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Energy consumption, pollutant emissions and growth in the long run: Sweden through 200 years

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This article examines the evolution of energy use and pollution emissions in Sweden over the past two centuries – a much longer period than has been investigated in the large literature on the environmental Kuznets curve. In this article we show that both energy consumption and pollution emissions in Sweden declined relative to GDP over the last two hundred years. In absolute terms both energy use and pollution increased up until 1970, after which date energy consumption stabilised and pollutant emissions declined, leading to less environmental stress. The energy intensity results are decomposed to determine the relative impact of structural changes in the output structure *versus* within-sector changes. For the period after 1970 another decomposition for pollution emissions is performed to separate out changes in preferences from energy-related changes. The analyses show that technical change in a broad sense has been crucial for explaining the long-term decline in both energy intensity and pollutant intensity, while the transition to the service economy had negligible effects. Changed preferences affected the decline in emissions after 1970.

1. Introduction

The relationship between economic growth and the environment has been hypothesised to resemble an inverted U-curve. In the early stages of economic growth pollution increases, but beyond a certain level of income the trend reverses and pollution declines. This idea reached a broad audience through the 1992 World Development Report and was later named the Environmental Kuznets Curve (EKC) after Simon Kuznets, who proposed a similar hypothesis between economic growth and the environment (Panayotou 1993). This hypothesis spurred a multitude of EKC studies, too numerous to discuss here. An assessment of these studies shows that they are often of poor econometric quality and that in fact the EKC does not exist in the sense that income *per capita per se* determines the level of pollution (Perman and Stern 2003). Instead, it seems that most environmental indicators are monotonically increasing in income though the income elasticity is less than 1. Time-related effects, for instance the level of technology, reduce environmental impacts in all countries at all levels of income, though the rate of change may differ across countries and income might be one factor generating differences in the adoption of technology across countries (Stern and Common 2001, Stern 2004a). In rapidly growing middle income countries, the scale effect outbalances the time effect and pollution increases. In richer countries growth is slower, and the time effect may be strong enough to result in reduced emissions. This is the reason for the apparent EKC pattern (Brock and Taylor 2004, Stern 2004b). These conclusions are based on the analysis of panel datasets for periods since 1960.

However, these conclusions seem tentative and are still controversial. If, as Brock and Taylor (2004) claim, the patterns of change are fundamentally related to the long-term growth process, much longer term studies of the interrelationship between growth and the environment are called for. This article discusses the relationships between growth, energy and pollutants in Sweden during the last 200 years. The principle direct reasons for changes in pollution or energy consumption over time are:

(1) Scale of production;
(2) Changes in the output mix (structural change);
(3) Changes in the input mix (movements along the isoquants of a neoclassical production function);
(4) Technological change, which involves changes in both:
    (a) overall productivity (TFP) which may have unintended effects on pollution or energy;
    (b) emissions due to specific changes in process (such as innovations directly intended to reduce pollution emissions, for instance by improving the thermal efficiency of machinery).

The changes in energy consumption and pollution emissions over time can be decomposed into these effects (see for instance Stern 2004b), but of course there are underlying causes that drive these factors, such as environmental regulations, changing preferences, growing environmental awareness, better knowledge, changed foreign trade patterns, and so on.

Our article examines the development of energy use and pollutant emissions over time in Sweden both in absolute levels and in terms of intensities (energy/GDP and pollutants/GDP). We investigate whether there are any EKC-type relationships in the long run in Sweden, either in terms of total emissions, which we call the strong EKC hypothesis, or in terms of emissions per unit income or income intensities, which we call the weak EKC hypothesis. In addition, we decompose energy intensity according to the principal factors presented above. When it comes to energy intensity the scale effect is naturally irrelevant and the analyses focus on factors 2, 3 and 4 above.

The article is organised in the following way. Section 2 presents the long-term time series for energy and pollutants in Sweden both in absolute terms and relative to GDP. Section 3 summarises the empirical results in relation to the weak and strong EKC hypotheses. Section 4 analyses the results. Section 4.1 starts by decomposing the changes in energy intensity into the effects of changes in output mix versus the combined effects of changes in input mix and the state of technology. Section 4.2 follows with an exploration of the changes in input mix and the state of technology in their historic contexts. Section 4.3 discusses the principal reasons for different energy and pollutant emissions patterns, and Section 4.4 decomposes the substantial declines of pollutant emissions after 1970 into effects related to energy use and other effects. Section 5 provides the main conclusions of the article.

2. The Swedish historical case studies

The empirical basis of this article is derived from the doctoral theses of the two authors. Both those studies rely on a common pool of historical national accounts series, but differ when it comes to the environmental indicators investigated. Kander (2002) studied the interrelationships between growth, energy consumption and CO_2 emissions in Sweden for the period 1800–2000, while Lindmark (1998) studied growth in relation to several environmental indicators, pollutant emissions as well as natural resource depletion, weighted together into one meta-indicator, based on monetary evaluations of the environmental costs. The method in both studies involves the construction of time series for some variables, for which published statistics are lacking. These constructions are naturally subject to some uncertainty, which generally declines over time as data availability increases.

Kander's (2002) long-term study on energy and growth in Sweden is unique in several respects, especially in its richness of data and the decomposition analyses, which separate out the effects of structural and technical change, energy quality and the impact of foreign trade. Drawing on Martin's (1988) analysis of several countries, Reddy and Goldemberg (1990) suggested that energy intensity (energy/GDP) for most countries followed an inverted U-shaped curve over time. Really long-term country studies in the energy field that have been published until now are few in number. Examples include Schurr and Netschert (1978), Humphrey and Stanislaw (1979), Fouquet and Pearson (1998), and Schandl and Schulz (2002), but more such studies are underway for Germany, the Netherlands, Spain, Italy and the UK.[1]

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[1] See <http:/www.jiscmail.ac.uk/EGP-network>.

For environmental pollution in the long run there are some international datasets that have been created primarily for natural science purposes. Worthy of notice is the carbon dioxide emissions dataset developed by Marland *et al.* (2000) and the sulphur dioxide emissions dataset produced by Lefohn *et al.* (1999). Lindmark's study is the first quantitative study of growth and pollution spanning more than one hundred years, which attempts to assign monetary values to pollution costs. In the medium to long term (post-1950) there have been some attempts to assess the changing costs of pollution over time, for instance Daly and Cobb's (1989) calculation of the Index of Sustainable Economic Welfare (ISEW) for the USA from 1950 to 1986, followed up by other country studies (Cobb and Cobb 1994, Jackson and Stymne 1996, Castaneda 1999, Hoffrén 2001).

2.1. Energy use and growth

The study of Swedish historical energy use incorporated both modern energy 'carriers', such as coal, oil and electricity, and traditional energy carriers like muscle-energy, firewood and direct-working water and wind (see Appendices A and D, and definition or p. 320).

Figure 1 shows the development of energy use over time, estimated according to Swedish official standards, Energy (S), and European standards, Energy (E). The differences concern whether electricity is accounted for in terms of its direct heat content (Swedish standard) or the heat content of the fuels that would be needed to produce the electricity (European standard). The graphs clearly show that there is no support for a *strong* EKC relationship for energy use in Sweden. Instead, there is a steady increase of energy use until the 1970s, when energy demand flattens out.

It is also evident from Figure 1 that GDP experienced faster growth rates than energy consumption during the nineteenth century and the post-1970 period. The relative developments, which are needed to test for a *weak* EKC relationship, are seen in Figure 2, which depicts the development of energy intensity, including and excluding household energy consumption. The long-term development of energy intensity including household energy consumption shows an approximately linear decline with a total reduction of 85 per cent between 1800 and 2000. Around this declining trend there are two or three long-term fluctuations with substantial permanent declines in energy intensity taking place during both World Wars.

If household energy consumption is excluded, which is relevant if the energy requirements for production are focused on, the decline is less pronounced, but still substantial. This means there is no evidence of a weak EKC for Swedish energy as proposed by Reddy and Goldemberg (1990). Instead, a long-term decline is the pertinent feature, discernible from 1800

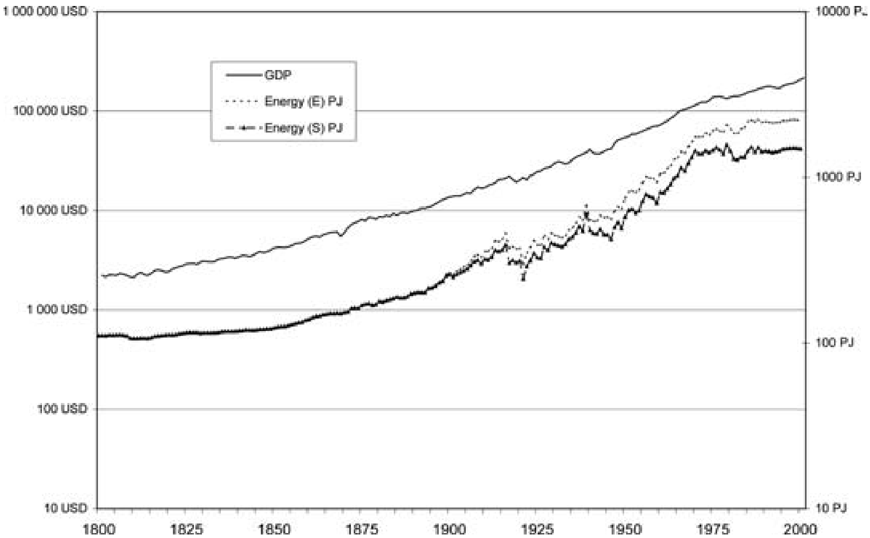

Figure 1. *Aggregate energy consumption in Peta Joule, Swedish (S) and European (E) estimation standards and GDP 1800–2000 in millions of 1999 Geary-Khamis international dollars. Log scale on left and right axes.*

Source: Kander (2002). GDP-series from Swedish Historical National Accounts, Krantz (1986, 1987a, 1987b, 1991), Ljungberg (1988), Pettersson (1987) and Schön (1988, 1995) were provided by Lennart Schön. Virtually identical GDP series are found in Krantz (2001). Conversion to 1999 Geary-Khamis international dollars is based on Maddison (2001).

in the case of energy use, including household energy consumption, and more clearly from the First World War, when household energy is excluded. The finding of such a long-term decline is not totally unexpected in the case of Sweden, since a similar pattern was found by Martin (1988) for the USA when firewood was included. This suggests that declining energy intensity is a pervasive feature that continues throughout modern economic growth and is not peculiar to high-income countries.

