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Energy efficiency developments in the Dutch energy-intensive manufacturing industry, 1980–2003

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Abstract

We studied energy efficiency trends in the Dutch manufacturing industry between 1995 and 2003 using indicators based on publicly available physical production and specific energy consumption data. We estimated annual primary energy efficiency improvements in this period at 1.3% on average, with the individual sub-sectors ranging between −0.1% and 1.5%. Energy efficiency developments with respect to electricity, fuels/heat and non-energy use have been monitored separately and are shown to differ significantly (for the sum of the sectors studied: 1.9% for electricity, 2.6% for fuels/heat and −0.1% for non-energy use). We combined our results with those from a previous, similar study for 1980–1995 and show that over the full time period, efficiency improvements of 1% per year have been achieved on average. Based on comparison with other sources and a detailed uncertainty analysis, we conclude that we developed a reliable top-down monitoring framework for studying energy efficiency trends of the manufacturing industry that can also be applied in other countries where similar data are available. We also showed that substantial differences exist between energy consumption data available from energy statistics and according to the Long Term Agreement monitoring reports, stressing the need for ongoing independent checks of available energy consumption data to avoid problems in future evaluations of energy efficiency policies.

Keywords: Monitoring; Energy efficiency; Physical indicators

1. Introduction

Improving energy efficiency is regarded as one of the most important options to reduce the emissions of greenhouse gases and the dependency of countries on energy imports (e.g. Metz et al., 2001; EZ, 2005). The large number of national and international policy measures directed towards energy efficiency improvements confirms that policy makers share this view. In order to assess the effectiveness of these policy measures, quantitative methods for measuring energy efficiency improvements are required as was recently also emphasised in the directive on energy end-use efficiency and energy services by the European Commission (2006a). We can monitor energy efficiency developments by quantifying the ratio of energy input and the useful output of a certain activity over time. A distinction can be made between bottom-up and top-down approaches for monitoring energy efficiency improvements (Bowie and Malvik, 2005). In bottom-up approaches, energy efficiency improvements are monitored by adding up the effect of individual specific energy efficiency improvement measures. In top-down approaches, efficiency improvements are based on more aggregate sectoral energy consumption data in relation to the output of the sector. The useful output of an activity can be defined in either physical (e.g. litres of beer produced or person kilometres driven) or monetary units (e.g. GDP of a country or value added of a sector). The choice for either physical or monetary indicators of activity in top-down monitoring of energy efficiency trends

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depends, among other things, on the desired aggregation level in combination with data availability and data quality (Freeman et al., 1997; Farla and Blok, 2000; Worrell et al., 1997; Boonekamp, 2006).

It is widely accepted that for the evaluation of energy efficiency developments in the manufacturing industry, the use of physical indicators of activity, either stand-alone or in combination with monetary indicators, contributes to a better understanding of energy efficiency developments. Examples of studies using physical indicators to analyse energy efficiency developments in the manufacturing industry (especially the energy-intensive manufacturing industry) are Phylipsen et al. (1998), Worrell et al. (1997) and Persson et al. (2006). Farla and Blok (2000) mention the close relationship with the concept of specific energy consumption (energy use at the process level) and the international comparability of the resulting energy efficiency indicators as arguments advocating the use of physical indicators in the manufacturing industry. Also, the use of physical production allows filtering out changes in energy use resulting from structural changes within industrial sectors (e.g. a different product mix or the switch from primary to secondary resources), although the ability to do so depends on the types and number of products included in the analysis.

In the Netherlands, physical indicators of activity have also been used intensively for energy efficiency monitoring within the framework of the two generations of Long Term Agreements (LTA-1 and LTA-2) and the Covenant Benchmarking energy efficiency. These agreements have been the main governmental policies to promote energy efficiency in the industrial sector in the Netherlands since the 1990s, supported by various other policy instruments summarised in Table 1.

Table 1
Policy instruments for industrial energy efficiency in the period 1995–2003

Instrument	Period
Covenants	
LTA-1	1989–2000
LTA-2	2001–2012
Benchmarking covenant	1999–2012
Environmental Action Plan (MAP)	1991–2000
Regulations	
Energy in the environmental permit	1993–present
Fiscal instruments	
Energy investment tax cut (EIA)	1997–present
Variable tax deduction (VAMIL)	1991–present
Regulating energy tax (REB)	1996–present
Subsidies	
Tenders industrial energy savings (TIEB)	1989–1999
Subsidy scheme for energy conservation techniques (BSET)	1993–1996
CO_2 reduction plan	1997–2002

Based on Boonekamp et al. (2002, 2005).

The first generation of LTAs on energy efficiency (LTA-1) were voluntary agreements contracted in the period 1992–1996 between the Dutch government and particular sectors of industry. The LTA-1 aimed to increase the energy efficiency of a sector by a specific percentage between a base year and an end year (for most sectors 20% between 1989 and 2000, corresponding to 2.0% per year). In 1999, the energy-intensive plants consuming more than 0.5 PJ per year signed the Covenant Benchmarking energy efficiency. In this covenant, running until 2012, they committed themselves to be among the world leaders in energy efficiency as soon as possible, but not later than 2012, resulting in required energy efficiency improvements that vary per sector and depend on e.g. the current distance to the world top and the expected development of the world top over time (SenterNovem, 2006).

Part of the less energy-intensive industries (companies with a yearly primary energy consumption below 0.5 PJ) signed the second generation of LTAs (LTA-2), also running until 2012. The LTA-2 does not focus on energy efficiency only, but also on other energy topics such as sustainable product development and renewable energy. Companies participating in the LTA-2 are obliged to set up an energy efficiency plan, which for a period of 4 years describes the goals with respect to energy efficiency improvements. For the first period (2001–2004), the goals for the 16 participating industrial sectors varied between 2.4% and 46% total efficiency improvement (0.8–14.3% per year) (SenterNovem, 2005), including improvements due to the use of renewable energy and sustainable product development.

The monitoring methodologies of the LTA-1, LTA-2 and the Covenant Benchmarking are based on confidential production and energy use data of the participating companies. For the industrial sector, mainly physical production data are used. In the LTA-1 monitoring reports, improvement in the energy efficiency indicator determined by top-down indicators is explained by bottom-up overviews of implemented energy efficiency improvement measures. The LTA-1 has been reviewed by Das et al. (1997), Rietbergen et al. (2002) and Farla and Blok (2002). In the latter study, the authors assessed the monitoring methodologies and also the quantitative results of the LTA-1 until 1996. They concluded that the monitoring methodologies of the LTA-1 were insufficiently transparent and recommended independent supervision and verification of the LTA monitoring results. For 1980–1995, independent estimates for energy efficiency trends in the energy-intensive manufacturing industry based on publicly available physical production data are available from a study by Farla and Blok (2000). This analysis was also used in the LTA assessment study mentioned above (Farla and Blok, 2002). No independent estimates are, however, available beyond 1995, the period in which the LTA-1 for the industrial sector has been replaced with the Covenant Benchmarking and the LTA-2.

This challenged us to analyse in detail energy efficiency trends in the manufacturing industry in the Netherlands since the middle of the 1990s, using a methodology based on publicly accessible physical production and energy use data. This is the main aim of this paper. In addition, we also aim to compare our results with those according to the LTA-1 in order to explore whether the LTA-1 monitoring results could be reproduced using an independent top-down monitoring methodology. Further aims of this paper are to quantitatively assess the effect of data uncertainties on the resulting energy efficiency indicators and to explore the feasibility of using our methodology in other countries also. We would like to stress that the focus of this paper is not on finding bottom-up explanations for the observed changes in energy efficiency of the manufacturing industry or to explain in detail differences in energy efficiency developments between sectors and over time.

In many ways, the methodology developed in this study resembles the methodology used in the study by Farla and Blok (2000). An important addition compared to their method is the focus on both final energy use data and primary energy use data. Other additions are the inclusion of more products per subsector of industry, the separate analysis of the ferrous and non-ferrous basic metal industry and the inclusion of an energy efficiency indicator based on physical production also for the food industry, one of the non-energy-intensive subsectors of industry. These latter results are discussed in a separate paper (Ramirez et al., 2006). Despite the differences between the two methods, it is possible to combine our results for 1995–2003 with the results for 1980–1995 obtained by Farla and Blok (2000), allowing to also present and analyse energy efficiency trends in the Dutch manufacturing industry for the total period 1980–2003. In Section 2, the methodology and data sources used in this study are discussed. In Section 3, we discuss per industrial subsector the realised energy savings and the data-related and methodological uncertainty related to our results. Where possible, we compare our results with the results according to the LTA-1. In a final paragraph, we also show the results for the total of the sectors studied. In Section 4, we draw some conclusions from our study that are relevant for policy makers and explore the feasibility of using the methodology for future monitoring of energy efficiency in the Netherlands and other countries.

2. Methodology and data collection

2.1. General methodology

We monitor the development of energy efficiency in industrial sectors via an energy efficiency indicator EEI:

$$\mathrm{EEI}_{j,k} = \frac{E_{\mathrm{actual},j,k}}{E_{\mathrm{reference},j,k}}, \tag{1}$$

in which k is the year of analysis with 0 denoting the base year 1995, j the type of energy demand (electricity, fuels/heat, non-energy use), $\mathrm{EEI}_{j,k}$ the energy efficiency indicator for type of energy demand j in year k, $E_{\mathrm{actual},j,k}$ the actual energy use from energy statistics for type of energy demand j in year k and $E_{\mathrm{reference},j,k}$ the reference energy use for type of energy demand j in year k.

The reference energy use represents the amount of energy an industrial sector would have used if no improvements in energy efficiency had taken place with respect to a certain base year (in our case 1995). The reference energy use is therefore also referred to as 'frozen-efficiency' energy use. The reference energy is based on the physical production of products of an industrial sector and the specific energy consumption for these products in the base year 1995:

$$E_{\mathrm{reference},j,k} = \frac{\sum_i \mathrm{SEC}_{i,j,0}\, P_{i,k}}{\sum_i \mathrm{SEC}_{i,j,0}\, P_{i,k}}\, E_{\mathrm{actual},j,0}, \tag{2}$$

in which $\mathrm{SEC}_{i,j,0}$ is the specific energy demand for energy demand type j to produce product i in the base year (e.g. in GJ per tonne of product) and $P_{i,k}$ the physical production of product i in year k.

