data and results found in *Chapter 3* and *4* and expands the analysis to a higher level of aggregation. In ***Chapter 5*** we develop indicators to monitor energy efficiency in the whole food, drink and tobacco industry (hereafter food industry). The analysis is based on physical production data at the firm level provided by the Statistics Netherlands on a confidential basis. The analysis was carried out for the time period 1993-2001.

We measure energy efficiency by using as indicator the ratio of the current energy used and a frozen energy efficiency development. We selected 49 product categories which account for 51% of the total food categories. The coverage obtained for the base year (1995) was about 81% for fuels/heat and 60% for electricity. Our results show that the Dutch food industry has improved its energy efficiency indicator in primary terms by about 1% p.a. (uncertainty range between 0.9 and 1.3). In terms of final energy, there has been a decrease of the indicator for final demand of fuels by about 1.8% p.a. while there has been no improvement in the indicator for final demand of electricity. Furthermore, we estimate that increased penetration of combined heat and power (CHP) in the food industry since 1993 has saved about 3 PJ primary energy in the Netherlands.

In order to assess whether or not the product mix studied is representative, we compare the average annual change in physical production of the products take into account in this chapter against those left out. We found that both groups exhibit similar behaviours. Hence, we conclude that the products selected reflect important structural changes in the food industry. Furthermore, we found that the development in energy efficiency found in this chapter is coherent with the reported implementation rate of energy conservation projects and with developments reported by the Long Term Agreements, which confirms the reliability of the approach and the results.

We conclude that the type and the quality of the data compiled by Statistics Netherlands for the food industry are sufficient to develop indicators as required by energy and climate policy. 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 (as done by the Agency for Energy and Environment NOVEM in the Netherlands). This is a very promising outcome not only because it is rather likely that similar analyses can also be conducted for other non-energy intensive industries in the Netherlands, it also gives rise to hopes that similar analyses for non-energy intensive sectors can be conducted for other countries. The sole condition is that detailed production data can be made available (for example on a confidential basis as in the Netherlands).

In **Part III** (*Chapters 6 and 7*), we expand the system boundaries by including into the analysis agriculture, fertilizers and transport. In this way, Part III takes a system approach when examining the dynamics and interrelations of energy and food production.

The first chapter of Part III, ***Chapter 6,*** assesses energy demand due to world fertilizer consumption in the time period 1961-2002. Energy embedded in fertilizer consumption is considered the most energy intensive part of the food chain. In the first part of *Chapter 6* we develop historical trends of specific energy consumption and gross energy requirements by kind of fertilizer and assess the energy embedded in world fertilizer consumption. The trends obtained are later used in *Chapter 7* as part of the inputs needed to calculate total energy demand in the food supply chain. In the second part, we explore whether technological development in the fertilizer industry can be analysed by using the concept of learning or experience curve.

According to our analysis, in the year 2001 the primary energy embedded in world fertilizer consumption was about 3660 PJ (1% of the world total energy demand in 2001) of which 72% was for the production of nitrogen fertilizers, 10% for phosphate fertilizers, 16% for complex fertilizers and only 2% for potassium fertilizers. Total energy demand increased by about 3.8% p.a. between 1961 and 2001. The highest average annual growth rate was shown for nitrogen fertilizers (4.5 % p.a.) followed by compound fertilizers (3.9% p.a.).

In order to understand the development in embedded energy, we apply a decomposition methodology which allow us to single out the effects of increasing fertilizer consumption and changes in fertilizer mix. There are three main findings. The first is not surprising: growth in fertilizer consumption has been the main driver of increasing energy consumption. Second, fertilizer mix has moved towards fertilizers that are more energy intensive per kilogram of nutrient, which has further increased energy demand. And third, significant improvements in energy efficiency have occurred, but they have not been able to offset the increasing effect of other factors. A comparison with best available technologies reveal a saving potential for the year 2001 of about 19% (687 PJ). This potential is mainly allocated to the nitrogen fertilizer industry.

In the second part of this chapter, we look at technological development in energy efficiency as a learning process. As far as we know no attempts have been previously done to use the concept of learning curves for the development of industrial energy efficiency. Most published material on experience curves relates prices to the cumulative production of a technology. We relate the historical trends in specific energy consumption of various nitrogenous fertilizers to cumulative production. Our results show that specific energy consumption of ammonia and urea developed in close concordance with the learning curve model, showing progress ratios of 71% for ammonia production (R^2=0.997) and 88% for urea (R^2=0.856). This is an important result since middle and long-term models of energy consumption and CO_2 emissions face the difficulty of how to consider technological change. The use of progress ratios can provide an alternative approach to include technological change into scenario developments. Another consequence of our findings is that for energy intensive industries for which classical learning curves (i.e. based on prices) cannot be developed due to high dependences on market prices and strong fluctuations of raw material prices, the analysis of specific energy consumption as a main indicator of technological development can provide a way out to analyse rates of technological change.

The final chapter of Part III, ***Chapter** 7*, provides an extended historical analysis of the relationships between fossil fuel demand and food production. The system studied includes the energy used by the agricultural, food processing, transport and fertilizer sectors. The physical flows taken into account are output of the agricultural sector, import of agricultural/semi-processed products, export of agricultural products, waste due to transport and storage, waste during processing and output used for sowing. The analysis was performed for thirteen European countries (Europe-13) in the period 1970-2002.

Our results show that in the year 2002 the food supply chain in Europe-13 required about 3960 PJ of primary energy. This corresponds to about 7% of the energy used by Europe-13 in the same year. In total primary energy use of the system studied increased by 1.6% p.a. We found that the only part of the system showing decreasing energy demand (about 2% p.a.) is the energy needed for the manufacture of fertilizers. Agriculture, food processing and transport have increased their energy consumption at a rate of 1.6%, 1.8% and 2.3% per annum respectively.

In this chapter, we choose as functional unit the output of food and fodder expressed in value added and calorie content. We estimated that the physical output of the total food supply chain in the year 2002 was about 924 petacalories (or 3868 PJ), while the economic output of agriculture and food processing was about €342 billion of value added (5% of total GDP). Physical output of the total system has grown at a rate of 1.8% p.a. while economic output has grown at a rate of 3.6% p.a. Our analysis also shows that economic energy intensity decreased at a significantly higher rate (2.7% p.a.) than physical energy intensity (0.2% p.a.).

One consequence of the system boundaries chosen is that we consider both food and fodder as outputs of the system. We found that if animal feed is excluded from the system, the rate at which the physical energy intensity of the system decreased in the last three decades is significantly lower (0.2% versus 0.04% per annum). We also assessed the influence of using calorie content as the functional unit of output by comparing the output trends both in terms of calories and protein content, and found no significant differences (less than 2% variation per year). Another consequence of the chosen system boundaries is that the system is not closed: the energy use for the production of imported agricultural/semi processed products is not taken into account. However, an assessment of the impact that energy embedded in imported products could have on the energy demand trend of the food supply chain indicates that our conclusions are not affected by the choice of system limits.

In this chapter we also examine the drivers behind the energy consumption developments. We found that between 1970 and 2002, increased demand for feed production, increased calorie consumption per capita, and increased tonne-kilometer transported have been the main drivers of energy demand of the system. Output growth has increased primary energy demand by 1.8% p.a. on average while changes in physical energy intensity offset this demand by only 0.2% p.a. Thus, with exception of fertilizer manufacture, changes in physical energy intensity have not played a significant role in decreasing total energy demand in the European food supply chain.

The limited role that physical energy intensity has played so far is an important result. In the ongoing debate on dealing with greenhouse emissions, expectations are high that improvement in energy efficiency can help to significantly decrease total energy consumption without hampering the future economic growth of the nations. Because of the increasing production of processed food, the increasing amount of tonne kilometres of food transported and given the findings of this study, unless there is a significant change in the rates at which physical efficiency improves, we are far away from curbing the net energy demand in the European food supply chain.

8.4 Lessons learned

There are several conclusions that need to be stressed. First, in this thesis we have shown that, from a methodological point of view:

- It is possible to monitor changes in energy efficiency based on physical production data in heterogeneous, non-energy intensive sectors.
- Physical energy intensities provide a fair and feasible way of comparing energy efficiency developments among countries.
- Decomposition methodologies, which are generally applied to monetary-based energy analysis, are an equally useful tool in physically based energy analysis. They allow large amount of information to be studied and provide a way to quantitatively analyze the impact of different factors in energy consumption/intensity.
- Technological development in energy efficiency in energy intensive sectors can be analyzed by using the learning curve concept.
- Provided that detailed and reliable data is *available* (in public databases as used in Chapter 4 and 5 or obtained on a confidential basis as in Chapter 6) and that detailed studies of energy efficiency at the industrial level for a base year exist, historical changes in physical energy intensities can be monitored without needing to implement task forces that depend exclusively on confidential reporting at the firm level.
- The biggest limitations found in this thesis are due to data availability and data quality. A sizeable amount of the research time has been spent obtaining reliable time series with sufficient level of detail to allow the drivers behind energy efficiency changes to be analyzed (e.g. this proved to be a major constraint in understanding energy efficiency changes in the meat sector). These limitations may be a major deterrent of performing the kind of analysis made in this thesis for other sectors and/or for other geographical regions.

Second, we have shown that in the last decade, the non-energy intensive manufacturing sector in the Netherlands has increased total industrial energy demand and that it has demanded more energy per unit of output. The results highlight the need for policy-makers and scientists to increase their attention to the non-energy intensive sector and encourage industries in these sectors to adopt energy-efficient technologies and management practices.

Third, comparisons of economic and physical energy intensities in the food sector reveal large differences in the rates of decline, with economic energy intensities declining up to 3% p.a. faster than physical energy intensities. In other words, the value added of the food sector has grown at a significant faster rate than physical production in the last three decades. This difference indicates a decoupling of physical production and economic growth in the European food sector.

