Economic growth, energy consumption and CO_2 emissions in Sweden 1800-2000

Astrid Kander

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Abstract

This thesis analyzes the interrelations of growth, energy and CO_2 in Sweden 1800-2000, using standard calculations, relative price analyses and energy quality factors, to determine the relative effects of structural and technical changes, including changes in energy carrier composition. The main result is a long-term delinking of energy consumption, CO_2 emissions and economic growth.

Technical change is the main reason for energy intensity decline. Total factor productivity gains, including improvements in technical energy efficiency, save energy in relation to output. Between 1870 and 1970 the most spectacular energy savings took place in transportation & communications and industry. Structural changes at the sector level tended to increase energy intensity. No correlation was found between increasing energy quality and decreasing energy intensity, but energy quality may have had an impact on economic growth rates. A consumers' surplus was exceptionally high during the interwar period and the three decades after the Second World War, and the total energy quality was outstanding during the latter period. The most rapid relative decline in energy intensity took place between 1970 and 2000, a period in which structural changes at the sector level no longer worked to increase energy intensity and the new growth direction of the third industrial revolution saved energy in relation to output. The decrease of energy intensity after 1970 was not caused by changed patterns of foreign trade for Sweden, but by changed patterns of demand in Sweden as well as abroad.

When only emissions from fossil fuels are counted, CO_2 intensity shows a pattern of either one long Environmental Kuznets' Curve, interrupted by the Wars, or three separate EKCs. The main determinants of this CO_2 intensity are energy intensity and energy carrier composition, with the latter turning out to be the most influential. The three costs involved in energy consumption, i.e. purchasing costs, handling costs and environmental costs, are regarded as playing different roles at different income levels, with effects on energy carrier composition.

Over the period 1800-2000 CO_2 emissions and sequestration by Swedish forests were of a magnitude well in parity with emissions from fossil fuels. The aggregate CO_2 emissions were not much altered, but the pattern of CO_2 intensity was profoundly changed when forest emissions were included. Furthermore, the idea that firewood caused net CO_2 emissions in the period is questionable from a dynamic perspective, because the demand for thin timber dimensions stimulated rational forestry.

Key words
Energy intensity, CO_2 intensity, technical change, structural change, energy quality factors, relative prices, standard calculations, forest management

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Tables

Figures

Conversion factors and prefixes

1 calorie = 4.19 Joule (J)
1 J = 1 Ws
1 Wh = 3600 Ws
1 hp=0.736 kW
1 toe=10 Gcal=11.6 MWh=42 GJ

1 m^3 solid wood = 1.92 MWh=6910 MJ=6.9 GJ
alternative measure for wood: 1 m^3 solid wood= 8.97 GJ
1 kg raw oil = 42 MJ
1 kg coke = 32 MJ
1 kg imported coal = 29 MJ
1 kg domestic coal = 22 MJ

Kilo (K) = 10^3
Mega (M) = 10^6
Giga (G) =10^9
Tera (T) =10^{12}
Peta (P) =10^{15}

Contents

Chapter 1
Introduction

Economic growth relies on the energy at man's disposal. On combustion some forms of energy emit carbondioxide, net increases of which amplify the greenhouse effect. This thesis aims at analysing the relations between economic growth, energy consumption and CO_2 emissions in a certain historic and geographic context: the Swedish economy 1800-2000.[1]

Growth and the environment

This study has its roots in the debate on options to reconcile economic growth with the environment. Although matters within the broad field of growth and environment were deliberated as far back as in the 19th century, the debate has become more intense during the last few decades as environmental awareness has increased. In the 1980s the debate shifted focus, from raw material constraints to limitations in the environment's capacity to absorb pollutants.[2] Presently, certain pessimistic growth critics, for instance human ecologists, claim that economic growth should be halted and even reversed and that an optimal stage was reached at some point in the 1950s.[3] The drawback of this viewpoint is that it equates economic growth with a physical increase in production. One of the primary aims of the present study is to stress the importance of quality aspects of growth. It is not possible to equate economic growth with a physical throughput of material and energy. Relative improvements do take place and one aim is to determine if this occurs of a magnitude that is significant, because the scale of human economy cannot expand infinitely.[4]

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[1] The Swedish Environmental Protection Agency (SNV) financed the work until the completion of my licentiate-thesis: Kander, A.(1998):*Energy consumption and forestry in Sweden 1800-1990, - implications for CO_2 emissions*, unpublished licentiate-thesis, presented at the Department of Economic History in Lund. After that, it was financed by the Swedish Council for Planning and Coordination of Research (FRN).

[2] The fear of natural resource depletion was prominent in the Club of Rome Report (1975):*The Limits to Growth*, New York. Wiman, B.L.B. (1988): *Att vidmakthålla naturresurserna*, Solna, pp54-55 describes the shift in environmental concern during the 1980s, as a shift from "råvarugolv till resurstak".

[3] Hubendick, B.(1991):*Mot en ljusnande framtid?*, Värnamo.

[4] See for instance: Boulding, K.(1966): "The economics of the coming spaceship Earth", in H. Jarret (ed.): *Environmental quality in a growing economy*, The John Hopkins Press.

The traditional and still dominant economic paradigm of the economy as a closed system, with circular flows, should be discarded. Ecological economists rightly emphasize that the economy constitutes a subsystem of the world ecology, which takes in natural resources and high grade energy from the surrounding world and disposes of residual products and energy of lower grade into it. There are limits to the size of the economy in this physical sense, because of finitude, entropy and ecological interdependence.[5] Mankind, with its related vegetable and animal species, has grown and eliminated other species, ever since the introduction of agriculture. Both from anthropocentric points of view and, more obviously, from biocentric points of view there are limits to how large the human economy should be in relation to the world ecology. Other constraints on the expansion of the economy are the finitude of raw materials, the degradation of energy (increasing entropy) and the limits for emissions set up by the assimilative capacity of the surrounding world. The flow of biophysical throughput of raw material and the degradation of energy should in general be limited for the sake of future generations, although some substitution of man-made capital for natural capital and human capital for physical capital is possible.[6] There are large variations between raw materials. Toxic metals and wood constitute examples of materials that are obviously impossible to compare and have very different environmental impacts. The environmental effects of more hydrocarbon throughputs are not severe if the atmospheric CO_2 remains balanced. The speed of hydrocarbon throughput may increase through more efficient harnessing of solar energy into crops, which has taken place on a grand scale during the last two centuries and there are still options for this development to continue, especially in poorly managed forests.[7] In this way more hydrocarbons may be used by the economy, in the form of food, biofuel or people as such.

There are connections between the performance of the economy, as measured by GDP, and the throughput of raw materials, resulting in waste products, which may harm the environment. Those connections are, however, neither linear nor simple in any other way. The demand for raw material and

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[5] Georgescu-Roegen, N.(1971): *The entropy law and the economic process*, Cambridge US. Daly, H.E. (1987):“The economic growth debate: what some econmists have learned but many have not”, *Journal of Environmental Economics and Manangement*, vol 14 , p 323-336.

[6] There are limits to this kind of substitution for instance expressed by Smith, V. K.(1979): “*Scarcity and Growth Reconsidered*”, Baltimore and London. P 98: “(Natural resources) are not just like any other production factor. A change in capital and labor can only diminish the amount of waste in the production of a commodity; no agent can make the material on which it works. Nor can capital create the stuff out of which it is made.”

[7] Ekins, P: *Economic Growth and Environmental Sustainability: The Prospects of Green Growth* Routledge, 2000, uses the term environmental growth for this increased hydrocarbon production.

energy, in relation to GDP and income, changes over time, as will be shown with regards to energy in this study.

The more recycling that takes place before products end up as waste, the less stress on the environment. Recycling thus constitutes one option for reducing the adverse environmental impacts of the economy. This has been going on for centuries, although more pronounced in recent decades.[8] The mountains of waste are however still growing in absolute terms, although the correlation with GDP growth has not been explored more systematically and variations may be large.[9] Energy cannot be recycled, but waste heat may be used more efficiently, for instance in combined heat and power plants. Another way of conserving energy is to increase the technical efficiency of energy converters, like machines. Here there is a large remaining potential, especially for motive power. Recycling and higher energy efficiency mean slowing down the process of biophysical throughput, while at the same time enabling the use of raw material and energy for economic growth. The material can be circulated in the economy and repeatedly used in the production of goods and services, the value of which contributes to GDP.

Economic growth does not take place as an even process over time. The structure of the economy changes and technical changes take place, with implications both for the demand for raw material and energy as well as for the output of emissions and solid waste. An agricultural society has different demands and produces different environmental effects to an industrial society, which in turn differs from a post-industrial society. Higher per capita income leads to changed demand. In addition, uneven productivity development between various sectors and sub-sectors of the economy results in changes in relative prices, which affects demand. The increased demand for industrial goods and transportation depends on relatively lower costs for these products and on income effects.

The GDP in constant prices is the aggregation of various products and services over time. Both quantity and quality aspects are included in the measure. Consequently, it is not correct to equate growth of GDP, or economic growth with a physical growth of production.[10] There may be growth of

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[8] Clapp, B.W.(1994): *An Environmental History of Britain since the Industrial Revolution*, Longman Group UK Limited, devotes two of his chapters (9 and 10) to the history of recycling.

[9] World Bank: World Development Report (1992): *Development and the Environment*

[10] Here I disagree with, for instance, Daly, H.(1992): *Steady-state economics*, Earthscan Publications Ltd, who overlooks the quality aspects when he says: "In calculating growth in real GNP, economists correct for price changes in order to capture only changes in quantity" (p 182) and "In calculating real GNP, efforts are made to correct for changes in price levels, in relative prices, and in product mix, so as to measure only real change in physical quantities produced" (p 18). Daly makes a similar erroneous statement regarding the quantities of production factors and technical change where he uses the low TFP results from Jorgenson, D. W. and Z. Griliches (1967):"The Explanation of Productivity

products/services with a low material content, but with a high value. And even if it were correct to equate economic growth with a physical growth of production, this would not imply that there would be a linear increase in the throughput of material from the environment and back, because of recycling within the economy. This means that transformation of products and structures always takes place in the growth process and that the efficiency of inputs generally increases.

To advocate a cessation of economic growth to save the environment is therefore an uninformed and too simplistic argument. Everything has both costs and benefits, and for something to prove worthwhile, benefits should exceed costs. There are different opinions on whether growth has already crossed the line from being largely positive to being largely negative.[11] I am unable to determine which picture is the most accurate. I do, however, agree with the opinion that poor countries have enormous needs for growth of per capita income and that continuous growth in general is still less painful than artificial restraint.[12] If there is a situation where additional economic growth will have a clearly negative impact on welfare and there is a need to stop or even decrease economic growth, the means for doing so are clearly unattractive. Daly has suggested three mechanisms for achieving a steady state economy (no growth in biophysical throughput): depletion quotas for non-renewable resources auctioned by the government, a distributing institution to limit inequality and transferable birth licenses for stabilizing population growth.[13] The actions suggested by Daly may be effective for managing the scale of human economy, but they are very costly. They rely on international agreements and decisions and require rigorous systems for enforcement, from the local to the global level of society. The inherent risks of abuse of power (corruption) as well as the large costs for information, control and enforcement, together with the losses of individual freedom, appear so negative that it is difficult to advocate these measures unless there is evidence of an approaching environmental collapse.

Change", *Review of Economic Studies*, July, p 249-283, when they account for quality aspects of the production factors, to claim that: "Such findings cast doubt on the notion that technology, unaided by increased resource flows, can give us enormous increases in output." (p 106).

[11] The Worldwatch institute has published gloomy reports on the condition of the world, which were recently questioned by Lomborg. See Lomborg, B.(2001):*Världens verkliga tillstånd*, SNS Förlag, and Brown, L. B. et al: *State of the World* A Worldwatch Institute Report on Progress Toward a Sustainable Society, annual publication since 1984.

[12] Brundtland, G.H. et al (1987): *Our common future*, The report of the world commission on environment and development, Oxford University Press, clearly saw the need for continued economic growth, but coined the term "sustainable development". Sustainable development means meeting the needs of the present without compromising the ability of future generations to meet their own needs, p 8.Likewise Becker, W.(1975): *Leve tillväxten*!, (In Defence of Growth), Stockholm, advocated continued growth for the sake of the developing countries.

[13] Daly, H.(1992), op. cite, chapter 3.

Politicians and economists often argue that economic growth is a prerequisite for environmental consideration, while their opponents emphasize the heavy use of material and energy in economic activities and claim its incompatibility with environmental management. The controversy can be resolved in a theoretical way by stating that the *content* of the economic growth decides whether it is compatible with environmental consideration; structural changes may lead to less environmental stress and outright environmental protective measures may be part of the growth process. In the present study the aim is to find out what evidence could be provided by history on this issue. The study focuses on the case of Sweden in the period 1800-2000, which was a period a profound transformation of Swedish society. Spectacular increases in income per capita took place and employment shifted from agriculture to industry to services. Technological changes affected production and relative prices and structures. What effects did structural changes have on emissions so far? Did technical change always work to decrease the relative environmental stress? What were the relative impacts of structural and technical changes? What was the role of quality in relation to quantity? Was decreasing energy quantity a result of increasing energy quality? Were improvements in Sweden reached through environmental dumping in less developed countries, through trade patterns? These are questions addressed by this thesis in relation to some aspects of Swedish development.

Environmental history

Environmental history is a multi-disciplinary research field that has emerged since the late 1960s, in close connection with the rise of environmental awareness and concern.[14] The research is too encompassing to present here; a thorough overview of both international and Swedish literature is provided in Sörlin & Öckerman.[15] Worster, one of the more influential environmental historians, has categorized three levels of analysis, or three clusters of issues, for environmental history: 1) understanding nature itself (including man) historically 2) exploring the physical relations between man and nature, i. e. the socio-economic interaction with nature 3) analyzing the purely mental interaction between man and nature (perceptions, values, laws, debates etc).[16]

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[14] The term environment (”miljö” in Swedish) had its breakthrough in the early 1960s. See Sellerberg, A.-M.(1994): *Miljöns sociala dynamik – om ambivalens, skepsis, utpekanden, avslöjanden mm*, Research Reports from the Department of Sociology, Lund University.

[15] Sörlin, S & Öckerman, A.(1998): *Jorden en ö – En global miljöhistoria*, the last chapter.

[16] Worster, D. (1988):”Doing Environmental History”Appendix in Worster, D (ed): *The Ends of the Earth*, *Perspectives on modern environmental history,* Cambridge University Press.

Most studies do not cover all three levels, and Swedish environmental history is clearly dominated by the two latter categories, mostly in separate works.

The development of environmental concern and protection could analytically be divided into nature's protection and environmental protection, where the former came earlier and was more easily accomplished, exemplified in Sweden getting the world's first modern forest law in 1903 and establishment of national parks in 1909.[17] More diffuse matters, covered by the concept "environment", like water and air pollution were to receive an important role on the political agenda much later, manifested in the first environmental protection law as late as in 1969. Swedish investigations within Worster's second sphere have mostly been preoccupied with man and nature. Landscape and forest history make up the bulk of them. A few exceptions exist: Svidén's investigation of sulfur and mercury emissions from ironworks in Kalmar county 1655-1920 and Lindmark's incorporation of costs for various pollutants during the 19th and 20th centuries in his green historical national accounts.[18] The present investigation is another study, which falls within Worster's second category, where the environment rather than nature is focused.

Environmental Kuznets' Curve (EKC)

One proposition about the relation between economic growth and the environment is that it resembles an inverted U over time. It is commonly referred to as the Environmental Kuznets Curve (EKC) after Simon Kuznets, who proposed a similar relation between economic growth and inequality.[19] There are two formulations of the EKC: the strong and the weak hypothesis. The strong variant suggests absolute improvements, while the weak only suggests relative improvements. The weak EKC suggests that initially an economic growth process will cause a relatively increased stress on the environment, but after a peak the reverse situation will appear: continuous economic growth leads to relatively decreased stress on the environment. According to the weak hypothesis absolute environmental conditions may continue to deteriorate, either because the absolute emissions continue to increase, or in those cases in which they actually decrease because some environmental problems are related to the stock of pollutants rather than to the flow. Radetzki was the first author to

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[17] This division is for instance made in Bohlin et al, (1995)*: " Människa och miljö – om ekologi, ekonomi och politik*, chapter one: Sveriges gröna historia, Tidens förlag.

[18] Svidén, J.(1996): *Industrialisering och förändrad miljöpåverkan*, Linköping Studies in Arts and Science, no 147; Lindmark, M.(1998): *Towards Environmental Historical National Accounts for Sweden*, Umeå studies in Economic History 21.

[19] Kuznets, S.(1955): "Economic Growth and Income Inequality", *American Economic Review*, vol 45, no 1, pp 1-28

propose the hypothesis of the weak EKC, without labelling it.[20] The political implications of both the strong and the weak EKCs are of course that economic growth does not necessarily have to cause environmental degradation, and that the rich countries therefore can go on striving for economic growth. For the poor countries the challenge is to improve the EKC for instance by pressing it downward, or by reaching the turning point faster, in their future development. Technology transfer from the developed countries could achieve this, it is argued. The argument gains psychological strength, because it incorporates the experience that growth in many cases does affect the environment negatively and then delivers the message that this is only a temporary condition. Normally the relation changes at higher income levels. Interpreters of the EKC do not always distinguish between a relative environmental improvement and an absolute improvement. They do not remember that some environmental indicators actually show steady deterioration with growth, or the fact that many environmental problems are caused by stocks of pollutants rather than flows, or that some environmental processes are irreversible. They often also overlook the fact that many countries in the world are on the upward slope of the curve rather than the downward slope, so that a global growth will deteriorate the present environment. Therefore hasty conclusions are drawn, for instance that economic growth is positive for the environment.[21] Still, the hypothesis is interesting for this study, since it concerns the relation between growth and the environment. The EKCs have been formulated for short periods of time, mainly from the 1960s and onwards and it is of interest to examine whether such patterns exist for longer periods of time as well. This study will contribute to answering that.

The hypothesis of the EKC has spurred empirical research. The World Development Report of 1992 describes the relationships between some environmental indicators (absolute levels of pollutants) and levels of income, based on cross section analyses.[22] For some indicators like urban concentration of SO_2 or PM the report finds support for the strong hypothesis, i. e. of an absolute improvement at higher income levels. However, since only urban concentrations were measured, one could not exclude the possibility that this

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[20] Radetzki, M.(1990): *Ekonomisk tillväxt och miljö*, SNS, first presented the weak hypothesis and then in the final pages drew the conclusion that economic growth is compatible with a good environment. This is a logical error, since one may not draw absolute conclusions regarding growth and the environment on basis of a relative improvement. The growth rates may for instance by higher than the rate of de-linking of environmental stress and growth, in which case the absolute environmental stress continues to increase. Kågesson, P. (1997): *Growth versus the Environment – Is there a Trade-off*, Lund , claims that Panayoto, T (1992): *Environmental Kuznets curve. Empirical tests and policy implications*, draft, November, was the person that labeled the EKC.

[21] Hermele, K.:*Ekonomerna tillväxten och miljön*, Stockholm, 1995, p 96-98, discusses some of the misinterpretations of the EKC.

[22] World Bank: World Development Report (1992), op.cite, p 9-11.

improvement was caused by emissions being efficiently diffused in the rural parts of the country (by means of higher chimneys for instance). Two indicators showed steady improvement with higher incomes; clean water provision and urban sanitation, while two other indicators showed steady deterioration; municipal waste amounts and CO_2 emissions. So the pattern was far from uniform and it only partly supported the EKC, but in its strong formulation: absolute emissions in relation to income. Further empirical studies emanating from the EKC and with cross section data have been performed. In 1993 Grossman and Kreuger found that urban concentrations of SO_2 and suspended particulate matter (SPM) had turning points around 5000$ (in 1985 US dollars) of per capita GDP.[23] In 1995 the same authors extended the range of environmental indicators to water oxygen, coliform bacteria and heavy metals, which meant that they also used rural indicators, and found that turning points were then higher, around 8000 $ (in 1985 US dollars).[24] Still, only indicators for which an inverted U pattern could be expected were included. Other indicators such as CO_2 emissions, waste disposal, soil degradation, deforestation and loss of bio-diversity were excluded. Holtz-Eakin and Selden investigated the relationship between CO_2, and economic growth and found that the ratio between CO_2 emissions and income never turned downwards within their sample, although there was a slower growth of CO_2 at high-income levels.[25] Their conclusion regarding global economic growth and CO_2 emissions was pessimistic; if present relations prevail in the future there will be large increases in emissions, since the fastest growing countries (not necessarily per capita, but in total with population increase also contributing to the growth of GDP) have the largest propensity to emit.

In the 1970s and 1980s there was a common belief that energy consumption and GDP developed evenly.[26] There was no sound theoretical ground for this assumption and it was later refuted on empirical bases. Energy intensities have exhibited inverted U- curves over time, at least in some countries, in line with the hypothesis of the EKC. Reddy and Goldemberg

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[23] Grossman, G.M. and A.B. Kreuger (1993): “Environmental Impacts of a North American Free Trade Agreement”, in *The U.S.-Mexico Free Trade Agreement* P. Garbier (ed), Cambridge.

[24] Grossman, G.M.& A.B.Kreuger (1995): “Economic Growth and the Environment”, *Quarterly Journal of Economics*, p 353-377.

[25] Holtz-Ekin, D.& T.M. Selden.(1995): “Stoking the fires? CO_2 emissions and economic growth.” In *Journal of Public Economics* 57, p 85-101.

[26] See for instance Adams, F. G. and P. Miovic (1968):”On relative fuel efficiency and the output elasticity of energy consumption in Western Europé”, *Journal of Industrial Economics*, vol 21, no 1, pp 41-45 and Brookes, L. G. (1977): “Energy-GDP relationships – The elastics snaps*” Energy Policy*, vol 5, no 2, pp 162-164.

presented these results to a broader audience in 1990.[27] Their proposition, based on a study by Martin, showed that the relationship was pretty much like an inverted U.[28] However Martin showed that with the inclusion of firewood the relation changed substantially in the case of the United States, which is a wood-rich and partly cold country. With firewood there was a continuous decrease in energy intensity for the United States. For Japan, Germany and France a less pronounced inverted U-shape persisted even with the inclusion of firewood.

Nilsson has examined energy intensities for 31 countries for the period 1950 to 1988, using GDP at purchasing power parities (PPP) and UN energy statistics, including non-commercial energy like fuelwood and animal wastes.[29] His results only support the EKC for some countries, but this might be because the time span is too short for the pattern to appear in all cases. Energy intensities decreased for 15 of the countries. In the U.S., Great Britain, Germany and France energy intensities steadily decreased during this period. In Japan, Finland, Sweden, Norway and Italy energy intensities increased until the 1970s and then decreased. In some industrial countries energy intensities steadily increased. This was the case for Switzerland, The Netherlands, Spain, Portugal, Australia and Greece. The situation in the countries with formerly centrally planned economies is marked by wasteful energy use, so their intensities for specific economic activities are generally higher. To construct national energy intensities for centrally planned economies is of course difficult since goods are not priced on markets. In general, Nilsson finds that energy intensities among the industrialised countries in his sample converge to a level around 0.3-0.5 tons of oil equivalent per 1000 international dollars. In many developing countries energy intensities increased during the period. This happened in Nigeria, Mexico, Argentina, Syria, Egypt, India, Pakistan and Tunisia. Developing countries with better economic performance like South Korea, Thailand, Indonesia and Brazil instead decreased their energy intensities. There was no possibility of analysing the reasons for the different outcomes within this study. Structural analyses were, for instance, not possible, because data on energy in various sectors of the economies was not available.

The empirical studies, which relate physical emissions or physical energy use to GDP, performed so far suffer from some weaknesses. One weakness is an unavoidable result of the analyses being based on cross sectional data instead of historical time series for single countries. It can never be ruled out that the

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[27] Reddy, A. K. N. & Goldemberg, J. (1990): ”Energy for the Developing World*”, Scientific American*, Sept, p 64.

[28] Martin, J.-M.(1988): “L’intensité Energetique de l’activite economique dans les pays industrialises. Les evolutions de tres longue periode livrent-elles des enseignements utiles?” *Eco. Soc*. Nr 4, p 9-27.

[29] Nilsson, L. J.(1993):”Energy intensity trends in 31 industrial and developing countries 1950-1988”, in *Energy* vol 18, no 4 pp 309-322.

historical developments in individual countries differ from what is suggested by the EKC. The development of a certain country could be influenced by its role in the global economy, by changes over time in technical levels, political structure, values etc. Cross section data is a poor source for explanations of patterns, since specific, historical explanations are expelled. Studies using time series (going back further than the 1960s) are still in short supply, but one study of the emissions of SO_2 in relation to GDP in Sweden for 1900-1993 shows an absolute decrease in sulphur dioxide emissions after 1970, which supports the EKC-hypothesis in its strong formulation.[30] The explanation behind this finding is the partial substitution of nuclear power for oil. My study makes a contribution by studying the long- term interrelations of growth, energy and CO_2.

Another weakness of both the hypothesis of the EKCs and the empirical studies performed so far is that analyses of the causes of changes are almost completely lacking. My study aims at analysing the causes of changes in greater detail than previous studies have done.

There exist some country studies on the long- term developments of energy intensities, but they do not reach very far, in terms of explaining changes. Netschert and Schurr have performed one study for the US between 1850 and 1975.[31] It did not use energy data on the sector level, only on the national level, and was therefore unable to provide structural explanations for changes in energy intensity; nor did it include CO_2 emissions. It did, however, cover the industrialisation phase and the results can, therefore, to some extent be compared to those of the present study. Schurr & Netschert find that during the period when industry increased its share of GDP most impressively, i. e. 1880-1910, energy intensity also increased, while it decreased in the period of 1920-1955, when industry did not increase as much in relative terms. The authors believe that the main reason for the trend break was the diffusion of electricity, which saved energy through new organisations of production. Firewood consumption was not included in this study, nor draught animal muscle energy, and therefore it somewhat exaggerates the increase in energy intensity for the period 1880-1910, since part of that increase simply was the substitution of commercial energy carriers for traditional. Humphrey and Stanislaw have analysed the UK energy consumption in relation to economic growth for 1700-1975.[32] They compare growth rates for energy consumption and GNP. Traditional energy carriers are not included in their study and the only structural

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[30] Brännlund, R & Kriström B.(1998): *Miljöekonomi*, Lund, pp 288-289.

[31] Schurr, Sam & Bruce Netschert (1978): *Energy in the American economy, 1850-1975, an economic study of its history and prospects*, Baltimore.

[32] Humphrey, W.S & J. Stanislav (1979): "Economic growth and energy consumption in the UK, 1700-1975", *Energy Policy*, vol 7, no 1, pp 29-42.

analysis they perform is to compare the iron-industry's share of industry with the energy intensity pattern. Their main results are that up until 1830 energy and GNP grew approximately at the same speed (but they stress that this result is very uncertain due to data deficiencies), for 1830-1880 energy consumption grew much faster than GNP, and for 1880-1975 the economy grew faster than energy. They find the share of iron industry in relation to GNP, peaking in 1880, to be a likely explanation for this pattern.

The aim of my study is not to relate the results to what the environment could take. To actually assess sustainability is a hard task, both for theoretical and practical reasons. Sustainable for whom and in what time-perspective are problematic questions to answer with regard to climate change. Kågesson, nevertheless, had the goal of using sustainability criteria when analysing growth and the environment in rich OECD countries for 1960-1995.[33] In the first instance Kågesson evaluated whether resource use or emissions were delinked from economic growth relatively and absolutely. In cases of absolute delinking he tried to assess the degree of sustainability. His general conclusion was that the specific damage to the environment decreased (there was a relative delinking between growth and the environment). For absolute delinking the picture was more diversified. In the case of CO_2 there was in general a stabilization of total emissions, but no decrease.[34] Sweden was an exception with absolute decreases, mainly as a result of the adoption of nuclear power to replace fossil fuels in electricity production. In comparison with his choice of sustainability criteria, which is a linear decrease of CO_2 emissions for 1990-2050, so that emissions only amount to 20% of the 1990 level in 2050, the present path is not sustainable.

The studies mentioned so far directly relate in physical terms certain pollutants to GDP. Another way of exploring the relationship between economic growth and the environment is to estimate costs of pollutants and natural resource extraction. This procedure has the advantage of making it possible to sum up environmental costs, but has the drawback of severe theoretical problems in establishing costs. Lindmark has estimated costs for several Swedish pollutants for the period 1800-1990 as well as costs for exhaustion of natural resources. He relates them to GDP and so provides an encompassing basis for time series analyses concerning the environment and economic growth in Sweden. His work attempts to broaden the traditional historical national accounts' framework to create green historical national accounts. Lindmark's main result is that the ratio between environmental degradation and growth was

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[33] Kågesson, P.(1997), op.cite., subdivides absolute delinking into three categories: 1) absolute delinking but moving only slowly towards sustainability 2) absolute delinking and moving rapidly towards sustainability 3) sustainable growth, see p 296.

[34] ibid, p 200.

generally decreasing throughout the twentieth century. He finds that there is not just one, but three different EKCs. The first curve starts in 1870 and ends in 1920, with a peak in 1898. The second curve ranges between 1920 and 1947 with a peak in 1937. The third curve occurs between 1947 and 1990, with a peak in 1972.[35] Lindmark's study is very encompassing in numbers of environmental indicators, but these are not attributed to different sectors, so it is not possible to perform a structural analysis.

Aim and scope of this study

The first objective of this investigation is to establish energy and CO_2 intensities for the Swedish economy in 1800-2000 in order to detect trends and possible trend-breaks. This necessitates a compilation of statistical energy data and construction of energy data series, which are lacking.

CO_2 is released to the atmosphere through combustion of fuels, but it is also sequestered in growing biomass and in oceans, and the sum of these effects equals the net contribution to the atmosphere. Forests can work either as sources of or as sinks for atmospheric $CO_{2,}$ depending on whether their standing timber volumes decrease or increase. The net uptake of CO_2 from Swedish forests has been substantial in recent decades and it is relevant to ask what the function of forests has been in the past: have forests worked mainly as sinks or sources for atmospheric CO_2?[36] What has the magnitude of these changes been in relation to the emissions from fossil fuels? Consequently, this study includes an estimate of changes in Swedish standing timber volumes as well as a calculation of the impact on net CO_2 emissions.

My analysis goes further than just describing the energy intensities and CO_2 intensities to check whether there are inverted U-curves or other trend patterns A second, and more important, aim is to provide an economic analysis of the results. The main focus of the analyses is on driving forces behind changes in energy and CO_2 intensities. In an economic analysis the changes could be divided into structural and technical, although in reality there are inter-linkages between the two. One goal is to determine the relative importance of structural and technical changes for changes in energy intensities. The relationship between the economy and energy is intermediated by the technologies and structures of a society. Technologies and structures change

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[35] Lindmark, M. (1998), op. cite, p 178, p 202. Lindmark does not consider it unlikely that avoidance costs for Swedish reductions in CO_2 emissions could be zero, and hence does not calculate these costs at all in his main ecomargin estimate, but provides an alternative measure, where some costs are included, see also p 150-151.

[36] Rodhe, H. et al (1991): "Sources and Sinks of Greenhouse Gases in Sweden: a Case Study", *Ambio*, vol. 20, no 3-4.

over time. Small incremental changes occur, but also major changes, characteristic of economic development, take place. This makes up an important perspective in my analysis. It affects energy carrier composition, structural changes in the economy and options to de-link energy and growth. Three ‘industrial revolutions’ have taken place, with fundamentally different growth directions. This constitutes an analytical periodization underlining my analysis. Technical changes influence both energy consumption and GDP. The impact of technical change on energy intensities is analysed and the framework is used to compare sector developments. Energy carrier composition changes over time and so do economic activities, which means that structural changes occur in both the numerator and the denominator.[37] For CO_2 intensities structural changes in energy carriers are important, because different energy carriers emit CO_2 to varying degrees. The energy carrier composition has changed over time as the society has moved from solar energy to stored energy, which has increased the CO_2/energy ratio. This study accounts both for traditional energy carriers like firewood, muscle energy and water and wind, and modern energy carriers like fossil fuels and electricity. This is because options to actually de-link energy and growth in the long run are focused, and it means that there will be large variations in the CO_2/energy ratios over time depending on the energy carrier composition. Transitions from traditional energy carriers to modern ones may also have affected growth and energy intensities. The higher quality of modern energy carriers may have meant possibilities of increasing growth more than relative quantities of energy.

Clarifications, definitions and methods

Some clarification of the title of this study is in place. The term economic growth is defined as growth of GDP and measured by conventional national accounts. Some readers might react to the term energy consumption. Strictly speaking, energy cannot be consumed. This we know from the first law of thermodynamics. Energy can only be converted. According to the second law of thermodynamics, energy in a closed system loses quality over time.[38] The quality of energy could be expressed as its potential to perform work, which may be measured in terms of exergy.[39] When energy carriers like oil or electricity are used they are deprived of their high quality. Their energy content

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[37] Energy carriers are, for instance, firewood, draught animal muscle energy, coal, oil and electricity.

[38] Georgescu-Roegen, N.(1971), op. cite., introduced the entropy law, or the second law of thermodynamics, into economics.

[39] Sundström, T.(1994): *Populär energi*, Forum för tvärvetenskap och Fysiska institutionen, Umeå universitet, p 104-107. Exergy is measured as the energy amount times a quality factor (between zero and one) so the unit of measurement is the same as for energy.

is converted into motion, goods and into low temperature heat, which is the least valuable energy form. Exergy is lost and entropy increases in the system. Energy carriers are consumed in the sense that they are irreversibly changed into other forms of energy with lower energy quality.

This study focuses on both economic and physical measures, and various ratios between such measures. The main focus is on ratios between physical and economic factors. Energy intensity is defined as the energy/GDP ratio (joule/SEK), and CO_2 intensity is the CO_2 /GDP ratio (kg/SEK). Energy intensity is thus a physical-economic measure and its inverse measure is energy efficiency. Energy efficiency expresses the amount of economic value that the energy has contributed to create (SEK/joule). This energy efficiency should not be confused with the physical-physical energy efficiency, here called 'technical energy efficiency', which expresses the amount of useful energy in relation to input energy, and is expressed in percent. This distinction is important for an analysis of the factors affecting energy intensity. For the analysis economic-economic ratios are also used, for instance the energy volumes/GDP ratio. An energy volume is the sum of energy carrier quantities times their respective prices.

All time periods have concerns of their own. The classical economists, who lived in a largely agricultural society, naturally took an interest in agricultural production and discussed land productivity. The neoclassical economists, who lived in a more industrial society, tended to neglect land in the production function and regarded capital and labor as the only important factors of production. In the mature industrial society, where environmental problems are viewed with greater concern, the role of natural resources, especially energy, is beginning to attract some attention from economists and economic historians.[40] The subject of this study is a product of the time we are living in. To write the history of energy consumption and CO_2 emissions in Sweden is of course to ask questions that in some respects were considered totally irrelevant by the people involved in the economy for most of the investigated period.

In search of answers to the research questions, data of different quality has been used, ranging from statistical information to my modelled estimates, which are based on a theoretical analysis of the relevant factors and their relative importance. While it has been possible to find rather good quantitative indicators

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[40] As far back as the latter part of the 19th century, when neoclassical theory had its breakthrough and thermodynamic laws were discovered, there were individuals who stressed that energy should be included in the economic theory. Geddes wrote to Walras to say that the new economy was insufficient on the supply side because it did not account for the losses of energy and material in the economic process. Podolinsky developed the concept of energy input/ energy output in various modes of agriculture. Soddy stressed in the early 20th century that there was no pure economic theory about growth, because growth in the end depended on physical factors, especially supply of energy. See Martinez-Alier, J.(1990): *Ecological Economics*, Oxford UK and Cambridge US, p 5-13.

of some factors, this has been impossible in other cases. For these factors assumptions have been made. These assumptions are clearly presented, which will enable improvements of the estimates if better knowledge is obtained in the future. Trends, rather than exact figures, are focused in the estimates and are therefore more accurately depicted than rates of increase or decrease. The severe uncertainties involved in the estimates render conventional source critique of the used statistical information inappropriate. It would be unsuitable to dwell upon small imperfections in the statistical material for some energy carriers in the energy aggregate, while others are modelled in a rough manner.

Some remarks on the methods of analysis are in place. The investigation requires aggregations of things that are not easily added up. Neither economic activities nor energy are homogenous entities. Prices constitute the basis for aggregating economic activities. The basis for aggregating energy is the heat content of various energy carriers. Economic activities change over time and so does energy carrier composition. The aggregation procedures conceal diversity, which means that structural changes of the aggregates may constitute powerful explanations for changed figures. The analysis therefore consists partly of a deconstruction of the constructed aggregates. Changes in energy intensity can be analyzed by counterfactual reconstruction, or factor analysis, performed by standard calculations. This enables assessment of the importance of changes in economic structure. What remains after structural changes have been deducted is increases or decreases of energy quantities in relation to a more homogenous production. In a broad sense changes in technology cause these changes.

Other methods used are relative price analyses. Price analyses are used for assessments of energy carrier transitions and for comparisons of regional forest developments. Prices are also used to assess whether the energy intensity changes are caused by the changed qualities of energy carriers.

My study uses energy costs for analysis of energy intensities and energy carrier transitions, but I refrain from establishing economic CO_2 volumes. Energy and CO_2 are two fundamentally different kinds of goods. Energy has been traded at market prices, while CO_2 emissions, during the period covered in this investigation, had no real price. They are social costs, occurring in the future, whose size is very uncertain. To put fictional prices on CO_2 is therefore an undertaking with severe value biases, where discount rates matter a great deal.[41]

The approaches I use are in many ways close to the methods used by Schön in his analyses of long-term economic growth and energy use in the industrial

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[41] Kågesson, P.(1997), p 194. Nordhaus concluded that the potential damage amounts to 3-107 US dollars per ton of carbon. Azar undertook sensitivity analyses and found discount rates to be very crucial for the conclusions from cost-benefit analysis in the Nordhaus manner.

sector. Schön has estimated and analysed total energy consumption of Swedish industry in 1890-1990 and also estimated industrial firewood consumption in 1800-1890. [42] He uses relative price analyses and structural analyses in order to discern periods marked by transformation of energy systems and the economy more generally, and other periods marked by rationalisation or more stable structures both in energy systems and in the wider economy. The present study benefits from his work, both with regard to data and methods, and attempts to broaden the analysis by including the energy consumption by other production sectors and households, which has never been done before. I incorporate the two main traditional energy carriers; firewood and muscle energy and make estimates of CO_2 intensities. My analysis also differs from Schön's in that other questions are posed, which results in partly different methods of analysis. One of my main concerns is economic efficiency of energy consumption and the driving forces for changes in that efficiency. Another is the driving forces for energy carrier transitions.

Why focus on energy and CO_2?

From an environmental perspective it is relevant to study CO_2 emissions, because climate change from global warming is regarded as a severe environmental threat. [43] Fourier realized as early as the beginning of the 19th century that the atmosphere functioned like the glass in a greenhouse, and Arrhenius stated back in 1896 that steam and CO_2 were greenhouse gases and that a doubling of CO_2 in the atmosphere would increase global average temperature by 5 to 6 degrees. Still it was not until the 1980s that the problem was put on the political agenda.[44] Greenhouse gas emissions caused by man are CO_2, methane, halocarbons and N_2O. CO_2 is not a very potent greenhouse gas compared to the other gases, but due to the large scale of CO_2 emissions it presently constitutes about half of the anthropogenic contribution to the

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[42] Schön, L (1990): *Elektricitetens betydelse för svensk industriell utveckling*, Vattenfall, and Schön, L.(1992): *Trädbränslen i Sverige 1800-1990 – användning och prisutveckling*, Vattenfall.

[43] The IPCC (International Panel of Climate Change) was set up in 1988 by the World Meteorological Organization and the United Nations Environment Programme. It regularly produces extensive reports on the human-induced climate change. Its main predictions are that: a) the atmospheric concentration of CO_2 will approximately double b) the mean global temperature will increase by 1.5 to 4.5 degrees c) precipitation will increase globally by 3 to 5 percent d) the sea level will rise by about 45 cm. See IPCC Third Assessment Report - Climate Change 2001, Working group 1, Summary for Policy Makers, p 1-20, available on www.ipcc.ch

[44] Wiman, B. L. B. (1992):"Växelverkan mellan vetenskap och policy inför osäkra miljöframtider", in Matthiessen, C. & Wärneryd, O.: *The Sound Connexion between Denmark and Sweden: Potentials, Barriers and Problems*, p 114, Arrhenius, S.(1896): *Naturens värmehushållning*, Stockholm, p 127.

greenhouse effect.[45] Since CO_2 is a gas, which remains in the atmosphere for a long time, it is of interest to study the history of man made emissions. In addition it is important to have historical perspectives on past development to be able to say something on possible future development.[46] Carbon dioxide recovery and removal have not been carried out historically, which facilitates calculating emissions from fuel use, although such options may become economically viable in the future.[47] A crucial question in international negotiations is each country's responsibility to cut down emissions, and the OECD has urged its member countries to elaborate CO_2- indicators, which relate emissions of CO_2 to specific national properties like population and GDP. [48] One important component of fair international agreements is that both present and past emissions are counted.

Anthropogenic CO_2 emissions mainly stem from fossil fuel combustion, which makes energy a crucial factor to study. In fact, energy consumption is of more importance than CO_2 in analysing the relation between economic growth and the environment. This is because energy is directly involved in production, while CO_2 emissions are an unintended consequence. CO_2 emissions are direct functions of energy use and energy carrier composition, and this thesis focuses on changes in these crucial factors. This means that reasons for changes in CO_2 emissions are analysed indirectly, and that the analyses focus on the relevant factors.

Why relative measures rather than absolute measures?

This dissertation focuses on relative measures rather than on absolute measures. Energy use relative to GDP, CO_2 emissions in relation to energy and to GDP, relative prices of energy and relative development of forests in the north and the south are investigated. These relations are of interest for the assessment of the

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[45] Committee on Science, Engineering, and Public Policy (1992): *Policy Implications of Greenhouse Warming*, Washington, D. C., p 380.

[46] Clark, W. C. & Munn, R. E. (eds) (1986): *Sustainable Development of the Biosphere*, Cambridge, p 7:"Most environmental studies, however focus on the more or less immediate impacts and ameliorative measures. Needed is a complementary program that adopts a sufficiently long-term time horizon to encompass the full interplay between developmental and environmental processes. Analyses of these processes indicate a time horizon one century into the future and, for perspective, at least two centuries into the past".

[47] Williams, R. H. (2000), "Advanced Energy Supply Technologies," ch 8 in Goldemberg, J. (ed): *World Energy Assessment: Energy and the Challenge of Sustainability,* United Nations Development Programme, United Nations Department of Economic and Social Affairs, and World Energy Council

[48] As a Swedish response the report by T. Levander: *Koldioxid - Utsläpp och beräkningsmetodik,* Nutek, R 1991:12 was written. The World Bank produces annual reports of *World Development Indicators on CD-ROM*. These reports contain, for instance, *modern* energy use for 24 countries from 1960, and *industrial* CO_2 emissions for 90 countries from 1960.

environmental aspects of societal development, but they are insufficient for a full assessment, which must also account for scale and finitude. Relative measures are of interest for comparisons between countries and over time and provide information on the development of absolute measures. For instance they enable some understanding of the economic implications of cutting down absolute emissions. In addition, relative measures are more interesting than absolute measures, when it comes to economic welfare. Then absolute levels of energy consumption and absolute levels of emissions are of little interest and it is rather the economic efficiency that is important, i. e. how much value added the energy and emissions have contributed to create. In fact, both environmental scientists and economists focus on relations, although on different ones. Environmental sciences focus for instance on energy consumption in relation to the stock of energy resources and absolute emissions in relation to the assimilative capacity of the environment. While the rates of emissions and consumption are well known, there are prevailing uncertainties concerning the assimilative capacity of the environment and the resource stocks. The mainstream opinion of today is that, from the perspective of energy resource exhaustion, global aggregate energy consumption is far from reaching a problematic level. In relation to the environment's capacity to absorb pollutants, present levels of energy consumption already cause a certain amount of damage, like eutrophication and acidification. Whether these present levels of CO_2 already influence weather calamities, such as droughts, windstorms and forest fires, is debatable. There is, however, a large consensus that a continued growth of net CO_2 emissions will threaten climatic stability, towards the end of the 21st century.[49] Trend breaks are necessary in order to escape future problems and several international negotiations have attempted to encourage such breaks.[50] There are three main ways to reduce the net CO_2 emissions: 1) to reduce the growth in energy consumption, which is possible either by halting economic growth or by changing the present energy to growth relations, i. e. reducing the energy intensity 2) to change the composition of energy supply in the direction of low CO_2 sources, such as, renewable energy, advanced fossil fuels with

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[49] IPCC (2001), op. cite.

[50] In 1992, the Framework Convention on Climate Change (FCCC) was adopted. It aimed at stabilizing the concentration of greenhouse gases in the atmosphere. The industrialized countries and transitional countries that are parties to the convention are called Annex 1 Parties. At their third meeting held in 1997 the Kyoto Protocol to the Framework Convention on Climate Change was adopted, in which 39 developed countries committed themselves to reducing their greenhouse gas emissions by at least 5% compared with 1990 levels between 2008 and 2012. Three flexible mechanisms are possible for the signatory countries to use to fulfill their commitments: joint implementation projects with other Annex 1 Parties, projects between Annex 1 and non-Annex 1 Parties (called the Clean Development Mechanism) and emission trading. The protocol is in the process of being ratified by the signatories.

carbon dioxide removal and storage, or nuclear energy and 3) to sequester more CO_2 in biomass, both in forests and soils.[51] This study will shed light on the future potential of these options. Such options are most interesting for any society that wants to continue the economic growth process, without jeopardizing the environment.

Limitations of the study

In this study, the country of Sweden constitutes one systemic boundary. The economic system is confined to what is conventionally measured by GDP, i. e. market activities, which omits unpaid household work and other non-priced activities.[52] Energy is limited to the energy that man uses consciously and with some effort. Not only modern energy carriers like fossil fuels and electricity but also firewood and animate energy are thus included. Direct solar energy for photosynthesis or heating is excluded. Since CO_2 emissions are addressed and they are related to the combustion of raw energy, I have chosen to calculate primary energy instead of useful energy.[53] Primary energy is the raw energy content of energy carriers prior to conversion in a machine or heating equipment into useful energy. Energy is always lost in these conversions, so useful energy always amounts to less than primary energy.

Energy consumption produces a number of environmental problems other than CO_2 emissions, which are not directly focused on in this study, for instance SO_2, NO_x or particulate matter (PM), loss of wildlife due to hydro-plant establishments and possible global warming from the flooded areas, threats of nuclear plant accidents or proliferation of nuclear weapons. To focus on CO_2 means choosing an environmental aspect of energy consumption, which has not been possible to decrease by purification and therefore makes up a tough test for the relation between growth and the environment.

The role of governmental policies is not analysed. It is only briefly mentioned in parts of the analyses, where it is especially relevant, for instance in

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[51] Brown et al (1996): *The State of the World*, suggest that 60-87 Gt of carbon may be sequestered in forests and another 23 to 44 Gt of carbon in agricultural soils over the next 50 years. This should be related to present net emissions of 3.5 Gt per year from the globe. Fossil fuel combustion consists of 6.5 Gt of carbon and deforestation 2.0 Gt of carbon, which together should mean a net increase of 8.5 Gt per year. The explanation for the puzzle is the existence of large sinks, which are believed to be the oceans (2 Gt) and terrestrial production (3 Gt). See Figure 18 at p 61 in part two of *State of the World's Forests 2001*, www.fao.org/forestry.

[52] GDP measures the value added produced within a country's borders, while GNP measures the value added by people of a certain nationhood, regardless of where this production occurs.

[53] For direct working waterpower and electricity, I normally count the useful energy instead, but I indicate the alternative magnitudes if this energy would also have been calculated by its primary energy content.

certain aspects related to forest history and energy carrier composition. The reason why I have paid so little attention to governmental policies is that I concentrate on the most fundamental factors in explaining energy intensities and energy carrier composition. These are structural and technical changes that occur during the growth process, giving rise to relative price changes which stimulate changes in energy carrier composition, in forest management and in production structure, which affects energy intensity and CO_2 intensity. The technical changes result in higher capital/labor ratio and save raw production factors in relation to economic output, which affects energy intensities. Governmental policies to some extent influence the two main explanatory variables, the technical and structural changes, but how much is very hard to determine. Comparative country studies may offer a possibility for assessing the role of governmental policies.

Prices of energy play an implicit role for energy intensity. This is because energy prices affect value added, since energy is an input of production, and all input costs are subtracted from output to obtain value added. If energy prices increase over time this means that value added decreases, and energy intensity increases, *ceteris paribus*. Still, changing relative prices of energy lead to changing output prices, demand shifts and income changes, which influence the structure of production and the value added, so the ceteris paribus condition is highly unrealistic. Thus my study does not try to incorporate this implicit aspect of energy prices and energy intensity.

A historical study also necessitates some time limits. The long period 1800-2000 is chosen in this study for both theoretical and practical reasons. An investigation covering this period enables comparisons between pre-industrial, industrial and post-industrial phases, which is of theoretical interest. The length of the period is also justified because CO_2 stays in the atmosphere for about 120 years, so long perspectives are necessary for global warming effects. The exact starting year is chosen for more practical reasons; the year 1800 is as far back as the present historical national accounts for Sweden extend.

Structure

The outline of the thesis is the following. Chapter 2 provides the energy quantities. Chapter 3 establishes the energy and CO_2 intensities, which are briefly discussed in relation to previous research. Chapters 4-6 contain my economic analyses, where chapter 4 focuses on structural and technical change in relation to energy intensity, chapter 5 deals with the changed composition of energy carriers and chapter 6 treats the forests as source or sink for CO_2. Chapter 7 summarizes the results and points to further relevant research.

Chapter 2
Energy quantities

Until the late 19th century, traditional carriers, such as firewood, muscles, running water and wind, dominated energy consumption. This energy use was not registered in any statistical way. From the late 19th century new, modern energy carriers, such as coal, oil and electricity began to increase their share. For these energy carriers there is statistical information, because they were either imported or produced. For traditional energy carriers, like firewood and muscle energy, there are no statistics, so the consumption must be estimated. This is the main task of this chapter. The purpose is to systematize and quantify available knowledge, so that the long-term historical development can be assessed. The estimates are based on a combination of theory, facts and assumptions. The assumptions fill in the knowledge gaps. It is my intention to present the bases for the estimates in a straightforward manner to facilitate future revisions. The results of the estimates should not be regarded as exact figures, but are as accurate as possible in order of magnitude and trends.

There is always a margin of uncertainty in estimates that could be presented as intervals. Still, my constructions have been presented as point estimates and not as intervals. The use of intervals for all the assumptions may well be regarded as a more accurate and “scientific” approach, but this is not suitable for two reasons. One reason is that choices of intervals would be somewhat arbitrary, and therefore not more scientifically neutral than my point estimates. A second reason is that the constructions would be so complex that they would be virtually impossible to carry out and, if somehow still carried out, they would be extremely hard to present and have low transparency. I am aware that even the present constructions may be somewhat difficult to follow in every detail, but I still think it is possible for somebody who really tries. More complex constructions would be more difficult to understand, criticise or improve. Particularly when adding traditional carriers to modern ones, for which there is statistical information, the picture would become very blurred. Simple constructions are in general preferable to complex ones, if the complexity does not add important information.

Traditional energy carriers

Sweden is cold, wood-rich and endowed with iron ores and plenty of falling water as well as long coastlines and many lakes. The country is rich in natural resources, but lacks fossil fuels; Scanian mines have only made marginal contributions of low quality coal and shale-oil has been even less important. [1] Sweden's natural prerequisites have marked its energy consumption. Wood-fuels have been pertinent in the energy budget, more than in most countries and waterpower has been abundant. The high land to population ratio has encouraged relatively extensive use of draught animals. This chapter will illuminate the relative size of firewood, muscle and water energy.

Firewood

Households have consumed the bulk of firewood. Some firewood has also been used for heating of service premises. In addition firewood has been consumed by industry, mainly by the iron industry in the form of charcoal. Schön has estimated industrial firewood consumption and his figures are applied in this study.[2] I present my own estimates of household and service firewood consumption here. Household firewood consumption is estimated bottom-up and service firewood consumption is estimated in appendix D as a function of household firewood consumption.

Household firewood consumption

Household firewood consumption is not well documented. The supply was provided within the country and the lion's share has not been traded, but collected by consumers. Estimates must rely on benchmark investigations. In my opinion, no investigations that deserve the status of benchmark values existed before 1920. Therefore the estimates for the period 1800 to 1920 are based on estimates of the developments of certain crucial variables. For the period 1920-1990 some national investigations exist and can serve as benchmark values.

In "National Income of Sweden" (N. I.), which was a pioneering work for historical national accounts in Sweden, the consumption of firewood (both quantities and values) is estimated for the period 1861-1930.[3] This estimate only formed a minor part of the extensive account of economic activities that N. I. provided and it has some deficiencies that have deterred me from using it here. One weakness is that prior to 1920 there were no actual investigations that can serve as benchmarks, but N. I. uses some rough estimates as benchmark values. Only one estimate for the year 1880 exists, based on an estimate by Zellén,

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[1] Until the 1840s Scanian coal, from Höganäs, actually provided more coal to Sweden than was imported, but quantities were small. From the 1850s imports exceeded domestic coal. At the turn of the century Scanian coal only made up about 1/10 of imported coal. Its relative importance gradually diminished throughout the 20th century.

[2] Schön, L.(1992), op,cite.

[3] Lindahl, E./Kock, K./Dahlgren, E.(1937):*The National Income of Sweden 1861-1930*, Stockholm, see Appendix C, pp 142ff.

which in turn was based on estimates for Sachsen, Preussen and Copenhagen, which were adjusted for the Swedish climate. The result is 150 cubic feet per person and year.[4] This is a very uncertain figure, not based on a survey, and therefore in my opinion not suitable for use as a benchmark value. The other benchmarks used by N.I. before 1920 actually emanate from this 1880 estimate.

An investigation in the county of Värmland in 1924 was the first that could serve as a basis for national estimates.[5] This was a careful investigation of 666 households in the countryside, in the winter of 1920-21, which had more than 0.25 ha of cultivated land each. The result displayed large variation for areas of different climate. In the North the average consumption was 3.65 solid m^3, while it was 3.19 sm^3 in the Middle and 2.83 sm^3 in the South. With an adjustment for the mild winter the investigation ends up at an average per head consumption of 3.44 sm^3.[6] In a study Jonson generalised this inquiry to the national level and suggested the figures in table 2.1 for fuel in the countryside.

Table 2.1 Jonson's household firewood estimates, sm^3 means solid cubic metres.

Area	Consumption/head	Total consumption
Inner part of Norrland:	5 sm^3/person	1.23 million sm^3
Coastal Norrland:	4 sm^3/person	2.59 million sm^3
Bergslagen:	2.5 sm^3/person	2.17 million sm^3
South Sweden:	1.7 sm^3/person	4.07 million sm^3
Total sum:		10.06 million sm^3

For cities Jonson roughly assumes 1.25 m^3(s) /person, which adds 2.13 million sm^3 to the total, and the results are presented in the table below.[7]

	North towns	North country	South towns	South country
Consumption per head (cubic metres, solid, including bark)	2.40	3.00	1.20	2.00

Another weakness of N.I.'s estimate is a logical error. N. I. wants to take the differences in fuelwood consumption between town and countryside and between the northern and southern parts of Sweden into account, but

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[4] Zellén, J.O.:"Om skogshushållning", *Tidskrift för skogshushållning*, 1882, p. 140. Zellén warned that the foundation for his calculation was "rather problematic".

[5] SOU 1924:42:*Förbrukningen av virke till husbehov på Värmlands läns landsbygd*

[6] SOU 1924:42, p 61.

[7] Jonson, T.(1923): ”De nordiska ländernas skogsproduktion och dess framtida utvecklingslinjer”. Del 1: Sverige, in *Skogen*, p 254.

unfortunately makes the mistake of circular reasoning. To get regional figures N. I. relies on the estimates by Jonsson, and constructs the consumption table above.[8]Unfortunately, no more regional estimates exist for its period, but N. I. constructs regional estimates by assuming that the per capita figures in the four regions (north towns, north country, south towns and south country) have changed at the same rate as the national averages. Then N. I. recalculates national averages. A benevolent interpretation of its method is that it wanted to take the urbanisation ratio and "colonisation" of Norrland into account. However, the national benchmark values are already supposed to do that as weighted averages for the entire country, so all it accomplishes is a circular reasoning.[9]

Arpi, in his encompassing work on Swedish forests, models the Swedish household use of wood (not simply firewood) for 1850-1950.[10] His procedure is a real bottom up method, based on assumptions of regional differences and changes in these regional figures over time. His method is based on assumptions of simple linear decreases of per capita consumption in five different Swedish regions, except for the last period, 1951-55, when the reduction rate was supposed to have speeded up.[11] Because there are no investigations providing benchmark values for Arpi's five regions, nor any facts supporting the assumed rates of reductions, the figures can not be considered more than guesses. Arpi does relate to the local investigations concerning firewood consumption available until 1955, which demonstrated large differences between the North and South, but he uses them merely to justify his assumption of large differences between the regions and not directly for his estimates.[12] In contrast to N.I. Arpi did not explicitly take the differences between towns and countryside into account. The results of N.I.'s and Arpi's calculations are compared in figure 2.1.

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[8] Lindahl, E./Kock, K./Dahlgren, E.(1937), op. cite. p 160.

[9] The reason why they do not end up with exactly the same national figures as the original ones is that the population increase has not been quite even in the four regions. In 1880 the original estimate is 3,90 and their new estimate is 4,05, in 1900 the figures are 2,60 compared to 2,65 and in 1930 it's 1,68 compared to 1,67. Although I sympathise with their strive for regional estimates I consider it better in this case if they would have refrained from it and simply interpolated the national figures.

[10] Arpi, G.:*Sveriges skogar under 100 år*, Stockholm, 1959.

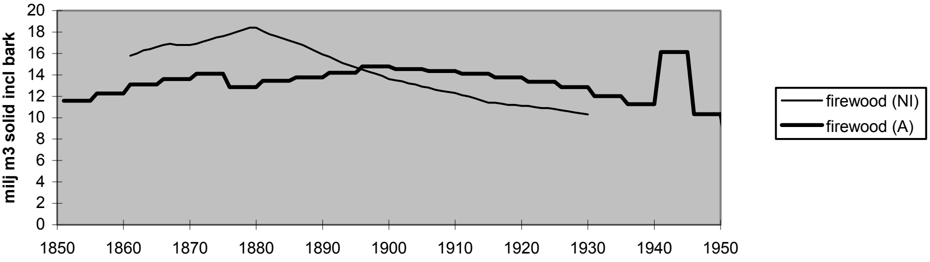
[11] ibid, table 38, p 197.

[12] For example two investigations, performed for Norrland, in 1914 and 1944 respectively, both give a value of 8 m^3 (solid measure including bark) per head, but Arpi assumes an average value of 5.9 m^3 (solid measure without bark) for 1914 and 4.7 m^3 for 1944. Despite a 20% increase of Arpis measures in order to calculate inclusion of bark, they do not come near the investigations results, and Arpi does not explain the deviation.

It is assumed that 70% of the wood consumption in Arpi's calculations is firewood.[13] Their results differ especially much for 1880-1910.

Schön, who took comparatively more interest in industrial firewood consumption, provided a rough estimate of household firewood consumption for 1800-1990. This estimate relied on the estimates by N.I. for 1860-1930, and for the period 1800-1860 it held per capita consumption constant according to the figure of 1861. For the period between 1931 and 1990 Schön used benchmark figures from the Second World War and from the 1980s to establish levels of household firewood consumption. Annual fluctuations between the benchmark years were modelled on the basis of the difference between total firewood consumption according to the forest statistics and the firewood consumption for industry according to SOS Industry.

Figure 2.1 Total household firewood consumption, according to N.I. and according to Arpi.



Sources: Lindahl, E./Kock, K./Dahlgren, E.(1937):"*The National Income of Sweden 1861-1930*", Stockholm, p 164 and Arpi, G.(1959):"*Sveriges skogar under 100 år*", Stockholm, part 1, p 206.

The period 1800-1920

The best method to estimate household firewood consumption for the period 1800-1920 is to generalise the Värmland- investigation to the national level, like Jonson did, to establish a benchmark value for 1920 and then construct a series backwards in time, based on changes in relevant variables. My benchmark value for 1920 uses Jonson's figures for rural consumption and the results are that in the countryside of southern Sweden, consumption in 1920 was on average 2.1 m^3(s)/head, while it was substantially higher, or 4.7 m^3(s) in northern Sweden. The average consumption for the national countryside was 2.6 m^3(s). Jonson assumed urban consumption to be 1.25 sm^3, but provides no

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[13] According to an investigation in Gävleborgs län in 1936-1941 the firewood consumption amounted to 64-76%. See Arpi, op. cite, p 195. Of course this figure might have been changing over time and might also have differed between regions.

support for this figure. The Värmland-inquiry does not contain investigations of the urban population, but it refers to an investigation of 252 urban persons (in Åmål, Ludvika and Karlskoga), who consumed on average 0.64 sm^3/head in 1913-1914.[14]Some guidelines for the urban population are found in an investigation from 1936, where an estimate of national firewood consumption on the regional level was made.[15] It relates the results of investigations of urban firewood (and other energy) consumption, but unfortunately without references. 12 cities are included, and the average is 0.9 sm^3/person and year, with a variation from 0.7 sm^3 to 1.4 sm^3.[16] This average is used for my benchmark value for 1920.

Four factors are important for modelling the amounts of household firewood:
1) Aggregate heating work increased. The demand for energy for heating rose as an effect of larger dwelling area/person and more comfortable indoor temperatures. [17] At the same time, better insulation offset this increase to some extent.
2) Heating efficiency was raised by new constructions like dampers, heaters and tiled stoves, which reduced heat losses. Investments in energy saving technology took place when stoves broke down and had to be rebuilt, and in addition became more frequent with rising income.
3) A partial substitution of firewood for coal and coke occurred, which reduced the demand for firewood.
4) The population distribution changed. During the second half of the 19th century migration streams went from the countryside to the cities and from the southern provinces to the northern. Differences in fertility and mortality also affected the population distribution between countryside and cities, and between the North and the South. Since heating demands differed between localities, changes in population distribution affected aggregate household firewood consumption.

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[14] SOU 1924:42, p 66.

[15] Östlin, E., Telander, N., Frölén, F.(1936): *Utredning rörande brännvedsförbrukningen och brännvedstillgången i Sverige,* utarbetad år 1936 inom Byggnadsstyrelsens värmetekniska avdelning. The method there is to attempt to obtain figures for firewood consumption by first calculating the total energy consumption and then obtain figures for firewood consumption by subtracting the known consumption of other energy carriers (mainly coke and gas, to lesser extent electricity, oil and peat). In principle this appears to be a fruitful method, but the main drawback of the study is that the total energy consumption (or need) is not known.

[16] ibid, table 2, p 10.

[17] During the 1960s, for instance, the housing volume increased by 2.4% /year according to SOU 1974:64:*Energi 1985-2000,* p 86, while the population increased by 0.7%/year.

Of these four factors the best data is available for heating efficiency and population distribution. Heating work and substitution are subject to rougher assumptions.