If for the base year all products are accounted for and the SECs reflect the real energy demand in the base year, the reference energy use could simply be calculated by multiplication of the production of all products of an industrial sector with the specific energy demand. In practice, the incompleteness of available data makes it impossible to include all products of sector (Section 2.3). We therefore scale the frozen-efficiency energy use for the products included in the analysis to the energy use of the total sector. We distinguish three types of final energy demand: electricity use, fuels/heat use and fuel use for non-energy purposes. Steam and fuel demand is first combined using a conversion factor of 1.11 for steam (corresponding with a boiler efficiency of 90%). The reference energy in primary energy demand is calculated by multiplying the reference energy use per final demand type with a conversion factor f per type of final energy demand for the base year 1995. For the fuels/heat and non-energy use, a conversion factor of 1 is used and for electricity a specific factor is used that already accounts for the penetration of combined heat and power in the sector in the base year. Division of the actual primary energy use with this reference primary energy demand yields a primary energy efficiency indicator.

2.2. Energy use data, sector classification and energy use in the base year

We used energy use data from the annual energy balances for the Dutch manufacturing industry (Statistics Netherlands, 2005). In these annual balances, the net available energy is given per industrial subsector and per energy carrier. The net available energy is calculated from a

Table 2
Final energy, net available energy use, total primary energy use in the Netherlands in the base year 1995 (all values in PJ) (Statistics Netherlands, 2005)

Sectors in bold covered with physical indicators	Fuels			Steam		Electricity		Total primary energy use[d]
All values in PJ	Final energy use[a]	Final non-energy use	Net available energy	Final energy use[a]	Net available energy[b]	Final energy use[a,c]	Net available energy	
Food, beverages and tobacco industry[e,f]	47.39	0.20	81.11	20.45	−1.17	20.57	14.03	114.90
Textile, clothes and leather industry	6.18	0.00	6.79	0.56	0.14	2.06	1.97	11.87
Paper industry, printing and publishing	9.41	0.00	36.95	15.06	−0.36	11.62	4.09	46.79
Paper industry[f,g]	7.39	0.00	33.79	15.06	−0.36	8.91	1.38	36.84
Fertilizer industry	27.70	75.75	110.65	3.24	4.01	3.65	1.20	118.11
Chemical industry, excl. fertilizers[f,h]	154.87	298.80	583.61	84.43	9.29	40.32	11.71	623.22
Building materials industry[i]	30.05	0.00	31.04	0.55	0.00	4.94	4.73	42.87
Iron and steel basic metals industry	33.01	55.97	93.91	3.37	0.00	8.39	7.57	112.84
Non-ferrous basic metals industry	4.10	2.95	7.53	1.49	1.16	16.56	16.51	50.09
Metal products industry	22.76	12.80	36.48	0.72	0.06	14.16	14.05	71.67
Plastics, rubber and other manufacturing industry	5.78	0.00	5.81	2.25	2.24	6.61	6.61	24.82
Manufacturing industry, not specified by branch	0.00	5.10	5.10	0.00	0.00	0.00	0.00	5.10
Total	348.64	451.57	1032.77	147.18	15.03	137.79	83.86	1259.11
Covered with physical indicators[e]	304.51	433.67	941.63	128.59	12.94	103.34	57.14	1098.85
Covered with physical indicators (%)	87	96	91	87	86	75	68	87

[a] Including the conversion losses (input–output) of the other energy conversions.

[b] For a definition of net available energy use, see Eq. (3).

[c] In the energy balance, non-energy use of electricity (use for electrolysis) is distinguished from other electricity use. In this study, we do not make this distinction and include all electricity use as final energy use.

[d] Net available fuel use + net available steam use/0.9 + net available electricity use/0.4.

[e] Results for the food, beverages and tobacco industry are discussed in Ramirez et al. (2006).

[f] For the food, chemical and paper industry, we corrected the net available energy to include combined heat and power plants operated by joint ventures between energy and industrial companies; this information is available from separate publications (1994–1997 (Statistics Netherlands, 1994–1998), 1998–2003 (Statistics Netherlands, 2006b)).

[g] Excluding printing and publishing industry using data from Statistics Netherlands (2006a).

[h] Non-energy use and total primary energy use are corrected upwards with 66 PJ for 1995 based on Neelis (2006a). For the other years of this study, non-energy use is corrected upwards by 47 (1996), 36 (1997), 44 (1998), 53 (1999), 33 (2000), 59 (2001), 75 (2002) and 63 (2003) PJ.

[i] In the Dutch energy balance, some of the fuels used in cement kilns (1.97 PJ in 1995) are included as non-energy use. For the purpose of this study, we include this part as final energy use.

number of balance items:

$$\begin{aligned}\text{Net available energy} &= \text{Purchased energy} - \text{sold energy}\\ &\quad + \text{own winning} + \text{stock changes}\\ &= \text{final energy use}\\ &\quad + \text{final non-energy use}\\ &\quad + \text{input to CHP}\\ &\quad - \text{output of CHP}\\ &\quad + \text{input to other conversions}\\ &\quad - \text{output of other conversions.} \qquad (3)\end{aligned}$$

For the food, chemical and paper industry, we corrected the basic data to also include combined heat and power (CHP) plants operated by joint ventures of energy and industrial companies. Non-energy use data for the chemical industry were corrected based on a study by Neelis (2006a). Energy use for the paper industry was first corrected to exclude energy use of the publishing industry. More details on these corrections are given in the footnotes below Table 2. Total primary energy use is calculated from the net available energy use of a sector using constant conversion factors of 2.50 for electricity bought from or delivered to the grid (reflecting an efficiency of 40%) and 1.11 for heat bought from or sold to third parties (reflecting an efficiency of 90%). From the total primary energy and the final energy use data for the base year 1995, we calculate conversion factors for electricity for use in the calculation of the reference primary energy use. An overview of the final energy use, net available energy use and total primary energy use is given in Table 2.

We calculated EEIs based on physical production data for 10 of the 14 industrial sectors distinguished in the annual energy balance of the Netherlands. These sectors cover 87% of the total primary energy of the Dutch manufacturing industry.

2.3. Selection of products, physical production data and specific energy consumption data

We included as many products as possible in the analysis with data availability (i.e. production or specific energy consumption data) being the only limitation. Compared with the previous study by Farla and Blok (2000), we have been able to include considerably more products for a number of sectors (e.g. the fertilizer and chemical industry), thereby increasing the energy coverage and reliability of the resulting EEI (see Table 4 for an overview of the energy coverage). The main source for production statistics is the Prodcom statistics (Eurostat, various years). Some of the Prodcom data are confidential (e.g. when a commodity is produced by a limited amount of producers), but for the purpose of this project, we had access to all data via the Centre for Research of Economic Microdata (CEREM) framework of Statistics Netherlands that allows researchers to use confidential data provided that results are only published in aggregated form. For some products, the Prodcom data contained obvious errors, e.g. in the chemical industry, where some companies tend to report only production for sale rather than total physical production including the part of production that is further processed on-site. This limited the number of products that could be included in the analysis. For some other sectors, other data were used, because they proved better suitable for the purpose of our study than the Prodcom statistics. Glass production is, for example, included in the Prodcom statistics in too much detail (more than 50 different products) and with various physical units (e.g. cubic metre for packaging glass and square metre for flat glass). In these cases, we use data from industry associations or data obtained via personal communications. Specific energy consumption data have been taken from a variety of open literature sources and were chosen to reflect as well as possible the situation in the Netherlands in the base year of our analysis 1995. In some cases, it was possible to use the energy balances directly to determine the specific energy consumption. An example is the production of ammonia. The non-energy use of natural gas in the fertilizer industry can be fully allocated to ammonia production. Combination of ammonia production data and the reported non-energy use yields an estimate for the specific feedstock (non-energy) use for ammonia production. An overview of the products included and the specific energy use figures is given in Table 3. The resulting energy coverage per type of final energy use is given in Table 4 and will be further discussed in Section 3.

2.4. Methodology for uncertainty analysis

We quantitatively assessed the uncertainty in the various input variables used in the analysis with the following method. First, we assessed the uncertainty of all input variables and translated these uncertainties into probability density functions (PDFs) for the input variables (i.e. production data, specific energy consumption data and data from the energy statistics). In a second phase, these PDFs were used to generate a PDF for the output variable using the Crystal Ball 2000 software package (Decisioneering, 2000). For the PDFs of the input variables, we use triangular distributions.[1] For data from the energy statistics, we assume the extremes of the triangular distribution to be ±5% of the reported value. The systematic errors resulting from the way energy statistics are compiled (e.g. sampling methodology) are estimated by Boonekamp et al. (2001) at 1% based on communications with Statistics Netherlands. We did, however, identify additional uncertainties related to e.g. wrong reporting by companies and therefore use a higher uncertainty range. For the specific energy consumption data, we use triangular distributions with the extremes based on an analysis of the range of specific energy consumption data as they were found in the literature, thereby taking into account the years and countries to which the literature data referred (resulting ranges are given in Table 3). For the production statistics, we used as default a triangular distribution with the extremes being ±5% of the reported value, equal to the estimated error in the energy statistics. It should be stressed that we only quantitatively assessed data-related uncertainties and not the methodological uncertainties associated with our approach such as the incomplete and changing energy coverage of the products included in the reference energy use over time. These aspects will be separately discussed when discussing our results.

2.5. Combining the results with results from 1980 to 1995

As explained in the introduction, we combine our results for the period 1995–2003 with the results obtained by Farla and Blok (2000) for 1980–1995. To do so, we had to deal with some differences between the current study and the study for 1980–1995. One difference is the use of updated energy use for 1995 in the current study, based on Statistics Netherlands (2005). To ensure consistency, we replaced the 1995 energy use data from the former study with the newly available data. Another difference is the use of other SEC data in the old study. We recalculated the EEIs for 1980–1995 using the SEC data applied in this study and the production data available from the old study. In this way, we obtained a consistent time series. An exception was the chemical industry for which this approach was not possible (see Section 3.2.1). A third difference is a different way of calculating primary energy use. Farla and Blok converted the net available energy use of a sector using actual grid

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[1] In 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 details 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).