Fourth, our results have shown that in the food sector changes in physical energy intensity have not even been close to offset energy demands imposed by growing output. In fact, there are no signs of decoupling between energy consumption and growing output in the period studied (a similar result is found in the analysis of the Dutch non-energy intensive manufacturing sector in Chapter 2). There is, of course, no contradiction between the third and fourth conclusion. Decoupling physical production and economic growth do not imply per se a reduction in the amount of energy used. Energy is only one of the factors of production. Decoupling can also be achieved by increasing labor or capital productivity. The comparison of economic and physical energy intensities not only reveals that energy efficiency has played a minor role in the decoupling of physical production and economic growth in the food sector, but also indicates that the use of economic energy intensity as an indicator of energy efficiency in the food sector fails to reflect current changes in energy efficiency.

Finally, the results found in this thesis are a source of concern because they suggest that energy policies have failed so far to make significant improvements in energy efficiency in the European food sector. Although some sectors have shown significant improvements in their energy efficiency (e.g. dairy industries), we found these improvements to have mainly been driven by concentration processes, which in most cases offer limited scope for the future. The general picture indicates that increased efforts should be made by industry and policy-makers if we want to reach energy savings that contribute significantly to the reduction of greenhouse gas emissions.

We conclude this thesis by pointing out the importance of including physical flows into energy analysis. Understanding and addressing the consequences of physical processes requires them to be dealt with not only in economic terms but also in physical terms. Ultimately, it is difficult to see how sustainability (and the ways to achieve it) can be addressed by policy makers in the absence of information regarding the time-dependency of energy and material flows within the various sub-sectors of economies.

Samenvatting en conclusies

Inleiding

Vóór de Industriële Revolutie waren mensen hoofdzakelijk afhankelijk van duurzame energiebronnen: dierlijke kracht, menselijke arbeid, stromend water, zonne-energie, windenergie en biomassaverbranding. Door de ontwikkeling van de stoommachine bij het begin van de Industriële Revolutie droeg het gebruik van steenkool en uiteindelijk andere fossiele brandstoffen bij aan diepgaande veranderingen in productieprocessen, de landbouw en huishoudelijke activiteiten. Het gebruik van fossiele brandstoffen heeft echter milieuproblemen veroorzaakt. Op lokaal en regionaal niveau heeft het gebruik van fossiele brandstoffen lucht- en waterverontreiniging veroorzaakt, maar het is vooral de rol van fossiele brandstofverbranding in de globale klimaatverandering die tot wereldwijde zorg heeft geleid. De verbranding van fossiele brandstoffen is de belangrijkste antropogene bron van broeikasgasemissies die de samenstelling van de atmosfeer veranderen en de gemiddelde oppervlaktetemperatuur op aarde verhogen. Dit proefschrift heeft als uitgangspunt dat het verminderen van de milieugevolgen van de energievoorziening een prioriteit is en dat energie-efficiëntie een cruciale rol speelt in de overgang naar een duurzaam energiesysteem.

Het bepalen van energie-efficiëntie, het meten ervan en het bedenken van specifieke programma's om de efficiëntie van het energiegebruik te bevorderen, zijn uitdagende taken. In dit proefschrift wordt met verbetering van energie-efficiëntie bedoeld het gebruik van minder energie voor het produceren van een gegeven hoeveelheid diensten of nuttige output. We analyseren veranderingen in energie-efficiëntie door de verhouding van energiegebruik en nuttige output te bepalen. De output kan worden gemeten in economische termen (bijv. toegevoegde waarde) of fysieke termen (bijv. tonnen product). In het eerste geval wordt de indicator de economische energie-intensiteit genoemd, in het tweede geval de fysieke energie-intensiteit. Voor processen die slechts één enkel product produceren, wordt de indicator van de fysieke energie-intensiteit gedefinieerd als de verhouding van de gebruikte energie ten opzichte van de fysieke hoeveelheid van het product. Wanneer meer dan één product wordt geproduceerd (bijv. door een industriesector) wordt de indicator van de fysieke energie-intensiteit berekend als de verhouding van de gebruikte energie en de gewogen optelling van de verschillende producten. De gewichten zijn gebaseerd op de hoeveelheid energie die nodig is om één fysieke eenheid van elk product (bijv. megajoule per ton product) te produceren. Door de gewichten constant te houden (bijv. voor een referentiejaar), geeft de gewogen optelling de hoeveelheid energie die gebruikt zou zijn indien de energie-efficiëntie in de bestudeerde periode gelijk zou zijn gebleven aan die in het referentiejaar (de zgn. frozen-efficiency ontwikkeling). Derhalve is de indicator van de fysieke energie-intensiteit inderdaad een vergelijking van het gerealiseerde energiegebruik en het frozen-efficiency energiegebruik. Deze bevroren efficiëntieontwikkeling verklaart jaarlijkse veranderingen in de productiestructuur. De fysieke energie-intensiteit is daarom een indicator die gecorrigeerd is voor structurele veranderingen.

Het gebruik van fysieke energie-intensiteit, hoewel erkend als een betere indicator van veranderingen in energie-efficiëntie dan economische energie-intensiteit, is over het algemeen beperkt gebleven tot energie-intensieve sectoren die gekenmerkt worden door een beperkt aantal kernproducten, technologieën en processen. Een belangrijke eigenschap van niet energie-intensieve sectoren is hun heterogeniteit. Het is daarom geen eenvoudige opgave om uit een uitgebreide lijst van producten, processen en technologieën diegene te identificeren die een voldoende groot deel van de veranderingen in de energie-efficiëntie verklaren. In dit proefschrift evalueren wij of de indicatoren van de fysieke energie-intensiteit geschikt zijn om veranderingen in energie-efficiëntie in niet energie-intensieve sectoren op verschillende niveaus van aggregatie te analyseren.

Van oudsher hebben niet energie-intensieve sectoren relatief weinig aandacht gekregen van beleidsmakers en wetenschappers. De aandacht is echter langzaamaan toegenomen aangezien men zich heeft gerealiseerd *i*) dat deze sectoren gezamenlijk verantwoordelijk zijn voor een omvangrijk deel van de energieconsumptie en *ii*) dat de mogelijkheden voor energiebesparing significant zijn. Indien beleidsmakers strategieën ter bevordering van de energie-efficiëntie wensen te ontwikkelen en toe te passen, dan is een grondig inzicht nodig in de economische, technische en gedragsmatige drijvende krachten die bepalend zijn voor het energiegebruik en de energie-efficiëntie in de niet energie-intensieve sectoren. Vanwege de geringe aandacht voor deze sectoren, is dit inzicht nog beperkt. Dit proefschrift concentreert zich zowel op het analyseren van historische ontwikkelingen van energiegebruik en energie-efficiëntie, als op het begrijpen van de belangrijkste onderliggende drijvende krachten in de niet energie-intensieve sectoren. Deze informatie is belangrijk omdat het modelmakers en beleidsmakers een goede analytische basis zal bieden van waaruit trends in energiegebruik en energie-efficiëntie geëxtrapoleerd kunnen worden. Bovendien biedt deze informatie een historische analyse van hoe verschillende factoren, zoals het activiteitenniveau, veranderingen in productiemix en efficiëntie, het energiegebruik beïnvloeden. Wij gebruiken de voedingsmiddelensector als *case study* van de niet energie-intensieve sector.

Doelstellingen van dit proefschrift

De algemene doelstelling van dit proefschrift is het onderzoeken van de rol die energie-efficiëntie en andere factoren hebben gespeeld in de ontwikkeling van energiegebruik in niet-energie-intensieve sectoren, met bijzondere nadruk op de voedingsmiddelenindustrie. De specifieke doelen zijn:

1. Het bestuderen van de ontwikkelingen in energiegebruik, energie-efficiëntie en sectorstructuur in niet energie-intensieve branches binnen de Nederlandse industrie.

2. Het ontwikkelen van indicatoren voor de fysieke energie-efficiëntie, met het oog op het monitoren van veranderingen in energie-efficiëntie in de voedings- en genotsmiddelenindustrie op verschillende aggregatieniveaus.

3. Het analyseren van de historische relaties tussen het gebruik van fossiele brandstoffen en de omvang van de voedselproductie in Europa.

In elk van deze drie doelstellingen identificeren en analyseren we de activiteit en de structurele drijvende krachten achter de ontwikkeling van het energiegebruik. Dit proefschrift bestaat uit drie delen, één voor elk van de hierboven vermelde specifieke doelstellingen. De resultaten van de afzonderlijke delen en hoofdstukken worden hieronder samengevat.

Samenvatting van de resultaten

Deel I van dit proefschrift (*hoofdstuk 2*) richt zich op het onderzoeken van patronen van energiegebruik en economische energie-intensiteit in het niet-energie-intensieve deel van de productiesector. De studie is uitgevoerd op basis van empirische gegevens voor Nederland voor de periode 1988-1999.

In ***hoofdstuk 2*** was de belangrijkste vraag of het gebrek aan aandacht voor de niet-energie-intensieve sectoren gerechtvaardigd is. Het antwoord is: ‘nee’. Enerzijds, konden we concluderen dat het energiegebruik in de niet-energie-intensieve sectoren tussen 1988 en 1999 gemiddeld met 3% per jaar steeg. Bovendien hebben de niet-energie-intensieve sectoren, in absolute termen, de verhoging van het totale energiegebruik van de Nederlandse productiesector veroorzaakt. Anderzijds steeg tussen 1988 en 1999 de gezamenlijke economische energie-intensiteit van de niet-energie-intensieve sector (met 6% in het geval van energiegebruik per eenheid van toegevoegde waarde, of met 2% voor energiegebruik per eenheid van productiewaarde).

Een decompositiemethodologie (de multiplicatieve Log-Mean Divisa-methode) werd toegepast om het effect van structuurveranderingen (industriële mix) en toegenomen productie te isoleren ten opzichte van veranderingen in de economische energie-intensiteit van de 55 individuele sectoren. De resultaten tonen aan *i*) dat de toename van de totale economische energie-intensiteit hoofdzakelijk werd veroorzaakt door een toename van de energie-intensiteit van individuele sectoren en niet door veranderingen in structuur; *ii*) dat structurele effecten slechts een belangrijke rol speelden voor brandstofintensiteit, en alleen als de toegevoegde waarde wordt gebruikt als maat voor economische output. In alle andere gevallen (elektriciteit en primaire energie voor toegevoegde waarde en alle types energie voor productiewaarde) speelden verschuivingen in industriële structuur een minder belangrijke rol in het beperken van toenames in energie-intensiteit; *iii*) dat output-groei een verdere groei in het energiegebruik heeft veroorzaakt boven op de groei die teweeg is gebracht door de verandering in de energie-intensiteit, en *iv*) dat het gebruik van toegevoegde waarde als maat voor de economische output leidt tot een hogere uitkomst voor de structuureffecten.