2.2. Carbon dioxide and growth

Energy use in itself is not an unambiguous environmental indicator. Simply put, fossil fuels tend to create numerous pollutant substances, while renewable energy is often less polluting. Considering renewable energy as completely unproblematic with respect to pollution is nevertheless erroneous. Extraction of renewable energy requires the building of hydroelectric dams, harvesting of firewood, the combustion of biomass and many other impacts. Pollution emissions caused by combustion of firewood are, therefore, considered in Section 2.3 that deals with the overall pattern

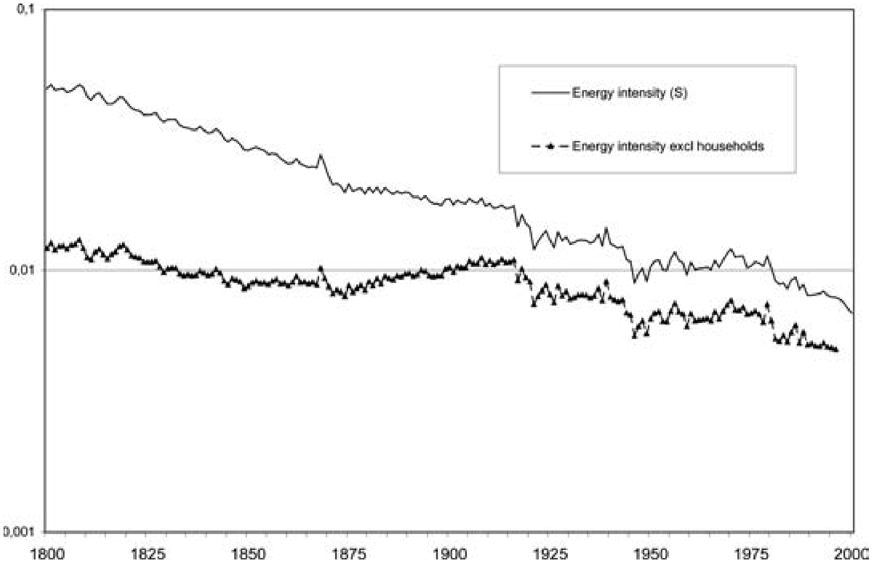

Figure 2. *Energy intensity in Sweden, including and excluding household energy, 1800–2000. Peta Joule per million 1999 Geary-Khamis international dollars.*

Source: Kander (2002).

of emissions. When we investigate the role of changing energy demand for pollution-related environmental problems, it is therefore relevant to examine the role of fossil fuels in total energy use. One of the most important and widely discussed pollutants is carbon dioxide, which in practice is more or less linearly dependant on fossil fuel energy inputs. The most severe impact of CO_2 is on the global climate. Although the theoretical reasons for a greenhouse effect, due to combustion of fossil fuels, were proposed in the 1890s (Arrhenius 1896), CO_2 was not established as an environmental problem until the 1980s. This makes it unlikely that environmental preferences have played a crucial role in explaining the reductions of CO_2 emissions in the long run. The first indication of evolving environmental preferences concerning CO_2 in Sweden did not appear until 1991 with the introduction of the CO_2 tax. Nevertheless, CO_2 may reveal an EKC pattern, but it is worth noticing that such a pattern should not be interpreted as a direct indicator of changes in environmental demand, but rather as an effect of technical change, changing relative prices of energy carriers, and other structural economic factors.

Figure 3 (upper panel) shows the historical development of fossil fuel-related CO_2 emissions in Sweden. As seen from the graph, a strong inverted U shape curve is clearly distinguishable, with a late turn in the 1980s. Even

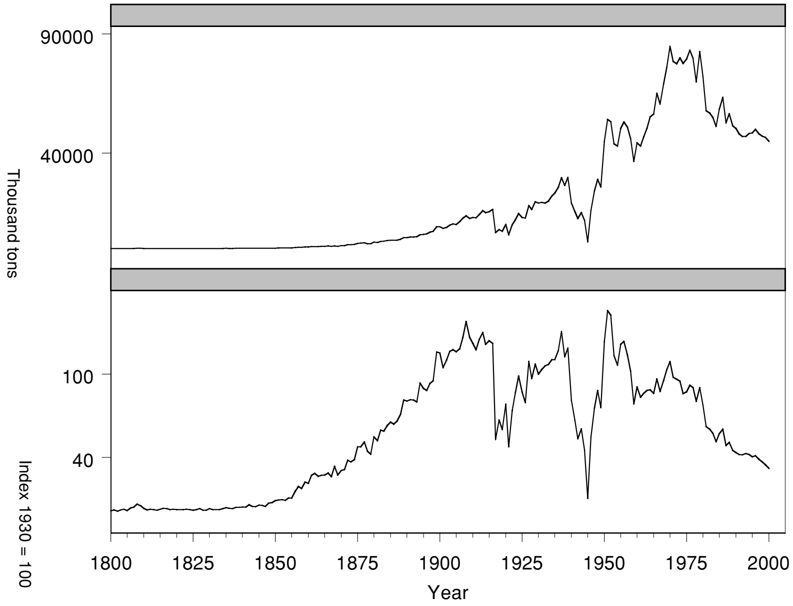

Figure 3. *Fossil CO_2 emissions in Sweden 1800–2000, 1000 tons (upper panel) and fossil CO_2 emission intensity (lower panel). Index 1930 = 100.*

Source: Kander (2002).

more pronounced is the pattern for the ratio of CO_2 to GDP in the bottom panel (see Appendices A and D).

One main source of anthropogenic CO_2 emissions, besides fossil fuel combustion, is changes in land use. Land is covered by biomass and when the amount of biomass increases or decreases carbon dioxide is added to or removed from the atmosphere. Because of their large biomass to land ratio, forests have an especially high potential either to emit CO_2, that is to work as a source for atmospheric CO_2, or to sequester CO_2, that is to work as a sink for it. Forest management thus constitutes one important way in which people have historically influenced atmospheric CO_2 concentration. When forestland is converted to other usage, such as agricultural fields or urban areas, some of its carbon is released into the atmosphere. In addition, tree density, or timber concentration of the forests, has changed substantially due to variations in forest management. The tree volumes of Swedish forests declined during the nineteenth century but increased again during the twentieth century. If the effects of this are included, the CO_2 intensity is profoundly different from when only emissions from fossil fuels are included (see Appendices A and D). This is shown in Figure 4, where the upper panel depicts absolute net emissions and the lower panel shows the long-term decline in intensities.

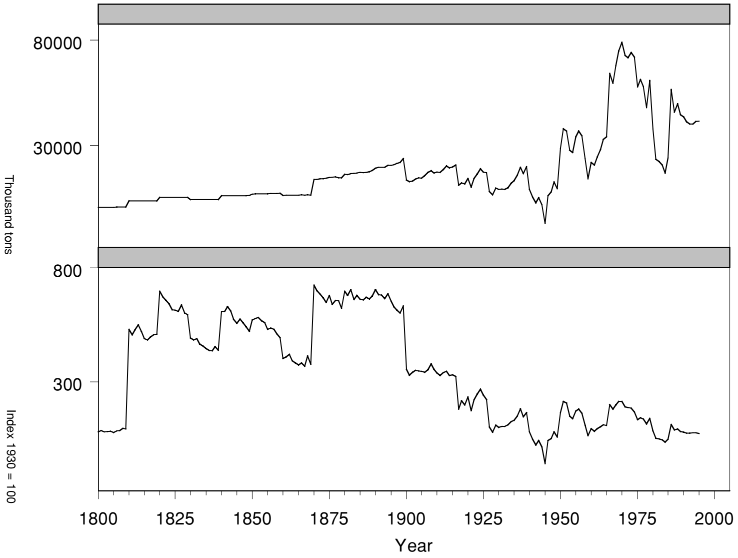

Figure 4. *Total fossil CO_2 emissions from fossil fuels and emissions related to forestry. Sweden 1800–2000, thousand tons (upper panel) and Swedish total CO_2 intensity, including the net impact from forests 1800–1995 (Index 1930 = 100).*

Note: Fossil fuel emissions and historical national accounts are provided as annual figures, while forest emissions are average values for the periods in between points of measurement/estimate. Therefore the graphs, where forest emissions are included, exhibit stable properties.
Source: Kander (2002).

2.3. Emissions of other pollutants and the eco-margin

In his investigation, Lindmark's point of departure is the concept of economic environmental historical accounting based on the System of Integrated Environmental and Economic Accounting (SEEA 1993), proposed by the UN, World Bank and others. The general assumption governing economic environmental accounting is that environmental problems are welfare issues. The environment is, therefore, treated in a similar way to other goods and services in the economy. Empirically, the investigation focuses on the long-term relationship between emissions of several pollutants and income, as well as on the monetary environmental accounting aggregate known as the 'eco-margin' and income. The eco-margin corresponds to the aggregated monetary value of degradation of the environment and depletion of natural resources. In this article, the eco-margin is limited to the effects of environmental degradation and does not take account of depletion of natural resources. Another aspect to bear in mind is that it accounts for pollutant emissions from production within the borders of Sweden, and some pollutants, like sulphur, are transboundary, which means that even if reductions in emissions take place in Sweden the level of pollution may not decline to the same degree, since for instance she receives SO_2 from Britain.

Basically, the SEEA shows how different sectors interact with the environment by using environmental goods and emitting residual waste. The main accounting idea is that the environment is treated as capital, in SEEA parlance non-produced natural assets. Environmental damage is thus analogous to the System of National Accounts' (SNA 93) concept 'use of capital', or depreciation. In short the SEEA is a combination of input-output tables, and accounts of non-financial assets. This makes it basically an extension of the asset boundaries used in the SNA accounts for stocks of fixed assets. The input-output tables show flows of environmental goods to the economy and flows of residuals (pollutants and waste) to the environment.

The question of how to estimate the environmental damage in monetary units is one of the most difficult and controversial issues in environmental accounting. Market prices are certainly the valuation approach that is preferred in the system of national accounts. Due to missing data, and even due to non-existing markets, environmental impacts do, however, require the use of imputed shadow prices. The main valuation principles that are recommended in the literature are avoidance costs (the cost of reducing environmental impact to acceptable levels) and damage costs (the reduction of the value of the environmental assets, in fact the assets' depreciation). Contingent valuation, based on willingness-to-pay is deemed unsuitable for national environmental accounting (SEEA 1999).