Increased heating work:
The first encompassing housing survey was performed in Sweden in 1912/14 and the next one in 1920.[18] Before that no housing statistics exist, so estimates of changed heating work must be based on some qualitative facts. The majority of people in Sweden lived in houses with chimneys, dampers and glass windows at the beginning of the 19th century. In most cases only one room was heated during the winter, although additional rooms for summer use existed. Norrland was somewhat backward and at the beginning of the 19th century approximately 20% of the inhabitants lived in simple smoke huts, without doors and windows.[19] In the South the smoke huts were less numerous. Gradually these filthy smoke huts were abandoned in favour of stoves with a chimney. Improvements in building techniques of the ordinary country houses occurred, like the diffusion of ceilings (in contrast to simple roofs), forming an attic, which was moss insulated. This brought about better heat economy. But when people became better off they started to heat two rooms instead of one, and occasionally even three or four rooms, which instead tended to increase the heating work. Rising income especially among the low to middle income strata of the population after the 1850s should have speeded up the diffusion of extra stoves per household.[20] Besides, with rising income, a more comfortable indoor temperature was strived for.

So we have on the one hand more rooms heated at a more comfortable temperature, which tended to increase heating work, and on the other hand better insulation that partly offset this increase. My model comprises an increase of

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[18] In 1912-1914 the first encompassing Swedish housing inquiry was performed, but the results were published for regions and not much information was presented on the national levels. In 1920 a housing inquiry was performed (Allmänna bostadsräkningen år 1920, SOS, socialstatistik, Stockholm 1924) encompassing 89 cities and villages and 1.1 million citizens (out of 5.9 million).

[19] This conclusion is drawn from comparison with Finnish figures for the western, most modern parts of Finland, that should be largely comparable with Norrland at the time, provided by Timo Mattila and Timo Myllyntaus, Department of Social History, Helsinki.

[20] Schön, L.(1979)*Från hantverk till fabriksindustri. Svensk textiltillverkning 1820-1870.* (*From handicraft to factories. Swedish textile industry 1820-1870.* Diss.) Kristianstad , shows that demand for rough qualities of cloth, consumed by the low and middle income groups of the population increased from the 1840s, and was further increased from the 1850s, when coarse cloth was produced in large quantities at factories. Also Schön, L.: *Jordbruk med binäringar*, 1995, p 37-38, stresses that the income increases from the 1850s mainly benefited the low income groups, which was demonstrated by an increased relative demand for animal products although prices of animal products rose more than prices of industrial goods or grain. Schön interprets this as income increases especially accruing to people with a high marginal propensity to consume animal products.

heating work in line with assumed increases in numbers of rooms.[21] This means that I assume that improved insulation was out-balanced by a more comfortable indoor temperature.

Improved heating efficiency:

Efficiency of stoves increased substantially during the 19th century, which reduced firewood consumption in relation to a certain amount of heating work. For fuel economy in the open fires the diffusion of chimney dampers was crucial.[22] Sweden was early in adopting dampers and they were widely spread at the beginning of the 19th century.[23] The major firewood saving technical invention in the field of stoves had been made in the 1760s, through the several vertical smoke-channels.[24] The Cronstedt kind of stove had 50% thermal

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[21] In 1920 the number of heated rooms per capita were 0.74 (Allmänna bostadsräkningen, op. cite, p 67). The average number of rooms per household was 2.7, including the kitchen (the estimate is based on table G on p 54). I here assume that 2.5 rooms per household was an approximate figure on the national level in 1920 . I assume that heated rooms per capita increased rather slowly in 1800-1850, so that 30% of the households had two rooms heated in 1800, and 50% in 1850. Household size changed from 4.3 persons on average in 1860 to 3.7 in 1920 (*Historisk statistik för Sverige, part 1,* calculated on the basis of table 25 on p 84). This change probably further stimulated firewood consumption. On the other hand average room size is not known, and it probably decreased somewhat with more rooms per apartment, because when there was only one room for all activities (working, cooking, eating and sleeping) its size was larger than the sizes of extra heated rooms later on. Also, construction techniques further improved with double-glazed windows during the period and offset the increase. I here assume a zero net effect from those three factors, and simply take the increased number of heated rooms per household into account. These assumptions result in a 15% increase of heated rooms between 1800 and 1850, and another 67% between 1850 and 1920. This change should not have resulted in a proportional increase of firewood consumption, since the initial stove was a combined cooking and heating stove, which consumed much more firewood than the additional stoves in sleeping rooms, which were not heated as frequently. I assume that additional stoves only consumed half as much firewood as the cooking stove in a household. Then I arrive at an increased consumption because of this variable of 8% between 1800 and 1850, and another 34% between 1850 and 1920.

[22] Lindqvist, S.(1984)"Naturresurser och teknik-energiteknisk debatt i Sverige under 1700-talet", in Frängsmyr, T.: *Paradiset och vildmarken*, Stockholm.: p 96, claims that the large interest in economising on firewood consumption in tiled stoves during the 18th century was of lesser quantitative importance than it would have been to put dampers on the many open fires. Lindqvist's view concerning the spread of dampers departs from Erixon's view in Erixon, S.:"Spjället, en exponent för svensk bostadsteknik", *Svenska kulturbilder*, ny följd, vol5, part 9-10. Still Lindqvist names Erixon as his source of information.

[23] Except on Gotland and in southern Skåne, according to Erixon. It does seem strange that the wood scarce counties Gotland and southern Skåne, lacked incentives or possibilities of introducing dampers, but Linnés testimony and surprise concerning Gotland's lack of dampers can not be mistaken. According to Erixon (p 16) Linné stated: "Uti inga Hus här på Orten brukte Bönderna några kackelugnar ej heller Spiäll til sina Spisar, utan måste om Wintren hafwa en stadig eld". Erixon claims that in northern Skåne dampers were introduced from the beginning of the 18th century (rather late compared to the rest of the country), but that southern Skåne was much later.

[24] Cramér, M.(1991) *:Den verkliga kakelugnen,* Stockholm, p 84. This invention is declared to have been appreciated and spread on a large scale thanks to its capacity to store heat and save firewood.

efficiency, while an ordinary open stove only had 10% thermal efficiency.[25] The new stoves were invented by direct commission of the state, and were readily commercialised. However, tiled stoves were expensive and mainly a city-phenomenon, although they existed in the countryside on the larger estates. In the countryside the same kind of technology, with several vertical smoke channels, spread, but the stoves were plastered instead of tiled. The diffusion of Cronstedt's stove should have been fairly rapid even in the countryside, because the heat destroyed the stoves so they generally had to be rebuilt every 20-30 years, and then new technology, if available, was introduced. I assume that Cronstedt's stoves diffused rather slowly during the 18th century, to speed up in the first half of the 19th century.[26] Thermal efficiency improvements continued. Double doors, with the possibility of regulating the inflow of air, improved efficiency to 60%, and counter flow smoke channels improved efficiency in the best cases to 85%.[27] Substantial improvements in thermal efficiency worked strongly in the direction of reducing firewood per capita.[28]

Coal substitution:

Coal and coke partly replaced firewood. Mainly urban households and rural households in wood-scarce counties like Skåne, Halland and Bohuslän used coal and coke for heating. Ordinary stoves could use coal and coke, if equipped with an iron bar that was inserted and removed according to need. Without this bar there was a risk that the stove would break from the heat. Coke was not imported until the 1880s, and then only on a small scale, but it was domestically produced as a by-product in gas-works and sold to the citizens of the city for use in their private heating stoves.[29] With the concomitant expansion of city-gas and coke production from the middle of the 19th century, firewood both for cooking

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[25] Larsson, H.(1979): *Vedeldning genom tiderna-från Cronstedts kakelugn till Hugos kamin,* tekniska högskolornas energiarbetsgrupp (the) rapport nr 5, p 8. An ordinary open stove had an efficiency of 10%, while Wrede's stove had an efficiency of 20% and Cronstedt's stove had 50% efficiency.

[26] In 1800 I assume that 20% of the stoves were of Cronstedt kind. In 1850 I expect the diffusion of Cronstedts' kind of stove to have reached 60% of the population.

[27] Ekman in Stockholm introduced the counterflow stove in 1883. *Finnish Industrial Journal. Uppfinningarnas bok.*

[28] I assume that these technical improvements together with higher incomes and concomitant more rapid diffusion resulted in an efficiency of Swedish stoves in 1920 of 70%. The technical development, with these diffusion assumptions, (ceteris paribus), thus resulted in a decreased consumption between 1800 and 1920 of 71%.

[29] See for instance: Gasverket i Lund. *Övriga specialer 1864-1872. Coces Conto Debet* (Stadsarkivet i Lund) The monthly sellings of coke to the population is there recorded, and display a large amount of private persons buying small quantities, together with some larger buyers such as glove-manufacturers, pharmacists and coppersmiths.

and for heating was increasingly replaced.[30] Ordinary coal was also used for heating of dwellings, but households preferred the purer coke.

The introduction of central heating raised the demand for coke.[31] In Lund, which was early in adopting central heating (10% of the apartments were so equipped in 1920), the book-keeping of the gas work shows an increasing importance for coke. However the growing importance was not obviously related to the diffusion of central heating, which indicated that coke was also used in ordinary stoves.[32] I use the estimate of appendix A as a basis of coal for firewood substitution in 1850 and for 1850-1920 I assume a linear increase in substitution rates.[33]

Population distribution:

During the 19th century population increased relatively more in the cities and in the North of Sweden. Firewood consumption was generally lower in urban households than in rural households, because of larger coal substitution and higher habitat density, and because the spread of more efficient stoves occurred more rapidly among urban households.[34] Despite an increase of population, from 2.4 million in 1815 to 3.8 million in 1860, urbanisation did not speed up during the first half of the 19th century. From almost a tenth living in cities in the

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[30] Olsson, S-O (1993):"Energihistoria med miljökonsekvenser", p 224-225, in *Äventyret Sverige,* Utbildningsradion och Bra Böckers Förlag.

[31] Central heating was not spread on a larger scale until the 1920s. See SOS: *Bostäder och Hushåll, enligt allmänna bostadsräkningen 1945 och därtill anslutna undersökningar*, p 87: "In Stockholm the proportion of apartments with central heating was 11% in 1915. In 1925 it was 22% and in 1930 it was 46%. It was thus during the 1920s that central heating became more common in Stockholm". In 1945 the figure for Stockholm was 79%. In other parts of the country the introduction was generally later and slower, see table 59, p 88. Central heating was not necessarily fuelled with coke; firewood or coal could also be used.

[32] Gasverket i Lund. *Verksamhetsberättelser 1886-1950*. In 1886 the income from selling coke was 16% of the income from selling gas. In 1901 it was 28%. In 1911 it was as much as 46%, in 1921 it was 21%, in 1925 it was 33% and in 1930 it was also 33%, while in 1950 it was as much as 66%.

[33] In appendix A coal for heating in households and service premises is estimated to have made up roughly 50% of total coal consumption in 1850. A rough indicator of substitution is provided by assuming that all that coal (only 1.3 PJ; not much relative to firewood) was used by households. Household coal consumption reduced household firewood consumption proportionally. In 1850 total household coal substitution amounted to 1.3 PJ and in 1913 to 33 PJ. Per capita this substitution equals 420 MJ in 1850 (or 0.06 m^3 of firewood) and 5850 MJ (or 0.85 m^3 of firewood) in 1913. So substitution resulted in an absolute decrease of firewood consumption per capita of 0.8 m^3 between 1850 and 1913. Assuming the same proportion of household coal consumption in 1920 as in 1913 gives an absolute decrease of firewood consumption per capita of 0.53 m^3 between 1850 and 1920 or a relative decrease of about 20% between 1850 and 1920.

[34] Järnegran, A., F. Ventura and O. Wärneryd, (1980): *Samhällsutbyggnad och energiförsörjning*, suggests that in the 1860s population density in the countryside was extremely low (only 2-3 persons per house), while urban density was around 10-12 people per house. Of course in urban areas houses were in general larger, with several apartments, but they still suggest that habitat density was much higher in the urban areas.

middle of the 18th century, the proportion was no more than 11 % in 1860.[35] In 1880 the share had increased to 15 %, in 1900 to 22 % and in 1920 to 30%.[36] This implies that from the middle of the 19th century the increased urbanisation tended to decrease the aggregate household firewood consumption. Most of this effect is already encompassed in the substitution factor and the technical efficiency factor. The only thing not yet taken into account in the modelling is the higher density of persons in urban dwellings compared to rural, which worked in the direction of reducing firewood consumption.[37]

When Norrland increased its share of the population aggregate firewood consumption also increased, because the firewood consumption of the North, due to colder climate and better access, was about double as high as in the South.[38] In 1800 10% of the Swedish population lived in Norrland, in 1900 the share was 16%, and in 1920 it was 17.5%.

Changes in population distribution resulted in a minor net increase of firewood consumption.[39]

Net result from the four factors

The model is an extrapolation of figures from 1920 back to 1800, with four parameters: 1) a changed heat work variable 2) an efficiency variable 3) a substitution variable and 4) a population distribution variable.

In the period 1800-1850 only small increases in number of heating stoves per household took place because of fairly low increases of income. Thermal efficiency gains through the diffusion of Cronstedt's technology were widely experienced. Coal imports were still too low to affect firewood consumption, and urbanisation had not yet started, and the share of northern population had only increased from 10% to 11%.

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[35] Högberg, S.:"Sex hundra år av svenska äventyr", p 37, in *Äventyret Sverige*, 1994, Bra Böcker och Utbildningsradion.

[36] Historisk statistik för Sverige, part 1: *Population*, table 14, p 66.

[37] The relative development of firewood consumption in urban versus rural areas we know little about; still this relation is of importance when deciding the impact of urbanization on total household firewood consumption. In 1920 urban firewood consumption was roughly 35% of rural firewood consumption. Prior to that, before coal substitution had permeated household heating to that extent and the faster technical development in cities had shown its impact, urban firewood consumption should have been more like the rural consumption. Here I simply assume that 1/3 of the lower consumption in cities could be explained by higher habitat density (while substitution and technical advance together explain 2/3). This means that a redistribution of the population from the rural to the urban areas would reduce the firewood consumption by 20% only because of the density factor. This results in a *decreased* firewood consumption of 4% for 1850-1920.

[38] This suggests an *increase* of household firewood consumption between 1860 and 1920 of 7%. 1860: $0.10*2x+0.9x=1.1x$, 1920: $0.175*2x+0.825x=1.175x$. The increase is thus $1.175/1.1-1=$ 7%.

[39] The net result of migration during the period is +3%.

Between 1850 and 1920 the number of heating stoves increased more rapidly than between 1800-1850, due to increases in income. The thermal efficiency gains continued on a wide scale. In this period coal substitution and population distribution also affected firewood consumption.
The results are presented in table 2.2.

Table 2.2 Relative changes in household firewood consumption, 1800-1850 and 1850-1920, in percent, per capita.

	Effect from heating work	Effect from efficiency	Effect from substitution	Effect from population distribution	Net effect	Annual change
1850-1920	34%	-51%	-20%	4%	-33%	-0.47%
1800-1850	8%	-41%	0%	0%	-33%	-0.66%

These calculations, besides serving the purpose of providing the foundation for a series of household firewood consumption for 1800-1920, indicate the relative importance of the four factors. The two factors, heating work and thermal efficiency, had a larger influence on the development of aggregate firewood consumption than substitution and population distribution, especially since they worked during the entire period 1800-1920.

The results of per capita firewood consumption are presented in table 2.3.[40]

Table 2.3 Estimated household firewood consumption per capita in 1800, 1850 and 1920

	1920	1850	1800
Firewood/capita	2.1 m^3	3.1 m^3	4.7 m^3

The household firewood consumption series for the period 1800-1920 has been constructed through linear interpolation.[41]

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[40] The change between 1920 and 1850 is -33%. In 1920 the per capita firewood consumption was 2.1 m^3. This gives: 2.1=x*0.67, where x= per capita firewood consumption in 1850. x=3.1m^3. Between 1850 and 1800 there was also a change of -33%. Thus, in 1800 the firewood consumption per capita was 3.1m^3/0.67=4.7 m^3

[41] A more elabourated method for annual figures was considered, where factor 1 could be related to income increases, factor 2 still be a victim of linear interpolation, factor 3 related to coal imports (with a linear interpolation of the benchmark proportions of household coal consumption) and factor 4 be related to actual population distribution. This method was dismissed on the ground that its elabouration is too fine compared to the very rough assumptions influencing the benchmark years in 1850 and 1800, and thus potentially deceptive.

The period 1920-1990

Between 1920 and 1990 there were inquiries that can serve as benchmark values. There was one national inquiry, sampling 20 000 farms with at least 2 ha cultivated land, performed by the Agricultural Investigation of 1938, which was never published, presumably because forest land was not well represented in the sample.[42] In 1950 there was a new national inquiry with better representativity, but it was somewhat biased towards large units. The sample was 28 000 agricultural units (amounting to 10% of the agricultural units of more than two hectares of land), and the result was that 8.5 million piled m^3, or 5.1 million solid m^3, were consumed by the total agricultural population, 87% of which was from their own cutting.[43] Total quantities of sold firewood for households and buildings amounted to 6 million piled m^3, or 3.6 million solid m^3.[44] Agricultural households used 0.7 million sm^3, so what remained for other usage was 2.9 million sm^3. The state and the county councils used approximately 0.24 million sm^3, so about 2.7 million sm^3 was consumed by urban households.[45] This means that in 1950 the aggregate household firewood consumption amounted to 7.8 million sm^3, which equals 1.1 sm^3/capita.

During the 1960s household firewood consumption was mainly estimated from the cutting side, in wood balance investigations. In these investigations consumption of industry is well accounted for and household firewood consumption is a large residual.[46] In 1964/65 household firewood consumption amounted to around 80% of 5/6 of 7.2 million pm^3=0.8*5/6*4.3 million sm^3= 2.9 million sm^3, or 0.37 sm^3/capita.[47]

In 1975 household firewood consumption was 1.0 million sm^3, which is only 0.12 sm^3/capita.[48] It may appear strange that the substantial rise of oil prices in 1973 did not lead to an immediate response in the form of substantially increased firewood consumption. One explanation is a technical lock in effect: unlike the situation during the wars years, when coke could be replaced by firewood, many households at this time only had access to oil specific stoves that could not be used for solid fuels.

For the 1980s there are several estimates by the SCB (Statistical Central Bureau) on household firewood consumption, based on inquiries. During the 1980s household firewood consumption rose rapidly, showed a peak in 1985 and

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[42] SOU 1954:29 *Klenvirke: användning av barrklenvirke, lövvirke och sågverksavfall*, p 94.

[43] SOU 1954:29, p 105.

[44] SOU 1956:58, p 42. They refer to an estimate by statens bränslekommission, which I have not been able to trace.

[45] See *Skogsstatistisk årsbok 1952*, p 50 for a table.

[46] SOS *Industri*

[47] Skogsstatistisk årsbok 1964/65

[48] Skogsstatistisk årsbok 1976, p 83.

in 1990 amounted to 5.1 million sm^3, but only 3.6 million sm^3 of this was stem wood; the rest was branches etc.[49] In addition households used firewood indirectly, through district heating from plants that combusted firewood.[50] Per capita the direct consumption by households in 1990 (branches etc. included) was 0,59 sm^3.

In the early inquiries only stem wood was counted and not tree tops and branches. It seems reasonable that the proportions of trash and branch wood were about the same in 1950 as in 1920, because forestry was not then mechanised, with large-scale district cutting and lorry transports, which was a technical development that facilitated the use of tops and branches.[51] In 1965 and in 1975 when investigations were from the cutting side, tops and branches were already included in the statistics, so no adjustment is necessary.

Table 2.4 Household firewood consumption, 1920-1990, solid cubic metres per capita

1920	1950	1965	1975	1980	1985	1990
2.1	1.1	0.37	0.12	0.47	0.72	0.59

Sources: 1980-1984: ”Virkesbalanser 1985”, p 59-60, 1985-1990: Skogsstatistisk årsbok 1994, p 203. Other sources, see text above.

The War periods

The impacts of the World Wars on household firewood consumption must be taken into account. Imports of coal and oil were severely restricted during the War years and domestic energy sources were exploited to cover for the losses. During the First World War the state took responsibility for firewood provision by cutting their own forests and buying standing trees from private holders. The state also sold firewood to households at a subsidised price according to the estimated need for different counties.[52] The firewood sold to households by the state amounted to about 1,5 million pm^3/year in the years 1917-1919, but households also bought firewood elsewhere and some farmers cut their own firewood. [53] Here I assume that the annual amount sold by the State Fuel Commission to households, both as subsidised fuel (0,9 million sm^3) and at

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[49] Fridh, M. *Virkesbalanser 1992,* Skogsstyrelsen 1993:2, pp 40-47.

[50] In 1990 the firewood used in district heating plants was 1,3 million m^3 (s). See *Virkesbalanser 1992*, p 46. Only part of this was used for heating of household dwellings, the rest for public buildings, greenhouses etc. Unfortunately the household part is not known.

[51] Johnson assumed that the figures of the Värmland investigation should be increased by 10% to cover for the branch and trash wood. I have made the same assumption for 1920 and for 1950.

[52] SOU 1922:14: *Statsmakterna och bränsleanskaffningen under krigsåren- av bränslekommissionen avgiven berättelse över dess verksamhet åren 1917-1921*, p 14ff

[53] SOU 1922:14, p 214-215. During the first years of the war the coal imports were not much affected, but from 1917 they almost ceased. Pm^3 means piled cubic metres.

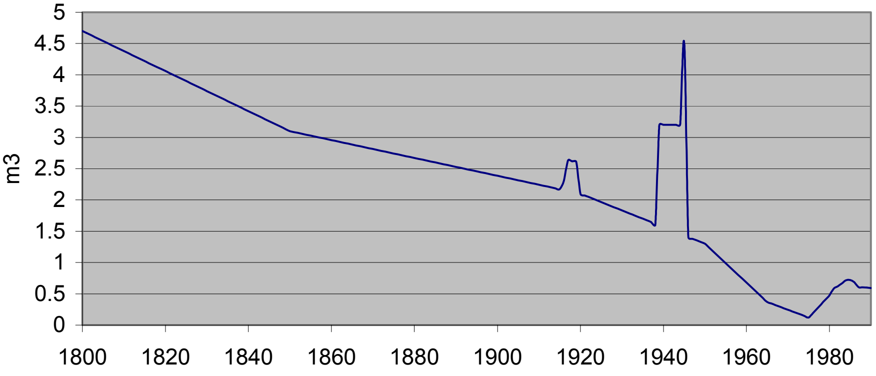
normal prices (1,2 million sm^3, corresponding to 0,36 sm^3/cap), made up the increase of firewood during the First World War.[54]

During the Second World War the state was more passive in ordering private holders to cut and sell at fixed prices. An estimate by the State Fuel Commission indicated that total firewood consumption approximately doubled during the Second World War; from 20-25 million pm^3/year before the war to 35-40 million pm^3/year.[55] Here I assume that household consumption also doubled during the war, and trebled in 1945 when coal imports almost ceased (the same assumption is made for service firewood). This assumption produces a peak in firewood consumption in 1945 that overstates the actual firewood consumption of that special year, but gives a total energy consumption that is reasonable. This is because I do not count changes in stocks of coal, only what was imported each year, and it is likely that coal consumption was larger in that year than indicated by the import statistics.

Results

The household firewood consumption expressed as per capita figures is depicted in figure 2.2 and the aggregate amount is depicted in figure 2.3.

Figure 2.2 Household firewood consumption per capita and year 1800-1990, in solid m^3.



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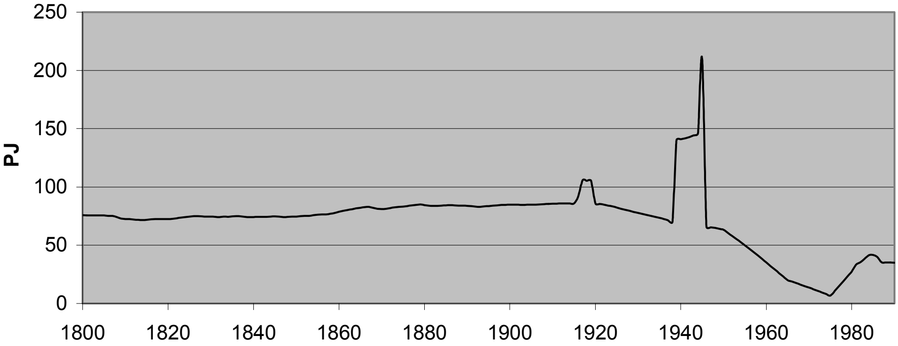
[54] SOU 1922:14, p 218.

[55] SOU 1954:29, p 11. The State Fuel Commission = Statens bränslekommission.

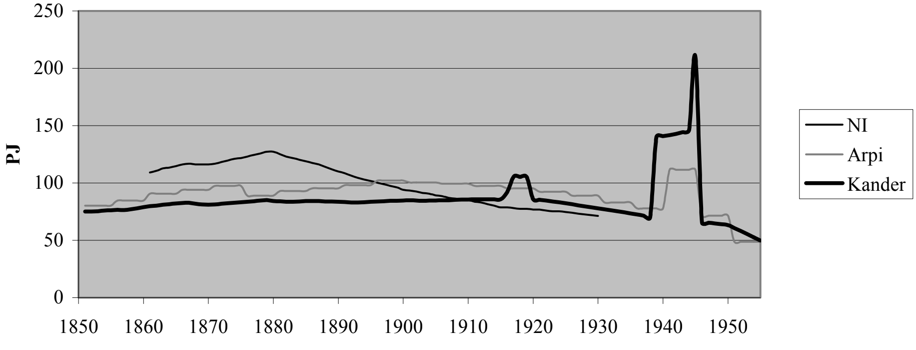
Figure 2.3 Total household firewood consumption 1800-1990, in PJ



Method: The energy content of firewood is according to Skogsstatistisk årsbok 1.92 MWh/m^3(S). 1 Wh=3600 Ws, 1Ws=1joule (J), hence the energy content of 1 m^3 firewood expressed in joule is 1.92*3600=6910 MJ. PJ = 10^{15} J. The energy content of firewood depends both on the kind of tree and how wet the tree is on combustion. Variations are rather large, so the conversion measure I use here must be considered uncertain.[56]

Figure 2.4 shows Arpi's, N.I.'s and my results for the period 1850-1955. My results coincide fairly well with Arpi's, but have larger impacts of the wars and a smoother appearance.

Figure 2.4 Various household firewood estimates 1850-1955, PJ.



Sources: Kander: own estimates, Arpi and N.I.: see figure 2.1

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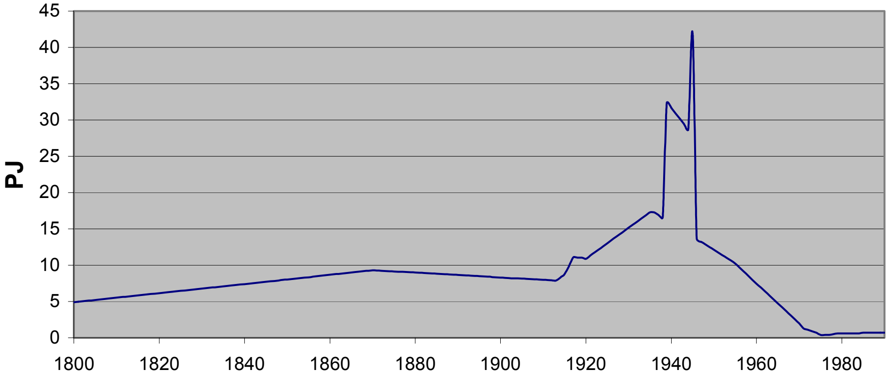
[56] Håkansson, M & C. Steffen (1994) *Praktisk skogshandbok*, Sveriges skogsvårdsförbund, Danderyd, p 145-146.

Service firewood consumption

There is very little direct information on energy consumption in the service sector. In my study service firewood consumption is estimated as a varying share of service energy consumption, which in turn is estimated as a varying share of household energy consumption. An important similarity between service energy and household energy is that the bulk consists of heating. A difference is that larger residences are a more likely outcome of increased income/capita in the long run than is larger heated area per employee in the service sector. Dwelling area is an end in itself and therefore tends to become larger, if not infinitely so at least up to income levels that are relatively high. In the service sector, heating is just a means for production. Once optimal working conditions have been achieved in the service sector every further increase in heated area per employee only represents an increased cost, thus reducing profitability. I assume that heating standards developed evenly in services and households until the turn of the century, after which heating standards in households developed more quickly. The assumptions and calculations are described in appendix D and in figure 2.5 I just present the series of service firewood.

Figure 2.5 Service firewood consumption in Sweden 1800-1990, in PJ.

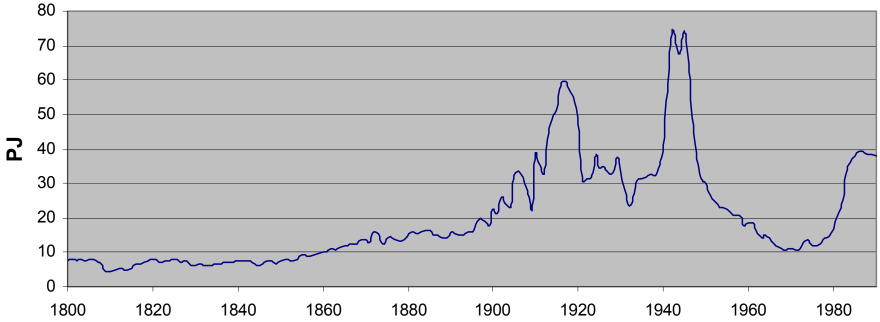


Industrial firewood consumption

Schön has estimated industrial firewood use back to 1800 on branch level. For the period 1800-1890 the main firewood consuming industry was the metal industry and Schön has access to good sources of its relative fuelwood consumption.[57] For production in the iron industry Schön has elabourated and revised previous estimates, on the basis of both public statistics and archive material. For the other minor industrial branches, together only making up a small share of industrial firewood, constant firewood intensities have been assumed for the period 1800-1900.

The industrial statistics present detailed energy data on branch level from 1921. For the period 1900-1920 Schön based his estimates on extrapolated trends for branch energy intensity (energy use/production volume) of the period 1921-1935, combined with production figures.

Figure 2.6 Industrial firewood consumption in Sweden 1800-1990, PJ



Source: Schön, L. data-files for the study: "Trädbränslen i Sverige 1800-1990". Included here in industrial use is firewood for charcoal production and after 1900 firewood for electricity production, and later also for combined electricity and heat production. Spent pulping liquor is not included here, since it is not a pure wood fuel: it also consists of chemical fluids.

Total firewood consumption

With sector constructions it is possible to calculate the aggregate firewood consumption, which is presented in figure 2.7. It also contains a series of wood-based waste from the pulp industry (spent pulping liquor).

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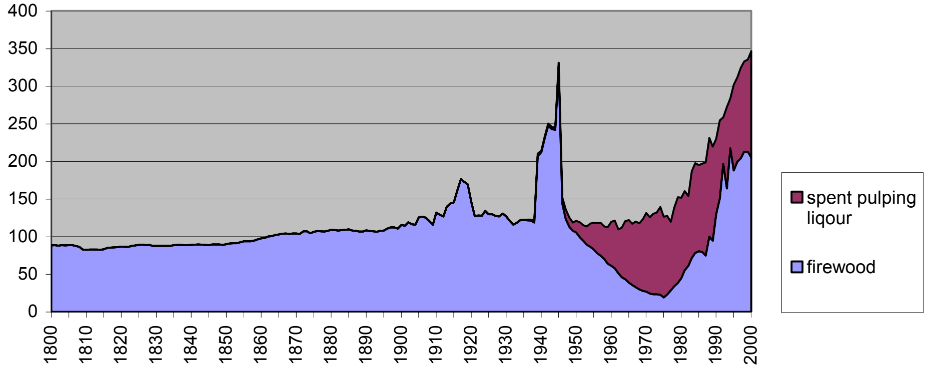
[57] Schön, L.(1988) *Industri och hantverk 1800-1980*, HNA, Lund, p 135-140.

Figure 2.7 Firewood and spent pulping liquor consumption in Sweden 1800-2000, PJ.



Sources: My estimates of household and service firewood consumption 1800-1990. For industrial firewood see figure 2.6. Firewood 1990-2000: SCB. Spent pulping liqour: data file from Lennart Schön 1935-1987, 1988-1989: Wiberg, Rolf: *Energiförbrukning i massa och pappersindustrin 1988*, estimate based on Nutek *Energirapport 1991*, R 1991:1, 1990-2000: SCB.

Animate power

The second large traditional energy carrier, for which we do not have statistical information, is animate power. Hamilton suggests that muscle power made up 79% of the motive power in Sweden in 1850, or 382 000 hp, out of which human power made up 104 000 hp and animal power 278 000 hp. Steam-power only amounted to 1%, or less than 5000 hp, and wind and water amounted to 20%, or 95 000 hp.[58] Hamilton assumes that 60% of the population were engaged in hard work and that a hard working individual is capable of 0.05 hp. Hamilton chooses to account for power (energy/time-unit) instead of energy, which means that he does not have to make assumptions of the time that animals or humans worked.

Human muscle energy

The proposition by Hamilton that human muscle energy was very important compared to other motive sources does not necessarily imply that it was significant in relation to total energy, since energy amounts for heat were large. In order to estimate the size of human energy one must first decide on method. An overview of nine alternatives to calculate human energy, and their typical

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[58] Hamilton, U.(1982): "Den blygsamma ångmaskinen. En studie av arbetsresurser i Sverige 1800-1850", in *Fataburen*, p 31.

outcomes, for agricultural workers is provided by Fluck.[59] The most narrow calculation, which means that only the extra food consumed for work is calculated, results in a typical value of 1 MJ/day (240 kcal) per worker. To count energy spent during work gives a value of 5 MJ/day (1200 kcal). If total food for the worker is counted this results in 12,5 MJ/day (3000 kcal).[60]

The appropriate method for this study is to count all food energy consumed while working as inputs to production and regard the rest of human food consumption as final energy consumption. The energy consumed while working varies with the number of work hours and intensity of work. Both these variables change over time in Sweden. In addition there have been changes in workforce participation rates as a consequence of changes in child work, female participation rates and length of working careers.

A dynamic modelling of human energy consumption from the work-side would be interesting in relation to historical food energy studies.[61] It would have the advantage of paying regard to the crucial balance between energy intake and energy expenditure, which is overlooked in several economic historical works.[62]

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[59] Fluck, R. C.(1991): *"*Energy of Human Labour*"* , p 31-36, in Stout, B.A.: *Energy in World Agriculture*, vol 6, Elsevier.

[60] ibid, p 32.

[61] See Morell, M.(1987):*Studier i den svenska livsmedelskonsumtionens historia. Hospitalshjonens livsmedelskonsumtion 1621-1872*, Uppsala, pp 3 - 31 for a pertinent summary of Swedish historical food research.

[62] Abrahamsson, L. (et al) (1983): *Näringslära för högskolan*, Solna, p 67. If an individual consumes more energy than is spent he/she is in a state of positive energy balance, and grows fat. The reversed case with too low energy intake compared to the expenditure (negative balance) initially releases energy from fat and protein reserves, and if it continues it leads to starvation and eventually death.
The most well-known Swedish estimate of food energy consumption is probably Eli Heckscher´s broad investigation regarding food consumption of agricultural workers, from the 16th until the 19th century, published in *Sveriges ekonomiska historia från Gustav Vasa*, 1:1-2:2, Stockholm 1935-49. His investigations were based on payments in kind on a large number of crown estates. The results showed very large differences between the centuries, with very high energy consumption during the 16th century, much lower during the 17th, and a consumption somewhere in between during the 18th century. Heckscher´s figures have given rise to intense debates and several revisions, to some extent levelling out the differences between the centuries. Morell, M. *Eli F. Heckscher, utspisningsstaterna och den svenska livsmedelskonsumtionen från 1500-talet till 1800-talet*, Uppsala papers in Economic history, 1986, presents a scrutinising overview of the previous debate and provides convincing support for his own critique of Heckscher´s conversions of certain old units. The results, solely based on the conversion-critique, and not on his other qualitative critique suggest that the 16th century did have high energy consumption as well as a large proportion of animal energy intake. However, the differences from the 17th and 18th centuries were not as large as Heckscher had suggested. The connection between different levels of energy intake and the work that could possibly have been carried out during different centuries is not discussed, which may seem odd in economic historical works, where economic performance and conditions normally are addressed.
In Essemyr, M.(1989) *Bruksarbetarnas livsmedelskonsumtion. Forsmarks bruk 1730-1880*, p 143-147, the question of whether the iron-workers could really have worked as hard as we think they did, is

However, in this study, where the aim is to quantify total energy consumption, estimates of human muscle power do not deserve too much effort, for two reasons. First, one can easily show that its order of magnitude is not large enough. If only the part of the food intake that is actually consumed during work is counted and with the unrealistic assumption that everyone in the population worked hard, the amount will be around 1/ 12 of the firewood consumption for the beginning of the 19th century (1 200 kcal compared to 15 000 kcal).[63] Over time, with increasing total energy/capita the human muscle energy will be less significant. Second, the change of this factor over time is not very high per capita. Even with an assumption of the highest possible variation, say from all population occupied in physically strenuous occupations 60 hours per week to all population occupied in low-physical-intensity occupations 40 hours per week, the change on a daily basis would not exceed 1200 kcal/day and capita.[64]

I have modelled human muscle energy in the following way: average food consumption per capita and day has been assumed to be 2600 kcal.[65] It has been argued that there was an industrious revolution preceding the industrial, implying longer workdays and harder work from people in response to increased supply from the evolving market economy, which seems reasonable.[66] Industrious and industrial revolutions are supposed to have increased intensity of work up until 1890, so that average food intake then was 1.05*2600 kcal. After 1890 the gradual substitution of machines for labour is supposed to give a continuous decrease back to 2600 kcal in 1990. The data for apportioning human food consumption to work input and final consumption are fetched from Sanne for the period 1890-1990: 15% of all human time was used for labour in 1890-1930, 9% in 1980 and 10% in 1990.[67] I assume that 12% of all human time

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surprisingly not put. Instead Essemyr assumes that the discrepancy between the assumed energy needs of his workers and the calculated energy provision could be eliminated by some (to him) unknown food source.

[63] Actually the ratio is even less since all humans did not participate in production; small children and the sick and elderly did not.

[64] FAO/WHO: *Energy and Protein Requirements*, 1973, p 30, state the difference to be 800 kcal. However this estimate of differences between the needs of light occupations compared to very active occupations, is based on a 40 hour work week. With longer workweeks, like 60 hours which was common in Sweden during the 19th century (see for instance Tegle, S. *Den ordinarie veckoarbetstiden i Sverige 1860-1980, en översikt*, Lund, Meddelande från Nationalekonomiska institutionen, 1983:86, p 13.) the magnitude of possible differences grows by 50%.

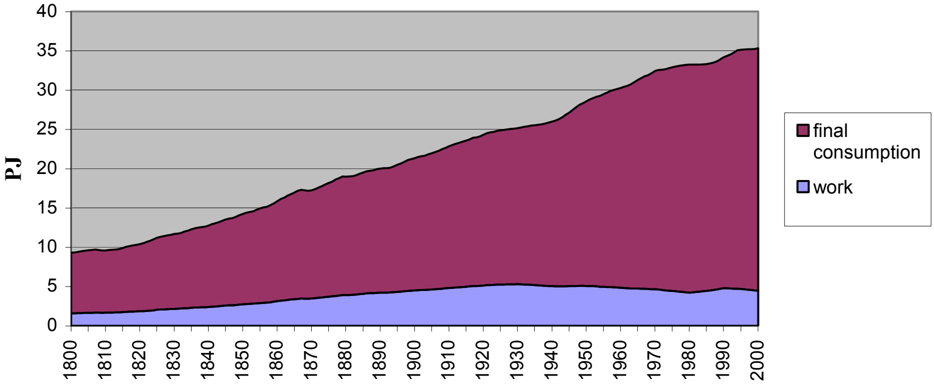
[65] FAO/WHO (1973), op. cite, p 28, suggests that 3000 kcal is needed per day for an average man (65 kg, moderately active) and 2200 kcal for an average woman (55 kg).

[66] De Vries, J.(1994): ”The Industrial Revolution and the Industrious Revolution”, in *The Journal of Economic History*, vol 54, June, p 249-270. Voth, H-J.(2000): *”Time and Work in England 1750-1830*”, Oxford, estimates that the length of the annual working year increased by 20% in England between 1750 and 1830.

[67] Sanne, C.(1995) *Arbetets tid. Om arbetstidsreformer och konsumtion i välfärdsstaten*, Carlssons, my reading of figure 2.4 on p 38.

was used for labour in 1800 and that it increased linearly until 1890, because the diversification of agriculture prolonged the working seasons and because people had larger incentives to work more as the market economy expanded. People generally consume more energy at work than in their leisure time; therefore I increase the labour time-share by a factor of 1.4.[68]

Figure 2.8 Human energy in Sweden 1800-2000, PJ, apportioned to work and final consumption



Source: own estimates

Draught animal muscle energy

Draught animal muscle energy plays a larger role than human muscle energy and varies more over time. Horses, oxen and occasionally even cows were used as draught animals in Sweden. It was not until mechanisation in the middle of the 19th century that oxen were gradually replaced with horses as draught animals, because of their greater strength and suitability for the new tools.[69]

From the human perspective horses and oxen could be regarded as living machines that convert chemical energy into motive energy. The motive energy is to a large extent employed for human purposes, for instance when the draught

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[68] WHO/FAO (1973), op. cite, p 29. An average 65-kg man who consumes 3000 kcal per day and is occupied 8 hours per day in moderately hard work spends 1400 kcal at work. This means that 47% of his energy is spent during 33% of his time, i e. energy at work is about 1.4 times as high as in rest (47/33=1.42).

[69] Szabó, M.(1982):"Jordbrukets tidiga mekanisering", in *Fataburen*, p 39-40. Oxen were, however, not used as draught animals in all European countries, for instance Malanima, P.(1997):"*Between two energy systems – Energy consumption in Europe 1600-1800*", Paper presented at the Journeés Braudeliènne, The Hague, 23-24 May, claims that oxen were not used in the Netherlands or England , but in France and Italy.

animals are harnessed to a plough, a wandering or a carriage. All fodder consumed by the animal, also the energy needed for rest, is from the human perspective a necessary cost for the draught work of the animal. To calculate the primary energy of the fodder consumed by draught animals there is a need for information on the numbers of animals, size, work time and the energy content of the fodder. All this information is not available and assumptions, based on indications of trends, are necessary for the estimates.

Numbers

There is statistical information on the number of horses and oxen from 1805.[70] Linear interpolation has eliminated some obvious data inconsistencies.[71] At the age of two the taming process of the ox started and a year or two later it was fully trained and worked hard for 2-3 years.[72] Then the ox was sold to a large farm for fattening over another two years and eventually it was slaughtered. It seems reasonable to reduce the oxen numbers by a figure, around 20%, to account for final fattening, when numbers of draught oxen are calculated. [73] Because statistics of horses include foals I reduce their number by 10%. More generally, Sweden had access to as many draught animals in relation to its population at the beginning of the 19th century as France, one of the few other countries for which statistics exist, had at the end of the 18th century: one draught animal per every four humans.[74]

Size development

The breeding of horses and cattle, where domestic breeds were crossed with foreign kinds, became common during the 19th century. Horse breeding was mainly designed to provide strong working horses. Cattle breeding was devoted to increased beef and milk production and the emphasis changed over the century according to market conditions for beef and milk. During the 1860s and

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[70] *Historisk statistik för Sverige, part 2*, tables E 31, E33, E34.

[71] For oxen the figures in table E32 have not been used since they probably included bulls. Instead a linear interpolation for the years between 1820 and 1860 has been carried out. For horses the figures for 1820-1860 seem unreliable; in many cases Stockholm city and some counties are excluded. Therefore an interpolation has been conducted there too.

[72] Petersson, G.(1997): ”Häst eller oxe”, p 46 in Myrdal, J & B Liljewall (eds) *Arbetshästen under 200 år*, Lund.

[73] Oxen under the age of two years were not reported as oxen, but as young cattle. Oxen between the ages of 6-8 years were fattened, if they had not perished before. This would lead us to conclude that 1/3 of the oxen were not used as draught animals anymore. Allowing for the fact that all oxen did not live until they were fattened and also the fact that cows to some extent were used as draught animals, we instead choose to reduce the oxen numbers by 20%.

[74] Malanima, P(2001):"The energy basis for early modern growth 1650-1820", p 53 in M. Prak (ed.), *Early modern capitalism. Economic and social change in Europe 1400-1800*, Routledge.

1870s, when England imported living beef cattle from Sweden, breeds with good beef qualities, for instance the short-horned-breed, were used for cross rearing. From the 1880s, when the Laval separator cut costs for butter production, good milk properties were valued higher. It seems reasonable that the draught capacity of oxen increased more when beef-properties were favoured than when good milk properties were aimed at.

Warm-blooded horses from the continent were crossed with the Swedish domestic country-horse during the first half of the 19th century, but this was a failure since the horses became too light and nervous to make proper working horses.[75] During the second half of the century foreign cold-blooded horses were used with better results. However, it was not rare that the crossed horse became an able work-horse but a lousy breeding horse. Most successful was the breeding of the Belgian Ardenner horse that started in 1873. The Ardenner became very popular. Its main competitor was the North Swedish horse, which was the result of rearing of the Swedish country horse with the Norwegian Gudbrandsdal breed. The Ardenner horse soon took the lead and in 1944 Ardenner stallions covered 83% of the Swedish mares and the North Swedish horse only 17%.[76] Furugren suggests that the Swedish country horse, at the beginning of the 19th century, was rather small and weaker than an ox; its height in hands should have been around 150 cm compared to 165 cm for the Ardenner, so breeding with the Ardenner increased horse size.[77]

Besides these genetic causes of animal size there are fodder aspects. When animals were insufficiently fed, as they often were during the winters, they did not develop their maximum size and draught capacity. The feed appears to have been especially poor during the winters in the period 1800-1840, when meadows were turned into cultivated land, which reduced hay production, and land consolidations eliminated common grazing lands. In the woodlands forests could provide additional feed through forest grazing and leaf collections, which to some extent offset these losses, but in the plains cattle were worse off. In the plains animals were mainly fed with straw and distillery waste. From the 1840s clover was more generally cultivated in the fields, which improved the feed, and during the second half of the 19th century seed and rape cakes further enriched the cattle diet.[78]

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[75] Dyrendahl, S.(1997): "Arbetshästens förändrade uppgifter i jord-och skogsbruket", p 19, in Myrdal, J & B Liljewall (eds): *Arbetshästen under 200 år*, Lund.

[76] ibid, p 26.

[77] Furugren, B.(1997): "Arbetshästen och svensk hästavel", p 132, in Myrdal, J & B Liljewall (eds): *Arbetshästen under 200 år*, Lund.

[78] Axelsson, J.(1933) *Den svenska husdjursavelns utveckling. Från 1800-talets början fram till våra dagar*, Lund, p 103, p 118, p 132.

My conclusion is that cattle or horses are not likely to have grown stronger and bigger during the first half of the 19th century.[79] During the second half of the 19th century both horses and oxen benefited from better feed. Breeding also affected size development during the second half of the century. During the 1860s and 1870s, when beef properties were stressed, draught oxen benefited from breeding. From the 1880s, when milking was stressed, it is less certain how breeding affected oxen draught capacity. Horses grew bigger and stronger from breeding, especially from the 1870s, when the Ardenner breed was introduced. These developments are included in the modelling.[80]

Working time

There are two reasons to expect that working times increased for the draught animals during the 19th century. First, diversification of agriculture prolonged the working seasons both for humans and their draught animals. Second, the substantial growth of agricultural production during the 19th century was not followed by a similar increase in the number of draught animals. Number of draught animals in agriculture only grew about half as fast as agricultural production. It seems likely that some of the explanation for this was that animals worked longer days and more days in a year. To reach any exact figures on the development of average working times for the animals is not possible, but I include an increase in my modelling.[81]

Fodder energy

Oxen and horses differ in one fundamental way when it comes to energy requirements; horses demand relatively more feed when they rest than oxen. This is because horses are also more active when they do not work. This difference is important, since it implies that it is easier to improve the thermal energy efficiency of horses than oxen. Efficiency in this case is the ratio between work energy and fodder energy on an annual basis. If the number of workdays increases horses need comparatively less additional food for that work than oxen.

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[79] More support for the idea that cattle, especially in the South, grew bigger from the mid 1850s is given by the relative prices of milk and beef in relation to cows, presented in chapter 6.

[80] For the modelling the following rough assumptions are made. Average horse weight is assumed to be 300 kg in 1800-1840, 350 kg in 1860, and 500 kg in 1900. The weight of an ox is assumed to have been 350 kg in 1800-1840 and 500 kg in 1880-1900.

[81] In the modelling it is assumed that horses (who were employed in forestry during the winter) on average worked 200 days in 1800 and 275 days in 1900, while oxen worked 150 days in 1800 and 200 days in 1900. The increase is supposed to have been linear between the benchmarks.

Bigger animals generally need less energy for their own subsistence because their body surface is relatively smaller and so heat losses are relatively smaller too. So, as the draught animals grew bigger they needed less feed per body weight unit in rest and their technical energy efficiency increased.

Hansson provides feed recommendations for oxen (500 kg) and horses (500 kg), which are summarised in the table below[82]:

	Ox (fodder units per day)	Horse (fodder units per day)
Subsistence feed	3.3	4.5
Easy work	6.0	6-7
Average work	7.0	7-8.5
Hard work	8.0	8.5-10.0
Very hard work	9.0	10+

There are no fodder recommendations for smaller animals, but the recommendations for a 600 kg workhorse provide some clues for the relations between size and feed, that I use to estimate the needs of smaller animals in this study.[83] The assumed needs of smaller horses and oxen are presented in the table below:

	Subsistence (fu/day)	Average work (fu/day)	Hard work (fu/day)
300 kg horse	3.4	6-7	7-8
350 kg horse	3.7	6.5-7.5	7.5-8.5
350 kg ox	2.5	6	7

The fodder unit equals the digestible energy content of 1 kg barley.[84] One kg barley contains 2800 kcal useful energy and approximately 3000 kcal digestible energy.[85]

I assume an increased intensity of work for draught animals until 1900 after which it stayed constant.[86]

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[82] Hansson, N.(1928): *Husdjurens utfodring. Dess teoretiska grunder och ekonomiska genomförande*, Stockholm, p 235.

[83] A 600-kg horse needs 5.4 fodder units (fu) in rest and 7-8 fu in easy work, 8-10 fu in average work, 10-12 fu in hard work and 12+ fu in very hard work. So increasing the weight by 20% (from 500 kg to 600 kg) only leads to an increased demand of 1/9 (11%) for subsistence.

[84] Hansson, N.(1928), op.cit, p 25, 43.

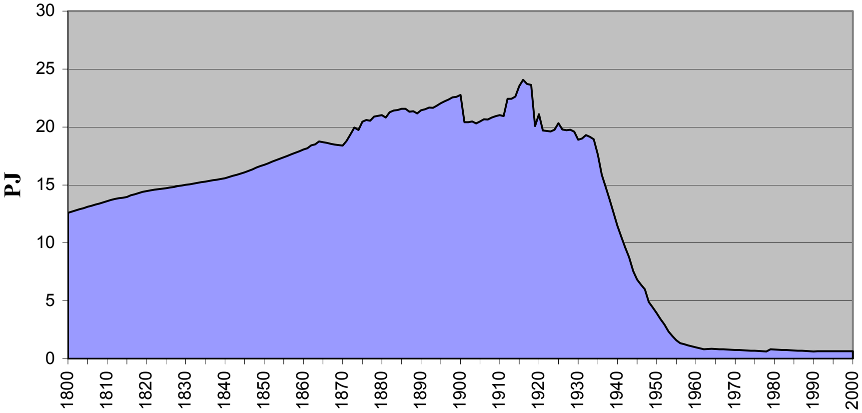
[85] Larsson, S.(1945): *Husdjurslära, del 2, Husdjurens utfodring och vård*, Stockholm, p 42. 30% of the gross energy in the fodder is not digestible; it simply passes through the body. The remaining 70% is called digestible energy. 61% of the gross energy is useful energy and 9% ends up as urine and methane. 1 kcal = 4190 joule.

[86] For my modelling I further assume that ox work-intensity was "average" for 1800-1840, that it increased gradually until 1880 when it was "hard" and that it stayed "hard". I assume that horses worked an "average" until 1840 and that their work intensity increased from "average" to "hard"

Results for draught animal muscle energy

The facts and assumptions above provide the basis for estimating draught animal muscle energy for the period 1800-2000. The draught animal energy series is presented in figure 2.9. The steep decline in draught animal muscle power as a consequence of tractorization is pertinent in the figure.

Figure 2.9 Draught animal muscle energy 1800-2000, in PJ.



Water and wind

There were five areas of direct working water and wind-power use during the 19th century: (1) flourmills, (2) sawmill-industry, (3) iron-industry, (4) factories and (5) transportation. This brief section aims at indicating the size of water and wind energy.

(1): During the 19th century, the number of watermills and windmills increased substantially in Sweden, mainly because of the growing population. Watermills dominated the Swedish scene, especially in areas with many forests. On the southern plains, windmills had a natural advantage and were more common. Watermills were either larger mills driven by a vertical wheel (an overshot wheel), which required falling water, or they were smaller mills with horizontal

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1840-1900, and then stayed "hard". For the period 1900-1990, when draught animal muscle energy was less important compared to other sources of energy, and horses had almost completely ruled out oxen, I put less effort into the modelling. I assume that horses in 1950 had reached an average weight of 600 kg. I further assume a linear decrease of the proportion of work-horses/riding horses between 1950 and 1990.

wheels, (undershot wheels) that were designed to operate in streams.[87] Private milling was originally performed in these smaller mills only for a few days each spring and autumn, and they were gradually replaced by larger "duty-mills", where farmers had seeds ground and paid part of the flour as duty to the owner.[88]

Towards the end of the 19th century, the watermills and windmills were gradually replaced first by steam-engine mills and later by electric mills. The steam-engine mills were used for flour grinding in cities. The electric mills however, made private grinding of fodder grain on the farms possible.
To quantify number of mills during the 19th century is a difficult task and it is still more difficult to calculate the energy use of those mills since they differed in size as well as capacity use. Hamilton has made an estimate of the power of mills (i. e. he has not taken capacity use into account) and presents the following figures:[89]

year	type	number	power	total power
1825	duty-mill	4100	6-10 hp	24 600-41 000 hp
1831-32	household mills	20 000	1-2 hp	20 000-40 000 hp

Compared to other pre-industrial European countries, that normally had one mill per village, or one mill per 250 inhabitants, this number of mills (one mill per 120 inhabitants) was substantial, but most of the mills were small with low capacity use.[90] With reasonable capacity use and an assumption of 20% efficiency the total energy amount of mills in 1830 was 0.7 PJ.[91] Animate energy

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[87] These mills were called ”hjulkvarnar” and "skvaltkvarnar".

[88] Ek, S. B.(1962) *Väderkvarnar och vattenmöllor*, Lund., p 131. In Fjäre in 1697, 292 of 332 watermills could only be used for a couple of days each spring and autumn.

[89] Hamilton, U.(1982), op. cite, p 27. The estimate is based on number of mills presented in Ek, S. B.(1962), op. cite, and on power figures for various constructions presented in Singer, Ch. (ed) (1958): *A history of technology*. 5.

[90] Malanima, P(2001), op. cite, p 53.

[91] In Sundin, B.(ed.)(1987) *I teknikens backspegel* , Carlsson Bokförlag, p 82, an investigation shows that old-fashioned waterwheels produce about 5 hp, while a modern waterturbine produces 45 hp, from the same amount of flowing water. This indicates a ten times better efficiency of modern turbines, and their efficiency is around 90%, which means that the efficiency of old fashioned water wheels would be about 9%. Munro, however, suggests that the efficiency of the undershot wheel was 15-30% and 50-70% of the overshot wheel. See Munro, J.H. *Industrial Energy from Water-mills in the European Economy, 5th to 18th Centuries: the Limitations of Power*, paper presented at the Datini-conference on pre-industrial economy and energy, in Prato, Italy, 15-19 April 2002. If the power is supposed to be in the middle of the range, we get a figure of 63000 hp for the entire population, which for the population in 1830 gives an average horsepower of 0.02 per capita. 1 horsepower = 0,736 kW, thus 15 W/capita. Many of the household mills seem only to have been used for a couple of weeks per year, while the duty mills were used more frequently. With the rough assumption that household mills on average were used 200 hours per year, and the duty-mills were used 50 hours/week for 30 weeks per year, the total energy of mills was (20 000*200*3600*1,5*0,736) kWs +

in the same year amounted to 27 PJ and firewood to 88 PJ. It is quite obvious that, even with assumptions of higher capacity use, flourmill energy was small compared to other energy consumption.

(2) The second important use of waterpower was in the sawmill-industry. Since the sawmill industry expanded rapidly in Sweden during the second half of the 19th century, it is reasonable to assume that water energy use increased until the water saws were replaced by steam saws in the 1840s and by electric saws in the 1890s. But sawmills were not as numerous as flourmills. In Västernorrland county (the most sawmill-rich county) there were 195 saws for selling-purposes and 150 saws for household needs in 1860, according to Gårdlund.[92] Hamilton, on the basis of Gårdlund, estimates that the number of sale-saws was 250-400 in 1850, while the number of household-saws was 1000-1500. Their total power he judges to have been in the range 2500-7000 hp. It is thus quite obvious that this energy consumption per capita in 1850 was smaller than the flourmill-energy, even if we assume higher capacity use. In 1896, when statistical information for the first time was available, 13 300 hp were installed in the sawmill industry.

(3): The third use was as a motive source for the metal-industry. In the metal-industry waterwheels were used for lifting rocks and heavy hammers and pumping water, but animal wanderings were also used when the mine did not have access to a waterfall. Also the forming of iron demanded motive power. There is no information of direct working waterpower in the metal industry until the early 1890s. In 1892 there were 50 000 installed hp of waterwheels and water turbines in the metal industry. [93]

(4) The fourth use was in factories. In 1870 448 factories reported that they used waterpower, and the average power was 7.7 hp/factory, which indicates a total instalment of 3400 hp. In 1896 the factories (including sawmills and flourmills) had 140 700 hp waterpower.

(5) The fifth use was for transportation. Sailing ships were gradually replaced by steam-ships during the 19th century. Sailing ships' energy consumption has not been estimated here; it is a difficult task, which probably would end in the same conclusion as for mills and saws; that it was small compared to muscle energy or firewood.

(4100*1500*3600*8*0,736) kWs = 1,46 * 10^{11} kWs (or kJ). With an efficiency of 20% the primary energy was thus 0.7 PJ

[92] Gårdlund, T.(1942) *Industrialismens samhälle*, Stockholm.

[93] BiSOS: Series C: *Bergshandtering*

In one sense it is reasonable to calculate the water energy involved in log driving, since this practice competed with dam-building and electricity production, and therefore economic considerations were made. However, it is a direct use of energy, without any conversions, like the direct use of solar energy to heat the earth, and is therefore not included.

So in the 1890s the installed direct working waterpower amounted to 140 700 hp in factories (including sawmills and flourmills) and 50 000 hp in the metal industry.[94] With reasonable assumptions of capacity use and efficiencies I get the conclusion that 3.5 PJ waterpower was used in the early 1890s.[95] This amounted to 1.5% of the total energy consumption at the time, and it made up an important part of industrial energy consumption (one fourth of the industrial firewood consumption). If the useful waterpower is calculated instead, i. e. the energy, which is actually used for production, the amount is 1.2 PJ, or 0.5%. Both calculations produce results, which are clearly within the error margin of industrial firewood consumption.

The estimates here show that direct working water and wind energy, although important sources of motive energy for specific tasks, were rather insignificant compared to firewood consumption or muscle energy. This energy is therefore not treated separately in the energy aggregate.

Modern energy carriers

To quantify the consumption of commercial energy carriers like coal, oil and electricity is easy compared to the quantification of the traditional energy carriers, because statistical information exists. Most of the coal was imported and is accounted for in the import statistics. Statistics of the production of Scanian coal is also available. Oil is accounted for in the import statistics and electricity production in the industrial statistics. I also include quantities of peat and natural gas in my study, but they were of comparatively low significance so I do not present them graphically here. All energy figures are presented in appendix F.

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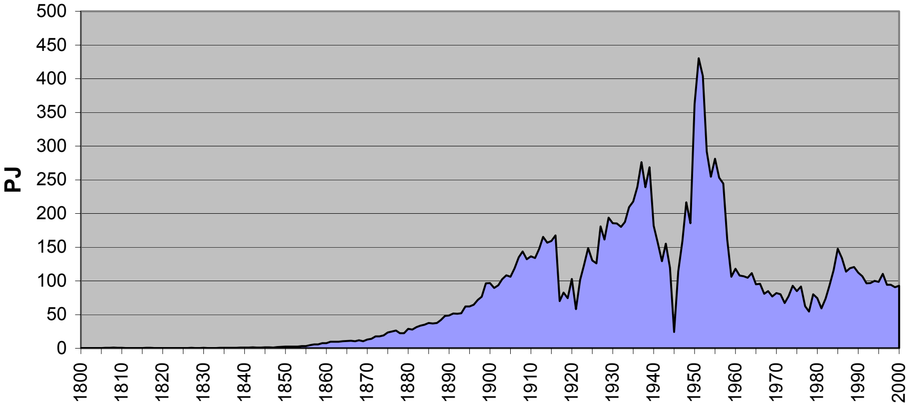
[94] There are no figures for flourmills and saw mills until 1896 so I use the information from that year in BiSOS series D, combined with the number of hp in the metal industry in 1892, which is the first year for which such information is given in BiSOS series C.

[95] I assume that the water wheels were used 40 hours/week 52 weeks per year at 30% efficiency. This gives: 190 000*0.736*40*52*3600*(100/30)=3.5 PJ

Coal

Coal imports started in the 1820s and increased substantially after 1850. Coal was employed for steam-ships in the 1820s and for railways in the 1850s Industrial steam machines and agricultural loco-mobiles also used coal. Besides, it was used for heating of dwellings and buildings. Coal was the raw material for town-gas works, which started in Sweden in the 1840s. Gasworks produced gas for outdoor and factory light, and at the same time coke that could be used for household heating or for processes in industry that needed a sulphur free fuel.

Figure 2.10 Coal consumption in Sweden 1850-2000, in PJ



Sources and methods: 1800-1950: *Historical Statistics of Sweden part 3: Foreign trade*, and *De skånska stenkolsfälten och deras tillgodogöranden*, Erdman, E., SGU, 1911-1915, bilaga A, table h. 1951-1990:*Statistical Yearbook of Sweden*. The imported coal was of high quality and had an average energy content of 29 MJ/kg, while the domestic only had an energy content of 22 MJ/kg[96]. Coke had the highest energy content: 32 MJ/kg.[97]

There are various qualities of coal. The three main kinds of coal are anthracite (hard coal) and bituminous (black coal) and lignites (brown coal). Their energy densities vary considerably from 31-33 MJ/kg for anthracite, 20-29 MJ/kg for bituminous coals and 8-20 MJ/kg for lignites. Bituminous coals make up the bulk of global extraction.[98]

In 1800 Britain produced more than 4/5 of the coal extracted worldwide. Its share was still over 50% in 1870.[99] For European markets Germany produced

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[96] Olsson, S-O.:(1975) *German Coal and Swedish Fuel*, Göteborg, dissertation, p. 222.

[97] Svensk Uppslagsbok.

[98] Smil, V.(1994), op. cite, p 218-219.