Table 3
Overview of data sources and assumptions uncertainty analysis

Product and physical unit of measurement (tonne if nothing is mentioned)	Prodcom code (PC) or source for production statistics	SEC, electricity		SEC, fuels/heat		SEC, non-energy use		Sources for SEC values[a]
		GJ/physical unit[a]	%	GJ/physical unit[a]	%	GJ/physical unit[a]	%	
Chemical industry, excl. fertilizers								
Ethylene	24141130; Neelis (2006b)	0.30	20	30.00	20	72.00	20	Neelis et al. (2003a), Chauvel and Lefebvre (1989), Patel (2003)
Methanol	24142210	0.20	10	8.10	10	25.40	10	Neelis (2006c)
Carbon black	24131130	1.70	10	17.20	10	37.00	10	Neelis (2006c)
Basis aromatics[b]	24141223/25/ 43/45	1.00	20	5.00	20	–	–	Neelis et al. (2003b)
Phosphorus	24131160	46.50	20	12.50	20	34.30	10	Struker (1994), Neelis (2006c)
Silicon carbide	24135450	25.70	10	3.30	10	22.90	10	Struker (1994), Neelis (2006c)
Chlorine[c]	24131111	11.00	10	2.40	10	–	–	IPTS (2001a)
Polyethylene	24161035/39/ 50/90	2.50	40	0.80	40	–	–	Hydrocarbon Processing (2003)
Polypropylene	24165130/50	0.40	40	0.80	40	–	–	Hydrocarbon Processing (2003)
Polyethyleneterephthalate	24164060/6/64	0.70	10	4.80	10	–	–	Boustead (2002)
Ethylene glycol[d]	24142310	1.10	20	9.90	20	–	–	Neelis et al. (2003b)
Salt	14401000	0.10	20	1.90	20	–	–	Struker (1994)
Caustic soda	24131525	0.00		6.70	20	–	–	Struker (1994)
Disodiumcarbonate	24133310	0.80	20	12.20	20	–	–	Struker (1994)
Polystyrene	24162035/39/90	0.50	30	1.40	30	40.50	20	Hydrocarbon Processing (2003); calorific value
Terephthalic acid	24143435	1.70	10	3.80	20	27.00	20	Boustead (2002); calorific value
Styrene[e]	24141250; Neelis (2006b)	0.20	10	6.30	10	–	–	Neelis et al. (2003b)
Styrene[f]	24141250; Neelis (2006b)	1.40	40	10.40	40	–	–	Neelis et al. (2003b)
Cyclohexane	24141213	0.10	10	−1.70	10	37.50	20	Neelis et al. (2003b); calorific value
Natriumtripolyphosphate	24133270	–		5.00	20	–	–	Struker (1994)
Plasticisers[g]	24664640	0.30	20	6.90	20	–	–	Neelis et al. (2003b)
Fertilizer industry								
Nitric acid (tonne N)	24151050	0.50	30	−12.00	30	–	–	Worrell (1994)
Ammonia (tonne N)	24151075/77	0.08	40	10.12	5	28.95	5	Chauvel and Lefebvre (1989), Nieuwlaar (2001a), Neelis (2006c)
Urea (tonne N)	24153013/19	0.16	30	5.78	30	–	–	EFMA (2000)
Ammonium nitrate (tonne N)	24153030	0.05	30	−1.90	30	–	–	EFMA (2000)
Other nitrogen fertilisers	24153043/45/ 80/90	0.69	40	2.54	40	–	–	EFMA (2000)
Iron and steel industry								
Total pig iron production	Eurostat (2001, 2003), IISI (2004)	0.46	30	3.58	30	10.20	10	Neelis (2006c), Eurostat (2001), Annema et al. (1992); IPTS (2001b)
Crude steel (basic oxygen furnace)	Eurostat (2001, 2003), IISI (2004)	0.08	30	0.05	30	–	–	Annema et al. (1992)
Crude steel (electric arc furnace	Eurostat (2001, 2003), IISI (2004)	1.72	30	0.47	30	–	–	Gielen and van Dril (1997)
Hot rolled products	Eurostat (2001, 2003), IISI (2004)	0.40	30	1.80	30	–	–	Gielen and van Dril (1997)
Cold rolled products	Eurostat (2001, 2003), IISI (2004)	0.50	30	1.10	30	–	–	Gielen and van Dril (1997)

Table 3 (*continued*)

Product and physical unit of measurement (tonne if nothing is mentioned)	Prodcom code (PC) or source for production statistics	SEC, electricity		SEC, fuels/heat		SEC, non-energy use		Sources for SEC values[a]
		GJ/physical unit[a]	%	GJ/physical unit[a]	%	GJ/physical unit[a]	%	
Paper industry						–	–	
Newsprint paper[h]	VNP (1993–2002)	4.80	10	7.70	10	–	–	Mulder and Sinon (1994)
Coated paper and writing paper	VNP (1993–2002)	2.30	10	7.80	10	–	–	Mulder and Sinon (1994)
Uncoated paper and writing paper	VNP (1993–2002)	4.80	10	7.70	10	–	–	Mulder and Sinon (1994)
Household and sanitary paper	VNP (1993–2002)	3.60	10	7.50	10	–	–	Mulder and Sinon (1994)
Corrugated case materials	VNP (1993–2002)	1.40	10	5.90	10	–	–	Mulder and Sinon (1994)
Wrapping papers[i]	VNP (1993–2002)	1.40	10	5.90	10	–	–	Mulder and Sinon (1994)
Grey board (including specialties)[j]	VNP (1993–2002)	1.40	10	5.90	10	–	–	Mulder and Sinon (1994)
Folding box board	VNP (1993–2002)	2.60	10	8.80	10	–	–	Mulder and Sinon (1994)
Building materials industry								
Clinker	Mergelsberg (2004, 2005)	0.25	20	3.42	20	–	–	Nieuwlaar (2001b)
Cement	PC 26511230/ 50/90	0.19	20	0.63	20	–	–	Nieuwlaar (2001b)
Tiles (1000 pieces)	PC 26401250	0.29	30	7.02	30	–	–	de Castro (1992)[k]
Bricks (1000 WF[l])	KNB (2003–2004)	0.19	30	4.67	30	–	–	de Castro (1992)[k]
Paving bricks (1000 WF[l])	KNB (2003–2004)	0.21	30	5.13	30	–	–	de Castro (1992)[k]
Glass	Beerkens (2004, 2005)	1.30	10	6.81	10	–	–	Nieuwlaar (2001b)
Non-ferrous basic metal industry								
Primary aluminium	PC 27421153	54.90	5	3.70	20	–	–	Alsema (2000)
Secondary aluminium	PC 27421155	0.60	40	5.70	40	–		Alsema (2000)
Primary zinc production	PC 27431230, Keijssers (2004)	14.80	5	2.40	20	–	–	Alsema (2000)
Anode production	Frijlink (2004), Alcan (2004)	0.40	20	3.90	20	27.57	10	Alsema (2000), Neelis (2006c)

[a] The percentages refer to the boundaries used in the triangular distributions (Section 2.4). For more information about the sources used for the specific energy consumption values, we refer to Neelis et al. (2004, 2005).

[b] The production processes for benzene, toluene, *p*-xylene, *o*-xylene and *m*-xylene are highly integrated. Separate SECs are therefore difficult to distinguish.

[c] Assuming 50% of chlorine to be produced with membrane cells, 32% with mercury cells and 18% with diaphragm cells (Nieuwlaar, 2001a).

[d] Including the production of ethylene oxide.

[e] Including ethylbenzene manufacture.

[f] Including ethylbenzene manufacture, via the combined propylene oxide/styrene route.

[g] Including alcohol production.

[h] In the study by Mulder and Sinon (1994), the company producing newsprint paper was categorised in the uncoated paper and writing paper. Therefore, the SEC values for this category are used for newsprint paper.

[i] Values for corrugated case materials used.

[j] According to Mulder and Sinon (1994), the division between specialties and grey board was 16% vs. 84%. The SEC values of specialties and grey board are added using these percentages.

[k] In de Castro (1992), SEC values of 2.70 GJ fuels/tonne and 0.11 GJ electricity/tonne are given. We use a specific weight of 1.73 kg/WF bricks, 1.90 kg/WF paving bricks and 2.60 kg per tile (Huizinga et al., 1992) to come to the SEC values given here.

[l] WF stands for Waal Formaat, a brick with dimensions 20 × 10 × 5 cm (Novem, 2000).

Table 4
Energy coverage of products included in the reference energy use in this study (%)

	Fuels/heat	Non-energy use	Electricity	Total primary energy use
Paper industry	89	–	86	87
Fertilizer industry	82	100	58	91
Chemical industry, excl. fertilizers	52	84	46	66
Building materials industry	70	–	57	66
Iron and steel basic metals industry	87	101	82	93
Non-ferrous basic metals industry	41	100	91	86
Total covered in this study	61	89	64	78

electricity conversion efficiencies (increasing from 36% to 38% between 1980 and 1995) and by valuing steam with 75% of its heat content. Also, climate correction was applied. We ensured consistency by recalculating primary energy use for 1980–1995 based on the assumptions used in this study (i.e. no climate correction and fixed conversion efficiencies of 40% for electricity and 90% for steam, respectively). We would like to stress that our recalculations for the period 1980–1995 to correct for the three differences mentioned did not result in any significant changes in the estimate annual efficiency improvements between 1980 and 1995 compared with the estimates by Farla and Blok (2000). The fourth difference concerns the product coverage. In this study, we have been able to include more products per sector, thereby increasing the quality of the reference energy use as indicator for the frozen energy efficiency developments. In the discussion of the results per sub-sector we will further discuss this.

3. Results and discussion

3.1. Summary of results

In Fig. 1, we summarise the average annual reduction in the EEI between 1995 (the base year of the analysis) and 2003. Detailed yearly results are given in Appendix A. We include the uncertainty bars (95% confidence interval) determined with the method described in Section 2.4. In Table 5, we include the average reduction in EEI between 1980 and 1995, the period between 1989 and 2000 (the full period of the LTA-1) and 1995 and 2000, the period of the LTA-1 studied in detail in this paper. Below, we discuss the results per individual sub-sector and for the total of the sectors analysed.

3.2. Chemical sector

3.2.1. Chemical industry, excl. fertilizers

The development of the reference energy use in the Farla and Blok study was based on specific energy use data including non-energy use. Since the underlying production data in the analysis for 1980–1995 were confidential (Farla and Blok, 2000), we could not calculate EEI developments excluding non-energy use before 1995. The upward correction of non-energy use in the energy statistics for the chemical industry, excl. fertilizers in the period 1995–2003 based on Neelis (2006a) could not be made before 1995. As a result, no consistent time-series for total primary energy use including non-energy use are available for the period 1980–1995. These two factors explain the omission for 1980–1995 in Table 5.