Proper data for either damage or avoidance costs are unlikely to be found for historical environmental accounting. Instead, Lindmark used environmental indicators linked to contemporary damage or avoidance costs. Since the mid-1980s various investigations have made elaborate assessments of avoidance cost in terms of either actual or imputed market prices. These costs have, thus, served as benchmark estimates that are used for weighting the historical emissions. The resulting series are, therefore, historical proxies for environmental damage, expressed as hypothetical contemporary avoidance costs. The pollutants included in the Swedish eco-margin are sulphur dioxide (SO_2), carbon monoxide (CO), nitrous oxides (NOx), lead (Pb), heavy metals (HM), biological oxygen-demanding emissions (BOD7), nitrogen leakage from artificial fertilisers, volatile organic compounds (VOC) and particulate matter (PM) (see Appendices C and D).

The historical development of the eco-margin is shown in Figure 5 (upper panel). The main features of the eco-margin are increasing emissions until 1914, pronounced fluctuations during the period 1914–1947, and decreasing emissions from the late 1960s/early 1970s. The trend of the Eco-margin series therefore reveals the typical *strong* EKC-pattern over time. This shape is also reproduced if the Eco-margin is plotted as a function of income (Lindmark 2001a).

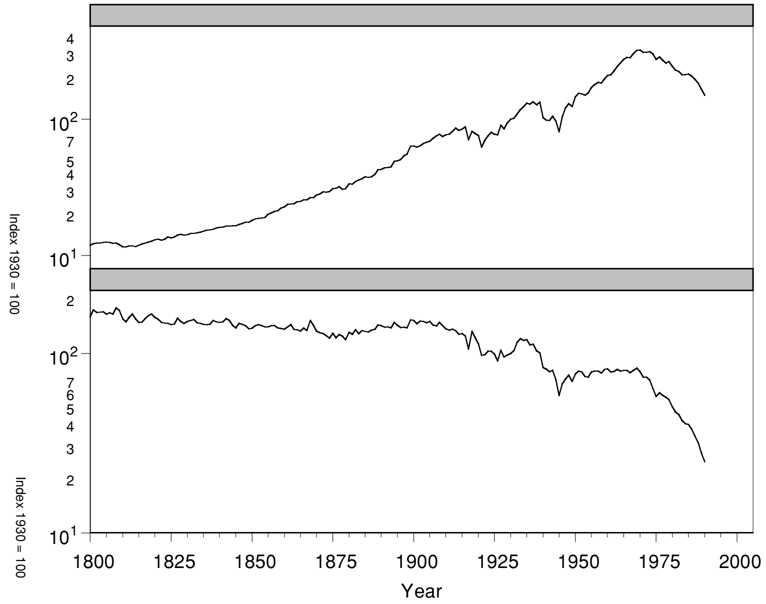

Figure 5. *The eco-margin in Sweden 1800–1990 (upper panel) and the eco-margin-to-GDP ratio 1800–1990 (lower panel). Index 1930 = 100.*

Source: Lindmark (1998).

The lower panel of Figure 5 shows the development of the eco-margin-to-GDP ratio, which offers the following tentative interpretation. First of all there is a long-term decline of the eco-margin relative to GDP, similar to that reported for energy relative to GDP. In addition there are possibly three long-term fluctuations, from the second half of the nineteenth century and onwards. The first starts in 1870 and peaks around 1898, reaching its lowest point in approximately 1920. It should also be noted that there is, tentatively, an even earlier phase that begins in approximately 1820, peaks during the early 1840s and ends around 1870. The second long-term fluctuation occurs between approximately 1920 and 1947, with a peak around 1937, while the third fluctuation occurs between 1947 and the present, with a peak around 1972.

3. Empirical summary

In conclusion, strong EKC relationships were found for fossil fuel CO_2 and the eco-margin, while a strong EKC pattern could not be distinguished for energy use. In essence, energy consumption kept increasing in absolute terms, while the pollutant emissions reached a peak after which there was a decline.

Turning to the weak EKC-hypothesis, there was no such obvious pattern except for fossil CO_2. Both for energy use relative to GDP and the eco-margin relative to GDP there was instead a trend of continuous delinking, around which there were secular waves. In addition a relative delinking for CO_2, including forestry, was detected.

Besides this general pattern of relative decline of energy intensity and the eco-margin, the results coincide in other respects. For instance, the long waves around the declining trend, found in the eco-margin-to-GDP ratio, can also be discerned for energy intensity, when household energy consumption is excluded. In addition the periods almost completely correspond. For both energy use and pollutant emissions the period after 1970 is especially remarkable in that it is marked by a steady decline of absolute environmental emissions and by a rapid decline of the energy-to-GDP ratio. This makes the period unique in comparison to all other phases.

4. Analyses

First we analyse the factors behind the falling energy intensity, by decomposing the results into the effects of structural *versus* technical change in a broad sense, in Section 4.1. Using the terminology presented in the Introduction this can be perceived as effects of changes in output mix *versus* the combined effects of changes in input mix and state of technology. Section 4.2 discusses the reasons why technical change results in a net decline in energy intensities in our historical case study.

In Section 4.3, attention is directed to the different development of energy and pollutant emissions. In particular, we investigate why there has been a much more substantial relative decline of pollutant emissions than of energy use in relation to GDP, especially since the early 1970s. Section 4.4 attempts to decompose the decline in pollutant emissions into effects directly related to energy *versus* other effects.

4.1. Decomposing energy intensity changes

It is possible to decompose the changes in energy intensity (excluding households) into technical and structural change. Both technical and structural changes occur simultaneously in economies over time, which means that in reality these changes are interrelated and difficult to separate. Technical changes often give rise to unbalanced productivity changes, which may change relative production costs and in interaction with the various price elasticities for different goods, lead to changes in relative prices and structural changes in final demand. Furthermore, technical change usually results in income increases, which through differences in income elasticities for

Table 1. *Impacts of structural shifts and changes within sectors on the annual percentage change in energy intensity.*

	1800–1870	1870–1913	1913–1970	1970–1998
Annual change in energy intensity	−0.61	0.48	−0.74	−1.6
Of which changes within sectors:				
Agriculture	−0.28	−0.16	<0.01	−0.02
Industry	−0.32	−0.41	−0.42	−1.1
Services	−0.02	−0.07	<0.01	−0.4
Transport	0.01	0.67	−0.86	−0.07
Structural shifts	<0.01	0.45	0.54	−0.02

Source: Kander (2002).

various goods additionally affect the structure of final demand and thus the output structure. Finally, technical change may influence the demand for intermediate goods throughout the entire production chain. Taken together all these factors may lead to changes in the output structure.

Given the fact that there are as yet no input-output tables for the Swedish Historical National Accounts, a decomposition bringing together changes in final demand (including foreign trade) and changes in intermediate consumption with changes in the output structure was not attempted. For the purpose of analysis it is, however, possible to undertake a static decomposition of changes in energy intensity due to changes in output structure and technical change at the sectoral level, similar to the analysis in Selden *et al.* (1999).

In a simplification, changes in energy intensity on the national level may partly be ascribed to variations in the sectoral shares, that is, structural changes, and partly to changes within the sectors, here labelled technical change. The high level of aggregation does certainly affect the possibility of distinguishing between structural changes and technical change, since the latter may include structural changes that would be revealed at a lower level of aggregation. Table 1 presents the results of the decomposition regarding the impact of structural changes and 'within sector changes' in the four sectors agriculture, industry, services, and transportation and communication (for calculations see Appendix B).

The results, which are presented in Table 1, demonstrate that structural changes at the sector level were of little importance for the long-term decline in energy intensity. At the sector level they either counteracted the decrease in energy intensity or had no impact. Within the industrial sector, structural changes did contribute to the decline, but they were of minor importance compared to the changes within the branches (Schön 1990).

Prior to the industrialisation of the Swedish economy, the impact of structural change was virtually non-existent. It was only during the period of rapid industrialisation (1870–1913) that structural changes played a decisive role in the increase in energy intensity. The impact of the relative growth of the industrial sector and of the transportation and communication sector was of the same magnitude as the total increase in energy intensity during this period.

The industrialised period from 1913 to 1970 saw declining energy intensity, due to changes within the sectors, despite structural shifts working in the opposite direction. The last period, 1970–1998, the period of the proposed third industrial revolution, saw the largest reduction in energy intensity. Also worth noticing is that this reduction was entirely accomplished by changes within the sectors.

4.2. Technical change and energy intensity

The strong influence of technical change, or within sector changes, leads us to consider the factors driving such technological change. We find that the reason for the decline in national energy intensity in the long run in Sweden is that energy intensity declines within the principal sectors. It is not due to shifts in sector shares, which work in the opposite direction, increasing national energy intensity, but due to what takes place within those sectors.

The reason for a decline in energy intensity within the sectors may of course be structural changes within those sectors. This is the case in the industrial sector after 1970 (Schön 1990), but for the other sectors this does not seem to be the case (Kander 2002); however, the lack of historical energy data at the sub-sector level hinders firm conclusions.

Why would then energy intensity decline within a homogenous sector in the long run? As stated in the introduction there are two main possibilities: (1) improvements in the state of technology, which in turn may be divided into (a) emissions-specific changes and (b) general productivity improvements, and (2) changes in input mix (movements along the isoquant of the production function). We will briefly discuss these aspects in their historical context.

(1a) When it comes to historical energy intensity within sectors one obvious reason for decline is that the thermal efficiency (or the ratio of useful energy output to energy input) of the machines used within sectors has improved, as a direct result of energy-saving innovations. When such innovations were intended to reduce emissions, improved thermal efficiency is an example of emission-specific change.[2] This means that less energy is needed for a specific work task. All human energy use entails a less than 100 per cent conversion efficiency due to the second law of thermodynamics. An improvement in thermal efficiency, therefore, means that less energy is wasted. There are economic incentives to reduce such energy losses, and

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[2] Thermal efficiency can also improve due to changes in the use of inputs within an existing technology, for example by adding insulation to a boiler.

an abundance of improvements in specific techniques has increased thermal efficiency over time (Smil 1994).

At first it may seem obvious that improvements in thermal efficiency will lead to decreases in energy intensity. A complicating factor is, however, that some of the savings will be eaten up by more consumption of energy services. Ever since Jevons (1886) it has been well known that thermal efficiency gains do not necessarily reduce energy consumption, since energy services will become cheaper and hence be used more (Howarth 1997, Herring 1998); at the least the reduction in consumption is less than the initial energy saved by the innovation. This rebound or take-back effect will manifest itself as structural change and growth of the economy. It may also to some extent hamper the decline of energy intensity, or the relative energy use, within individual economic sectors. The take-back effect is, however, not likely to be strong enough to outweigh all the effects on energy intensity of thermal efficiency improvements. This is, for one thing, because energy services are not only provided by energy, but also by capital (Neij 1999), which means that energy services do not get proportionally cheaper to the same extent as energy costs *per se*, because the necessary capital investments cost money. In addition, the money saved on energy bills is not likely to be used completely by consuming more energy services, since people have other wants and relative price changes take place across the economy.