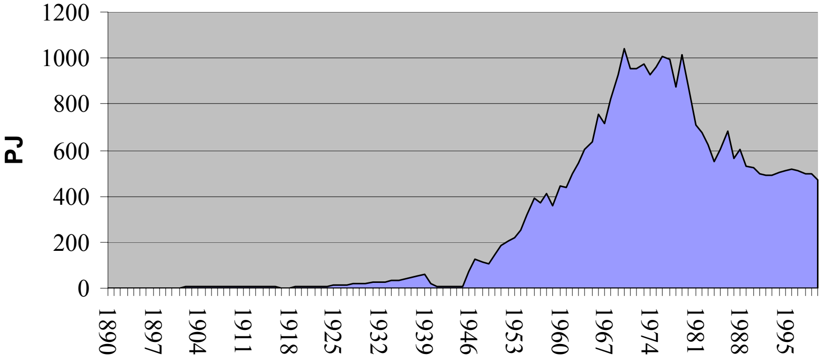
[99]ibid, p 161.

large amounts of coal and after the First World War Poland became another large coal producer. About 90% of Swedish coal imports came from Britain up to the First World War. Sweden had some small coal deposits of low quality at Höganäs in Scania and in the period 1800-1850, when coal consumption was still very low, domestic coal actually made up half of the coal consumption in Sweden. After the 1850s domestic production was unable to respond to the rapidly increasing demand so the import ratio increased over time.

Oil

Oil extraction started in the late 1850s in the US. The first application for oil was in the form of kerosene in lamps and the large share of raw oil that could not be used at the time was destroyed.[100] Oil diffusion on a larger scale was linked to the possibility of using petrol in combustion engines, both in automobiles and in industrial motors, from the turn of the century. Raw oil can be refined into different categories of oil products like kerosene, petrol, heating oils, diesel oil, lubricants and asphalt. Petrol is a large fraction of raw oil, and cracking increased the potential of obtaining petrol from raw oil, but heavy oils still remained. Heavy oils in general found application in heating. The heaviest oils are used for asphalt for roads.

Figure 2.11 Oil consumption in Sweden 1890-2000, PJ



Sources and methods: BiSOS, series F: Utrikeshandel och sjöfart, SOS Industri, The share of the oil that is used for non-energy purposes is excluded. The energy content of oil is on average 42 MJ/kg.[101]

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[100] SOU 1947:14 *Handeln med olja*, p 17.

[101] Smil, V.(1994), op.cite, p 12.

Sweden only had marginal assets of shale oil. The oil concentration was only about 5% and the extraction never assumed an important role for Swedish oil supplies.[102]

The oil consumption in Sweden for 1890-2000 is presented in figure 2.11. There was a substantial increase after the Second World War and a gradual decline after 1970.

Electricity

The discovery of electromagnetic induction in the 1830s demonstrated the important principle that mechanical energy can be converted into electricity and vice versa. Electricity's first application was for light bulbs in the 1880s, substantially improving indoor lighting, facilitating both studying and working. Since the production of electricity, in contrast to its consumption, is best performed in large plants, the wide diffusion of its use necessitated large systems for transferring the energy, from the producer to the consumers. This procedure entailed large transmission losses. The invention of transformers and the adoption of three-phase alternating current in the 1890s substantially decreased those losses. Another important application for high-tension electricity was the electric motor. Electric motors were applied for railways, as prime movers in industry and in household apparatus. Certainly the natural resource endowments were important for the Swedish willingness to switch system from steam engines to electric motors for railways. Countries with other natural resources did not embark as early upon the railway electrification project.[103]

Swedish electrification started in the 1880s and electricity soon became an important energy carrier by international standards. The Swedish hydropower resources facilitated the electricity intensive structure by offering cheap primary energy for electricity. The first users of electricity were the industrial sector and the urban households. In the 1930s electricity was diffused on a large scale to the countryside as well. Until the Mid 1960s almost all electricity was produced by hydropower, but after that oil started to be employed more widely. Hydropower produced 70% of Swedish electricity at the beginning of the 1970s and oil produced the rest. In an ambition to be more self reliant and less vulnerable to oil price increases, the Swedish nuclear program finally started in the early 1970s, after extensive planning and research starting in the late 1940s.

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[102] SOU 1947:14, p 68.

[103] The US, for instance, rich in fossil fuels but relatively poor in hydro-power, stuck to coal-based steam engines for railroads until after the Second World War, when they were rapidly replaced, not by electric engines but by diesel engines. Schurr, S.& B.C. Netschert (1978), op. cite, p 77.

Nuclear power is presently the source of approximately half of Swedish electricity production.

Electricity production causes environmental and health costs, if produced by fossil fuels, and health risks if produced by nuclear energy. Even electricity produced from hydropower causes Greenhouse gas emissions, but not CO_2 emissions, so they are not included in this study.[104]

In the production of electricity, which is a secondary energy form, energy losses take place. Two different methods are used for the calculation of electricity's energy content. One method, which is frequently used in Sweden, is to simply count the heat content of the electricity. This method results in comparatively low values of the energy content of electricity. Another method, frequently used in most other European countries, is instead to calculate the energy content of the primary energy used for the production of electricity. Since electricity in most European countries is produced in fossil-fired plants, this method in practice means calculating the energy content of the necessary amount of fossil fuels given the technology of the time. Some recent Swedish energy statistics instead calculate the primary energy content of the hydropower and nuclear power used for Swedish electricity production. This investigation mainly sticks to the ordinary Swedish way of counting electricity i. e. just counting its direct heat content, in line with how direct working water and wind power is treated. But, for the sake of possible comparisons with other countries and studies and alternative calculations for anyone interested, I also provide a calculation with the normal European method. To provide both alternatives in every calculation and analysis of this thesis would, however, make the presentation too hard to grasp.

Table 2.5 Probable evolution of efficiency of thermal power plants in industrialised countries, 1890-1938, in kg of coal equivalent used to generate one KWh of electricity.

	1890	1900	1913	1920	1930	1938
Advanced countries	3.5	3.2	2.1	1.4	0.7	0.61
Average countries	3.6	3.4	2.31	1.71	1.05	0.75
Backward countries	3.75	3.6	2.47	1.95	1.21	0.87

note: Sweden belongs to the advanced group.

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[104] Rudd, J.W.M. (et al) (1993):"Are Hydroelectric Reservoirs Significant Sources of Greenhouse Gases*?", Ambio*, no 4, p 246-248.

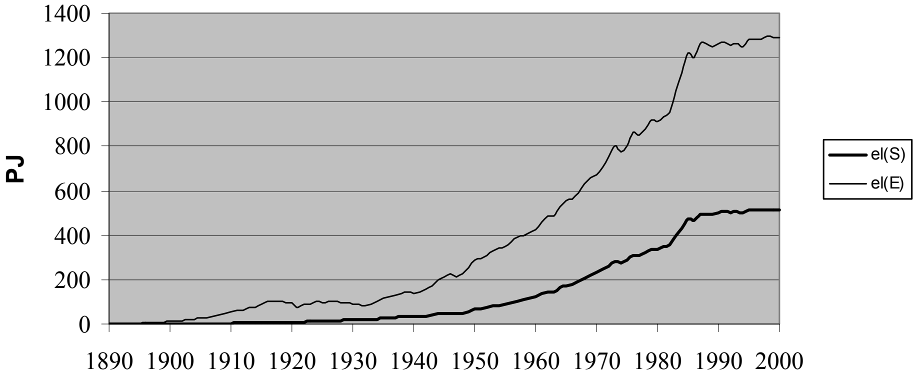
Today it takes about 2.5 units of fossil energy to produce one unit of electricity.[105] In the past the conversion efficiency was much lower. It has been suggested that the efficiency of thermal power plants developed as depicted in table 2.5 and 2.6[106]. The improved efficiency of thermal power plants in Sweden between 1890 and 1990 resulted in a 10 times more efficient production by the end of the period, which implies that around 25 units of coal were needed to produce one unit of electricity in 1890.

Table 2.6 Evolution of efficiency of thermal power plants in industrialised countries, 1950-1980, in kg of coal used to generate one KWh of electricity.[107]

	1950	1960	1970	1980
6 most efficient countries	0.570	0.420	0.357	0.343
Average of 31 industrialized countries	0.613	0.488	0.412	0.383
6 least efficient countries	0.660	0.570	0.472	0.418

note: Sweden belongs to the middle group

Figure 2.12 Swedish production of electricity 1890-2000, counted in the traditional Swedish way, el(S), and in the European way, el(E), in PJ.



Sources and methods: SOS Industry 1912-2000. For the period 1890-1911 Schön's estimates for the industry have been used. Other uses, such as households and railways, have been estimated to amount to 8% of the industrial use, as was the case in 1912. The produced electricity (not the consumed), with corrections for imports and exports, is the measure used here. Losses in the electricity plant and for transmissions are thus included. In the series Electricity (E) the electricity has been counted as if produced in a fossil-fuelled plant.

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[105] Nutek: *Energy in Sweden 1992,* p 4. "Normally, about 2,5 energy units of fuels are required to produce one unit of electricity in a fossil-fired power station".

[106] Etemad, B.&J.Luciani (1991) *World Energy Production 1800-1985*, Geneva, p 35 of Preface.

[107] ibid, p 31.

Conclusions

This chapter contains my constructions of firewood consumption for the period 1800-1920, and of muscle energy both from humans and from draught animals for 1800-2000. The constructions should be regarded as "backwards" scenarios, showing my interpretation of facts and theories, linked together with the assumptions I find reasonable.

Naturally the reliability of these energy accounts increases over time as statistical sources provide more and more of the energy data, just as the reliability of national accounts increases over time, with better access to statistics. In order to show this I have added up the estimates on the one hand and the energy, for which there is statistical information, on the other hand. Figure 2.13 depicts the proportion of my constructed/estimated energy, i. e. all firewood before 1920, household firewood for the period 1920-2000 and muscle energy throughout the period, in relation to the statistically reported energy.

Figure 2.13 The share of estimates and the share of statistical sources in the energy aggregate, 1800-2000

Figure 2.13 provides a picture of declining uncertainties over time, but it does not say anything about how certain the estimates in fact are. The main trends, however, are quite robust. I am confident that the *trends* of decreasing firewood per capita and decreasing muscle energy per cultivated hectare are reliable, although there is uncertainty regarding the *magnitude of changes* in consumption of traditional energy carriers. In order to help the reader to assess

the reasonability of the trends of the firewood and muscle energy estimates I summarize the main arguments below.

1) A decline in per capita firewood consumption in the period 1800-1920 is highly probable. The technical energy efficiency of stoves improved from 10% up to 85% in the best cases. Besides, coal took market shares on the heating market at least from the 1850s. Higher dwelling standards, and the relative increase of population in Norrland, had a weaker impact and could not have offset this relative decline.

2) The estimates of animate energy from humans and draught animals are not subject to as large uncertainties as the firewood estimates, because we know the number of individuals and there is less possible variation in individual food and fodder consumption than in firewood consumption. The main uncertainty regarding draught animal energy is the size development of animals and how much they worked. Still, reasonable assumptions of size increase and extra work, which raise the muscle energy per animal, cannot erase the conclusion that animate energy was economized upon in relation both to agricultural land and to agricultural output.

In the next chapter the energy quantities will be related to the economic performance of Sweden for the period 1800-2000. Energy intensities and CO_2 intensities will be established and the results will be briefly discussed. More profound analyses follow in chapters 4-6.

Chapter 3

Energy intensity and CO_2 intensity

Energy intensity is the ratio between aggregate energy consumption and GDP and is measured in joule per SEK of GDP. Carbondioxide intensity is the ratio between CO_2 emissions and GDP and is measured in kg CO_2 per SEK of GDP. Trends and trend breaks of the energy intensity and the CO_2 intensity are presented in this chapter and the results are briefly discussed in relation to previous research.

Aggregate energy

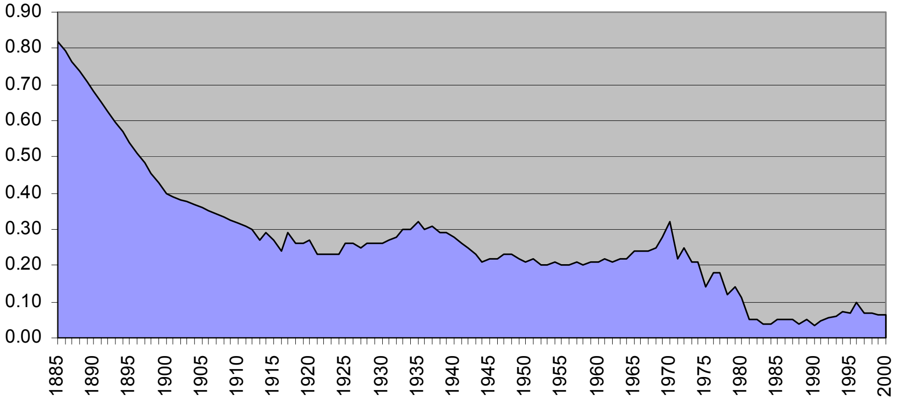
There are two problems involved in aggregating energy. First there is the inescapable quality problem; different energy carriers have different properties and simply counting their heat content does not do justice to these quality differences. An alternative way to account for energy is to express it as an economic volume (price times quantity for each energy carrier). This is done in chapter 5 and the influence on energy intensity of changed energy carrier composition is discussed. In this chapter energy is simply accounted for by its heat content.

Second there is a problem of a practical nature concerning the inclusion of electricity. Electricity is produced by means of primary energy like hydropower, coal, firewood, oil or nuclear power. If all electricity and in addition the coal, firewood and oil used for its production were included a mistake of double calculation would be made. To avoid double calculation I have excluded the share of electricity that has been produced by steam-power, fuelled with firewood, coal or oil, demonstrated in figure 3.1.

The steam ratio fell rapidly in the period 1885-1910, as hydropower increased its share of electricity production. The reason was the breakthrough of the three-phase system, which reduced transmission losses and made hydropower a viable alternative to steam. The rather constant share for steam-produced electricity between 1910 and 1974 is striking. Thereafter nuclear power expanded both at the expense of steam power and hydropower.

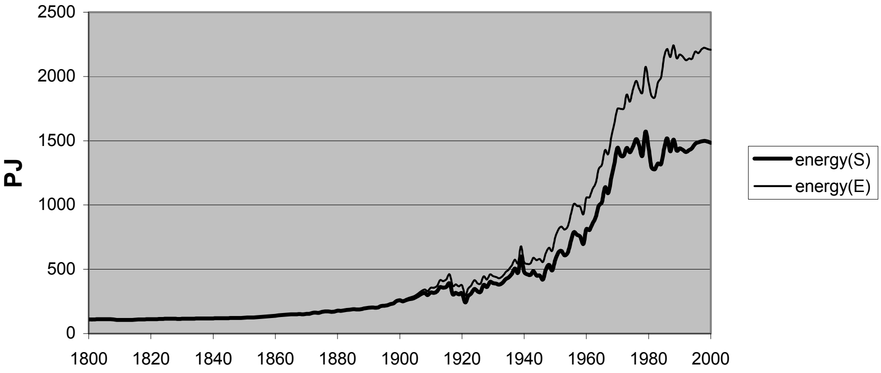
The aggregate energy consumption in Sweden for 1800-2000 is presented in figure 3.2.

Figure 3.1 The steam-share of Swedish electricity 1885-2000



Sources and method: SOS Industri 1912-2000, Hjulström, F. (1940) *Sveriges elektrifiering*, Uppsala, provides benchmark values for 1885 (0,82) and for 1900 (0,4) on p 34. Linear interpolations for 1885 -1900 and 1900 -1912 have been performed.

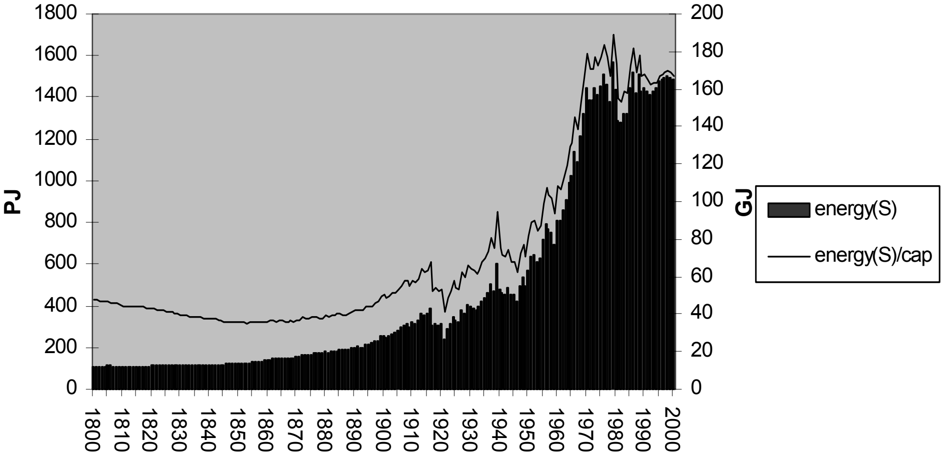
Figure 3.2 Total energy consumption in Sweden 1800-2000, in PJ.



Sources and methods see figures and text in chapter 2. The energy carriers of the aggregate are firewood, draught animal muscle energy, human muscle energy, coal, oil, peat, natural gas, hydro and nuclear produced electricity and spent pulping liquor. Energy (S) means that electricity is counted by its heat content, energy (E) means that electricity is counted as the heat content of the fossil fuels needed for its production, if all electricity were produced in a fossil fired plant.

Swedish energy consumption increased exponentially from the late 19th century until 1970, except during the War years. When electricity is calculated in the typical Swedish manner there is a stabilisation of total energy consumption after 1970, whereas it continues to increase after 1970, but at a lower rate than before, when electricity is calculated in the typical European manner. In figure 3.3 both aggregate energy and energy/capita are presented.

Figure 3.3 Aggregate energy (PJ) and energy/capita (GJ) 1800-2000.



Sources: see figure 3.2, Historical Statistics of Sweden , part 1*: Population,* SCB.

An average Swede consumed 47 GJ per year in 1800 and 167 GJ in 2000, which means that per capita energy consumption was 3.5 times larger in 2000 than in 1800. Total energy consumption was 14 times larger in 2000 than in 1800. It can thus be concluded that the population increase explains 30% of the total energy increase, while variations in energy per capita explain 70%.[1] During the 19th century the entire energy increase was explained by the population increase, since in this period energy/capita actually fell. During the 20th century variations in energy per capita played an important role for the increase. The pattern is, however, not linear in relation to income, as shown in the following.

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[1] The population increased by a factor of 4 in the period 1800-2000. The total energy increased by a factor of 4*3.5=14. The population increase explains 4/14 of the energy increase, i. e. 30%.

Gross Domestic Product

Gross Domestic Product (GDP) is the sum of market activities in a country. It can be calculated in three different ways: either as the sum of value added in different branches, or as the sum of incomes and profits, or as the sum of expenditures. [2] The project "Historical National Accounts in Sweden 1800-1980" (SHNA) was an encompassing work to reconstruct the Swedish economic development and the results are used here.[3] It established time series at a much more detailed production level than its predecessors: National Income (N.I.) and Östen Johansson's historical national accounts (Ö.J.).[4] One major weakness of both N.I. and Ö.J. is the lack of proper price deflators. N.I. only deflates total income with the cost of living index, while Ö.J. extends the deflators to sector deflators.[5] Neither N.I. nor Ö.J. have constructed series at the branch level. This has, however, been done in SHNA which contains numerous tables, with the drawback of making the accounts difficult to survey, but has the advantage of allowing a flexible use. The present SHNA, unfortunately, is not yet balanced in consistent input -output matrixes. So far only the industrial sector is carefully accounted for both concerning inputs and outputs. Another drawback with N.I. and Ö.J. is that value added is not a main concern of theirs. It is a residual, with strange fluctuations due to their schematic apportioning of output to various sectors.

The series of outputs and inputs in SHNA are of various qualities for various branches and periods. The industrial production is well accounted for in the statistics even during the 19th century, while for instance the reconstruction of agricultural production and some service branches involves rougher estimates. Still, SHNA accounts for value added of branches as carefully as possible and for studies of long-term economic growth and structural transformation it is an improvement compared to previous historical accounts.

In order to account for real economic growth over time the price changes must be taken care of. For this purpose a price index is constructed. The nominal GDP in current prices divided by the price index gives the real GDP in constant prices. The index is a ratio between the sum of series of weighted prices and this

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[2] Value added is the output minus the inputs

[3] The project Historical National Accounts for Sweden 1800-1980 has so far published 8 volumes. They are Schön, L *Jordbruk med binäringar 1800-1980*, Schön, L.*Industri och hantverk 1800-1980,* Pettersson, L. *Byggnads och anläggningsverksamhet 1800-1980* , Krantz, O. *Transporter och kommunikationer 1800-1980*, Krantz, O *Privata tjänster och bostadsutnyttjande 1800-1980,* Krantz, O. *Husligt arbete 1800-1980*, Krantz, O. *Offentlig verksamhet 1800-1980*, Ljungberg, J. *Deflatorer för industriproduktionen 1800-1980*. I use the data series provided by Schön.

[4] Lindahl, E./Kock, K./Dahlgren, E.(1937): op. cite, Johansson, Ö. (1967) *The Gross Domestic Product of Sweden and its Composition 1861-1955*, Uppsala.

[5] Lindahl, E./Kock,K./Dahlgren, E.(1937), op.cite, part one, p 250-251.

sum for another year, a base year. There are basically two different kinds of price indexes; the Laspeyre-index and the Pasche-index. The Laspeyre-index is weighted with constant quantities and the Pasche-index with changing quantities. Schön used the ratio between a Pasche index and a Laspeyre index, which he labelled a structural coefficient, as an indicator of structural changes in the economy.[6] Ljungberg later used structural coefficients for analysing patterns of industrial price developments for the period 1885-1969.[7]

The construction of a price index involves three main problems; the quality problem, the weighting problem and the base year problem, the latter often referred to as *the* index problem.

The quality problem has to do with the fact that many goods improve their quality over time, which means that not every price increase is a real price increase, because it may be connected to higher quality of the product. The SHNA has dealt with this problem by linking overlapping price series for similar commodities with different quality. When this has not been possible price has instead been related to performance. In this way long price series for various homogenous commodities have been created.

When price series over different kinds of commodities have been constructed there is the problem of weighting them together. Basically prices should be weighted with respect to the relative quantities of the investigated aggregate. For instance, when the production of a branch is focused on, the weighting of prices should be done according to production structure of that branch, and when total GDP is of interest, its quantitative composition should be accounted for.

The index problem stems from the fact that there is no given base year or weights for the construction. An expression of this problem is that economic growth may change speed with different base years. This problem only arises with changing relative prices and quantities. The structural coefficient, used by Schön and Ljungberg, is equivalent to dividing growth of a Pasche index with an early base year by growth of a Pasche index with a late base year in the end of an investigated period.[8] The SHNA used 9 deflating periods, which were chosen so they correspond to periods of transformation and rationalisation.[9] These 9 deflators are linked together to one deflator. Typically, growth during periods of

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[6] Schön, L. (1979), op. cite, Gerschenkron, A. (1962), “Problems of Measuring Long-Term Growth in Income and Wealth”, in *Economic Backwardness in Historical Perspective*

[7] Ljungberg, J.(1990): *Priser och marknadskrafter i Sverige 1885-1969*, dissertation, Lund.

[8] A Pasche-index divided by a Laspeyre-index has the following formula: $(\Sigma (p_1*q_1)/\Sigma (p_0*q_1))/(\Sigma (p_1*q_0)/\Sigma (p_0*q_0))$. This is exactly the same thing as dividing the growth of a Pasche-index with an early base-year by growth of a Pasche-index with a late base-year: $((\Sigma (p_1*q_1)/\Sigma (p_0*q_1))/1)/(1/(\Sigma (p_0*q_0)/\Sigma (p_1*q_0))$, but only in the final year of the investigated period.

[9] The periods are 1800-1826, 1826-1848, 1848-1869, 1888-1910, 1910-1929, 1929-1954, 1954-1969, 1969-1980.

transformation, when relative prices and quantities change a lot, will be larger with an early price-base than with a late one. During periods of rationalisation, when stability dominates, relative prices and quantities change less, and growth rates do not vary so much with an early and a late base-year. On the basis of the energy deflator results in this study (presented in appendix B), it may be suspected that the long deflating periods produce a bias of growth exaggeration for output of industry and transportation and also of total GDP. The size of such biases would depend on how large the Gerschenkron effects were (relative growth of quantity with concomitant price fall) in the respective aggregates. To check this and produce new, more neutral deflators Schön and I revised the sector deflators and the GDP deflators into annual chain deflators. The new deflators were different from the old ones, but the deviations were large only for certain short periods and not remarkable for long term growth rates. The method and results are presented and briefly discussed in appendix C, written by Schön and me. The new deflators are used throughout this study, because they are considered more neutral than the old ones.

Another problem, related to *the* index problem, is that when deflated value added, called volumes, at branch level are summed up they differ from the separately deflated sector volumes, and when sector volumes are summed up they differ from the separately deflated GDP. This is the additivity problem.[10] This study treats the discrepancy by proportional adjustments of the shares to give a sum that is equal to GDP, when the sum is of importance. In most of my analyses it is the relative development of sectors that is of interest and not the sectors' absolute sizes and then this problem has no practical bearing. Lindmark and Vikström advocate that ratios, like industry's share of GDP, should always be given in nominal rather than constant figures, to avoid the additivity problem. I do not find it suitable to follow this recommendation in this study, where the aim is to come as close to changes of the production structure as possible. Price changes should not in general be allowed to distort the picture. Only price changes, which are related to changes of quality, should be included; therefore constant prices are to be preferred.

Another problem with the SHNA deflators is that they are output deflators. It is not quite correct to deflate value added (which is output minus inputs) with output deflators. Instead the output and inputs should be deflated separately. In the SHNA this has not been consistently carried out, since it would have demanded too much work effort and because it sometimes has awkward consequences. Schön instead used an intermediate method for industry in the period 1800-1955. He held the output/input ratio constant throughout every

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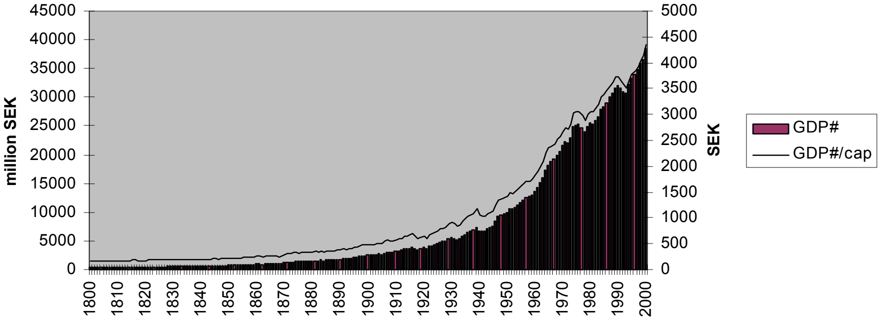
[10] Lindmark, M. & Vikström, P.(1999):"Den deflaterade kvotens dilemma", pp 177-190, in Honningdal Grytten, O. (ed) *Nordiske Historiske Nasjonalregnskaper*, Fagbokforlaget, Bergen.

deflating period according to the relation in the base year.[11] By multiplying the deflated output every year with the (output-input)/output ratio (i.e. the value added ratio) in the base year a value added series was created, which is innocent of the theoretical mistake of deflating value added with a price index for output, but has the weakness of embedding an implicit assumption that technical change (altering the output/input ratio) did not take place during the deflating period. Schön is well aware of this assumption, and suggests that the ratio between his growth series and the alternative growth series, calculated with double deflating, would be a measure of technical change. For the period 1955-1980 SHNA used the double deflating, since this was already done in the national accounts. To use simple deflating is less troublesome for periods and sectors where inputs are relatively small, like for services, than it is for industry.

Figure 3.4 Swedish GDP 1800-2000 (million SEK) and GDP/cap (SEK), constant prices, 1910-12 price level.



Sources: Data-series provided by L. Schön from the project Historical National Accounts for Sweden 1800-1980", SCB. GDP# denotes that the power industry is excluded.

The development of Swedish real GDP over the period 1800 to 2000 is depicted in figure 3.4. GDP was 97 times larger and per capita income was 25 times larger in 2000 than in 1800. Just like energy consumption, GDP grew exponentially from the late 19th century but, unlike the case of energy(S), the exponential growth did not end after 1970.

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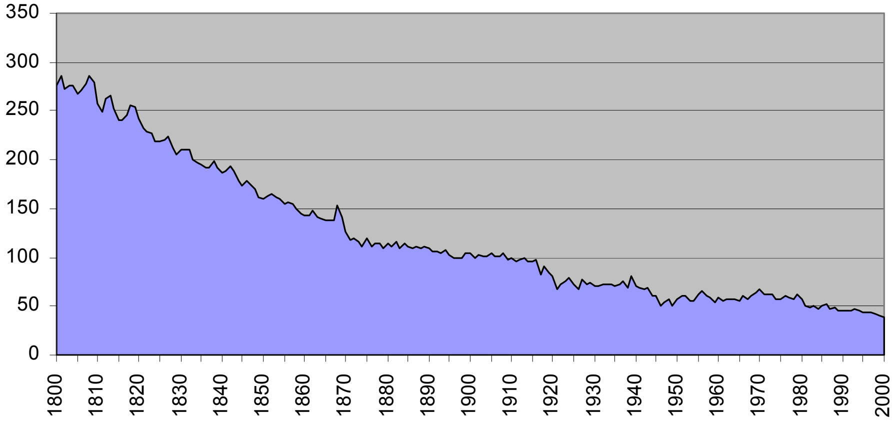
[11] Schön, L.: *Industri och hantverk 1800-1980*, p 199.

Energy intensity

The aggregate energy measure and GDP enable calculation of the aggregate energy intensity, which is depicted in figure 3.5.

Figure 3.5 Swedish Energy Intensity 1800-2000, MJ/SEK, constant prices, 1910-12 price level



Sources: see chapter 2 for energy data and estimates and figure 3.4 for GDP. The power industry is excluded from GDP.

The major feature of the energy intensity development is a substantial decrease in the period 1800-2000: from 270 MJ/SEK to 40 MJ/SEK, or by 85%.[12] The decrease did not occur evenly in this period. A substantial decline took place between 1800 and 1870. In this period energy intensity fell from 270 MJ/SEK to 140 MJ/SEK, or by 50%. In the period 1870-1915 energy intensity decreased by 25%. During the two World Wars energy intensity fell rapidly. Between 1914 and 1919 energy intensity fell by 15% and between 1939 and 1945 it fell by 25%. Also, in the period 1970-2000 there was a marked decline of 40%. In the inter-war period energy intensity was stable and in the period 1945-1970 energy intensity actually increased by 10%.

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[12] if electricity is measured in the Swedish way, or to 60 MJ/SEK, if electricity is measured in the European way.

Two main sectors

Energy is needed for the two main sectors in the economy: production and households, which are referred to as the formal sector and the informal sector. In production energy is used as a means to a goal, which is the production of goods and services, and therefore that energy consumption is intermediate consumption, but for households the energy services are a goal in themselves and energy is therefore final consumption. When energy is used as an input to the formal economy it contributes to GDP, but not when it is used in the informal economy. Therefore household energy consumption should be excluded from the national energy intensity. Long-term studies for other countries have not been able to do so, because the household energy has not been known. Schurr & Netschert excluded all fuelwood because they regarded it mainly a household fuel, but this was not a satisfactory solution since households used other energy carriers than fuelwood and the formal economy to some extent used fuelwood. I have estimated the household share of total energy consumption in appendix D and my results are presented in table 3.1.

Table 3.1 Household energy share of total energy consumption, in percent.

	Residential share	Car share	Food share	Household share
1800	69		7.0	76
1870	53		9.0	62
1913	33		5.0	38
1936	32	1.6	4.4	38
1955	29	4.8	3.4	37
1970	27	6.6	1.9	36
1990	23	10	2.0	35
1998	23	9.4	2.0	34

Sources: My estimates for 1800 and 1870. For 1913, 1936 and 1955 see the passage on distribution key between service premises and dwelling premises in Appendix C. 1970-1998: SCB. For car estimates, see appendix D.

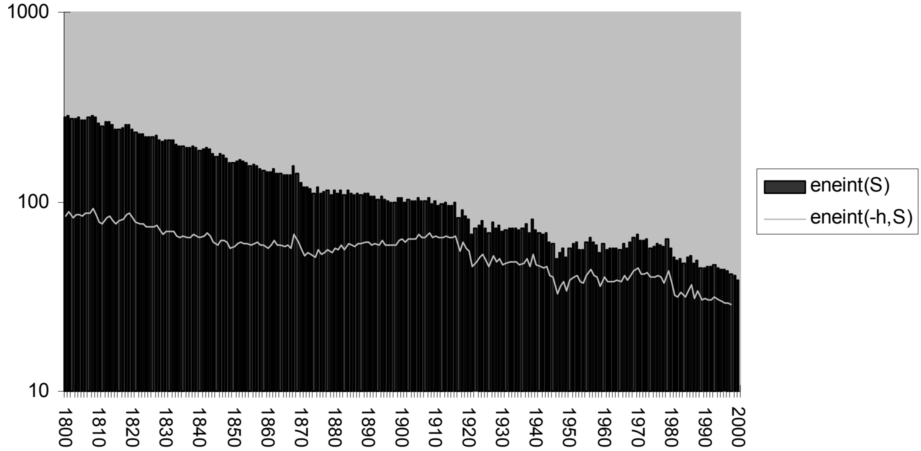
The household share of total energy consumption decreased substantially until 1913 after which it remained rather constant. The economy grew quickly in the period 1870-1913 and an increased production per capita raised the demand for energy in the formal economy to larger extent than in the household sector. In this period industrial consumption goods did not yet demand any energy at the point of consumption, so the household energy share declined.

From 1913 until 1998 the household energy share stayed fairly constant, something that might appear odd given the large changes that occurred both within the formal and informal economy. An important explanation for the trend break in energy share for households (from decreasing to constant) was that industrial products started to demand energy at their point of consumption. The relevance of this aspect can be illustrated by the household energy consumption for cars. The household share of energy for residential use decreased from 33% to 23% between 1913 and 1998 and the share for food energy decreased from 5.0% to 2.0%, but households' energy consumption for private cars increased from 0% to 9.4%.

Alternative energy intensity

The estimate of household energy makes it possible to calculate an alternative energy intensity measure, where only intermediate energy consumption is included. This is depicted in figure 3.6. The relative decrease in energy intensity in the period 1800-2000 when household energy is excluded is much smaller than when household energy is included. This is an effect of the declining share of final energy consumption. Another difference in outcome is that energy intensity increased substantially between 1870 and 1914 when households are excluded and decreased slightly when households are included. The fact that energy intensity (excluding households) increased in this period supports the idea that the industrialisation process would bring about a rise in energy intensity. This idea is further analysed in the next chapter.

Figure 3.6 Swedish energy intensity for the period 1800-2000, both including and excluding household energy, MJ/SEK, constant prices, 1910-12 price level, lin-log scale.



Comment: Dwelling usage and the power industry have been excluded from GDP in the eneint (-h, S) measure, while eneint(S) only excludes the power industry. Sources: see chapter 2 for energy data and estimates and figure 3.4 for GDP and my estimates of households' energy in appendix D.

Comparisons with previous research

The energy intensity results may be compared to previous research, outlined in the introductory chapter.

First Nilsson's finding of increasing energy intensity for Sweden between 1950 and 1970 and then decreasing energy intensity until 1988 is also confirmed by this investigation, although his energy aggregate was compiled differently. Nilsson uses UN statistics, which do not contain muscle energy, but this kind of energy was not very large in the period after 1950.

Energy intensity when household energy is excluded shows amazing resemblance with the results Lindmark presented for the ratio between environmental degradation in monetary terms and GDP.[13] First the general decrease he found for the period 1800-1990 is found here as well. Second his finding of three EKCs can also be discerned for energy intensity, when household energy is excluded. Third the periods almost completely correspond. Here the periods are 1870-1921, 1921-1946 and 1946-1998. Lindmark's periods were 1870-1920, 1920-1947 and 1947-1990. However the peak years in each EKC differ. Here the peaks occurred in 1913 (el E) or 1908 (el S), 1939 and 1970. Lindmark's peaks occurred around 1898, 1937 and 1972. Except for the first peak the results are close. The similarity of the results shows the importance of energy related environmental stress. Twisting the argument the other way round the results of this investigation provide support for Lindmark's results. Two separate estimates of relative environmental stress indicators with similar results mutually reinforce each other when data and methods vary.[14]

Since industry made up a large and growing share of GDP in the 20th century it is of interest to compare Schön's industrial energy intensity results and the energy intensity results I have come up with here, to detect similarities and differences. Figure 3.7 presents industrial energy intensity and total energy intensity for the period 1890-1987 with el (S).

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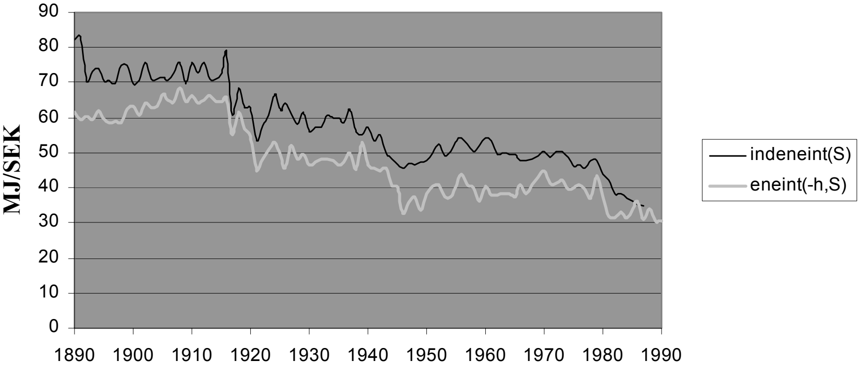
[13] Lindmark, M.(1998), op cite, p 202-204.

[14] Although GDP comes from the same sources the environmental indicator is very different, as is obvious from chapter 1.

Figure 3.7 Swedish industrial energy intensity and total energy intensity (excluding households) 1890-1987, MJ/SEK, constant prices, 1910-12 price level.



Sources and comments: Lennart Schön (1990) has provided data files for the industrial sector. The power industry is excluded. See chapter 2 for energy data and estimates and figure 3.4 for GDP. Dwelling usage and the power industry are excluded from GDP.

The total energy intensity develops similarly to the industrial energy intensity. One difference is that industrial energy intensity decreased more than total energy intensity in the period 1890-1987. Industrial energy intensity decreased by 58% while total energy intensity decreased by 50%. A second difference is that total energy intensity declined more during the wars than industrial energy intensity.

The long-term pattern of energy intensity when households are included does not appear consistent with the general pattern for energy intensity over time presented for several countries in Reddy and Goldemberg.[15] Their results reveal one inverted u-curve for energy intensity over time, but it must be noted that they only take account of modern energy, while I include firewood and animate energy. The Swedish energy intensity is profoundly different if firewood and animate energy is excluded, as demonstrated in figure 3.8.

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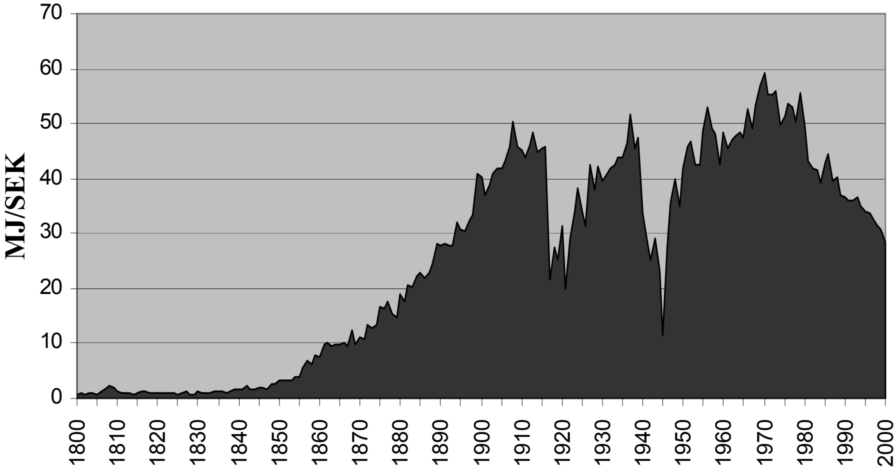
[15] Reddy, A. K. N. & Goldemberg, J. (1990), op. cite, p 64.

Figure 3.8 Swedish modern energy intensity 1800-2000, MJ/SEK, constant prices, 1910-12 price level.



Sources: see chapter 2 for energy data and estimates and figure 3.4 for GDP. The power industry is excluded from GDP, firewood and muscles are excluded from energy.

Swedish modern energy intensity basically grew over time, except during the war periods, until 1970. If the war years, when large amounts of fossil fuels were replaced with firewood, are overlooked the figure with some imagination resembles an inverted U curve, albeit the period 1970-2000 is rather short.

The great difference in energy intensity for Sweden when traditional energy carriers are included and excluded is not very startling. A large difference was also found for the US, also wood-rich and partly cold, when firewood was included.[16] The explanation for the profound difference of energy intensity is that traditional energy carriers played a pertinent role for Swedish energy supply until the 1920s. The reason why modern energy intensity increases over time, while the entire energy intensity decreases, is that fossil fuels and electricity gradually replace firewood and muscle energy.

CO_2 intensity

CO_2 intensity, or the amount of emitted CO_2 per SEK in GDP, is rather easily calculated once the amounts of fossil fuels are known, since eventually all carbon in the fuel will become CO_2, although with incomplete combustion part

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of it will first become CO. The emission ratios for different fossil fuels are presented in table 3.2.

Table 3.2 CO_2 emissions from different fossil fuels

Fuel	Emission factors (g CO_2/MJ)
coal	92
coke	103
raw oil	74
natural gas	56

Source: Levander, T.: Koldioxid-Utsläpp och beräkningsmetodik, Nutek, Rapport 1991:12, p 8.

On combustion animate energy and firewood also cause CO_2 emissions. However animate energy and firewood are different from fossil fuels, since they do not necessarily cause *net* emissions of atmospheric CO_2. This depends on the CO_2 cycle. Green plants sequester CO_2 from the atmosphere as they grow and the same amounts are then released on combustion. The implication is that as long as there is enough re-growth, i. e. as long as forest timber volumes and quantities of fodder plants stay constant, there are no *net* CO_2 emissions from using firewood or animate energy.

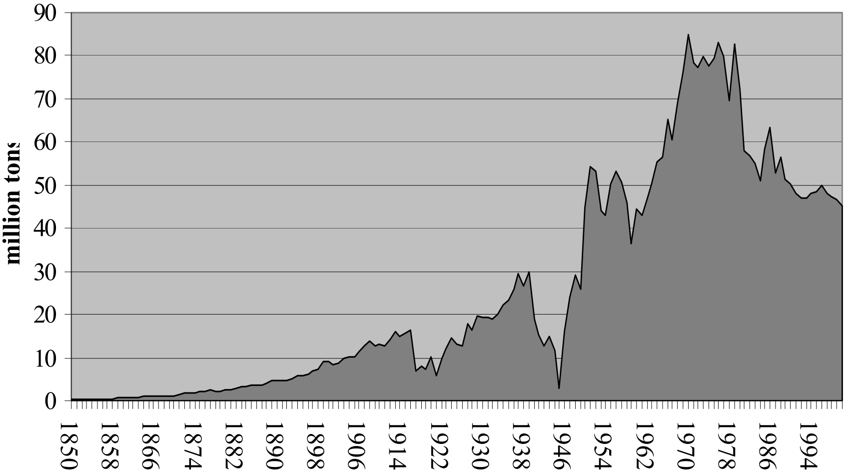
However, the Swedish standing timber volume did not stay constant in the period 1800-2000. Its impact on total CO_2 emissions is explored in chapter 6. Here I only take CO_2 emissions from fossil fuels into account, which are presented in figure 3.9. The shape of the long- term emission curve, if the World Wars are overlooked, resembles an inverted U, with a peak in the 1970s.

Figure 3.10 depicts the fossil fuel CO_2 intensity of the Swedish economy 1800-2000. Emissions from households are included.

In several respects the figure of CO_2 intensity resembles the curve of modern energy intensity in figure 3.8. One difference is that CO_2 intensity declines more than modern energy intensity during the wars. The reason for this is mainly that electricity consumption did not decrease during the wars like fossil fuel consumption did. A second difference is that CO_2 intensity in 1970 peaked at a lower relative level than modern energy intensity did. Part of the explanation for this is an increasing electricity share after the Second World War. The other part of the explanation is the concomitant rapid oil expansion at the expense of coal, which decreased the CO_2 emissions in relation to fossil fuels, since oil emits relatively less CO_2 than coal.

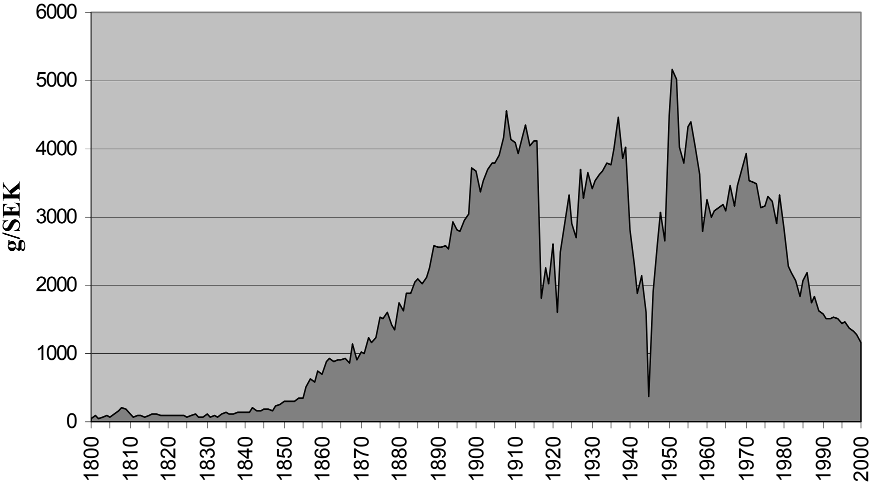
The impressive decline in CO_2 intensity and even in absolute CO_2 emissions after 1970 is in line with Kågesson's results. This study also shows that during the World Wars Sweden experienced both relative and absolute declines in CO_2 intensity.

Figure 3.9 Fossil CO_2 emissions in Sweden 1850-2000, 1000 tonnes.



Sources: Historisk statistik för Sverige, del 3, Utrikeshandeln, and De skånska stenkolsfälten och deras tillgodogöranden, Erdman, E., SGU, 1911-1915, bilaga A, table h. SOS Industri, SOS Utrikeshandel.

Figure 3.10 Fossil fuel CO_2 intensity in Sweden 1800-2000, g/SEK, in constant prices, 1910-12 price level



Sources: see figures 3.4 and 3.9.

Conclusions

1) This chapter shows that energy intensity experienced a long-run decline over the period 1800-2000. Energy intensity declines by approximately 85%, if household energy is included, and by approximately 50% if it is excluded. In addition to this time trend there are cyclical patterns around the long-term decline, which resemble three EKCs.
2) CO_2 intensity does not show a long- term decline, but a more pronounced pattern of EKCs. It may be regarded as either one long EKC, interrupted by the Wars, or as three separate EKCs.

The long-term decline in energy intensity is the main focus of the following analyses. The impacts of structural and technical changes will be focused in the next chapter.

Chapter 4

Structural and technical change

A long-wave perspective

Many technologies have systemic properties. They consist of various parts that interact and are strongly interdependent. When one part is improved the system becomes unbalanced and there is a need for other parts to follow suit. Until they do there are “bottlenecks” or “reverse salients” in the development of the system. Such systemic properties make technologies diffuse in clusters rather than as individual inventions.

Technology clusters are sometimes of a complexity and significance large enough to form the basis for long-term expansion and structural transformation of economies. The long-term impact stems from the pattern of technology diffusion. It takes time to develop new technologies to make them technically and economically viable. It also takes time for society to change income levels and demand enough to fully incorporate the new technologies. The structural impact comes from the uneven impact the new technologies have on various sectors of the economy. Production is eased more in some sectors than in others, which means that relative prices and consumption patterns change.

Technology diffusion typically exhibits an s-shape pattern, normally referred to as the technology life cycle.[1] The concept “life-cycle” makes an analogy between technology growth and biological growth. During the introduction/childhood phase many possible technological designs are explored in search of technological viability rather than low costs and the market is highly uncertain. Only slowly does the technology diffuse. During the growth/adolescence phase diversity gives way to standardization and efforts are concentrated to production economics. Increasing the certainty of technological viability provides reduced risks for investors, the scale is increasing, costs and prices are lowered and markets expand. The technology finds wider applications. During the saturation/maturity phase the growth rates for the technology level out. Competition is almost entirely based on cost reductions. The fact that technology diffusion does not expand forever, although there are no physical obstacles to it like there is for biological diffusion, is more difficult to explain than the diffusion patterns during the childhood and adolescent phases. Some reasons for market saturation could be the appearance of a new competitive technology, decreasing personal or social utility of wider diffusion or that negative externalities become large enough to arrest a further diffusion.

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[1] Grubler, A.(1998) *Technology and Global Change*, Cambridge university press, p 50-62.

Technology diffusion is both a temporal and spatial phenomenon. It emanates from innovation centres and diffuses to the periphery. Typically the periphery catches up with the centre in the sense that diffusion is faster there, but intensity never reaches as high levels. The construction of railway networks in England, for instance, spanned approximately 100 years, but took only half that time in Sweden and the net never became as wide as in England.[2]

During the period investigated in this study there are three main clusters of technologies that characterize the economic development, profound enough in socio-economic impact to be referred to as the first, second and third industrial revolution. All three industrial revolutions centered on innovations in the field of energy systems.

The *first industrial revolution* centered on an innovation in the field of inanimate power: the steam engine. Steam engines replaced traditional energy sources but also provided power for new fields of usage. They had several advantages, compared to traditional prime movers, that affected substitution patterns. The main advantage compared to animate power was that the steam engine was more powerful. Compared to waterwheels its main advantage was that it was site-independent. Steam engines not only replaced other prime movers; they also opened up new application possibilities for prime movers. For instance steam powered railways revolutionised land transportation.

The *second industrial revolution* took off in the 1890s with the diffusion of the internal combustion engine and the electric motor. The novel prime movers had then passed their childhood/introduction stage and were ready for market expansion, but it is unclear if this merely coincided with a maturity/saturation phase for steam engines or if it rather caused the steam engine's decline. The steam engine had a major drawback in being heavy and clumsy, which limited its expansion. The electric engine and the internal combustion engine were not plagued by size.[3] They could be made small, powerful and still energy efficient. Another advantage of both engines compared to steam engines was that they could be turned on and off at short notice. Hence they widened the market for inanimate engines. Steam engines stood up against the competition through technical improvements, for instance the steam turbine, but were still gradually replaced.

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[2] Ibid, p 65.

[3] The main differences between electric motors and internal combustion engines for consumers are that the former are non-polluting at the point of usage but grid-bound, while the latter are site independent but produce exhaust gases. Electric motors are therefore excellent prime movers in permanent industrial plants, where a clean working environment is valuable. Internal combustion engines are superior for transportation, where connection to electricity nets restricts the motive range and the exhaust gases are less severe because they are diffused over large outdoor areas.

The *third industrial revolution* can be dated to the Mid 1970s, when the growth phase for microelectronics took off with the miniaturisation of hardware for information treatment, manifested in the microprocessor.[4] It was a revolution in information treatment and exchange relying on low-tension electricity just like the previous profound breakthroughs in communication: the telegraph and the telephone.

To assess the economic impact of these new technologies in quantitative terms is virtually impossible, because they are so complex. The direct growth effects that stem from the growth of industries and branches involved with production of the new engines and related systems of energy and communication do not justify the term industrial revolutions, but the indirect effects on growth are substantial. The indirect growth effects of the technologies of the first and second industrial revolutions were at least threefold. First, the new engines in sea, land and air transportation implied increasing market integration with concomitant specialisation and economies of scale, which increased overall economic efficiency and growth. Second, the new engines established a growing production apparatus that augmented the motive power at the workers' disposal. The stock of machinery grew incrementally and brought about a long-term growth of industrial production. Third, the new engines enabled more efficient organisations of production. This was particularly so with electric engines when applied to group-drive or unit-drive.

The growth of the third industrial revolution is still difficult to assess because it is only in its wake. One obvious growth effect was the expansion of industries of information technology and bio-technology. There are no direct transportation effects that may give scale advantages, although better information exchange is created, which is important for wider markets and growth. Although the physical capital stock has increased, this is mostly a matter of quality improvements, not a matter of inserting machines to perform motive labour, like during the first and second industrial revolutions. Solow has formulated the problem to assess the growth impact of information technology in the following way: "you see computers everywhere except in productivity statistics".[5] That labour productivity has not increased tremendously in recent decades might be because it takes time to realise the full potential of a complicated technology. But, on the other hand, software technologies are

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[4] The transistor was invented in 1947 and made possible fast treatment of electrical signals via binary cutting and amplification. Transistors were gradually miniaturized and combined into semiconductors (also called chips) and in 1971 microelectronics had a fundamental breakthrough, when the microprocessor, a computer in chips form, was invented. The microprocessor enabled the diffusion of microelectronics to all machines. In 1971 2300 transistors could be packed on a chips of nail size, and in 1993 the numbers were impressive 35 millions, see Castells, M. (2000): *Nätverkssamhällets framväxt*, Daidalos, p 52-54.

[5] Solow, R. L. (1987) "We'd better watch out", *New York Times*, July 12, Book Review, p. 36.

progressing at a rate that is difficult for people to catch up with, so realising this potential is perhaps not possible. Time will show.

The perspective of industrial revolutions cannot be used for strict assessments of economic developments or energy intensity developments. It mainly gives an idea of the structure of the economy and the kind of technical development, preponderant during certain periods. In explicit terms this chapter focuses more on the third industrial revolution than on the previous two because of the interesting implications for options to delink energy and growth. The third industrial revolution seems to offer reasons to expect a fundamental trend break for energy intensity.

The long wave perspective of development above discerns three long periods, or three industrial revolutions. There is a related long wave perspective for the Swedish economy that divides the second period into two. Schön and Krantz have found a pattern where the two main ingredients in growth, renewal and effectiveness, dominate in different periods. Times marked by renewal of the production structure and a more general transformation of society followed upon deep crises in the 1890s, the 1930s and the 1970s. During these transformation periods (of about 25 years' length) diffusion of innovations (appearing decades before) occurs on a broad basis. Imbalances in the new structures request development of the underdeveloped parts. This invokes reallocation of resources, but that does not suffice; new institutional arrangements and large investments are also needed. The investment to production ratio in industry consequently rises. As the imbalances gradually are overcome and the new structures work more friction-less, a period of stabilization emerges. During this period, which is normally referred to as a rationalisation period and approximately is 15 years' long, the structure becomes ever more efficient and international competition more fierce. The growth structure eventually meets its limitations and a new deep crisis occurs. In the wake of this crisis new growth structures, based on diffusion of innovations from the last rationalisation phase, appear. Thus there are limits to every specific growth structure, but not to growth as such.[6]

The development blocs, forming the new expansion periods, have been centred on basic innovations in the fields of power generation and

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[6] Schön, L.(1994) *Omvandling och obalans. Mönster i svensk ekonomisk utveckling.*Bilaga 4 till Långtidsutredningen, Finansdepartementet. (Transformation and imbalances. Patterns of Swedish economic development. Supplement to the long term planning, Ministry of Finance) Stockholm. Schön, L.(1995):"Growth and Energy in Sweden - on Innovation, Efficiency and Structural Change", in Lundgren, L. et.al. (ed), *Expanding Environmental Perspectives. Lessons of the Past - Prospects for the Future*. Lund.Schön, L.(1998):"Industrial Crises in a Model of Long Cycles; Sweden in an International Perspective", in Myllyntaus, T. (ed), *Economic Crises and Restructuring in History*. Stuttgart.

communication. After the 1850s railways and modernisation of the steel industry were fundamental for development. At the centre of the second wave, after the 1890s, was the diffusion of the electric dynamo and the combustion engine. After the 1930s wider electrification, automobiles and aircraft were basic ingredients in development. The wave from the 1970s onwards, was centred on the advent of the microprocessor and the rapid diffusion of electronics.

Schön has found interesting connections between this general growth pattern and energy carrier composition in industry. During periods of transformation electricity's share of energy consumption increased, while the ratio remained stable during rationalisation phases. Also, fuel composition stands in a certain relation to the general growth pattern; during transformation phases new fuels gained ground. Transformation means renewal of energy systems.[7]

This study analyses the impacts of grand structural transformations of the economy on energy intensities and CO_2 intensities. These transformations rely on development waves. Important questions are the impacts of industrialisation and whether the transition to a service economy reduces energy intensity.

Scope of this chapter

This chapter deals with the effects of structural and technical changes on energy intensity. 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 give rise to unbalanced productivity changes, which change relative prices and thereby relative consumption, manifested in structural changes of production. Technical change also results in income increases, which change demand, which in turn influences the production structure. New energy carriers change the structure of energy supply and stimulate technical development of energy systems, etc. For the purpose of analysis it is, however, possible to separate structural and technical changes.

Any analysis of structural change refers to structural changes at a specific level. This may be the sector level, the sub-sector (branch-level) or still more disaggregate levels. The answer to what impact structural changes have had on energy intensity will therefore depend on the level of analysis. Most of the structural effects are captured at the sector level, and the structural effects decline at a lower level of analysis. The economic sectors: agriculture, industry, services and transportation & communications differ much in their respective

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[7] Schön, L. (1990), op. cite, Schön, L.(1991):"Development blocks and transformation pressure in a macro-economic perspective- a model of long-term cyclical change.", *Skandinaviska enskilda banken quarterly review* 3-4.

levels of energy intensity as well as in their energy intensity development. Changes in energy intensity on the national level may therefore partly be ascribed to variations in the respective size of sector shares, i. e. structural changes, and partly to changes within the sectors, which may be called technical change. At the sector level, variations may be due to sector-specific structural changes or they may be related to technical change. I thus use the concept technical change in an abstract sense, referring to what is not explained by structural changes, i. e. changes in energy consumption relative to a fairly homogenous production.

In spite of obvious connections between changes in energy carriers and technical changes, I have chosen to treat them in two different chapters. This chapter focuses on structural changes and technical change in relation to energy intensity. The analysis of structural change is mainly performed at the sector level, but for the heterogeneous sectors industry and transport & communications some analysis of the impact of sub-sector structural changes is made. The next chapter addresses energy carrier composition in relation to both energy intensity and CO_2 intensity.

Structural changes at the sector level

Determining the relative impact of changes between and within the sectors requires energy data at the sector level, which is only partly attainable. Schön provides a full annual account of energy carriers in the industry sector for the period 1890-1990. For the earlier period 1800-1890 Schön has estimated industrial firewood consumption, but not coal. No energy information is available for the other sectors until the period of 1970-1998 for which most of the necessary information exists on an annual basis. [8]

In order to analyze long-term trends, I have established benchmark energy data at the sector level for the years 1800, 1870, 1913, 1970 and 1998 and these are presented first in this section.[9] Using these estimates makes it possible to analyze four different periods of energy intensity: (1): 1800-1870; the pre-industrial society, with decreasing energy intensity (2): 1870-1913; the industrialization phase, with increasing energy intensity (3) 1913-1970 the maturing industrial society, with fluctuations but with a long-term decline and

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[8] Schipper, et al: *Energianvändningen i Sverige*, Nutek R 1994:10, SCB

[9] The benchmarks are chosen both with respect to data availability and structure of the economy. For the period 1800-1870 the economic structure was rather constant and dominated by agriculture. For 1913 there is an investigation, which provides most of the necessary energy information. 1970 is the first year, for which more detailed statistics at the sector level is available. 1998 is the latest year, for which energy data is available.

(4): 1970-2000: the post industrial society, when a substantial decline is displayed.

In this analysis I will estimate to what extent trends in energy intensity may be explained by structural changes at the sector level of the economy. We may then proceed to address questions such as: Is the hypothesis that industrialization causes an increase in energy intensity and transition to a service economy a decrease in energy intensity confirmed?

I calculate the impact of changes between sectors in relation to changes within sectors for all periods, and I also determine the relative effects of the changes within the different sectors.

The estimates of energy consumption at the sector level in the benchmark years of 1800, 1870, 1913, 1970 and 1998 are presented in table 4.1.

Table 4.1 Energy consumption by the sectors 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

Sources and methods: 1800 and 1870**:** approximately 90% of draught-animal muscle energy was employed in agriculture and the rest in transportation.[10] Human muscle energy is apportioned in line with relative occupation for 1870 and in relation to relative production in 1800 (level adjusted).[11] Coal consumption, apportioned to different uses and sectors, is estimated in appendix A. Schön's estimate of industrial firewood is used. Service firewood consumption is estimated in Appendix D. 1913: The main source of information for establishing energy estimates of the sectors in 1913 is a special inquiry by The National Board of Commerce.[12] I have combined that information with Schön's accounts of industrial energy, my animate energy estimates and my estimates of private service energy consumption (described in appendix D). The bulk of electricity was consumed by industry. The small share of electricity, 0.6 PJ out of 5.2 PJ that was consumed by others has been arbitrarily ascribed to other user categories (including households). The part of oil consumption, 4.9 PJ out of 7.6 PJ that was not consumed by the transportation or industry sectors was at that time mostly used for illumination and the bulk has consequently been divided between households and the service sector. Only a small share was used for vehicles, some private and some in the

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[10] Krantz, O: Transporter och kommunikationer 1800-1980, p 121. Krantz bases his figures of draught animal transportation work on estimates by Thorburn, Th (1958):*Sveriges inrikes sjöfart, 1818-1949*, Uddevalla, and Thaers, A.(1846) *Grundsatser i den Rationella Landthushållningen*, Stockholm, and arrives at an estimate of roughly 10 percent of the horse and oxen time devoted to transport work.

[11] Employment figures available only from 1870. I use employment figures provided by Schön, who has made some revision of Jungenfelt, K.G.(1966) *Löneandelen och den ekonomiska utvecklingen*, Almqvist & Wiksell, and brought the series up to date.

[12] *Special inquiry by the National Board of Commerce. Energy consumption of industrial plants, transportation, and public buildings for the period of 1913-1917.*

transportation sector. The 11 PJ of coal used by the power industry has not been counted here to avoid double calculation of electricity. 1970: the estimates are based on Schipper, et al.[13]

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[13] Schipper, L. et. al.(1994) op. cite. Schipper et al have performed an analysis of Swedish energy consumption for 1970-1990. The data they provide is useful for this study for 1970 and it could not readily be found elsewhere. The data does however need to be developed further to fit the purposes of this study. Schipper et al divide society into four main sectors: 1) the residential 2) the premises 3) the industry and 4) transportation. Industry is divided into two main categories: manufacturing and other industry. Construction, mining and agriculture comprise the branches of other industry. Transportation is divided into a) personal transportation (by means of cars, trains, buses and aeroplanes) and b) goods transportation (by means of lorries, trains and ships). They separate changes in energy consumption within a sector according to a) activity change b) structural change and c) intensity change (technical change). Their approach is therefore basically relevant to an economic study. Their analyses are, however, not immediately applicable in this investigation because of their method of dividing the sectors and their inconsistent method of measuring sector activity. Another problem is that they restrict their structural analyses to changes within sectors and do not include structural changes between the sectors.