De analyse van de groeipercentages van productiewaarde en energiegebruik liet geen ontkoppeling van energie en output zien. Vanwege het waargenomen sterke verband tussen beide en indien geen veranderingen optreden in de huidige trends, wordt verwacht dat zonder aanvullend beleid de niet energie-intensieve sector in de toekomst zal bijdragen aan een verhoging van energiegebruik in Nederland. Gezien de in dit hoofdstuk aangetroffen trends, dient de niet energie-intensieve sector te worden beschouwd een als zeer belangrijk beleidsterrein voor de verbetering van energie-efficiëntie en de vermindering van kooldioxidemissies.

Gebaseerd op de in *hoofdstuk 2* gevonden resultaten werd nader gekeken naar de niet-energie-intensieve productiesectoren. Gebruik makend van de voedingsmiddelenindustrie als *case study*, analyseren wij historische patronen van energiegebruik en energie-efficiëntie op verschillende aggregatieniveaus. **Deel II** (*hoofdstuk 3, 4 en 5*) onderzoekt of het mogelijk is indicatoren van fysieke energie-intensiteit te ontwikkelen die een betrouwbare raming geven van veranderingen in energie-efficiëntie in de voedingsmiddelenindustrie.

Het eerste hoofdstuk van deel II, ***hoofdstuk 3***, is gewijd aan de zuivelindustrie. Dit hoofdstuk heeft twee doelstellingen. Ten eerste om de trends te analyseren in het energiegebruik van de zuivelindustrie in vier Europese landen: Frankrijk, Duitsland, Nederland en het Verenigd Koninkrijk. Ten tweede om indicatoren te ontwikkelen en toe te passen die kunnen worden gebruikt om trends in energie-efficiëntie te monitoren. Wij voeren de analyse uit voor de periode 1986-2000.

In het jaar 2000 gebruikte de zuivelindustrie ongeveer 52, 34, 16 en 14 PJ aan primaire energie in respectievelijk Frankrijk, Duitsland, Nederland en het Verenigd Koninkrijk. De zuivelindustrie van deze vier landen was verantwoordelijk voor de emissie van ongeveer 6 Mt CO_2 (waarvan 39% te maken heeft met het elektriciteitsverbruik). Veranderingen in energie-efficiëntie werden gemonitord op twee verschillende manieren. Ten eerste door het energiegebruik te bekijken per ton melk die door zuivelfabrieken wordt verwerkt (EEI_{p1}). Ten tweede door het daadwerkelijke energiegebruik te vergelijken met een frozen-efficiency ontwikkeling van de energie-efficiëntie (EEI_{p2}). De laatstgenoemde indicator corrigeert (voor) verschillen in de productenmix tussen landen en in de loop van de tijd. De eerste indicator, EEI_{p1}, heeft verschillende aantrekkelijke kenmerken. De indicator is gemakkelijk te berekenen, vereist weinig gegevens, kan door niet-specialisten worden begrepen en gemakkelijk worden gecommuniceerd. Het heeft echter een belangrijk nadeel: het weerspiegelt niet de belangrijke veranderingen in de productenmix die aanzienlijk bleken te zijn. EEI_{p2} is daarentegen een veel complexere indicator om te berekenen en vergt meer data. Daarentegen houdt deze rekening met verschillen in productiestructuur tussen landen evenals met veranderingen in de productenmix. Deze indicator kan bovendien verder verfijnd worden indien betere data beschikbaar komen. Wij constateerden dat veranderingen in productenmix belangrijk zijn in drie van de vier landen. De EEI_{p2} verdient daarom de voorkeur bij het vergelijken van niveaus van energie-efficiëntie in de zuivelindustrie.

Wanneer rekening wordt gehouden met veranderingen in productenmix tonen onze resultaten dat, terwijl in Duitsland, Nederland en het Verenigd Koninkrijk de zuivelindustrie haar waarden EEI_{p2} met meer dan 1% per jaar (2,1%, 1,2%, en 3,8% respectievelijk) heeft verminderd, de afname van de waarden EEI_{p2} voor de Franse zuivelindustrie beduidend lager is (0,4% per jaar). Wij constateerden dat gedurende de bestudeerde periode, de EEI_{p2} -waarden voor de Franse zuivelindustrie hoger waren dan voor de andere landen (in 2000 waren de EEI_{p2} -waarden bijvoorbeeld 30-40% groter).

Een analyse van de mogelijke oorzaken achter de verschillen tussen landen, vooral tussen Frankrijk en de andere drie landen, toont aan dat de hogere EEI_{p2} -waarden die voor de Franse zuivelindustrie zijn berekend in verband kunnen worden gebracht met het feit dat de Franse zuivelindustrie kleinschaliger werkt, zeer gefragmenteerd is en een relatief langzaam tempo van concentratie laat zien. Hoewel er een gebrek aan gedetailleerde informatie is, suggereren onze resultaten dat de Franse zuivelindustrie andere technologieën gebruikt (die meer energie-intensief zijn) om zuivelproducten te produceren. Een meer gedetailleerde analyse van de Franse zuivelindustrie bracht aan het licht dat, terwijl de kaas en boter producerende subsectoren hun EEI_{p2} -waarden substantieel hebben verminderd, de daling teniet is gedaan door een verhoging van EEI_{p2} -waarden in de categorie ‘overige zuivelproducten’ (melkpoeder en gecondenseerde producten). Als gevolg daarvan lijken de waarden voor de gehele Franse zuivelsector bijna constant te blijven. Tot slot tonen onze resultaten ook aan dat de Britse, Duitse en Nederlandse zuivelindustrie zijn geconvergeerd naar vergelijkbare (lagere) waarden in hun energie-efficiëntie-indicatoren en dat de Franse zuivelindustrie ongeveer 30% zou besparen indien het zou convergeren naar vergelijkbare waarden van EEI_{p2} zoals die door Duitsland of het Verenigd Koninkrijk worden bereikt.

Op dezelfde manier als in *hoofdstuk 3*, worden in ***hoofdstuk 4*** patronen van productie, energiegebruik en energie-efficiëntie in de vleessector (productie en conservering van vlees plus de verdere verwerking van vleesproducten) van Frankrijk, Duitsland, Nederland en het Verenigd Koninkrijk onderzocht. De analyse wordt uitgevoerd voor de periode 1986-2001. In het jaar 2001 vroeg de vleesindustrie ongeveer 39, 35, 10 en 32 PJ aan primaire energie in respectievelijk Frankrijk, Duitsland, Nederland en het Verenigd Koninkrijk. 40-60% van deze hoeveelheid werd gebruikt in de verdere verwerking van vleesproducten. De vleesindustrie van de vier bestudeerde landen was verantwoordelijk voor de emissie van 4,5 Mt CO_2 (waarvan 58% in verband staat met de indirecte emissies die door elektriciteitsverbruik worden veroorzaakt). Onze resultaten tonen significante toenames van primair energiegebruik per ton product: Frankrijk (3,2% per jaar), Duitsland (3,4% per jaar), Nederland (1,4% per jaar) en het Verenigd Koninkrijk (1,6% per jaar). Wij constateerden in alle landen een trend naar hoger elektriciteitsgebruik als gevolg van de toenemende vraag naar koeling en het toegenomen gebruik van elektromotoren.

Om de drijvende krachten achter de trends te (kunnen) begrijpen, werden factoren zoals het aandeel bevroren producten, het aandeel in stukken gesneden producten en de toegenomen maatregelen op het terrein van de voedselhygiëne geanalyseerd. Wij constateerden dat het corrigeren van de indicator voor veranderingen in de aandelen bevroren, gesneden en uitgebeende vleesproducten *i*) de absolute waarden van de energie-efficiëntie indicator verminderde, *ii*) de kloof tussen landen verminderde, en *iii*) enkele van de schommelingen verklaarde die door de trends werden getoond op afzonderlijk niveau. Niettemin kunnen deze veranderingen in productenmix niet de toename verklaren van de energie-efficiëntie indicator zoals die in de gehele vleessector is te zien. Het effect van de strenge hygiëneregels op het energiegebruik was sterker. Het verklaart één derde tot tweederde van de toename van de energie-efficiëntie indicator.

De *hoofdstukken 3 en 4* tonen aan dat de patronen van energiegebruik en energie-efficiëntie op lage aggregatieniveaus kunnen worden gemonitord en geanalyseerd. ***Hoofdstuk 5*** bouwt voort op de gegevens en resultaten uit *hoofdstuk 3 en 4* en tilt de analyse naar een hoger aggregatieniveau. In *hoofdstuk 5* ontwikkelen we indicatoren om energie-efficiëntie in de gehele voeding- en genotmiddelenindustrie (hierna gezamenlijk aangeduid als voedingsmiddelenindustrie) te monitoren. De analyse is gebaseerd op fysieke productiegegevens op bedrijfsniveau die door het Centraal Bureau voor de Statistiek op vertrouwelijke basis zijn verstrekt. De analyse werd uitgevoerd voor de periode 1993-2001.

Wij meten energie-efficiëntie door de verhouding van de huidige gebruikte energie en de frozen-efficiency ontwikkeling van het energiegebruik als indicator te nemen. Wij selecteerden 49 productcategorieën die 51% van de totale voedselcategorieën vertegenwoordigen. De dekking die werd verkregen voor het basisjaar (1995) was ongeveer 81% voor brandstoffen/warmte en 60% voor elektriciteit. Onze resultaten tonen aan dat de Nederlandse voedingsmiddelenindustrie zijn energie-efficiëntie indicator in primaire termen met ongeveer 1% per jaar heeft verbeterd (onzekerheidsmarge tussen 0,9 en 1,3). Per jaar is er een afname geweest van de indicator voor het finaal verbruik van brandstoffen met ongeveer 1,8%, terwijl er geen verbetering is opgetreden in de indicator voor de finale vraag naar elektriciteit. Voorts schatten wij dat de verhoogde penetratie van warmtekrachtkoppeling

(WKK) in de voedingsmiddelenindustrie sinds 1993 ongeveer 3 PJ primaire energie in Nederland heeft bespaard.