(1b) Another, neglected (but see Stern 2002) reason for declines in sectoral energy intensity in the long run is general productivity improvements (TFP increases). Ever since the development of the first TFP measures (Abramowitz 1956, Solow 1956) we know that economic growth has occurred largely as a consequence of an increase in the quality of production factors both individually and combined (Denison 1962, Crafts and O'Mahoney 2001, Crafts 2002). This means that $(L+K)/Y$ declines.[3] This may lead to an expectation of at least some decline in E/Y (energy intensity), because energy is used by machines and labour.

If energy was used in exact proportion to the production factors labour and capital, the consequences of TFP improvements on energy intensity would be very simple. In reality this is not the case. In order to figure out in more detail how TFP increases affect energy intensity it is therefore necessary to know how energy interacts with capital and labour.

We can hypothesise that the E/K ratio will decline, because increasing thermal efficiency will tend to increase the value of capital employed at the same time as the energy demands of the machines are reduced, so both the numerator and denominator work to lower the E/K ratio. Another aspect that affects the E/K ratio is changes in the composition of the capital stock, which may work either to increase or reduce the E/K ratio. Numerous studies have been performed that try to sort out the exact relationship

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[3] Where (L+K) is a weighted index of the inputs.

between capital and energy, with varying results (Jorgenson 1978, Berndt and Wood 1979, Siddayo 1986). The debate has so far been hampered by a confusion regarding definitions of the elasticity of substitution (there are several different definitions) and consequently methods (Stern 2004c). What we discuss here is not the tricky issue of whether energy and capital are substitutes or complements, but only the long-run changes of aggregate ratios such as E/K. This ratio has in fact declined in Sweden in the long run (Kander and Schön 2003). Given this long-term relationship between energy and capital, it is quite likely that TFP increases lead also to a decline in energy intensity.

(2) Apart from technical change in the sense of production function shifts we have cases of factor substitution that may be perceived as movements along the isoquant of the production function. One relevant example of factor substitution, or perhaps a combination of factor substitution and technical change with biased shifts of production functions, with which economic historians are very familiar, is the development of the K/L ratio, which has increased substantially over time. This would lead to expectations of an increase in the E/L ratio as well. The increase in K/L may at first be assumed to increase energy intensity, rather than decrease it. It is true that replacing labour with machines, which require inanimate energy, leads to an increase in energy use unless human muscle energy is included. This study does, however, include human food consumption and then the answer to the question of the effects on energy intensity from such a substitution is not clear-cut. It depends for one thing on the actual effects on energy use, but it also depends on whether the value of production is affected by this substitution *per se* (rather than by the increased use of production factors in total) or not, which is a tricky issue. The effect on energy *per se* depends on the efficiency of 'biological machines', such as humans and animals, in transforming energy to work, compared with that of the inanimate machines that replace them. This has changed over the time encompassed by this study. When machines still had low thermal efficiency, and thus a large energy input was needed to operate one unit of capital, replacing workers with machines may have caused an increase in energy intensity. The effect should, however, have been reversed as machines reached higher average efficiency. It is difficult to determine when the increasing K/L ratio in general could reduce energy intensity, but it is clear that it occurred under our period of investigation, at the time when the average thermal efficiency became higher for inanimate machines than for animate machines, but before it counteracted the fall in energy intensity.[4]

In conclusion, the most important reasons for the energy intensity decline within the sectors would be improvements in the state of technology, here

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[4] We know that thermal efficiency of modern machines is in the range of 25–40 per cent, while humans still only have thermal efficiencies of 10–15 per cent.

exemplified by energy-related innovations that result in thermal efficiency gains together with general TFP improvements, while changing input mix, here the increasing K/L ratio, played a more ambiguous role over time.

These long-run relationships between the factors of production and energy, together with relative price information and cost shares, are crucial for modelling growth in a correct manner. The integration of energy in production functions has been an issue since the 1970s and the literature provides examples of various classes of production functions, perhaps most notably the KLEM production functions, which include energy as an input (Conrad and Unger 1986). Economic history can provide important lessons for such modelling by empirically showing what are the real trends of important factors in such models. Modelling can also provide answers to questions in economic history if applied to high quality datasets.

4.3. Energy and pollutants – why does their evolution differ?

The reason for the more substantial delinking of pollutants and GDP than of energy and GDP depends on a fundamental difference between the two kinds of indicators. While energy services are perceived as ‘goods’ (utility is derived from them), pollutants are either neglected or considered as ‘bads’. The terminology has been used for explaining the EKC in economic theoretical terms (Kriström 2000). This means that preferences are likely to work differently in relation to energy and to pollution. While people at higher income levels will prioritise pollution abatement, they may very well at the same time choose to increase their consumption of energy services, for instance by travelling more, having larger dwellings and using air conditioning.

It makes sense that people at higher incomes will care more about reducing pollution emissions than people at low-income levels, where survival is at stake or the prospects for higher material consumption are very tempting. With income increases, the marginal utility of increased consumption declines. It may also be that the disutility of pollution increases. That will depend on how bad or serious pollution is perceived to be in each case. This in turn can depend either on the actual state of the environment and/or the interpretation of these conditions. Historically people have sometimes put up with very bad environmental conditions, rationalising and defending them (Mosley 2003). Hence environmental history informs us that it has generally taken quite some time for an environmental problem to be established as a problem on the political agenda, sometimes 50–70 years after its discovery (Bolin *et al.* 1995).

Another important aspect of environmental preferences is that technical development enables the adoption of more clean production methods at a relatively lower cost over time. Technologies diffuse internationally, which means that later industrialisers do not necessarily need to follow the path of previous countries. This means that we should expect some time-dependent effect on pollutant emissions that is separate from the income-level effect.

Energy services and pollution emissions show differing behaviour for reasons other than those relating to income and the state of technology across countries over time. A recent household investigation in Sweden has shown that energy-saving behaviour has to do with lifestyle (busy people taking a shower instead of a bath) or upbringing (fathers being very angry if electric lights were not turned off): see Carlsson-Kanayama *et al.* 2004. There is certainly need and scope for more empirical studies combining environmental behaviour with economics. Various kinds of path dependence, like upbringing or government actions, that shape and underlie the individual country performances, are likely to play an important role.

4.4. Energy versus pollutants after 1960

The period from the 1960s onward is extraordinary when it comes to energy use and pollutant emissions. Energy intensity declined more rapidly in this period than in any period before and pollutant emissions declined even more. Especially for energy, and to some extent also for the emissions, it is likely that some explanatory power may be attributed to the microelectronic revolution. Its impact should have been threefold. First, microelectronics may enhance the fine-tuning of production, thereby reducing waste. Second, the new growth engines of the third industrial revolution, information technology and bio-technology, are knowledge intensive rather than material and energy intensive, which means that the industrial structure imposes less stress on the environment. Third, products of the new growth structure do not bring about as much energy consumption in final use, as did the typical products of the second industrial revolution such as refrigerators, washing machines and cars. The third industrial revolution is still only in its beginning, so it is difficult to quantify its historical impact on energy intensity and energy consumption. Still, it may have contributed to a fall of the energy to GDP ratio. The first two impacts also tend to reduce pollutants.

The more substantial decline of the eco-margin/GDP ratio than of energy/GDP after 1970 may be related to the introduction of modern environmental legislation. Sweden introduced its first comprehensive environmental protection law in 1969, which included air pollution, after more than sixty years of dispute in the Swedish Parliament. This increasing environmental awareness could in turn be the result of a high income-elasticity of environmental demand paired with the high rates of economic growth during the 1950s and 1960s. Since economic development by the late 1960s had caused a convergence of GDP *per capita* levels, the close timing of the launching of environmental legislation in many countries could be interpreted as a function of income levels. But the income effect may also have been reinforced in Sweden by changing environmental preferences in countries such as the USA and Britain, exemplified by the British 1956 Clean Air Act. In turn, these developments may have affected preferences in countries like Sweden, despite the fact that the environmental problems were not as grave as in for instance London, and incomes not as high as in the USA.

Changes in the patterns of international trade have been suggested as an explanation of falling emissions in high-income countries. The role of foreign trade for the Swedish development of energy use and CO_2 emissions after 1970 has been explored in two independent studies by the authors (Kander 2002, Lindmark 2001b), and in neither was any substantial impact of foreign trade found. Furthermore, Statistics Sweden (SCB 2000) has shown that exports contributed more to higher CO_2 emissions than imports did during the 1990s.

To at least roughly examine some of the structural factors that affected the development of pollution between 1965 and 1990, the following exercise has been performed. First, we normalised the series for GDP, energy use, carbon dioxide, the eco-margin, and those pollutants that are clearly related to fossil fuels (index 1970 = 100). Then the increase between 1965 and 1990 in percentage terms was calculated. Finally, the change in pollutants was decomposed into the effects of (a) economic growth, (b) energy intensity and (c) fossil fuels' share of energy. The resulting residual, or what cannot be explained by these three factors, is interpreted as an indicator of changed environmental demand.

The increase in GDP during the period was nearly 48 per cent. In the counterfactual case of no other changes, the pollutant emissions would have increased as much. However, since energy intensity fell by 22.6 per cent and the share of fossil fuels in total energy consumption fell by 65 per cent, this would have resulted in a 40 per cent decline in the eco-margin. Since our estimates indicate that the eco-margin declined by almost 53 per cent, nearly 13 per cent of the reduction of pollutants cannot be explained by changes in the three factors above, which may not seem much. On the other hand this residual should definitely be interpreted as a minimum indicator of environmental preferences, since such preferences have also affected energy intensity and fossil fuels' share of energy use. Substantial governmental support was given to save energy from the 1970s and energy taxes became environmentally differentiated during the 1980s. Thus, energy taxes do not only have the purpose of raising state revenues and reducing the foreign trade deficit by making imports more expensive, but are also designed with environmental targets in mind. Environmental concerns also played a role with regard to both hydro-electricity and nuclear power. Additionally, the eco-margin utilises avoidance costs for the weighting, rather than prices that reflect the negative welfare contributions of the bad outputs. It is, therefore, relevant to look at the unexplained residual for some of the individual pollutant emissions that constitute the eco-margin. Here we find that environmental demand contributed to nearly 50 per cent of the reductions in SO_2, PM and heavy metal emissions. On the other hand, NOx and VOC changed less than the effect of the structural factors. These emissions are both related to road traffic. Thus, the disutility of the pollutants must have been low compared to the utility of road traffic. Additionally, it is likely that the avoidance costs were high prior to the introduction of catalytic converters, which became common only in the late 1980s.