First, a few words on Schipper et al's sector division. One problem is that agriculture is included in their industry-sector. This is, however, not that problematic because they provide special figures for agricultural energy consumption in the appendix, which facilitates another sector aggregation. Second, buildings in the transportation sector are included in the premises sector and separate statistics of energy consumption for transportation buildings are not available. This cannot easily be corrected for. It must be endured, which means that energy in transport & communications will be slightly underestimated, while service energy will be overestimated. But buildings in the transport sector are not as numerous as in the service sector; most of the work is performed in vehicles. Besides, the buildings of this sector are not heated to as large an extent as other sectors. According to SOU 1975:96 *Energiförsörjningen 1975-1980*, p 31, only about 50% of the buildings in the transportation sector were heated compared to 80% of premises used for trade, banking, insurance-companies, cinemas, restaurants and hotels. 100% of other service buildings were heated. A third problem is that transportation by car is not divided into commercial use (taxi-driving) and non-commercial. I solved this problem by estimating taxi fuel consumption through the following procedure. I assumed that 75% of the inputs (current prices) into the taxi-sector consist of petrol. The value of the inputs is provided in "*Appendix 4 till nationalräkenskaperna: Produktion och faktorinsats*". Taxes and services/repairs are roughly estimated to make up 25% of the inputs. Depreciation of the cars is (as usual) not included in the input costs. Annual prices of petrol were used to calculate the numbers of litres obtained. The data was obtained from *"Oljeåret i Siffror*,. Esso, 1975-1982, and combined with a price index for petrol from *Statistiska meddelanden. Serie P. Prisindex* . The number of litres of petrol were converted to joule according to Nutek´s *Energy in Sweden 1992*, conversion factor 36 MJ/liter.

Schipper et al are not consistent when they measure sector activity. In some cases they measure activity in economic terms, where quality matters, but in other cases they measure activity simply in physical terms, which is a more simplistic measure, where quality aspects like time savings are not included. For the industrial sector they use real value added from the National accounts and thus an economic evaluation of the work. For transportation they do not use any economic values for production at all; instead they use person-km and ton-km as measures of transport activity. Compared to an economic measure, this method has the drawback of not taking speed development and time savings into account in a positive sense. By their method, speed increase is not noticeable in an increased quality of the work performed, like in an economic evaluation. It is only noticeable in increased fuel for transport. In this study, activities are consistently measured in economic terms, as value added. Because of this difference my estimate of energy intensity in the transportation & communication sector is fundamentally different from theirs. For premises, they use both real value added from the National accounts and heated area as measures of activity and they use heated areas to measure residential energy consumption. Because their approach is not consistently economic, their

The transportation energy for 1970-1990 has been level adjusted upward according to its relationship to figures by SCB in 1990. 1998: SCB: Slutlig användning av energi, fördelat på sektorer. I have apportioned the transportation energy to households and to the transportation sector according to SCB: tablå B for 1987, thereafter according to tablå G in *Energibalanser, statistiska meddelanden*, kindly provided by Mikael Sjölin SCB.

Table 4.2 Sector energy intensities in certain benchmark years expressed with different price level years, 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, SCB. 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 (see

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results are not applicable in this investigation and I have made my own analysis, based on their energy consumption figures with the addition of my animate energy series and the value added for all production sectors.

appendix C) and its production in constant prices has been proportionally adjusted so the sums equal GDP, minus dwelling usage and the power industry.

Production values of the sectors can be expressed at different price levels and the choice of price level year will influence the denominator and hence provide different energy intensity results, which are shown in table 4.2. 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, because choosing a price level year far outside the period will render production values and energy intensities anachronistic for no reason. I have consistently chosen early price level years.

Counterfactual analyses

The effect on energy intensity, due to structural changes at the sector level and due to changes within the sectors, is analyzed during the four periods mentioned: the pre-industrial period 1800-1870, the industrialization phase 1870-1913, the maturing industrial society 1913-1970 and the post-industrial phase 1970-1998.

The method is standard calculations, which consists of counterfactual calculations, where one factor is held constant and the outcome is compared with the actual outcome. In principle, this method enables assessment of the relative importance of different changes. Although standard calculations is the best method available it is still too simple to capture complex changes, where different variables change simultaneously. The result will vary depending on which factor is held constant. The consequence for my analysis is that the relative importance of changes between or within the sectors will differ, depending on whether sector structure or sector energy intensities are held constant.

1) One possibility is to hold sector shares constant according to the initial year of the period. The outcome of 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, i. e. what is not explained by structural changes.

2) Another possible counterfactual 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, i. e. technical change, to be calculated directly. In this calculation, the relative importance of structural changes at the sector level is a residual, i.e. what is not explained by technical change.

Although the results of these two counterfactual calculations are not the same, they are not substantially different. They provide rough indicators of the relative importance of structural and technical changes. Because the aim of my analysis is also to assess the *relative* importance of changes within the *various* sectors, it is best to use the latter kind of counterfactual calculation, which holds sector energy intensities constant and hence directly calculates the impact of changes within the sectors, or technical change.

The results

The results are presented in tables 4.3 to 4.6. Table 4.3 presents the relative impacts of structural shifts and within sector changes, so-called technical change.[14]

Table 4.3 Relative impacts of technical change and structural changes, according to counterfactual calculations with constant sector energy intensities.

	1800-1870		1870-1913		1913-1970		1970-1998	
Energy intensity, MJ/SEK	230	150	65	80	64	42	6.4	4.1
Counterfactual energy intensity, MJ/SEK		230		79		80		6.4
Technical change explains		100%		7%		173%		100%
Structural changes explain		0%		93%		-73%		0%

Sources: see tables 4.1 and 4.2

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[14] If instead the method of using constant sector shares is chosen for the counterfactual calculations the result is the following:

	1800-1870	1870-1913	1913-1970	1970-1998
Technical change	100%	-19%	116%	107%
Structural changes	0%	119%	-16%	-7%

Table 4.4 The sectors' relative contributions to the aggregate impact of technical change.

	1870	1913	1970	1998
Agriculture, actual energy	20	27	30	29
Agriculture, counterfactual energy	36	32	30	34
Absolute deviation	-16	-4.6	0	-4.7
Agriculture's contribution to technical change	52%	510%	0%	1%
Industry, actual energy	16	100	580	560
Industry, counterfactual energy	31	111	840	920
Absolute deviation	-16	-11	-260	-360
Industry's contribution to technical change	52%	1300%	33%	70%
Services, actual energy	11	27	170	170
Services, counterfactual energy	11	29	170	300
Absolute deviation	-0.69	-2.2	0	-130
Service's contribution to technical change	2.3%	240%	0%	25%
Transports, actual energy	7.2	62	92	160
Transports, counterfactual energy	5.3	43	610	180
Absolute deviation	+1.9	+19	-520	-20
Transports' contribution to technical change	-6.2%	2100%	67%	5%
Sum of actual energy	54	216	870	920
Sum of counterfactual energy	84	215	1650	1440
Aggregate impact of technical change	-30	+0.90	-780	-520

Sources: see tables 4.1 and 4.2. Comment: Actual energy consumption and counterfactual energy consumption with constant sector energy intensities, in PJ.

According to table 4.3, structural changes at the sector level had no impact on overall energy intensity in two periods: 1800-1870 and 1970-1998. They had a large positive impact on the increase in energy intensity between 1870 and 1913 and a fairly large negative impact on the decline in energy intensity between 1913 and 1970. This means that during the long period of 1870-1970, structural changes worked to increase energy intensity. Technical change generally worked to decrease energy intensity and the relative importance of changes within *each* of the sectors is determined in table 4.4. Since table 4.3 and table 4.4 both report the *relative* importance of changes within the sectors, or so-called technical change, it is possible to combine the results. This is done in table 4.5, where the relative importance of structural shifts at the sector level and changes within each of the sectors are presented.[15]

Table 4.5 ***Relative*** *importances of structural shifts and changes within each sector for the* ***total*** *change in energy intensity, in percent*

	1800-1870:	1870-1913:	1913-1970:	1970-1998:
Structural shifts explain	0	93	-73	0
Agriculture explains	46	-34	0	1
Industry explains	52	-85	57	70
Services explains	3.4	-16	0	25
Transportation explains	-1.4	140	116	4.6
Total explanation	100	100	100	100

Sources: see tables 4.1 and 4.2

The results of table 4.5 can be recalculated into *absolute* importance for the *annual* change in energy intensity and this is done in table 4.6.

Table 4.6 ***Absolute*** *impacts of structural shifts and changes within each sector for the* ***annual*** *change in energy intensity, in percent.*

	1800-1870	1870-1913	1913-1970	1970-1998
Annual change in energy intensity	-0.61	0.48	-0.74	-1.6
Of which:				
Agriculture	-0.28	-0.16	0	-0.02
Industry	-0.32	-0.41	-0.42	-1.1
Services	-0.02	-0.07	0	-0.4
Transport	0.01	0.67	-0.86	-0.07
Structural shifts	0	0.45	0.54	0

Pre-industrial energy intensity

Any perception that the pre-industrial society was non-progressive and stationary is refuted with regard to energy. This study demonstrates that 1800-1870 was a period of impressive improvements in efficiency for traditional energy carriers in relation to economic output. Energy intensity declined from 230 to 150 MJ/SEK, or by 35%, i. e. 0.61% per annum. Structural changes in the period 1800-1870 were small and the entire decline in energy intensity was due to changes within the sectors. Two sectors experienced declining energy intensity: industry and agriculture. The energy intensity changes of the

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[15] The percentage units accrued to technical change according to table 4.3 are attributed to each sector according to its relative importance for aggregate technical change according to table 4.4.

transportation & communication sector and of the service sector are so small that they are within the error margin. The sectors' relative impacts on energy intensity do not depend only on their relative development of energy intensity, but also on their absolute energy consumption, which is related both to their level of energy intensity and their size. The industrial sector, closely followed by agriculture, had the largest effect on the overall decline.

Industrialization and energy intensity

In the period 1870-1913, energy intensity increased from 65 MJ/SEK to 80 MJ/SEK, or by 23%, i. e. 0.48% per annum.[16] This was a period of rapid industrialization in Sweden and it is of interest to know to what extent this increase was caused by the relative growth of industrial production. My standard calculations show that almost the entire increase was due to the industrialization process. A large structural transformation at the sector level occurred during this period, which resulted in increased energy intensity within the formal economy. The industrial sector's share of GDP increased from 21% to 46%, at the expense of agriculture. The disparity in energy intensity levels between industry and agriculture was so large, that the relative growth of industry caused a substantial increase in the overall energy intensity. Besides the growth of the industrial sector there was a related growth of the transportation & communication sector, which further expanded the increase in energy intensity.[17]

The *net* influence of the changes within the sectors was marginal, but this does not mean that changes within each of the sectors were small. In three sectors the energy intensity decreased and in one sector it increased substantially. Within the three sectors industry, agriculture and services there was a decline in energy intensity, which counteracted the overall increase in energy intensity. The effect of the decline in industrial energy intensity was especially strong and almost outweighed the effect of structural changes. At the same time there was a substantial increase in energy intensity in the transportation & communication sector, which worked even stronger to increase energy intensity, than structural changes per se. The changes within the four sectors balanced each other almost completely and structural changes caused the increase in energy intensity.

Continued industrialization and energy intensity

In the period 1913 to 1970 the industrial society matured and energy intensity fell from 64 to 42 MJ/SEK, or by 35%, i. e. 0.74% per annum. The decline was

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[16] Constant prices, 1870 years' price level.

[17] The share of GDP for the transportation and communication sector increased from 6% to 11%.

not an even process. During the two World Wars, energy intensity fell substantially and it was not restored to previous levels after the wars, even though there was a slow relative increase between 1945 and 1970.[18] In the period 1913-1970, like in the period 1870-1913, structural changes worked in the direction of increasing energy intensity, but now the declines within the sectors were strong enough to cause a net decrease in energy intensity. Agriculture and services had no impact on the decline. The transportation and communication sector contributed most to the decline, followed by industry, which is remarkable, since the former sector exhibited a substantial increase in energy intensity during the previous period.

The post industrial society and energy intensity

Between 1970 and 1998 energy intensity declined from 6.5 to 4.0 MJ/SEK, or by 38%, i. e. 1.6% per annum. This was a period of relatively rapid decline and a reasonable idea is that structural change in the form of an increased service sector played a positive role in this process. [19] The proposition that the transition to a service economy lowers the relative energy intensity is however refuted by the previous standard calculations. Structural changes at the sector level in the period 1970-1998 had no effect on the decline in energy intensity, but the sole reasons for the decline are to be found within the sectors. Again, the industry sector was responsible for most of the decline, but this time the service sector also had a rather large influence, while the transportation & communication sector played a more modest role than in the previous period and agriculture had a negligible effect.

The notion that a decrease in energy intensity is an effect of the transition to a service economy is mainly founded on a misconception. There are two indisputable facts regarding this transition. First, relative employment has decreased in the industrial sector and increased in the service sector. Second, value added in current prices has increased more in the service sector than in the industrial sector. Based on these facts, some people draw the conclusion that production of services has increased more than production of industrial goods and it seems reasonable to expect the production structure in a service economy to be less energy intensive and less polluting. The conclusion that service production has increased more than industrial production is nevertheless, erroneous.

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[18] The rapid declines during the World Wars are interesting and worthy of more attention than is possible within the framework of this investigation. It would, for example, be interesting to compare this outcome with the result of studies from other countries.

[19] The idea that a transition to a service economy brings about a less materialistic production which reduces environmental stress and degradation has been promoted for example by Kahn, H.(1979): *World economic development*, and by Grossman, G.M.& A.B.Kreuger (1995), op. cite.

This misconception occurs because the different productivity and relative price developments in industry and services are overlooked. Baumol was the first to emphasize the implications of the fundamental difference in productivity between industrial production and service production.[20] While the goal of industry is to produce goods and human labour is only used as a means, human labour is a more necessary ingredient in service production. While machines may replace labour in industry, this is not possible to the same extent in the service sector. Equipping industrial workers with more and better machines has brought about a tremendous increase in their productivity. A similar increase in labour productivity of services has not been possible, because speeding up work in services frequently reduces the quality.

When the real output relationship between industry and services stays fairly constant, the difference in productivity tends to increase relative employment in services over time.

The difference in productivity has also resulted in profoundly different relative price developments for industrial goods and services. While wages in the service and industry sectors have followed each other to a large extent, the productivity of workers has not, which has led to a relative increase in prices of services compared to industrial goods. The implication is that when output is measured in current prices, the increase in service production is exaggerated, because it is influenced by the relative price development.

The different outcomes for sector shares when output is measured in current or constant prices are demonstrated by a comparison of figures 4.1 and 4.2. According to figure 4.1, which uses constant prices, the service sector stayed roughly constant over the two hundred years while the transportation & communication sector increased its share throughout the period. The industry increased its share until the early 1970s after which it experienced a small decrease. The share of agricultural production decreased until the 1970s, when it stabilized at a low level. In conclusion, it appears as if the transition to a service economy is characterized by an increase in the transportation and communication sector and not, as is normally assumed, by an increase in services.

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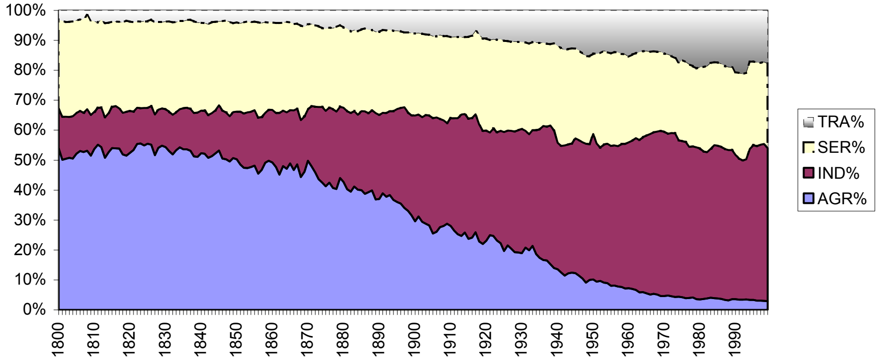
[20] Baumol, W. J.(1967): "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crises", *The American Economic Review*, pp 415-426

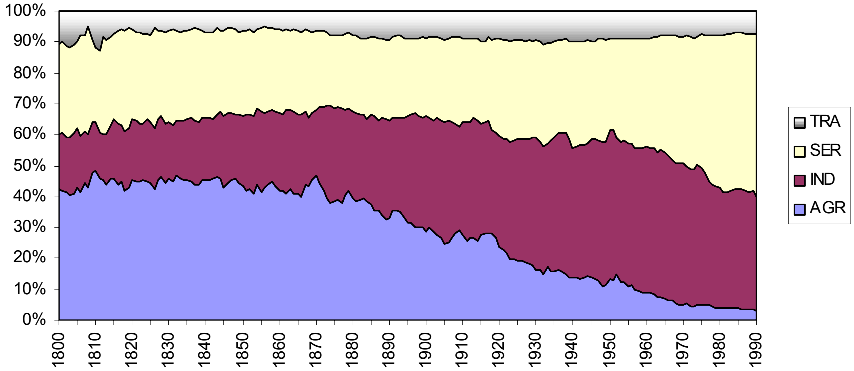
Figure 4.1 Sectors' shares in Sweden 1800-2000, in constant prices, 1910-12 price level.



Sources: SHNA, SCB, elabourated deflators, see appendix C. Comments: The service sector is without dwelling usage, the industrial sector is without power industry, but includes building & construction.

Figure 4.1 may be compared to figure 4.2, which uses current prices. Here, the service sector shows a remarkable increase as early as in the 1920s and its relative growth accelerates from the 1960s. This relative expansion of services is, thus, caused by relative increases in the price of services and not by a relative growth of service quantities.

Figure 4.2 Sectors' shares in Sweden 1800-1990, in current prices.



Sources: SHNA, SCB. Comments: the service sector is without dwelling usage, the industrial sector is without power industry, but includes building & construction. The reason why this figure is not extended until 1999 is that SCB does not provide data in current prices, detailed enough for my compilation of sectors.

The smaller productivity and increased costs in the service sector makes the transition to a service economy somewhat of an illusion when it comes to what is important for energy intensity: a society's actual production.

Should we then not expect some increase in real service production and consumption in a country as it becomes more developed and richer? Sometimes Engel's law is put forth as an argument for why service consumption should increase its (real) relative share in an advanced society.[21] The idea is that there is a connection between a society's income levels and relative expenditure. A person with low income devotes a larger proportion of his/her income to basic needs (mainly food and industrial goods), while a person with a higher income spends a larger share on less pressing needs like services. At first glance, this "law" appears to lend some credibility to the proposition that service consumption increases its share in a high-income society, but this is not so**.** While Engel's law holds for households at different income levels within a society at a given time, it neither holds between countries of different income levels nor when a country's income rises over time. This is because, with higher income levels, prices of services will rise, and people will not be able to afford them to larger extent than in a country with a lower level of income. The only conclusion from Engel's law is that the relative income position of a household in a certain society determines what proportion of its income is spent on services. The absolute income does not matter.[22] Engel's law provides no reason to believe that real service production will increase relative to real industrial production in a high-income country.

Structural changes at the sub-sector level

So far, the impact of structural changes at the sector level versus changes within the sectors has been determined. The changes in energy intensity within the sectors may be due to technical change in a broad sense, but they may also be due to structural changes at the sub-sector level (branch level). If the branch composition changes in a more energy conserving direction, it contributes to a decrease in sector energy intensity, while a change in the opposite direction partly or completely offsets such a fall. The potential impact of structural changes at the branch level is naturally stronger for heterogeneous sectors than for homogeneous ones. There is a larger degree of homogeneity with regard to energy for agriculture and services than for the transportation & communication and the industry sectors. Transportation thus has higher energy intensity than

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[21] After the German statistician Ernst Engel (1821-1896).

[22] Ingelstam, L. (1997) *Ekonomi för en ny tid,* Carlssons, chapter 3, discusses the implications of the unbalanced growth in detail, although he never relates the matter to environmental impacts.

communication and different transportation branches also vary with respect to energy intensity. Industrial branches could be divided into high-energy intensive and low-energy intensive ones, where process industries typically belong to the former group.

One reasonable hypothesis is that the rapid decline in energy intensity in the industry sector in the period 1800-1998 and in the transportation & communication sector in the period 1913-1970 was to some extent caused by structural changes within the sectors, at branch level. It also seems most plausible that the increase in energy intensity of transportation and communications between 1870 and 1913 was due to the relative expansion of railways and steam ships.

Industrial structure and energy intensity

Schön found that only ¼ of the decrease in industrial energy intensity for 1890-1987 depended on structural changes at the branch-level, which means that ¾ of the decrease was due to changes within the branches, which may be referred to as technical change. [23] Schön's results rely on energy data at the branch level of the industrial sector for the period 1920-1987, and in relevant cases on even more disaggregated data.[24] In total he deals with about 60 industrial groups for this period. Prior to 1920 his data is based on a careful exploration of the metal industry, while the development for the other main branches for the period 1890-1920 consists of extrapolated trends.[25] Schön apportions the branches to two aggregates: heavy and light industries and uses standard calculations to assess the impacts of structural changes at the branch level versus changes within the branches. One important result is that energy intensity decreased during the industrialization phase due to a relative expansion of energy light branches such as engineering and textiles.[26] A general feature of the industrialization phase is that heavy industries, closely related to natural resource extraction, decrease their relative importance and that light engineering industries and consumption industries like clothing increase their share. Another important outcome is that during the structural crises around 1890, 1930 and 1975, heavy industry rapidly decreased its share of industrial production. In the transformation periods after 1890 and 1930 heavy industry regained some of its position and during the following rationalization phases the branch structure remained relatively stable. The structural pattern after 1975 is different from the

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[23] Schön, L.(1990), op. cite, p 24, Appendix, p 116-120.

[24] For instance the paper and pulp industry is too heterogeneous with respect to energy to keep it in one aggregate and it is disaggregated.

[25] Schön, L, (1990), op. cite, p 122-123, Schön, L. (1994), p 37.

[26] Energy intensive branches (heavy industries) typically demand heat for processes, while light industries demand motive power.

previous cycles, because light industry appears to have increased its share more permanently. The rising oil-prices in 1973, which were accompanied by a fiercer international competition, produced a deep crisis for heavy industry like iron and pulp. Swedish industry was hit severely by this crisis and there was a strong incentive to restructure and to find new paths of development. The composition of Swedish industry changed during the 1970s when light industry expanded, while heavy industry shrank in absolute terms. During the 1980s heavy industry grew again, but at a slower pace than light industry. This resulted in an overall increase in light industry between 1970 and 1987. Schön has estimated that this structural change led to a decrease in industrial fuel consumption by 20% and a corresponding decrease in electricity by 5% in the period 1970-1987.[27] This more permanent change in industrial composition in the direction of light industry was of course not only due to the combined energy and structural crisis of the 1970s, but also due to the profoundly different character of the new growth engine of this third industrial revolution: the microelectronics. Microelectronics has formed the basis for several development blocs, which are still only in the beginning of their expansion. Its application in PCs, in which hardware and software interact, constitutes one obvious expansive bloc of development. Its application in telecommunications, both wirebound and wireless, has enabled both a substantial growth in telephone contacts and in network communication between computers. Another progressive development bloc that relies on microelectronics is biotechnology. The relative expansion of these, knowledge intensive, energy light branches, based on microelectronics, has resulted in a decline in the overall energy intensity of industry.

Structure of the transportation and communication sector

Energy data for the transportation & communication sector is generally not available at the branch level. This means that standard calculations are ruled out as a method for determining the impact on energy intensity of structural changes at the branch level, and that the assessment must be rougher. I have apportioned the branches of transportation & communication to one heavy and one light aggregate, according to what kind of work they perform.[28] For each of the aggregates, I have constructed a special price deflator, with one-year linked indices.

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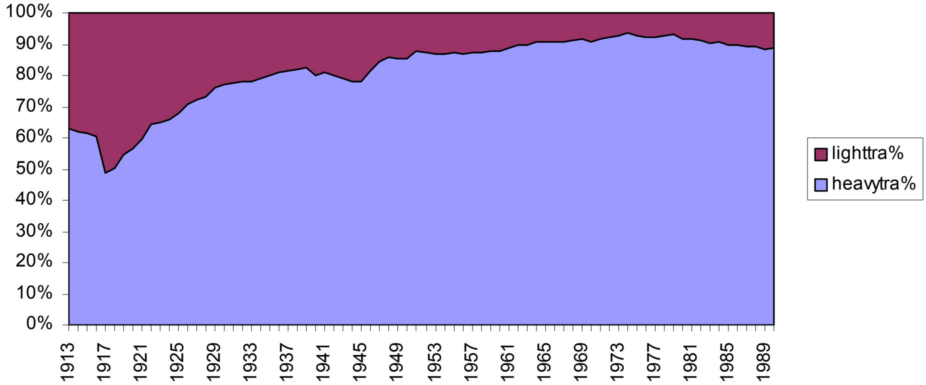
[27] Schön, L. (1990), op. cite. p 99.

[28] In the light group I include: postal services, telegraphs, stevedoring, transport agencies, carriages and floating. In the heavy group I include: foreign shipping, domestic shipping, railways, trucks, taxis, buses, tramways, domestic and foreign aviation.

Figure 4.3 Light and heavy transportation and communication 1913-1990



Sources: SHNA, Krantz, O.: Transporter och kommunikationer 1800-1980, SCB 1980-2000.

In figure 4.3 the relative size of the aggregates is shown with the price level of 1913. The price level affects the *relative size* of the two aggregates, because relative prices have increased over time in labour intensive, light branches. The *relative change* of the two aggregates over the period is, however, the same with different price levels, because with constant prices only quantities matter for the changes.

My result is that the heavy aggregate *increased* its share of value added in constant prices 1913-1970. This structural change should have *counteracted* the rapid decline in energy intensity of the transportation and communication sector. Explanations for the impressive decline of energy intensity during this time must therefore be found within the branches. This will be further discussed when the impact o technical change on energy intensity is treated.

The transportation & communications sector did not only stand out in its decline in energy intensity between 1913 and 1970. Equally remarkable was the substantial increase between 1800 and 1913, at the same time as the energy intensity of the other three sectors declined. Two things were decisive for this increase. First, there was a gradual shift from sailing ships to steam ships and, since the wind used by ships is omitted in my study, this naturally leads to an increase in energy intensity. Second, there was a shift from horse carriages to steam railways. During the 19th century the energy intensity of railways was about 5-6 times higher than for carriages. It follows that the shift from horse carriages to railways implied increased energy intensity of the sector.[29] The

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[29] The energy intensity of carriages was 42 MJ/SEK in 1800 and 40 MJ/SEK both in 1870 and 1913, while energy intensity of railways was 200 MJ/SEK in 1870 and 237 MJ/SEK in 1913 (1910/12 years price level), when human muscle energy is excluded. Including muscle energy only makes a small

railways, having higher energy intensity than the average intensity of the sector, increased its share of the sector rapidly in this period.[30] The increase in energy intensity in the transportation and communication sector between 1800 and 1913 is thus to some extent, and perhaps wholly, due to shifts between branches.

Foreign trade and industrial energy intensity

An important question for a small, open economy like the Swedish one is the influence from international trade. One may, for instance, ask whether a long-term decrease in energy intensity is the result of foreign trade. If foreign trade plays a significant role in a country, the structure of production may differ quite a lot from the structure of consumption. The structure of the Swedish industry, with more light industry after 1970, may for instance be a result of Swedish international trade. A frequently asked, relevant question about development, trade and the environment is to what extent the more developed countries (the North) dump their environmental problems in less developed countries (the South). Evidence of such transfers indicates that the cleaner environment that characterizes richer countries may be a result of moving the problems instead of eliminating them.[31] This suggests that analyses of national development are difficult to generalize. For example, it would be wrong to conclude that if all countries were rich today they would all show the same domestic environmental characteristics as the rich countries do presently. People, who view the relationship between economic growth and the environment in a pessimistic light, emphasize examples of environmental dumping.[32]

World systems' theories have stressed the unequal exchange between rich and poor countries. One example is the Dependency School, which regarded the development of the North as a consequence of the appropriation of resources of

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difference, reducing the gap marginally, because horse carriages are more labour intense than railways. For example, in 1880, 7771 persons (almost entirely men) were occupied in railways according to *Befolkningsstatistik 1880, part 3*. Reasonable assumptions give that they consumed 3000*1.4*10/24*6/7*365 kcal each in a year for work. In total they consumed 0.018 PJ. This should be compared to coal consumption by railways that was 4.95 PJ. Only 0.4% of the coal for railways was for human muscle energy. At the same time, 75 400 animals were used in horse and ox carriages, consuming 2.1 PJ. With the reasonable assumption of one person taking care of two animals, 37 700 persons were occupied in carriage transportation. They consumed 0.0865 PJ, which is 4% of the energy of draught animals. This calculation shows that it will make hardly any difference for the relative branch energy intensity of railways and carriage transportation if human energy is included.

[30] The railways increased its value added 13 times in the period 1870-1913, while the sector increased by a factor of 6 (current prices). In constant 1910-12 prices railways increased its value added 17 times, while the sector increased 6 times.

[31] There are studies confirming such environmental dumping, for instance Clapp, J.(1994): ”The toxic waste trade with less industrialised countries: economic linkages and political alliances”, *Third World Quarterly*, Vol. 15, no 3.

[32] See for instance Daly, H.(1993): ”The perils of free trade”, *Scientific American*, Sept.

the South. Development is viewed as a zero-sum game, in which some countries win at the expense of others. This worldview was expressed by the mercantilists much earlier, but without the same moral indignation. In the present environmental debate, ideas of unfair exchange are used repeatedly as ethical imperatives for rich countries to cut down on their consumption and give back to the poor what they have unjustly taken from them. Levelling out consumption is regarded as the proper means to achieve a sustainable development at the global level, because both extreme poverty and excess consumption have negative environmental effects. This is however an oversimplification. Economic growth does not normally occur as a result of "stealing" natural resources and an ethical imperative to help the poor does not need to be founded on causation (the rich being the cause of poverty). A strong case for international aid may instead be made on the grounds that we are all human beings with certain basic rights that are not satisfied for a large number of people today. Questions of unequal exchange due to power structures on the international arena should still not be abandoned. These matters are difficult, but important. But current attempts to abandon economic measures in favour of measuring land, EMERGY or human labour time have the weakness of not allowing for quality aspects and human preferences. [33] It would be better to deepen our analyses of price mechanisms in time and space, taking income distribution and power structures into account.

In this study the objective is less ambitious, but more concrete, namely to analyze changes of Swedish international trade in goods with respect to their energy content. Did Sweden in the 20th century benefit from her position in the rich, developed world in the sense that she imported more energy in goods than she exported? If this were the case, Swedish energy intensity in production would be lower than her energy intensity in consumption. Obvious differences between energy intensity of production and consumption, through the mediation

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[33] Howard. T. Odum introduced the emergy concept in the 1970s. It denotes the energy memory inherent in commodities or services, all prior work required to make a product or a service, expressed in units of one kind of energy, often solar energy. Odum develops this accounting in *Environmental Accounting. Emergy and Environmental Decision Making*, John Wiley & Sons, Inc, 1996. Together with a forester, an historian and another systems ecologist Odum wrote a study "Forest EMERGY basis for Swedish power in the 17th century", *Scandinavian Journal of Forest Research*, Supplement No1 (1994) more extensively presented in *Skogens användning och roll under det svenska stormaktsväldet – perspektiv på energi och makt*., Kungliga Skogs och lantbruksakademin, 1995. On p 49 of the Swedish version the unequal exchange between developed and underdeveloped countries is expressed in EMERGY-terms: " Sweden, in the 17th century may be compared to the developing countries of today. They export large amounts of EMERGY per monetary unit, but they pay high prices for imports in terms of EMERGY. This constitutes a biophysical explanation for the imbalance in the world trade and it illustrates the ongoing impoverishment of the developing countries. The EMERGY analysis thus incorporates the management of resources, which is the cause of the increasing gap between the industrialized world and the developing nations.

The basis for these analyses is an energy value theory, in some respects comparable to the labour value theories of Ricardo and Marx.

of trade, would partly undermine the relevance of focusing on production, without accounts of international trade, when Swedish economic growth in relation to energy consumption is studied. Changes in the net-export of energy of goods might be part of an explanation of changes in Swedish industrial energy intensity.

Sweden is richly endowed with natural resources, especially wood, iron and hydropower, and its population density is low. As a consequence, Sweden comes out very well in international comparisons of ecological footprints, which basically means that Swedes to a large extent confine their consumption to what could have been produced within their national borders.[34] This means that even though Sweden is connected to the rest of the world through extensive trade, it is not a typically developed country, since it is not a net importer of goods with a heavy content of natural resources. The iron industry and the pulp and paper industries have long made up a large share of Swedish exports, and in the 20th century Swedish industry was extremely electricity intensive, by international standards, due to the accessibility of hydropower.

Between 1880 and 1950, the exports' share in Swedish production exhibited a cyclical pattern, ranging from 18 to 40%. After the Second World War there was a sharp increase from 22% to 53% in 1980, which means that it is more likely that international trade explains variations in industrial energy intensity after 1950. [35] Swedish exports are generally energy intensive. It is of special interest for this study to know whether changing patterns of international trade may have contributed to the decrease in energy intensity after 1970. If Sweden in 2000 was a larger net importer of energy in goods than in 1970 this would tend to decrease energy intensity. The trend break around 1970 would then not only have been a result of changing demand and technical change within Sweden, but also depended on the country's position in the global economy. Hermele suggests that: "while we live in the service society, more and more of our consumption goods are produced in the developing countries".[36] The following analysis will illuminate whether this is correct or not.

In my analysis, I combine the results of previous studies on energy in Swedish international trade between 1955 and 1975 with the results of my own investigation for the period 1970 to 1987.[37]

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[34] Wackernagel, M. et al (1999): "National natural capital accounting with the ecological footprint concept", *Ecological Economics 29*, 375-390.

[35] Krantz, O. & L. Schön: *Energi och strukturförändring i Sverige*, Efn/AES 1984:1, p 4.

[36] Hermele, K, (1995), op.cite, p 93.

[37] I have chosen the year 1987 instead of 1998, since energy intensity of the various branches and sub-branches are calculated by Schön up to 1987. By using Schön's figures I have consistent energy intensities for 1970 and 1987, which I would not have if I extended the series on my own to 1998, because my methods would most likely differ from Schön's in some respects. I do not think the result would be profoundly different if 1998 were chosen instead.

It must be noted that studies on energy in commodity trade tend to be rough for three reasons. First, the level of aggregation is high and actual structures within these aggregates may vary over time. Second, these studies assume that producing certain specific commodities abroad requires the same amount of energy as producing them at home, i. e. technical differences between countries are not taken into account. Third, these studies frequently include only energy in the last production branch, and disregard the energy of inputs. Using an input-output technique would not have this problem, but it is too demanding for this study. One can, however, compare outcomes with results from such an input-output analysis. In an input-output study, Östblom found that Sweden was a net exporter of energy in goods and services in 1965, 1970, 1973 and 1975.[38] The import of energy intensive products rose and the exports became less energy intensive between 1965 and 1975, but at the same time the exports increased their share of final use. Because exports were still the most energy-intensive category of final use, this resulted in an increase in the net exports of energy in goods. This increase contributed to an increase in total energy consumption in Sweden between 1965 and 1975. Another investigation by SOU 1978:64, which was limited to trade in goods and used the simpler method of just counting energy consumption of the export branch, showed a similar result. Sweden was a net exporter of energy in goods in 1955, 1963 and 1970. These results are summarized in table 4.7.

Table 4.7 Net exports of energy in goods from Sweden 1955, 1963 and 1970, PJ.

	1955			1963			1970		
	El(S)	Fuel	total	El(S)	Fuel	total	El(S)	fuel	total
Net export, PJ	8.81	38.3	47.1	18.7	86.4	105	21.5	119	140.5
Net export's share of industry's energy	19%	17%		25%	27%		18%	27%	

Source and method: All the figures are from table 6.23 on p 127 in SOU 1978:64. The original figures were given in GWh for electricity and in ktoe for fuels. The standard conversion figures for expressing these units in PJ are: 1GWh=0.0036 PJ and 1 ktoe=0.0419 PJ.

SOU 1978:65, a supplement to SOU 1978:64, reported the result of an input-output analysis for 1971, which showed that the net export of energy was about 50% higher if all energy in the production chain was included.[39]It may be

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[38] Östblom, L.(1980) *Energianvändningen i Sverige 1965-1978*, Skrift nr 1980:1, forskningsgruppen för energisystemstudier, Nationalekonomiska institutionen, Stockholms universitet, p 8.

[39] SOU 1978:65, p 78. The input-output study was performed by Lars Bergman and reported in appendix 9.

concluded that Sweden was a substantial net exporter of energy in goods in the period 1955–1975 and that its net exports of energy in goods increased. This contributed to the rise in energy intensity between 1955 and 1970.

The question is then whether there are any indications that this pattern changed, or weakened, thereafter? If so, this might provide a partial explanation for the decrease in energy intensity after 1970. To answer this question I compare the net energy content of goods in 1970 and in 1987.[40] My investigation, like SOU 1978:64 is conducted without taking energy of inputs into account, since it counts only the direct energy consumption of the exporting branch. I primarily use energy data at the branch level, which is a rather high level of aggregation. The commodities of each category are however still rather homogenous when it comes to energy. The dividing line is between heavy and light branches, because on average, heavy industry consumes ten times as much energy, in relation to its production value, as light industry. Basically the production of material like iron, pulp, plastics etc. demands much energy, while mechanical work, as in the textile industry or in the engineering industry, demands less energy.[41] In several cases the division was more detailed than at the branch level, like in the paper and pulp industry. The energy figures are divided by the sales value of each branch in current prices and not by value added. These energy intensity figures are used to calculate the energy content of the net export of goods (energy in exports minus energy in imports) for each branch. Unfortunately the import/export statistics do not correspond very well with the production statistics, and I have had to do my own apportioning of the imports and exports to relevant production branches. The result was related to total industrial energy consumption.

My results are presented in table 4.8, both with the inclusion and exclusion of internal fuels. A substantial part of energy in the Swedish pulp industry consists of spent pulping liquor, and the wood industry uses waste wood. The fact that net export’s share of total industrial consumption remained roughly constant between 1970 and 1987 means that the energy content fell in both imports and exports, but the balance remained unchanged. This may be interpreted as changed consumption in an energy light direction both in Sweden and abroad. Thus the relative expansion of light industry in Sweden after 1970 was not due to Sweden importing more heavy industrial products from abroad.

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[40] I have received data series from Schön, L (1990) and 1987 is as far as the series are extended.

[41] SOU 1978:22 *Energi, strukturomvandling och sysselsättning*:, p 135: ”Det processindustriled som följer närmast efter råvaruutvinningen har markant högre specifik energiförbrukning än såväl det föregående som de efterföljande leden. Exportindustriernas energiförbrukning räknad per sysselsatt eller per enhet produktionsvärde blir högt om exporten sker närmast efter processledet (obearbetat stål, baskemikalier, pappersmassa) Vidareförädling därefter är i allmänhet mindre energikrävande.”

Table 4.8 Energy in internationally traded goods, 1970 and 1987.

	Import energy PJ	Export energy PJ	Net export PJ	Net export's share of total industrial energy consumption
Internal fuels excluded				
1970	175	254	79	18%
1987	116	200	84	23%
Internal fuels included				
1970	176	339	163	36%
1987	123	296	172	35%

Sources: Statistisk årsbok, SOS Industri, fuel and electricity series from Schön's electricity study (1990), Schön's series for internal fuels from his wood fuel study (1994) (unpublished data series).

Technical change and energy intensity

The changes in the energy intensity of the sectors that are not related to structural changes can be attributed to technical change in a broad sense. The results of the previous structural analyses indicate that energy intensity decreased in all the sectors during all the periods, except for the transport and communication sector between 1870 and 1913, which was largely a structural effect on the branch level. This indicates that the net outcome of technical change is a decrease in energy intensity. Why is this so? A narrow-minded answer to this question is that energy efficiency in the technical sense has improved over time, i. e. that the ratio of useful energy in relation to the inserted energy has been improved. This is however not the whole story. We know three things, based on empirical research of growth, which all have a bearing on the energy intensity. First, substantial shifts of aggregate production function have occurred, i. e. TFP (total factor productivity) has increased. Second, technical energy efficiency has increased. Third, the capital/labour ratio has increased. The impact of these factors upon energy intensity will be discussed in the following section and this framework will subsequently be used to compare the energy intensity development of the sectors. Important differences between the sectors, which constitute explanations for different rates of de-linking of energy and value added, will be highlighted.

Shifts of production functions

Growth of output in society is achieved either by a quantitative increase of production factors or by finding ways to create higher value from the factors, i. e. by an increase in TFP. Investments, or increase of the capital stock, have constituted the most important extensive growth factor in industrialized countries. Empirical research of growth has, however, shown that factor growth only explains part of the economic growth over several decades; a large part is due to shifts of the aggregate production function, or TFP growth.[42] This cause of economic growth was labelled the residual and referred to as a "measure of our ignorance". Since then, several attempts have been made to reduce the residual by ascribing higher values to production factors and by quantifying organizational improvements like economies of scale, all of which contain problems of ascribing the correct quality factor to the production factors. For my analysis of the impact of technical change on energy intensity it is, however, sufficient to conclude that higher quality of production factors has mattered more for economic growth than larger quantity. Economic growth has occurred largely as a consequence of an increase in the quality of the production factors both individually and combined. My study concerns the relationship between GDP and raw energy consumption.[43] This has generally not been studied in empirical research of growth. The impressive de-linking of raw labour and capital in relation to GDP may lead to an expectation of a similar de-linking of raw energy and GDP, especially if energy works as a relative complement both to capital and labour.[44]

There have been numerous shifts of production functions, or TFP increases. Here, I will only mention a few examples, some of which have obvious

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[42] Abramovitz, M. (1956): "Resource and Output Trends in the United States Since 1870", *Am. Econ. Rev., Papers and Proceedings*, May, p 5-23, Kendrick, J. W. (1961): " *Productivity Trends in the United States*", Princeton University Press. Solow, R. M. (1957), "Technical change and the aggregate production function" *Rev Econ.Statistics* (Aug), p 312-320), The original residual was as large as 90%, but later results, when more quality changes are attributed to the production factors, have reduced it to about 50% and in some cases even erased it.

[43] Energy is raw in the sense that its value is measured only as its heat content, overlooking qualitative differences of energy carriers.

[44] It is not clear from empirical studies whether energy and capital work as relative complements or as relative substitutes. Several studies were performed in the 1970s with the intention of determining whether energy and capital were relative substitutes or relative complements and what relation energy had to labour in that respect. The results were mixed and varying with methods, functional forms and levels of disaggregation. Time-series studies have been more likely to find energy and capital to be complementary and cross-country studies have found evidence of substitutability, but for labour in relation to energy no such relation was established. See Siddayo, C. M.(1986) *Energy Demand and Economic Growth – Measurement and Conceptual Issues in Policy Analysis*, Westview Press, p 83. My argument here naturally becomes weaker the more energy works as a substitute and stronger the more it works as a complement to capital and labour.

connections to the energy field. There are, however, also shifts that are not explicitly linked to energy. They are nevertheless relevant for energy intensity, because of their indirect consequences for energy, and such an example is taken from agriculture.

In the industry sector, assembly line production, which was crucial for specialization and economies of scale, was initiated in the car industry and diffused to other industrial branches in the 1920s. Especially products related to the diffusion of electricity like electric motors, telephones and vacuum cleaners were subject to assembly line production, but also agricultural tools and other kinds of products, with production series that were large enough to carry the high capital costs.[45] Increased specialization also emerged from dynamic inter-linkages between an increased use of electricity and the car industry. The assembly line system made the car industry dependent on a large number of specialized subcontractors, who provided the standardized parts. The possibility of starting new, rather small and specialized enterprises increased when the use of electricity was diffused. In addition, the relationship between subcontractors and producers was facilitated by improved transportation, in the form of electric railways and trucks. The relative savings on production factors were large as a consequence of these combined processes and organizational innovations.

Another example from the industrial sector is the expansion of electronics, which facilitated exchange of information, specialization as well as the fine-tuning of processes. Electronics, or technical applications for low-tension current electricity, were already important for the diffusion of information and specialization with the telegraph and telephone, but the innovation of the transistor, or semiconductor, enabled communication with machines. The decisive step toward microelectronics was taken with the integrated circuit, which combined several transistors. In the industry sector, microelectronics has enabled a far-reaching automation and coordination of production systems, which influences both demands for labour and energy consumption. The relative reductions in the industrial sectors' energy consumption during the 1960s, in spite of decreasing energy prices, would hardly have occurred without process computers.[46] Another decisive step for the wider diffusion of microelectronics was taken when the chip, or microprocessor, was invented. Chips became increasingly complex in relation to their size, thus saving natural resources. Since their miniaturization, microelectronics has permeated nearly all machine usage. Cars and household electric devices such as TV sets, stereos, VCRs and microwave ovens are literally full of microelectronics. Microelectronics produces savings in old energy consuming activities, because it enables the fine-

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[45] Rosenberg, D. &D.C.Mowery (1999) *Förnyelsens vägar – teknologiska förändringar i 1900-talets Amerika*, SNS, p 51.

[46] Schön, L.(1990), op.cite, p 81-82.

tuning of material and energy use in production processes and thus reduces waste and makes more energy efficient climate holding of buildings possible.

In agriculture, the most important de-linking of raw production factors and output was accomplished by improvement in land productivity. Until 1950 this de-linking of agricultural output and land took place without an accompanying increase of animate or inanimate energy. How the increased agricultural production was possible without a concomitant increase of draught animal power or a considerable replacement of animate power with inanimate power, is an intriguing question. How were the higher returns of energy in agriculture achieved? Two main explanations stand out; technical changes in the soil preparation and improved land productivity. Draught animals were mainly used for soil preparation. The necessary amount of muscle energy for soil preparation did not increase at the same speed as production for two reasons. First, the diffusion of better soil preparing tools reduced the required amount of muscle energy input.[47] Iron ploughs for deep cultivation and harrows (partly made of iron) for the shallow tilting of the soil diffused as an offshoot of industrial development.[48] Second, land productivity increased substantially and explains the major part of the increase in production. One important ingredient of improved land productivity was the diffusion of potatoes, because they need only one third of the area required by grain.[49] Another important explanation for the improved land productivity was the increased amounts of nutrients, first provided by leguminous crops and later by artificial fertilizers.[50] Higher land productivity enabled an increased agricultural production without a proportional increase of soil preparation. Thus energy for motive power did not have to increase at the same rate as production. In other words higher land productivity meant that solar energy was used more efficiently (for more output/hectare) and substituted for muscle energy (for soil preparation).

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[47] Iron ploughs also diffused to the eastern provinces that previously solely used "årder". The energy saving potential was focused in tests of new ploughs, and a dynamometer was sometimes used to measure it according to Moberg, H.A.(1989) *Jordbruksmekanisering i Sverige under tre sekel*, Borås, p 100-101.

[48] ibid, p 147.

[49] Gadd, C-J (1983) *Järn och potatis – Jordbruk, teknik och social omvandling i Skaraborgs län 1750-1860*, Göteborg, dissertation.

[50] Only from the 1920s were artificial fertilizers diffused on a large scale, and the production of these fertilizers demanded a lot of energy, which is not visible as direct energy consumption by agriculture, but as inputs to agriculture from industry, where this energy is reckoned. The subsequent expansion of tractors along with ever increasing amounts of fertilizers and pesticides has made agriculture an energy intense production if all energy is counted and has encouraged statements "industrial man no longer eats potatoes made from solar energy; now he eats potatoes partly made of oil" , Odum, H.T.(1971) *Environment, power and society*, John Wiley & Sons, Inc. , p 116.

The point I want to make is that these shifts of production functions save energy as well as raw labour and raw capital, regardless of whether this is intended or not.

Increasing capital/labour ratio

The relative increase in capital compared to labour may at first seem to be a factor that has offset the energy intensity decline. It is true that replacing labour with machines, which demand inanimate energy, leads to an increase in energy intensity unless human muscle energy is included. My study does include human food consumption and then the response to the question of the effects on energy intensity from such a substitution is not clear-cut. It depends on the efficiency of biological machines, like humans and animals, compared to that of the technical machines, which replace them. There are difficulties involved in determining energy efficiency of human labour, because, although the level of food consumption is fairly well known (around 3000 kcal for a 65-kg man in average hard work) and also the effect within an interval (60-100W), it is difficult to know the amount of power actually released, which leads to rather rough estimates.[51] With an assumption that the man in question develops 40W during a 10-hour working day, the work is 1400 kJ.[52] Approximately 7300 kJ food is needed**,** which results in an efficiency of 19%.[53] This is a fairly good number in comparison with many technical machines. For example, almost all steam engines during the 19th century had lower efficiency. If the person's daily food consumption is calculated instead, the efficiency rate is reduced to 11%. This can be compared with a 500 kg horse which consumes 97 000 kJ of fodder daily, working 10 hours with an effect of 350 W.[54] This horse has a daily efficiency of 13% and an efficiency rate of 11% per year. Biological machines are thus not particularly inefficient. Their limitation in production is mainly on the power-side. They are not powerful enough individually to perform very heavy work and to combine several people or draught animals into one powerful machine causes organizational problems.

When machines still had low energy efficiency, replacing workers with machines should have caused an increase in energy intensity. The effect should however have been reversed as technical machines reached higher average

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[51] Smil, V. (1994) op cit, p 227

[52] 40Ws*3600*10=1400kWs=1400kJ.

[53] Smil, V. (1994), op cit, p 244: Sustained delivery of human power could not be higher than about 100 Watts. The efficiency of muscle could not exceed 20 to 25 percent.

[54] For horses' fodder consumption see Hansson. N, op.cite.p 235.
The effect for a 500 kg horse is stated by Smil, V. (1994), op. cite, p 86, to 600-700 W, but he reckons an average effect of draught animals in work of 350 W, p 87.

efficiency.[55] Then the increasing capital/labour ratio should have decreased energy intensity. I cannot determine when the break point occurred, where increasing the machine/labour ratio in general reduced the energy intensity, only that it has taken place.

Technical energy efficiency and energy intensity

Increasing technical energy efficiency may be perceived as a special case of shifts of aggregate production functions, or TFP increases, which is relevant for energy intensity.[56] While shifts in general, or de-linking of production factors and output, save capital (including land) and labour and produce energy savings as indirect consequences, the increased technical energy efficiency is a direct effect of energy saving innovations.

From a human perspective, all energy use entails losses. An improvement in technical energy efficiency means that less energy is wasted. For example, a car engine converts chemical energy of the fuel into motive energy, but a large fraction of the energy will become spill heat. There are economic incentives to reduce such energy losses and an abundance of improvements of specific techniques has increased technical energy efficiency over time. There are numerous examples from the last two centuries, from the savings in charcoal during the 19th century to oxygen methods and electro-steel of the metal industry during the 20th century, as well as similar changes in other branches.[57]

Innovations of products, processes and organizations have interacted to produce savings in energy. One interesting combination of process and organizational innovations was the adoption of electric motors in industry. There was not much improvement in energy efficiency when industry first began using electric engines, because the electric engine was installed in the steam engine's place and the inefficient power transmission, via belts and shafts in the roof, to the individual machines remained. Gains in energy efficiency became larger

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[55] For example, the substitution of carriages for railways during the 19th century took place at a time when steam engines were inefficient compared to horses and oxen, a circumstance that contributed to the substantially higher energy intensity in railways than in carriages at the time.

On the other hand, when tractors replaced horses and men in agriculture after the Second World War, combustion engines had comparatively high-energy efficiency, which meant that the replacement did not increase energy intensity.

[56] This is if energy is perceived as a production factor.

[57] Smil. V.(1994), op. cite, p 150: "By the end of the eighteenth century typical charcoal to metal ratios were 8:1 and by 1900 the ratio was generally as low as 1.2:1. The best ratios, 0.77:1, were found in Swedish charcoal furnaces." See also Arpi, G.(ed)(1959), op. cite, part 1, p 180-182: at the beginning of the 19th century about 120-hl charcoal was consumed per ton of pig iron and in 1850 the amount was 80-85 hl. In 1870 the total amount for refined iron was only 40-45 hl and at the beginning of the 20th century 30 hl. Schön, L(1990), op. cite, p 78: melted iron was sent directly to the steel ovens, fed by pure oxygen. This saved large amounts of fuel.

when the electric motor was used for a group of machines, because some of the transmission belts became superfluous and energy losses were reduced. Electric unit drive, with a separate electric motor for every machine, was even more efficient. The unit drive could in principle be arranged in two ways: the electric motor was either integrated into the machine or connected to it via belts. The integrated version was the most efficient and diffused rapidly during the inter-war period. After the Second World War the last belts disappeared from the factories. Technical energy efficiency was substantially improved with the unit-drive.[58]

In agriculture, the switch from oxen to horses meant improved technical energy efficiency. A good pair of horses may perform 25-30% more fieldwork in one day than four oxen.[59] Horses consume 20% more fodder, but their technical energy efficiency is still 25% higher than that of oxen.[60] This implies that when horses increased their share of the draught animal stock, muscle energy intensity decreased.

In the transportation and communication sector, technical energy efficiency was improved both by the diffusion of railway electrification and by improvements of combustion engines. In railways, a branch for which there is some benchmark energy data in the period 1913-1970, energy intensity declined by 96%. A part of this decline was connected to the improved technical energy efficiency from electrification. Large-scale electrification of railways took off in the 1920s and in 1950 80% of the railway traffic used electricity.[61] In 1980 only an additional 10 % of the traffic were electric.[62] Electricity's share of the branch's energy consumption (table 4.9) did not increase as rapidly as its share of total railway traffic. This implies that electric traffic was more energy efficient than non-electric traffic until 1980, when efficiencies appear to be more equal. The massive electrification of railways correlates well in time with the decline in energy intensity. The slowing down of electrification corresponds to the relative stabilization of the energy intensity of railways after 1970. This implies that the gains from electrification were exhausted in 1970 and there were no other forces strong enough to produce additional decreases in energy intensity.

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[58] Devine, W. D. :"From Shafts to Wires. Historical Perspective on Electrification", *The Journal of Economic History*, June 1983, pp 347-372.

[59] Smil, V.(1994), op. cite. p 68.

[60] For example, if it was possible to get an additional 50 percent of work from one horse during a day, while food inputs were 20 percent higher. The horse then had 1.50/1.20 times the efficiency of oxen, which is 25% higher than oxen efficiency.

[61] Blomquist, E.(1951): *Sveriges energiförsörjning*, Industriens upplysningstjänst, serie C, Stockholm, p 62

[62] Rönn, G.(1984): "Elektrifieringen av svenska järnvägar", in *Daedalus/Tekniska Museets Årsbok*, p 104.

Table 4.9 Energy intensity and electricity share of railways 1913-1990

	Energy intensity (el S), MJ/SEK, constant prices, 1910/12 years'price level	Index 1913=100	Electricity share
1913	237	100	0%
1935	113	48	8%
1955	33	14	33%
1970	10	4.2	75%
1975	11	4.6	66%
1980	10	4.2	90%
1985	11	4.6	88%
1990	14	5.9	88%

Comments: 1935 and 1955 refer to railway traffic and trams. The other years just to railway traffic. Sources: Specialundersökning av kommerskollegium: Bränsleförbrukningen åren 1913-1917 vid industriella anläggningar, kommunikationsanstalter samt allmänna verk och inrättningar, SOU 1956:46 tabell 1, Svenska elverksföreningens statistik, järnvägar och spårvägar, Schipper, L. et al : Energianvändningen i Sverige. Ett internationellt perspektiv, Nutek R 1994:10, Krantz, O: Transporter och kommunikationer 1800-1980, Appendix 4 till Nationalräkenskaperna: Produktion och faktorinsats. Årsrapport 1970-1990.

Some figures are necessary to illustrate the size of these improvements in technical energy efficiency in the economy. Early steam engines had energy efficiencies of only 0.7%, while the best steam engines of the late 19th century had reached efficiencies of 20-25%.[63] Open fires had energy efficiencies of around 10% and the Cronstedt stove of the 1760s, with several vertical smoke channels, increased the efficiency to 50%, after which gradual improvements produced an efficiency of 85% for the best iron stoves of the late 19th century.[64] In 1890, 25 energy units of fossil fuels were required to produce one unit of electricity compared to only 2.5 units in 1990.[65] Edison's incandescent lamp had an efficiency of only 1% while today's best lamps have efficiencies of 20%.[66] An ordinary combustion engine in the 1920s had a thermal efficiency of 10% and this figure has improved to around 20% to date, while thermal efficiency for diesel engines is as high as 45%.[67]

So far the argument suggests that higher technical energy efficiency should lead to decreasing energy intensity. The picture is partly modified if the so-

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[63] Smil V. (1994), op. cite, p 161-164 , suggests 25%, while Grubler, A.(1998), op. cite, p 209, says 20%.

[64] Cramér, M. (1991), op.cite,, p 84. Larsson, H.(1979) op.cite, p 8.

[65] Etemad, B.&J.Luciani,(1991) op.cite,, p 31-36 of the preface.

[66] Smil, V. (1994)op cit, p 12.

[67] Grubler, A. (1998), op cit, p 320, Smil, V. (1994), op cit, p 169.

called rebound–effects are taken into account. When the amount of energy services is constant, the sum of improvements in technical energy efficiencies leads to decreasing energy consumption over time. But these improvements in technical energy efficiency actually contribute to an increase in energy services, because of changing relative prices and growth. Some economists have even suggested that improved technical energy efficiency will bring about higher energy consumption. This idea is called the Khazzom-Brookes postulate, or the "rebound-effect" or the "take-back" effect and was expressed by Jevons as early as 1866.[68] The size of these rebound effects has caused lively debates in scientific journals as well as in newspapers.[69] The public interest in this matter depends on its policy implications. If increasing technical efficiency brings about increased energy consumption, it is, of course, not the best way to reduce energy consumption and the related environmental problems.

For energy intensity in the formal economy, not all rebound effects are relevant, only the ones related to an economy of a given size. [70] Re-distributions take place both in the formal and informal economy in response to decreasing costs per unit of energy service, but only the ones within the formal economy are relevant here. There will be a tendency for companies to change their mix of production factors by replacing labour with machines, because using machines becomes cheaper as they become more energy efficient. Companies may also increase premise standards, for example by larger areas per employee, instalment of air-condition or higher indoor temperatures. The rebound argument is partly undermined by the fact that energy services are not only provided by energy but also by capital.[71] Realistic models for technical change of energy systems takes all energy costs into account, not just the cost for energy per se.[72] Energy costs are therefore not reduced proportionally to the increase in

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[68] Saunders, H.:"The Khazzoom-Brookes Postulate and Neoclassical Growth", *Energy Journal*, vol 13, no 4, p 131-148, 1992. Saunders coins the concept the Khazzoom-Brookes postulate, thereby giving attention to Brookes, L.:"Energy Efficiency and Economic Fallacies", *Energy Policy*, vol 18, no 2, p 199-201, och Khazzoom, D.:"Energy Savings from the Adoption of More Efficient Appliances", *Energy Journal*, vol 8, no 4, p 85-89, 1987. Jevons, W.S. (1886) *The Coal Question:An Inquiry concerning the progress of the nation and the probable exhaustion of our coal mines*, London , said "it is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth."

[69] An overview of the debate is presented in Herring, H *Does Energy Efficiency Save Energy: The Economists Debate*, EERU Report No 074- July 1998, http:/www-tec.open.ac.uk/eeru/statt/horace/hh3.htm.

[70] There are two kinds of rebound effects: a) growth of the economy and b) redistribution of resources within an economy of a given size, in terms of GDP. Khazzom stressed the redistribution effects, while Brookes extended the analysis to growth effects.

[71] Howarth, R.:"Energy efficiency and economic growth", *Contemporary Economic Policy*, vol XV, Oct 1997, pp 1-9.

[72] See for instance Neij, L.(1999) *Dynamics of Energy Systems, Methods of analysing technology change*, Lund, dissertation, p 27.

technical energy efficiency, even if energy prices stay constant. Besides, energy prices have increased in relation to prices of capital goods.[73] Companies' price elasticity of demand for energy services depends on how a large share energy makes up of their total production costs. If it makes up a relatively small part the price elasticity will not be very high.

My conclusion is that the rebound effects, which are relevant for energy intensity, i. e. within the formal economy, are not large enough to outweigh all the gains from the technical energy efficiency. Therefore the technical energy efficiency, despite certain take-back effects, works in the direction of reducing energy intensity.

Conclusion

It is not possible to draw a completely unambiguous conclusion regarding the development of energy intensity as a consequence of technical change. But it seems reasonable that the net result would be lower energy intensity over time due to the powerful de-linking of raw production factors and output. Energy has been saved upon, both by improving technical energy efficiency and as consequences of savings of raw labour and capital (including land). Rebound effects have partly outweighed these gains, but not completely. The higher machine/labour ratio should work in the same direction when the technical energy efficiency of inanimate machines is high compared to animate machines. Only in special cases with low TFP and high rebound effects together with a substantial increase of the machine/labour ratio at a time when machines have low technical energy efficiency compared to humans, could the result be an increase in energy intensity. This means that the net effect of technical change on energy intensity is normally a decline.

Growth rates and energy intensity

Sometimes a simplistic proposition is advanced, which states that high economic growth rates have a positive impact on the environment, because of high investment rates and rapid replacement of old inefficient machinery. For instance Mäler states: "It appears quite clear that increasing growth, via increasing efficiency, will favour the environment".[74] Wibe, in the same spirit, claims that it is "difficult to avoid the conclusion that an increased growth in the economy reduces emissions. The introduction of newer and cleaner techniques

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[73] Schön, L. (1995), op. cite, p 176.

[74] Mäler, K-G. (1993) *Growth and environment*, supplement 19 to SOU 1993:16, p 235 (my translation)

will then be so much faster that emissions will be reduced, despite increases in the total production."[75] Schipper et al have a similar argument, directly applied to energy efficiency. They try to explain why improvements in energy efficiency were not more impressive in the US in the period 1973-1987 than in the period 1958-1973, despite heavy increases of energy prices. They conclude that the price increases probably led producers to invest in energy saving technology, but that growth rates were reduced concomitantly and thus also investment rates.[76]

To scrutinize this idea I calculated growth rates for GDP and energy in the formal economy during some rather homogenous periods together with energy coefficients (ratios between growth rates for energy and for GDP). An energy coefficient larger than 1 means that energy increases faster than the economy, and an energy coefficient smaller than 1 means that the economy grows faster than energy. The results are presented in table 4.10.

Table 4.10 GDP growth, energy growth and energy coefficients

	GDP	Energy(-h)	Energy coefficient
1800-1870	1.7	1.1	0.65
1870-1913	2.8	3.2	1.1
1920-1938	3.4	1.5	0.44
1946-1975	3.8	4.4	1.2
1975-2000	1.4	0.092	0.066

Sources and comments: SHNA, SCB, see figure 3.2, GDP here does not include dwelling usage or the power industry.

Table 4.10 demonstrates that energy grew more slowly than the economy during periods with relatively low economic growth (1800-1870 and 1975-2000). In periods of rapid economic growth the pattern was mixed. In the periods 1870-1913 and 1946-1975 energy grew faster than the economy, while energy grew more slowly than the economy in the period 1920-1938. The idea that high economic growth would reduce the growth of energy and low economic growth increase it, is contradicted in four out of five periods. Only in the period of 1920-1938 the expected pattern appeared.