For the period 1995–2003, we estimate the reduction in EEI at 2.8% per year for fuels/heat (95% confidence range between 2.0% and 3.6%) and 3.4% per year for electricity use (95% confidence range between 2.6% and 4.2%). The EEI for non-energy use fluctuates between 0.90 and 1.11. A change in the EEI for non-energy use can be expected if the yield of the different products from steam cracking changes over time (e.g. as a result of changing feedstock distributions), but is most probably caused by remaining inconsistencies in the energy statistics. This is further discussed below. In primary energy terms, we estimate efficiency improvements at 3.2% per year on average between 1995 and 2003, excluding non-energy use (95% confidence range between 2.6% and 3.8%). This is equivalent to 103 PJ savings on primary energy use per year. Increased use of combined heat and power contributes 9 PJ to this total. The uncertainty ranges given above relate to estimated data uncertainties. In addition, methodological uncertainties are also important:

- The products included in the reference energy use cover only 66% of the total primary energy use of the sector (Table 4) and are biased towards the energy-intensive products. Products of a number of sub-sectors are not covered in the analysis (e.g. industrial gases, fine chemicals, specialty polymers). Different growth rates of the products included and not included in the reference energy use could therefore lead to wrong results. We visualise this in Fig. 2. Between 1995 and 2003, the reference energy use increased by 35% and the actual energy use by only 20%, resulting in an observed EEI of 0.89 in 2003, i.e. an energy efficiency improvement of 11% in this time period. If the non-covered products have grown in this period by only 20% rather than 35%, the actual energy efficiency improvement for the industry is only 7.5% instead of the 11.0% observed. If, on the other hand, the growth rate of the non-covered products has been 50%, actual savings would be 14.2% rather than the observed 11.0%. These ranges are in the

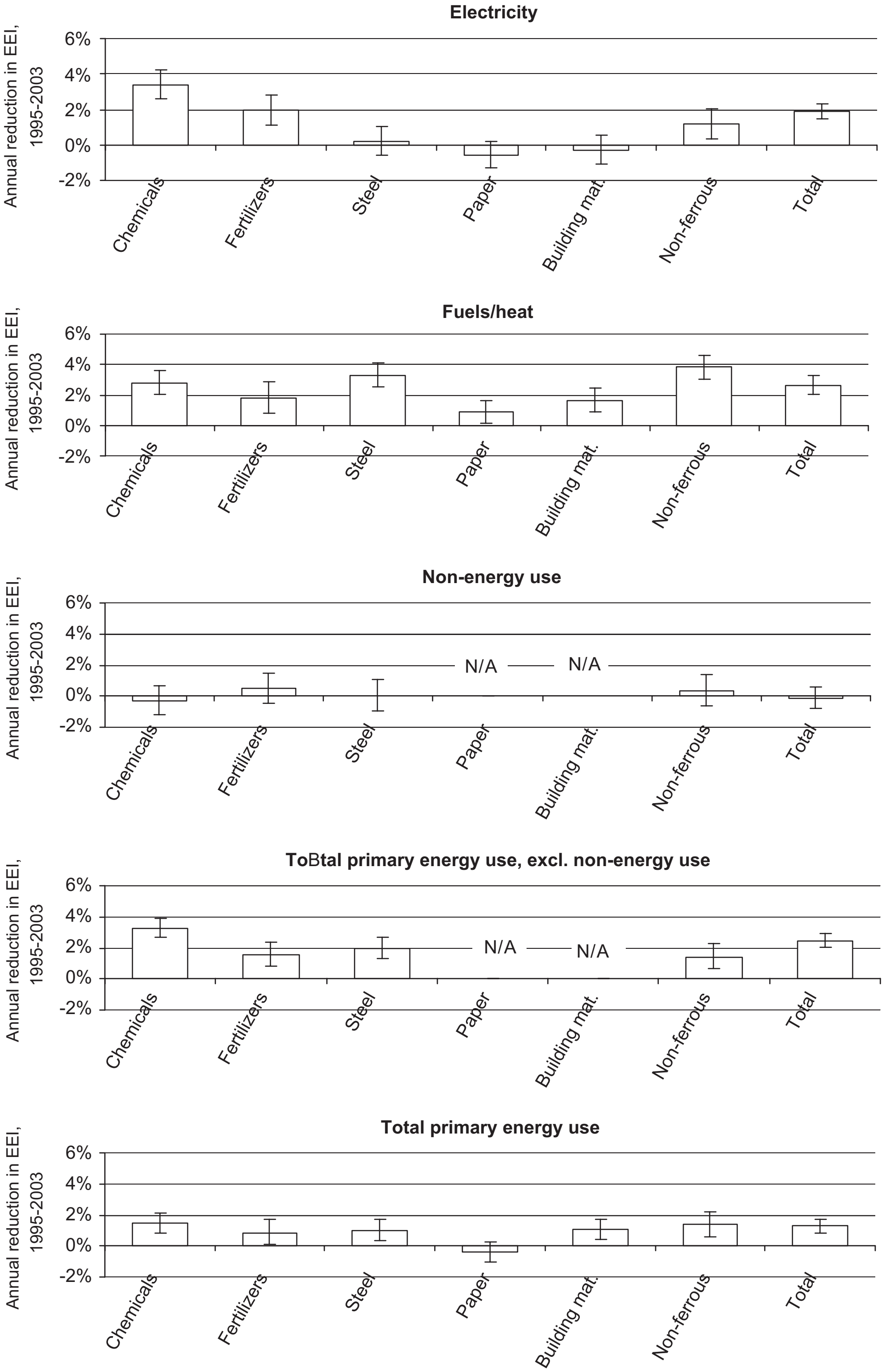

Fig. 1. Annual reduction in EEI between 1995 and 2003 (%/year).

same order as the data-related uncertainties estimated via the method explained in Section 2.4. We also show for comparison the effect of different growth rate of covered and non-covered products in case the covered products cover 90% of the energy use in the base year. In that situation, the difference between observed and actual energy efficiency improvements is far less. Based on the comparison with the LTA-1 data (Section 3.2.3), we are confident that for the period until 2000, our indicator is a reliable indicator for the frozen efficiency energy use of the chemical industry. The effect of low and changing coverage could, however, be studied in more detail, e.g. by comparing the value-added growth of sub-sector of the chemical industry that is not covered

Table 5
Average annual decrease in the primary energy efficiency indicator (%)

	1980–1995[a]	1995–2003	1980–2003[b]	1989–2000	1989–2000 LTA	1995–2000	1995–2000 LTA
Chemical industry, excl. fertilizers		1.5				1.5	
Chemical industry, excl. fertilizers, excl. non-energy use		3.2				4.0	
Fertilizers	2.3	0.9	1.8	0.7		1.9	
Fertilizers, excl. non-energy use[c]	*6.8*	1.6	*4.9*	*3.6*		3.6	
Total chemical sector		1.4				1.6	
Total chemical sector, excl. non-energy use		3.1			2.6	4.0	3.6
Iron and steel basic metals industry		1.0				0.2	
Iron and steel basic metals industry, excl. non-energy use		2.0			1.6	0.4	1.3
Non-ferrous basic metals industry		1.4				0.3	
Non-ferrous basic metals industry, excl. non-energy use[d]		1.4			1.6	*0.4*	2.0
Total basic metals industry	0.4	1.1	0.6	−0.1		0.3	
Total basic metals industry, excl. non-energy use[d]	0.4	1.7	0.9	*−0.1*	1.6	*0.4*	1.4
Building materials industry	1.5	1.1	1.3	1.2	1.2	0.4	0.7
Paper industry	2.5	−0.1	1.6	0.9	2.2	−0.2	2.1
Total industry		1.3				1.3	
Total industry, excl. non-energy use[d]		2.5			2.3	*2.7*	3.0
Total industry, excl. total chemical industry	0.9	0.9	0.9	0.3		0.2	
Total industry, excl. total chemical industry, excl. non-energy use[d]	0.9	1.2	1.0	*0.4*	1.7	*0.3*	1.4

[a] Data exclusive non-energy use are for the period 1982–1995. For 1980 and 1981, no non-energy use estimates available.
[b] Data exclusive non-energy use are for the period 1982–2003. For 1980 and 1981, no non-energy use estimates available.
[c] Data in italics are uncertain estimates, because of the unclear definition of non-energy use in the fertilizer industry (see text).
[d] Data in italics cannot directly be compared with the LTA-1 data (see text).

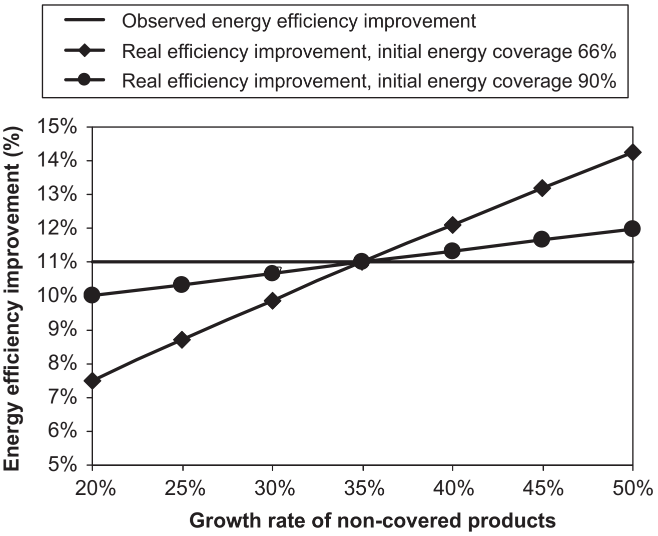

Fig. 2. Actual energy efficiency improvements in case of different growth rates of covered and non-covered products for initial coverage of 66% and 90%. Growth rate of covered products 35%.

with those covered and by analysing detailed energy use data at the level of individual firms or sub-sectors. We leave this for further analysis.