In conclusion, this decomposition exercise has provided at least circumstantial evidence of growing environmental preferences after 1965, apart from those directly related to energy use.

4.5. Future research possibilities

This study shows long-term interrelated declines in energy use and pollutant emissions relative to economic output and presents an explanation for this phenomenon, and might, therefore, be seen as delivering a very optimistic message. However, we emphasise that the speed of this relative decline may not be fast enough to actually reduce pollution emissions. And our results show that total energy use has increased though in recent decades emissions of pollutants have declined. From an environmental perspective it is relevant to study periods with especially rapid declines in emissions to see what can be learnt from them. It would, for instance, be of interest to explore the permanent effects of crises, such as World Wars and oil crises, and determine what relative roles policy and market forces played in these periods.

It would also be of value to extend the research to comparative country studies, to investigate similarities and differences across nations, something that would also provide an insight into the relative impact of different policies.

5. Conclusions

This article has shown that both energy intensity and pollution intensity have declined over the last two hundred years in Sweden. In absolute terms both energy use and pollutant emissions increased up until 1970 after which energy consumption flattened out, while pollutant emissions declined.

The combined results, therefore, suggest that the development of pollutants was to a large extent determined by energy use and the composition of energy ‘carriers’ (see Appendix A) up until 1970. It is, therefore, likely that the environment was attributed a low value in Sweden until the 1970s. The observation that pollutants started to decrease thereafter, while energy consumption stabilised, suggests an increasing value attributed to the environment and that deliberate action involving monetary costs were taken in order to prevent further pollution. The difference between the development of energy use and pollutant emissions since the 1970s also suggests that neither a transition to a service economy nor changes in foreign trade can be the main explanation for the apparent EKC relation found for pollutant emissions. This is further illuminated by the decomposition of the changes in energy intensity for the period 1800–2000, in which the relative effects of changes in output structure *versus* changes within the main economic sectors (agriculture, industry, services and transport and communication) were determined. During the period 1800–1870 both agriculture and manufacturing industries contributed to decreasing energy intensity, while effects from structural changes on the sectoral level were negligible. During the industrialisation period 1870–1913 there was an increase of energy intensity since the transport and communication sector experienced the highest increases of energy intensity at the same time as overall structural change also accentuated energy intensity. The industrialised period from 1913 to 1970 revealed small changes in all sectors, apart from transport and communications where energy intensity at this time decreased. Structural changes did, however, contribute to an increase in energy intensity. The last period, which is presumably the post-industrial phase, showed a considerable decrease of energy intensity foremost in manufacturing industry, while the impact from structural change was negligible. The service sector in this period did not increase its share in constant prices, which also shows that the decline of pollutant emissions in this period could not have been caused by a general move towards a service economy. The overall finding in our study is thus that structural changes at the sectoral level have either counteracted or had a negligible effect on negative trends in energy intensity during the last two hundred years. The long-term decline was caused by technical change in a wide sense, consisting both of improvements in TFP and thermal efficiency.

The decline in pollutants after 1965 was decomposed into the effects of growth, energy intensity, the fossil fuels-to-energy ratio, and a residual interpreted as non-energy-related environmental preferences. This decomposition showed that expressed preferences for environmental quality changed during this time. Welfare accounts by definition take preferences into account, so this suggests that welfare is incorrectly measured if the negative value of 'bad' output is not included. If productivity were measured on the basis of both bad and good outputs this could show that productivity performance during the dismal 1970s and troublesome 1980s was not as poor as previously believed.

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Appendix A: Energy carriers and CO_2 emissions

The 'carrier' is the physical medium conveying the energy, as listed below. The term 'carrier' is preferred to 'source' because it gives less annotation of original source; for instance, electricity is a secondary energy carrier.

Firewood

Household firewood consumption: the series is modelled for the period 1800–1920 and after that based on real investigations. The model departs from an investigation in 1920 and uses four relevant factors to extrapolate the values backwards: (1) heating work, which increased as more rooms were heated; (2) efficiency of stoves (large effect from the diffusion of more efficient stoves); (3) coal for firewood substitution; (4) population distribution (numbers increased relatively more in the cold north).

Service sector firewood consumption is modelled as a function of household firewood consumption, which takes into account that larger residences are a more likely outcome of increased income/*per capita* in the long run than a larger heated area per employee in the service sector. An assumption is made of even heating standard development in services and households until the turn of the century, after which heating standards in households developed more quickly. One rationale for this assumption is that many service premises were initially not heated at all, but became increasingly so.

Industrial firewood consumption is well documented in statistics from the 1910s. For dates before that Schön (1990, 1992) has modelled industrial firewood consumption based on relative energy savings in the metal industry, which is the largest firewood consuming branch, and constant energy intensities in the other branches.

The energy content of firewood varies due to kind of wood and humidity. Here we use the figure 6.9 GJ/m3 (solid wood).

Muscle energy

Draught animals, such as horses and oxen, are regarded as animate machines, combusting fodder. The muscle energy for animals is calculated as the energy content of their fodder. Their subsistence energy should also be regarded as necessary energy input for their work. The changing size of animals and changing intensity of work are included in the model.

Fodder demands for animals are often presented in fodder units (fu). One fu equals the digestible content of 1 kg barley, which is 3,000 kcal. A 500 kg ox with a medium working load needs 7 fu per day and a horse of the same size and work intensity requires 8 fu per day. In the early nineteenth century animals weighed only around 300–350 kg and consequently they consumed less energy, which is included in the modelling.

For humans, on the other hand, only that share of food which is consumed during work is calculated as energy consumption in the formal economy, and the rest is attributed to final energy consumption (household consumption). Changes in work hours are included in the modelling. Humans' average food consumption is calculated at 2,600 kcal/day. Work intensity is assumed to have increased linearly until 1890 so that average food intake then was 1.05 × 2,600 kcal and then declined back to 2,600 kcal in 1990. Investigations show that 15 per cent of all human time in Sweden was devoted to work between 1890 and 1930. In 1980 it was 9 per cent and in 1990 it was 10 per cent. For the period 1800–1890 we have assumed a linear increase from 12 per cent to 15 per cent, due to the industrial revolution.

Direct working water and wind

From statistical figures of direct working water in industry around 1890 it is evident that this energy consumption only amounted to around 1.5 per cent of total energy at the time. This is within the error margin of firewood consumption, so this energy is not modelled here. Direct wind for sails may be substantial, but has so far been omitted for theoretical and practical reasons.

Peat

Peat consumption was never very large in Sweden, despite large areas of peat land. The energy content of peat was very low compared to firewood, which was available in large amounts. Statistics are available from the 1890s and then the amount is less than 1 per cent of total energy consumption. It is still included from then onwards.

Coal

Imported coal is well documented in the statistics. The energy content of imported black coal was 29 GJ/ton and the energy of coke and anthracite was 32 GJ/ton. Domestic coal was produced in small quantities in Scania, and its energy content was 22 GJ/ton.

Oil

Practically all oil was imported, and this is well documented in the statistics. Sweden only had marginal assets of shale oil, with an oil content of 5 per cent, and this was never of any importance. The energy content of raw oil is 42 GJ/ton.

Not all oil is used for energy purposes; some is used as raw material and this share has been subtracted from the imports or the refining statistics of Sweden.

Electricity

Electricity production is well documented in the statistics. Electricity is a secondary energy carrier, produced from primary energy sources like fuel, hydropower and nuclear power. There are thus two principal ways of accounting for its energy content: either you calculate the heat content of the electricity *per se* or the energy content of the primary energy carriers used for its production. In either case it is important to know and subtract the share of electricity produced by fuels, when calculating aggregate energy consumption, in order to avoid double calculations. Here the method of just calculating the heat content of electricity, el (h), is used, but the other method is also explored in Kander (2002).

Spent pulping liquor

Large amounts of energy-rich waste is produced in the paper and pulp industry, called spent pulping liquor. This energy has increasingly been employed in this industry and the amount is substantial in relation to total energy consumption. For instance, in 2000 it made up 10 per cent of total Swedish energy consumption.

Natural gas

Like many other countries, Sweden used to produce gas from fossil fuels, which need not be taken into account here, since this is only a refinement of primary energy sources already accounted for. From 1985 she has imported natural gas, but only in small amounts. In 2000 natural gas made up 2 per cent of total energy consumption.

CO_2 emissions from energy

CO_2 emissions can easily be calculated if the amounts of various energy sources are known, because all carbon eventually becomes CO_2. The emission factors used for the various fuels are the following (g CO_2/MJ): coal 92, coke 103, raw oil 74 and natural gas 56. Firewood does not produce any net CO_2 if the trees are replaced with new ones.

CO_2 emissions from forests

A forest with a constant amount of trees does not produce any net CO2 emissions. When the timber volume increases the forest acts as a sink for CO_2 and when it decreases it works as a source. Standing timber volumes declined in Sweden during the period 1800–1920 and then increased again, almost reaching the same level in 1995 as in 1800. The emissions (positive or negative) can be calculated on the basis of 1 m^3 (solid) wood = 1.036 tons CO_2. Since forest investigations (1920 and onwards) as well as the estimates for the nineteenth century are only available for some benchmarks, the changes in tree volumes between those years are divided by the number of years. This gives the graphs of forest-related CO_2 emissions stable properties.

Appendix B: Decomposition analyses

The relative effects of between-sector changes and within-sector changes for changes in energy intensity are calculated in three steps. The first step is to calculate the relative effects of changes in the sector structure with respect to changes within all sectors together. The second step is to calculate the relative importance of changes within each sector. The third step is to combine the results of the first two calculations.

The information needed for the first step is energy consumption at the sector level, which is presented in Table B1, and energy intensities in constant prices, which are provided in Table B2.