My analysis of technical change offers some explanation for why the hypothesis of growth rates and relative improvements is not confirmed. The hypothesis is based on three assumptions: first that the efficiency of new machines is higher than that of older models, which appears to be a reasonable idea, but it overlooks the rebound effects in the form of more powerful

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[75] Wibe, S. (1990) *Miljöeffekter av skattereformen*, Lantbruksuniversitetet Umeå, p 27. (my translation)

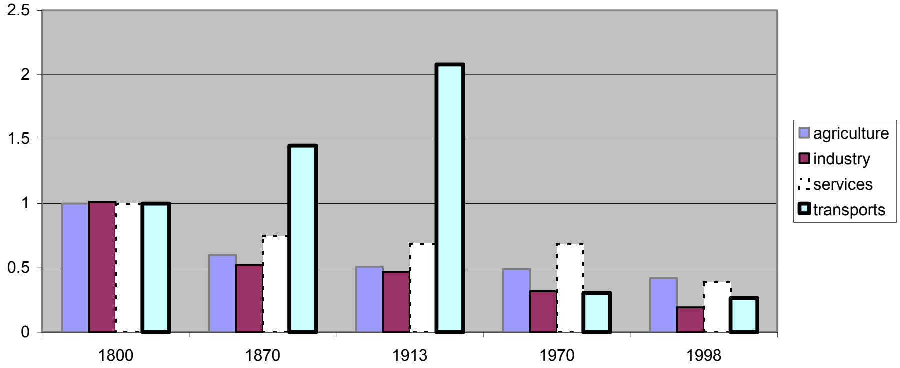
[76] Schipper, L et al.(1990):"United States Energy Use from 1973 to 1987. The impacts of improved efficiency", *Annu.Rev.Energy*, 15:455-504. p 476.

machines, which consume more energy. A second assumption is that technical efficiency is all that matters for economic efficiency, which is clearly refuted by my analysis, where TFP encompasses much more than technical energy efficiency, and factor substitution takes place. The third assumption is that there is a simple linear relationship between growth rates and investment rates for machine capital, which is refuted by Schön, who demonstrates cyclical patterns for machine and building investments in relation to growth.[77] There is, consequently, no sound theoretical basis for expecting high growth rates to lead to a relatively rapid de-linking of energy and GDP.

Comparison of the sectors' energy intensity developments

The reasons for the different long-term development of energy intensity within the sectors may be discussed on the basis of the framework of technical change and energy intensity. It is reasonable to compare TFP increases, technical energy efficiency and rebound effects between the sectors. Such comparisons will mainly be of a qualitative kind, since quantitative data is scarce. In figure 4.4 sector energy intensities, expressed as indices with the value 1 in 1800, are shown for my benchmark years.[78] The relative development of each sector's energy intensity may be followed in this figure.

Figure 4.4 Benchmark energy intensities of the sectors, constant prices, indices 1800=1.



Sources: see table 4.1, SHNA, SCB.

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[77] Schön, L.(1994), op. cite.

[78] Only the relative development of each sector is possible to discern in this figure. The levels cannot be compared between the sectors.

One result that merits attention is the larger long-term decline in energy intensity of the industry and transportation & communication sectors, than of services and agriculture. In the transportation and communication sector almost the entire decline took place between 1913 and 1970, when it experienced a remarkable decline, while it appeared to be very different in the 19th century. There are two main possible explanations for the different energy intensity patterns of the sectors. First, shifts of production functions, including improvements in technical energy efficiency, may have been more substantial in transportation & communication and industry than in services and agriculture.[79] Second, there may have been a relatively larger increase of energy services in the sectors of service and agriculture than in transportation and industry, i. e. more "take-back effects" or rebound effects.

It may be argued that the transportation & communication sector experienced the most impressive de-linking of raw production factors and output, followed by industry, while agriculture and services had less de-linking. In order to really determine TFP of the sectors one must have data on capital, labour and value added of the sectors. Data of capital for all sectors is lacking for most of the period, so a strict evaluation of TFP cannot be made. Still a tentative argument based on figures of raw energy, raw labour and value added can be made. If raw energy is regarded as a proxy for capital it is possible to compare labour productivity rates with energy/labour ratios. One may then draw conclusions about the relative TFP developments of the sectors. One implication would be that a high relative increase of labour productivity without a high relative increase of energy/labour suggests high relative TFP.

In figure 4.5 it is possible to discern the *relative development* of labour productivity of the sectors. The *relative levels* of labour productivity are however only possible to get a reasonable picture of in 1913, which is close to the price level years.[80] While labour productivity of agriculture and of the transportation & communication sector did not show any fundamental changes compared to the industry sector during the period 1870 to 1990, services showed a steady relative decline.

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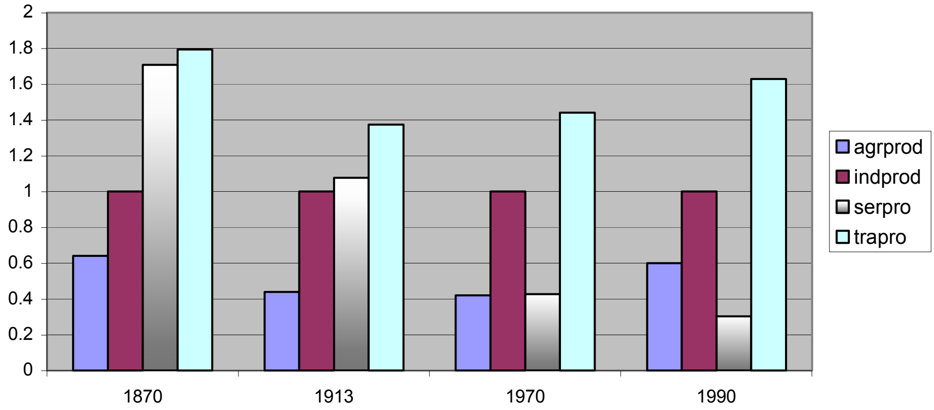
[79] Shifts of production functions, TFP gains or de-linking of raw factors of production denote the same phenomena.

[80] The choice of price level year will influence the respective levels of labour productivity of the sectors, but not the relative developments. This is always the case with constant prices. It is only appropriate to study and compare levels of production or productivity close to the year of the price level. If, for instance, 1990 had been chosen as the price level year instead, the labour productivity of services compared to industry in 1913 would have been much higher, since prices of services compared to industrial products were higher in 1990 than in 1913. Still, the relative development of the service sector compared to industry will be the same regardless of price level year, and that is what is focused in my analysis.

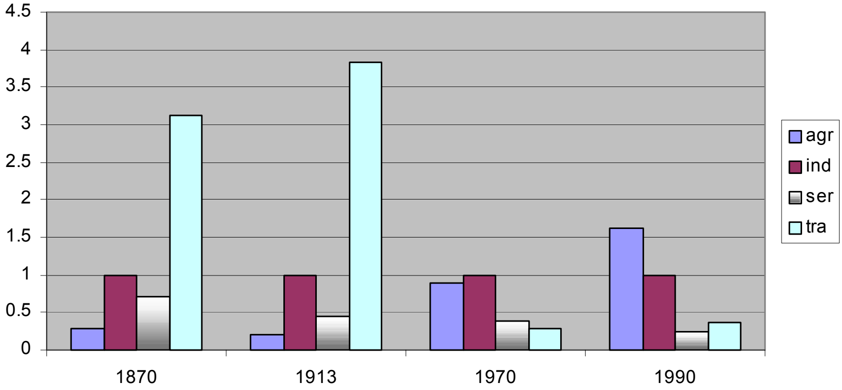
Figure 4.5 Labour productivity index, constant prices, 1910/12 price level, industry=1



Sources and methods: I use material received from Schön (2000) to measure employment in the sectors. The employment figures are the numbers of persons occupied in the respective sectors, because the numbers of work hours, which would be a better measure, are not available for 1870 and 1913. People are in general apportioned to the sector where their main occupation is, and, since many people from the agricultural sector also worked part-time within transportation, this tends to underestimate the number of people in transportation and exaggerate the numbers of people employed in agriculture. Therefore employment has been adjusted here in 1870 and 1913 by adding one person for every four draught animals to the transportation sector and subtracting the same number from the agricultural sector. This procedure has a large impact both on labour productivity and on the energy/labour ratio in the transportation & communication sector: in 1870 the number of employees rises by 75% and in 1913 by 17%.

These labour productivity indices may be compared to the indices of energy/labour in figure 4.6. In this figure, like in figure 4.5, the industry sector serves as the basis for comparisons

Figure 4.6 Indices of the energy/labour ratios of the sectors, industry=1



Sources: see table 4.1 and figure 4.6

Compared to the industry sector, the energy/labour ratio declined exceptionally in the transportation & communication sector between 1913 and 1970, while it increased in the agricultural sector.[81] Because the period from 1913 to 1970 saw the most dramatic relative changes between the sectors, I restrict the following discussion of relative TFP progress to what took place in this period. During this period, the labour productivity of the transportation & communication sector stayed fairly constant in relation to industry at the same time as its relative energy/labour ratio experienced a tremendous fall. This indicates a substantially more rapid de-linking of output and raw production factors in the transportation & communication sector than in industry. The labour productivity of agriculture remained rather constant in relation to industry in the period 1913-1970, at the same time as its relative energy/labour ratio increased substantially. This suggests that agriculture had a less impressive TFP increase than industry, i. e. there was less scope for changes in the composition of output, organization, skills etc. The service sector decreased both its relative labour productivity and its relative energy/labour ratio compared to industry. The decline in relative

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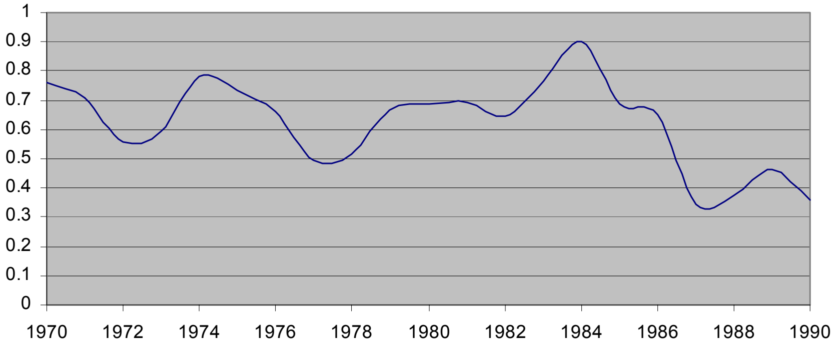
[81] This may seem surprising because in this period both transportation and agriculture experienced the diffusion of the internal combustion engine. The main reason for the different effects is that capital for labour substitution was higher in agriculture than in the transportation & communication sector. (This supports the procedure of regarding energy as a proxy for capital) In agriculture, tractors made many workers redundant, while the transportation sector still required employees to serve people on their journeys. One phase of remarkable increase in the energy/labour ratio in agriculture occurred between 1950 and 1970, when agriculture was motorized and electricity diffusion to the countryside reached its maximum. In this period the motorization of forestry was also rapid, and it speeded up even more after 1970, see Lundgren, N-G (1984) *Skog för export- skogsarbete, teknik och försörjning i Lule älvdal 1870-1970*, dissertation, Umeå studies in economic history 6, p 171

labour productivity was, however, larger than the decline in the relative energy/labour ratio, which indicates that the service sector had lower TFP development than industry. There is not enough information to distinguish between the agriculture and services with regard to TFP developments. Labour productivity in agriculture stayed constant in relation to industry at the same time as the relative energy/labour ratio increased substantially. Labour productivity in the service sector declined a great deal in relation to industry at the same time as the relative energy/labour ratio stayed constant. In conclusion, this analysis indicates the expected pattern of largest TFP increases in the transportation & communication sector followed by industry and lower TFP development of agriculture and services.

TFP growth seems to have been largest in the transportation & communication sector and it remains to be determined why. Structural changes at the branch level did not seem to explain the decline in energy intensity. But because changes in the branch composition were large in this period, they may still have contributed to TFP gains. This means that some of the gains may have been due to the redistribution of the work force from low-productive to high-productive branches, but it is not within the scope of this study to examine that idea further. I believe there is another main explanation for the high TFP growth and rapid decline in energy intensity: the increasing value of time. Time gains are important in all sectors on the supply side, through the cutting down of labour costs, but they play a specific role in the transportation & communication sector, where they also strongly affect the demand side. Time gains may be conceived as a type of quality improvement. Faster transportation and faster communication generally mean higher quality for the consumers. Also in some products from the industrial sector time gains constitute part of the quality, for instance in cars equipped with powerful motors, but this is more unusual than in transportation and communication. Swift personal transportation has been given increasing value over time, both for travel connected to work, where the increasing labour costs play a large role, and for travels in spare time, where the alternative usage of time is crucial for the evaluation of the costs involved. The quality of communication, by mail, telephone or telegraph, is also highly linked to the time it takes to convey the messages. As the speed of transportation accelerated, through railway traffic or air traffic, mail was also delivered faster and the quality of communication rose. Faster transportation means that energy consumption in relation to the transported distance has increased, because using high power requires more energy than low power, but the value of the transportation service may have increased even more, thereby lowering energy intensity. It should, however, be noted that new modes of travelling, for instance in trains with comfortable working conditions including internet connections, may change the evaluation of time costs of travelling.

Figure 4.7 Energy intensity of air-traffic in relation to railway-traffic, 1970-1990, in constant prices, 1970 price level.



Sources: Schipper et al, Krantz 1970-1980, SCB: Nationalräkenskaperna 1980-1990.

This idea of high value of time gains being the reason for relatively high TFP growth in the transportation & communication sector cannot be directly supported by historical empirical evidence. A possible hypothesis is that energy intensity for the fast transportation of today, like air traffic is lower than energy intensity for railway travels. The energy intensity of air-traffic in relation to railway traffic is presented in figure 4.7. There are large fluctuations in the ratio of energy intensity in air traffic and energy intensity in railways. Still, the result of this comparison is that energy intensity in air-traffic is lower than energy intensity in railway traffic for all years, which supports my idea of the high quality attributed to time gains.[82] This result is reinforced if the fact that technical energy efficiency is much lower (about half) in jet turbines of aeroplanes than in electric railways is considered. If railways had had the same combustion technique they would have had even higher energy intensity compared to airplanes than in figure 4.7. This analysis lends support to my idea that the more substantial TFP improvements in the transportation & communication sector than in the other sectors is due to the relative importance of time-savings. While time reductions are also important in the other sectors, because they cut down labour costs, they do not increase the quality of the products to the same extent as they do in the transportation & communication sector.

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[82] The result is naturally very different if energy per personal km is compared. Energy per personal km or ton km is the most frequently used method of comparing energy of transportation, for instance adopted by Schipper et al. (11994), op. cite, It does not do justice to the value of time saving.

Regarding the more specific question of the relative improvements in technical energy efficiency of the sectors, two aspects may be important to emphasize: 1) It is easier to achieve improvements if they are initiated at a low level, than at a high level. 2) The incentive to achieve technical changes to save energy varies with the energy's share of total production costs.

1) Energy services may be divided into two main categories from the perspective of starting levels and relative improvements. Motive power dominates in transportation and agriculture, while the service sector mainly consumes energy for low temperature room heating. In the industry sector, motive power and high temperature process heat dominate. A fundamental difference between heat and motion is their rates of improvements in technical energy efficiency. Heat production was easier to accomplish with low conversion losses than mechanical work.[83] Consequently in the early 19th century technical energy efficiency was much higher in room heating than in steam engines. Because of these different starting levels, the relative progress was larger for steam engines than for room heating. While efficiencies of optimal heating rose from 50% to 85% during the 19th century, the efficiencies of the best steam engines rose from 3% to 25%. Best cases are, of course, not the same as average figures, but it is still likely that the relative improvements were larger for motive power than for low temperature heating during the 19th century. This probably resulted in a larger fall in energy intensity of industry than of services, ceteris paribus, which is in agreement with my results. Yet, the decline in industrial energy intensity is to a larger extent explained by efficiency improvements in high temperature heating. In high temperature heating the scope for relative improvements was also larger than for low temperature heating during the 19th century. During this time, the bulk of industrial energy consumption was charcoal for high temperature heating in the metal industry. The consumption underwent a subsequent impressive, relative decrease of more than 75%, which was far more than was possible in room heating. Technical energy efficiency in

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[83] The highest possible technical energy efficiency is also lower for mechanical machines than for burning to get heat. The theoretically highest possible efficiency when converting heat into mechanical energy is expressed as the Carnot process:

$$\eta = \frac{T_1 - T_2}{T_1}$$

The burning of fuel to achieve mechical power is a circular process, where the efficiency is determined by the highest and lowest temperature in the process. T1= the maximal heat (very reliant on the materials), T2= the heat of the cooling medium. The temperatures are given in absolute values (Kelvin). When Carnot formulated this theory in the early 19th century he believed that the maximum efficiency for converting heat to motive power was around 30%, but subsequent development has pressed the figures up to almost 50% efficiency to date.

low temperature heating was already approaching the physical limit in the late 19th century. The remaining potential efficiency improvements were therefore larger for motive work than for room heating during the 20th century as well. This means that in sectors that were dominated by motive power, technical energy efficiency should have developed more rapidly, which should have led to a more rapid decline in energy intensity than in sectors where room heating was the predominant energy consumption. This indicates that energy intensity of the service sector, where heating is the dominant energy consumption, should have continued to fall less rapidly than energy intensity of the other sectors during the 20th century. Energy intensity does decrease less rapidly in services than in industry and transportation & communication, but it decreases more than in agriculture. This only means that factors other than starting levels and relative improvements are involved.

2) The incentive structure to accomplish energy savings differs between the sectors. The larger the energy/labour ratio the larger the incentive to save energy. The transportation & communication sector had by far the highest energy/labour ratio during the 19th and part of the 20th century. The savings were also large between 1913 and 1970. The ratio was low in 1970 and the incentives were weaker and in return the energy/labour ratio increased in relation to industry between 1970 and 1990.

Agriculture and the service sector have had relatively low incentives to save energy compared to saving labour, because energy's share of the production costs has in both cases been low and the labour share high.

Rebound effects, or the relative increase in energy services due to technical energy efficiency improvements, differed between the sectors. Heating standards increased over time in the service sector. This could be regarded as a take-back, or rebound effect, a relative increase of energy services that counteracted the technical energy efficiency improvements. Technical energy efficiency of stoves improved very rapidly during the 19thcentury and although heating standards also improved, the net result was a rapid decline of service energy intensity. In the period 1913-1970 there was only a small decline in energy intensity, probably because heating standards increased at a comparatively higher rate than the improvement in technical energy efficiency. Between 1970 and 1998 energy intensity declined rapidly, probably because of saturation in heating standards and as an effect of a concerted effort at energy savings, including better insulation, more appropriate ventilation and decreased area per employee in the open landscape offices.

In agriculture the introduction of fans, dryers etc, as relative electricity costs fell, implied that electricity replaced free energy services from the sun and wind, which would counteract a fall in energy intensity.

There is also some room for take-back effects in the transportation sector. More efficient motors increase the demand for higher speed, which requires more energy.

During the 20th century, industry also experienced a take-back effect in the form of better climatic conditioning of buildings, but this was probably too subordinated to other energy services to have a large impact on the industrial energy intensity development.

In conclusion, the relevant comparisons between the sectors, like those of TFP including improvements in technical energy efficiency and take-back effects, support the finding of the most rapid energy intensity decline in the transportation & communication sector, followed by industry, while agriculture and services had slower rates of improvements.

Conclusions

The main conclusions of this chapter are the following:

1) Structural changes at the sector level, together with strong increases of energy intensity within the transportation & communication sector, explained the entire increase of energy intensity during the period of rapid industrialisation, 1870-1913.

2) The decline in energy intensity, which occurred between 1913 and 1970, took place despite the continued industrialisation, as an effect of changes within the sectors.

3) The belief that transition to the service economy should lead to declining energy intensity is not confirmed. This is because the purported transition to the service economy does not consist of a growing amount of services, but in a growing transportation & communication sector. The development of this sector’s energy intensity is therefore crucial for future development in overall energy intensity.

4) The decline in energy intensity in the period 1970-1998 was larger per year than in the period 1913-1970, and this was the result of within sector changes, or technical change. The structural changes at the sector level had neither a positive nor a negative impact, since the relative increase of

the transport & communication sector took place at the expense of industry, and those sectors had approximately the same energy intensity.

5) Technical change has generally worked to decrease energy intensity. This is because the net effect from TFP growth, technical energy efficiency improvements, rebound effects and increasing capital/labour ratio is normally a decline in energy intensity.

6) In the period 1870-1913 all sectors experienced declining energy intensity, except the transport & communication sector, which displayed a substantial increase, largely as an effect of changes in branch composition, where railways grew at the expense of horse carriages and steam ships expanded at the expense of sailing ships. Between 1913 and 1970 the energy intensity decline was, however, most substantial in the transport & communication sector, followed by industry, while agriculture and services lagged behind. This was because a) TFP growth of the sectors displayed the corresponding relative development b) the potential for further technical energy intensity improvements were larger in mechanical work than in heating, which stimulated a larger relative decline in industry and transport & communication than in services and agriculture and c) because of relatively larger rebound effects in services and agriculture than in industry and transport & communication.

7) The belief that relative environmental improvements in the developed countries is the result of moving the problems to less developed countries instead of solving them, is not confirmed by the present case study of Swedish international trade, where energy in imported goods is compared with energy in exported goods. Sweden has, for a long time, been a net exporter of energy in goods and this pattern did not change after 1970. This means that the decline in Swedish energy intensity in the period 1970-2000 was an effect of changed demand both within the country and abroad and not the result of Swedes living in the service economy, while consuming industrial products from abroad.

8) The hypothesis that high growth rates are better than low growth rates for the environment (because of higher rates of investments and consequently higher efficiency improvements) was tested with respect to energy intensity. No correlation was found between high growth of GDP and rapid de-linking of value added and energy. The pattern was mixed and rather suggested the opposite.

Chapter 5

Energy carrier composition, energy intensity and CO_2 intensity

Analytical perspectives

Man's capacity to harness increasing amounts of energy for reproduction, production, and transport forms a physical basis for population and welfare increase in the rich world.[1] This energy increase relies on the transition from the use of direct solar energy to stored solar energy. Man has channelled ever more solar energy to be used for his/her own needs. The Neolithic revolution meant that man started to deliberately grow certain edible plants, first in the form of slash and burn cultivation, and gradually more as permanent cultivations. This meant that a larger proportion of the sun's energy was channelled to green plants that man could make use of, and increased the number of humans that a certain area could sustain. Until the industrial revolution man was obliged to resort to the contemporary energy flow from the sun. This energy constraint imposed limits on the number of people fed from a certain area, on the transport options, as well as on the growth of cities. Although there was great potential for improving soil productivity within traditional farming, which was also used to an impressive extent, the efficiency of photosynthesis put the ultimate limit to this human expansion.[2] What could at best be achieved was a skilful management of contemporary solar energy into desired green plants, whose growth was promoted by ensuring good soil properties, enough nutrients and water.

The adoption of proper methods to use coal, first in the British iron industry, signalled new and hitherto unimaginable possibilities for the human population to grow and oust other species.[3] The steep increase in the use of coal and coke from the mid 19th century, and the subsequent use of oil, meant that

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[1] This passage in a broad sense depends on the characterization by Sieferle, R. P. (1990): "The Energy System-A Basic Concept of Environmental History", in *The Silent Countdown*, Springer-Verlag, Berlin Heidelberg, pp 9-20.

[2] Walker, D.(1979) *Energy, Plants and Man*, Hampshire, p 13: "Unfortunately, photosynthesis is not 100% efficient, and, (---), the maximum efficiency of a crop is unlikely to exceed 5%." , p 15: "Some plants and some crops can convert light energy into chemical energy more effectively than others, but all are ultimately limited by the efficiency of their photochemical apparatus." In practice plants are not as efficient as 5%, rather the rates varies between 0.2 and 0.4%. (p 26). This means that substitution of crops may cause an increase in total photosynthetic efficiency.

[3] Nef, J.U. (1932) *The Rise of the British Coal industry*, London.

human society was no longer forced to rely on contemporary solar energy, but could make additional use of stored solar energy. This energy-restriction relief made possible a huge increase of human population through the impressive growth of food production. It also brought about an immense expansion of transportation, the growth of industrial production and urbanisation. Fossilised carbon, produced by past photosynthesis millions of years ago, formed a basis for the industrialisation process.

A calculation that illustrates this profound change (from the use of contemporary energy flows to the use of stored energy resources) is estimates of how large a land area would have had to be planted with trees to cover the English demand for energy, had there been no coal to use. Between 1681 and 1690 about 30 000 km^2, or about one-fifth of the whole area of England and Wales, should have been used for firewood production had there been no coal. In the early 19th century, however, the whole area of England would have been needed for that purpose![4] Needless to say that would have been an impossibility, not to mention the subsequent increase in energy consumption.[5]

This transition from contemporary energy flows to stored solar energy is the reason why the greenhouse effect has been amplified from the mid 19th century. Burning fossil fuels releases more carbondioxide into the atmosphere than is sequestered in new green plants.

The analytical perspective of three industrial revolutions, outlined in the previous chapter, is important for changes in energy carrier composition. The first two industrial revolutions centred on innovations in the energy field. The new prime movers were connected to the introduction of new energy carriers, coal, oil and electricity. Energy carrier substitution is focused in this thesis both because the reasons for substitution are interesting per se and because of the implications for energy and CO_2 intensity. There are three main explanations for the diffusion of new energy carriers. One possibility is that the new energy carriers diffused in correspondence with their special technical applications. Another possibility is that they diffused as a consequence of decreasing price in relation to other energy carriers. A third option is that they diffused because people had larger incentives to pay a quality premium for energy as their income rose. These explanations need not exclude each other; they are complementary to some extent.

New energy carriers were introduced and found applications, which increased the substitution possibilities. Still consumers' freedom of choice did not expand proportionally to the number of new energy carriers on the energy

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[4] Sieferle, R. P. (1990), op. cite, p 14.

[5] Some caution towards calculations of that kind is, however, warranted, since they are based on implicit assumptions of firewood production from a certain area, figures that have been immensely improved lately, with fast growing species like salix.

market. As energy systems have developed from small-scale, local provision of energy to complex grid bound technical systems, based on, for instance, electricity or gas, restrictions on freedom of choice have followed. The lock-in effects in modern energy systems originate both in the large investments in plants and grids and in the clustering of technology.[6] It has been suggested that large technical systems, like energy systems, should be regarded as socio-technical systems, i. e. as complex systems consisting of physical artefacts such as generators, transformers and transmission lines, as well as organisations, scientific components and legislative artefacts. Not just impersonal factors like economic and technical factors give rise to the path-dependence; actors do too. Technological determinism is thus not a necessary implication of the large systems.[7] Thomas B. Hughes set the research agenda for socio-technical system studies with the formulation of a set of useful concepts, which have been used by several historians since.[8] For one thing he stresses that old, mature technical systems are more rigid and obstinate to change by actors than new evolving systems. In Sweden Arne Kaiser was the first to introduce the socio-technical perspective in historical energy studies. In his dissertation Kaiser analysed the struggle between two competing large systems: gas and electricity in three Swedish cities and he has developed the socio-technical perspectives in some of his following studies.[9] Myllyntaus analysed the reasons for the rapid Finnish electrification after the First World War in a framework of economic, political and cultural factors.[10] Olsson has used the theoretical framework by Hughes to analyse the attempt to introduce natural gas in Nordic countries. Denmark was most successful in introducing natural gas, because it did not have rigid actors,

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[6] Arthur, W.B.(1988):"Competing technologies: an overview", in G. Dosi, C. Freeman, R. Nelson, G.Silverberg, and L. Soete (eds): *Technical change and economic theory*, London.

[7] A number of essays in Merritt, R.S. & L. Marx (1994) *Does technology drive history?*, discuss technology determinism.

[8] Eva Jacobsson explains the relevant concepts in her dissertation: *"Industrialisering av älvar. Studier kring svensk vattenkraftutbyggnad 1900-1918*", Göteborg, 1996, pp 42-48. The theoretical framework is worked out in Hughes, T. P.(1987):"The evolution of Large Technological Systems", in *The Social Construction of Technological systems. New Directions in the Sociology and History of Technology*, Bijker, W. /Hughes, T.P./Pinch, T. (eds) Cambridge, Massachusets. Empirical support in conjunction with the theory is provided in Hughes, T. P.(1983):"Networks of power. Electrification in Western Society, 1880-1930, Baltimore and London.

[9] Kaijser, A.(1986) *Stadens ljus. Etableringen av de första svenska gasverken*, Kristianstad. Kaijser, A.(1989):"De svenska energisystemens framväxt och framtid", in Tengström, E.(ed), *Energin, makten och framtiden. Samhällsvetenskapliga perspektiv på teknisk förändring*, Statens energiverk 1989:R16, Kaijser, A.(1990):"Ledningen och makten", in *Teknokrati, arbete och makt*. Beckman, S. (ed), Stockholm, Kaijser, A.(1994): "*I fädrens spår. Den svenska infrastrukturens historiska utveckling och framtida utmaningar*", Stockholm, Kaiser, A (1995):"Makten över elsystemet-den opolitiska energidebatten", in *Kilowatten. Fakta i energifrågan*. Lothigius, J. (ed) Falköping.

[10] Myllyntaus, T.(1991):"*Electrifying Finland – The Transfer of a New Technology into a Late Industrialising Economy"*, Macmillan Academic and professional Ltd.

who attempted to preserve the strong position for electricity, like Sweden had.[11] Hård and Olsson used Hughes' theory in combination with organisational theory to explain why combined district heating has been comparatively difficult to introduce in Sweden, where traditional power producers have had the responsibility for such an introduction.[12] Jacobsson in her dissertation focused on how Swedish natural water systems were exploited and inserted in the socio-technical electricity system. She developed Hughes' rather harmonious framework by stressing the non-linear shaping of a socio-technical system through the struggle between advocates of the new technology and its antagonists.

In this study the perspectives of dynamics in large technical systems, do not play a pertinent role for the analysis. They are mainly relevant for this study as explanations for the pattern of energy carrier transitions, explaining whether these are gradual or fast. In addition, the perspectives of large technical systems are included implicitly in my modelling of changes in energy quality over time, where they make up restrictions on the increasing substituting possibilities between energy carriers.

Aims

If energy carriers of higher quality have replaced inferior energy carriers, this may constitute an explanation of the reduced energy intensity, because higher quality may have compensated for lower quantity. There is no perfect method to evaluate the quality of energy carriers, but prices, although having the drawback of reflecting supply conditions as well as demand conditions, may be used in the analysis with some caution. Energy volume, i.e. price x quantity for each energy carrier summed up to a total, can be related to GDP. This provides an alternative energy intensity measure, where quality aspects of the energy carriers have a larger influence on the results than the energy quantity/GDP measure. In this chapter, my construction of energy volumes as well as my augmented energy volumes, which are supposed to reflect demand side conditions more closely, are presented and discussed in relation to the physical energy intensity measure.

Another aim of this chapter is to discuss the impact of changed energy carrier composition on CO_2 intensity. Energy carrier composition has an effect on CO_2 intensity, because energy carriers have different CO_2 emission factors. All fossil fuels emit CO_2, but their hydrogen to carbon ratios differ and consequently so do their CO_2 to joule ratios. Coal, oil and natural gas constitute

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[11] Olsson, S-O. (1992): "*Energiorganisation i Norden*", Göteborg.

[12] Hård, M. & S-O Olsson (1994): "*Istället för kärnkraft – kraftvärmens framväxt i fyra länder*", Uddevalla.

falling CO_2 emission factors. Traditional energy carriers like firewood and muscle energy normally emit only as much CO_2 as is sequestered from the atmosphere when trees and green plants grow and are therefore regarded as nil emitters of CO_2 in this context. In a long-term perspective, however changes in the use of land occur, which may affect the carbon storage of the vegetation and soil. The next chapter describes changes in Swedish standing timber volumes and estimates the effects on CO_2 emissions. Special attention is given to the role of firewood consumption for these changes.

Because the composition of energy carriers is crucial for CO_2 intensity, it is of interest to understand the driving forces behind past transitions in energy systems and naturally there are additional reasons for such an interest. My analysis focuses on the costs involved in energy consumption: purchasing price, costs for handling as well as external costs and the relative shifts in emphasis between these costs as income rises.

The substitution pattern

The energy carrier substitution pattern is frequently presented as linear and simple. The idea is that new energy carriers are introduced because of their superiority and that they replace inferior energy carriers. Environmentalists, who for ideological reasons want traditional energy carriers to be competitive with modern ones, have recently questioned this view. One example is Greenberg who attempts to kill the myth of simple serial transitions, which state that wood was replaced by coal, which was replaced by oil, electricity and gas. She believes that this view has distorted historical investigations because traditional sources of energy have not been included, only "commercial" ones.[13] This proposition is too simplistic. In reality "a far more complex pattern prevailed in which adoption of coal-fuelled technologies supplemented rather than replaced renewable energy sources" and oil did not replace coal after the introduction of the automobile; its dominance was not established in most Western European countries until the 1960s.[14]

Let us examine how the idea of serial transition applies in the case of Sweden. Was there a simple substitution pattern? My quantitative account of energy carriers forms the basis for an answer to this question. Most previous studies of the relative shares of Swedish energy carriers have the deficiency of

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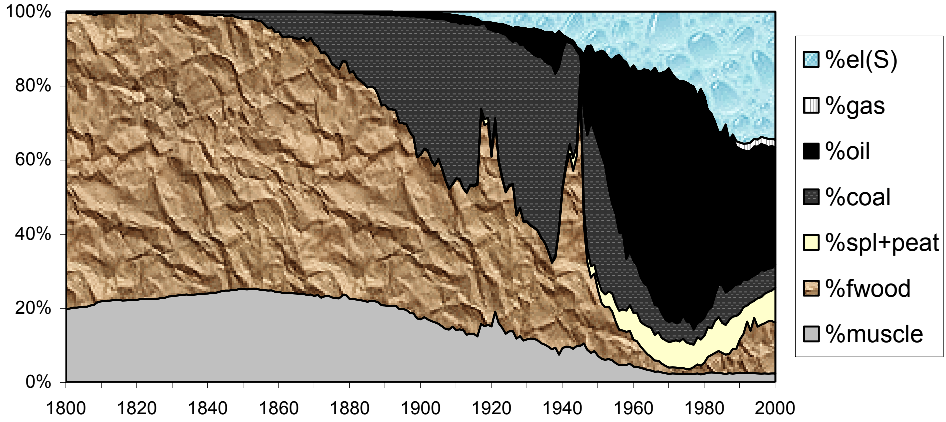
[13] Darmstadter, J. (1971): *"Energy in the World economy: A Statistical Review of Trends in Output, Trade and Consumption Since 1925",* Baltimore, for instance totally excluded renewables.

[14] Greenberg, D. (1992): "Fuelling the Illusion of Progress: Energy and Industrialisation in the European Experience", in Byrne, J. & D. Rich (eds) *Energy and Environment, The Policy Challenge*, Energy Policy Studies, vol 6, London, p 90.

not disclosing their sources, which is especially troublesome when it comes to the firewood estimates. The graph by IVA for the period 1800-1975 leaves out all information of its sources and it has been reprinted in some articles in spite of not incorporating, for example, changes in firewood consumption during the World Wars.[15] Kaijser's figure for the period 1870-1990 is less schematic and it allows for impacts of the World Wars, but it completely lacks information of its sources. His figure is almost identical to a figure provided by Johansson, which does not contain any source information either. [16] Kaijser and Johansson have probably used the available statistics for modern energy carriers, but for most of the period there are no statistics for firewood and it is important that the authors disclose either the basis for their own firewood estimates, or that they provide references for the estimates. Ljungberg estimated the relative shares of firewood, coal, electricity and heating oil in the period 1890-1980, and did include source information, but the accounts were not complete, since petrol and kerosene were omitted and the firewood series ended in the mid 1950s.[17]

Figure 5.1 Relative shares of the energy carriers 1800-2000



Sources: see figure 3.2. Comment: The energy carriers are: natural gas, peat, spent pulping liquor (spl), electricity (calculated in the Swedish manner), raw oil, coal, firewood and animate energy.

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[15] For instance it was uncritically used in Olsson, S-O.(1993), op. cite, p 229.

[16] Kaiser, A.(1994), op. cite, p 158. Johansson, T.B. *Nationalencyclopedin*, volume 5, 1991, p 496. The only difference is the relative share of oil after 1970.

[17] Ljungberg, J.(1984):"Perspektiv på energipriserna" in *Energi och strukturförändring i Sverige*, Allmänna energisystemstudier, Energiforskningsnämnden, Efn/AES 1984:1, p 26. Ljungberg uses Arpi as source for his household firewood estimate.

My results of the relative shares of the energy carriers in the period 1800-2000 are depicted in figure 5.1. The most conspicuous feature is that there have been spectacular changes in the energy carriers' relative shares. Transitions have taken place. A closer look at figure 5.1 does, however, reveal that in most cases they were neither abrupt nor simple. Some of them were gradual and they were also temporarily reversed during the World Wars. The diffusions of coal and electricity occurred at a particularly gradual pace, while oil had a more rapid breakthrough. A gradual diffusion of electricity is hardly surprising, given the systemic properties of electric provision. The reason why coal diffused more slowly than oil may also be linked to the infrastructure of supply. While coal was diffused on the basis of ships and railways and was restricted to urban areas, oil diffusion was related to the establishment of a road structure, which enabled a more far-reaching diffusion of oil into rural areas.

Until after the Second World War there were no rapid transitions at all and the only abrupt changes were substitution effects of the Wars. Coal gradually replaced firewood from the 1820s and at the onset of the First World War it had passed firewood. Firewood did however temporarily regain its leading position when coal imports were restricted during the war. Electricity diffused slowly from the 1890s and the rate accelerated during the First World War. In addition, during the Second World War there was a relative increase in domestic firewood and hydropower at the expense of imported fossil fuels.

After the Second World War more spectacular changes took place. First of all oil increased its share immensely during the 1950s and 1960s. Second, electricity rapidly increased its share in the early 1970s at the expense of oil, due to the introduction of the nuclear program. Third, traditional energy carriers rapidly lost ground after the Second World War until 1975. Firewood continuously lost shares of the energy consumption until 1970 but in the 1980s it regained some of its lost ground. The retrogression of firewood was partly outbalanced by a related expansion of spent pulping liquor, a wood based waste product of the pulp industry, which gained a fairly important position after the Second World War. Muscle energy became completely insignificant in relative terms after the Second World War, as an effect of the diffusion of tractors in agriculture and the subsequent motorization of forestry, which were the two remaining areas, where muscle energy was still used to a significant extent.

Substitution patterns have been gradual and sometimes reversed, which is not in accordance with the notion of a simple serial transition and one might wonder why such an idea has won ground. One obvious reason for the belief in the serial transition idea is its appealing simplicity and the fact that fundamental transitions have occurred. Another reason may be the myth of salvation. Basalla portrays the myths surrounding new energy carriers. He discerns a historically repeated pattern of immense expectations of new energy carriers in the US, until their problems, in the form of environmental costs and/or insufficient supply, make the expectations erode at a later stage. These high expectations leave traces in the historical relationships at certain periods, while the less mythical, older energy sources do not leave as many. [18] There is therefore a risk that historians will overestimate the new energy carriers and neglect the old ones. In the Swedish context the importance of fuel-wood has been particularly neglected. Another reason for oversimplified schematic figures, like the one presented by IVA, may be that relative shares of the energy carriers have been based on benchmark data instead of annual figures.

It is not easy to characterize the development in a simple and unambiguous manner. The appropriate choice of method of characterization depends on the goal, but the basis should be consistent and clearly stated. If the organizing principle is the relative consumption of the energy carriers the following characterization may be suggested: (1) 1800-1850: the firewood and muscle period (2) 1850-1900: the firewood, coal and muscle period (3): 1900-1950: the coal, firewood, oil, electricity and muscle period (4): 1950-2000: the oil, electricity, firewood, spent pulping liquor and coal period. This characterization rather indicates a larger variety in supply over time than a serial transition. If the label is based on only the main energy carrier of each period, the following pattern may be suggested: (1) 1800-1900: the firewood period, (2) 1900-1950: the coal period, (3) 1950-2000: the oil period. If the guiding principle is instead relative progress of energy carriers and only the most expansive energy carrier is to be mentioned the following pattern is appropriate: (1) 1800-1850: the muscle period (2) 1850-1950: the coal period (3) 1950-1970: the oil period (4) 1970-1990: the electricity period. 5) 1990-2000: the bio-energy period.[19]

Energy quality and energy intensity

If the fundamental changes in energy carrier composition have produced a higher quality of energy, this may have contributed to the long-term decline in

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[18] Basalla, G.(1982):"Some Persistent Energy Myths", pp 27-38, in Daniels, G.H. & M.H.Rose (eds.) *Energy and Transport-Historical Perspectives on Policy Issues*, London.

[19] Schön (1990), op. cite, combines relative dominance and relative progress in his characterization of energy carrier patterns. He divides the period 1890-1990 into periods marked by stability in the composition of energy carriers and periods marked by change. He does not label the periods according to the most important one or two energy carriers. This would have been confusing, because in some periods the most important energy carriers were the dominant ones and in other periods the most important energy carriers were the most progressive ones, in his framework. Olsson (1993), op. cite, makes another periodisation, where he labels the periods in an inconsistent way, because sometimes it is the most progressive energy carrier that gives the name to a period, in other periods it is the most dominant energy carrier.

energy intensity. Quality may have compensated for quantity. The relative prices of energy carriers indicate how they were evaluated in society. In order for people to pay a higher price for one energy carrier than another, that energy carrier had to have higher qualities (either for energy carrier specific purposes or by lower costs for handling).

The basic energy quality factor

Price x quantity for an energy carrier is an economic volume and all these volumes may be added into an aggregate economic energy volume. This aggregate energy volume should be deflated with an appropriate deflator to avoid the influence of price changes, which are unrelated to quality improvements. Such a deflator should reflect changes in relative quantity over time and the Paasche-index is therefore the best for this purpose.[20] When developing these energy deflators, it became obvious that the length of the deflating periods was crucial for the size of the “deflating problem”, i. e. the differences in growth rates with early and late base years that arise as soon as there are Gerschenkron effects. The deflating problem normally becomes smaller with shorter deflating periods, but cannot be completely eliminated. To depict the development of energy volumes as neutrally as possible I developed a price deflator that produced the smallest “deflating problem”. The basket of goods constitutes another problem, which must be addressed when constructing a price deflator. To deal with diversification in the energy carrier market, with new competitors, it was appropriate to divide the 200-year period into shorter ones. I used 1800-1870, 1870-1890, 1890-1913, 1913-1930, 1930-1950, 1950-1970 and 1970-2000. For most of these periods the optimal method was to use annual Paasche- indices linked together (a chain index), but in war periods, when there were sharp fluctuations in annual prices, it turned out to be better to use deflating periods of 5-7 years. It is impossible to eliminate the deflating problem and a choice of whether to use early or late base years had to be made. I chose early base years to be consistent with the way the GDP deflators have been constructed. The different outcomes for energy volumes with early and late base years and varying length of the deflating periods are presented in appendix B.

The most neutral energy volume in constant prices divided by the energy quantities is a basic indicator of energy quality and is presented in figure 5.2. The basic energy quality factor indicates that the quality of energy stayed relatively constant between 1800 and 1910, after which a dramatic increase of

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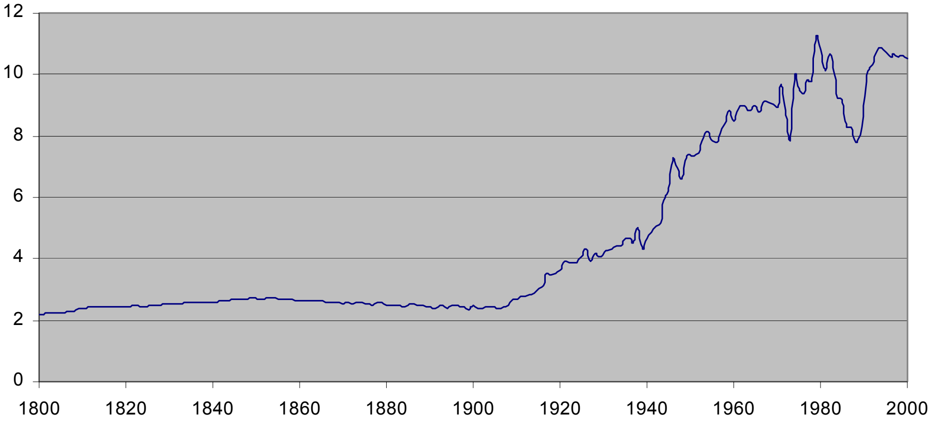
[20] If only the price development is focused it may be better to use the Laspeyre index, which holds quantities constant. Here, however, I wish to deflate the actual consumption of energy, with varying quantities and I therefore think the price deflator should take changed quantities into account.

400-500% took place, ending around 1980. Between 1980 and 2000 the pattern was cyclical with no apparent trend.

Figure 5.2 The basic energy quality factor 1800-2000, SEK/J, in constant prices, 1910-12 price level.



Sources: For energy carriers see chapter 2. For prices of firewood, muscle energy, coal, oil and electricity see figures 5.8, 5.9, 5.11 and 5.12. Prices for gas, district heating, spent pulping liquor are taken from SCB.

The augmented energy quality factor

Prices do not fully reflect the consumers' benefit from goods, because price is determined on the margin, which means that there are always consumers that would be willing to pay more for the goods, i. e. they get a greater value from the consumption. That extra benefit, which is not paid for, is normally called consumers' surplus.[21] The size of the consumers' surplus depends on the price elasticity of demand and on the quantities. I have attempted to arrive closer at the consumers' benefit from energy carriers by including the consumers' surplus

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[21] Economists have mainly used the consumers' surplus in welfare theory and decisions based on cost-benefit analysis. Some well-known economists, like Mishan and Hicks, find this most useful and appropriate, while others, for instance Samuelson, think that we may do better without the concept. The two main objections put forward against using the consumers' surplus are that 1) when relative prices change, real income will be altered if expenditure on this good make up a considerable proportion of total expenditure, and then demand curves will be shifted, so the size of consumers' surplus will be changed. 2) the total consumers' surplus will be affected when goods, which are close substitutes for other goods, enter the market. See Greenwald, D.(1982): *Encyclopedia of Economics,* McGraw-Hill Inc., p 198. Both these aspects are included in my modelling and this is easier to do in historical studies than in welfare decisions regarding the future, so I find the consumers' surplus appropriate to use in a study like mine.

in my calculations.[22] I regard this augmented energy volume, i. e. the basic energy volume plus the consumers' surplus, divided by the energy quantity as a principally better energy quality factor than the one above. The disadvantage of such a measure is that it relies partly on assumptions, which makes it more uncertain than the basic energy quality factor. The reason for constructing it anyway is that it more accurately illustrates the quality of the aggregate over time, than when only prices and quantities are taken into account.

According to standard economic theory the price elasticity of demand for a certain commodity/service is determined by: a) the size of the proportion of people's income that is spent on the commodity/service and b) the possibilities of substitution for the commodity/service. The price elasticity of demand is higher the larger the proportion of income that is spent on the commodity/service. This occurs because options to cut costs for the particular good/service make a large difference for a household's economy if these costs make up a large proportion of its total expenditure. The price elasticity of demand is also higher with more possibilities for substitution, because with more choices, people are more sensitive to relative price changes. The possibilities for substitution vary among energy carriers, depending on the amount of specific applications. In theory the energy carriers may be ordinally, but not cardinally, ranked with respect to their substitution possibilities. There is a negative relationship between price elasticity and consumers' surplus. High price elasticity results in a small consumers' surplus and low price elasticity results in a large consumers' surplus, ceteris paribus. This is because with a high sensitivity to the price more consumers will pay a price in line with their marginal benefits, and there will be a smaller surplus.

In order to operationalize the theory of consumers' surplus for energy into a construction it is necessary to make some simplifications and assumptions. First the demand curves are supposed to be linear. This means that the consumers' surplus can be calculated as $Q^2/2a$, where $a=dQ/dP$ (or the slope of the linear curve) and $dQ/dP=\text{elasticity}*Q/P$ (because the price elasticity of demand is defined as: $(dQ/Q)/(dP/P)$, a relative quantity response to a relative price change). With known values of price (P) and quantity (Q) and assumed values of price elasticity, it is hence possible to calculate the consumers' surplus. Second, the ordinal ranking of the price elasticities of the energy carriers have been translated into a cardinal ranking (sensitivity analysis has been done for different intervals in the cardinal ranking). Third, whether to use a time trend or not has been determined based on the developments of energy's income share

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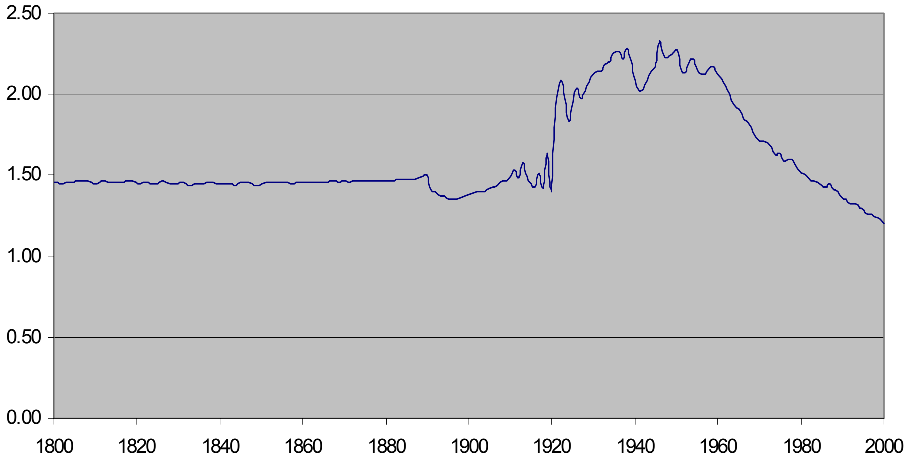
[22] This has not been done before in economic historical research as far as I know. The construction means an extension of the theoretical consumers' surplus in economics. My measure, which is empirically based, incorporates changes over time in income, population and preferences, since these are manifested in prices and quantities.

and on the possibilities for substitution. Energy's share of income has been operationalized as the energy volume/GDP, in current prices. The possibilities for substitution have generally increased for energy over time as new energy carriers have entered the market, but more complex grid-bound energy carriers do not lead to proportional substitution increases. This, together with knowledge of when new energy carriers entered the market and when they became price competitive for various purposes, has guided the estimates. The energy's share of income and the substitution possibilities, showed different developments in different periods and the net result determined whether to use a time trend for the overall price elasticity of the energy carriers or not. Sensitivity analyses have been done both by omitting the time trends and by changing the rates of change in the trends. More detailed accounts of the constructions are presented in appendix E. The result for a middle range series of consumers' surplus (with moderate intervals between the elasticities of various energy carriers and some time trends, but not extreme ones) is presented in figure 5.3.

Figure 5.3 Consumers' surplus divided with the energy volume, current prices



Sources: same as for figure 5.2.

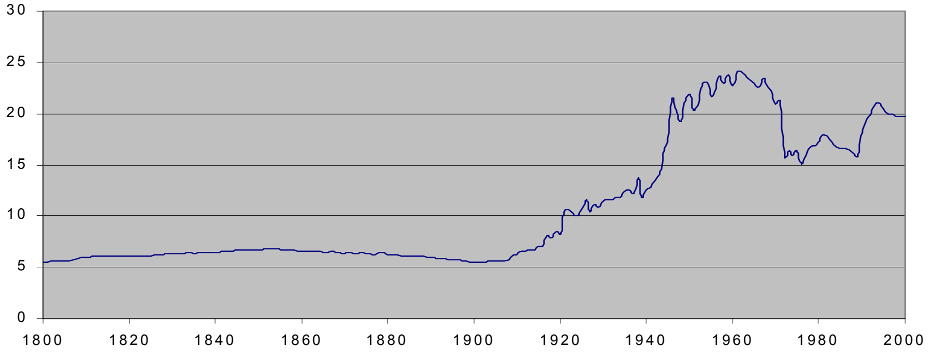
The consumers' surplus was largely stable in relation to the energy volume until 1920 when it changed levels, from 1.4 to 2. This was an effect of the increased consumption of coal, oil and electricity, energy carriers with relatively low price elasticity, at the expense of firewood and muscle energy. The consumers' surplus moved cyclically in the range of 2-2.3 until around 1960, after which there was a steady decline reaching 1.2 in 2000. The pattern is rather robust even with other elasticity assumptions. Alternating the intervals in the cardinal ranking only produces different magnitudes. The time trends play a larger role for the shape of the curve. If no time trend is included the surplus will not decline much after 1960, but I find the exclusion of a time trend an unrealistic assumption (for motivation see appendix E). The reason for the decline after 1960 is that the price elasticities of energy carriers generally increased because of increased possibilities for substitution.

An interesting result in relation to Swedish economic growth is that the consumers' surplus is especially large during the two phases of rapid economic growth: the interwar period, with an annual growth rate of 3.4%, and the period 1946-1975, with an annual growth rate of 3.8%.[23] In these periods the users of energy had large, extra benefit from their energy consumption, which they did not have to pay for. Thus, one can claim that growth was spurred by 'a surplus value' of the energy.

A varying consumers' surplus in relation to the energy volume implies that it makes a difference if the consumers' surplus is included in the aggregate energy quality factor or not. Not only levels of the energy quality factor are influenced, but, more importantly, so are the trends per se.

In figure 5.4 the augmented energy quality factor is presented, i. e. the energy volume plus consumers' surplus in constant prices, divided by the energy quantity. One striking difference between the basic and the augmented energy quality factor is that the latter turned downwards two decades earlier. Another difference is that the relative increase between 1910 and 1960 was larger for the augmented factor than for the basic one. Last it may be noted that the magnitude of the cyclical curves after 1960 was different.

Figure 5.4 The augmented energy quality factor 1800-2000, SEK/J in constant prices, 1910-12 price level.



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[23] Excluding the power industry and dwelling usage.

The explanations for the different time patterns for the basic and augmented factors are that between 1910 and 1960 energy carriers of relatively low price elasticity, and high consumers' surplus, increased their importance, while there were no trends towards generally increasing price elasticity. After 1960 consumers' choices in the energy carrier market increased, due to a larger number of energy carriers on the heating market. This, in combination with the absence of a concomitant decline in energy's income share, led to generally increased price elasticities for the energy carriers, which decreased the consumers' surplus. The effect was reinforced after 1980, when energy carriers like coal and bio- fuel, with relatively high price elasticity and low consumers' surplus, increased their shares.

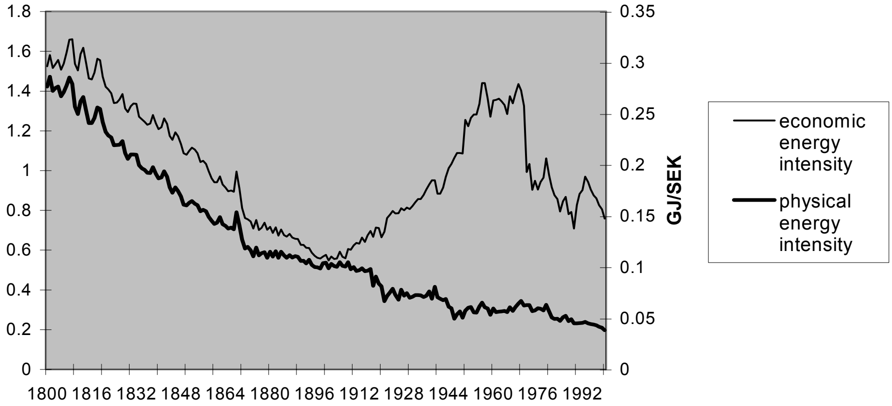
Figure 5.4 depicts the changing quality of Swedish energy over time. The quality did not change very much until 1910, but then there was a rapid increase in quality until 1945, especially during the two World Wars. The quality increase slowed down until around 1960, when it first declined until the early 1970s and then showed a more cyclical pattern.

It thus appears as if energy quality had a positive impact on economic growth during the long wave of the second industrial revolution. This is not very surprising given the growth propelling engines of this era: the development blocs centered on the automobile and the electric network. It may be stressed that the level of energy quality was especially high during the phase of rapid economic growth after the Second World War. This was a combined effect of the consumption of more expensive energy carriers and of a large consumers' surplus. In the interwar period, which also had high growth rates, but not equally high, the consumers' surplus was as large as in the growth phase after the Second World War, but the consumption of expensive energy carriers was not equally high. Thus, in the "Golden Age" growth was based on technologies with high quality energy.

Economic energy intensity

The aggregate energy volume, including consumers' surplus divided by GDP, is a measure of economic energy intensity. This energy intensity may be compared to the physical energy intensity in order to highlight periods in which a decline in physical energy intensity was partly or completely caused by higher quality of the energy. This is done in figure 5.5.

Figure 5.5 Economic and Physical Energy Intensity 1800-2000



Sources: see figures 3.5 and 5.2.

The striking result is that during the 19th century the physical and economic energy intensities developed in the same direction, while they differed very much during the 20th century. During the 19th century both the physical and economic energy intensities declined rapidly, since energy quality remained constant. Around 1910 there was a conspicuous trend-brake, when the physical energy intensity continued to decline at the same time as the economic energy intensity increased substantially. This went on until around 1950, after which both intensities showed cyclical patterns. After 1970 there was a much larger decrease in economic energy intensity than in physical energy intensity.

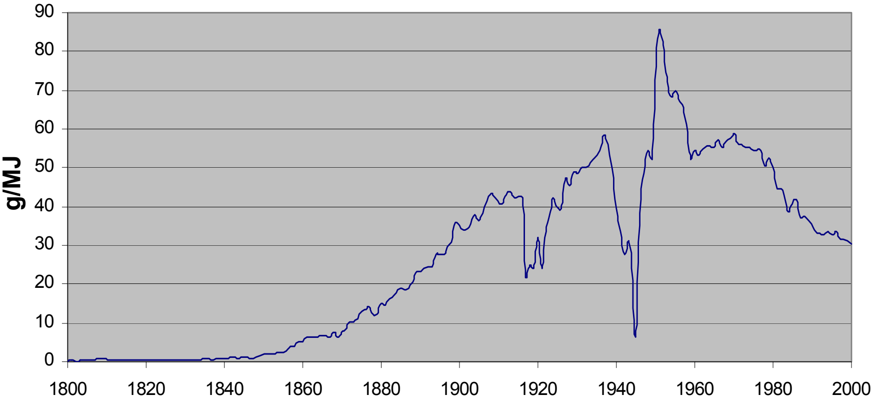
The conclusion of the comparison of economic energy intensity and physical energy intensity is that the long-term decline in physical energy intensity did not largely depend on the increasing quality of energy carriers. In the period 1800-1910, physical energy intensity fell heavily without a concomitant increase of energy quality. In the subsequent period, 1910-1945, there was a sharp decline in physical energy intensity, especially during the war periods, which was accompanied by an increase in quality. In the period 1945-1970, physical energy intensity increased somewhat despite an increase in quality. Between 1970 and 2000, physical energy intensity fell despite decreasing quality. Only in one period, which is the turbulent period of the World Wars was there a positive correlation between energy quality and physical energy intensity, while in the other periods there was in fact a negative correlation. Even if energy quality has some influence, it does not have a particularly strong influence on the physical energy intensity pattern. Other factors matter more, i. e. structural and technical change.

While there was a weak inverted U pattern for the physical energy intensity from the 1940s, there was a marked such pattern for the economic energy intensity from the 1910s. In the 1970s both energy intensities turned downwards. Rapidly declining physical energy intensity in this period, when energy quality was also rapidly decreasing, may be interpreted to mean that the growth during the third industrial revolution was less dependent on energy and high quality of the energy carriers than the previous growth. Another interpretation of the development after 1970 is that economic growth was still highly dependent on energy quality, and when energy quality were deteriorating the growth rate fell.

Energy carriers and CO_2 intensity

The mix of energy carriers had a fundamental impact on the CO_2 intensity, since energy carriers vary in emission factors. The average CO_2/ energy ratio in figure 5.6 shows the impact of the energy carrier mix on the CO_2 emissions. It expresses the amounts of CO_2, in grams, which was released from the use of one mega-joule of energy in Sweden 1800-2000. It is an average of the specific emission factors for the energy carriers in the Swedish energy system, weighted according to the consumption each year.

Figure 5.6 The average CO_2- emission factor 1800-2000

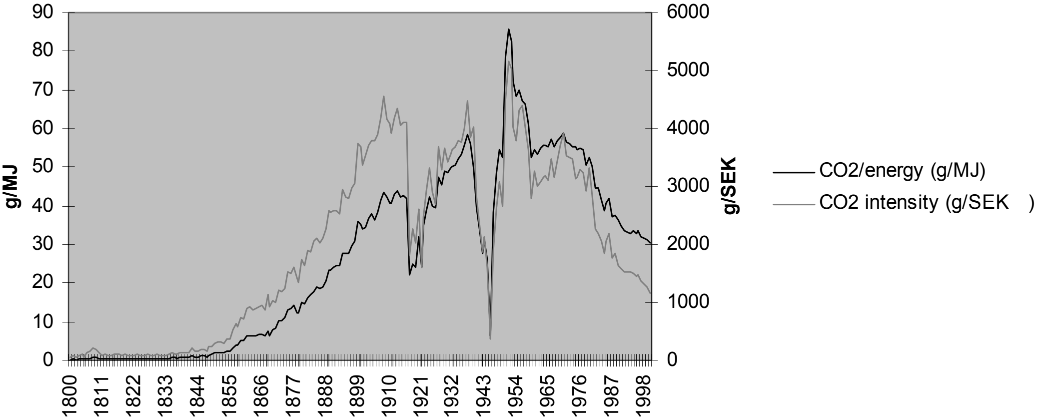


Sources: see figure 3.2 and table 3.2

With the exception of the war periods, the average emission factor has a shape of an inverted U. The emission factor increased from almost zero to 35 g/MJ between 1800 and 1900, and reached a maximum of 85 g/MJ in the mid 20th century, after which it decreased down to 30 g/MJ in 2000. The increase of the emission factor until 1950 was due to the expansion of coal, which was temporarily reversed during the two World Wars. The different developments of the 1950s and the 1960s may seem remarkable, but they were the results of the combined effects of a relatively more substantial increase of hydro-electricity and of oil and a less rapid decline of traditional energy carriers during the 1950s than during the 1960s. After 1970 there was a steady decline in emissions, due to the nuclear program and the expansion of bio energy.

The CO_2 intensity may be regarded as an effect from energy carrier composition on the one hand and from energy intensity on the other hand. In figure 5.7 CO_2 intensity and the average CO_2 emission factor are compared. It is clear from a visual comparison of the CO_2 intensity and the average CO_2 emission factor that the energy carrier composition had a profound effect on the CO_2 intensity. The residual in the CO_2 intensity development, when the CO_2 emission factor is accounted for, is the physical energy intensity, because the CO_2 intensity/ CO_2 emission factor = physical energy intensity (MJ/SEK).

Figure 5.7 Comparison of the CO_2 intensity and the CO_2 emission factor



Sources: see figures 3.10 and 5.6

It is in principle possible to quantify the relative impacts of changes in energy intensity and changes in the emission factor, through standard calculations. This would however demand a finer division of energy carriers in the formal versus the informal sector than I have established.[24]

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[24] Lindmark, M.(2001) *Koldioxideffektivitet i ekonomisk-historiskt perspektiv*, Occasional Papers in Economic History, Umeå University, no 5, has used an input-output analysis to account for the factors

The energy carrier composition

The historical CO_2 intensity is mainly explained by the composition of energy carriers and to lesser extent by energy intensity. Because of this profound role of the energy system it is of interest to analyze its historical changes. Current attempts to guide energy demand in directions that will result in less carbon-dioxide emissions make it important to understand the driving forces behind past energy carrier transitions, because they may provide insights that are valuable for successful policies. There are some fundamental transitions worthy of attention: (1) coal replaced firewood (2) oil replaced coal (3) electricity increased its share (4) muscle energy decreased its share (5) wood-based fuels and coal regained some of these lost positions after the late 1970s.