- We included the steam cracking process using production of ethylene only, because the production statistics of the other steam cracker products (e.g. propylene and butadiene) proved to be unreliable. We also did not correct for yearly differences in feedstock distribution for steam cracking, because data were unavailable. Varying product yields and feedstock distributions can have an effect on the specific energy consumption, but our indicator cannot capture these effects. Variations in the type of feedstock applied in the steam cracking process can change the specific non-energy use (expressed per tonne of ethylene) by up to 15%[2] and can have an even larger effect on the fuels/heat and electricity use of the steam cracking process. This methodological uncertainty could therefore explain part of the fluctuation in EEI for non-energy use between 0.90 and 1.11 in the years of the study and can also add to the uncertainty in the EEI for fuels/heat and electricity use. However, given the good match between our reference energy use and the reference energy use according to the LTA-1 (Section 3.2.3) and the relatively stable feedstock distribution,[2] we consider it more likely that the fluctuation in the EEI for non-energy use is caused by remaining inconsistencies in the non-energy use data from the energy statistics. The default uncertainty range for data from the energy statistics (±5%) might therefore not be valid for non-energy use data in the chemical industry.

3.2.2. Fertilizer industry

For the fertilizer industry, the annual reduction in primary EEI is estimated at 0.9% per year between 1995 and 2003 (95% confidence level between 0.1% and 1.7%).

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[2] We base this range on the specific energy use in butane, propane, naphtha and gas oil cracking as given by Neelis et al. (2003a). The actual fluctuation will be less, because the feedstock mix normally does not change much from year to year. For 1993–1999, the feedstock mix has for example been more or less stable (Neelis et al., 2003a).

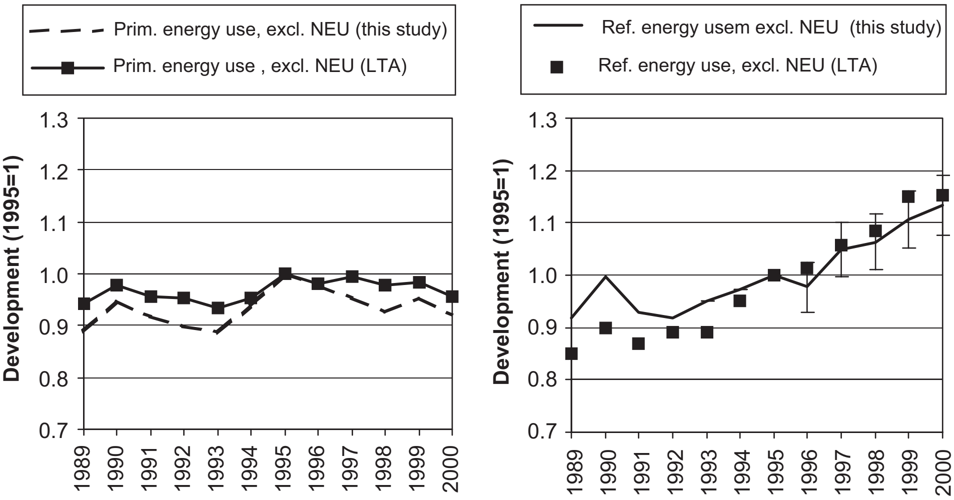

Fig. 3. Primary energy use and reference use according to our study for the total chemical industry and according to the LTA (Novem, 2001a).

This corresponds to primary energy savings of 4 PJ primary energy use per year in 2003 compared with 1995. Average annual EEI reductions for electricity are estimated at 2.0% (confidence range between 1.1% and 2.8%) and for fuels/heat at 1.8% (range between 0.8% and 2.9%). Changes in the efficiency and use of CHP in the fertilizer industry had a negative effect on the EEI for primary energy of about 1 PJ, resulting in lower primary savings compared with the savings on final fuels/heat and electricity use. Annual reductions in the EEI for non-energy use of fuels are estimated at 0.5% per year. Reduction in EEI with respect to non-energy use are possible, because the feedstock into ammonia plants is not defined as the calorific value of the ammonia product, but probably as the natural gas input into the reforming process. Different plant setups or differences in operation might result in different amounts of natural gas used in the reformer and can therefore also change the EEI for non-energy use. It should be noted, however, that in the surveys used to prepare the Dutch energy statistics, feedstock use is not precisely defined. Therefore, practices might differ from plant to plant and it can be questioned whether the allocation between final energy and final non-energy use is made in a consistent way throughout the years, especially before 1995. We therefore put the results without non-energy use before 1995 in italics in Table 5.

The detailed results per year (Appendix A) reveal a sudden increase in EEI in 2002 and 2003. This increase can possible be attributed to low-capacity utilisation factors as a result of a declining production. The drop in EEI in 2000 and 2001 can most probably be attributed to the closure of the oldest (and least efficient) ammonia production facility in the Netherlands. The reference energy use is based on products that cover the majority of the fuels/heat and non-energy use of the sector (82% and 100%, respectively) and slightly more than 50% of the electricity use. Based on this energy coverage, we conclude that the reference energy use is a reliable indicator for the frozen efficiency developments in the fuels/heat and non-energy use, but might be less accurate for the electricity use of the sector. Over the full period 1980–2003, the average annual drop in EEI was 1.8%. It should be noted, however, that in the reference energy use by Farla and Blok for 1980–1995, only ammonia was included and structural changes between different types of nitrogen fertilizers are therefore not monitored in that period.

3.2.3. Total chemical sector, comparison with the LTA-1

We further assessed the methodological uncertainties, the quality of the energy statistics and the reliability of our results by comparing our results with the results obtained within the LTA-1 framework (Fig. 3), including the total chemical sector. To ensure consistency with the LTA, we excluded from the primary energy use figures (left graph), the non-energy use of fuels, but also the non-energy use of electricity as it is reported in the energy statistics. For the reference energy use, this was not possible, because it is unknown which part of the electricity use in e.g. chlorine production is regarded non-energy in the energy statistics and which accounting practices the various firms use. The trend of the reference energy use according to the LTA is comparable in the years of the current study (1995–2000). Since in the LTA index, all products of the companies that took part in the agreement are included, it is likely that the reference energy use according to the LTA reflects quite accurately the actual frozen efficiency development in the chemical industry. The fact that the LTA index corresponds so well with the reference energy use developed in this study for the years 1995–2000, is an indication that the reference energy use is a reliable indicator for the frozen efficiency development, despite the relatively low-energy coverage of approximately 50% in the base year.[3]

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[3] The coverage including non-energy use is 66%, but for fuels/heat and electricity use, the coverage is about 50%.

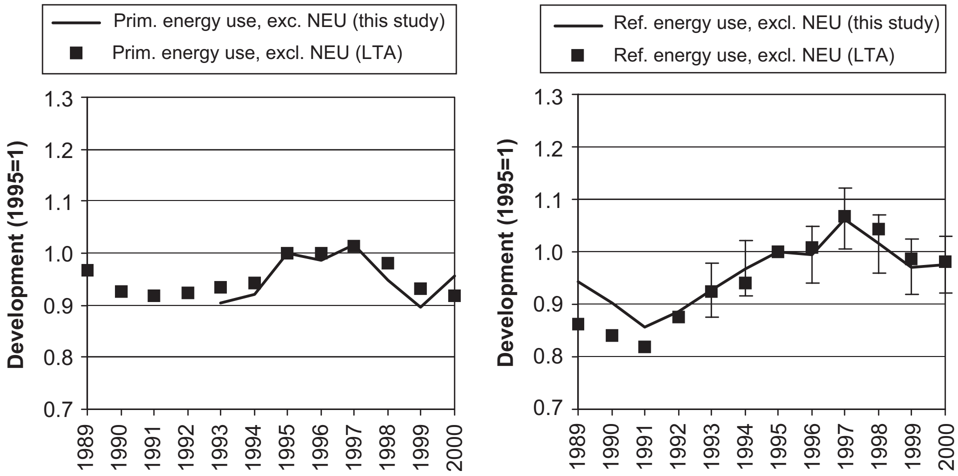

Fig. 4. Primary energy use and reference energy use for the iron and steel industry according to our study and the LTA (Novem, 2001b).

The development of the total primary energy use in the LTA differs significantly from the development of the total primary energy use in our study (Fig. 3, left side). In absolute values, the difference fluctuates between 0 PJ (1992) and 20 PJ (1995), corresponding to 0–6% of the value reported in the statistics. Studying the background of the observed differences in more detail is difficult, because underlying company data from both the LTA and the energy statistics are confidential and some methodological differences exist between the energy statistics and the LTA-1. We conclude that, despite the efforts at Statistics Netherlands to make the LTA-1 and the data from energy statistics consistent (Pouwelse, 1997), there are still differences between the two datasets, a conclusion also drawn by Farla and Blok (2002). The differences between the LTA-1 and our calculations in the average annual reductions of the EEI for 1995 and 2000 (4.0% vs. 3.6%, Table 5) can be attributed to these differences.

3.3. Basic metals industry

3.3.1. Iron and steel basic metal industry

The average annual reduction in the EEI for the iron and steel industry between 1995 and 2003 is estimated at 1.0% per year (confidence interval between 0.3% and 1.7%) when we include non-energy use and 2.0% (confidence interval between 1.3% and 2.7%) when we exclude non-energy use. This corresponds to yearly primary energy savings of 10 PJ in 2003 compared with the base year level. Changes in the efficiency and use of CHP are not important for this industry (<1 PJ). Efficiency improvements have mainly been achieved with respect to fuels/heat use (3.3% per year) and less with respect to electricity use (0.2% per year). Non-energy use (coal and coke use as reductant in the blast furnace) has been stable in the period 1995–2003. The products included in the reference energy use cover 93% of the total primary energy use of the iron and steel basic metals industry.

We compare our results with the LTA for the iron and steel industry in Fig. 4. The system boundaries are not 100% comparable, because the LTA includes the energy use resulting from the production of coke, whereas this is excluded in this study (difference is approximately 6 PJ in 1995). We therefore show an indexed line (1995 = 1). The development of the reference energy use according to our study coincides well with the development according to the LTA-1 in the period 1993–2000 when indexed to 1995. The match for 1989–1991 is less convincing. This might be caused by different growth rates of coke versus iron and steel production or by different growth rates in the various types of steel products. These changes are taken into account in LTA-1 where 26 different products are distinguished, whereas they are not included in the reference energy use in this study. Without further detailed analysis on the company level, it is very difficult to assess the difference in more detail. The realised energy use from the energy statistics for 1993–2000[4] fits well with the energy use according to the LTA with the exception of 2000, where the energy statistics indicate an increase of 3.5 PJ, whereas the energy use according to the LTA-1 remains stable. This difference also explains fully the different estimate of annual EEI reduction (0.4% vs. 1.3%) between 1995 and 2000 between the LTA-1 and our study (Table 5). In 2000, a new thin slab caster was taken into use in the iron and steel industry. According to the text of the LTA-1 monitoring report (Novem, 2001c), this resulted in an additional primary energy use of 1 PJ due to testing of the new machine, which is however not visible as increased energy consumption in the energy use figures in the monitoring report of the LTA-1.