Om te beoordelen of het bestudeerde pakket producten al dan niet representatief is, vergelijken wij de gemiddelde jaarlijkse verandering in fysieke productie van de hier bestudeerde producten met die van producten die hier niet zijn meegenomen. Wij constateerden dat beide groepen een vergelijkbare ontwikkeling vertonen. Derhalve concluderen we dat de geselecteerde producten belangrijke structurele veranderingen in de voedingsmiddelenindustrie weerspiegelen. Voorts stelden we vast dat de ontwikkeling in energie-efficiëntie die in dit hoofdstuk werd gevonden coherent is met de gerapporteerde implementatietempo van energiebesparingsprojecten en met ontwikkelingen die gerapporteerd zijn door de Meerjarenafspraken. Dit ondersteunt de betrouwbaarheid van de benadering en de resultaten.

We concluderen dat het type en de kwaliteit van de gegevens betreffende de voedingsmiddelenindustrie zoals bijeengebracht door het Centraal Bureau voor de Statistiek volstaan om indicatoren te ontwikkelen zoals vereist voor energie- en klimaatbeleid. Dit is een belangrijke constatering aangezien het betekent dat energie-efficiëntie in de voedingsmiddelensector gemonitord kan worden door een energie-agentschap, zonder een speciale werkgroep op te zetten die afhankelijk is van gegevens van bedrijven die uitsluitend plaatsvindt met het doel om ontwikkelingen in energie-efficiëntie te monitoren (zoals in Nederland gebeurt door SenterNovem). Dit is een belangrijke constatering, niet alleen omdat het waarschijnlijk is dat gelijksoortige analyses ook voor andere niet-energie intensieve industrieën in Nederland kunnen worden uitgevoerd, maar tevens omdat het de hoop versterkt dat gelijksoortige analyses voor niet-energie-intensieve sectoren ook voor andere landen kunnen worden uitgevoerd. De enige voorwaarde is dat gedetailleerde productiegegevens beschikbaar gesteld kunnen worden (bijvoorbeeld, zoals in Nederland, op een vertrouwelijke basis).

In **deel III** (*hoofdstuk 6 en 7*) verleggen we de systeemgrenzen door landbouw, meststoffen en transport op te nemen in de analyse. Op deze wijze, bevat deel III een systeembenadering bij het beoordelen van de dynamiek in de relaties tussen energiegebruik en voedselproductie.

Het eerste hoofdstuk van deel III, ***hoofdstuk 6***, bestudeert het energiegebruik als gevolg van het wereldwijde gebruik van kunstmest in de periode 1961-2002. De productie van kunstmest geldt als het meest energie-intensieve deel van de voedselketen. In het eerste deel van hoofdstuk 6 ontwikkelen we historische trends van specifiek energiegebruik en gross energy requirement (energiegebruik gecumuleerd over de productieketen) per soort kunstmest en bepalen we de energie nodig voor de wereldwijde kunstmestproductie. De verkregen trends worden later in *hoofdstuk 7* gebruikt als deel van de input die nodig is om het totale energiegebruik in de keten van de voedsellevering te berekenen. In het tweede deel onderzoeken we of technologische ontwikkeling in de meststoffenindustrie geanalyseerd kan worden door het concept te hanteren van de leercurve (ook wel experience curve genoemd).

Volgens onze analyse was de primaire energie ingebed in het wereldwijde meststofverbruik in het jaar 2001 ongeveer 3660 PJ (1% van het totale wereldenergiegebruik in 2001), waarvan 72% voor de productie van stikstofhoudende meststoffen was, 10% voor fosfaatmeststoffen, 16% voor samengestelde meststoffen en slechts 2% voor kalimeststoffen. Het totale energiegebruik steeg tussen 1961 en 2001 met ongeveer 3,8% per jaar. Het hoogste gemiddelde jaarlijkse groeipercentage betrof stikstofhoudende meststoffen (4,5% per jaar), gevolgd door samengestelde meststoffen (3,9% per jaar).

Om de ontwikkeling in het cumulatieve energiegebruik te kunnen analyseren, passen we een decompositiemethodologie toe die het ons mogelijk maakt om de gevolgen van stijgende meststoffenconsumptie en veranderingen in mix van kunstmeststoffen te scheiden. Er zijn drie belangrijke bevindingen. De eerste is niet verrassend: de groei in meststofverbruik is de belangrijkste drijvende kracht van toenemend energiegebruik. Ten tweede is de mix aan meststoffen verschoven in de richting van meststoffen die per kilogram voedingsmiddel meer energie-intensief zijn, waardoor het energiegebruik verder is toegenomen. En ten derde zijn er significante verbeteringen van de energie-efficiëntie opgetreden, maar zij hebben niet het effect van andere factoren ongedaan kunnen maken. Een vergelijking met de beste beschikbare technologieën laat voor het jaar 2001 een besparingspotentieel zien van ongeveer 19% (687 PJ). Dit potentieel bevindt zich voornamelijk bij de productie van stikstofhoudende kunstmest.

In het tweede deel van dit hoofdstuk bekijken we technologische ontwikkeling in energie-efficiëntie als een leerproces. Voor zover wij weten zijn er geen eerdere pogingen ondernomen om het concept van leercurves te gebruiken voor de ontwikkeling van industriële energie-efficiëntie. Het meeste gepubliceerde materiaal inzake leercurves brengt prijzen in verband met de cumulatieve productie van een technologie. Wij relateren de historische trends in het specifieke energiegebruik van diverse stikstofhoudende meststoffen aan de cumulatieve productie. Onze resultaten tonen aan dat het specifieke energiegebruik van ammoniak en ureum zich ontwikkelde in nauwe overeenstemming met het het leercurve-model, waarbij zgn. progress ratios van 71% voor ammoniakproductie (R^2=0.997) en 88% voor ureum (R^2=0.856) werden gevonden. Dit is een belangrijk resultaat aangezien de middellange- en lange-termijn modellen voor energiegebruik en CO_2-emissies kampen met de moeilijkheid hoe zij technologische veranderingen moeten modelleren. Het gebruik van progress ratios kan een alternatieve benadering bieden om technologische verandering op te nemen in de scenario's. Een ander gevolg van onze bevindingen is dat voor de energie-intensieve industrieën, waarvoor klassieke leercurves (d.w.z. gebaseerd op prijzen) niet kunnen worden ontwikkeld wegens grote afhankelijkheid van marktprijzen en sterke schommelingen van grondstofprijzen, de analyse van specifiek energiegebruik als een hoofdindicator van technologische ontwikkeling een uitweg kan bieden om de mate van technologische verandering te analyseren.

Het laatste hoofdstuk van deel III, ***hoofdstuk*** *7*, biedt een uitgebreide historische analyse van de verbanden tussen fossiele brandstofvraag en voedselproductie. Het bestudeerde systeem omvat de energie die wordt gebruikt door de agrarische, voedselverwerkings-, transport- en kunstmestsectoren. De volgende fysieke stromen zijn in de analyse meegenomen: output van de agrarische sector, de import van agrarische/semi-verwerkte producten, de export van landbouwproducten, verliezen door vervoer en opslag, afval als gevolg van verwerking en output die als zaad wordt gebruikt. De analyse werd uitgevoerd voor dertien Europese landen in de periode 1970-2002 (verder aan te duiden als Europa-13).

Onze resultaten tonen aan dat in het jaar 2002 de keten van de voedsellevering in Europa-13 ongeveer 3960 PJ primaire energie vereiste. Dit komt overeen met ongeveer 7% van de energie die door Europa-13 in het zelfde jaar werd gebruikt. In totaal nam het primaire energiegebruik van het bestudeerde systeem toe met 1,6% per jaar. Wij constateerden dat het enige deel van het systeem dat een dalend energiegebruik laat zien (ongeveer 2% per jaar) de energie is die nodig is voor de vervaardiging van meststoffen. In de landbouw, de voedselverwerking en het vervoer nam het energiegebruik toe in een tempo van respectievelijk 1,6%, 1,8% en 2,3% per jaar.

In dit hoofdstuk kiezen we als functionele eenheid de output van voedsel en veevoeder uitgedrukt in toegevoegde waarde en calorie-inhoud. We schatten dat de fysieke output van de totale keten van de voedsellevering in het jaar 2002 ongeveer 924 petacalories (of 3868 PJ) was, terwijl de economische output van landbouw en voedselverwerking ongeveer €342 miljard van toegevoegde waarde was (5% van het totale BBP). De fysieke output van het totale systeem is met 1,8% per jaar gegroeid terwijl de economische output gegroeid is met 3,6% per jaar. Onze analyse toont tevens aan dat de economische energie-intensiteit veel sterker verminderde (2,7% per jaar) dan de fysieke energie-intensiteit (0,2% per jaar).

Eén gevolg van de gekozen systeemgrenzen is dat we zowel voedsel als veevoeder beschouwen als output van het systeem. We vinden dat als het veevoeder niet als output wordt meegeteld, het tempo waarmee de fysieke energie-intensiteit van het systeem afneemt nog weer lager is in de laatste drie decennia (0,2% tegenover 0,04% per jaar). Wij beoordeelden ook de invloed van het gebruik van calorie-inhoud als functionele eenheid van output door de outputtrends zowel in termen van calorieën als eiwitgehalte te vergelijken, en vonden geen significante verschillen (minder dan 2% variatie per jaar). Een ander gevolg van de gekozen systeemgrenzen is dat het systeem niet gesloten is: het energiegebruik voor de productie van geïmporteerde agrarische/semi-verwerkte producten wordt niet meegerekend. Nader analyse wijst uit dat onze conclusies niet worden beïnvloed door de keuze van de systeemgrenzen.