Qualities of the energy carriers should have played a role for these transitions. Natural scientists tend to regard the qualities of the energy carriers from a purely physical perspective. One way of illustrating the differences in the physical quality of energy carriers is through an index, like the one in table 5.1.[25]

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that determine the absolute CO_2 emissions in the period 1913-1998. Lindmark uses more economic sectors (7 sectors) than I do and has also used the national company survey of 1931 to establish benchmarks in that year: Kommerskollegium (1935): 1931 Års företagsräkning, Statistiska meddelanden, series A, band IV:10, Stockholm, which contains energy accounts for industrial firms, and for private service companies and firms in the transportation & communication sector, but not for public services or for agriculture. He separates economic growth effects, structural effects and CO_2 efficiency (broadly called technical change). Input-output analysis has frequently been used in various investigations of structural change. It has, however, not been frequently utilized in Swedish economic historical research, perhaps due to the fact that the latest historical national accounts have not yet been given a balancing input-output structure. Thus, the structure of Östen Johansson's HNA is, in a way, more suitable for structural analysis, while the latest HNA value added estimates are superior to Johansson's. Also worth noting is that the Lindmark investigation does not aim at decomposing the causes of changes in CO_2 efficiency. Historical input-output analysis may, therefore, in the future be developed by making a distinction between energy intensity and energy carrier substitution in CO_2 efficiency, and, if possible, also to assess the impact of structural changes by employing a finer level of aggregation. A precondition is, however, that the Swedish historical national accounts are given a proper structure of balancing accounts. As it is now, the SHNA is basically a collection of independent value-added estimates, which also determines the approach chosen in this investigation, namely to approach structural change as changes in value-added shares. I have discussed with Lindmark the option of pooling our studies both to refine our benchmark divisions of energy carriers between the sectors, and our analytical methods, and we hope to get the financial opportunity to do this.

[25] Sundström, T.(1993), op. cite,, p 106: exergy = heat amount * quality-factor. The quality factor depends on the temperature difference between the energy source and its surroundings.

Table 5.1 Quality factors of different energy forms

	Energy form	Quality factor
Extra prime	kinetic energy	1.00
	potential energy	1.00
	electric energy	1.00
Prime	nuclear energy	1.00
	solar light	0.95
	fuels	0.85
	hot steam	0.60
Second-rate	waste heat	0.05
Worth less	heat radiation from earth	0

Source: Sundström (1993), p 108.

The base for table 5.1 is exergy values for different energy forms, which are related to their ability to perform work. For example, the higher temperature a fuel can reach on combustion, the higher its exergy, because the efficiency rate for conversion of the heat to mechanical power increases with temperature. Exergy is a theoretical concept, defined under certain combustion conditions, and it is not the same as technical energy efficiency of actual combustion in society. According to table 5.1, electricity is an energy carrier with the highest possible quality value, of 1, and there is no principal difference between fuels, which all have a quality factor of 0.85. It is therefore not possible to classify the historical mix of fuels according to their exergy values, and the historical development cannot be understood as exergy-inferior fuels paving the way for exergy-superior ones. But the relative increase of electricity could be described as an expansion of an energy carrier with the highest possible exergy.

Energy carriers may be assessed from other physical aspects than their exergy properties. Reynolds classifies energy sources according to four different physical aspects: a) *Weight-grade*, which is the same as energy density (or energy/weight) b) *Volume-grade*, which is the energy/volume c) *Area-grade*, which is energy/area d) *State-grade*; defines the state in which the resource occurs: gas, liquid or solid. [26] All four aspects are connected to the costs of handling the fuels. Fuels that have high energy density as well as high-energy volume have comparatively little dead weight and volume, which is an advantage for transportation and storage. A geographically more concentrated energy carrier is cheaper to handle than one that is dispersed. The area grade distinguishes between fossil fuels and firewood. A geographically concentrated

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[26] Reynolds, D. B. (1996):"Energy Grades and Economic Growth", in "*The Journal of Energy and Development*", vol 19, no 2, p 245-264.

energy resource, like coal and oil, has the advantage of scale, because the extraction capital can be stationary and large. Long before Reynolds, Wrigley had emphasized the relevance of the area-grade, although he did not use that expression, by underlining the cheaper options for transportation of “punctiform“ natural resources, compared to “areal“ resources.[27] The liquid state is the optimal condition of a fuel, because liquid fuels are easiest to transport and to use; second best is the gas form and third best is the solid state. Reynolds makes no attempt to combine the four grades into one energy grade index, but since oil comes out well in all grades, coal is in the middle and firewood has the lowest quality, he concludes that mankind has advanced historically from low-grade to high-grade energy. He even suggests that economic periods have been founded on technical innovations in combination with energy carriers of higher grade than the previously dominant energy carriers of the time. Reynolds accordingly believes that a future change to oil-substitutes is likely to impede economic development, although improved technology could outweigh some of the disadvantages of lower grade energy carriers.

Even if the grade approach developed by Reynolds is valuable, it is not sufficient when analysing why transitions occur, because it disregards several aspects. In order to understand the energy carrier transitions, an economic, rather than a physical approach is necessary, which results in an increased emphasis on demand-side factors. For consumers, one important aspect of energy carriers is their different number of special applications. An energy carrier, which can be used for several purposes, like light, motion and heat, is naturally of higher value for consumers than an energy carrier, which can only be used for one or two purposes. Energy carriers thus compete in different markets where the price elasticity of consumer demand differs in line with the number of competitors. This means that energy carriers are not perfect substitutes for each other.

The demand side

I want to lift forward two aspects of energy carriers that are important for consumers, in cases where energy carriers can actually substitute for each other.[28]

1) The price of the energy carrier relative to the price of other energy carriers and other goods. The purchasing cost of energy does not only depend on the price per energy unit, but also on the quantities needed, and the quantities are

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[27] Wrigley, E. A.(1962): “The Supply of Raw Materials in the Industrial Revolution“, p 1- 16, in “*The Economic History Review*“, volume 15, no 1.

[28] There are of course also other aspects, which are of importance, for instance reliability of supply, freedom of localization and usage and immediate health costs.

affected by the technical energy efficiencies. Higher technical energy efficiency means less spill energy and lower energy costs.

2) The costs for handling, which are all additional costs taken into consideration in the usage of the energy. The main handling costs are:.[29]

a) Equipment. Energy services are mediated through capital goods like stoves, cars etc, the cost of which matter for the total costs of receiving the energy services.

b) *Time.* It takes time to provide energy services and this aspect is to a large degree related to the fuel's energy density. Handling a low-density fuel involves the time consuming task of handling substantial dead weight. The time costs varies with alternative uses of time (by the individual) and with labor costs relative costs for energy (by the company). The cost of time connected to an energy carrier also depends on the development of power. The possible power development, i. e. the flow of energy, "energy /time – ratio", is not only dependent on the physical quality of the fuel, but it is also and mainly dependent on the technical solutions for the conversion of heat into mechanical power. The higher the power development, the more the work that may be performed during a certain time interval, which means time savings.

The supply side

For energy producers, it is mainly the price in relation to production costs that is important. Here I would just like to lift forward the importance of the geographic conditions for this relation. The costs largely depend on the concentration of the energy carrier. The more spatially concentrated an energy carrier, the easier it is both to extract and transport. This tends to lower production costs for energy carriers with high volume-grade, weight grade and area grade. The technical development of both transportation and extraction naturally plays a large role for the dynamics of this factor over time.

The market: aggregate supply and demand

On an aggregate level, individual supply and demand functions, which relate quantities to price on the margin, may be combined into aggregate supply and demand functions. Historically, the supply and demand functions shift, which leads to changes in price. The high level of abstraction necessitates precaution when drawing conclusions about what the reasons for changes in demand and supply are, and even more so what the reasons for price-changes are. Aggregate

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[29] In Peterson, A.(1990) :"Det svenska energisystemets utveckling 1850-1920 - en idé och teknikhistorisk betraktelse", *Polhem*, p 308-311, the aspects of price and comfort in use are emphasized as determinant factors for the choice of energy carriers, when the technical performance is granted.

demand curves are theoretical constructions that cannot be empirically related historically, but may be used in models of reasoning and estimates.

Outside the market (externalities)

There are costs that are usually not taken into account, like health costs and environmental costs, which are external to the market process to the extent that they do not hit the users of energy proportionally. External costs create a social trap situation; i. e. for the individual the costs (shared by everybody) seem comparatively low in relation to the benefits (granted to him personally), unless every person is emitting the same amounts (in which case the costs will be larger than the benefits). What is rational for the individual is thus not rational on a social scale. Unless a situation is established where people can trust that their efforts to avoid emissions will be complied with loyally by others, society will most likely fall into the trap. External costs can be internalized in markets, through political decisions to "put a price tag" on them, by means of taxation.

Dynamics

The framework presented so far is weak because of its static perspective and assessing the historical *changes* in energy carrier composition requires a more dynamic perspective. The two essential dynamic mechanisms are technology changes and increases in income.

Technology changes have both altered the relative costs of the energy carriers and opened up new specific applications for them. In some cases there have been direct casual effects of technology, reducing costs for certain energy carriers, on their application in new fields, especially heating. The technology changes have thus had great impact on the purchasing costs of various energy carriers, which play a fundamental role for the choice of energy carriers.

It may be argued that there is a shift in cost emphasis as income rises. The three kinds of costs involved in energy consumption are: 1) the purchasing costs 2) the handling costs and 3) the social costs (or external costs). Two shifts seem to take place over time. First there is a shift from purchasing costs towards handling costs. Time costs rise with income. Both for companies and households income increases have an effect on the time costs. For companies this relation is more obvious, because time costs increase with wages, which means that there is less willingness to handle energy carriers that are time-consuming. As wages go up it will be more expensive for companies to use labor for handling time-consuming energy carriers and it may prove worthwhile to instead buy an energy carrier with a somewhat higher purchasing price. For households the time costs are not quite as explicitly linked to income, but there is an indirect effect, which consists of their assessment of alternative uses of their time. They may, for instance, work extra hours and get paid for that instead of devoting time to chopping firewood or removing ashes from their coal oven. In addition, with rising income and a larger supply of recreational activities, the options for households to use their spare time, in more attractive ways than fuelling their stoves, increase.

The power development of machines has also become increasingly important with rising income, because, although more power demands more energy, it also saves time, and the cost of labor has in general increased more than the purchasing price of energy. One way of substituting capital for labor and saving time is to equip workers with powerful machines, and another way of saving human labor time, both for companies and households, is to transport people faster in more powerful vehicles, or in better equipped vehicles where transportation time can be used in a meaningful way.

Second, when incomes have become "high enough", external costs begin to be internalized in market behavior. This seems to be something between a threshold shift and a gradual shift. Values as well as the actual severity of the environmental problem interact to accomplish the internalization. The long time interval between the scientific discovery of an environmental problem and its acceptance in society probably depends on high income sensitivity for external costs and on the fact that many environmental problems grow in scope and scale, which finally makes it impossible to doubt their severity.[30] In addition, the relationship between who is affected by an environmental problem and who has the power to set the political agenda influences when the problem is established. As long as decision-makers and the groups they represent are spared from the adverse environmental effects they are not very likely to decide on internalizing the external costs that hit other groups of people, be it on the local, national or global level. There are larger possibilities for internalizing external costs with higher degrees of democracy in society. For environmental problems, which are global in scope, like the Greenhouse effect, it is especially difficult to achieve this matching of decision makers and people affected, because the largest emitters of CO_2 are not those that will suffer most from problems related to global warming such as rising sea levels. Nations still have their sovereignty to decide to what degree they will internalize costs, even though they are under

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[30] "Sveriges Gröna Historia" in Bohlin et al, (1995), Människa och miljö. Om ekologi, ekonomi och makt, gives some examples. Acidification for instance was already known in the 1870s, but did not become accepted as an environmental problem until 1967 when Svante Odén wrote a famous article in Dagens Nyheter. Eutrophication of water was discovered by Einar Nauman in the early 20th century, but did not become established as an environmental problem until about 50 years later. The greenhouse effect, pointed out by Svante Arrhenius in 1896, did not become an environmental problem until the 1980s.

pressure from international negotiations. Free riding on the political wave of internalizing costs of global warming is thus a tempting option for many nations, which delays the internalizing process.

The growing worldwide environmental awareness over recent decades, demonstrated in national environmental legislation in both poor and rich countries and in growing membership figures of environmental NGOs (Non-Governmental Organizations), is likely to affect the internalization of environmental costs. It is thus too simplistic to regard the internalization of external costs as a pure income effect, as something that will come automatically with higher income. Income level, level of democracy and environmental awareness are factors, which all play a role in political struggles at various levels and decide when and to what extent environmental costs are internalized. A 'high' level of income is a necessary, but not sufficient, condition for the internalization of environmental costs.

The two factors used here as dynamic forces in a simple conceptual model to explain energy carrier transitions, technology and income levels, are closely interrelated. For one thing, as technology has opened up new applications for energy carriers, the amount of energy at man's disposal has risen. This has led to increased production per capita, which has given higher income levels. Another example of interconnections is that there is a correlation between income levels and expenditure on education and research, which spur the technical development. In my analysis the income effect is regarded as crucial for the changing emphasis on the three kinds of costs, while the technical changes mainly influences the relative purchasing price of energy carriers.

Transitions

The aim of the following discussions on transitions is to show the relevance of the dynamic perspective outlined above, with shifts in cost emphasis over time, from purchasing price to time costs to environmental costs. The data used for the analyses is mainly data on the purchasing price of different energy carriers. A full analysis would also require data on average costs for equipment, so this analysis is not a stringent one. It still provides a check of my conceptual model. The underlying question in all the analyses is whether there is a need to include time costs for handling and external costs to explain why the transitions took place.

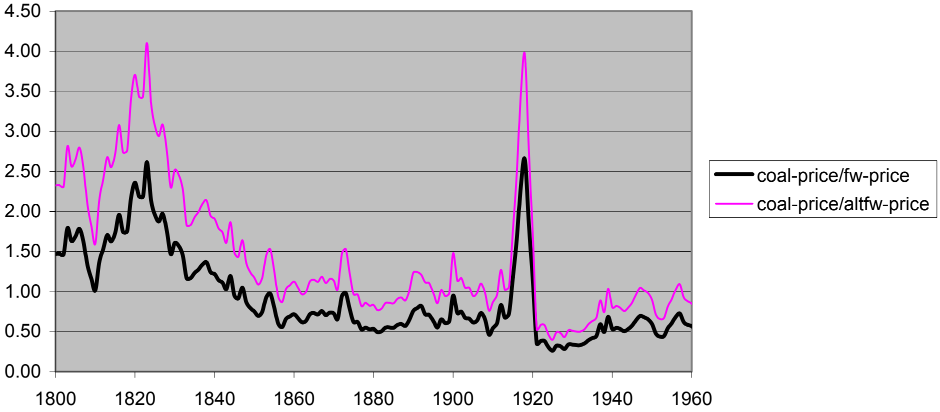
Coal for firewood substitution

Coal gradually substituted firewood. The main advantage of coal compared to firewood for consumers is its high energy density. Because coal has less dead weight than firewood, there are comparatively low costs involved in dealing with it. Consumers differ in their evaluation of the energy density. All consumers will save time if they use an energy carrier with high energy density, but for transportation there are extra gains in choosing an energy carrier of high density, in that it saves space and fuel, which means that there is no out-crowding of other goods and/or passengers. In a low-income country like Sweden at the beginning of the 19th century, wage costs were not very high and handling costs therefore not so important compared to the purchasing price of fuels. Transportation was therefore the only consumer category that was willing to pay a quality premium for coal's energy density. Coal had a clear quality advantage in its high energy density, but this does not mean that coal in all respects was superior to firewood. Some consumers, especially those for which the time costs mattered little, like wealthy people with servants who took care of the heating, preferred the cosy wood fires and were reluctant to use coal. For most consumers the purchasing price of coal compared to firewood would have been crucial for their choice.

The estimates of appendix A suggest that about half of the coal was used for room heating in 1850 and in 1870. Room heating is a usage where the high energy density of coal does not matter as much as in transportation. Was the purchasing price of coal compared to firewood low enough to make room heating by coal economical around the mid-1800s or did consumers pay some quality premium for the low costs for handling, or were they rather persuaded to use the less cosy coal by a lower relative price? Figure 5.8 depicts the relative price of coal compared to firewood 1800-1960.

There was a substantial decline of the coal price compared to the firewood price between 1820 and 1860. The price of firewood increased substantially compared to coal during the 19th century, because of increased demand from a growing population and a rather inelastic supply due to decreasing stocks and long production periods. There was at the same time a relative decline in the coal price. Punctiform energy resources like coal have fewer points of departure and are thereby easier to transport. The invention and diffusion of railways created excellent opportunities for connecting the mines with consumption centers, thereby lowering the transportation costs for coal. Firewood, by its area dispersion, could not benefit to the same extent from the railways. Thus, railways and coal contributed to urbanization and made coal cheaper in relation to firewood.

Figure 5.8 Coal price in relation to firewood price 1800-1960.



Methods and sources: The method has been to link together different price-series, with level adjustments, to create long coherent price series for firewood and for coal. A first aim has been to get as close to consumer prices as possible, i. e. retail prices have been used when available and they set the price level, i. e. other price series, like import prices, have been level adjusted. A second aim has been to mix prices to reflect consumption patterns. For firewood a mix of 50% birch and 50% pine has been used, because information of relative shares of various fuelwood is not available. For coal annual relative shares of coal and coke have been estimated from the import statistics and from the industrial statistics from 1890 onwards. From 1950 “stybb”, or fragmented coal, is included as a third category, with somewhat lower quality and price. The prices for firewood and coal are expressed in relation to energy units. This is easier for coal than it is for firewood, because variation in energy content is larger for firewood. I have used two different figures of average energy content of mixed fuelwood. In my fw-price series I use the figure 6.9 GJ/m3(s), which is taken from Skogsstatistisk årsbok (according to which one solid cubic meter gives 1.92 MWh, or 6.9 GJ). In my second alternative (altfw-price) I use the figure 8.97 GJ/m3 (solid) for mixed wood taken from “Föreningen för kraft och bränsleekonomi: *Koks, kol eller ved för centralvärmeanläggningar*, Helsingfors, 1924. The figures for coal and coke have in both cases been taken from the second source, stating that one ton of coal contains 29 GJ and one ton of coke contains 32 GJ.[31] The firewood price series are from Jörberg, L. (1972): *“A history of prices in Sweden 1732-1914”*, Lund, as far as they extend and they are then linked to Ljungberg’s (1990) series. Jörberg’s series set the level since they are retail prices.[32] The coal price series are from Ljungberg and linked backwards in time to Schön’s elaboration of Hansen’s price index for coal.[33]

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[31] The figures for coal are also subject to some uncertainty, for instance recent energy statistics by SCB state the energy of one ton of coal to be 27 GJ and one ton of coke to 28 GJ.

[32] **Birch**: 1800-1869 table on p 691-692 in Jörberg’s price history. The national values are non weighted averages between regions. For 1870-1875 I have calculated average prices for 10 regions from the table on p 496. From 1876 only the prices for two expensive regions exist. I have therefore corrected the price level according to the relation in 1869 for the average of those two expensive regions and the average for the whole country, (1.4) Jörberg’s birch prices are used as far as they go, i. e. until 1892 and then they are linked to Ljungberg’s series. Ljungberg in his birch series uses purchasing prices for the State Railways (SJ)1904-1919, for 1890-1903 Ljungberg extrapolates the series with the help of market scales for Stockholm (1904=100), for 1920-1963 Ljungberg uses the primary material for the wholesale price index from SCB’s archive, 1964-1980: extrapolating of the wholesale price(1964=100) with help from quantity and value figures for fuel-wood (Kastved, långved

In 1820 heating by coal was on average 150-300% more expensive than using firewood, which means that coal heating should have been negligible at the time. People would only be willing to pay such a quality premium for transportation. But the price improved rapidly for coal. In 1850 firewood prices and coal prices were fairly equal on average and in some regions coal was cheaper. In wood scarce regions like Stockholm, Uppsala, Malmöhus and Göteborg & Bohuslän, with access to import ports for coal and consequently low domestic transportation costs, coal had a clear price advantage in 1850. This relative price comparison supports my results in Appendix A that a substantial part of the coal was used for room heating in 1850 and 1870.

When coal consumption increased rapidly after the 1850s it seems like people no longer had to pay a quality premium for coal. Prices of coal were generally lower than prices of firewood from then onwards, according to figure 5.8.

Some of the environmental costs of coal consumption were experienced in Swedish cities, where the dust was annoying, but not to the same degree as it was for example in England, where household coal combustion was much larger and caused severe breathing problems.[34] The fact that carbon-dioxide emissions influence the climate was not yet known, although it was to be argued as early as in 1896, but it was then considered a social advantage for a cold country like Sweden instead of a cost.[35] If we allow ourselves an anachronistic exercise and impose the knowledge and values of today on the past by a fictive tax on CO_2 emissions what would relative prices then have been? Several recent Swedish estimates use a social cost for CO_2 emissions of 0.1 SEK/kg.[36] Deflated with the general GDP deflator this cost corresponds to a cost of 1.6 SEK/ton in 1850. Imposing this fictive tax on the coal price in 1850 would have led to a price

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och dylik brännved) in SOS Industry. **Pine**: Jörberg's national series as far as it goes, i e. until 1914, linked to Ljungberg's series by the average values for 1912-1914. Ljungberg's pine series is constructed in the same manner as the birch series.

[33] Retail price for **coal** is taken from Ljungberg, series P9157, for the period 1890-1918, linked to the wholesale prices (P9159) for the period 1918-1980. The retail price is naturally higher than the wholesale price, but variations in the difference are rather big, so the linking has been done according to the average relative price difference for 1890-1919, when retail prices were 29% higher than wholesale prices. For the period 1800-1890 I have used Schön's unpublished price index for coal, which he has based on coal prices in Hansen, S-A. (1974*): "Ökonomisk växt i Danmark*, del 2, Köpenhamn, and exchange rates between Sweden and Denmark for the period 1815-1890, and in the period 1800-1815 on price development for similar goods. The retail price for **coke** is taken from Ljungberg (series P9166) for the period 1920-1964. For the period 1890-1919 wholesale prices (series P9166) have been used, but have been level adjusted, according to the average price differential between retail coke and wholesale coke in 1920-1964, when retail prices were 35% higher.

[34] Clapp, B. W. (1994), op.cite, p 14-23.

[35] Arrhenius, S.(1896), op. cite, p 127.

[36] Jackson & Stymne (1996), op. cite, Lindmark, M.(1998), op.cite, p 151.

increase of 30%.[37] If such taxes had been imposed coal would at that time scarcely have been able to compete with firewood for room heating except in extreme cases.

What were the main reasons for the increasing coal consumption during this period? The diffusion of steam engines is frequently mentioned as crucial on the demand side.[38] This study has indicated that steam engines in Sweden did consume a large share of the coal during the period, but that households consumed relatively more. It is therefore reasonable to state that steam engines had a double impact on coal consumption, on demand as well as on supply, and that they were even more important on the supply-side. Steam engines were employed in British coalmines for pumping water away, and they were used for long distance transportation over sea and on land. [39] This lowered costs for extracting coal as well as distributing it and thereby lowered the price. Railways, powered by steam engines, accelerated the urbanization process. Coal was relatively cheap in cities and coal consumption enabled their expansion, which in turn gave an impetus to the railway traffic. One could expect this to have a reinforcing effect with lower and lower prices of coal compared to firewood. Still the relative decline in the coal to firewood price came to a halt in the 1880s. This was due to limitations on the supply side of coal and on a less rapid increase in the firewood price. But from the 1850s coal became and remained cheaper than firewood.

The rapid expansion of coal consumption after the 1850s took place at a time when the purchasing price of coal was lower than the price of firewood. Time costs in dealing with the energy carriers, which directly affected the consumers, did not play any obvious role for the coal expansion.[40]

Oil for coal substitution

Another transition that has taken place is the oil for coal substitution. Oil has quality advantages compared to coal because of its higher energy density and because of its liquid condition, which makes it easier to transport and store. It

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[37] The emission factor for coal is 92g CO_2/MJ, or 92 kg/GJ. In 1850 the coal price was 0.47 SEK/GJ without any CO_2 tax. The cost in 1850 for the emission of 92 kg CO_2 would be 0.15 SEK. So imposing this tax would have raised the coal price by 30%.

[38] S-O. Olsson (1993), op.cite, p 224-225, for instance suggests that the coal import development after1850 was driven by increased demand from steam engines, and says nothing about supply-factors or relative prices. Also Smil, V.: (1994), op. cite, p 160-161, stresses the importance of steam engine demand for coal: “During the nineteenth century coal’s most important role was providing the fuel for steam engines”. Smil does also stress the dynamic interaction between supply and demand in the limited sense of mine pumps demanding coal at the same time as they increased production.

[39] As open cast coal was depleted, mines had to be sunk deeper and deeper. Below ground water level, the mines tended to be filled with water and had to be pumped.

[40] Time costs in dealing with the energy carriers naturally also affect the supply side and the price.

has advantages for all types of consumption, but its greatest advantages are in transportation. This is so for the same reasons that coal has advantages compared to firewood, but also because of the internal combustion engine, which was designed for liquid fuels and especially suitable for smaller vehicles like fishing boats, cars and lorries. There were thus incentives for the transportation sector to pay a quality premium for oil and oil expansion was clearly connected to the diffusion of motorized transportation by road and, later, air transportation. But raw oil consists of other products than diesel oil or petrol. Heavier oils, which make up a large fraction of the raw oil, competed with coal on the heating market.

After the Second World War oil rapidly took coal's place as the leader in the energy carrier market. Sometimes the expansion of oil at the expense of coal is presented as a simple price mechanism; oil became cheaper and therefore outdistanced coal.[41] Is this the simple explanation? Or did the oil expansion merely take place for oil specific uses like cars or airplanes? Or were people, who at this time had substantially higher incomes compared to when coal had its breakthrough a hundred years earlier, willing to pay a quality premium for oil, even for uses that were not oil specific, like room heating, to reduce time costs? There is no uniform oil price because oil consists of kerosene, petrol, diesel oil and heating oils with large differences in price. For coal the price disparities are not as large as for oil, but coal and coke differ in price. In figure 5.9 the oil price is weighted according to the annual consumption of kerosene, petrol and heating oils and the coal price according to the annual consumption of coal and coke.[42]

The price of oil compared to coal reached a low level after the Second World War, but oil still remained on average twice as expensive as coal per energy unit, which implies that in general a quality premium was paid for oil. Much of that premium was paid for oil-specific uses like cars and airplanes, since petrol and kerosene were 3-4 times as expensive as heating oils.

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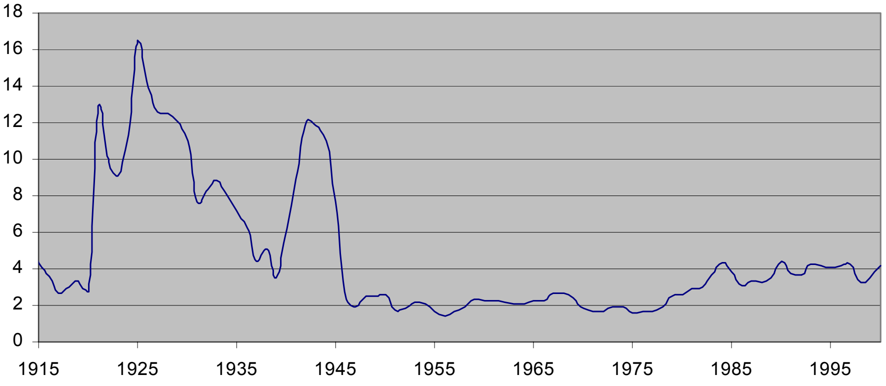
[41] For instance SOU 1956:58, p 28:"Oljan har räknat på bränslevärdet varit billigare än stenkol och koks"

[42] For the construction of coal and oil consumption according to kinds I have excerpted the import and export statistics and also the industrial statistics (to get hold of information of the refined products from Swedish refinement).

Figure 5.9 Relative price of oil compared to coal 1915-2000



Sources: For coal until 1964 see figure 5.8. For coal prices between 1964 and 1980 I use Ljungberg's series over wholesale prices for coal until 1980 (unpublished material) and level-adjust them. For 1980-1984 I linked the series to unit prices in the import statistics. Coke: 1964-1984 the retail prices were linked to unit prices of the import statistics.[43] For the period 1984-2000 it was necessary to take the higher taxes on coal into account, which made unit prices in the import statistics unsuitable.[44] Instead I used the average price of energy coal for industry and power plants according to SPK (The State Price and Competition Agency). **Oil**: Price series have been established for three categories of oil: kerosene, petrol and heating oil. The heating oil price has been constructed as an un-weighted average of diesel oil and eo3/4, which is reasonable from the consumption pattern.[45] The kerosene series is based on

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[43] One problem that had to be addressed, was the probable diminishing relative margin for distribution (i. e. the difference between wholesale prices and retail prices decreased over time) that should have come with trucks after WW2 and the relative increase in the number of large consumers at the expense of small consumers. In the period 1890-1918 retail prices were on average 28% above wholesale prices, but in the 1980s the difference was only 12% on average between import prices and retail prices, when the tax is deducted. Naturally the difference between wholesale prices and retail prices would be even smaller. I made the assumption that the distribution margin decreased linearly from 28% in 1950 down to 8% in 1980. For coke I also decreased the discrepancy between retail prices and import prices that was 35% on average in the period 1920-1964, so that the difference was 12% in 1984. Despite these measures of diminishing the distribution premium1984-2000 the average coal price I come up with is 27% higher than the average price for industry and power plants according to SPK Energiaktuellt in 1984. I do not know why this is so. Either the entire series prior to 1984 could thus be adjusted downwards or the series continued by using the figures after 1984 as an index. No way is theoretically superior. I chose the latter method, because then the prices for most of the period will seem right according to statistics.

[44] According to *Energifakta*, information från AB Svensk Energiförsörjning, there was a steep increase of taxes on coal from 1984, from insignificant values.

[45] It was not possible to make a difference between eo1 and diesel oil when excerpting the energy quantities in the trade and industrial statistics, so which price should be used for the lighter oils: diesel or eo1 price (where diesel is somewhat more expensive) is an arbitrary choice. The kerosene price series was only possible to construct until 1969, but from the 1970s and onwards kerosene only made up a couple of percent of oil consumption, so it can be neglected in an oil price series.

Ljungberg, series P8620 for 1885-1920.[46] 1920-1969 I use a wholesale price index (series P8621).[47] The petrol series is based on Ljungberg's P8613 for the period 1922-1969.[48] This series has been linked backwards until 1904 to series P8612.[49] 1969-1986: Esso: Oljeåret i siffror. 1986-2000 SCB: average petrol prices. Diesel oil: Ljungberg's P8634 until 1980[50], 1980-1985 SPK: Oljemarknaden, 1985-1992 SPK: Energiaktuellt, 1993-2000 SCB: Bränslepriser. Heavy heating oils: Ljungberg's P8641 until 1980.[51], 1980-1984 SPK Oljemarknaden.[52] 1985-1990: SPK Energiaktuellt[53] 1991-1993 there was no price information for heavy oils, so I used heating oil 1 for industry as an index, 1993-1998: SCB Bränslepriser[54] and for 1999-2000 again I had to use heating oil 1 as an index because of lacking data.

Energy and environmental taxes are complex matters, which I had to simplify in order to be able to deal with them. There is a large difference between taxes for ordinary consumers and industry. The industry pays lower taxes. I have used industrial taxes for coal, since almost all coal was used by industry after 1984 when taxes started to increase from very low levels. For oil I have used taxes for other consumers than industry for petrol and diesel oil/light heating oil, but used the tax for industry for heavy heating oils. This fairly well reflects the actual consumption pattern.

At the aggregate level of figure 5.9 it cannot be discerned whether there was any quality premium paid for room heating. This can be better seen in figure 5.10, which compares retail prices of heating oils and coal and coke in the decades prior to and after the War.

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[46] These are retail prices (for a large consumer).

[47] The series are linked in the only overlapping year 1920, so that P8620 sets the level.

[48] That is OK's price at pump

[49] These are wholesale prices, that have been level adjusted upwards according to the average price differential between retail and wholesale prices 1922-1930.

[50] P8634 is wholesale prices for diesel oil, but his P8640, which is the retail price for heating oil 1 is much lower, so in my aggregate of diesel and eo1 P8634 would be most reasonable to use.

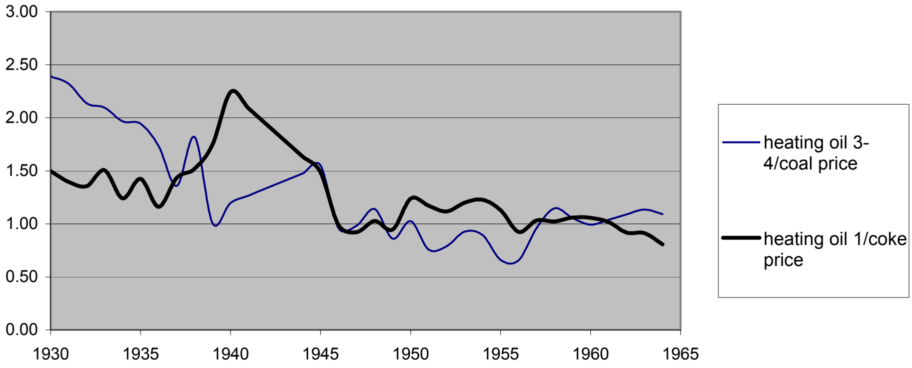
[51] OK's price list, delivery in truck. Heating oil 3 is used until 1951 heating oil 4 is used from 1952.

[52] Eo4

[53] But tried to adjust the levels so it would reflect industrial costs instead of costs for other users. I assumed the same absolute tax differential as for heating oil 1 between industry and other users

[54] I used eo WRD (which is heating oil 3 and 4)

Figure 5.10 Price of heating oil in relation to coal and coke 1930-1964



Sources: See figures 5.8 and 5.9. The only deviation from the sources of these figures is that Ljungberg's series P8640 is used here for heating oil 1. 1941-1944 values are missing and the series has been created by linear interpolation.

Heavy heating oil was cheaper than coal for several years during the period 1945-1965, which means that there was a price incentive to replace coal with oil.[55] In a comparison of the higher qualities of the respective kinds, i. e. heating oil 1 compared to coke, coke was actually cheaper than oil in most years. In order to switch from coal or coke to the heavy heating oils no quality premium had to be paid, but some premium had to be paid to exchange coke and (even more so coal) for the lighter heating oil. In advertisements from oil companies in the 1950s the quality advantages in oil heating compared to coal and coke heating was greatly emphasized, but they also claimed that substitution was justified from a purely fuel economic perspective.[56] Figure 5.10 shows some support even for the latter argument.

Ljungberg found stronger support for a quality premium paid for heating oil after the War than I find here.[57] The main reason for the discrepancy between my results and Ljungberg's is that he uses retail prices for oil, but wholesale prices for coal, while I have tried to come as close to retail prices as possible for both categories.

In conclusion, the reason why oil took over the role of coal as a leader in the energy carrier market was not a matter of pure price competition, because consumers had to pay substantially more for oil. The extra amount was,

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[55] Heating oil 1 is mostly used in smaller dwellings, while heating oils 3 and 4 demand pre-heating and a larger combustion plant and are hence used more in larger buildings.

[56] See for instance Svenska Shell's publication: *Väderleksrelaterad värme*, Stockholm ,1953.

[57] Ljungberg, J.(1984), op. cite, p 39-41.

however, paid for oil specific usages, where price elasticity of demand is rather low. The willingness to pay more for oil was related to higher incomes, but did not express itself in a willingness to pay a quality premium for heating processes in industry or for room heating, but rather in increased demand for transportation.[58] This demand in turn was connected to the new habitat structure, with one-family dwellings and separation of working and dwelling areas that came with higher incomes. There is no need to speak of a shifting cost emphasis from purchasing price to handling costs following rising incomes, when explaining the oil for coal substitution, since heating oil became competitive to coal and coke. Still the lower handling costs should have given an extra impetus to the increase in oil consumption, when the price of oil had become low enough compared to coal.

If external costs, for instance a CO_2 tax, had already been imposed on oil and coal after the War, the outcome probably would have been an even swifter expansion of oil, because it emits relatively less CO_2, so its price relative to coal would have been lower.

In conclusion, the effects on oil consumption of the relative price fall of oil compared to coal were reinforced by lower handling costs and by income increases, which stimulated the automobile expansion.

Electricity expansion

Electricity has gradually expanded on the energy market. It has the highest possible quality factor and can be efficiently converted to any kind of energy. The flip of a switch converts it into light, heat, motion, or chemical potential. The energy flow is easily adjustable, facilitating precision, speed and process control. It does not produce any noise and gives no pollution at the point of consumption. It is an industrial product, a secondary energy carrier, produced from primary energy. Technical energy efficiency in electricity production and long-term transmission has improved considerably since its invention, making electricity cheaper relative to primary energy. Consequently consumers, who are less prone to pay a high quality premium for electricity, have gradually entered the market and electricity has expanded at the expense of other energy carriers.

Electricity is an energy carrier with paradoxical properties in its combination of flexibility and rigidity. At the point of consumption its flexibility is extremely high. But at the same time electricity is rigid because it is a “fresh product”, which cannot be stored and used on a later occasion. Production and consumption must be balanced, which may be best achieved in a large system,

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[58] The oil companies set the prices of their different oil qualities according to willingness to pay. They could offer heavy oils to prices that were competitive to coal by “subsidizing” it and taking out a higher price for petrol that was consumed in oil specific usages.

where several producers and many consumers are combined. When such large technical systems have developed, this rigidity has in practice been mitigated.[59] But electricity's other rigid property, the grid bound delivery, poses more severe restrictions on its expansion. Road transportation, which has been the fastest growing energy consumption category since the Second World War, has so far proven impossible to electrify.

Electricity expanded at first for electric specific appliances, but from the mid 1960s it was also used for room heating. Until 1980 many new single-family houses were equipped with direct electric heating thus minimizing capital equipment. After 1980 the introduction of government subsidies for construction led to more investments in water-borne electric heat, which meant that an electric stove or a combined stove replaced the oil stoves. The amount of electricity used for room heating rapidly increased until the mid 1980s when it peaked at 100 PJ or 20% of the total electricity consumption at the time. Since then, the absolute quantity of electric room heating has stabilized. [60] The expansion period for electric room heating correlates well with a period of decline in the price of electricity relative to heating oil, as demonstrated in figure 5.11. Electric heating took off in the mid 1960s, after some years of substantial price decrease for electricity compared to heating oil. Electricity, however, was still 6 times more expensive per energy unit. Technical energy efficiency is higher for electricity than for heating oils, which partly makes up for electricity's higher price per energy unit. The costs for equipment are also lower, especially for direct electric heat. Besides, Vattenfall promoted electricity for room heating by lowering the price for large consumers in their tariff system. The proportion between the fixed costs for electricity networks and the power costs changed, so that the fixed costs took a larger share of the production and distribution costs. This meant that consumers of electrical heat paid a price slightly lower than the price indicated in figure 5.11, which is average household electricity price. [61]

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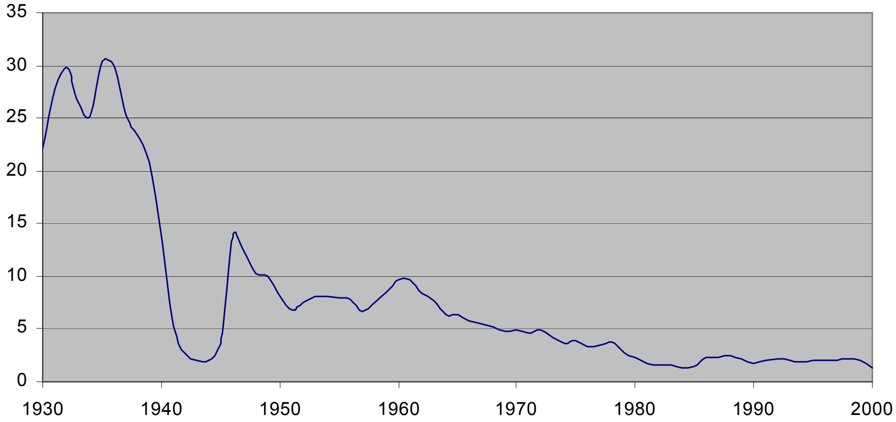
[59] Schön, L. op. cite, (1990), Schön, L. (2000) *En modern svensk ekonomisk historia. Tillväxt och omvandling under två sekel*. SNS Förlag, Stockholm, pp241-246.

[60] Sjögren, A.(1995) *Elvärmen i Sverige. En tillbakablick på utvecklingen och läget 1995*, p 2-3, Elvärmegruppen, Stockholm.

[61] See Lundgren, L (1978) *Energipolitiken i Sverige 1890-1975*, Sekretariatet för framtidsstudier, Stockholm, p 47-48.

Figure 5.11 Price of electricity in relation to price of heating oils 1930-2000



Sources: heating oil see figures 5.9 and 5.10. Electricity: the series is based on average prices for retail electricity delivered by Sydkraft, for 1924 – 1980,[62] 1980-1990: Vattenfall's series for household electricity, 1990-2000: KPI (Consumer Price Index) for electricity.[63]

The price of electricity compared to oil was still much higher and the substantially lower costs for equipment could hardly by themselves have led to investments in electric heating at the time. The decisive factor may rather have been expectations of a continued relative price fall in addition to savings of time.[64] From 1980, the improvement in relative price came to a halt and so did the expansion of electric heating. It appears necessary to involve costs for handling, and not least the time costs, in the analysis of why electricity eventually took market shares even in low temperature heating. In the mid 1960s Swedes had reached income levels that made the gradual shift, in cost emphasis from purchasing price of the energy to time costs in handling the energy, pronounced enough to manifest itself in the introduction of electric room heating.

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[62] The series has been linked backwards to Ljungberg's series P9111: Electricity from Stockholm's power station until 1892.

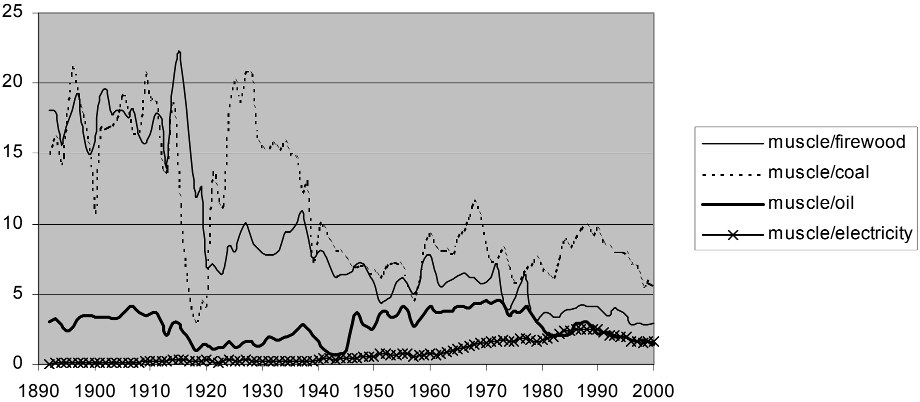
[63] The series for Sydkraft and Vattenfall have been kindly provided by Anders Sjögren, Vattenfall, and KPI for electricity has been kindly provided by Siw Grimsvik, SCB.

[64] Lindskoug, N.-E.(1967) *Elvärmefrågor*, Stockholm, advocates electric heating. Comparisons are provided for total costs for various kinds of heating. Only in special kinds of houses, with additional insulation, does electric heating prove to be cost effective, when capital costs, fuel costs and service costs are accounted for. Lindskoug emphasizes the falling raw power price development as another argument in favor of electric heating.

Declining shares of muscle energy.

Animate energy has decreased its share of total energy consumption substantially over the last two centuries. To some extent this has been related to high costs for powering animate machines. A rough comparison of the price of muscle energy in relation to other energy carriers is provided in figure 5.12.

Figure 5.12 Muscle energy price relative to prices of other energy carriers 1892-2000



Sources. See figures 5.8, 5.9 and 5.11. Muscle energy: The price series is based on prices of barley, which is part of the diet for both animals and people, because the energy content of barley is well known, since it is the basis for the fodder unit. One kg of barley contains 11.8 MJ useful energy. The series is based on Ljungberg P0136, 1912-1969 average price in the country according to SOS *Jordbruk och boskapsskötsel*, and linked backwards to Jörberg's barley series 1800-1911 (linking years 1912-1914). For 1969-2000 the series has been linked to KPI (Consumer price index) for foodstuff.

Muscle energy is an expensive source of energy compared to all inanimate energy carriers. Only electricity was more expensive than muscle energy until the 1960s, after which the relationship changed. The relative decrease of muscle energy has certainly been affected by the fact that muscle energy is relatively expensive.

Still, the most important reason for the relative decline in muscle energy since the 1890s has not been the relative price of muscle energy compared to other energy, but rather the technological changes, which opened up new possibilities to use non-human energy for motion, through the internal combustion engine and the electric motor, and led to higher income. The expansion of non-human energy logically implies the relative decline of animate energy. In addition, the increases in income brought about demand for inanimate machines that are more powerful than animate machines.

Increasing market shares for wood and coal after the late 1970s

In the 1970s, rising oil prices and plans to gradually replace nuclear power caused the government to initiate attempts to reduce the country's dependency on oil. Examples of governmental initiatives were subsidies, funding of research and new laws designed to increase the use of solid fuels such as coal and wood.[65] At the same time the tax on oil was increased.[66] Consequently, both coal and wood fuels increased their market shares during the first half of the 1980s, when oil prices were high. After that, their relative expansion came to a halt because of falling world market prices of oil.

The environmental aspects influenced the relative prices of energy carriers after 1991, when sulfur and carbon dioxide taxes were introduced.[67] The tax on carbon dioxide had the largest effect on customers who could not avoid it, like households and heating plants. Industry, which was able to move production abroad if taxes became too high, received concessions.

In the 1980s both bio-energy (bio fuels, peat and spent pulping liquor) and coal increased their shares. In the 1990s only bio energy increased its share continuously, while coal and oil decreased their shares, as an effect of the environmental taxes. Bio energy increased its share from 10% to 23% between 1980 and 2000. Bio fuel (bio energy excluding peat and spent pulping liquor) increased its share the most and the potential for additional increases in production remains. This will require higher environmental taxes for industry including power plants, which is not politically feasible without higher environmental taxes in other developed countries. Swedish energy taxes have been linked to the EU taxes on energy, since its membership in 1995 and the EU

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[65] For instance "oljeersättningsfonden" was established to provide funding for attempts to replace oil. A multitude of government-funded research plans were carried out. Laws were passed that, for instance, necessitated the installment of technique for possible combustion of solid fuels in new large heating plants.

[66] SOU 2000:73, Supplement 7 *Beskattning av bränslen och el i Sverige- en historisk översikt.*, p 10: "The general energy tax was introduced in 1957 and encompassed oil and coal. Until the first oil crisis in the beginning of the 1970s the taxes were low and stable. (---) After the oil-crises the point taxes, on especially oil, were substantially increased."

[67] Environmental taxes had long been advocated by economists as the most efficient means for reducing environmental costs. See for instance Dahmén, E.(1968) *Sätt pris på miljön*, Stockholm and Bergman, L. (ed)(1989) *Värdera miljön*, Stockholm. An important public investigation was: SOU 1991:37: *Räkna med miljön.*The carbon tax initially was 0.25 SEK/kg CO_2 and in 1998 it was 0.37 SEK/kg CO_2. On the introduction of the carbon-dioxide tax the general energy tax was reduced by 50% and energy intensive industry received tax reductions.

is less environmentally progressive than Sweden when it comes to energy taxes.[68]

Another, but less important, reason for the increasing share of bio fuels, besides the internalizing of environmental costs for fossil fuels, is that they have been refined to a larger extent than before, which has reduced the time costs involved when dealing with them. Dried chips and pellets are some of the forms that modern bio-fuels take. These bio fuels contain less water than normal fuel-wood, which improves the weight and volume grade, and concomitantly their competitiveness. Their share of the bio-fuel market is steadily increasing.[69]

In conclusion, the last transition with an increasing share of bio energy cannot be explained without taking the impact of internalization of environmental costs into account. Environmental taxes have made bio fuels competitive. This internalization of environmental costs is to some extent dependent on the level of income in Sweden, but other factors also play a role for the political process, which has resulted in this internalization, but this is not the place to investigate these relations. The success of bio-fuels has also depended on the refinement of bio fuel, which has lowered the time costs for consumers and transferred them to capital-intensive factories. Households, for instance, find it more reasonable to use pellets than firewood per se, because it takes less time.

Conclusions

This chapter aimed at analyzing the impact of changes in energy carrier composition on energy intensity and on CO_2 intensity. Another aim was to categorize the pattern of energy carrier transitions and try to understand why these transitions have occurred. My main conclusions are the following:

1) The energy intensity is not correlated with aggregate energy quality. This means that the idea that lower energy intensity has largely been accomplished by higher quality of the energy carriers is refuted. Technical

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[68] The EU has a set of minimum energy and carbon-dioxide taxes that the member countries are free to surpass, but must not go under. The levels of the minimum taxes in the EU are not especially low, but they only encompass mineral oil and not coal, because coal is produced in several EU countries. Several EU commissions tried to work out more encompassing suggestions during the 1990s, but did not receive enough support from the member countries. One reason is that most EU countries find it necessary to first convince the other OECD countries, especially the US and Japan to join the stricter energy tax policies. See for instance Ds 2000:73 *Utvärdering av skatteväxlingskommitténs energiskattemodell*, p 62-68. Holm, S.(1999) *PM alternativa styrmedel*, p 15-16, Statens energimyndighet.

[69] Ds 2000:73, table 2.3 at page 32. In 1991 the refined wood fuels made up 10% of the marketed bio fuels and in 1998 they made up 18%.

and structural changes, which were analyzed in the previous chapter, are instead the main determinants of energy intensity.

2) Energy quality may have had an impact on growth rates in the economy. The extra benefits not paid for by consumers, the consumers' surplus, was exceptionally high during both periods of rapid economic growth: the interwar period and the three decades after the Second World War. The total energy quality, including both benefits paid for and not paid for, was outstanding during the most rapid growth phase after the Second World War. Whether lower energy quality had an adverse impact on growth from the 1970s is an open question. The case may also be that the new growth directions were less dependent on large amounts of high quality energy.

3) There is a very strong relationship between energy carrier composition and CO_2 intensity, which means that changes in energy carrier composition explain the bulk of changes in CO_2 intensity. The part, not explained by changes in energy carrier composition is explained by energy intensity.

4) Energy carrier transitions were gradual up to 1950 for coal and electricity. After the Second World War much more rapid transitions took place. First oil replaced coal. From the 1970s electricity expanded rapidly at the expense of oil. The rapid expansion of electricity was related to the nuclear program, and politically enforced. After 1980 there was a relative increase of coal and even more of bio energy, which was also politically directed, through energy taxes and environmental taxes.

5) A simple model for understanding the energy carrier transitions has been put forward. This model stresses the three cost aspects involved in energy use: the purchasing price, the handling costs and the environmental costs. It is argued that there is a shift in cost emphasis as income rises. At relatively low incomes the purchasing price will be crucial for the choice of energy carrier, while at higher incomes the cost of handling increases. At still higher income levels people may be willing to internalize environmental costs.

6) The model for energy carrier transitions was partly investigated through relative price analyses, which compared the purchasing price of the relevant energy carriers. The analyses suggested that the substitution of coal for firewood was accomplished because the purchasing price of coal became competitive, which was in accordance with expectations, since

income was low, and time costs were accordingly low. The substitution of oil for coal after the Second World War, took place both because people with higher income levels allocated more of their resources to road and air transportation and because oil became competitive to coal on the heating market. Lower handling costs of oil compared to coal reinforced the transition, but did not play a decisive role. It does not seem possible to explain the entrance of electricity in the heating market in the 1960s without including handling costs. The latest transition with an increasing share for bio energy from the 1980s cannot be explained unless environmental costs, internalized through taxes, are included in the analysis.

7) The expansion of new energy carriers has always been preceded by their relative price fall, making them more price-competitive. Handling costs have always played some role for the expansion of new energy carriers, but this role has increased with higher income and consequently higher time costs. External costs did not play an important role until they were internalized through political decisions on taxes and affected the relative purchasing price.

These analyses show the importance of energy carrier composition for CO_2 intensity. There is, however, another main determinant of CO_2 emissions: forest development. In the next chapter changes in standing timber volumes will be estimated and translated into sink-source functions for CO_2. The net emissions from forests will be added to emissions from fossil fuels to determine the total CO_2 intensity of the Swedish economy for the period of 1800-2000.

Chapter 6

Swedish forests as source and sink for CO_2

CO_2 emissions are not only caused by the combustion of fossil fuels but also by changed land use. Land is covered by biomass and when the amount of biomass increases or decreases it affects the concentration of CO_2 in the atmosphere. When the biomass on earth increases, some of the atmospheric CO_2 is sequestered and the atmospheric concentration consequently decreases, and when the biomass decreases the atmospheric level of CO_2 increases. Because of their large biomass to land ratio, forests have an especially high potential either to emit CO_2, i. e. to work as a source for atmospheric CO_2, or to sequester CO_2, i.e. to work as a sink for it. Forest management thus constitutes one important way in which man has historically influenced atmospheric CO_2 concentration. When forestland is converted into other usage, like agricultural fields or urban areas 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.

This chapter contains an estimate of the development of the Swedish standing timber volumes in the period 1800-2000. Special attention is given to the different forest developments in southern and northern Sweden. The variations in the quantities of timber are converted to amounts of CO_2 emitted into the atmosphere or sequestered from it. These results are then related to the emissions from fossil fuel combustion. It is of special interest to outline the magnitude of forest emissions in relation to fossil fuel emissions during various periods.

The chapter is divided into three parts. The first part relates the development of the standing timber volumes to the period in which they are measured. It also creates models for the development of earlier times. The second part explores the regional differences in forest management between the North (Norrland) and the South (Svealand and Götaland), which influence the timing of the trend breaks in standing timber volumes. Relative price analyses are used for regional comparisons, when direct data is unavailable. The third part of the chapter estimates the CO_2 emissions from forestry and relates these emissions to the emissions from fossil fuels.

Development of the standing timber volumes

The first Swedish National Forest Inventory was carried out in the 1920s and there are measurements of standing timber volumes from that time on. In spite of increased felling, timber volumes have increased since the 1920s, because the forests have become more productive due to improved silviculture and airborne nitrogen. In the late 1980s, forest companies boasted that there had never been so much standing timber in Sweden. This claim was however challenged by a study, which demonstrated that timber volumes had actually been much higher in 1870 than in 1920 in four districts in the northern part of Sweden (Norrland), which indicated that forest development may resemble a U-curve over time, rather than a linearly increasing curve.[1] There are reasons to believe that the pattern may be U-shaped for southern Sweden (Götaland and Svealand) as well, but with an earlier bottom-point. A map study of Halland shows that forests in this county decreased from the 17th century until the 1850s, when they started to recover.[2] Halland is, however, a special southern county, where the severe lack of forests initiated early silvicultural efforts, so the average turning point for southern Sweden is likely to be later than in 1850.

To quantify the development of standing timber volumes before 1920 is a difficult task and all attempts, including this study, should be treated with sound caution. Many Swedish forest experts were concerned with forest development in the 19th century, because of a grave fear of diminishing stocks, and quite a few attempts were made to estimate the forest development. All these attempts estimated changes in timber volumes as the forest growth minus cuttings and natural losses and they all had their weakest point in the data of forest growth, which actually was no better than sheer guesses. Forest growth is a complicated issue. It depends on the size of the standing timber volume as such, and also on the age structure of the forests, the composition of the tree species and on the climate. But it also depends on the cutting methods and silviculture. In addition, if cattle graze in the forests, this hinders rejuvenation and thereby growth. The habit of slash and burn cultivation, both permanent and occasional also has a negative impact on growth because it results in a smaller stock. The influence of cutting on growth is complex. In one way cutting has a positive impact on growth, because mature old trees do not grow much anymore. Cutting old trees and replacing them with younger ones thus promotes growth with a time lag. But if rejuvenation is not secured, or is actively hindered, cutting can, of course, decrease the standing timber and result in slower growth rates. Constant or

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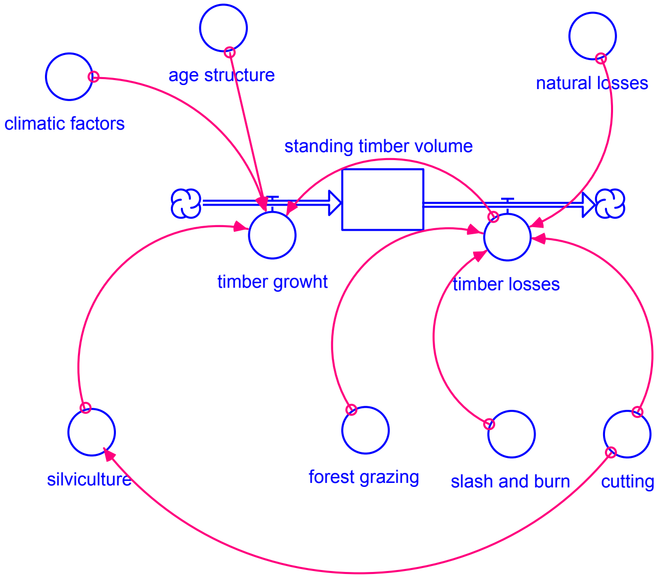
[1] Linder, P. & Östlund, L.(1992) *Förändringar i Sveriges boreala skogar 1870-1991*, SLU, Umeå..

[2] Malmström, C. (1939) *Hallands skogar under de senaste 300 åren*, Meddelande från Statens skogsförsöksanstalt, Stockholm.

increased cutting may in those cases result in a swift decrease in standing timber volumes since the resource base is eroded. A dynamic model of the standing timber volume is presented in figure 6.1. The feed back loops, connecting losses to growth, give dynamic properties to the system.

Figure 6.1 A dynamic model of the standing timber volume



The many variables involved and the dynamic feed-back-loops render it difficult to estimate standing timber volumes. Obviously it is not sufficient to know the felled amounts. The experience between 1920 and 2000, when growth rates increased continually despite, or thanks to, concomitant increases in the cutting highlights the problem.

Mainly because of the difficulties in assessing growth rates, I do not estimate changes in standing timber volumes as a result of forest growth minus cuttings and natural losses. The method I use instead is to model changes in standing timber volumes directly on the basis of a) the purported U-shaped pattern of the timber volumes and b) the figures in the study by Linder and Östlund and c) the population growth.

The Linder and Östlund study

The study by Linder & Östlund, which is based partly on the inquiry of 1870 by the Forest Committee, and partly on four local studies, gives rather good data for Norrland for the period 1870-1926. The local studies have merely served as sources for comparison for the regional estimates presented in the inquiry by the Forest Committee. Because trends in the local material coincide with the regional estimates, the latter have been deemed plausible.

The total standing timber volume in Norrland was 1456 million m^3 in 1870. According to the National Forest Inventories, the stock had decreased by 35 % in 1926 and amounted to 948 million m^3. Whether rock bottom was reached in the 1920s or earlier cannot be known with certainty, since there are no corresponding values at the regional level. Still, the four local investigations by Linder & Östlund indicate a negative trend during the entire period 1870-1926, with one exception (Orsa besparingsskog), which had a negative trend until 1900 and a positive one after that.[3] I here assume that the standing timber volumes of Norrland decreased linearly in the period 1870-1926.

My estimates

This study also assumes a slight negative change in standing timber volume in Norrland between 1800 and 1870. In support of this assumption the following facts are given:

a) Contemporary data indicates a decreased timber volume. For example, the report by the forest committee in 1856 stated that the forest resource had decreased in all counties, except Gävleborg, in the decades prior to 1850.[4]

b) The large population increase (an increase of 118% in Norrland between 1800 and 1870), which entailed the ”colonization” of coastal land and increased the number of wood-fed cattle.[5]

c) The local examples in the study by Linder & Östlund showed that the standing timber volume in forests that were totally unexploited in 1870 had decreased by as much as 25-40% in 1990, while the average for Norrland decreased by only 15%. This implies that an exploitation of virgin, natural forests decreased the standing timber volume, and that a considerable part of the forests in Norrland had already been exploited in 1870. Some of this exploitation must have occurred between 1800 and 1870 and caused a decrease in the standing timber volume.

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[3] Linder,P. & Östlund, L.(1992), op.cite, pp.13-17.

[4] Arpi, G (1959) op.cite, p 318.

[5] According to the censuses there were 239.132 inhabitants in Norrland in 1800 and 520.338 inhabitants in 1870.

My estimate of the forest development for the period 1800-1870 is an extrapolation of the per capita development of timber volumes in Norrland for the period 1870-1920. If the entire household proportion (around 50%) of the decrease in the timber stock in the period 1870-1926 is attributed to the population increase, this means a decrease of 450 m^3 per additional inhabitant. With the same yearly assumption for the period 1800-1870, i. e (-) 450*70/56 m^3/additional inhabitant, apportioned to the population increase each decade a so-called maximum series is constructed. In order to demonstrate the uncertainties in the estimates especially before 1870 and to provide a sensitivity analysis, a so-called minimum-series (-) 225*70/56 m^3/ additional inhabitant has been calculated. The minimum series is based on the assumption that the negative influence of the population increase was only half as large in the period 1800-1870 as between 1870 and 1920.

My estimates of forest development in the South (Götaland and Svealand) have taken into account the fact that a population increase in the South causes a smaller per capita impact on the forests than the same population increase in the North. The colder climate and the more readily available firewood in the North means that approximately twice as much firewood is used per capita in the North as in the South. It thus seems reasonable to make a maximum-assumption of 225 million m^3/new inhabitant, and a minimum-assumption of 112.5, between 1800 and 1870. An assumption of an average trend-break for southern Sweden in 1900 is also made.

The results of the modelling are presented in figure 6.2, together with the figures from the National Forest Inventories for 1920-2000.

The modelled results for the period 1800-1920 are fairly consistent with the results that Lindmark obtained using another method.[6] Lindmark also started from the Linder & Östlund estimate for Norrland for the period 1870-1926 and extrapolated the development backward based on estimated cutting for the sawmill industry and two factors influencing growth; the climatic variations and ditching during the latter part of the 19th century. The ditching variable was used as a proxy for the increased silvicultural efforts. The country was treated as a homogenous entity and no difference was made between forest development in the South and the North. With this method, Lindmark reached the conclusion that in 1800 the standing timber volume was approximately 2600 million cubic metres, while the result here is in the range of 2550-2900 million cubic metres. Lindmark's results are thus consistent with the results based on the minimum assumptions in this study.