3.3.2. Non-ferrous industry

Annual EEI reductions in the non-ferrous basic metals industry between 1995 and 2003 have been 1.4% per year

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[4] No separate data for the iron and steel industry are available before 1993.

(confidence interval between 0.6% and 2.2%), corresponding to annual primary savings of 7 PJ per year in 2003 compared with 1995. Efficiency improvements have mainly been accomplished with respect to fuels/heat use (3.8% per year), but also with respect to final electricity use (1.2%). The EEI for non-energy use fluctuates between 0.88 and 1.19 in the years of the study. Non-energy use in the non-ferrous industry relates to the use of petroleum cokes for the production of anodes by one of the primary aluminium producers. The variation in the EEI is most probably caused by the different shares of petroleum coke (monitored in the energy statistics) and other raw materials used such as coal tar and the remaining parts of old anodes, which are not monitored in the energy statistics.

The products include all non-energy use of the sector in the base year and almost all (91%) of the electricity use. The energy coverage for fuels/heat use is, however, much lower with 41%. This might be due to the fact that the energy use for downstream processing of the metals is not taken into account in the SEC figures uses. In the LTA-1 for the non-ferrous industry, the electricity used for electrolysis in aluminium and zinc production was not taken into account, because it was considered there as non-energy use. Since we took all electricity use into account, it is not possible to make a sound comparison between the LTA-1 results and our study for the non-ferrous industry.

3.3.3. Total basic metals industry—developments 1980–1995 and comparison with LTA

For the period before 1993, no separate data for the ferrous and non-ferrous basic metals industry were available and the analysis for 1980–1995 has therefore been done for the total basic metals industry by Farla and Blok (2000). The average annual EEI reduction between 1980 and 2003 is estimated at 0.6% per year. If, for reasons of comparison with the LTA-1, we would exclude the use of coal and coke in the blast furnace and the use of petroleum coke in the production of anodes (both allocated to non-energy use), average annual reductions are 0.9%. The comparison with the LTA-1 results for the total basic metals industry for 1989 and 2000 reveals much higher savings in the LTA-1 compared with our results, but the two are not fully comparable as a result of the inclusion of the total electricity use in the reference energy use for the non-ferrous industry in our study and the inclusion of coke production in the LTA-1. The main reasons for the differences between the LTA-1 and our study are (1) the difference in realised energy use in the iron and steel industry in 2000 between our study and the LTA-1 and (2) the different development of the reference energy use in the iron and steel industry between 1989 and 1991, maybe as a consequence of the number of products covered.

3.3.4. Paper industry

According to our study, there has been a small increase of annually 0.1% in the EEI (confidence interval between −0.6 and +0.6%) in the paper and board industry between 1995 and 2003, corresponding to an additional energy use of 0.5 PJ in 2003 compared with 1995. The sector has become more fuel efficient (0.9% per year), but this is offset by additional electricity use (−0.6%). In addition, there was a small decrease in the use of CHP in the paper industry, which is equivalent to an additional fuel use of 1.5 PJ. The energy coverage of the products included in the reference energy use in the base year is 87%. This is about the same as the energy coverage of 85% found for 1986 by Farla and Blok (2000). The industry converting paper and board to final products is included in the primary energy use in the energy statistics, but is not included in the reference energy use. The inclusion of the paper and board-converting industry in the observed energy use of the sector can offer an explanation for the absence of efficiency improvements according to our indicator as becomes clear from the comparison of our results with the results obtained within the framework of the LTA-1 (Fig. 5). The comparison shows an almost identical development of the reference energy use according to our study and the LTA. The realised energy use in the LTA, however, grows

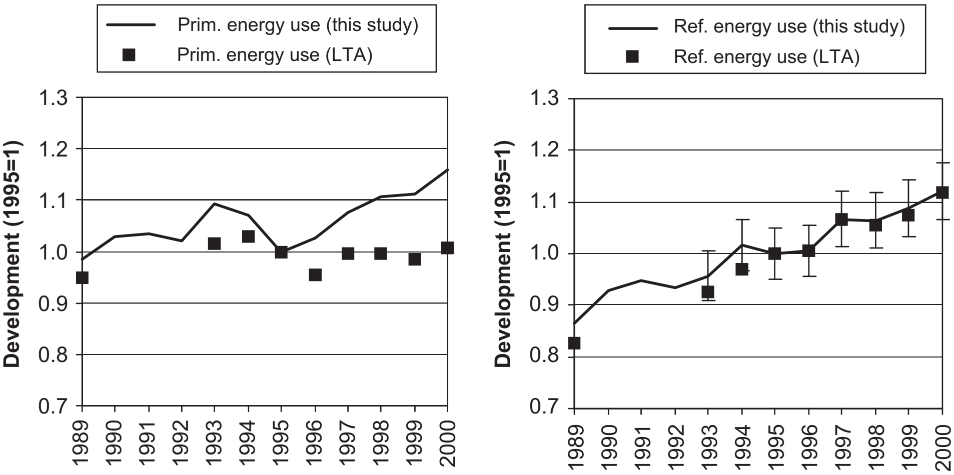

Fig. 5. Primary energy use and reference energy use for the paper industry according to our study and according to the LTA (Novem, 2001c).

much slower compared to the energy statistics. In 1995, the realised energy use in the LTA is 86% of the realised energy use according to the energy statistics (well in line with the energy coverage of 87% as given above), whereas this share drops to 75% in 2000. Farla and Blok (2002) have already drawn a similar conclusion in their evaluation of the LTA-1 when comparing data for 1989 and 1996. If we assume both the LTA and the energy statistics to be right, this indicates that in 2000 the paper and board-converting industry consumes a much larger share of the energy use of the sector and has doubled its energy use between 1995 and 2000. This is not confirmed by energy use data at the level of industrial sub-sectors (Statistics Netherlands, 2006a). According to these statistics, the paper and board-converting industry consumes a rather constant fraction of the energy use of the total paper and board industry. The comparison therefore raises questions about the validity of the LTA-1 and/or Statistics Netherlands energy consumption data. A more detailed assessment would only be possible based on confidential data at the level of individual firms. As a result of significant reductions in EEI in the period 1980–1995 (2.5% per year), the annual reduction in primary EEI between 1980 and 2003 is still estimated at 1.6% per year despite the absence of savings in the last decade.

3.3.5. Building materials industry

Between 1995 and 2003, annual reductions of the EEI in the building materials industry are estimated at 1.1% (confidence interval between 0.4% and 1.8%), corresponding to savings of 3.5 PJ per year in 2003 compared with 1995 levels. The industry has become slightly less efficient with respect to electricity use (annual EEI reduction of −0.3%) and more efficient with respect of fuels/heat use (EEI reduction of 1.7% per year). Over the total period 1980–2003, the average annual reduction in primary EEI is estimated at 1.3%.

The energy coverage of the products included in the reference energy use is relatively low (66%). This corresponds with the 67% found by Farla and Blok for 1986 using a comparable set of products, indicating that the relative share of the products included in the reference energy use has not changed over time. Overall comparison with an LTA is not possible, because there is no single LTA for the building industry. We show the comparison of the reference energy use according to our study and the LTA for the cement and glass industry in Fig. 6. For the cement industry, the reference energy use according to our study and the LTA are consistent, showing the reliability of the clinker and cement production statistics used in our study. For glass, the overall trend is comparable with the LTA, but deviations are substantial (up to 10%). A possible explanation is the lack of detail that can be obtained with our study. Physical production figures are only available for the total glass production, whereas a further specification to various types of glass has been used in the LTA.

3.3.6. Total of sectors studied

For the sum of the sectors studied in this paper, the annual primary EEI reduction is estimated at 1.3% between 1995 and 2003 (confidence interval between 0.9% and 1.7%), corresponding to annual savings of 120 PJ in 2003 compared with 1995. Annual reductions in the EEI for electricity were 1.9% and for fuels/heat even 2.6% per year. Efficiency improvements on non-energy use have been −0.1%. If we exclude non-energy use, annual EEI reductions have on average been 2.5% per year between 1995 and 2003. The savings are dominated by the chemical industry. If we exclude the chemical industry, annual reductions are 0.9% (including non-energy use) and 1.2% (excluding non-energy use) for 1995–2003.

Unfortunately, we cannot show energy efficiency developments for the sum of all sectors studied for the total period 1980–2003, because of the lack of consistent data on energy use in the chemical industry before 1995. If we exclude the chemical industry, we obtain the results given in Fig. 7. On average, annual EEI reductions have been 1.0% per year between 1982 and 2003 excluding

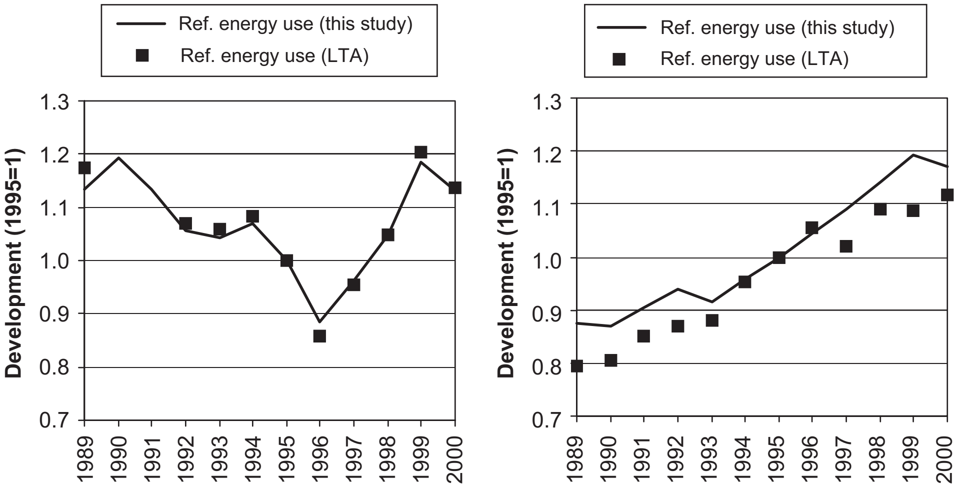

Fig. 6. Reference energy use for cement and glass according to our study and the LTA (Novem, 2001d, e).