In dit hoofdstuk onderzoeken wij ook de drijvende krachten achter de energiegebruikontwikkelingen. Wij constateerden dat tussen 1970 en 2002 de toegenomen vraag naar veevoederproductie, de toegenomen calorieconsumptie per hoofd, en de toename van het transport van voedingsmiddelen de belangrijkste drijvende krachten van energiegebruik van het systeem zijn geweest. De groei van de output heeft het primaire energiegebruik gemiddeld met 1,8% per jaar verhoogd terwijl de veranderingen in fysieke energie-intensiteit deze vraag per jaar met slechts 0,2% compenseren. Met uitzondering van kunstmestproductie, hebben de veranderingen in fysieke energie-intensiteit dus geen significante rol gespeeld in de afname van het totale energiegebruik in de Europese keten van de voedsellevering.

De beperkte rol die de fysieke energie-intensiteit tot dusver heeft gespeeld is een belangrijk resultaat. In het voortgaande debat over de aanpak van broeikasemissies zijn er hoge verwachtingen van de bijdrage die verbetering van energie-efficiëntie kan leveren om het totale energiegebruik te verminderen zonder de toekomstige economische groei van landen te belemmeren. Wegens de toenemende productie van verwerkt voedsel, de toenemende hoeveelheid getransporteerd voedsel, zijn we ver verwijderd van het onder controle krijgen van het energiegebruik in de Europese voedselleveringsketen - tenzij er een significante verandering optreedt in het tempo waarin de fysieke efficiëntie verbetert.

Lessen die we kunnen trekken

Er zijn verschillende conclusies die benadrukt dienen te worden. Ten eerste hebben we in dit aangetoond dat, vanuit een methodologisch oogpunt:

- Het is mogelijk om veranderingen in energie-efficiëntie te monitoren op basis van fysieke productiegegevens van heterogene, niet-energie-intensieve sectoren.
- De toepassing van fysieke energie-intensiteiten biedt een eerlijke en redelijke uitvoerbare manier om de ontwikkelingen van de energie-efficiëntie tussen verschillende landen te vergelijken.
- Decompositie-methoden, die over het algemeen worden toegepast in energie-analyse op monetaire basis, zijn ook een bruikbaar hulpmiddel in energie-analyse op fysieke basis. Zij maken het mogelijk om het effect van verschillende factoren, die energiegebruik en energie-intensiteit bepalen, kwantitatief te analyseren.
- Technologische ontwikkeling in energie-efficiëntie in energie-intensieve sectoren kunnen worden geanalyseerd door het leercurve-concept te hanteren.
- Indien gedetailleerde en betrouwbare gegevens beschikbaar zijn (in openbare gegevensbestanden zoals gebruikt in hoofdstuk 4 en 5, of verkregen op vertrouwelijke basis zoals in hoofdstuk 6) en indien er gedetailleerde studies van energie-efficiëntie op industrieel niveau bestaan voor een basisjaar, kunnen historische veranderingen in fysieke energie-

intensiteit gemonitord worden zonder dat men afhankelijk hoeft te zijn van vertrouwelijke rapportages op bedrijfsniveau.

- De belangrijkste beperking die in dit proefschrift werd gevonden is de beperking van de beschikbaarheid en kwaliteit van gegevens. Een aanzienlijke hoeveelheid onderzoektijd is besteed om betrouwbare tijdreeksen te bemachtigen met een toereikend detailniveau om de drijvende krachten achter de veranderingen in de energie-efficiëntie te kunnen analyseren (dit bleek bijv. een belangrijke beperking te zijn in het begrijpen van de veranderingen in energie-efficiëntie in de vleessector). Deze beperkingen vormen de belangrijkste belemmering voor het uitvoeren van de in dit proefschrift gemaakte analyses voor andere sectoren en/of voor andere geografische gebieden.

Ten tweede hebben wij aangetoond dat in het laatste decennium de niet energie-intensieve industrie in Nederland het totale industriële energiegebruik heeft doen toenemen en dat deze meer energie per eenheid output is gaan vragen. De resultaten benadrukken de noodzaak voor wetenschappers om hun aandacht voor de niet-energie-intensieve sectoren te vergroten en voor beleidsmakers om de bedrijven in deze sectoren aan te moedigen om energie-efficiënte technologieën en managementpraktijken over te nemen.

Ten derde laten de vergelijkingen van economische en fysieke energie-intensiteit in de voedingsmiddelensector grote verschillen zien in het tempo van afname, met economische energie-intensiteit die tot 3% per jaar sneller afneemt dan fysieke energie-intensiteit. Met andere woorden: de toegevoegde waarde van de voedingsmiddelensector is significant sneller gegroeid dan de fysieke productie in de laatste drie decennia. Dit verschil wijst op het loskoppelen van fysieke productie en de economische groei in de Europese voedingsmiddelensector.

Ten vierde hebben onze resultaten aangetoond dat in de voedingsmiddelensector de veranderingen in fysieke energie-intensiteit zelfs niet in de buurt zijn gekomen van het compenseren van energiegebruik dat het gevolg is van de toenemende output. Er zijn zelfs geen signalen van het ontkoppelen van energiegebruik en output in de bestudeerde periode (een vergelijkbaar resultaat wordt gevonden in de analyse van de Nederlandse niet-energie-intensieve verwerkende sector in hoofdstuk 2). Er is, natuurlijk, geen tegenspraak tussen de derde en vierde conclusie. Het ontkoppelen van fysieke productie en economische groei impliceert niet per se een vermindering van de gebruikte hoeveelheid energie. Energie is slechts één van de productiefactoren. Het loskoppelen kan ook worden bereikt door toename van arbeids- of kapitaalproductiviteit. De vergelijking van economische en fysieke energie-intensiteit toont niet alleen aan dat energie-efficiëntie een minder vooraanstaande rol heeft gespeeld in het loskoppelen van fysieke productie en economische groei in de voedingsmiddelensector, maar wijst er ook op dat het gebruik van economische energie-intensiteit als een indicator van energie-efficiëntie in de voedingsmiddelensector niet voldoet om huidige veranderingen in energie-efficiëntie te monitoren.

Tot slot zijn de in dit proefschrift gevonden resultaten een bron van zorg omdat zij suggereren dat het energiebeleid er tot dusver niet in is geslaagd om significante verbeteringen in de energie-efficiëntie van de Europese voedingsmiddelensector te bewerkstelligen. Hoewel sommige sectoren beduidende verbeteringen van hun energie-efficiëntie hebben laten zien (bijv. de zuivelindustrie), constateerden wij dat deze verbeteringen hoofdzakelijk worden veroorzaakt door concentratieprocessen, die in de meeste gevallen slechts beperkte effecten in de toekomst zullen hebben. Het algemene beeld wijst erop dat zowel het bedrijfsleven als de beleidsmakers zich meer dienen in te spannen als we een tempo van energiebesparing willen bereiken dat significant bijdraagt aan de vermindering van broeikasgasemissies.

We besluiten dit proefschrift door te wijzen op het belang om fysieke stromen op te nemen in de energie-analyse. Voor een goed begrip van de gevolgen van fysieke processen, en voor het aanpakken daarvan, is het nodig om deze niet alleen in economische termen maar ook in fysieke termen te behandelen. Uiteindelijk is het moeilijk om te zien hoe duurzaamheid (en de manieren om het te bereiken) door beleidsmakers aan de orde kan worden gesteld wanneer informatie ontbreekt over de ontwikkeling van energie- en materiaalstromen binnen de diverse deelsectoren van de economie.

Resumen y Conclusiones

Introducción

Anterior a la revolución industrial, los seres humanos dependían esencialmente de los recursos renovables como fuentes de energía: fuerza animal, fuerza humana, corrientes de agua, energía solar, viento y la combustión de biomasa. El desarrollo de la máquina a vapor al comienzo de la revolución industrial, el uso de carbón y eventualmente otros combustibles fósiles contribuyeron al desarrollo de cambios significativos en los procesos de producción, agricultura y actividades domésticas. No obstante, el uso de combustibles fósiles, ha originado problemas ambientales. A pesar de que a escala local y regional el uso de combustible fósiles ha causado contaminación atmosférica y acuífera, ha sido el papel de la combustión de combustible fósiles en el cambio climático a escala global lo que ha causado preocupación mundial. La combustión de combustibles fósiles es la fuente más importante de gases de efecto invernadero que están cambiando la composición de la atmósfera y aumentando la temperatura media de la superficie terrestre. La presente tesis reconoce que es una prioridad reducir los impactos ambientales del ciclo energético y que la eficiencia energética desempeña un papel crucial en la transición hacia un sistema de energía sostenible.

Definir la eficiencia energética, medirla e idear programas específicos que la fomenten son tareas que constituyen un desafío. En esta tesis, la mejora en la eficiencia energética es definida como el uso de menos energía para la producción del mismo nivel de actividad o producto generado. La eficiencia energética es calculada como el cociente entre el consumo energético y el nivel de actividad. El nivel de actividad puede ser medido en términos económicos (Ej. unidad de valor agregado) o en términos físicos (Ej. toneladas de producto). En el primer caso, nos referimos al indicador como intensidad económica energética, en el segundo caso como intensidad física energética. Cuando un proceso genera sólo un producto, la intensidad física energética es la razón entre la energía usada y la cantidad física del producto. Cuando se genera más de un producto (Ej. si el análisis se hace a nivel industrial), la intensidad física energética es la razón entre la energía usada y una suma ponderada de los diferentes productos. Los pesos se basan en la cantidad de energía necesaria para producir una unidad física de cada producto (por ejemplo, kilojulios por tonelada). Al mantener los pesos constantes correspondientes a un año de referencia, la suma ponderada proporciona la cantidad de energía que habría sido utilizada si la eficiencia energética en el período estudiado se hubiera mantenido igual al año de referencia (lo cual se denomina desarrollo congelado de eficiencia energética). De esta manera, la intensidad física energética compara la energía usada con el desarrollo congelado de eficiencia energética. Este último toma en cuenta los cambios anuales en la estructura de producción. Por lo tanto, la intensidad física energética es un indicador que provee valores que ya han sido corregidos por cambios en la estructura de producción.

A pesar de que la intensidad física energética ha sido reconocida como un mejor indicador de cambios en la eficiencia energética que la intensidad económica energética, su uso se ha limitado a sectores intensivos en el uso de energía. Estos sectores se caracterizan por tener un número limitado de productos, tecnologías y procesos. Una característica dominante en los sectores no intensivos en el uso de energía es su heterogeneidad. No es, por lo tanto, una tarea sencilla el identificar de una larga lista de productos, procesos y tecnologías, aquellos que tienen suficiente poder explicativo en relación con el consumo energético. En esta tesis, se evalúa si los indicadores físicos de intensidad energética proporcionan una manera viable de analizar cambios en la eficiencia energética en sectores no intensivos en el uso de energía a diferentes niveles de agregación estadística.