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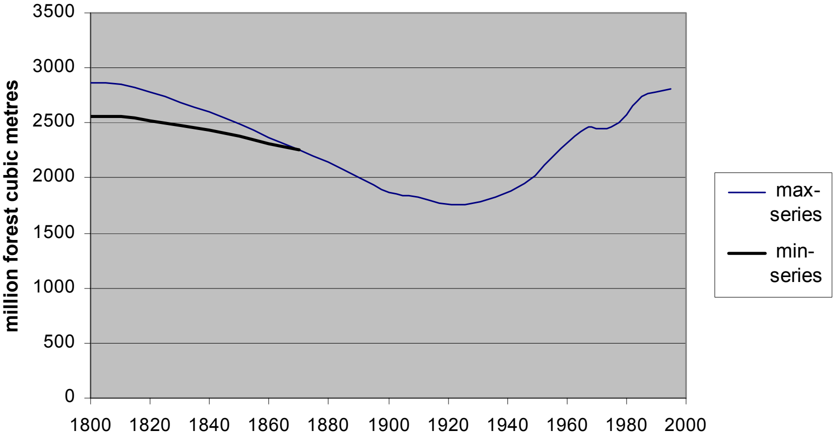
[6] Lindmark, M.(1998)op cite, p 102-113.

Figure 6.2 Development of Swedish standing timber volumes 1800-2000, in million forest cubic metres.



Sources: National Forest Inventories 1926-1995, Linder & Östlund for Norrland 1870-1926, My estimates for Norrland 1800-1870, and for South Sweden 1870-1926.

Regional comparisons

There are indications that forest volumes began to recover earlier in the South than in the North. My estimate of the standing timber volume, which is the sum of developments in the South and in the North, is partly based on that assumption. The aim of the following part of the chapter is to explore the possible rationale for such different developments in the South and in the North.

Although the dynamic forest model in figure 6.1 may not be used as a basis for estimates of absolute timber volumes, because of the lack of necessary data, it may still be useful for regional comparisons and relative developments, because for such analyses only relative answers are required. Four different aspects are compared between the North and the South. These are a) cutting b) silviculture c) cattle grazing and d) slash and burn cultivation. The focus of the comparisons is on whether there are indications of different developments in the North and the South supporting the idea of an earlier trend break in the South. For cutting and silviculture there are some regional statistics, which may be compared, but for cattle grazing in forests and slash- and- burn cultivation, relative prices have been used as indicators of different developments.

Cutting

Arpi has estimated the regional cutting for the period 1850-1950, and a first result is that cutting in the South exceeded cutting in the North throughout the period.[7] Another result is that there was a relatively larger increase in cutting in the North. How should this be assessed when it comes to regional forest development? The productivity of the southern forests is about twice as high as that of the northern forests, because of the warmer climate, which means that a higher level of cutting in the South does not necessarily imply a larger decrease in standing timber volumes. It is also not possible to draw any conclusions on the development of the timber volumes on the basis of the faster increase in the cutting in the North than in the South. But because other indications emphasize unsustainable cutting, it is possible to conclude that the higher increase in cuttings in the North than in the South tended to prolong the period before a trend break occurred in the North.

Silviculture

Silviculture, i. e. the elaborated management of forests, consists of various measures to improve rejuvenation (i. e. the re-growth speed), for instance sowing, planting, preparing the ground for self-sowing, removing vegetation that competes with the trees etc. Silviculture is thus an active positive force for the development of standing timber volumes. If the trend break occurred earlier in the South, it may seem reasonable to expect that more active measures of replanting/sowing were undertaken in the South than in the North during the 19th century.

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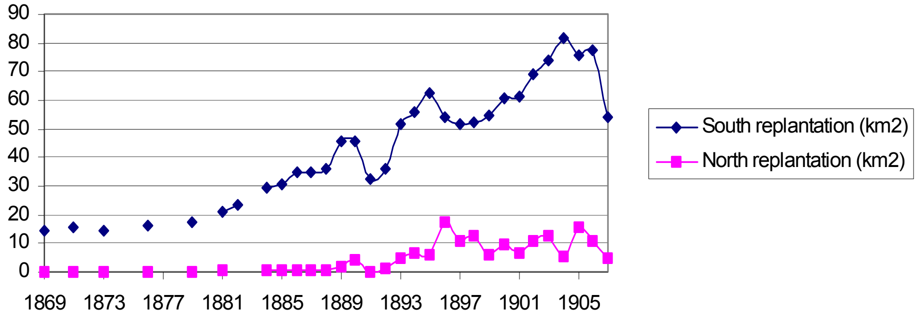
[7] Arpi,G.(1959), op.cite., p 206.

Figure 6.3 Replanted and sown areas (km^2) in the Crown forests 1869-1907, in the South and the North of Sweden.



Source: BiSOS, series Q: Forestry.

Unfortunately no complete statistics of silviculture exists for the 19th century. There are only accounts of replanting and sowing in the government forests from the 1870s, which are presented in figure 6.3. [8] More re-planting took place in the southern than in the northern government-owned forests, according to figure 6.3. Of course, the replanted areas should be related to the felled amounts, but even if felling, which was 2-4 times larger in the South than in the North, is considered, sowing and replanting were substantially higher in the South. The national government owned a decreasing share of the forests throughout the 19th century and in 1878 its share only amounted to 8 percent. [9] Silviculture on government land is hardly representative for all forests. It is likely that replanting/sowing measures were larger per hectare in the crown forests than in the privately owned forests. The government, for a long time during the 18th and 19th centuries, was more interested in "peasant colonizing" of the northern part of Sweden, so that tax revenues could be increased, than in managing its forests. Therefore large forest properties were sold cheaply to peasants.[10] In 1865, however, the government changed its policy in favour of owning and managing the forests itself.[11] Once the government started to value the forests, it seemed to

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[8] BiSOS, series Q *Forestry*. The series starts in 1865, but the first volumes do not contain any information on tree planting or sowing. The figures are available from1869.

[9] Stridsberg, E. & Mattsson, L.(1980) *Skogen genom tiderna. Dess roll för lantbruket från forntid till nutid*, Stockholm, p. 197.

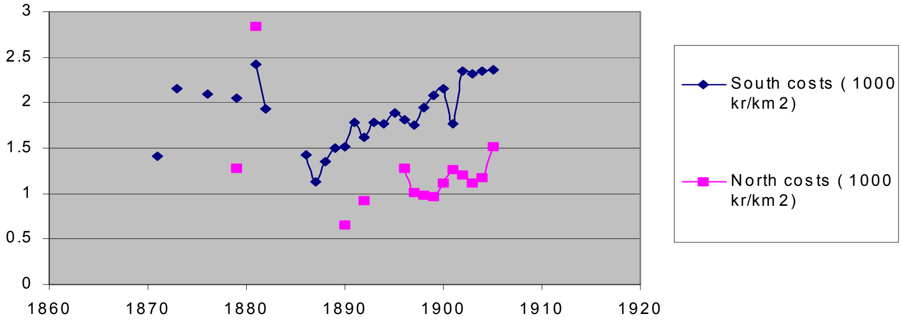
[10] In 1823 there was a parliament decision to allow the splitting of common forest land and selling off crown forests to private owners. The reasons for this decision have been discussed, and both ideological and economic reasons have been put forward, see Eliasson, P.(2002) *Skog, makt och människor, en miljöhistoria om svensk skog 1800-1875*, dissertation, Lund, p 51-52.

[11] Stridsberg, E. & Mattsson, L.(1979) *Det industriinriktade skogsbruket sett ur ett historiskt perspektiv* , Kulturgeografiskt Seminarium, 8/79, Stockholm, p 18.

become a good administrator of its remaining ones. It seems reasonable that silviculture undertaken on crown property was more comprehensive per hectare than the efforts undertaken on the private holdings. The interesting point of comparison between the North and South is however not mainly the absolute magnitude of silviculture, but rather the relationship between silviculture in the North and in the South and for that purpose figure 6.4 could probably be regarded as rather representative for the regional differences between the North and the South. For the restricted purpose of supporting the idea of an earlier trend-break in the South, this result, based on empirical material from the crown forests, seems sufficient. When examining the question of the economic rationality of the forest sowing in the South and in the North, the matter, however, turns out to be more complicated.

One may expect that the profitability of replanting/sowing was higher in the South, and therefore was undertaken there to a larger extent. Profitability is difficult to assess, because costs are undertaken in present time, while there is no income until several decades later, when it is time to fell the trees. The costs, with compound interest, must be well recovered in the future, in order to make silviculture seem worthwhile. The climatic differences between the North and the South, resulting in half the maturing time for trees in the South, have naturally been important for forest owners' assessment of the profitability of silviculture. Either costs have to be lower in the North to outweigh the climatic disadvantage, or the expected profit in the future has to be higher. Actually both of these circumstances were present. Costs in the North per sown area-unit were substantially lower than in the South, as demonstrated in figure 6.4.

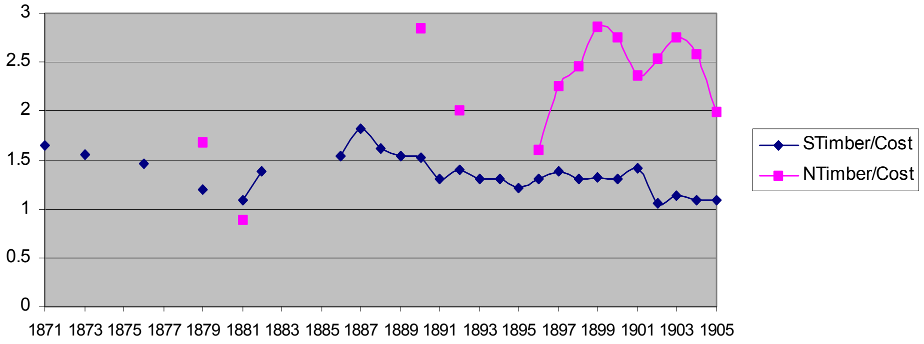
Figure 6.4 Costs of sowing in forests in the North owned by the government compared to forests owned by the government in the South, 1871-1905, 1000 SEK/km^2.



Source. BiSOS, series Q.

Regarding future income it may be argued that the relative development of timber-prices, compared to sowing costs, in the North and in the South should constitute the guiding principle, because people tend to extrapolate trends into the future. This relation is depicted in figure 6.5.

Figure 6.5 Timber price/Sowing costs in the South and in the North, 1871-1905.



Sources: BiSOS, series Q: Forestry and Jörberg, L. (1972)

The main result is that the timber price/sowing costs increased substantially in the North, while it remained rather constant in the South. This indicates a higher expected future income from sowing/replanting in the North. Still, silviculture was undertaken to a larger extent in the South and this remains to be explained.

I believe that the main reason for the different amounts of replanting in the South and the North was different methods of cutting. There are basically two methods of cutting: district cutting and selection systems. In district cutting all trees in a certain area are cut and the rejuvenation is either secured by leaving some seed trees or by planting/sowing trees. Selection systems, or uneven-aged-forestry, means that only certain trees are cut in an area and the rest of the trees are left to continue to grow (at an increased speed because of the more favorable environment when some trees have been removed) and leave seeds. Of course there is a close link between the cutting method and the need for replanting/sowing. While district cutting requires sowing/replanting, unless seed-trees are left, there is less need for such activities with selection systems. The basic silvicultural requirement, after cutting according to some selection principle, is to improve the growing possibilities for the best trees through removing undesired vegetation, i. e. clearance work.

It is not clear what kind of cutting methods have dominated Swedish forestry in different periods. Öckerman has made a periodization according to which district cutting was the main method in the period 1820-1890, selection systems dominated in the period 1890-1930, and district cutting again in the period 1930-1990.[12] After 1990 he sees traces of a shift towards more uneven-aged forestry again. His characterization is based on what was taught in higher forestry education in Stockholm in different periods, so there may be substantial deviations in practice, especially during the 19th century. Öckerman makes no difference between the North and the South. Lisberg Jensen also stresses a shift in emphasis after 1990. She categorizes this development as ecological modernization. Instead of appealing to aesthetic and moral values, forest conservationists used seemingly neutral, scientific and economic arguments, expressed as biodiversity and market shares, and this worked on the forest industry.[13]

From the accounts in BiSOS, it seems reasonable to point out different cutting methods in the North and in the South. Quite explicit is the statement in 1905: “In the selection-system-forests of the northern districts, where forest-sowing only exceptionally is used, (...) the natural rejuvenation has been promoted through ditching, clearing of creeks, but also directly through clearance of the cut areas, burning of brushwood and sorting out the deciduous trees. In the southern districts however, where the district-cutting-method is used, forest-sowing works are performed to a larger extent”.[14]

There was a financial reason for the different cutting methods: the different demand for thin dimensions of wood. With a large demand for thin dimensions it is worthwhile to district cut, but if only thick dimensions are in demand, the selection-system is chosen. A high demand for thin dimensions of wood is not only positive in the sense that it makes economic sense to clear the areas of trashwood, but will also provide stronger incentives for thinning the young stands, which is positive for growth rates.[15]

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[12] Öckerman, A.(1996):”Kalhygge eller blädning – svensk skogshistoria som miljöhistoria”, in “*Miljöhistoria på väg*”, Tema V, Rapport 22, Linköping.

[13] Lisberg Jensen, E.(2002) *Som man ropar i skogen: modernitet, makt och mångfald i kampen om Njakafjäll och i den svenska skogsbruksdebatten 1970-2000,* , dissertation, Lund, p 259-262.

[14] BiSOS, Series Q, *Forestry*, 1905, p 12.

[15] Streyffert, Th.(1938) *The Forests of Sweden*, Stockholm, p 41:”There will also be greater opportunities for thinning the young stands in Southern and Central Sweden with the greater demand for thin wood by the local population.” Carbonnier, C.(1978):”Skogarnas vård och föryngring”, in *Skogshögskolan 150 år – problem och idéer i svenskt skogsbruk 1828-1978*”, SLU, Uppsala, p 109:”Gallring förekom överhuvudtaget endast inom Bergslags- och söder därom belägna distrikt och den behandlade arealen uppgick till endast 0.2 procent av totalarealen, d.v.s. obetydligt mera än den areal som samma år (1878) skogsodlades.”, p 110: ”Cellulosaindustrins snabba frammarsch skapade även förutsättningar för gallring i vidgad omfattning genom att avsättningen för klenvirke ökade.” Holmgren. A (1933):”Det norrländska skogsbruket vid tiden för bildandet av föreningen ’Skogskultur i Norrland’”, in Norrlands skogsvårdsförbund 1883-1933, *Skogsvännen*, p 10.:”någon vård av ungskogarna kunde ej ifrågakomma, då klenare sortiment icke kunde utnyttjas av den dåtida industrien.”

In the South, where the population was much larger, the demand for thinner dimensions for charcoal burning, firewood, furniture, tools etc. was much higher than in the North. In addition, the establishment of the wood-based chemical pulp-industry towards the end of the 19th century, which was first introduced in the South, increased the demand for thinner dimensions. In Bergslagen (in the South) with the tightening competition among the mining industries, the new possibilities for employment and forest resource utilization through the pulp industry were welcomed. With the hardening competition in the iron industry, the need for charcoal decreased and in the 1880s charcoal use culminated.[16] The decline of the charcoal industry and the growth of the pulp industry still resulted in an increase in the demand for thinner dimensions of wood in the South.[17] Gradually, the North was also influenced by the pulp industry, but it was not until around the turn of the century, when the sawmill industry was experiencing difficulties, that it was diffused there on a wider basis.[18] In conclusion, both household and industrial demands for thinner dimensions were higher in the South than in the North in the 19th century, and the increased demand from the pulp industry came earlier in the South. This made it rational to district cut, sow or replant and thin the young stands to a larger extent in the South than in the North.

To a modern person, this division between demand in the North and in the South may seem artificial. Why did the higher demand in the South not lead to increased district cutting in the North? Were markets really that local? Actually, timber markets were not fully integrated in the 19th century, but became increasingly so with improved transportations. Integration was even weaker for thinner dimensions, since their value per cubic meter was smaller, and consequently could not bear as high transportation costs. Charcoal had to be produced locally because it was very fragile and could not stand long shaky transportation.[19] The development of railways at the end of the 19th century, together with large investments in floating channels, improved the situation for exporting wood from the North. But it was not until the introduction of trucks and the construction of inland roads during the inter-war period that transportation of thinner dimensions over longer distances could be performed.

The crucial question for evaluating possibilities of forest growth in the North versus the South is which cutting method is best for forest growth, but there does not seem to be any consensus among today's forest specialists. There

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[16] Arpi, G.(1959), op. cite.,p 163 and table 36, p 190.

[17] Arpi, G.(1959) op. cite, figure on p 209.

[18] Mattson, L. & Östlund, L.(1992): "Människan och skogen – en tillbakablick" in (eds) Elmberg et al: "*Vår skog – vägvalet*", Arlöv, p 31.

[19] Eliasson, P. (1995): "Ett och annat om det svenska träkolets betydelse", *Osby Hembygdsförenings årsbok.*

was no consensus in the past either. Eliasson shows that Sweden adopted ideas of district cutting and sowing from Germany in the early 19th century, which prevailed until around 1860, when a shift towards selection cutting and natural rejuvenation took place in response to some rejuvenation failures of too large areas of district cutting and the impact of peasants with multiple interests in the forests.[20] The cheap, shortsighted selection cutting and reliance on natural rejuvenation held a strong position during the wars and interwar period. Then the assessment shifted. For a long period of time, i. e. the 1940s to 1990s, it was believed that district cutting and concomitant sowing were outstanding.[21] An argument in favor of district cutting is that, when all trees are removed, it could be ensured that seeds or plants with good genetic composition will be allowed to grow afterwards. With selection systems, which only leave the thin trees, it cannot be excluded that those trees are thin because they have a bad genetic composition and not because of their young age and local circumstances. Another similar, more empirical, argument is that selection cutting during the inter-war period was bad for forest re-growth. It was performed during an economically difficult period and was mainly chosen to cut expenses. The assessments of the devastating results initiated large restoration projects in the 1950s, which meant that large areas of slow-growing open forests were cut down and replaced with sown forests.[22] Today some specialists argue that a properly managed uneven-aged forest can grow as fast as a homogeneous one, and also that a more diverse forest has advantages such as richer bio-diversity and less vulnerability to shocks, be it in the form of drastic climatic changes or parasitic attacks. It is difficult to settle the ongoing debate, because assessments must be made over periods of 100-200 years, because trees grow slowly and at different pace at different ages. My task here is, however, not to judge whether selection systems can, in optimal cases, be as growth promoting as district cutting. The task is somewhat less complicated: to evaluate selection cutting during the 19th century. I do not find any reasons to believe that it was better performed than the selection cutting during the inter-war period, which left many forests in bad shape. For example Obbarius was very certain of the

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[20] Eliasson, P. (2002), op. cite, p 367-368. Eliasson highlights the conflicts between peasants and the crown. One conflict concerned the oak tree, which was important for the royal navy, but was hated by the peasants because it had adverse effects on the grazing possibilities for cattle, since the leaves were acid and prevented grass growth. The oak tree also competed with food production, since it demanded rich soil (chapter 3). Another conflict was between maximal timber production, promoted by the crown, and a more diversified forestry, strived for by peasants, with open forests suitable for grazing and multi-species trees of uneven ages providing timber of various dimensions for various purposes.

[21] Carbonnier, C.(1978), op. cite, relates the discussion regarding district cutting versus selection cutting from the 19th century; he himself clearly takes stand for district cutting.

[22] Andersson, S.:“Dagens skogsbruk växer fram, 1950-1991”, p 39-40, and Mattson, L. & Östlund, L.(1992) op. cit, p 38

detrimental effects of selection systems in the middle of the 19th century.[23] It is not possible to make any definite assessment on the re-growth during the 19th century in the selection systems forests and the district cutting forests, but I consider it likely that the re-growth of the forests in the North was worse.[24]

In conclusion, it appears that silviculture in the North and the South was very different in the 19th century, which is mainly demonstrated in the adopted cutting methods. In the North the demand for thicker dimensions of wood prevailed and therefore cutting according to selection systems was performed, while district cutting was adopted in the South. As a consequence, sowing was performed on a far larger scale in the South. It seems likely that the district cutting and concomitant sowing in the South were superior in promoting growth during this period.[25] The importance of the short-term economic profitability of silviculture has thus been stressed. When the demand for thinner dimensions rose, this had a positive impact on forest growth, since it gave an immediate economic reward both for thinning out and district cutting. The circumstance that more district cutting and concomitant forest sowing occurred in the South should have facilitated the trend-break for its standing timber volume. It

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[23] Obbarius, C. L.(1845):”*Lärobok i skogsvetenskapen*”, part 1, Westerås. After listing detrimental effects from selection cutting he concludes (p 206): ” Detta äro ganska vigtiga olägenheter, hvarföre äfven blädningshushållningen i alla öfriga länder längesedan är afskaffad, och äfven i Sverige blir man mer och mer öfvertygad om dess ändamålsvidrighet, hvarföre det icke behöfs, att mer tala derom”

[24] See for instance Holmgren, A.(1933) op. cite, p 11:”Under 1870-talet torde den allmänna uppfattningen bland skogsmännen ha varit, att timmerblädningen var den enda för norrlandsskogarna lämpliga avverkningsmetoden, men snart kom man dock till insikt om, att denna avverkningsform ej lämnade de resultat man väntat sig. Bestånden utglesnades för att vid upprepade genomblädningar starkt söndertrasas, och återväxten infann sig endast sparsamt eller uteblev helt och hållet.”

[25] Tillander, T.(1955): ” Skogens föryngringsfråga”, in *Våra skogar under ett halvsekel*, minnesskrift av Sveriges skogsvårdsstyrelser med anledning av deras femtioårsjubileum år 1955, Uppsala, p 68 accounts for the opinion of the 1896 års skogskommitté betänkande: ”Även inom de båda nordligaste länens kustland var dimensionshuggning den normala avverkningsformen. Med skärpa framhålla överjägmästarna i båda länen, att skogens föryngrande starkt försvårades genom detta huggningssätt. Några åtgärder för att efter avverkning hjälpa fram självföryngring förekom inte heller. Tillfredsställande föryngring kunde man endast finna efter skogseldar eller i trakter närmast byarna, där avverkningarna lokalt fått karaktär av kalhuggning. (---) På bruks- och bolagsskogarna inom Värmland, Bergslagslänen och Uppland hade ordnad skogsskötsel i regel införts med trakthuggning som den normala avverkningsformen. Efter avverkningen brändes och skogsodlades hyggena, varför föryngringen i regel blev tillfredsställande. Sämre var tillståndet på de flesta bondeskogar, där dominerade alltjämt dimensionshuggning. Skogen glesställdes utan att verkliga föryngringsytor uppstodo. Endast i trakter, där man kunde kola småvirket, blev skogen rensad så att självföryngring kunde uppkomma.” *Betänkande afgifvet den 16 mars 1912 af Norrländska skogsvårdkommittén,* Stockholm 1912, part 1, p 53:”Äfven om ganska betydande mängder af gammal , skadad skog och rensningsvirke sålunda uttagits, får dock icke däraf dragas den slutsatsen, att en fullständig rensningshuggning skulle vara genomförd å de ofantliga arealer statens skogar omfatta i Norrland, hvilket motsäges redan däraf att hittills utförd avverkning av smärre virke endast afsett de bättre belägna trakterna, (---)dels med hänsyn till de mycket begränsade afsättningsmöjligheter, som varit och fortfarande äro rådande i förevarande delar av landet.”

therefore provides support for the assumption that the trend break occurred earlier in the South than in the North.

Cattle grazing in forests

For thousands of years forests had been used both for direct grazing and for fodder collections (leaves). In the middle of the 19th century leaf collections for winter fodder were still done on a large scale. This became rare in the 20th century, although it was common during drought years.[26] The diminishing practise of using the forests for fodder provision will be analysed here. The main purpose is to discuss whether the practise ceased earlier in the South than in the North, thereby helping forests to recover earlier in the South.

First it must be ascertained that forest grazing and leaf collection really did harm the forests. The opinion of many forest experts was that it did. Obbarius (1845), for instance, held forth the damages occurring in the forests through leaf collection, and so did Wahlgren (1914) and Stoltenberg (1933).[27] Hamilton also stressed the damage from grazing, especially when performed by goats.[28] An empirical investigation concerning the detrimental effects from grazing in forests was performed in Norway in the 1960s.[29] The investigation was very thorough and the main result was that the detrimental effects from grazing were confirmed. Trees are damaged more in grazed areas than in fenced areas and the rejuvenation (germination and growth of seedlings) is also harmed.

What was then the effect of forest grazing in the South compared to the North? To get an indication of the damage from forest grazing in the North and the South it would be justified to look both at absolute numbers of cattle and the number of cattle relative to the number of humans. The latter measure would hint the intensity of grazing near the villages.

At the beginning of the 19th century the sum of horses, cattle and sheep was 6.2 times larger in the South than in the North compared to 4.8 in the year 1900. Because the majority of the population, like the majority of animals, lived in the South, no clear conclusion regarding the grazing intensity in the North and the South in the outskirts could be drawn on the basis of number of animals alone. A better measure of intensity is the ratio animals/population, depicted in figure 6.6.

The animals /inhabitant ratio was higher in the North at the beginning of the period, but this difference leveled out during the century. There are two

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[26] Curman, J.(1993):”Lövfoderkultur och skottskogar”, *Kungliga skogs-och lantbruksakademins tidskrift* 132:47-78, p 48.

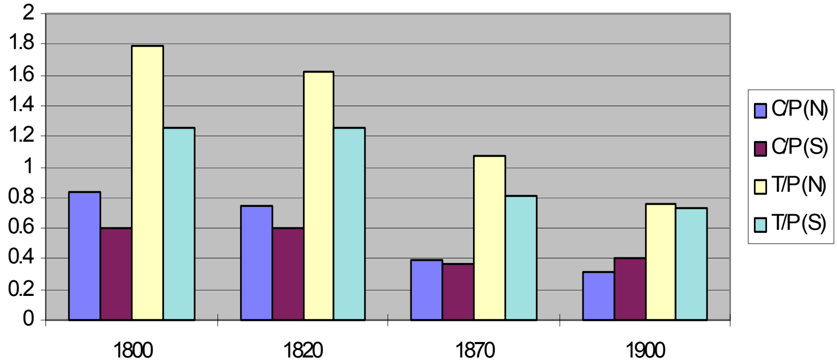
[27] Curman, J. (1993) op.cite., refers to Wahlgren, A.(1914) *Skogsskötsel*, Stockholm.

[28] Hamilton, H.(1983) *Hundra år i skogen*, Sveriges skogsvårdsförbund/SKOGEN-förlag, Borås, p 16:”Men kreaturens betning gick hårt åt skogen. Särskilt getterna såg till att inte ens granplantor fick en chans att sticka upp”

[29] Bjor, K & Graffer, H.(1963):”*Beiteundersökelser på skogsmark*”, Gjövik.

possible conclusions. First, the negative effects per animal should have been higher in the North than in the South at the beginning of the 19th century, but towards the end of the century the effects should have been approximately the same. Second, the absolute effects were still much higher in the South, since the number of cattle and other grazing animals were 5-6 times higher there.

Figure 6.6 The ratios between cattle and people and between total forest grazing animals and people in the North and in the South 1800-1900.



Sources: Historisk statistik för Sverige, part 1 and 2. C/P (N) = Cattle/People in the North, C/P (S) = Cattle/People in the South, T/P (N) = Total (i. e. cattle + sheep + horses)/People in the North, T/P (S) = Total (i. e. cattle + sheep + horses)/People in the South.

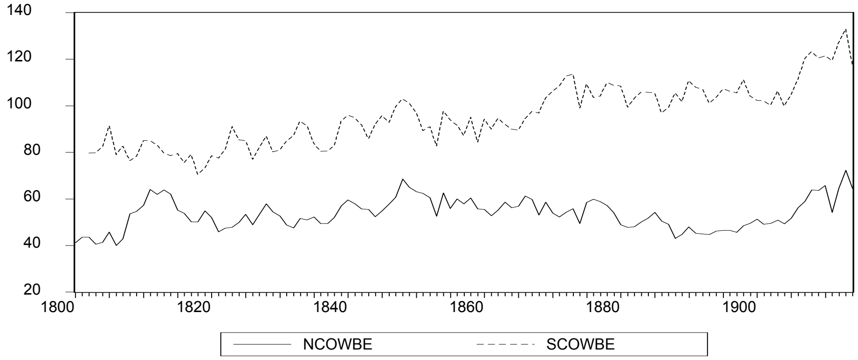
Another aspect is that the colder climate in the North prevented the animals from grazing in the forests for as long as in the South. This meant that the cattle of the South had much longer time during a year to cause forest damage, something that probably far out-weighted the less detrimental effects of less cattle/inhabitant in the South at the beginning of the 19th century.

The implication of this argument is that forest grazing did cause forest damage both in the North and in the South, but everything points to the damage being much larger in the South. This means that the abandonment of forest grazing would be much more influential for forest re-growth in the South than in the North. Abandoning forest grazing in the South and in the North would help the southern forests more in their recovery. If grazing was abandoned earlier in the South it would provide additional support to the idea of an earlier trend break there.

Are there any indications that forest grazing was abandoned earlier in the South? The price development of cattle products, such as butter and beef, in relation to the price development of the cattle themselves, indicates higher productivity of cattle in the South compared to the North. This is probably due to earlier modernisation of fodder production in the South, with less grazing and dry leaves, and instead more fodder grown in the fields. The energy content of leaves is nearly as high as that of hay. Cattle need this kind of fodder, and cannot manage only on concentrated feed (grown in the fields), but when additional concentrated fodder is provided they become bigger and produce more milk.[30]

The ratios of cow-price/beef-price in the South and in the North are shown in figure 6.7.

Figure 6.7 Ratios of cow-price/beef-price in the south and the north of Sweden, 1800-1914.



Sources: Jörberg, L. (1972): *"A history of prices in Sweden 1732-1914"*, Lund

Of course no conclusion can be drawn regarding whether the differences between the North (where the ratio does not exhibit any increasing trend) and the South (where the ratio increases over time) depend on changes in the price of cattle or changes in the price of beef. The prices for butter and beef in the North and the South are, however, shown to follow each other fairly well in figure 6.8. Therefore it seems valid to draw the conclusion that the differences in cow/cow-product prices between the South and the North were totally a matter of different quality developments of the cows. The cows in the South grew fatter and became better milk-producers, than those in the North, and were consequently more expensive. The growing size and higher productivity probably were the

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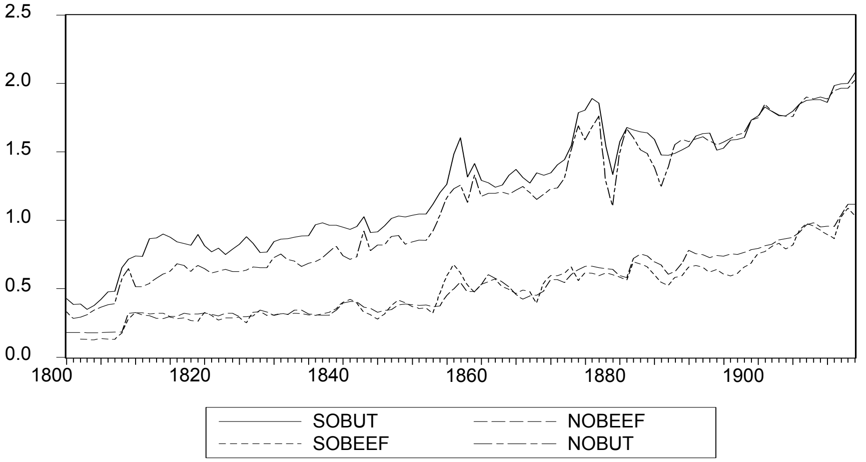
[30] Curman, J,(1993), op. cite., p 62, states that the energy content of leaves is 15% lower than energy in hay.

results of new, better cow breeds, which needed more nutritious fodder than could be provided by forest grazing.

Figure 6.8 Butter-and beef- prices in the North and in the South, SEK/kg.



Sources: Jörberg, L. (1972): *"A history of prices in Sweden 1732-1914"*, Lund

The results of this analysis support the idea that forest grazing was abandoned earlier in the South for more nutritious fodder grown in the fields. This gives some support to the assumption that forests in the South got a chance to recover earlier from the drawbacks of intensive forest grazing. Together with the fact that forest grazing generally should have had a more negative impact on forests in the South, this strengthens the main assumption that the trend break, when deforestation turned into restoration, occurred earlier in the South than in the North.

Swidden cultivation

The practice of burning forests to pave way for permanent cultivations, as well as for occasional fields, is very old, and continued into the 20th century.[31] Naturally the success of permanently turning forests into agricultural fields implied decreasing standing timber volumes. In addition the practice of occasional slash-and-burn, by constantly keeping some part of the forests without trees (although the actual areas changed), affected the timber volumes.

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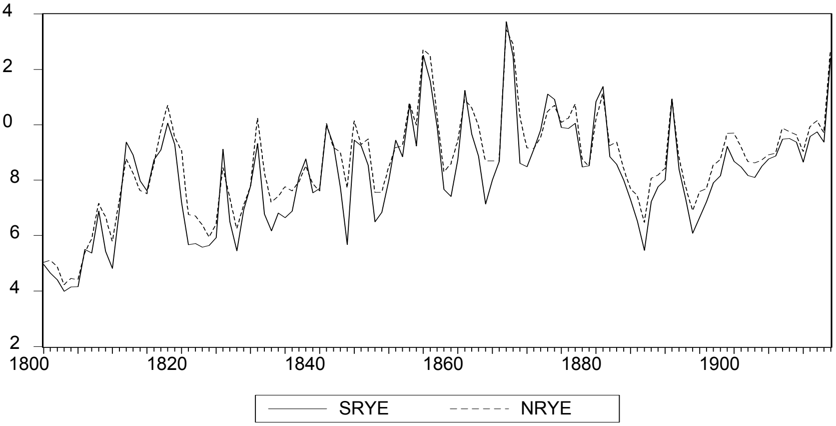
[31] Lindman, G.(1995):"Forntida svedjeodling i Västsverige", in Larsson, B.(ed) *Svedjebruk och röjningsbränning i Norden*, Nordiska museet, Stockholm, p 51, says that the last slash and burn cultivation took place in Småland (southern distric of Sweden) in 1938.

Because the tradition of occasional slash-and-burn of forests for rye production was more diffused in the South than in the North, for climatic reasons, the eventual abandonment of the practice had a larger impact on standing timber volume in the South than in the North, and may have contributed to an earlier trend break there. [32] Was the practice large enough to have had any impact on the development of the timber volume? Although it is impossible to get exact numbers of the total areas involved in slash-and-burn cultivation, local studies suggest that large areas were involved. Weimarck, for instance, shows that in north- east Scania the swidden land was four times bigger than the permanent fields in 1831, and Kardell found that 30% of the land was swidden for one property in Östergötland in 1845.[33] Examples like these make the conclusion of a large impact on the standing timber volume of occasional swidden cultivation, and from its gradual abandonment, convincing.

Were there different economic incentives for turning forestland into fields in the North and in the South? One possibility of examining economic incentives is to look at rye prices, since rye was one of the major crops, compared to timber prices. Rye prices in the North and the South are compared in figure 6.9.

Figure 6.9 Rye-prices in the South and in the North, SEK/ hectoliter.



Sources: Jörberg, L. (1972): *"A history of prices in Sweden 1732-1914"*, Lund

It is striking that rye prices in the North and the South followed each other pretty closely. No differences in trends can be discovered. In contrast to this the price

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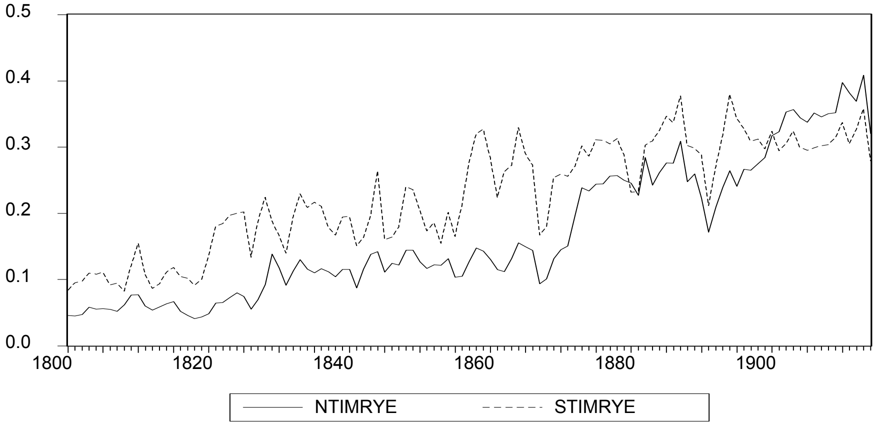
[32] Kardell, L.(1980) *Svedjebruk förr och nu*, SLU, p 22. Segerström, U.(1995):"The Pollen-analytical Evidence for Prehistoric Cereal Cultivation in Northern Norrland, Sweden:the issue of permanent fields versus slash-and-burn cultivation", in Larsson, B.(ed) op.cite.

[33] ibid, p 23-24.

developments of timber in the North and the South differed. The timber-price/rye-prices in the North and in the South are depicted in figure 6.10

Figure 6.10 Timber-price/rye-price in the North and the South



Sources: Jörberg, L. (1972): *"A history of prices in Sweden 1732-1914"*, Lund

For the period 1800-1870 the development of timber/rye price was markedly different in the South compared to the North. In the North, two periods with rather stable relative prices can be discerned: 1800-1825 and 1830-1870. In between the relative price increased. For the whole period of 1800-1870 the relative price doubled. For southern Sweden the relative price was stable until 1820, after that there was a clear trend of higher prices over the period, resulting in a three-time increase of the ratio by the end of the period. At first thought this relative increase in the price of timber compared to the price of rye may seem to contradict the idea of forest land being turned into fields at all, since why would the land owners turn land into uses with less beneficial price development? For this to be rational there must initially be higher profits in rye production than in timber production, a difference, which is leveled out over time. At the beginning of the 19th century timber could not compete with rye on soil suited for both, but in the South, timber became a product that could compete with rye much earlier. Gothenburg was the first harbor to start exporting timber, which was taken from the southwest inland. The price of timber in the South therefore became high enough sooner to put a brake on burning forests to pave way for rye.

The results of this analysis support the idea of an earlier trend-break in the South by showing that timber earlier became a commodity that could compete with rye for the scarce resource of land. This probably led to an earlier abandonment in the South, than in the North, of both slash-and-burn for the permanent reclamation of forests and of the occasional slash-and-burn cultivation, which had been more widely used in southern Sweden, and promoted an earlier trend-break for the standing timber in the South.

CO_2 emissions from forests

Simply put, when forests increase their biomass they take CO_2 from the atmosphere and when they decrease their biomass they release CO_2 into the atmosphere. During periods of forest *net growth*, more CO_2 is sequestered than released and hence the forests function as a *sink* for atmospheric CO_2. During periods of *negative net growth* the opposite occurs and forests act as a *source*. Information regarding sink-source functions of forests is crucial for an understanding of Sweden's contribution to the Greenhouse effect. This function is here related to CO_2 emissions from fossil fuel combustion in Sweden during the period of investigation.

Forests have always been a very important natural resource for Sweden. In the past, their capacity to provide crucial goods like timber, charcoal, firewood and cattle food was emphasized. Presently, the perspective has broadened to include their carbon dioxide assimilating capacity, recreational value and their value for preserving bio-diversity.

The changes in timber volumes may be expressed as carbon dioxide sources or as carbon dioxide sinks according to the relation that $1m^3sk = 1.036$ ton CO_2, shown in figure 6.11.[34]

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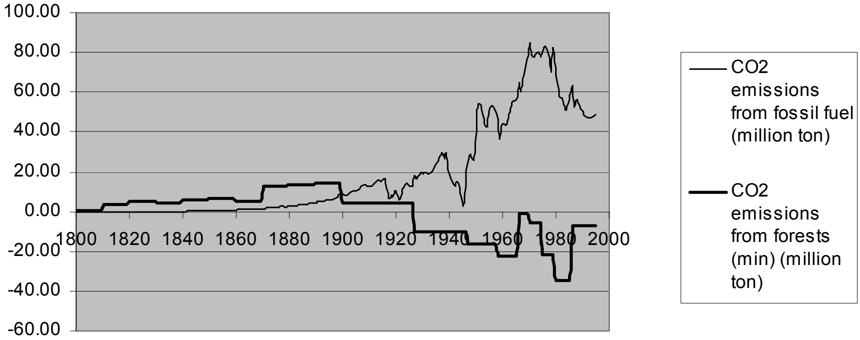
[34] m^3 sk, means forest cubic metres. To arrive at the CO_2 content of 1 m^3 sk one should first multiply by 1.4 to get the amount of biomass (0.3 below the stub and 0.1 as branches etc), thereafter one should multiply by 0.4 to get the dry weight in tons and finally multiply by 0.5 to get the carbon content in tons. Hence $1m^3sk = 1.4*0.4*0.5 = 0.28$ tons C. Since the molar weight of CO_2 is $(12+16+16)=44$, the relation between C and CO_2 is 12:44, i.e., 1:3.7. This implies: $1m^3sk=0.28$ tons C=1.036 tons CO_2. See Hultkranz, L.(1992): "National Account of Timber and Forest Environmental Resources in Sweden", in *Environmental and Resource Economics*, vol.2, p 295.

Figure 6.11 Average annual emissions of CO_2 from Swedish forests (million tons) and from fossil fuels (million ton). Negative emissions mean sequestration.



Sources: see figures 3.9 and 6.2. Comment: The annual forest emissions are calculated on the basis of average values for changes of the timber stock in between points of observation/estimate. Therefore the graph has staple properties.

This procedure of immediate transformation of changes in standing timber volumes into CO_2 emissions is not quite correct, since only the part used for burning (firewood, charcoal, slash-and-burn) or cattle grazing has this direct connection. The part used for paper retains its content for approximately 10 years prior to emissions and timber may on average retain its CO_2 for 100 years.[35] The main reason why I have refrained from lagging part of the emissions is that the full human impact on forest resources is not quantified (slash-and-burn cultivation, forest grazing, silviculture) and it is therefore problematic to apportion the decrease or increase of the standing timber stock to any certain uses, like timber or paper. Another reason is that in order to take the time lags into account, a period of 100 years *before* 1800 must be accounted for in order to include timber use. Another aspect to be considered is that some of the wood was exported and consequently some of the emissions did not actually occur in Sweden, but abroad, but the emissions were nevertheless caused by Swedish forestry. If only the Swedish consumption of wood is to be counted as Swedish emissions the emissions until the 1920s would be lower, while subsequent net emissions would be higher.

The standing timber volume was approximately the same in 1800 as in 1995, which means that the cumulative CO_2 emissions did not change much with the inclusion of forests as sinks or sources for CO_2 during the full period of investigation. But trends and periodizations of CO_2 emissions change with the

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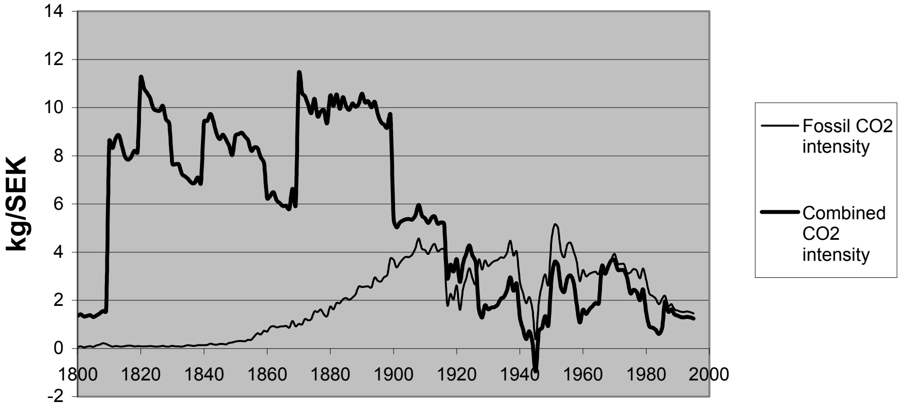
[35] These are the assumptions made in Calander, K.,(1989) et al, *Emissioner av koldioxid. En jämförelse av biobränslen och naturgas*, IVL Rapport B950, Göteborg, p 32.

inclusion of forest emissions. At the same time, CO_2 intensities are altered. In the 19th century, forest CO_2 emissions were already substantial when fossil fuel emissions started at a low rate. Between 1870 and 1900 there was a concomitant increase of both kinds of CO_2 emissions, but after the turn of the century, as fossil fuel emissions continued to increase, there was a decrease in forest emissions, which lowered the combined emissions. Between the turn of the century and the outbreak of the Second World War, combined emissions showed a declining trend, while fossil fuel emissions increased. After the 1920s, combined emissions were lower than emissions from fossil fuels alone, i. e. the forests worked as sinks for CO_2 and counteracted emissions from fossil fuels. This counteracting impact was substantial, except for a few years at the end of the 1960s and early 1970s, when forest net growth was very low. The relative peak in total CO_2 emissions in 1970 was consequently even more pronounced for the combined emissions than for fossil emissions alone.

Figure 6.12 Swedish CO_2 intensity, kg/SEK, including and excluding the net impact from forests 1800-1995



Comment: 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 staple properties.

It makes an even greater difference for CO_2 intensity to include the net forest impact, especially during the 19th century, when GDP was relatively low, as demonstrated in figure 6.12. The most striking result is that the combined CO_2 intensity was several times higher in the 19th century than the combined or the pure fossil CO_2 intensity during the 20th century. This means that Swedes caused more greenhouse gas emissions during the 19th century than they did in the 20th century in relation to their economic activities. Another noteworthy result is that during the rapid industrialization between 1850 and 1914, the combined CO_2 intensity decreased, while the pure fossil fuel intensity rose rapidly. This means that industrialization and modernisation, which led to increasing energy intensity and more fossil fuels, still led to a relative decline in total CO_2 emissions.

Firewood and CO_2

There seem to be obvious linkages between energy use and deforestation, because firewood is collected from the forests. In a situation with decreasing timber stocks firewood may be regarded as a large contributor of CO_2, because it has the highest emission factor of the fuels.[36] Grubler provides two alternative graphs of global carbon intensity of primary energy, measured as carbon emissions per energy unit. One of the graphs uses a completely static perspective of firewood combustion, where all carbon from firewood is calculated as net emissions, thus not taking timber re-growth into consideration, and another graph excludes firewood. Both graphs, however, result in a long-term decline in the carbon/energy ratio of the global primary energy between 1850 and 1990. In a study of the cold, forest-rich Sweden the way firewood is calculated makes a larger difference than in a global study.

The role of firewood consumption for deforestation and afforestation is, however, complex. Naturally, it contributed to a decrease in timber stocks as long as silvicultural efforts were insufficient, but it also contributed to the demand for thin timber dimensions, which encouraged a rational silviculture with clear cutting, replanting/sowing and thinning out the young stands. This forest management eventually turned the negative trend with decreasing timber volumes into a positive trend with increasing timber volumes. Therefore I believe it does not make sense to calculate a specific contribution from firewood to CO_2 emissions in the Swedish context.

Conclusions

This chapter has made an attempt to model the absolute changes in Swedish standing timber volumes, and the general difficulties involved in estimating *absolute* changes in standing timber volumes historically have been emphasized. It has further explored some methods that may be used for *relative* forest developments between regions or countries. The major conclusions are:

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[36] Its emission factor is 15% larger than that of coal, Grubler, A.(1998) op. cite., p 280-281.

1) The estimate of CO_2 emissions and sequestration by Swedish forests shows a magnitude well in parity with emissions from fossil fuels. Consequently it can make sense to include forest emissions in historical greenhouse gas budgets, and calculations of environmental debts. Still, over this period of time (1800-2000) the sum of net contributions from forests is almost zero, since timber volumes are approximately the same in 2000 as they used to be in 1800.

2) The pattern of CO_2 intensity is profoundly altered when forest emissions are included. Then CO_2 intensities were for instance much higher during the 19th century, than during the 20th century. Another result is that the industrialisation phase of 1870-1913 caused relative increases in fossil CO_2 emissions, but not in combined CO_2 emissions, which instead declined.

3) The analysis has questioned the idea that firewood combustion caused net CO_2 emissions in a dynamic perspective, because the demand for thin timber dimensions stimulated a rational forestry, which eventually turned the negative net growth of standing timber volumes into a positive net growth.

Chapter 7

Major conclusions and relevant future research

This dissertation has highlighted the long-term relationships between energy and economic growth. The aims were to establish energy intensities and CO_2 intensities for the Swedish economy for the period 1800-2000 and to analyse the reasons for trends and trend breaks. My conceptual model is that economic growth is characterized by structural and technical changes, which are the main determinants of both energy intensities and CO_2 intensities. Structural and technical changes are interlinked, but may be analytically separated and their relative impacts determined, at different levels of aggregation. Technical change and structural change affect energy and CO_2 intensities both indirectly and directly. Technical changes give rise to fundamental changes in relative prices, which affect the structure of the economy and the structure of energy carrier composition. The direct impacts of technical change on energy intensities are increases in TFP (total factor productivity), including improvements in technical energy efficiency (higher ratio of useful energy in relation to inserted energy) and changes in capital/labour ratios. Technical change opens up opportunities to use new energy carriers and influence the relative price of energy carriers, which affect CO_2 intensities. Structural changes in the economy affect the overall energy intensity, since economic sectors and sub-sectors differ with respect to energy intensities. Structural changes in energy carrier composition naturally affect CO_2 intensity, since energy carriers differ in emission factors, and whether they also affect energy intensity, through quality changes is analysed in the thesis.

In the analysis more focus has been laid upon the energy intensity and the energy carrier composition than CO_2 intensity, although this may seem less relevant from an environmental perspective. The reason for this choice is both that CO_2 intensity is a function of energy intensity and energy carrier composition, and that it makes more sense in an economic analysis of production and production sectors. Energy is a prerequisite for production and is used directly in the production process, while CO_2 emissions are unintended consequences. Growth is thus more directly linked to energy than to CO_2.

The intensive growth, or the sustained growth of per capita income, in Sweden and many other countries during the last 200 years, is largely a consequence of the use of more energy. This would hardly have been possible without the transition from solar based to stored energy resources. Major technical innovations like the steam engine, the internal combustion engine, the electric generator and electric motor have widened the field of applications for new energy carriers. The diffusion of these technical innovations have stimulated lowered costs on the supply side, both in extraction/production and transportation/transmission, which have influenced the relative prices of energy carriers. In addition the relative costs of production factors have been influenced by technical changes. Energy and capital costs have decreased in relation to labour. This has led to increases in the capital/labour ratio in production, with impacts on energy intensity, and affected the choice of energy carriers, since they differ in convenience of handling, i. e. the time-costs involved in using them differ. For companies there is an interlinking of time, wages and costs, where 'time' costs increase more when wages rise. For households there is a shadow cost of time at higher income levels, but less clearly proportional to wages than for companies, since preferences and alternative possible usage of time in reality also play roles. The willingness to internalise externalities, for instance environmental costs, increases at higher income levels. This willingness, expressed as environmental taxes, also affects the energy carrier composition and hence the CO_2 intensity.

One hypothesis tested was the EKC (Environmental Kuznets' Curve), or the inverted U-curve, which states that the relative environmental stress increases up to a certain income level, after which it decreases. The aim was to see if there were such patterns in the Swedish development of energy intensities and CO_2 intensities. My expectation was that by including traditional energy carriers a very different picture would emerge. An explicit aim of my study was to test whether the structural explanation, which is often linked to interpretations of the EKC, was valid. This explanation is that the relative environmental stress increases during the transition from an agrarian to an industrial economy, while the subsequent transition to a service economy leads to a decreased relative stress. In this thesis energy and CO_2 intensities were chosen as examples of environmentally linked indicators to be tested.

Another hypothesis tested in the thesis was whether relative environmental improvements in industrialized countries at high-income levels, in fact, meant that these countries were merely moving the problems to more peripheral, developing countries, instead of solving them. "While we live in the service economy, more and more of our industrial goods are produced in the developing countries", is one formulation of this idea.

The two aims of the study have been fulfilled to a reasonable extent. Chapter 2 contained my estimates of firewood and muscle energy, as well as the quantities of the energy carriers, for which there is statistical information. Chapter 3 presented the energy and CO_2 intensities, and briefly discussed the outcome in relation to previous research and the EKC. Chapter 4 analysed the relative importance of structural and technical changes for energy intensities. It focused on the so-called service transition and analysed the net impact of technical change on energy intensity. This analysis was used to explain why the idea, that high growth rates are positive for the environment, is not valid. The analysis of technical change was also used to explain the relative differences in energy intensity development of the four main sectors: agriculture, industry, services and transport & communication. Chapter 5 analysed the relevance of changes in energy carrier composition for both changes in energy intensity and CO_2 intensity. It used economic volumes, and 'augmented' energy volumes, where the consumers' surplus is included, for assessing the quality of energy carriers from the users' perspective. It also suggested a framework for understanding energy carrier transitions, which was partly tested, through relative price analyses. Chapter 6 estimated the changes in Swedish standing timber volumes and to what extent the Swedish forests consequently worked as sources or sinks for CO_2. The forest related emissions were compared to the fossil fuels' related emissions. It also contained an analysis of the relative developments of forests in the north (Norrland) and south (Svealand and Götaland) of Sweden, based on relative prices. In the following sections the main results will be summarized and the relevance of these results for future development pointed out.

Energy intensity

The main long-term pattern of energy intensity in Sweden for the period 1800-2000, when traditional as well as modern energy carriers are included, shows a decline. This is the same pattern as in the forest- rich US. The hypothesis of the EKC in its weak formulation, i. e. of relative improvements, appears to be based on too short a time perspective.[1] With longer perspectives the most important trend is a long – term decline around which cyclical patterns appear, which possibly may be interpreted as several EKCs.

Three kinds of explanations for the changes in energy intensity have been analysed: structural changes, technical change and energy quality. In addition, I have examined whether the relative improvements in the national energy intensity were caused by changes in foreign trade patterns.

Structural changes at the sector level or the sub-sector (branch) level were of little importance for the long-term decline in energy intensity. At the sector level they actually counteracted the decrease. Within the industrial sector, structural changes did contribute to the decline, but they were of minor

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[1] Most studies of the EKCs are based on the recent four decades.

importance compared to changes within the branches, which may be regarded as technical change in a broad sense.

During the period of rapid industrialisation (1870-1913) structural changes played a decisive role for the increase in energy intensity. The relative growth of the industrial sector and of the transportation & communication sector, together with structural changes within transportation, caused the entire increase in energy intensity.

The transition to the service economy does not provide a relief for the environment in the sense that services make up a larger share of real output (this idea is a misconception) but it has other positive impacts for material and energy use. The impact is threefold. First, it works in the form of inputs to other branches and sectors, through microelectronics, which enables the fine-tuning of production and reduces 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 energy consumption at their final use, like the products of the previous revolution, based on electric motors and combustion engines. The third industrial revolution is still only beginning, so it is difficult to determine its future impact on energy intensity and energy consumption. It appears, however, to indicate a potential for continued relative improvements of the energy to GDP ratio.

The service transition, in fact, means that the proportion of the transportation & communication sector in real GDP is relatively larger. The implications for energy consumption depend on the relative energy intensity of this sector. In Sweden, the energy intensity of the transportation & communication sector after 1970 is roughly equal to the energy intensity of industry, but this is because Sweden has an unusually large share of heavy industries.[2] In other countries, with a less energy intensive composition of industry, the transportation & communication sector may well have higher energy intensity than industry. The implication is that the growth of the transportation & communication sector did not affect the overall energy intensity in Sweden in the period 1970-2000, but it may have done so in other countries.

The development of the growing transportation & communication sector appears crucial for future development of energy intensity in industrialised countries. Previous investigations have suggested that transportation displays little technical progress in terms of energy efficiency. This idea is refuted by the

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[2] This is only so if electricity is counted by its heat content. If electricity is counted by the primary energy for its production energy intensity is relatively higher in industry, because of its high electricity share compared to transportation & communication.

findings of this study. The result here is that the transportation & communication sector had the most rapid de-linking of output and energy of all sectors in the period 1913-1970, after which the rate of improvements slowed down substantially. The rapid de-linking was not due to a relative growth of energy light branches, such as telecommunications and postal services, but took place in transportation, for instance in railways. Previous investigations tend to calculate the output in pure physical terms, for instance kilometres per person, and not the economic value, which results in low rates of improvements in efficiency. When the economic value is calculated the value of time gains reached through faster transportation grows faster than the energy, thus making the sector progressive. Although saving of time is important for all sectors on the supply-side, because they save human labour, it is only in the transportation & communication sector that time gains play a pertinent role also on the demand-side, where they constitute a part of the increased quality of output, thereby contributing to value added and consequently to a decline in energy intensity.

Technical change has generally worked to decrease energy intensity. It has affected energy intensity in two main ways: by substituting capital for labour and by increasing output in relation to inputs, i. e. by raising the TFP. Capital for labour substitution can work either to increase energy intensity or to decrease it depending on the technical efficiency (useful energy/inserted energy) of the inanimate machines compared to the animate machines (humans or draught animals) they replace. In the early 19th century the technical efficiency of inanimate machines were in general lower than the technical efficiency of humans. Humans may be perceived as animate machines combusting food. At some point in time, which cannot be determined precisely, but ranging from the late 19th century into the 20th century, the average technical efficiency of inanimate machines became larger than the average technical efficiency of humans. As long as the technical energy efficiency of inanimate machines remained lower than the technical efficiency of animate machines, the increase in machine/labour ratios meant an increase in energy intensity, ceteris paribus. When the technical efficiency of inanimate machines became larger than that of humans, a further increase in the machine/labour ration led instead to a decline in energy intensity.

Concerning the de-linking of energy and growth in the long run, it is important to stress that it is a normal feature of economic growth that increases of raw production factors only explain part of the growth. Quality aspects of growth are important. Empirical research of growth shows that TFP generally increases, which has implications for the analysis of energy intensity. If energy is regarded as a relative complement to labour and capital, the TFP increases suggest that there will also be a de-linking of raw energy and value added, in line with the de-linking of value added and raw labour and capital. In addition, there are technical energy efficiency improvements of machines and systems, with direct consequences for energy intensity. Technical energy efficiency improvements may be regarded as a special case of TFP increases, if energy is perceived as a production factor. It is important to emphasise that improvements in technical energy efficiency, although important, are not the sole explanation for the de-linking of growth and energy, since the indirect effects of savings of capital and labour are substantial.

In a dynamic sense improvements in technical energy efficiency have resulted in certain take-back effects, i. e. increases in energy services as these become cheaper due to improvements in technical energy efficiency, but these effects have generally not been strong enough to outweigh all the gains. The reductions in energy intensity are much smaller than the gains in TFP, as found in most empirical studies of growth i. e. the de-linking of raw energy and output has not been as strong as the de-linking of output in relation to raw labour and capital. Take-back effects certainly have played a role in this.

The higher quality of energy carriers did not offer a general explanation for the long-term pattern of energy intensity, which was a bit surprising. No correlation was found between energy intensity and energy quality, measured as ‘augmented energy volumes’, which means that in periods of declining energy intensity, higher quality did not compensate for reductions in quantity.

Environmental dumping, or the idea that relative improvements in industrialised countries are caused by energy intensive production being moved to poor countries, is not confirmed in this study. The decrease in energy intensity after 1970 was not caused by changed patterns of foreign trade for Sweden, but by changed patterns of demand in Sweden as well as abroad. This implies that relative environmental progress is not necessarily the result of moving the problems instead of eliminating them.

The implication for present attempts to cut down energy consumption in relation to growth is that technical change will reduce the ratio over time, but that this de-linking is not likely to be fast enough to compensate for the growth, unless there are profound changes in efficiency rates compared to growth rates. In Sweden the energy consumption in fact stabilised after 1970, but only if electricity is counted by its heat content. If, instead, the primary energy content of electricity is counted, the energy consumption continued to increase. In other developed countries, with a smaller electricity proportion, energy consumption continued to grow after 1970, even when electricity is counted by its heat content. One imperative of this is that improvements in efficiency should be accelerated in order to reach a more sustainable development. By this I do not mean single-minded efforts to increase technical energy efficiency, even though this is of great importance, but rather concerted efforts to create more value from raw inputs. On the supply side, this includes concentrating on human knowledge and skills, organisational improvements, institutional changes etc. It may also include a shift in demand towards products with a high quality (value) in relation to inputs. This is the challenge for society if a more sustainable development is to be achieved.

Energy carrier composition

In addition to analysing the historical development of energy intensity, this dissertation has offered an analytical framework for understanding the composition of energy carriers at different income levels. This is relevant today when there is a strong push to increase the proportion of renewable energy in order to reduce the CO_2 to energy ratio. The three costs involved in energy consumption, purchasing price, handling costs and environmental costs, are intended to play different roles at different income levels. At lower income levels purchasing price and costs for technical equipment dominate the decision-making. At higher income levels where time costs are higher, companies and households are willing to pay a quality premium for energy carriers that are comfortable to use. At still higher incomes people may become willing to internalise the environmental costs, which makes renewable energy more competitive.

The implications of this analysis for the future energy situation of the world is that renewable energy sources will have difficulties competing with fossil fuels in the majority of the countries of the world. In all countries where income is low, focusing on purchasing price and capital equipment price is likely to make fossil fuels, not least coal, more competitive. In countries of the third world, where per capita income is growing, demand for transportation is likely to increase and there will consequently be an increasing demand for oil, unless viable alternatives to the combustion engine appear. The majority of countries are not at income levels where they naturally will internalise external costs, and therefore bio-fuel is not going to be competitive on a large scale in cities. Only in rural areas of developing countries, where relative prices for energy carriers are different, will bio-fuels continue to play a large role on their own merits. If large-scale transitions in energy systems are to take place in developing countries, developed countries will have to encourage these shifts by offering subsidies for bio-fuel, direct solar techniques, fuelcells etc. Such subsidies can be justified on the grounds of environmental debts.[3] The developed countries

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[3] Krantz, O (1989) *Ekonomisk tillväxt och miljö*, Lund: LO Förlag, is very growth optimistic. He tries to calculate what it would cost to pay off the environmental debt, i. e. to restore the environment to an acceptable standard, and finds it to be a small share of GDP increase. More pessimistic are SOU

have reached their level of affluence because of heavy use of fossil energy, which has built up problematic concentrations of CO_2 in the atmosphere. Stabilizing the levels is therefore primarily their responsibility.

Forests as sources or sinks for CO_2

The developing countries contribute to the greenhouse effect mainly through deforestation.[4] This dissertation has shown that Swedish forests were managed badly during the 19th century, when the nation was still poor. At that time the net emission from Swedish forests was far greater than the emissions from fossil fuels. This was due to decreasing stocks of standing timber, which had many causes. High demand for wood, forest grazing and slash and burn cultivation, in combination with insufficient means for forest re-growth, were the main explanations. Forest management was improved towards the end of the 19th century, in line with the growing concern for forests and as a consequence of relatively rising prices of timber. Two different modes of cutting were dominant in the north and south: selection cutting and district cutting. Selection cutting was mainly caused by the unbalanced demand for thick timber dimensions in relation to thinner dimensions. In the south of Sweden rational forest management was introduced earlier than in the north, because with a higher demand for thin dimensions of wood it made more economic sense to clear-cut, replant and thin the young stands. Not until the demand for thin dimensions increased in the north, through the pulp industry, did it prove worthwhile to district cut, and then re-growth was increasingly secured. The demand for firewood thus had a positive impact on the standing timber volumes, in a dynamic sense, because it stimulated rational forest management with district cutting and sowing/replanting, but it had a negative influence on forest conditions until the more scientifically based silviculture was initiated.

The deforestation in developing countries of today is to some extent driven by similar forces to those of the Swedish deforestation in the 19th century, but there are also differences. The lack of management plans, which means that forests are deprived of their wood without proper consideration to re-growth, plays a large role for deforestation today like it used to do in Sweden. Forest

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1992:58, *Miljöskulden*, and Jernelöv, A. *Mer om miljöskulden*, miljövårdsberedningens rapport 1993:3.