Table B1. *Energy consumption by sector in 1800, 1870, 1913, 1970 and 1998, in PJ.*

	1800	1870	1913	1970	1998
Agriculture	12	20	27	29.9	28.9
Industry	7.9	16	100	582	557
Services	5.2	11	27	169	169
Transports	1.2	7.2	62	92.4	155
Sum	27	54	220	873	910

Table B2. *Sector energy intensity in certain benchmark years expressed in different price levels, MJ/SEK.*

Energy intensity	1800	1870	1913	1970	1998
Price level 1800					
Agriculture	260	160	130	130	110
Industry	400	210	190	130	76
Services	160	120	110	110	62
Transports	100	140	210	31	26
Total	230	150	180	120	76
Price level 1870					
Agriculture	89	54	46	44	38
Industry	170	90	80	55	33
Services	68	51	47	46	26
Transports	97	140	200	30	25
Total	100	65	80	53	33
Price level 1910–12					
Agriculture	64	38	33	31	27
Industry	160	83	74	50	30
Services	46	34	31	31	18
Transports	100	140	210	30	25
Total	82	52	64	42	27
Price level 1970					
Agriculture	9.2	5.5	4.7	4.5	3.9
Industry	29	15	14	9.4	5.6
Services	4.5	3.4	3.1	3.1	1.7
Transports	27	39	55	8.2	6.8
Total	13	7.9	9.7	6.5	4.0

Sources: SHNA, no. 1. Kander (2002). Comment: Dwelling usage is excluded from the service sector, since the energy connected to that service is accounted for as final energy consumption by households. The power industry is excluded from the industrial sector, since energy is the outcome of that branch and is studied in relation to the sectors. The building and construction sector is included in the industry sector. Each sector has been deflated separately and its production in constant prices has been proportionally adjusted so the sums equal GDP, minus dwelling usage and the power industry.

Table B3. *Relative impacts of technical change and structural changes, according to counterfactual calculations with constant sector energy intensities.*

Line	Formula		1800–1870		1870–1913		1913–1970		1970–1998	
			x 1800, price level 1800	y 1870, price level 1800	x 1870, price level 1870	y 1913, price level 1870	x 1913, price level 1913	y 1970, price level 1913	x 1970, price level 1970	y 1998, price level 1970
a		Energy intensity, MJ/SEK	230	150	65	80	64	42	6.4	4.1
b		Counterfactual energy intensity, MJ/SEK		230		79		80		6.4
c	ay − ax	Absolute actual change		−80		15		−22		−2.3
d		Counterfactual change		0		14		+16		0
e	(c−d)/c	Within sector changes explain		100%		7%		173%		100%
f	d/c	Structural changes explain		0%		93%		−73%		0%

Table B4. *The sectors' relative contributions to the aggregate impact of 'within-sector changes'.*

Line	Formula		1870	1913	1970	1998
A		Agriculture, actual energy consumption, PJ	20	27	30	29
B		Agriculture, counterfactual energy, PJ	36	32	30	34
C	A − B	Absolute deviation in agriculture, PJ	−16	−4.6	0	−4.7
D	C/S	Agriculture's contribution to within-sector changes	52%	510%	0%	1%
E		Industry, actual energy consumption, PJ	16	100	580	560
F		Industry, counterfactual energy, PJ	31	111	840	920
G	E − F	Absolute deviation in industry, PJ	−16	−11	−260	−360
H	G/S	Industry's contribution to within-sector changes	52%	1,300%	33%	70%
I		Services, actual energy consumption, PJ	11	27	170	170
J		Services, counterfactual energy, PJ	11	29	170	300
K	I − J	Absolute deviation in services; PJ	−0.69	−2.2	0	−130
L	K/S	Service's contribution to within-sector changes	2.3%	240%	0%	25%
M		Transports, actual energy consumption, PJ	7.2	62	92	160
N		Transports, counterfactual energy, PJ	5.3	43	610	180
O	M − N	Absolute deviation in transports, PJ	+1.9	+19	−520	−20
P	O/S	Transports' contribution to within-sector changes	−6.2%	2,100%	67%	5%
Q	A + E + I + M	Sum of actual energy consumption, PJ	54	216	870	920
R	B + F + J + N	Sum of counterfactual energy, PJ	84	215	1,650	1,440
S	C + G + K + O	Aggregate impact of within-sector change, PJ	−30	+0.90	−780	−520

Table B5. *Relative importance of structural shifts and changes within each sector for the total change in energy intensity, percentages.*

	Formula referring to lines in Tables B3 and B4	1800–1870:	1870–1913:	1913–1970:	1970
Structural shifts explain	f	0	93	−73	0
Agriculture explains	D*e	46	−34	0	
Industry explains	H*e	52	−85	57	
Services explains	L*e	3.4	−16		
Transportation explains	P*e	−1.4	140	116	
Total explanation		100	100	100	

The choice of price level year will provide different energy intensity results, which are shown in Table B2. While relative changes within the sectors are not affected by the choice of price level years, the relative sizes of the sectors are. Choosing different price level years will yield different responses to the question of the relative impact of changes within and between sectors on total changes in energy intensity. The most appropriate method is to choose a price level year within the period under scrutiny, for example at the beginning or the end. Therefore, early base years were chosen.

The first step can be calculated in two different ways:

(1) One possibility is to hold sector shares constant according to the initial year of the period. The overall energy intensity that would be the outcome at the end of the period is calculated and compared to the actual energy intensity. The relative importance of structural changes at the sector level of the economy may be calculated directly this way, while the relative importance of changes within sectors, or technical change, is a residual, that is, what is not explained by structural changes.

(2) Another possible calculation is to hold sector energy intensities constant according to the initial year of the examined period. The results in the final year are compared to the sectors' actual energy intensities and their relative deviations are calculated. This allows the relative effects of changes within the sectors, that is, technical change, to be calculated directly. In this calculation, the relative importance of structural changes at the sector level is a residual, that is, what is not explained by technical change.

Unfortunately these two calculations do not produce quite the same result when it comes to the overall question of the relative effects of changes within and between sectors. This may be perceived as a kind of index problem. Table B3 presents the results of the second method, which is used here.

The second step, aimed at determining the relative importance of each sector for the 'within sector' variable above, is presented in Table B4. The counterfactual energy consumption calculations here are based on hypothetical assumptions of constant energy intensities within the sectors in each of the periods 1800–1870, 1870–1913, 1913–1970, 1970–1998.

The results of the third step, combining the results of table B3 and B4, are presented in Table B5.

Recalculating table B5 leads to the results in Table 1 in the main text.

Appendix C: Environmental accounting

The basic approach followed is the SEEA version based on avoidance cost accounting. The main accounting aggregate is the Environmentally Adjusted Net Product (EDP), which is the Net National Product (NNP) less consumption of natural capital, that is, environmental costs or the eco-margin, valued at contemporary avoidance costs. Ideally, damage costs should have been used. These were at the time of the investigation fewer in number than the avoidance cost investigations, which is why the latter were chosen.

Conceptually, the environmental costs are reflecting mid-1990s preferences and technology. In the original work an attempt to estimate natural resource rents for iron ore and virgin forests were also made. This approach is not compatible with the avoidance cost concept, which is why costs for natural resource depletion are not included in this article.

The procedure followed was to estimate indices for various pollutant emissions, linking these to emission level benchmarks. Finally the emissions were weighted by avoidance costs. The preferred cost data are those reflecting the estimated costs for reaching the goals set by the Environmental Protection Agency in Sweden. Appropriate data for these indices have been elaborated separately for each pollutant. The most common procedure, however, has been to perform a back-cast based on benchmark observation of emission levels, often distributed over various forms of emission sources. In many cases the costs were, however, estimated on basis of mainly American investigations, due to lack of Swedish investigations at the time.

It is worth noting that avoidance cost investigation draws on different assumptions and can be expected to vary over time. International comparisons therefore require a common set of cost weights. The approach in which contemporary avoidance costs are used should be seen as preliminary. One goal in a co-operative project (called The Dynamics of the Environmental Kuznets Curve in Sweden) between Umeå University and the Swedish University of Agricultural Sciences is therefore to use econometric methods for estimating historical environmental shadow prices (Balk *et al.* (2004). *Environmental Performance in Swedish Manufacturing 1913–1990.* Arbetsrapport 346, Department of Forest Economics, Swedish University of Agricultural Sciences, Umeå).

The environmental costs for the nineteenth century are composed of (1) a coal consumption index linked in 1900 to the combined costs of fossil fuel related emissions (SO_2, NOx, Fine Particulate, CO and CO_2) (2) an index of urban population linked to BOD7, and (3) a firewood consumption index linked to VOC emissions.

Table C1 summarises the main approaches and sources used for emission estimates and avoidance cost. Table C2 summarises the main sources and approaches for estimations of lead avoidance costs. For exact references, please consult the reference list.

Table C1. *Summary of the environmental accounting investigation.*

Emission	Cost (1994 SEK per ton)	Source for cost estimate	Source (s) for emission series	Method for historical back cast if not directly adopted from source
SO2	20,404	CR	Kindbom *et al.* (1993)	
NOx	15,143	SNV	Kindbom *et al.* (1993)	
CO	5,052	CR	SOU 1975:98 SNV PM 1078 SCB 1993	Indices for car traffic, coal consumption and Stone and Quarrying industries linked to mentioned investigations for historical back-cast
Fine Particulate	3,830	CR	SOU 1975:98 SNV PM 1078 SCB 1993 Na 24 SM 9501	Emission factor 25 mg/MJ for coal for back-casting
VOC	4,667	CR	SNV 4532 SNV 3379	Indices for transports, various industrial activities and household firewood consumption
Lead	See table C:2		Anderberg *et al.* 1990	
CO2	95	SNV 4632	Emission factors from SCB 1996	Fossil fuel consumption with emission factors
Toxic air (heavy metals)	18,974	Wheeler *et al.* 1994	Mercury: Levander 1989 Benchmark SCB 1993	Indices for metal inputs in relevant manufacturing industries. Output indices prior to 1930
Toxic water (heavy metals)	3,369	Wheeler *et al.* 1994	SCB 1993	Indices for metal inputs in relevant manufacturing industries. Output indices prior to 1930

Table C1. *Continued.*

Conventional Water (BOD7)				
ISIC 32	552	Wheeler *et al.* 1994	SOU 1975:98	Output indices for branch
ISIC 34	1,802	Wheeler *et al.* 1994	SCB Na 17 SM 8501, 8601, 8701, 8801 Na 29 SM 8901, *Water in Sweden*, Rydberg (1990)	Indices based on paper and pulp production prior to 1955
ISIC 35	653	Wheeler *et al.* 1994	SOU 1975:98	Output indices for branch
Municipal	81	Own		Total cost for Swedish municipal sewage treatment per unit of estimated abated BOD7
Fertilizers	1,850	SNV 4735	NA15 9001	
Pesticide	30,000	Contemporary tax rate		Official statistics: pesticide sales 'active substance' from 1960. Prior to 1960 production data.