Históricamente, los sectores no intensivos en el uso de energía han recibido poca atención por parte de los decisores de políticas y de la comunidad científica. Sin embargo, el nivel de atención ha comenzado a aumentar lentamente puesto que se ha reconocido que tomados en conjunto, los sectores no intensivos en el uso de energía representan una porción importante de la demanda energética, y que los potenciales de ahorro energético son significativos. Sin embargo, si los decisores y planificadores de políticas han de desarrollar e implementar estrategias que promuevan de manera efectiva la eficiencia energética en sectores no intensivos en el uso de energía, es necesaria una clara comprensión de los factores económicos, técnicos y de comportamiento social que determinan la demanda y la eficiencia energética. Debido a la poca atención que estos sectores han recibido, esta compresión es limitada. Esta tesis se enfoca en analizar la evolución histórica en el uso de energía y la eficiencia energética así como en entender los factores clave que subyacen en el sector no intensivo en el uso de energía. Esta información es importante porque proveerá a decisores y planificadores con una base analítica de la cual extrapolar tendencias en el uso de energía y eficiencia energética, al igual que proveerá información sobre factores tales como el nivel de actividad, cambios en la estructura de producción y eficiencia que han afectado la demanda energética. La industria de alimentos se utiliza en esta tesis como estudio de caso de los sectores no intensivos en el uso de energía.

Objetivos de esta tesis

El objetivo principal de esta tesis es examinar el papel que la eficiencia energética y otros factores han desempeñado en el desarrollo del consumo energético de sectores no intensivos en el uso de energía. El análisis se enfoca principalmente en la industria de alimentos. Los objetivos específicos son:

1. Estudiar el desarrollo del uso de energía, de la eficiencia energética y de la estructura en las industrias no intensivas en el uso de energía del sector manufacturero holandés.
2. Desarrollar indicadores físicos de intensidad energética que permitan monitorear cambios en la eficiencia energética en la industria de alimentos a diferentes niveles de agregación estadística.
3. Analizar las relaciones históricas entre demanda de combustibles fósiles y producción de alimentos en la cadena europea de suministro de alimentos.

En cada caso, se identifican y analizan los factores que determinan el desarrollo en el consumo energético. Esta tesis se divide en tres partes, una por cada uno de los objetivos específicos enunciados con anterioridad. Los resultados de cada una de las partes y de los capítulos que las componen se resumen a continuación.

Resumen de los resultados

La **Parte I** de esta tesis (el ***capítulo 2***) se enfoca en el estudio del consumo energético y de la intensidad económica energética de los sectores industriales no intensivos en el uso de energía. El análisis usa datos empíricos para los Países Bajos en el período comprendido entre 1988 y 1999.

Una de las preguntas subyacentes que guiaron el análisis en este capítulo fue la de evaluar si la falta de atención prestada a los sectores no intensivos en el uso de energía es justificada. La respuesta es no. En primer lugar, en el período 1988-1999 el consumo energético en estos sectores aumentó en promedio 3% por año. Si el análisis se hace en cantidades absolutas, los sectores no intensivos en el uso de energía fueron responsables por el incremento en el consumo total energético mostrado por el sector industrial de los Países Bajos. En segundo lugar, se observó un aumento en la intensidad económica energética de los sectores no intensivos en el uso de energía (6% en el caso de energía usada por unidad de valor agregado, ó 2% en el caso de energía usada por unidad del valor bruto de producción).

Con el fin de separar la influencia de cambios estructurales de la industria (composición industrial), cambios en los niveles de producción y de cambios en la eficiencia energética se aplicó una metodología de descomposición (Multiplicative Log-Mean Divisia Method) a los 55 sectores no intensivos en el uso de energía estudiados. Los resultados demuestran que: *i*) el incremento en la intensidad económica energética primaria agregada no fue causado por cambios en la estructura industrial; *ii*) cambios estructurales solo afectaron de manera significativa la intensidad económica energética de combustibles derivados del carbón y el petróleo, y esto sólo en el caso en que la unidad de valor agregado es usada para representar la actividad del sector, en el resto de los casos (electricidad y energía primaria para el valor agregado y todos los tipos de energía para el valor bruto de producción), los cambios en la estructura de producción jugaron un papel menor en la limitación de aumentos en la intensidad energética; *iii*) el crecimiento en el nivel de actividad del sector ha incrementado la demanda de energía mas allá de las ya inducidas por cambios en la intensidad energética, y *iv*) el impacto de cambios en la estructura de producción tiende a ser mayor cuando el valor agregado se usa como medida económica de la actividad del sector.

Finalmente, el análisis de los cambios en el valor bruto de producción y en el crecimiento de consumo energético muestra que no hay signos de desacoplamiento entre estos dos factores. Debido a la fuerte relación entre el nivel de actividad industrial y la demanda energética se espera que en la ausencia de políticas adicionales, los sectores no intensivos en el uso de energía contribuirán en el futuro a incrementar el consumo de energía en los Países Bajos. Teniendo en cuenta las trayectorias encontradas hasta el momento en esta tesis, los sectores no intensivos en el uso de energía deben ser por lo tanto considerados como un área importante en la reducción en las emisiones de dióxido de carbono.

Con base en los resultados encontrados en el *capítulo 2*, se ha procedido con un análisis detallado de la evolución histórica de consumo energético y eficiencia energética usando el sector de alimentos como estudio de caso. El análisis se ha realizado a distintos niveles de agregación estadística. La **Parte II** de esta tesis (*capítulos 3, 4 y 5*) examina la posibilidad de desarrollar e implementar indicadores físicos de intensidad energética que proporcionen una estimación confiable de los cambios en la eficiencia energética en el sector de alimentos.

El primer capítulo de la segunda parte, el ***capítulo 3***, tiene como tema de investigación la industria láctea. Los principales objetivos son, en primer lugar analizar y comparar la evolución de consumo energético en cuatro países europeos: Alemania, Francia, los Países Bajos y el Reino Unido. En segundo lugar, desarrollar y aplicar indicadores que puedan ser usados para monitorear la eficiencia energética de la industria láctea. El período estudiado comprende los años entre 1986 hasta el 2000.

En el año 2000, la industria láctea consumió cerca de 52, 34, 16 y 14 PJ de la energía primaria en Francia, Alemania, los Países Bajos y el Reino Unido respectivamente. Por lo tanto, la industria láctea fue responsable de una emisión de dióxido de carbono cercana a los seis millones de toneladas (39% de estas toneladas son emisiones secundarias causadas por la combustión de carbón y productos derivados del petróleo durante la producción de electricidad). Los cambios en la eficiencia energética fueron monitoreados de dos maneras diferentes. Primero, monitoreando la energía usada por tonelada de leche procesada (EEI_{p1}). En segundo lugar, comparando la energía usada con un desarrollo congelado de eficiencia energética (EEI_{p2}). EEI_{p2} toma en cuenta las diferencias en la estructura de producción entre países y diversos años. El primer indicador, EEI_{p1}, tiene varias características atractivas: es fácil de calcular, requiere pocos datos, puede ser entendido por audiencias no especializadas en el tema y es fácil de comunicar. No obstante, este indicador tiene la desventaja significativa de que no refleja cambios importantes en la estructura de producción. EEI_{p2}, por otra parte, aunque es un indicador mucho más complejo de calcular y con una carga de datos más grande, refleja cambios en la estructura de producción y permite posterior refinamiento cuando más información y mejores datos lleguen a estar disponibles. En el caso de la industria láctea, se encontraron cambios significativos en la estructura de producción en tres de los cuatro países estudiados y por lo tanto se concluye que EEI_{p2} debe ser el indicador preferido para comparar desarrollos de eficiencia energética.

Una vez que los cambios en la estructura de producción han sido tomados en cuenta, se encontró que mientras en Alemania, los Países Bajos y el Reino Unido, la industria láctea ha reducido sus valores en EEI_{p2} por más de 1% por año (2.1 %, 1.2%, y 3.8% respectivamente) los valores de EEI_{p2} en la industria láctea francesa han cambiado a una tasa anual significativamente más baja (0.4%). También se encontró que en el período estudiado, los valores absolutos de EEI_{p2} en la industria láctea francesa fueron más altos que para los otros países (por ejemplo, en el año 2000, los valores de EEI_{p2} fueron 30-40% más altos).

Al analizar las posibles causas detrás de las diferencias encontradas entre los países, especialmente entre Francia y los otros tres países, se encontró que los altos valores de EEI_{p2} calculados para la industria láctea francesa están relacionados con el hecho de que la industria francesa trabaja a una escala más pequeña, es altamente fragmentada y ha demostrado un paso relativamente lento de concentración. Adicionalmente, y a pesar de que no hay mucha información disponible, los resultados de este capítulo sugieren que la industria láctea francesa usa tecnologías que son más intensivas en el uso de energía. Un análisis más detallado del sector lácteo francés revela que mientras las ramas de queso y mantequilla han disminuido substancialmente sus valores de EEI_{p2}, el efecto ha sido compensado por un aumento en los valores de EEI_{p2} en la rama de 'otros productos lácteos' (tales como leche en polvo y productos condensados). Como consecuencia, los valores para la totalidad de la industria láctea francesa parecen permanecer constantes. Finalmente, los resultados también muestran que la industria láctea del Reino Unido, Alemania, y los Países Bajos han convergido hacia valores similares y menores en sus indicadores de eficiencia energética y que la industria láctea francesa podría ahorrar cerca de 30% si lograra obtener valores similares a los de Alemania o el Reino Unido de EEI_{p2}.