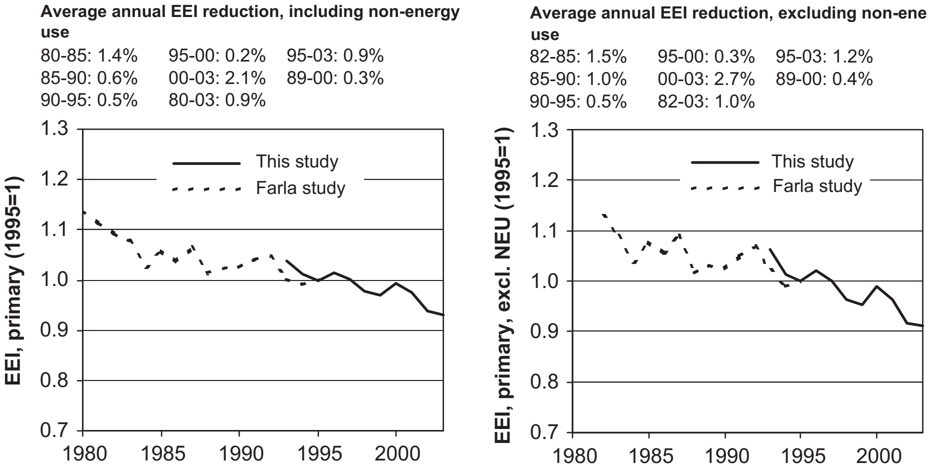

Fig. 7. EEI for sum of the sectors studied, 1980–2003, excluding the total chemical industry.

non-energy use (i.e. coal and coke use in the iron and steel industry and the use of petroleum coke for anode production in aluminium production). If we include non-energy use, annual reductions have been 0.9% per year between 1980 and 2003.

4. Overall conclusions, policy relevance and recommendations

We studied in detail energy efficiency developments in the Dutch manufacturing industry for the period 1995–2003 based on publicly available physical production and energy use data. We conclude that since the middle of the 1990s, significant energy efficiency improvements have been made in the industrial sectors studied. The efficiency improvements vary widely from sector to sector, from year to year and also between the various types of energy use distinguished (electricity, fuels/heat and non-energy use). Further bottom-up studies are required in addition to this to-down analysis to find the explanatory factors behind the observed differences. In the study by Ramirez et al. (2006) for the industry, a good match could be found between the top-down analysis and bottom-up data based on implemented energy efficiency projects. Based on the comparison of our results with those from a previous study for 1980–1995, we conclude that the rate of energy efficiency improvement is not slowing down in the last decade compared with the period before. Over the full time period 1980–2003, energy efficiency improvements are estimated at about 1% per year, excluding the chemical industry for which no reliable data are available. This is rather low compared with the goal of 2.7% efficiency improvement per year recently advocated in for the EU (European Commission, 2006b). We can conclude that additional energy efficiency policies are required to reach these more ambitious goals. For the Netherlands, additional policies required to increase the rate of energy efficiency improvements from 1% to 2% per year are explored in a recent study by Daniels et al. (2006).

For some of the LTA-1 sectors (e.g. the paper, iron/steel and chemical industry), we showed that still substantial differences exist between the development of the energy use according to the LTA-1 monitoring reports and the publicly available energy statistics, resulting in different and often higher efficiency improvements estimated in the LTA-1 compared with our study. It is not possible to further assess these differences, because underlying data used in the LTA-1 monitoring are confidential. Although no longer relevant for the LTA-1, we strongly recommend introducing yearly checks in the various data flows from the individual companies to the government (monitoring Benchmarking Covenant, energy statistics survey, environmental reports, production statistics, emission reports, etc.) to detect inconsistencies at the lowest level of aggregation and avoid similar problems in future policy evaluations. A detailed analysis on the company level comparing production and energy statistics data for the most important chemical companies in the Netherlands has proven that, with relatively little effort, major improvements can be made in improving the quality of official statistics (Neelis, 2006a).

The quantitative uncertainty analysis performed as part of this study makes clear that the uncertainty ranges of the input data result in uncertainty ranges of 3.5–8% in the resulting energy efficiency indicator (95% confidence interval). This makes it difficult to draw robust conclusions on energy efficiency developments from year to year. We also analysed the contribution of the various input parameters on the final uncertainty in the energy efficiency indicators. These analyses showed that the contribution of the production data and energy consumption data exceed by far the contribution of the specific energy consumption data. On top of the data-related uncertainty, we also assessed methodological uncertainties caused by the fact that our reference energy use does not include all products of the individual sub-sectors. We did this by comparing the development of our reference energy use with the development of the reference energy use according to the LTA-1.

In the LTA-1, all products of a sector were included in the reference energy use and the LTA-1 reference energy use is therefore in principle a very reliable indicator for the frozen efficiency energy use of the sectors. For the sectors studied, a good match was found between the LTA-1 and the reference energy use in this study based on publicly available production data. Therefore, we are confident that the reference energy use used in this study is a reliable indicator for most sectors of industry at least for the period of the LTA-1 (1989–2000). Ramirez et al. (2006) have also drawn this conclusion for the food industry, based on similar and additional evidence. We would like to stress, however, that the incomplete energy coverage of the products included in the reference energy remains a source of methodological uncertainty and might result in erroneous results, especially in analyses over long time-series or for heterogeneous sectors such as the chemical and building materials industry. We recommend further studying the effect of these methodological uncertainties, e.g. via a specific case study as outlined for the chemical industry in Section 3.2.1, also using economic and more detailed energy use data at the level of sub-sectors or individual firms.

We demonstrated in this paper that for the Netherlands, a framework for energy efficiency monitoring could be developed using physical production and energy use data that are in principle publicly available for research purposes. The framework allows a good insight into the energy efficiency trends in the manufacturing industry. The main source of physical production data used (the Prodcom statistics) is also available for the other EU countries as are national energy statistics. The methodology could therefore also be used to conduct similar analyses in other EU countries, allowing cross-country comparisons of energy efficiency levels. The method could therefore contribute to reliable and independent cross-country monitoring of energy efficiency developments and cross-country comparisons of energy efficiency levels, which is an important conclusion in view of the increasing importance of European-wide energy efficiency policies.

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Appendix A

For the detailed results, see Table A1.

Table A1
Detailed results

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Chemical industry, excl. fertilizers									
Reference final electricity use	1.00	1.02	1.10	1.12	1.13	1.21	1.12	1.25	1.33
Final electricity use, energy statistics	1.00	0.98	1.00	1.00	0.96	0.98	1.00	1.02	1.01
Energy efficiency indicator (EEI)	1.00	0.96	0.91	0.89	0.85	0.81	0.89	0.82	0.76
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference final fuels/heat use	1.00	0.97	1.04	1.05	1.12	1.13	1.21	1.25	1.37
Final fuels/heat use, energy statistics	1.00	0.98	0.95	0.92	1.01	0.98	0.99	1.08	1.09
Energy efficiency indicator (EEI)	1.00	1.01	0.92	0.88	0.91	0.87	0.82	0.86	0.80
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference non-energy use	1.00	0.96	1.00	1.00	1.06	1.02	1.10	1.16	1.34
Final non-energy use, energy statistics	1.00	0.86	0.91	0.91	1.03	1.09	1.22	1.28	1.37
Energy efficiency indicator (EEI)	1.00	0.90	0.91	0.90	0.97	1.06	1.11	1.10	1.02
95% Confidence interval EEI		7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Reference primary energy use (excl. non-energy use)	1.00	0.98	1.05	1.07	1.12	1.14	1.19	1.25	1.36
Reference primary energy use, energy statistics, excl. non-energy use	1.00	0.98	0.96	0.93	0.97	0.93	0.96	1.04	1.05
95% Confidence interval EEI		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Reference primary energy use	1.00	0.97	1.03	1.04	1.09	1.09	1.15	1.21	1.35
Primary energy use, energy statistics	1.00	0.92	0.94	0.92	1.00	1.01	1.09	1.15	1.20
Energy efficiency indicator (EEI)	1.00	0.95	0.91	0.88	0.92	0.93	0.95	0.95	0.89
95% Confidence interval EEI		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Fertilizer industry									
Reference final electricity use	1.00	0.95	1.02	1.02	0.97	1.04	0.99	0.85	0.90
Final electricity use, energy statistics	1.00	1.07	0.95	1.03	0.93	0.88	0.77	0.75	0.77
Energy efficiency indicator (EEI)	1.00	1.12	0.93	1.01	0.96	0.85	0.77	0.87	0.85
95% Confidence interval EEI		7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%

Table A1 (*continued*)