Sources: Kindbom, K., Sjöberg, K. and Lövblad, G. (1993). *Beräkning av ackumulerad syrabelastning.* Göteborg: Delrapport 1. IVL. SOU 1975:98 Långtidsutredningen (1975). Bil. 6: *Miljövård i Sverige 1975–1980*: rapport av Utredningen om kostnader för miljövården. Anderberg, S., Bergbäck, B., Lohm, U. (1990). Pattern of lead emissions in Sweden 1880–1980. Department of water and environmental studies, Linköping University. Levander, T. (1989). Utsläpp av kvicksilver till luft i Sverige 1860–1987. SNV rapport 1989-04-14. Wheeler, D., Hartman, R. S. and Singh, M. (1994). *The Cost of Air Pollution Abatement.* The World Bank: PREDI (The Industrial Pollution Projections Project).

Table C2. *Avoidance costs for various sources lead emissions.*

Emission source	Cost per ton (current)	Cost in SEK 1994	Source
Leaded petrol	200 (NOK 1997)	202	Statoil, additional cost for unleaded petrol
Patrages	2,500 (SEK 1996)	2,366	SNV 6462
Lead shot	67,000 (SEK 1997)	63,000	Additional cost for non-lead shots according to pricelists 1997.
Mining waste	80 (SEK 1992)	84	Jernelöv 1992
Metal non-ferrous industries	1,284 (USD 1993)	10,290	Wheeler *et al.* 1994
Iron and steel industries	779 (USD 1993)	6,170	Wheeler *et al.* 1994
Accumulator (production)	26 (USD 1993)	210	Wheeler *et al.* 1994
Rubber production	132 (USD 1993)	666	Wheeler *et al.* 1994
Glass production	186 (USD 1993)	1,490	Wheeler *et al.* 1994
Coal/oil combustion	Same as leaded petrol		Informed guess
Miscellaneous	Mean of other sources	2,100	Informed guess
Accumulators	40 per battery (SEK 1996)	38	Current Swedish tax

Sources: PREDI The Industrial Pollution Projections Project, The World Bank. CR Convergence Research: Electric generating resource emissions cost database, Feb 1994, <http://www.converger.com/index.htm> (1997-12-02). NA Statistiska meddelanden. Serie NA, SCB. SNV Statens naturvårdsverk (EPA Sweden) report. SCB Statistics Sweden. SOU Statens offentliga utredningar (Official investigations). JERNELÖV, A. *Miljöskulden* (SOU 1992: 58).

Appendix D: Data

Year	Energy (S)	Energy (S,-h)	Energy (E)	Energy (E, -h)	CO_2 emissions from fossil fuel	CO_2 emissions from forests	Eco-Margin
	Peta Joule	Peta Joule	Peta Joule	Peta Joule	Mega ton	Mega ton	Mill. 1994 SEK
	Swedish standard	Swedish standard excl. households	European Standard	European Standard, excl. households		Minimum estimate	1994 Avoidance costs
1800	110.5	26.9	110.5	26.9	0.022	0.516	1,056
1801	110.8	27.4	110.8	27.4	0.032	0.516	1,087
1802	110.4	27.0	110.4	27.0	0.020	0.516	1,100
1803	111.3	27.8	111.3	27.8	0.032	0.516	1,102
1804	111.2	27.7	111.2	27.7	0.039	0.516	1,107
1805	111.7	28.1	111.7	28.1	0.027	0.516	1,119
1806	112.0	28.7	112.0	28.7	0.052	0.516	1,109
1807	111.2	28.0	111.2	28.0	0.063	0.516	1,090
1808	110.4	28.1	110.4	28.1	0.085	0.516	1,099
1809	106.7	25.8	106.7	25.8	0.073	0.516	1,067
1810	106.2	25.7	106.2	25.7	0.051	3.511	1,028
1811	106.5	26.1	106.5	26.1	0.034	3.511	1,027
1812	106.8	26.7	106.8	26.7	0.041	3.511	1,046
1813	106.6	26.8	106.6	26.8	0.034	3.511	1,046
1814	106.5	26.8	106.5	26.8	0.031	3.511	1,038
1815	107.5	27.4	107.5	27.4	0.045	3.511	1,059
1816	109.7	29.1	109.7	29.1	0.053	3.511	1,080
1817	110.1	29.4	110.1	29.4	0.051	3.511	1,100
1818	110.7	29.7	110.7	29.7	0.036	3.511	1,114
1819	111.3	30.4	111.3	30.4	0.043	3.511	1,134
1820	111.9	30.8	111.9	30.8	0.042	5.153	1,157
1821	111.7	30.4	111.7	30.4	0.042	5.153	1,171
1822	112.1	30.6	112.1	30.6	0.043	5.153	1,151
1823	113.6	31.0	113.6	31.0	0.046	5.153	1,170
1824	114.4	31.3	114.4	31.3	0.047	5.153	1,215
1825	115.2	31.4	115.2	31.4	0.038	5.153	1,198
1826	115.8	31.5	115.8	31.5	0.047	5.153	1,220
1827	115.5	31.2	115.5	31.2	0.056	5.153	1,256
1828	115.7	31.4	115.7	31.4	0.041	5.153	1,272
1829	114.5	30.4	114.5	30.4	0.041	5.153	1,257
1830	115.1	30.9	115.1	30.9	0.060	4.137	1,261
1831	114.9	31.0	114.9	31.0	0.044	4.137	1,288
1832	115.0	31.0	115.0	31.0	0.045	4.137	1,293
1833	115.4	31.0	115.4	31.0	0.046	4.137	1,303
1834	115.5	31.2	115.5	31.2	0.063	4.137	1,320
1835	117.0	32.1	117.0	32.1	0.079	4.137	1,341
1836	117.5	32.4	117.5	32.4	0.071	4.137	1,366
1837	117.4	32.5	117.4	32.5	0.064	4.137	1,372
1838	117.4	32.8	117.4	32.8	0.079	4.137	1,385
1839	117.8	33.4	117.8	33.4	0.087	4.137	1,416
1840	118.4	33.8	118.4	33.8	0.089	5.886	1,432
1841	118.8	34.0	118.8	34.0	0.091	5.886	1,443
1842	119.6	34.7	119.6	34.7	0.123	5.886	1,462
1843	119.5	34.4	119.5	34.4	0.103	5.886	1,462

Appendix D. *Continued.*

Year	Energy (S)	Energy (S,-h)	Energy (E)	Energy (E, -h)	CO_2 emissions from fossil fuel	CO_2 emissions from forests	Eco-Margin
	Peta Joule	Peta Joule	Peta Joule	Peta Joule	Mega ton	Mega ton	Mill. 1994 SEK
	Swedish standard	Swedish standard excl. households	European Standard	European Standard, excl. households		Minimum estimate	1994 Avoidance costs
1844	119.2	33.9	119.2	33.9	0.102	5.886	1,467
1845	119.6	33.9	119.6	33.9	0.131	5.886	1,468
1846	120.6	35.0	120.6	35.0	0.124	5.886	1,506
1847	120.7	35.3	120.7	35.3	0.113	5.886	1,528
1848	121.8	36.2	121.8	36.2	0.167	5.886	1,565
1849	121.8	35.9	121.8	35.9	0.186	5.886	1,559
1850	123.4	37.3	123.4	37.3	0.225	6.576	1,607
1851	124.8	38.2	124.8	38.2	0.238	6.576	1,647
1852	125.4	38.5	125.4	38.5	0.238	6.576	1,661
1853	125.5	38.4	125.5	38.4	0.233	6.576	1,678
1854	127.5	39.7	127.5	39.7	0.284	6.576	1,691
1855	129.5	41.2	129.5	41.2	0.300	6.576	1,789
1856	131.0	42.4	131.0	42.4	0.432	6.576	1,827
1857	132.6	43.9	132.6	43.9	0.545	6.576	1,882
1858	133.7	44.3	133.7	44.3	0.524	6.576	1,894
1859	137.3	46.9	137.3	46.9	0.692	6.576	1,986
1860	139.0	47.4	139.0	47.4	0.688	5.407	2,026
1861	142.2	49.6	142.2	49.6	0.883	5.407	2,111
1862	144.7	51.3	144.7	51.3	0.902	5.407	2,124
1863	145.5	51.2	145.5	51.2	0.896	5.407	2,143
1864	148.0	53.0	148.0	53.0	0.952	5.407	2,209
1865	149.2	53.5	149.2	53.5	0.989	5.407	2,226
1866	150.6	54.3	150.6	54.3	1.021	5.407	2,273
1867	150.5	53.7	150.5	53.7	0.953	5.407	2,274
1868	151.5	55.7	151.5	55.7	1.118	5.407	2,359
1869	150.5	55.5	150.5	55.5	0.976	5.407	2,360
1870	153.0	58.1	153.0	58.1	1.224	12.506	2,474
1871	153.9	59.3	153.9	59.3	1.305	12.506	2,517
1872	162.0	63.4	162.0	63.4	1.653	12.506	2,613
1873	162.6	64.5	162.6	64.5	1.640	12.506	2,598
1874	161.8	65.1	161.8	65.1	1.793	12.506	2,625
1875	168.7	68.8	168.7	68.8	2.172	12.506	2,745
1876	171.8	71.0	171.8	71.0	2.330	12.506	2,776
1877	173.0	72.5	173.0	72.5	2.456	12.506	2,844
1878	169.3	71.8	169.3	71.8	2.083	12.506	2,721
1879	170.5	73.3	170.5	73.3	2.100	12.506	2,745
1880	178.2	77.7	178.2	77.7	2.689	13.542	2,983
1881	176.9	78.1	176.9	78.1	2.611	13.542	2,979
1882	180.6	80.7	180.6	80.7	2.950	13.542	3,113
1883	183.3	82.9	183.3	82.9	3.143	13.542	3,189
1884	185.8	85.1	185.8	85.1	3.297	13.542	3,250
1885	189.3	87.8	189.3	87.8	3.555	13.542	3,357
1886	187.2	87.9	187.2	87.9	3.479	13.542	3,333
1887	187.4	89.0	187.4	89.0	3.536	13.542	3,364