Siguiendo una estructura similar a la desarrollada en el *capítulo 3*, el ***capítulo 4*** examina la evolución en la producción, el uso de energía y la eficiencia energética en el sector cárnico (matanza de animales, conservación y procesamiento de carnes) de Alemania, Francia, los Países Bajos y el Reino Unido. El análisis se realizó para el período comprendido entre 1986 y 2001. En el año 2001, la industria cárnica usó aproximadamente 35, 39, 10 y 32 PJ de energía primaria en Alemania, Francia, los Países Bajos y el Reino Unido respectivamente. Aproximadamente un 40-60% de estas cantidades fueron usadas en la conservación y procesamiento de carnes. La industria cárnica de los cuatro países fue responsable de la emisión de 4.5 millones de toneladas de dióxido de carbono (58% de las cuales están relacionadas con las emisiones indirectas causadas por el consumo de electricidad). Los resultados de este capítulo también muestran un aumento significativo en la energía primaria usada por tonelada de producto: Alemania (3.4% anual), Francia (3.2% anual), los Países Bajos (1.4 % anual) y Reino Unido (1.6% anual). De igual manera, se encontró en los países estudiados una tendencia hacia un mayor consumo de electricidad ocasionada por un incremento en la demanda de refrigeración y generación de poder.

Para entender las causas que originan las tendencias encontradas se analizaron factores tales como los cambios en las unidades de productos congelados, de productos cortados en pedazos y los cambios en las normas de higiene de alimentos. Se encontro que al corregir el indicador físico de intensidad energética por los cambios en las unidades de partes de congelado, los productos de carne cortados en pedazos y deshuesados: *i*) disminuyen los valores absolutos del indicador del rendimiento energético, *ii*) la diferencia en los valores absolutos entre los países disminuye, y *iii*) se explican algunas de las fluctuaciones mostradas por las tendencias a un bajo nivel de agregación estadística. Sin embargo, se encontró que los cambios en las partes de congelado, los productos de carne cortados en pedazos y deshuesados no explican el aumento en los valores del indicador de eficiencia energética exhibido por la industria cárnica. El impacto de los cambios en las normas de higiene en la demanda energética fue más significativo. Los cambios en las normas de higiene explican entre una y dos terceras partes del aumento observado en la intensidad física energética.

Los *capítulos 3 y 4* demuestran que los patrones en el consumo de energía y en la eficiencia energética se pueden monitorear y analizar a niveles bajos de agregación estadística. El ***capítulo 5*** se basa en los resultados encontrados en los *capítulos 3 y 4* y amplía el análisis a un nivel más alto de agregación estadística. En el *capítulo 5* se desarrollaron indicadores para monitorear la eficiencia energética en la industria de alimentos. El análisis se basa en datos físicos de la producción de cada empresa proporcionados por la oficina estadística de los Países Bajos. Estos datos tienen carácter confidencial. El análisis fue realizado para el período 1993-2001.

En el *capítulo 5* se estudió la eficiencia energética usando como indicador el cociente entre la energía utilizada y el desarrollo congelado del rendimiento energético. Se seleccionaron 49 categorías de productos alimenticios que corresponden al 51% del total de las categorías de productos alimenticios. La cobertura energética obtenida para el año de referencia (1995) fue del 81% para los combustibles fósiles y 60% para la electricidad. Los resultados muestran que el sector de alimentos holandés ha mejorado su indicador de eficiencia energética en términos primarios en aproximadamente 1% por año (con un rango de incertidumbre entre 0.9 y 1.3). En términos de la energía final, se encontró una disminución del indicador para la demanda final de combustibles de cerca del 1.8% anual, mientras que el indicador para la demanda final de la electricidad no ha disminuido. Además, se ha estimado que desde 1993, un aumento en la penetración de cogeneración (CHP) en el sector alimenticio ha significado un ahorro de energía primaria de cerca de 3 PJ en los Países Bajos.

Para determinar si la mezcla de productos estudiada es representativa o no, se compararon los cambios anuales en la producción física de los productos seleccionados en este capítulo contra aquellos que no fueron tomados en cuenta. Se encontró que ambos grupos exhiben comportamientos similares. Por lo tanto, los productos seleccionados reflejan cambios estructurales importantes en la industria alimenticia. Además se encontró que el desarrollo en la eficiencia energética es coherente con los valores de implementación de medidas de ahorro energético reportados en los Países Bajos y con los progresos divulgados por los Acuerdos a Largo Plazo (conocidos en inglés como Long Term Agreements). Estos resultados confirman la solidez de la metodología utilizada y de los resultados obtenidos.

Se concluye por lo tanto, que el tipo y la calidad de los datos compilados para el sector de alimentos por la oficina de estadística de los Países Bajos son suficientes para desarrollar indicadores como los que se requieren por las políticas energéticas y de cambio climático. Este es un resultado importante puesto que significa que la eficiencia energética en la industria de alimentos puede ser monitoreada por una agencia oficial, sin necesitad de utilizar un grupo especializado que dependa exclusivamente del reporte de datos confidenciales por parte de las compañías de alimentos, que se hacen con el único propósito de supervisar progresos en la eficiencia energética (como lo hace por ejemplo, la Agencia para la Energía y el Ambiente SenterNovem en los Países Bajos). Este es un resultado prometedor porque es probable que análisis similares se puedan desarrollar para otras industrias no intensivas en el uso de energía, con la única condición de que las estadísticas detalladas de la producción industrial sean accesibles (por ejemplo, con carácter confidencial como en los Países Bajos).

En la **Parte III** (*capítulos 6 y 7*) de esta tesis, se amplían los límites del sistema analizado hasta el momento y se incluyen los siguientes sectores: agricultura, fertilizantes y transporte. De esta manera, la parte III toma una mirada sistémica al examinar la dinámica y las interrelaciones entre la energía usada y la producción de alimentos en la cadena Europea de suministro de alimentos.

El primer capítulo de la parte III, ***capítulo 6***, analiza la demanda energética debido al consumo global de fertilizantes en el período 1961-2002. La energía usada en la manufactura de fertilizantes es generalmente considerada como la parte más intensiva de la cadena alimenticia. En la primera parte del capítulo 6 se desarrollan tendencias históricas del consumo específico de energía y de las necesidades energéticas brutas por clase de fertilizante y se calcula la energía usada como consecuencia del uso de fertilizantes. Las tendencias obtenidas se utilizan luego en el *capítulo 7* como parte de los datos necesarios para calcular la demanda energética total en la cadena del suministro de alimentos. En la segunda parte de este capítulo, se explora si el desarrollo tecnológico en la industria de fertilizantes puede ser analizado usando el concepto de curva de aprendizaje.

De acuerdo al análisis realizado, la energía primaria debida al consumo de fertilizantes a nivel global fue de aproximadamente 3660 PJ en el año 2001 (corresponde al 1% de la demanda global energética 2001). De esta cantidad 72% fue utilizada en la producción de fertilizantes de nitrógeno, el 10% para los fertilizantes de fosfato, el 16% para los fertilizantes complejos y solamente 2% para los fertilizantes de potasio. La demanda energética total aumentó cerca de 3.8% por año entre 1961 y 2001. La tasa de crecimiento anual media más alta fue la de los fertilizantes de nitrógeno (4.5 % por año) seguido por los fertilizantes compuestos (3.9% por año).

Para entender el desarrollo en la demanda de energía, se aplicó una metodología de descomposición que permite estudiar el efecto de cambios en el consumo de fertilizantes y los cambios en la mezcla de fertilizantes utilizados. Se encontraron tres resultados principales. El primer resultado es esperado: el crecimiento en el consumo de fertilizantes ha sido el factor principal del incremento en el consumo de energía. El segundo resultado sugiere que la mezcla de fertilizantes se ha trasladado hacia el uso de fertilizantes que son intensivos en el uso de energía por kilogramo de nutriente, lo cual ha aumentado la demanda energética. El tercer resultado sugiere que aunque han ocurrido mejoras significativas en la eficiencia energética durante la producción de fertilizantes, éstas no han podido compensar el efecto de otros factores. Una comparación de las mejores tecnologías disponibles revela un potencial del ahorro energético en el año 2001 de aproximadamente el 19% (687 PJ). Este potencial se asigna principalmente a la industria de fertilizantes de nitrógeno.

En la segunda parte de este capítulo, se analiza el desarrollo tecnológico en la eficiencia energética como un proceso de aprendizaje. Hasta el momento no han habido tentativas previas en utilizar el concepto de curvas de aprendizaje para estudiar el desarrollo de la eficiencia energética industrial. La mayoría del material publicado en curvas de aprendizaje relaciona los precios del producto en el mercado con la producción acumulativa de una tecnología. En este Capítulo, se relacionan las tendencias históricas en el consumo de energía específica de varios fertilizantes nitrogenados con la producción acumulativa. Los resultados encontrados muestran que cambios en el consumo de energía específica del amoníaco y de la urea ocurren en concordancia con el modelo de la curva de aprendizaje, mostrando cocientes de progreso del 71% para la producción del amoníaco (R^2=0.997) y 88% para la urea (R^2=0.856). Este es un resultado importante porque hasta el momento los modelos a largo plazo de consumo energético y de las emisiones de CO_2 encuentran dificultades a la hora de incluir cambios tecnológicos. El uso de los cocientes del progreso puede por lo tanto, proporcionar una manera alternativa de incluir cambios tecnológicos en el desarrollo de escenarios. Otra consecuencia de los resultados obtenidos es que para las industrias intensivas en el uso de energía en las cuales curvas clásicas de aprendizaje (basadas en precios) no pueden ser desarrolladas debido a fuertes dependencias en los precios de mercado y a fluctuaciones en los precios de materia prima, el análisis del consumo de energía específica como indicador principal del desarrollo tecnológico puede proporcionar una manera viable de analizar cambios tecnológicos.

El capítulo final de la parte III, el ***capítulo*** *7*, proporciona un análisis histórico de las relaciones entre la demanda de combustibles fósiles y la producción de alimentos. El sistema estudiado incluye la energía usada por el sector agrícola, el procesamiento de alimentos, la producción de fertilizantes y el sector de transporte. Los flujos físicos considerados son la producción del sector agrícola, la importación de los productos agrícolas y semiprocesados, la exportación de productos agrícolas, los residuos generados en el transporte y almacenaje de productos agrícolas, los residuos generados durante el procesamiento de alimentos y la cantidad de semillas usadas para la siembra. El análisis fue realizado para trece países europeos (Europa-13) en el período 1970-2002.