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Reference final fuels/heat use	1.00	0.95	1.01	1.03	1.02	1.06	0.93	0.88	0.82
Final fuels/heat use, energy statistics	1.00	0.94	0.93	0.97	0.92	0.86	0.69	0.72	0.71
Energy efficiency indicator (EEI)	1.00	0.99	0.91	0.94	0.90	0.82	0.74	0.82	0.86
95% Confidence interval EEI		8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
Reference non-energy use	1.00	0.99	1.04	1.04	1.03	1.06	0.94	0.89	0.84
Final non-energy use, energy statistics	1.00	0.95	1.00	1.01	1.00	1.01	0.85	0.81	0.81
Energy efficiency indicator (EEI)	1.00	0.96	0.96	0.97	0.97	0.95	0.90	0.91	0.96
95% Confidence interval EEI		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Reference primary energy use (excl. non-energy use)	1.00	0.95	1.02	1.02	1.01	1.05	0.94	0.87	0.84
Reference primary energy use, energy statistics, excl. non-energy use	1.00	0.97	0.95	0.99	0.92	0.87	0.73	0.74	0.74
Energy efficiency indicator (EEI)	1.00	1.02	0.94	0.97	0.92	0.83	0.77	0.85	0.88
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference primary energy use	1.00	0.98	1.03	1.03	1.02	1.06	0.94	0.88	0.84
Primary energy use, energy statistics	1.00	0.96	0.98	1.01	0.98	0.96	0.81	0.79	0.78
Energy efficiency indicator (EEI)	1.00	0.98	0.95	0.97	0.95	0.91	0.85	0.89	0.93
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Iron and steel basic metals industry									
Reference final electricity use	1.00	0.98	1.05	1.00	0.96	0.99	1.04	1.08	1.16
Final electricity use, energy statistics	1.00	0.96	1.00	0.98	0.97	1.13	1.13	1.10	1.14
Energy efficiency indicator (EEI)	1.00	0.98	0.95	0.98	1.01	1.14	1.08	1.02	0.99
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference final fuels/heat use	1.00	1.00	1.07	1.02	0.98	0.97	1.04	1.06	1.15
Final fuels/heat use, energy statistics	1.00	1.00	1.01	0.92	0.85	0.85	0.87	0.87	0.88
Energy efficiency indicator (EEI)	1.00	1.00	0.95	0.90	0.86	0.88	0.84	0.82	0.76
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference non-energy use	1.00	1.00	1.05	1.01	0.96	0.90	0.96	0.97	1.06
Final non-energy use, energy statistics	1.00	0.99	1.06	1.03	0.98	0.89	0.97	0.98	1.06
Energy efficiency indicator (EEI)	1.00	0.99	1.01	1.02	1.02	0.99	1.01	1.01	1.00
95% Confidence interval EEI		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Reference primary energy use (excl. non-energy use)	1.00	1.00	1.06	1.02	0.97	0.98	1.04	1.07	1.15
Reference primary energy use, energy statistics, excl. non-energy use	1.00	0.99	1.02	0.95	0.90	0.96	0.96	0.96	0.98
Energy efficiency indicator (EEI)	1.00	0.99	0.96	0.93	0.92	0.98	0.93	0.90	0.85
95% Confidence interval EEI		5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Reference primary energy use	1.00	1.00	1.06	1.01	0.97	0.94	1.00	1.02	1.10
Primary energy use, energy statistics	1.00	0.99	1.04	0.99	0.94	0.93	0.96	0.97	1.02
Energy efficiency indicator (EEI)	1.00	0.99	0.98	0.98	0.97	0.99	0.97	0.95	0.92
95% Confidence interval EEI		5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Paper industry									
Reference final electricity use	1.00	1.00	1.07	1.05	1.08	1.12	1.07	1.10	1.13
Final electricity use, energy statistics	1.00	1.01	1.10	1.11	1.13	1.20	1.11	1.19	1.19
Energy efficiency indicator (EEI)	1.00	1.00	1.03	1.06	1.05	1.07	1.04	1.08	1.05
95% Confidence interval EEI	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Reference final fuels/heat use	1.00	1.01	1.07	1.07	1.10	1.13	1.07	1.12	1.13
Final fuels/heat use, energy statistics	1.00	1.12	1.14	1.11	1.09	1.09	1.03	1.05	1.05
Energy efficiency indicator (EEI)	1.00	1.11	1.07	1.03	0.99	0.97	0.97	0.94	0.93
95% Confidence interval EEI	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Reference non-energy use									
Final non-energy use, energy statistics									
Energy efficiency indicator (EEI)									
95% Confidence interval EEI									
Reference primary energy use (excl. non-energy use)									
Reference primary energy use, energy statistics, excl. non-energy use									
Energy efficiency indicator (EEI)									
95% Confidence interval EEI									
Reference primary energy use	1.00	1.01	1.07	1.06	1.09	1.12	1.07	1.11	1.13
Primary energy use, energy statistics	1.00	1.01	1.09	1.08	1.09	1.13	1.10	1.13	1.14
Energy efficiency indicator (EEI)	1.00	1.01	1.02	1.02	1.00	1.01	1.03	1.01	1.01
95% Confidence interval EEI	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Paper industry									
Reference final electricity use	1.00	1.00	1.07	1.05	1.08	1.12	1.07	1.10	1.13
Final electricity use, energy statistics	1.00	1.01	1.10	1.11	1.13	1.20	1.11	1.19	1.19
Energy efficiency indicator (EEI)	1.00	1.00	1.03	1.06	1.05	1.07	1.04	1.08	1.05

Table A1 (*continued*)

	1995	1996	1997	1998	1999	2000	2001	2002	2003
95% Confidence interval EEI	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Reference final fuels/heat use	1.00	1.01	1.07	1.07	1.10	1.13	1.07	1.12	1.13
Final fuels/heat use, energy statistics	1.00	1.12	1.14	1.11	1.09	1.09	1.03	1.05	1.05
Energy efficiency indicator (EEI)	1.00	1.11	1.07	1.03	0.99	0.97	0.97	0.94	0.93
95% Confidence interval EEI	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
Reference non-energy use									
Final non-energy use, energy statistics									
Energy efficiency indicator (EEI)									
95% Confidence interval EEI									
Reference primary energy use (excl. non-energy use)									
Reference primary energy use, energy statistics, excl. non-energy use									
Energy efficiency indicator (EEI)									
95% Confidence interval EEI									
Reference primary energy use	1.00	1.01	1.07	1.06	1.09	1.12	1.07	1.11	1.13
Primary energy use, energy statistics	1.00	1.01	1.09	1.08	1.09	1.13	1.10	1.13	1.14
Energy efficiency indicator (EEI)	1.00	1.01	1.02	1.02	1.00	1.01	1.03	1.01	1.01
95% Confidence interval EEI	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Building materials industry									
Reference final electricity use	1.00	1.00	1.05	1.10	1.16	1.14	1.11	1.07	1.05
Final electricity use, energy statistics	1.00	1.07	1.14	1.10	1.13	1.23	1.18	1.13	1.07
Energy efficiency indicator (EEI)	1.00	1.07	1.09	1.00	0.98	1.08	1.06	1.05	1.02
95% Confidence interval EEI	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference final fuels/heat use	1.00	0.96	1.01	1.06	1.09	1.08	1.07	1.02	0.99
Final fuels/heat use, energy statistics	1.00	1.05	1.04	0.99	1.00	1.01	0.99	0.86	0.87
Energy efficiency indicator (EEI)	1.00	1.09	1.03	0.93	0.91	0.94	0.93	0.85	0.87
95% Confidence interval EEI	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference non-energy use									
Final non-energy use, energy statistics									
Energy efficiency indicator (EEI) 95% Confidence interval EEI									
Reference primary energy use (excl. non-energy use)									
Reference primary energy use, energy statistics, excl. non-energy use									
Energy efficiency indicator (EEI)									
95% Confidence interval EEI									
Reference primary energy use	1.00	0.97	1.02	1.07	1.11	1.10	1.08	1.04	1.01
Primary energy use, energy statistics	1.00	1.05	1.07	1.02	1.04	1.07	1.05	0.94	0.93
Energy efficiency indicator (EEI)	1.00	1.08	1.05	0.95	0.93	0.98	0.96	0.91	0.92
95% Confidence interval EEI		5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Non-ferro basic metals industry									
Reference final electricity use	1.00	1.04	1.07	1.23	1.28	1.30	1.30	1.41	1.39
Final electricity use, energy statistics	1.00	1.04	1.07	1.19	1.24	1.29	1.26	1.25	1.27
Energy efficiency indicator (EEI)	1.00	1.00	1.00	0.96	0.97	1.00	0.97	0.88	0.91
95% Confidence interval EEI		7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%
Reference final fuels/heat use	1.00	0.93	0.98	1.09	1.14	1.19	1.17	1.18	1.20
Final fuels/heat use, energy statistics	1.00	0.93	1.00	0.99	0.91	1.00	0.86	0.87	0.88
Energy efficiency indicator (EEI)	1.00	1.00	1.02	0.90	0.80	0.84	0.73	0.74	0.73
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference non-energy use	1.00	0.84	0.86	0.99	1.08	1.09	1.09	1.12	1.04
Final non-energy use, energy statistics	1.00	0.85	0.78	0.88	1.16	1.18	1.20	1.34	1.01
Energy efficiency indicator (EEI)	1.00	1.01	0.91	0.88	1.08	1.08	1.11	1.19	0.97
95% Confidence interval EEI		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Reference primary energy use (excl. non-energy use)	1.00	1.03	1.06	1.22	1.26	1.29	1.29	1.38	1.37
Reference primary energy use, energy statistics, excl. non-energy use	1.00	1.03	1.06	1.16	1.20	1.26	1.21	1.20	1.22
Energy efficiency indicator (EEI)	1.00	1.00	1.01	0.96	0.95	0.98	0.94	0.87	0.89
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Reference primary energy use	1.00	1.02	1.04	1.20	1.25	1.27	1.28	1.37	1.35
Primary energy use, energy statistics	1.00	1.02	1.04	1.15	1.19	1.25	1.21	1.21	1.21
95% Confidence interval EEI		6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%
Total industry									
Reference final electricity use	1.00	1.01	1.08	1.12	1.13	1.18	1.14	1.22	1.27
Final electricity use, energy statistics	1.00	1.00	1.03	1.06	1.05	1.09	1.08	1.09	1.09
Energy efficiency indicator (EEI)	1.00	0.99	0.96	0.94	0.92	0.92	0.95	0.89	0.86
95% Confidence interval EEI		3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%

Table A1 (*continued*)

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Reference final fuels/heat use	1.00	0.97	1.04	1.05	1.09	1.10	1.15	1.17	1.26
Final fuels/heat use, energy statistics	1.00	0.99	0.97	0.94	0.99	0.97	0.95	1.00	1.02
Energy efficiency indicator (EEI)	1.00	1.02	0.94	0.90	0.91	0.88	0.83	0.86	0.81
95% Confidence interval EEI		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Reference non-energy use	1.00	0.97	1.01	1.01	1.04	1.02	1.05	1.09	1.22
Final non-energy use, energy statistics	1.00	0.89	0.95	0.94	1.02	1.05	1.13	1.16	1.23
Energy efficiency indicator (EEI)	1.00	0.92	0.93	0.93	0.98	1.03	1.07	1.06	1.01
95% Confidence interval EEI		5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Reference primary energy use (excl. non-energy use)	1.00	0.99	1.05	1.07	1.10	1.13	1.15	1.20	1.28
Reference primary energy use, energy statistics, excl. non-energy use	1.00	0.99	0.99	0.97	0.99	0.98	0.98	1.02	1.03
Energy efficiency indicator (EEI)	1.00	1.01	0.95	0.91	0.90	0.87	0.85	0.86	0.82
95% Confidence interval EEI		3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Reference primary energy use	1.00	0.98	1.03	1.04	1.08	1.08	1.11	1.15	1.24
Primary energy use, energy statistics	1.00	0.95	0.97	0.96	1.00	1.01	1.04	1.08	1.12
Energy efficiency indicator (EEI)	1.00	0.97	0.94	0.92	0.93	0.94	0.94	0.94	0.90
95% Confidence interval EEI		3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%

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