Appendix D. *Continued.*

Year	Energy (S)	Energy (S,-h)	Energy (E)	Energy (E, -h)	CO_2 emissions from fossil fuel	CO_2 emissions from forests	Eco-Margin
	Peta Joule	Peta Joule	Peta Joule	Peta Joule	Mega ton	Mega ton	Mill. 1994 SEK
	Swedish standard	Swedish standard excl. households	European Standard	European Standard, excl. households		Minimum estimate	1994 Avoidance costs
1888	190.6	91.6	190.6	91.6	3.933	13.542	3,521
1889	197.8	96.1	197.8	96.1	4.590	13.542	3,778
1890	200.0	98.3	200.2	98.5	4.624	14.578	3,806
1891	202.5	100.7	202.8	101.0	4.899	14.578	3,915
1892	201.8	101.4	202.1	101.7	4.900	14.578	3,934
1893	202.0	108.5	202.8	109.3	4.944	14.578	3,982
1894	213.8	109.9	214.8	110.9	5.867	14.578	4,350
1895	215.2	111.8	216.6	113.2	5.921	14.578	4,403
1896	220.4	115.7	222.4	117.7	6.123	14.578	4,497
1897	230.2	122.1	232.9	124.8	6.831	14.578	4,766
1898	235.3	126.2	238.9	129.8	7.270	14.578	4,937
1899	254.1	137.6	259.0	142.5	9.133	14.578	5,640
1900	259.8	142.2	266.2	148.6	9.160	4.218	5,651
1901	250.0	138.2	258.0	146.2	8.496	4.218	5,544
1902	258.9	144.6	268.8	154.5	8.881	4.218	5,675
1903	266.6	150.4	277.9	161.7	9.777	4.218	5,886
1904	271.7	154.7	285.7	168.7	10.307	4.218	6,035
1905	279.9	161.0	295.9	177.0	10.145	4.218	6,135
1906	293.9	170.6	312.2	188.9	11.305	4.218	6,413
1907	309.6	181.5	331.3	203.2	12.867	4.218	6,730
1908	315.9	187.0	342.1	213.2	13.746	4.218	6,905
1909	299.7	179.0	329.0	208.3	12.676	4.218	6,646
1910	320.9	193.5	355.9	228.5	13.091	4.218	6,843
1911	316.7	192.7	355.6	231.6	12.932	4.218	6,903
1912	329.8	202.5	371.0	243.7	14.226	4.218	7,237
1913	362.8	224.7	416.0	277.9	15.931	4.218	7,629
1914	356.7	221.0	407.0	271.3	15.003	4.218	7,353
1915	363.9	225.4	423.6	285.1	15.537	4.218	7,524
1916	390.7	242.1	461.5	312.9	16.375	4.218	7,826
1917	304.3	188.6	370.4	254.7	6.777	4.218	6,300
1918	315.6	195.6	383.7	263.7	7.859	4.218	7,230
1919	304.9	189.0	368.0	252.1	7.368	4.218	6,967
1920	312.6	193.8	374.6	255.8	10.057	4.218	6,762
1921	243.5	151.0	295.2	202.7	5.831	4.218	5,546
1922	289.3	179.4	349.1	239.2	10.003	4.218	6,208
1923	313.5	194.4	375.4	256.3	12.139	4.218	6,697
1924	347.8	215.7	415.7	283.6	14.637	4.218	7,113
1925	327.6	203.1	390.9	266.4	13.039	4.218	6,897
1926	324.3	201.1	388.8	265.6	12.810	4.218	6,821
1927	379.8	235.6	445.1	300.9	17.998	−10.049	7,997
1928	362.3	224.7	421.1	283.5	16.476	−10.049	7,569
1929	401.8	249.3	461.5	309.0	19.651	−10.049	8,345
1930	392.9	243.8	447.2	298.1	19.141	−10.049	8,900
1931	387.9	240.7	440.2	293.0	19.319	−10.049	9,024

Appendix D. *Continued.*

Year	Energy (S)	Energy (S,-h)	Energy (E)	Energy (E, -h)	CO_2 emissions from fossil fuel	CO_2 emissions from forests	Eco-Margin
	Peta Joule	Peta Joule	Peta Joule	Peta Joule	Mega ton	Mega ton	Mill. 1994 SEK
	Swedish standard	Swedish standard excl. households	European Standard	European Standard, excl. households		Minimum estimate	1994 Avoidance costs
1932	381.3	236.6	429.9	285.2	19.070	−10.049	9,682
1933	393.8	244.4	444.9	295.5	19.906	−10.049	10,479
1934	422.2	262.1	478.2	318.1	22.055	−10.049	10,977
1935	435.6	270.4	497.1	331.9	23.238	−10.049	11,665
1936	462.6	287.2	528.6	353.2	25.733	−10.049	11,441
1937	505.7	314.5	575.0	383.8	29.640	−10.049	11,907
1938	473.3	294.8	547.6	369.1	26.469	−10.049	11,326
1939	599.5	374.1	677.8	452.4	29.894	−10.049	11,848
1940	480.1	300.1	555.9	375.9	19.039	−10.049	9,111
1941	460.0	288.0	542.2	370.2	15.395	−10.049	8,781
1942	456.0	286.0	546.2	376.2	12.665	−10.049	8,720
1943	485.9	305.3	589.2	408.6	15.103	−10.049	9,316
1944	450.3	283.4	570.7	403.8	11.800	−10.049	8,621
1945	450.2	283.9	579.6	413.3	2.822	−10.049	7,186
1946	421.6	266.3	556.5	401.2	16.090	−10.049	9,289
1947	497.5	314.8	624.6	441.9	24.180	−16.369	10,733
1948	534.1	338.5	667.8	472.2	28.992	−16.369	11,557
1949	491.7	312.2	643.9	464.4	25.803	−16.369	11,055
1950	573.7	364.8	749.9	541.0	44.967	−16.369	12,994
1951	633.2	403.4	812.0	582.2	54.185	−16.369	13,814
1952	642.7	410.1	831.4	598.8	53.105	−16.369	13,687
1953	608.8	389.2	808.4	588.8	43.985	−16.369	13,390
1954	629.0	402.8	834.6	608.4	42.886	−16.369	13,855
1955	720.0	455.0	929.6	664.6	50.369	−16.369	15,169
1956	789.1	505.0	1,008.8	724.7	53.089	−16.369	15,969
1957	767.0	490.9	992.6	716.5	50.826	−16.369	16,602
1958	754.6	482.9	986.0	714.3	46.063	−22.404	16,372
1959	696.9	446.0	929.5	678.6	36.531	−22.404	17,582
1960	811.6	519.4	1,055.7	763.5	44.271	−22.404	18,570
1961	805.7	515.6	1,059.9	769.8	42.998	−22.404	18,862
1962	855.8	547.7	1,125.3	817.2	46.899	−22.404	20,095
1963	906.9	580.4	1,173.0	846.5	50.388	−22.404	21,668
1964	992.3	635.1	1,279.2	922.0	55.264	−22.404	23,080
1965	1,020.9	653.4	1,313.3	945.8	56.419	−22.404	24,498
1966	1,136.9	727.6	1,426.6	1,017.3	65.165	−1.036	25,282
1967	1,093.0	699.5	1,396.0	1,002.5	60.569	−1.036	25,180
1968	1,214.1	777.0	1,530.5	1,093.4	68.988	−1.036	27,029
1969	1,319.6	844.5	1,633.8	1,158.7	75.986	−1.036	28,383
1970	1,444.5	924.7	1,747.6	1,227.8	84.748	−5.712	28,649
1971	1,386.0	876.4	1,746.9	1,237.3	78.442	−5.712	27,549
1972	1,385.5	866.6	1,752.2	1,233.3	77.427	−5.712	27,614
1973	1,445.1	927.4	1,859.6	1,341.9	79.924	−5.712	27,902
1974	1,409.4	942.4	1,804.8	1,337.8	77.644	−5.712	26,834
1975	1,455.2	963.6	1,900.4	1,408.8	79.474	−21.756	24,387

Appendix D. *Continued.*

Year	Energy (S)	Energy (S,-h)	Energy (E)	Energy (E, -h)	CO_2 emissions from fossil fuel	CO_2 emissions from forests	Eco-Margin
	Peta Joule	Peta Joule	Peta Joule	Peta Joule	Mega ton	Mega ton	Mill. 1994 SEK
	Swedish standard	Swedish standard excl. households	European Standard	European Standard, excl. households		Minimum estimate	1994 Avoidance costs
1976	1,511.8	983.2	1,964.6	1,436.0	83.127	−21.756	25,391
1977	1,462.4	938.5	1,904.3	1,380.4	79.662	−21.756	24,014
1978	1,382.5	846.4	1,873.5	1,337.4	69.777	−21.756	22,972
1979	1,572.0	1,033.6	2,073.7	1,535.3	82.604	−21.756	23,539
1980	1,440.6	912.0	1,950.5	1,421.9	72.119	−34.395	21,788
1981	1,292.0	775.4	1,847.2	1,330.6	57.788	−34.395	20,398
1982	1,276.7	776.5	1,839.0	1,338.8	56.767	−34.395	19,906
1983	1,323.8	839.1	1,952.1	1,467.4	54.955	−34.395	18,843
1984	1,319.0	828.7	1,993.7	1,503.4	51.150	−34.395	18,858
1985	1,442.7	917.4	2,157.6	1,632.3	58.391	−34.395	19,061
1986	1,518.7	1,001.1	2,214.2	1,696.6	63.352	−6.838	18,450
1987	1,417.7	886.3	2,151.7	1,620.3	52.691	−6.838	17,494
1988	1,508.7	998.2	2,243.1	1,732.6	56.518	−6.838	16,342
1989	1,424.3	919.6	2,141.7	1,637.0	51.459	−6.838	14,711
1990	1,441.3	937.4	2,170.3	1,666.4	50.318	−6.838	13,384
1991	1,428.3	905.0	2,154.8	1,631.5	48.017	−6.838	
1992	1,412.4	888.4	2,125.9	1,601.9	46.995	−6.838	
1993	1,427.8	901.6	2,140.5	1,614.3	47.005	−6.838	
1994	1,442.0	915.2	2,137.2	1,610.4	48.264	−6.838	
1995	1,477.2	943.9	2,193.8	1,660.5	48.426	−6.838	
1996	1,488.4	941.8	2,181.5	1,634.9			
1997	1,495.9	na	2,212.6	na			
1998	1,500.0	986.5	2,223.8	2,223.8			
1999	1,492.7	na	2,214.6	na			
2000	1,485.0	na	2,208.9	na			

Note: The underlying series, energy carriers and pollutant emissions, may be requested from the authors.
Sources: Kander (2002) and Lindmark (1998).