Los resultados muestran que en el año 2002 la cadena de suministro de alimentos en Europa-13 requirió cerca de 3960 PJ de energía primaria. Esto corresponde a aproximadamente 7% de la energía usada por Europa-13 en el mismo año. La energía primaria total del sistema ha aumentado a una tasa anual de 1.6%. Se encontró además que la única parte del sistema que ha mostrado una disminución en la demanda energética (2% por año) es la energía usada para la fabricación de fertilizantes. La agricultura, el procesamiento de alimentos y el transporte han aumentado su consumo de energía anual con tasas del 1.6%, 1.8% y 2.3% respectivamente.

En este capítulo se seleccionó como unidad funcional de la producción de alimentos y el forraje el valor agregado y el contenido calorífico. Se calculó que la producción física de la cadena de suministro de alimentos en el año 2002 fue de 924 petacalorías (o 3868 PJ), mientras que el valor agregado de la agricultura y la transformación de alimentos fue de €342 billones (el 5% del PIB). La producción en términos físicos del sistema total ha aumentado con una tasa anual del 1.8% mientras que la actividad económica ha aumentado 3.6% por año. El análisis también muestra que la intensidad económica energética disminuyó a una tasa significativamente más alta (2.7% por año) que la intensidad física energética (0.2% por año).

Una consecuencia de los límites elegidos del sistema es que se consideran alimentos para el consumo humano y animal como flujos de salida del sistema. Si el forraje se excluye del sistema, la tasa a la cual la intensidad física energética del sistema disminuye en las tres décadas pasadas es perceptiblemente más baja (0.2% contra 0.04% por año). Otro aspecto que ha sido analizado es la influencia del uso del contenido calorífico como unidad funcional de la actividad del sistema. Con este fin se compararon los resultados obtenidos en términos de calorías y del contenido proteínico y no se encontraron diferencias significativas (la variación es de menos del 2% por año). Otra consecuencia de los límites del sistema escogidos es que el sistema no es cerrado: el uso de la energía para la producción de productos agrícolas o semiprocesados importados no es considerado. Sin embargo, el estudio del impacto que la energía usada durante la de artículos importados podría tener en la tendencia de la demanda energética de la cadena del suministro de alimentos muestra que los resultados no son afectados por la selección de los límites del sistema.

En este capítulo también se examinaron los factores detrás de los cambios en el consumo de energía. Se encontró que los principales determinantes del incremento en la demanda energética total del sistema entre 1970 y 2002 fueron el aumento en la demanda de forraje, el aumento en el consumo de calorías por capita, y el aumento en la cantidad de tonelada por kilómetro transportadas. El incremento en la producción ha aumentado la demanda energética primaria en 1.8% por año mientras que los cambios en la intensidad física energética sólo compensaron esta demanda por 0.2% por año. Con excepción de la fabricación del fertilizantes, se concluye que los cambios en la intensidad física energética no han desempeñado un papel significativo en la disminución de la demanda energética total en la cadena europea del suministro de alimentos.

El papel limitado que la eficiencia energética ha desempeñado hasta el momento es un resultado importante. En la discusión de cómo manejar las emisiones de gases de invernadero hay altas expectativas sobre cual sería el rol que puede jugar mejoras en la eficiencia energética. Un incremento en la eficiencia energética puede ayudar a disminuir el consumo total de energía sin obstaculizar desarrollo económico a futuro. Debido a que siguen aumentando tanto la demanda por alimentos procesados como las cantidad de toneladas por kilómetro transportadas, y dados los resultados de este estudio, la eficiencia energética esta lejos de disminuir la demanda energética neta en la cadena europea del suministro de alimentos. Ello seguirá ocurriendo a menos que haya un cambio significativo en las tasas de cambio de la intensidad física energética.

Lecciones aprendidas

En esta sección se resaltan varias conclusiones importantes. Primero, en esta tesis se ha demostrado que desde un punto de vista metodológico:

- Es posible monitorear cambios en la eficiencia energética en sectores que son heterogéneos y no intensivos en el uso de energía utilizando datos físicos de producción.
- La intensidad física energética es una manera apropiada y viable de comparar los progresos en la eficiencia energética entre distintos países.
- Las metodologías de descomposición que generalmente se aplican al análisis de energía basado en medidas monetarias, son igualmente una herramienta

útil en el análisis basado en medidas físicas de actividad. Estas metodologías permiten que grandes cantidades de información sean procesadas y proporcionan una manera cuantitativa de analizar el impacto de diversos factores en el consumo e intensidad energética.

- El desarrollo tecnológico de la eficiencia energética en sectores intensivos en el uso de energía puede ser analizado usando el concepto de curva de aprendizaje.
- Con la condición de que tanto los datos disponibles sean detallados y confiables (en bases de datos públicas como las utilizadas en los capítulos 4 y 5 o con carácter confidencial como en el capítulo 6) y que existan estudios detallados del rendimiento energético a nivel industrial, el desarrollo histórico de las intensidades físicas de la energía puede ser supervisado sin necesidad de implementar grupos de trabajo que dependan exclusivamente de la divulgación confidencial de datos a nivel de empresas individuales.
- La calidad y disponibilidad de los datos fue la limitación más grande que se encontró en esta tesis. Una porción importante del tiempo de investigación fue usada en obtener series de tiempo confiables, con el suficiente nivel del detalle para permitir que los factores detrás de cambios del rendimiento energético fuesen analizados (Ej. La calidad y cantidad de datos demostró ser un constreñimiento importante en el analisis del rendimiento energético en el sector cárnico). Esta limitación puede ser un impedimento importante a la hora de realizar la clase de análisis presentado en esta tesis para otros sectores y/o para otras regiones geográficas.

En segundo lugar, se ha demostrado que durante la pasada década, el sector industrial no intensivo en el uso de energía en los Países Bajos ha aumentado la demanda total energética industrial y ha además usado más energía por unidad de actividad. Los resultados destacan la necesidad de que tanto decisores como la comunidad científica aumenten la atención prestada al sector no intensivo en el uso de energía y animen a las industrias de estos sectores a adoptar tecnologías y prácticas de gerencia en el manejo de la energía.

Tercero, las comparaciones entre las intensidades económicas y físicas energéticas en el sector alimenticio revelan significantes diferencias en las tasas de cambio, con las intensidades económicas energéticas declinando hasta 3% por año más rápidamente que las intensidades físicas energéticas. En otras palabras, el valor agregado del sector alimenticio ha aumentado más rápidamente que la producción física en las últimas tres décadas. Esta diferencia señala un desacoplamiento de la producción física y el desarrollo económico en el sector Europeo de alimentos.

Cuarto, los resultados han mostrado que en el sector de alimentos, los cambios en la intensidad física energética no llegan a compensar las demandas energéticas impuestas por el crecimiento en la actividad del sector. De hecho, no se encontraron muestras de desacoplamiento entre la producción física y la demanda de energía en el período estudiado (un resultado similar se encontro en el análisis del sector no intensivo en el uso de energía para los Paises Bajos mostrado en el capítulo 2). Por supuesto, la tercera y cuarta conclusión no son contradictorias. El desacoplamiento entre la producción física y el desarrollo económico no implica una reducción en la cantidad de energía usada. La energía es solamente uno de los factores de producción. El desacoplamiento se puede también alcanzar por aumentos en la productividad laboral o de capital. Una comparación entre las intensidades económicas y físicas energéticas revela que no solamente la eficiencia energética ha jugado un papel de menor importancia en el desacoplamiento entre la producción física y el desarrollo económico en el sector alimenticio, sino que también indica que el uso de la intensidad económica energética en el sector del alimentos no es lo suficientemente sensible para reflejar cambios reales en el rendimiento energético.

Finalmente, los resultados encontrados en esta tesis son una fuente de preocupación porque sugieren que las políticas energéticas implementadas hasta el momento no han sido capaces de promover mejoras significativas en el rendimiento energético del sector europeo de alimentos. Aunque algunos sectores han mostrado mejoras significativas en su eficiencia energética (como el sector lácteo), se encontró que estas mejoras han sido guiadas principalmente por procesos de concentración industrial. Procesos, que en la mayoría de los casos tienen un alcance limitado a largo plazo. La industria y los decisores y planificadores deben hacer por lo tanto mayores esfuerzos si se desean alcanzar ahorros energéticos que contribuyan significativamente a la reducción de las emisiones de gases de efecto invernadero.

Concluimos esta tesis resaltando la importancia de incluir los flujos físicos en el análisis de demanda energética. Entender las consecuencias de procesos físicos requiere que estos procesos sean tratados no solamente en términos económicos sino también en términos físicos. En última instancia, es difícil percibir cómo el desarrollo sostenible (y las maneras de alcanzarlo) puede ser tomado en cuenta por decisores y planificadores en la ausencia de información sobre la dependencia temporal de la energía y de los flujos materiales dentro de los varios subsectores de las economías.

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Curriculum Vitae

Andrea Ramírez Ramírez was born in Bogotá (Colombia) on April 9th, 1973. In 1996, she pursued a bachelor degree in Chemical Engineering at the National University of Colombia. From 1996 until 1998 she worked as engineer/researcher at the Solid Waste Research Program (PIRS) of the same university. Among the projects she was involved in were the Assessment of Hazardous Waste Management in Colombia, the Elaboration of Alternatives for Integrated Solid Waste Management for four Municipalities, and the Development of National Guidelines for Environmental Impact Assessments. Between August 1997 and July 1998 she also worked as part-time lecturer for the department of Chemical Engineering of the National University of Colombia. From 1996 until 1998 she was part of a national working group on the analysis of the ISO 14020 (ecological labeling) and 14040 (life cycle analysis) norms coordinated by the Colombian Institute of Technical Norms ICONTEC. In September 1998, she started a Master Degree in Human Ecology at the Free University of Brussels (Belgium). She graduated in September 2000, achieving a Magna Cum Laude distinction. Between May 2001 and May 2005, she worked as a PhD student at the Department of Science, Technology and Society, part of the Copernicus Institute for Sustainable Development and Innovation of Utrecht University. Since May 15, 2005 she works as a post-doctoral researcher on CO_2 sequestration and storage at the Copernicus Institute.