[4] *State of the World's forests 2001*, part 2, p 51. All the deforestation takes place in natural forests, which comprise 95% of the forests on earth. Forest plantations, which comprise 5% of the forests, are responsible for carbon sequestration instead. Only 6 % of the forests in developing countries have a formal forest management plan, while 89% of the forests in the industrialized countries have one. All theses plans do not fulfil the criterias for sustainable forest management agreed at the United Nations Conference on Environment and Development (UNCED) in Rio De Janeiro in 1992, but they do secure timber production and regrowth.

grazing and slash and burn cultivation are other factors, which still contribute to forest degradation. Today criminal activities in the developing countries, like bribing state officials, cause a large part of the unsustainable cutting, in many cases up to half of the felled amounts, and this lacks a counterpart in Swedish history.[5] The concept of sustainable forest management – and efforts to achieve it- has still gained growing momentum during the last decade and the forest area under ordinary management plans has grown. The deforestation has consequently slowed down. With continuous efforts at forest management it may well be that the Swedish u-shape pattern of standing timber volumes, with a bottom mark around 1920, will be repeated on the world scale with a delay of approximately 100 years.

CO_2 intensity

The main determinants of CO_2 intensity related to fossil fuels are energy intensity and energy carrier composition. This study showed that changes in energy carrier composition were more important than changes in energy intensity for the long-term pattern of CO_2 intensity. The forces behind changes in energy systems are therefore of great importance for understanding changes in CO_2 intensity.

The estimate of CO_2 emissions and sequestration by Swedish forests showed a magnitude well in parity with emissions from fossil fuels. The aggregate CO_2 emissions over the period 1800-2000 were not much altered, but the pattern of CO_2 intensity was profoundly altered when forest emissions are included. For instance the CO_2 intensities were much higher during the 19th century, than during the 20th century, when forest emissions were included. Another result is that the industrialisation phase of 1870-1913 caused relative increases in fossil CO_2 emissions, but not in combined CO_2 emissions, which instead declined. Furthermore, the analysis of forest management questioned the idea that firewood combustion caused net CO_2 emissions in a dynamic perspective, because the demand for thin timber dimensions stimulated a rational forestry, which eventually turned the negative net growth of standing timber volumes into a positive net growth.

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[5] *State of the World's Forests 2001*, part two, p 88-101. In Sweden some sawmill owners had timber illegally cut for them in the crown forests, so-called "baggböleri", but this never reached the extent of the present illegal cutting in developing countries.

Relevant future research

Additional country studies of long-term energy consumption in relation to economic development constitute one field where future research is urgent. This is important in order to distinguish between general and country-specific characteristics of the Swedish development. Research is currently going on in this field for Austria, Italy, Finland, Great Britain and the Netherlands.[6] It is important that researchers cooperate in order to combine methods and analyses.

A closer examination of the transportation & communication sector appears crucial for assessing the prospects of a future de-linking of energy and GDP, which needs to be faster than the historical de-linking, if the goals of stabilising CO_2 emissions are to be reached. This sector is increasing its share of real GDP and its energy intensity development is therefore important for total energy intensity. Its development in the Swedish context is spectacular and it would be of interest to compare this with the development in other countries, and also to examine relations between production factors and value added in different countries at more disaggregate levels.

The options for policy-induced technical change in energy systems should be examined further. There are some correlations between emphasis in politics and energy intensities over the last six decades in Sweden. Lundgren found that governmental policies were directed towards energy savings (reducing energy demand) in the period 1944-1955, while he found them more focused on increasing energy supplies in the period 1956-1973.[7] In the "energy saving" period of 1944-1955, energy intensities were either constant (households included) or decreasing (households excluded). In the "energy increasing" period of 1956-1973, energy intensities increased whether households were included or not, but relatively more when they were included. In the next "energy saving period" of 1973-2000 there was again a decline in energy intensity. It is at least likely that there was some impact of the emphasis of governmental energy policies upon energy intensities in all three periods. This idea may be checked by comparisons with other countries. It is obvious that the government has played a large role for relative CO_2 emissions. It has continuously stimulated the electrification process and, since 1980, it has used energy and environmental taxes, which have brought a relative increase in bio energy. It would be interesting to evaluate the importance of these policies by comparisons with other countries.

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[6] Fridolin Krausmann is working on Austria, Timo Myllyntaus and Jan Kunnas on Finland, Niels Schulz on Great Britain, Silvana Bartoletto on Italy, Jan Luiten van Zanden, Jan Pieter Smiths and Ben Gales on the Netherlands.

[7] Lundgren, L. (1978) *Energipolitik i Sverige 1890-1975*, Sekretariatet för framtidsstudier, p 25.

Appendix A

Coal consumption apportioned to usage

The aim of this appendix is to establish benchmark values for coal consumption in 1850 and 1870. Coal was used for motive power in steam engines, as raw material for gasworks and for heating and the amounts used for these purposes will be estimated on basis of available information.

Coal for steam engines

Steam engines supplied motive power for industry, agriculture and transportation.

Apart from coal wood could be used by steam engines. For example, steam saws, which were diffused after the 1850s, mainly used wood. Steam engines in locomotives and in ships were, on the other hand, mainly fuelled with coal, because dead weight and volume are particularly detrimental for transportation, and wood fuels contain a lot of water and require a lot of space. "Locomobiles" (the forerunner of the tractor), which were diffused in agriculture from the 1850s onwards, were probably mainly fuelled with coal in the beginning, since they found early application in Scania and Östergötland, where firewood was in short supply. In the 1870s locomobiles for threshing were diffused over the entire country, according to Lantbruksakademin, and this might indicate that some machines, in wood rich parts, were fuelled with wood and that some were fuelled with straw and waste.[1]

Steam in industry

Steam engines were used in industrial plants. Hamilton has estimated the total number of installed steam horsepower in 1850 to a maximum 5000 hp, but that included steamships, which amounted to 3000 hp.[2] Steam locomotives were not diffused in Sweden until the 1850s. Roughly 2000 hp might thus have been used for industrial purposes in 1850.

It is difficult to estimate actual energy consumption based on installed horse- power, since there is no information on the amount of time the machines were actually working, or on their exact efficiency. If I assume an average

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[1] Moberg, H.(1989), op.cite, p 179.

[2] Hamilton, U. (1982), op.cite.

working time of 10 hours per day, 250 days a year, allowing for holidays and technical problems and given that the efficiency of those old steam engines was 2-5 %, I arrive at the following estimate of primary energy: 2500 (hours)* 2000 (hp) *0.736 (kW/hp)* 30 (assuming 3.3% efficiency) = 110 GWh= 110*3600GJ = 396 TJ.[3] But since steam engines to a substantial extent were also fuelled with wood, straw and waste, assuming a proportion of 50%, implies that only 200 TJ coal was used.[4] Total coal consumption in 1850 was 2400 TJ, and this estimate suggests that 8% of the coal in 1850 was used by stationary steam engines.[5]

For 1870 there is some information on installed steam power in the statistics. The statistics are however not complete, because industrial production related to agriculture or forestry is not included.[6] Out of the 2183 factories that provided information, only 889 disclosed what kind of power they used. 317 factories used steam, 448 factories used waterpower and 124 factories used animal-drawn wheels. The total installed power was estimated to 11 573 hp. The power was, however, not evenly divided between different power systems. Factories that only used steam on average had 14.9 hp/factory and their total amount was 1000 hp. For water-wheel factories the average was 7.7 hp/factory. For factory categories where steam, water and sometimes also animal-drawn wheels were used in a mix only the sum of horsepower is presented. For such factories total horsepower cannot easily be apportioned to steam, water and draught animals, but since steam engines generally had higher power than water wheels or animal-drawn wheels, I have apportioned power so that steam factories get a double share. With that procedure steam gets an additional 4500 hp. Total steam horsepower for factories providing power information is then 1000+4500=5500 hp. What about the 1294 factories that did not provide any information on their use of motive power? The bulk of them did not have any machines driven by inanimate power or draught animals; they simply used human power. Some of them might, however, have used steam engines, but not reported it. Here I simply add 500 hp to the total to account for those possible report failures.

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[3] Smil, V. (1994), op. cite, figure 5.3, p 164. Watt's steam engines had efficiencies of 2-5%.

[4] In 1913 65% of the steam engines and other engines in industry were fuelled with coal, and the rest with wood (table N, p 23 in *Special inquiry by the National Board of Commerce. Energy consumption of industrial plants, transportation, and public buildings for the period of 1913-1917*)

[5] Obviously there are many uncertain figures involved in this estimate. If we choose figures that tend to maximize coal consumption we arrive at 3000 (hours) * 2000 (hp)*0.736 (kWh/hp)*50 =143 GWh=143*3600GJ=515 TJ. If only 35% were fuelled with wood, like in 1913, we arrive at coal consumption of 335 TJ, which is 14% of total coal consumption. It may be concluded that if installed horse powers in industry in 1850 did not exceed 2000 hp, which was a maximum assumption by Hamilton, steam engines in industry were not likely to have used more than 14% of the coal.

[6] Sawmills are not included in BiSOS at all. Information on the number of sawmills, which used steam in Västernorrland, the most prominent sawmill district, is available, and amounts to 31, but there is no information for the other districts.

The industrial branches, which are related to agriculture, are not recorded above, but they also used steam engines to some extent. In 1873/74 distilleries used 48 steam engines with a total power of 343 hp.[7] Beer breweries were included in the industrial statistics from 1872 and then only 8 steam engines were reported with a total capacity of about 20 hp.[8] Sugar factories used 52 steam engines with a total power of 1548 hp in 1887, and could be neglected in 1870. [9] Brick factories had 68 steam engines with a total power of 1417 hp in 1887, but only 11 steam engines in 1873, so their steam equipment could also be considered negligible for 1870. Sawmills also used steam engines, but they only used spill wood, and do not have to be considered here. In 1896 118 grain mills were equipped with steam engines and their total power amounted to 6383 hp.[10] If I assume the same pace of steam diffusion in grain mills as in beer breweries, the steam in grain mills was only about 60 hp in 1870.[11] It appears that, among food processing industries only distilleries need to be taken into account for 1870, adding 300 hp to the 6000 hp above. In 1870 the number of steam engines in mining and metal works was 74, with a total power of 1100 hp. This gives a total of 7400 hp installed steam engines in industry in 1870. Making the same assumptions for usage, efficiency and coal/firewood ratio as for 1850 the result is that 735 TJ, or 5.6% was used for industrial steam engines.

Steam in agriculture

In agriculture steam engines powered locomobiles, which could not easily be employed in fieldwork like ploughing, because they were heavy and packed the soil too much. A clumsy solution to this problem was to let the locomobiles go beside the field, with wires managing the tool in the field. The first Swedish steam plough was bought in 1861, and the next one in 1868. Steam ploughs, however never became important in Swedish agriculture.[12] Instead locomobiles were mainly used for stationary work like threshing. According to Moberg thousands of locomobiles were used in the late 19th century.[13] At the turn of the century an investigation concerning machine equipment on farms was carried out.[14] It was based on 3 640 estate inventories from all over the country. 2.4% of

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[7] BiSOS, series V, *Brännvinstillverkning och försäljning*, 1873-99, p xxvi. These steam engines were however also used for grinding in agriculture.

[8] BiSOS, series D, 1870-74, year 1873, p vii.

[9] Sugarworks (sockerbruk) in contrast to sugar refineries(sockerraffinaderier), which were included in BiSOS 1870.

[10] Grain mills were not included in the statistics before 1896, and also then only the big mills were included.

[11] Beer breweries had 2235 hp in 1896.

[12] BiSOS, series D, p 120-122.

[13] Moberg, H.(1989).op.cite, p 335.

[14] The central results of the investigation are presented in Moberg,H. (1989) op. cite, p 214-218.

the farms in the investigation had locomobiles. Moberg makes a generalisation of the result to the national level and concludes that about 130 000 threshing machines existed in 1900. If 2.4% of them were powered by a steam engine, the number was 3100. It is likely that locomobile diffusion accelerated substantially during the period 1850-1900, which means that linear extrapolation back to 1870 is not an acceptable procedure. If I assume diffusion rates to be the same as in distilleries, where steam also found an early adoption, I get the result that steam locomobiles amounted to 900 machines in 1870.[15] Their power varied, but 10 hp is a reasonable average.[16] This suggests a power installation of 9000 hp in agriculture in 1870. Threshing is however only a seasonal practice. When performed by hand it often continued until January or so, but with steam it should have been possible to finish much earlier. On the other hand, locomobiles were often jointly owned by several households in threshing associations, and this should have increased the annual period during which they were used. If I assume that they were used for 6 months per year, 50 hours per week, at 2% efficiency, and 65% coal consumption, I arrive at a total coal consumption of 0.290 TWh, or 1050 TJ, which is 8 % of total coal consumption.

For 1850 there are even fewer indications on which to base an estimate. I just assume that the amounts in 1850 were 100 machines with 8 hp each, i. e. a power installation of 800 hp. With the same usage and efficiency as in 1870 they used 90 TJ coal in 1850, which is only 4% of the coal.

Steam for transportation

Steam engines were used both for land and sea transportation. The method used here for estimating coal for railways and ships is based on approximate fuel costs for these branches and prices for coal. Krantz presents fuel costs for railways from 1856.[17] For steam ships estimates are more difficult since the statistics do not distinguish between sailing ships and steam ships in internal shipping before 1873. Here the increasing ratio of steam ships/ sailing ships after 1873 has been extrapolated backwards to 1820 when the first steam ships were introduced.[18] I have assumed that steam ships made up 1% of internal shipping volumes in 1820 and 30% in 1850, after which the increase accelerated to reach 70% in 1870. For foreign-ship trade, statistics of production values exist from 1820. Information on fuel costs for steam ships is not generally provided,

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[15] Steam engines in distilleries increased from 343 hp in 1872 to 1165 hp in 1897, i. e. 3.4 times.

[16] This figure is, of course, uncertain. It is based on occasional figures, in Finnish archive material provided by Timo Myllyntaus, in the range of 2-15 hp.

[17] Historiska Nationalräkenskaper för Sverige: Transporter och kommunikationer 1800-1980. Table T30, p 145.

[18] In 1873 the ratio was 71%, in 1890 it was 82% and in 1913 it was 90%.

but figures for a few companies exist and they indicate that 8% of the gross production volume was fuel costs both in 1850 for one company and in 1870 for another company involved in foreign shipping. These figures cannot be considered reliable, since we only have two observations. In 1913, for which better information is provided the fuel cost share was 14%. I make the assumption that the cost share was 14% throughout the period. Prices of coal have been taken from Ljungberg and combined with Schön's price index for coal.[19] I find that coal consumption for transportation came to 25 100 tons in 1851, which is 30% of the coal. Transportation in 1870 used up 167 500 tons of coal, i. e. 37%.

The procedure to calculate all ship coal involved in foreign shipping as bought in Sweden is of course wrong in principal; however since foreign ship coal only made up 4% of all ship coal in 1851 and 11% of transport coal in 1870, the trouble of deciding how much of the coal was actually bought in foreign harbors, has not been considered necessary to undertake. The bias of this neglect is a certain exaggeration of coal apportioned to transportation in my estimate.

Coal for gasworks

Gasworks statistics of coal consumption are available from 1913.[20] From 1874 there is information of total gas production, but not of the coal consumption.[21] For 1860 and 1870 there are overviews of gas production.[22] In 1870 the gas production was 6.4 million m^3. How much coal was used for this production? 320 m^3 gas was produced from one ton of coal in 1913. If the same coal to gas relationship was valid in 1870 the gasworks' coal consumption was 20 000 ton. The total coal consumption in 1870 was 443 000 tons, implying that gasworks were responsible for 5% of total coal consumption then. If I instead use the relationship between coal and gas in Malmö gaswork for 1895, which was 290 m^3 gas /ton coal, and extrapolate the technical development back to 1870, the relation is 250 m^3 gas /ton coal.[23] With that assumption I get an estimate of coal consumption by gasworks of 25 600 ton; still only 6% of the total coal consumption.

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[19] Ljungberg, J.(1990), op. cite, table 1.10, p 345, lokomotivkol. Prices for Schön's index have been taken from Hansen, S.-A.(1974): Ökonomisk vaekst i Danmark, band 2, Köpenhamn 1974, p 281-282.

[20] *Svenska Gasverksföreningens årsbok 1923*, p 67: A figure over coal consumption in gasworks for the period 1913-1923.The Swedish Gasworks association was formed in 1918 and they began publishing yearly statistics from 1923, but prior to that the statistics had been included in statistics from "Svenska kommunal-tekniska nämnden".

[21] BiSOS. Series: Fabriker och Manufakturer.

[22] Rygård, H.: "Gasindustriens nationalekonomiska betydelse", in *Svenska stadsförbundets tidskrift* 1913, p 219.

[23] Svenska gasverksföreningens årsbok 1925, calculated from table on p 58.

For 1850 the figures are even more uncertain. Schöns' production values combined with gas quantities in National Income of Sweden (N.I.) and the efficiency of gas production in Gothemburg in 1848 suggest that gasworks consumed 1020 ton coal, or 1 % of the total coal.[24]

Gasworks are not final consumers of coal; it is the gas and coke that actually should be reckoned in this study, but it does not seem worthwhile to attempt to do so with gasworks share of coal consumption so small. I therefore attribute coal consumption by gasworks to industry.

Coal for heat

Coal was also used for heat, both of high and low temperature. Coal and coke were used to provide high temperature heat for industrial processes and to warm dwelling premises and service premises.

The outstanding industrial branch in Sweden during this period was the mining industry, requiring large quantities of fuel for heat. Until the Bessemer process however, charcoal was the only appropriate fuel for this industry. As early as in 1709 Darby invented a process for iron production with coke, but the quality was lower than with charcoal and it was initially also more expensive. Arpi finds the share of coke in Swedish iron production negligible before 1896.[25] That the coke to charcoal ratio was very low does not of course logically imply that iron coke did not make up an important part of total coal consumption. But because total coal consumption in 1870 was approximately as large as total firewood consumption in industry (charcoal included), it means that the iron industry's consumption of coke in relation to total coal consumption was also negligible.

Other industries in 1870 used coal for heat in their production processes. Distilleries, which demanded large quantities of heat used 278 540 cubic feet of coal in 1870, and an additional 27 220 cubic feet of coke and charcoal.[26] This equals 4400 tons of coal, which only constitutes 1% of total coal consumption.[27] Breweries could not make use of coal because it inflicted a bad taste on the beer, but they could use the cleaner coke. Other industries, which required heat in their processes, probably used some coal, but there is no statistical information

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[24] Schön, L:, Industri och hantverk 1800-1990, p 55,89. Lindahl, E./Kock, K./Dahlgren, E.(1937), op. cite, part two, Appendix D, p 203. Svenska gasverksföreningens årsbok 1923: *Göteborgs gasverk och dess utveckling*, p 60.

[25] Arpi, G.(1951), op. cite, p 91ff.

[26] The main fuel for the distilleries was firewood; in 1873/74 they consumed 6 793 600 cubic feet firewood and 2 524 280 cubic feet peat.

[27] Transformation has been done according to figures from *Historisk statistik för Sverige, Utrikeshandel*. For the years 1861 and 1862 import figures are announced both in barrels and in tons, implying that 1 barrel=96 kg. One cubic foot is 10/63 barrels, and thus 15.2 kg. I have not calculated coke, since it is counted in gasworks coal consumption.

on the amounts. If I make the assumption that coal consumption/firewood consumption in distilleries in 1870 was representative of the share of coal for heat in industry generally the result is that industries in 1870 used 4% of all coal for heat. I assume that in 1850 4% of the coal was also used for industrial heat processes.

The part of coal consumption, which has not been apportioned to locomotives, ships, locomobiles, stationary steam engines, gas production or heat in industrial processes, was used directly for heating of dwelling houses and service premises. Coal for premise heating, a residual, according to my estimates, made up 50% of total coal consumption in 1850 and 40% in 1870. Households should have made up an overwhelming part of that consumption.[28]

Results

Table A.1 Coal consumption by economic sectors in 1850 and 1870

Year	Transportation		Industry (incl gasworks)		Agriculture		Households and services		Total
	PJ	%	PJ	%	PJ	%	PJ	%	PJ
1850	0.72	30	0.31	13	0.090	4	1.3	53	2.4
1870	4.8	37	2.0	15	1.0	8	5.2	40	13.1

This result is surprising; I did not expect that such a large share of the coal would be used for the heating of dwelling premises and service premises. Whether this application of coal made economic sense is discussed in chapter 5. I see no reason to suspect that all the components of the coal consuming activities above have been systematically overestimated, which would result in a too large residual and an exaggeration of the coal for heating. Granberg however, found no traces in the literature of any substantial coal consumption by households in Stockholm in 1850.[29] Yet Stockholm was one of the places where firewood was relatively expensive compared to coal, so household coal consumption could be expected to be relatively large there. One explanation for this puzzle is probably that in 1850 a large share, 22%, of the coal was of domestic origin and that coal was consumed locally in southwestern Sweden and not in Stockholm.[30] Domestic coal was of inferior quality and was probably

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[28] In appendix D the estimated coal consumption in 1870 was 4.4 PJ for households and 0.8 PJ for services.

[29] Granberg, B.(2001) *Stockholmshushållen och närmiljön, 1850, 1900 och 1950*. opublicerat arbetspapper (HUSUS), Institutionen för ekonomisk historia vid Stockholms universitet och Forskningsgruppen för Miljöstrategiska Studier, Stockholm.

[30] This share is based on heat content not on weight.

largely consumed by households.[31] In 1870, the share of domestically produced coal was only 6%. This reduction of the domestic share between 1850 and 1870 coincides with the reduced share of the residual (the heating share). An additional possible explanation for why Granberg did not detect any traces of coal consumption, only of firewood consumption, for 1850, is that firewood consumption was still so large compared to coal. Total household firewood consumption in 1850 was about 74 PJ, while household and service coal consumption together was only about 1.3 PJ.

My result of the household share of coal consumption could also be discussed in relation to the previous estimates by N. I., which suggests that households consumed 5% of the coal and 30% of the coke in 1860. [32] That estimate is however only an extrapolation of fixed actual shares in 1913-1917. Because there was a rapid decline in the household share of energy consumption in the period 1870-1913 (see chapter 3) this is not a reasonable assumption. My results of 50% in 1850 and 40% in 1870 seem more reasonable, given the households' coal and coke shares in 1913-1917 and the declining trend for households.

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[31] The Scanian coal together with domestic peat was tested as railway fuel, but the quality was too low for it to pass the test.

[32] Lindahl, E./Kock, K./Dahlgren, E.(1937), op. cite, p 252.

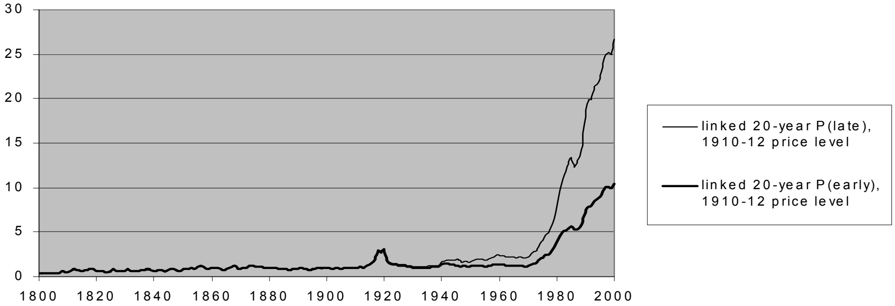
Appendix B

Energy deflators

One problem in constructing price deflators is the lack of a given base year. The choice of early or late base years will produce different results if changes in relative quantities as well as in relative prices take place during a deflating period. A normal feature of economic growth is a dominance of positive Gerschenkron-effects, i. e. relative growth of production with relative decreasing prices, which may be called a supply-dynamic scenario, although some periods may be dominated by negative Gerschenkron-effects, i. e. relative growth of production with relatively increasing prices, which may be called a demand-dynamic scenario. For energy production there have been strong dynamics on the supply side. For instance, electricity has played a larger role in the energy system at the same time as electricity production has become more and more efficient, which has lowered the price of electricity relative to other energy carriers. Also, the increased use of coal and oil at falling relative prices meant positive Gerschenkron effects. After the oil crises, when electricity, coal and bio-energy increased their relative role at falling relative prices, and oil consumption declined at rising prices, the positive Gerschenkron effects were also strong. In a period of Gerschenkron effects the magnitude of differences with early and late base years of the price indices depends on the lengths of the deflating periods, which are linked together for the period. There are in general smaller deviations between price indices with early and late base years the shorter the deflating periods are. The aim of this appendix is to report the different outcomes for early and late base years for energy deflators with various lengths of the deflating periods, to demonstrate this effect.

The first examples of energy price deflators have 20-year periods linked together to long indices and are presented in figure B.1. The discrepancy is negligible for the early and late deflators with 20 years periods, until 1940, after which the expansion of technically progressive energy carriers like electricity, at falling relative prices, makes the gap widen. After the oil crises the positive Gerschenkron effects are also very strong. The deflator with late base years is around 2.5 times as large in 2000 as the one with early base years. With shorter deflating periods, and consequently smaller changes in relative prices and quantities, the gap becomes smaller. Different lengths of the deflating periods (5-years, 2-years, 1-years) have been tested.

Figure B.1 Energy deflators 1800-2000 with 20- year deflating periods

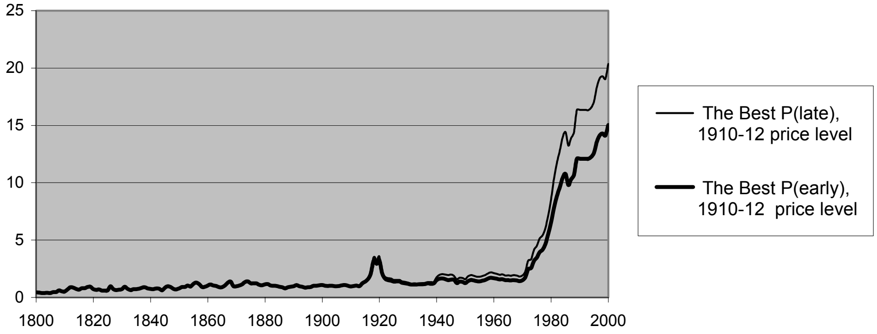


In figure B.2 the most neutral result is demonstrated, i. e. the chain indices that produce the smallest discrepancy for early and late base years. For the period 1800-1913 it consists of 5-year indices and for the period of 1913-2000 of 1-year linked indices, except for the wars. During the war periods it turned out better to use longer deflating periods (5-7 years).

The best indices with late and early base years are fairly alike until 1980, after which the drastic changes in relative prices and quantities of energy carriers result in a widening gap. In 2000 the index with late base years is 35% larger than the one with early base years. This is not negligible, but still much better than the 150% with 20-year periods.

I use the best index with early base years in my energy volume accounts and economic energy intensity measures. This seems most appropriate, since the GDP and sector deflators also have early base years. The energy volumes will grow more rapidly with the price deflator with early base years than they would if I had used the price deflator with late base years.

Figure B.2 The most neutral energy deflators 1800-2000



Revised price deflators for the GDP and for the economic sectors.

By Lennart Schön and Astrid Kander

The price deflators of each sector and of GDP constructed in the project of Swedish historical national accounts, consist of 9 periodic indices linked together to one long index for the period 1800-1980. The periods are approximately 20 years' long. They have been chosen to capture periods of structural change and are the following: 1800-1826, 1826-1848, 1848-1869, 1869-1888, 1888-1910, 1910-1929, 1929-1954, 1954-1969, 1969-1980. Early base years have consistently been chosen.

The aim of the periodization is to facilitate analyses of structural transformation versus structural stability in the economy; i.e. to analyse the combined structure of prices and quantities in the economy. For this objective the deflators are appropriate, but in periods of strong structural change they may give a bias in the growth rates of sectors and GDP. To avoid such effects it is appropriate to use chain deflators of 1-year periods linked together.

We have made a revision of the existing deflators in the following way. The price deflators of the branches are regarded as neutral price series, although they may have some minor bias due to structural changes within the branches. An investigation of the industrial sector has shown that structural changes internal to the branches are rather weak.[1] Thus, changes in the structure of prices and quantities are less usual at the branch level than at the sector level or the GDP level. These branch deflators are used to recalculate chain indices for sectors and for GDP in the following manner. The sum of the value added in branches in current prices is divided by the sum of the value added calculated in the prices of the preceding year. Thus, the formula for the calculation of a sectoral deflator with annual links is: $(\text{vabranch}_1 + \text{vabranch}_2 + \ldots \text{vabranch}_n)/(\text{dfbranch}_1(-1)/\text{dfbranch}_1 * \text{vabranch}_1 + \text{dfbranch}_2(-1)/\text{dfbranch}_2 * \text{vabranch}_2 + \text{dfbranch}_n(-1)/\text{dfbranch}_n * \text{vabranch}_n)$, where "va" means value added, "df" means deflator (i.e. price index) and (-1) denotes the value in the previous year.

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[1] Schön, L. (1990) op. cite.

Table C.1 Economy-wide and sector deflators 1800-1980 with annual and 20-25 year deflating periods. Annual percentage change.

Sector	One year deflating periods	20-25 year deflating periods	Effect on annual growth rate with one year deflation period
Agriculture with subsidiaries	1.73	1.79	0.06
Industry and handicrafts	0.96	0.89	-0.07
Transport and communication	0.70	0.68	-0.02
Private services	1.71	1.61	-0.10
Public services	2.50	2.47	-0.03
GDP	1.92	1.88	-0.04

In general the differences in results with the two constructions are not very large for the whole period 1800-1980. For the entire GDP there is only a slightly increased price rise (+0.04 percent per annum) with annual links and a consequently slightly reduced annual growth rate (-0.04 percent per annum) over the period of 180 years. The effect is, however, different for the 19th and 20th centuries. In the period 1800-1890 the deflator with annual links gives a 0.11 percent higher annual growth rate (lower price increase) while the effect is reversed for 1890-1980 with a 0.14 lower annual growth rate (higher price increase). The latter effect was particularly strong for the period 1890-1960. The reason is that up to the 1890s, sectors with a relatively increasing price level also increased their share of GDP (that is agriculture and services), while from the 1890s up to the 1950s the opposite was the case with increasing shares of industry and transport & communication. It was also the case that the structural change within the sectors changed in this direction after the 1890s with increasing shares for production with relatively decreasing prices. In private services, for instance, the share of domestic services declined while new professional services within banking, insurance and trade increased, which explains the relatively large structural effect in that sector.

Table C.2 Deflators of the industrial sector 1800-1980 with annual and 20-25 years deflating periods, annual percentage change.

Period	One year deflating periods, annual percentage change	20-25 year deflating periods, annual percentage change	Effect on annual growth rate with one year period
1800-1870	0.93	0.98	0.05
1870-1895	-1.39	-1.20	0.19
1895-1910	0.88	0.13	-0.75
1910-1945	0.91	0.81	-0.10
1945-1955	5.54	4.95	-0.59
1955-1980	4.06	4.03	-0.03
1800-1980	0.96	0.89	-0.07

One can, furthermore, discern structural effects of varying strength and direction within the industrial sector, shown in table C.2. For the whole period the effect of different deflation techniques was not very strong (a difference of 0.07 percent annually). But in some periods of strong structural and technical change the effect was considerable.

Thus, the structural effects are similar to those of the whole economy in the sense that short deflation periods give a somewhat higher growth rate before the 1890s and a somewhat slower one thereafter. The reason is mainly that up to the 1890s raw material based products with a rising relative price became more important (it was particularly the sawmill industry), while after that date technologically more sophisticated products with falling relative price increased in importance. Thus, periods of sharp breakthroughs of technologically new products – such as around 1900 and 1950 – show the largest differences in price change and in growth rates with the two methods. Between 1895 and 1910 annual growth rates in industrial production fall from 4.9 to 4.2 when shifting from 20-year to one-year deflation periods.

Appendix D

Household and service energy consumption

Household and service energy consumptions are related since both mainly consist of the heating of premises. They are also related in the sense that there are few statistics. Sometimes they are combined in statistics, which give the sum of their energy consumption.

It is necessary to know the service energy consumption for calculating the total energy consumption, since the firewood component is calculated bottom–up. Figures of service energy consumption are of course also necessary for structural analyses. The ratio between household energy consumption (final energy consumption) and energy inputs in the formal economy (intermediate energy consumption) determines the relevance of studying structural and technical changes in production in the search for explanations of the historical energy/GDP ratio. If the bulk of energy consumption is outside production (by households) it makes little sense to search for explanations of overall energy intensity within production. Then changes in household consumption, not least in households' share of total energy consumption, are more relevant.

It is not clear how final energy consumption is to be separated from intermediate energy consumption for the 19th century, since several work-related activities were performed in people's homes. Household energy consumption may therefore be regarded in two different ways. One way is to regard it wholly as an input for production, especially for services and handicrafts, which to a large extent were performed in homes. The other way is to treat household energy consumption as a final consumption, which is the normal procedure in national accounts. There is no optimal method, but I have chosen to regard all household energy as final energy consumption. This becomes more accurate over time, and the inherent bias of underestimating intermediate energy for the 19th century should be remembered when interpreting the results.

The primary similarity between service energy and household energy is that the bulk consists of heating. In both cases the space to heat is related to the number of persons (either in service occupation or in the population). A difference is that larger residences are a more likely outcome of increased income/capita in the long run than larger heated area per employee in the service sector. Once optimal productive working conditions have been achieved in the service sector, every further increase in heated area per employee only represents an increased cost, thus reducing profitability. Dwelling area on the other hand is an end in itself, and therefore tends to become larger, if not infinitely so at least up to high income levels, i. e. historically one can observe a rather high income elasticity for space and heating.

I assume that heating standards developed evenly in services and households until the turn of the century, after which heating standards in households developed more quickly. The justification of that assumption is merely that there was a rapid increase in the heating standards of service premises in the late 19th century, probably about equal to the increase in household heating standards, which mainly expressed itself in a transition from non-heated premises to heated ones. Once a majority of the service buildings were heated, I believe their standard development was less impressive than for households.

The increased heating of service premises in the late 19th century was related to the rapid economic development of the time. During the period of rapid industrialization in Sweden consumption and commerce increased rapidly. Increasing turnover would make heating costs a decreasing part of the total costs, and a more comfortable indoor climate was perhaps effective to attract customers. People also moved to the cities and the service sector generally expanded. This modernization resulted in many new buildings for service purposes and it is reasonable to assume that these buildings were equipped with stoves to an increasing degree.

Trade provides a concrete example of service heating development. It made up the largest part of private service production from the 1860s. During the first half of the 19th century trade was concentrated to the cities. In 1846 there was a new law allowing for free trade in the countryside outside a range of thirty km from the cities, and in 1864 the deregulation was complete.[1] After the late 1840s shops (handelsbodar) were established in the villages and from the mid 1860s these new enterprises appeared all over the country. In many cases the enterprise started in an existing building like an inn, and only after it was well established was a special building constructed. Prior to the 1870s, shops were normally not heated unless they were located in former inns where stoves already existed.[2] In 1930, shops were in general heated, which means that there was a change from non-heated to heated shops in the period 1870-1930.

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[1] Ulväng, G.:"Handelsbodar i Lagunda härad", *Lagunda Hembygdsförenings Skriftserie*- Nr 5, p 3.

[2] Saxon, J.L.:"*I handelsbod på 1870-talet"*, Stockholm, 1932, p 16:"Och som eldstäder ej funnos i handelsbodarna blev det (…) förfärligt kallt i dem. Söderbergs bod liknade alla andra däri att den ej hade eldstad. Det var då ej ovanligt att biträdena hade händerna mer eller mindre fulla av kylknölar"

Estimates

Separate data for household and service energy consumption exist only for the period 1970-1990. For 1913 there is enough information to create separate benchmarks for those two sectors. The relationship between the energy consumption of the two sectors in 1913 forms a starting point for a distribution key. Total energy for heating of dwelling premises and service premises is presented for 1936 and 1955.[3] They have to be separated and for that purpose a distribution key is constructed, based on the fact that employment in the service sector rose and on the assumption that heating standards developed more quickly in households.

Prior to 1913 service energy consumption is assumed to have increased its proportion of household energy in line with the increased service employment outside dwellings.

The period 1913-1990

My aim is to create a series for the period 1913-1970. The years 1913, 1936 and 1955 serve as benchmarks and the series is created through linear interpolation. There is data for the period 1970-1990.[4]

The year 1913 serves as a base for establishing a relationship between energy for dwelling premises and energy for service premises. Even for 1913, complete information is not available, which means that some assumptions have to be made. One assumption is that energy consumption per employee was the same in private services and municipal services as in government services. Another assumption is that per capita output in government services was the same as in other public services.[5] A third assumption is that the proportion of coal compared to firewood was substantially higher in government services, which were mainly located within the cities, than in municipal or private services. For municipal services and private services, I assume the same coal to firewood proportion as for households at the time. The distribution of coal between households and municipal and private services and the firewood consumption in municipal and private services are obtained through solving an equation system with two unknown variables. The results are that residents were responsible for 37.5% and services 8.1 % of total energy consumption in 1913 (el(S), muscle excl).

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[3] SOU 1956:46

[4] Schipper, L. et al, op. cite, NUTEK, R 1994:10

[5] Sources for 1913 were “Bränsleförbrukningen åren 1913-1917 vid industriella anläggningar, kommunikationsanstalter samt allmänna verk och inrättningar” Specialundersökning av kommerskollegium, Stockholm 1918, unpublished industrial data series from Schön (1990,1992), Historical National Accounts: offentlig verksamhet, privata tjänster och bostadsutnyttjande, my household firewood estimate and my muscle energy estimates .

SOS 1956:46 claimed that residents + services made up 45.6% of total energy consumption (el(S), muscle excl) in 1936 and 39.9% in 1955. Those figures are taken as valid here. I modelled the changed distribution as a function of the increased employment in the service sector (74% between 1913 and 1936 and 38% between 1936 and 1955) and the increased residential area/capita (20% between 1913 and 1936 and 29% between 1936 and 1955). The results were that dwelling premises consumed 35% of total energy and services 11% in 1936. In 1955 the share was 30% for dwelling premises and 10% for services.

I compared the results with the results of simply assuming a linear increase for the period 1913-1970 in the proportion of service energy consumption in relation to residential energy consumption. The results of linear interpolation were that the dwelling share of total energy consumption was 35% in 1936 and 29% in 1955. In 1936 the result was thus the same with the two methods and in 1955 the difference in outcome was only one percentage unit. The second method has the advantage of being simpler. The first method is better in the sense that it uses data, which, together with my assumption, provide the new distribution keys, instead of just interpolating values, and it is the one I have chosen.

Household energy is not restricted to energy for dwelling premises. Households also use energy for private transportation, which should be added to the figures above. Energy consumption by cars was not provided separately in the statistics, but only mentioned in consumption by lorries. The apportioning between cars and lorries was made according to the number of vehicles of the respective kinds in 1936 and 1955, and their relative energy consumption/vehicle in 1970[6]. For 1970 to 1990 Schipper (1994) was used. Food consumption is estimated in chapter 2. The part of the food consumption, which is consumed in leisure time is counted as final consumption.

Firewood for service consumption, which should be estimated and added to the aggregate energy measure, is estimated in the benchmark years 1936 and 1955 in the following manner. I calculated that the household firewood compared to coal share was 1.5 times bigger than the share of service firewood compared to coal in 1913. In 1970 the household firewood to (fossil fuels + electricity) share was 1.9 times bigger than service firewood to (fossil fuels + electricity). I assumed a linear increase from 1.5 to 1.9 in the period 1913-1970. The result is that household firewood to (fossil fuels + electricity) share was 1.66 times as large as the service firewood to (fossil fuels + electricity) share in 1936. In 1955 the household firewood share was 1.8 times larger than the service share. With these assumptions it is possible to calculate the service

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[6] Sources: *Historisk statistik för Sverige, översiktstabeller*, Schipper et al (1994).

firewood consumption.[7] In 1936 it amounted to 17.3 PJ and in 1955 to 10.2 PJ. I used linear interpolation for 1913-1936, 1936-1955, and 1955-1970, except for the war years when service firewood consumption is supposed to have increased to the same relative extent as household firewood consumption. For the period 1970-1990 Schipper's figures are used.

The period 1870-1913

There are no benchmark values for the period 1870-1913. There are only my estimates of household energy consumption and data for service employment. I consider it likely that heating standards in service premises per employee increased at least at the same pace as in dwelling premises per capita during this period. For simplicity and lack of contrary indications I assume the same increase in heating standard for households and services. I therefore extrapolate service energy consumption as a function of household energy consumption based only on the increase in the service employment ratio between 1870 and 1913.

The service employment ratio increased by 85% from 1870 to 1913.[8] I get the result that service energy consumption made up 12% of household energy consumption in 1870.[9]. I estimated that about 40%, or 5.2 PJ of the coal was used for heating of houses and service buildings in 1870.[10] With an assumption of the same relative difference in coal consumption between government

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[7] In 1936: hfw=72.5, h(foss+el)=x, sfw=y, s(foss+el)=z. We have the following three equations: (1): (72.5+x)=0.33(423.4+y), (2): y+z=0.11(423.4-19.4+y), (3):1.66y/z=72.5/x. The solution is that x=72.9, y=17.3 and z=29.0
In 1955: hfw=49.9, h(foss+el)=x, sfw=y, s(foss+el)=z. We have the following three equations: (1): 49.9+x=0.30(671+y), (2): y+z=0.10(671+y-8.8), (3): 1.8y/z=49.9/x. The solution is that x=154.5, y=10.2, z=57.0

[8] Paid household work is excluded, since it obviously did not cause energy consumption outside the dwellings. The series for service employment for 1870-1910 is estimated by Schön, and is so far unpublished. It is based both on Jungenfelt, K.:"*Löneandelen och den ekonomiska utvecklingen*", Uppsala 1966 and on " *Historical Statistics of Sweden , part 1: Population* ". Jungenfelt does not provide figures for private services until 1910, but does so for public services and transports for the period 1870-1950. The historical statistics, on the other hand, only provides aggregate estimates of the proportion of the population engaged in transport and private services, where all family members are apportioned to the same occupation as the master. Schön first estimates the actual employment ratio in the other parts of the society (agriculture, industry, construction, paid housework, public services) for all years 1870-1910 and then assumes the same ratio for private services and transport, for which he calculates the employment figures. From this aggregate he then subtracts the employment in transports provided by Jungenfelt and so obtains figures for employment in private services for the period 1870-1910. All the figures are then slightly modified due to the linking of these employment series to series in population accounts 1950-1970 (Statistical Yearbook of Sweden)

[9] The proportion of service consumption to household consumption in 1913 was 23%. In 1870 the service employment ratio (service employment/total population) was only 54% of the service employment ratio in 1913. Thus service energy consumption in 1870 was 0.54*23%, i.e. 12%.

[10] See Appendix A.

services and other services as in 1913 I get the result that service coal consumption was 0.76 PJ, while service firewood consumption was 9.5 PJ in 1870. Household coal consumption was then 4.4 PJ.[11]

The period 1800-1870

For the period 1800-1870, I use the production figures for services instead of employment.[12] I assume that the increase in service production performed outside the homes for the period 1800-1870 in relation to population was accompanied by the same relative increase of service to household energy consumption. During this period the increase in production volume of services (dwelling usage and paid housework are excluded) was 228%, i. e. the production volume in 1800 was only 30% of the production in 1870. With population changes also taken into account the conclusion is that service production/capita was 46% less in 1800 than in 1870. I accordingly assume that service energy consumption was 6.5% of the household energy consumption in 1800.[13] Because coal consumption at the time was insignificant all service energy consisted of firewood. Thus the service energy consumption was 4.9 PJ of firewood in 1800.

Results

The household share of total energy is reported in figure 3.1 of chapter 3. In table D.1 the service energy consumption is presented. The construction of service energy consumption is rather rough, especially for the period 1800-1913. The results are not suitable for detailed analyses of annual changes in the service sector per se but, given that my assumptions above are sound, they can serve as bases for analyses of changes at the sector level of the economy.

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[11] In government service for 1913 we get the result that the coal/firewood proportion was 5.2 times the proportion in other services (if we assume the same relative proportion between households and services other than state). 28% of the people employed in services (not counting people in paid housework) were employed in government services, if we assume that production volumes in state and municipal services were proportional to the number of persons employed there. This means that the service sector in general should be apportioned 1.46 times the coal/firewood proportion of households. So we have the following relations: $y+z=0.12(81.1+x)$, $x=5.2-z$, $z/y=1.46x/81.1$, where household firewood consumption is 81.1 PJ, household coal consumption is x, service firewood consumption is y and service coal consumption is z. The solution to this is $z=0.76$, $x=4.4$ and $y=9.5$.

[12] Krantz, O.:"Privata tjänster och bostadsutnyttjande 1800-1980, Krantz, O.: "Offentlig verksamhet 1800-1980". In all cases of private services, except for trade, the production estimates are based on employment and salaries. When it comes to trade a certain proportion of the industrial goods and agricultural products are regarded as traded in one way or another and so form the basis for volume of trade. However, the results for trade mainly coincide with the employment figures available for trade according to the analysis on p 89-90 in "Privata tjänster och bostadsutnyttjande".

[13] $0.54*12\%=6.5\%$

Service energy consumption was never so small that it was insignificant during the period 1800-1990 and has increased its share over time.

Table D.1 Service energy consumption in Sweden certain years 1800-1990.

Year	Firewood (PJ)	Coal (PJ)	Total (PJ)	% of total energy
1800	4.9		4.9	5.5
1870	9.5	0.76	10.3	7.5
1913	7.9	15.4	25.8	8.1
1936	17.3		46.4	11
1954	10.2		61.5	10
1970	2.0		204	13
1990	0.7		196	13

Comment: The share of total energy in the last column is calculated without muscle energy.

Appendix E

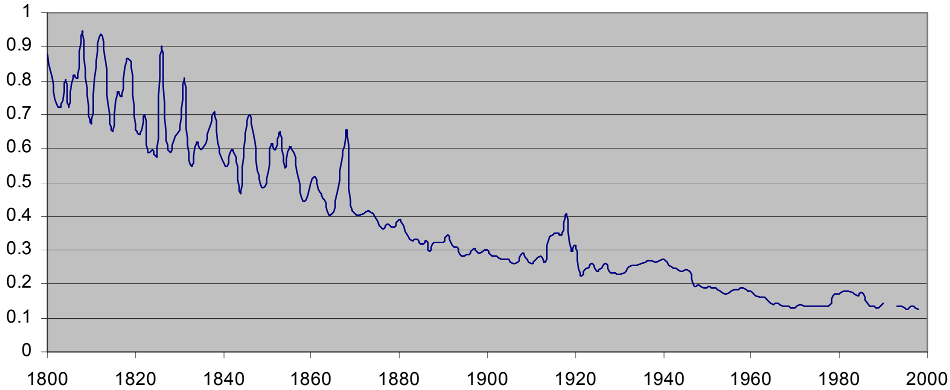
The consumers' surplus

In this appendix I will specify the assumptions I have made regarding price elasticities for different energy carriers in different periods of time, which form the basis for the calculations of the consumers' surplus and the augmented energy quality factor.

First of all the energy carriers were ordinally ranked as follows: firewood, muscle, coal, oil, electricity, with falling price elasticities, due to the number of various applications for each energy carrier. Muscle energy was admittedly the most difficult to rank, but was given a rather high price elasticity because it cannot be used for light or heat production, only for motion, but there it is very flexible. This ordinal ranking was "translated" into the following cardinal ranking in 1890: firewood: -0.4, muscle:-0.3, coal: -0.2. oil:-0.15, electricity:-0.1.

The long period 1800-2000 was divided into 5 periods, 1800-1890, 1890-1913, 1913-1950, 1950-1970, 1970-2000, chosen especially with regard to the timing of increased possibilities for substitution between the energy carriers. For each period it was essential to determine whether to insert a time trend or not. This decision was based on comparisons of the two factors that determine the price elasticity of demand: a) what proportion of people's income is spent on energy and b) the possibilities for substitution between the energy carriers. The larger the proportion of income and the more possibilities for substitution the larger is the price elasticity of demand. This means, for instance, that if the energy cost/income ratio decreases at the same time as the substitution possibilities increase, no certain conclusion regarding the trend in price elasticities can be drawn. But if the income share is constant or increases at the same time as the possibilities for substitution increase, this implies a trend of increasing price elasticity. The measure I use for income's share of energy is the energy volume divided by GDP, both expressed in current prices, because current prices best reflect the relationship between energy costs and GDP at the different points in time. Figure E.1 depicts the income share of energy.

Figure E.1 The income share of energy 1800-2000



Comments: The income share is calculated as the ratio between energy volumes and GDP, both expressed in current prices.

In the period 1800-1890 no time trend for price elasticity was assumed, because the share of income fell at the same time as there were increasing possibilities for substitution both with the steam engine, which enabled firewood and coal to be substituted for muscle energy and with the falling relative price of coal, which made coal a competitor to firewood for heat. The net effect is however difficult to assess. In the period 1890-1913 the proportion of income was rather constant, while the substitution possibilities increased with the internal combustion engine and with the introduction of electricity. This means that there was a trend of increasing price elasticity. In the period 1913-1950 there was a decrease in the income share and the possibilities for substitution increased somewhat with the expansion of the electricity network and the electric railways. Because of the decreasing income share and moderate new possibilities for substitution I assume constant price elasticity for this period. After 1950 the picture changed. The possibilities for substitution increased substantially with the introduction of oil on the heating market. Between 1950 and 1970 there was a certain reduction in the income share, but this is supposed to be outweighed by the increasing possibilities for substitution, and I assume increasing price elasticity. In the period 1970-2000 the income share was constant and the possibilities for substitution increased with electric heat and district heat, so for this period I also assume increasing price elasticity.

The elasticities of table E.1 are used in the calculation of the consumers' surplus.

Table E.1 Assumed elasticities for the energy carriers 1800-2000

	1800-1890	1890-1913	1913-1950	1950-1970	1970-2000
firewood	-0.4	-0.4 to -0.5	-0.5	-0.5 to-0.6	-0.6 to -0.7
muscle	-0.3	-0.3 to -0.4	-0.4	-0.4 to -0.5	-0.5 to -0.6
coal	-0.2	-0.2 to -0.3	-0.3	-0.3 to -0.4	-0.4 to -0.5
oil		-0.15 to -0.2	-0.2	-0.2 to -0.3	-0.3 to -0.4
electricity		-0.1 to -0.15	-0.15	-0.15 to -0.2	-0.2 to -0.3

For the sake of simplicity, the demand curves are supposed to be linear. This means that the consumer surplus can be calculated as $Q^2/2a$, where a=dQ/dP (or the slope of the linear curve) and dQ/dP=elasticity*Q/P (because the price elasticity of demand is defined as: (dQ/Q)/(dP/P), a relative quantity response on a relative price change). With known values of price (P) and quantity (Q) and assumed values of price elasticity, it is hence possible to calculate the consumer surplus.

Generally the relationship between price elasticity and consumer surplus is that the higher price elasticity the lower the consumer surplus (ceteris paribus). This means that assumptions of trends play a role for the outcome of the consumer surplus. Sensitivity analyses, where I make alternative assumptions on the magnitude of trends from no trends at all to smaller rates of changes, show that the trend assumption is particularly crucial for the period 1970-2000, where the ratio “consumers’ surplus/energy volume” increases without trend in the price elasticities and is constant with a weaker trend (1950-2000: firewood:-0.5 to -0.6, muscle -0.4 to -0.5, coal -0.3 to -0.4, oil: -0.2 to -0.3, electricity:-0.15 to -0.25), and decreases with the trend above. For the other period with a trend (1890-1913) the results remain more robust with alternative trend assumptions.

Appendix F

Table F.1 Energy, PJ

	draught animal energy	human energy	humene for work	humene for final consumption	total animate energy	firewood Households	firewood industry	firewood service	firewood power	total firewood	spent pulp-liquor	coal	oil
1800	12.60	9.29	1.56	7.73	21.89	75.90	7.62	4.9	0	88.42		0.234	
1801	12.70	9.33	1.57	7.75	22.03	75.63	7.85	5	0	88.44		0.349	
1802	12.80	9.40	1.59	7.81	22.20	75.66	7.33	5	0	88.02		0.222	
1803	12.90	9.47	1.60	7.87	22.37	75.66	7.87	5.1	0	88.62		0.353	
1804	13.00	9.54	1.62	7.92	22.54	75.62	7.52	5.2	0	88.29		0.428	
1805	13.13	9.61	1.64	7.98	22.74	75.66	7.79	5.2	0	88.67		0.298	
1806	13.20	9.65	1.65	8.00	22.85	75.33	7.98	5.3	0	88.60		0.569	
1807	13.30	9.69	1.66	8.03	22.99	75.14	7.01	5.3	0	87.49		0.69	
1808	13.40	9.65	1.66	7.99	23.05	74.23	6.74	5.4	0	86.37		0.925	
1809	13.50	9.57	1.65	7.92	23.07	73.01	4.41	5.5	0	82.88		0.79	
1810	13.61	9.58	1.65	7.93	23.19	72.55	4.36	5.5	0	82.44		0.559	
1811	13.70	9.65	1.67	7.98	23.35	72.47	4.74	5.6	0	82.80		0.374	
1812	13.80	9.68	1.68	8.00	23.48	72.16	5.09	5.7	0	82.91		0.445	
1813	13.86	9.71	1.69	8.02	23.57	71.78	5.15	5.7	0	82.65		0.372	
1814	13.90	9.77	1.71	8.07	23.67	71.66	5.08	5.8	0	82.52		0.335	
1815	13.97	9.88	1.73	8.15	23.85	71.90	5.4	5.8	0	83.15		0.485	
1816	14.10	10.02	1.76	8.26	24.12	72.30	6.77	5.9	0	84.97		0.573	
1817	14.20	10.12	1.78	8.34	24.32	72.43	6.85	6	0	85.25		0.552	
1818	14.30	10.23	1.80	8.42	24.53	72.59	7.13	6	0	85.75		0.394	
1819	14.40	10.29	1.82	8.47	24.69	72.46	7.58	6.1	0	86.13		0.47	
1820	14.46	10.39	1.84	8.55	24.85	72.53	7.85	6.2	0	86.54		0.458	
1821	14.52	10.50	1.87	8.64	25.02	72.69	7.34	6.2	0	86.25		0.458	
1822	14.58	10.65	1.90	8.75	25.23	73.09	7.01	6.3	0	86.39		0.469	
1823	14.64	10.83	1.94	8.89	25.47	73.68	7.56	6.3	0	87.58		0.503	
1824	14.68	10.99	1.97	9.02	25.67	74.11	7.69	6.4	0	88.21		0.511	
1825	14.71	11.17	2.01	9.17	25.89	74.70	7.78	6.5	0	88.95		0.409	
1826	14.77	11.31	2.04	9.28	26.08	74.99	7.68	6.5	0	89.21		0.514	
1827	14.83	11.41	2.06	9.35	26.24	74.98	7.06	6.6	0	88.64		0.613	
1828	14.90	11.50	2.08	9.41	26.40	74.85	7.33	6.7	0	88.85		0.441	
1829	14.95	11.57	2.10	9.47	26.52	74.65	6.21	6.7	0	87.58		0.445	
1830	15.01	11.68	2.12	9.55	26.69	74.66	6.33	6.8	0	87.78		0.655	
1831	15.06	11.73	2.14	9.59	26.79	74.35	6.45	6.8	0	87.65		0.482	
1832	15.12	11.83	2.16	9.66	26.95	74.26	6.35	6.9	0	87.52		0.487	
1833	15.18	11.98	2.20	9.78	27.16	74.53	6.18	7	0	87.69		0.503	
1834	15.24	12.09	2.22	9.86	27.33	74.48	5.98	7	0	87.49		0.68	
1835	15.29	12.26	2.26	10.00	27.56	74.86	6.61	7.1	0	88.57		0.858	
1836	15.34	12.41	2.29	10.12	27.75	75.03	6.84	7.2	0	89.03		0.767	
1837	15.40	12.48	2.31	10.17	27.88	74.76	6.87	7.2	0	88.85		0.696	
1838	15.46	12.55	2.33	10.22	28.01	74.42	6.85	7.3	0	88.56		0.864	
1839	15.52	12.62	2.35	10.27	28.14	74.12	7.23	7.4	0	88.71		0.947	

Table F.1(cont.) Energy, PJ

	draught animal energy	human energy	humene for work	humene for final consump-tion	total animate energy	fire-wood house-holds	fire-wood industry	fire-wood service	fire-wood power	total fire-wood	spent pulp-liquor	coal	oil
1840	15.58	12.76	2.38	10.38	28.33	74.20	7.43	7.4	0	89.05		0.97	
1841	15.68	12.90	2.41	10.49	28.58	74.31	7.41	7.5	0	89.20		0.988	
1842	15.78	13.05	2.45	10.60	28.83	74.39	7.55	7.5	0	89.48		1.338	
1843	15.88	13.18	2.48	10.70	29.06	74.36	7.36	7.6	0	89.32		1.12	
1844	15.98	13.34	2.52	10.83	29.32	74.52	6.62	7.7	0	88.81		1.108	
1845	16.09	13.52	2.55	10.96	29.61	74.73	6.13	7.7	0	88.59		1.426	
1846	16.21	13.63	2.58	11.05	29.84	74.59	7.07	7.8	0	89.45		1.343	
1847	16.33	13.72	2.61	11.11	30.05	74.27	7.3	7.9	0	89.42		1.223	
1848	16.50	13.87	2.64	11.23	30.37	74.30	7.37	7.9	0	89.58		1.818	
1849	16.62	14.06	2.68	11.37	30.68	74.50	6.59	8	0	89.09		2.024	
1850	16.74	14.23	2.72	11.51	30.97	74.62	7.31	8	0	89.97		2.448	
1851	16.87	14.38	2.76	11.62	31.25	75.00	7.86	8.1	0	90.97		2.582	
1852	17.00	14.48	2.78	11.70	31.48	75.16	7.95	8.2	0	91.28		2.59	
1853	17.13	14.59	2.81	11.78	31.72	75.30	7.7	8.2	0	91.23		2.537	
1854	17.26	14.78	2.85	11.92	32.04	75.89	8.17	8.3	0	92.35		3.085	
1855	17.39	14.92	2.89	12.03	32.31	76.22	9.33	8.4	0	93.91		3.265	
1856	17.52	15.06	2.92	12.14	32.58	76.53	8.8	8.4	0	93.75		4.691	
1857	17.65	15.13	2.94	12.18	32.78	76.47	8.9	8.5	0	93.85		5.924	
1858	17.78	15.33	2.99	12.34	33.11	77.06	9.27	8.5	0	94.88		5.7	
1859	17.92	15.55	3.04	12.51	33.47	77.79	9.85	8.6	0	96.25		7.522	
1860	18.06	15.86	3.11	12.75	33.92	78.89	10.1	8.7	0	97.63		7.48	
1861	18.17	16.10	3.16	12.94	34.28	79.68	9.95	8.7	0	98.36		9.593	
1862	18.41	16.31	3.21	13.10	34.72	80.28	11.1	8.8	0	100.18		9.803	
1863	18.50	16.55	3.27	13.29	35.05	81.03	10.8	8.9	0	100.68		9.734	
1864	18.76	16.76	3.32	13.44	35.52	81.58	11.6	8.9	0	102.13		10.32	0.026
1865	18.70	16.95	3.36	13.59	35.65	82.06	11.7	9	0	102.76		10.72	0.033
1866	18.62	17.15	3.41	13.74	35.77	82.58	12.1	9	0	103.77		11.05	0.061
1867	18.54	17.30	3.45	13.86	35.84	82.86	12.3	9.1	0	104.24		10.31	0.062
1868	18.48	17.22	3.44	13.78	35.70	82.00	12.5	9.2	0	103.64		12.04	0.133
1869	18.44	17.17	3.44	13.73	35.61	81.31	13.7	9.2	0	104.28		10.51	0.13
1870	18.39	17.22	3.45	13.77	35.61	81.09	13.6	9.3	0	104.03		13.15	0.2
1871	18.80	17.38	3.49	13.88	36.18	81.37	12.9	9.3	0	103.50		14.01	0.214
1872	19.37	17.58	3.54	14.03	36.94	81.84	16	9.2	0	107.05		17.75	0.266
1873	19.95	17.78	3.59	14.19	37.73	82.33	15.4	9.2	0	106.94		17.55	0.337
1874	19.74	17.97	3.64	14.33	37.71	82.74	12.6	9.2	0	104.50		19.2	0.366
1875	20.46	18.16	3.68	14.47	38.62	83.10	14.1	9.1	0	106.39		23.31	0.373
1876	20.60	18.36	3.73	14.62	38.96	83.54	14.8	9.1	0	107.41		24.99	0.417
1877	20.55	18.59	3.79	14.80	39.14	84.14	13.9	9.1	0	107.09		26.32	0.458
1878	20.90	18.80	3.84	14.96	39.70	84.58	13.2	9	0	106.85		22.27	0.459
1879	20.97	19.01	3.89	15.11	39.97	85.00	13.6	9	0	107.58		22.38	0.556
1880	21.02	18.96	3.89	15.07	39.98	84.30	15.6	9	0	108.86		28.83	0.5
1881	20.80	19.00	3.91	15.09	39.80	83.97	15.7	8.9	0	108.61		27.81	0.705
1882	21.27	19.04	3.93	15.11	40.31	83.65	15.6	8.9	0	108.13		31.39	0.749
1883	21.43	19.15	3.96	15.19	40.58	83.64	16.1	8.9	0	108.63		33.6	0.54
1884	21.47	19.33	4.00	15.33	40.80	83.92	16.3	8.8	0	109.06		34.9	0.994
1885	21.58	19.50	4.05	15.45	41.08	84.15	16.6	8.8	0	109.52		37.66	1.035

Table F.1 (cont.) Energy, PJ

	draught animal energy	**human energy**	**humene for work**	**humene for final consumption**	**total animate energy**	**fire-wood house-holds**	**fire-wood industry**	**fire-wood service**	**fire-wood power**	**total fire-wood**	**spent pulp-liquor**	**coal**	**oil**
1886	21.56	19.65	4.09	15.56	41.22	84.31	15	8.8	0	108.13		36.74	1.162
1887	21.31	19.74	4.12	15.62	41.05	84.16	14.9	8.7	0	107.82		37.37	1.161
1888	21.36	19.80	4.14	15.66	41.17	83.93	14.1	8.7	0	106.71		41.71	1.069
1889	21.17	19.92	4.17	15.75	41.09	83.92	14.1	8.7	0	106.71		48.16	1.871
1890	21.45	19.98	4.20	15.78	41.43	83.63	15.9	8.6	0	108.20		48.82	1.565
1891	21.53	20.04	4.21	15.83	41.57	83.47	15.4	8.6	0	107.49		51.64	1.738
1892	21.67	20.05	4.21	15.84	41.72	83.06	15.2	8.6	0	106.89		51.44	1.74
1893	21.65	20.11	4.22	15.89	41.76	82.88	14.9	8.6	0	106.31		51.9	2.026
1894	21.84	20.31	4.26	16.04	42.15	83.25	15.8	8.5	0	107.61		62	1.947
1895	22.06	20.49	4.30	16.19	42.55	83.55	15.9	8.5	0	107.93		62.17	2.453
1896	22.21	20.66	4.34	16.32	42.87	83.79	18.3	8.5	0	110.51		64.6	2.162
1897	22.37	20.85	4.38	16.47	43.21	84.09	19.7	8.4	0	112.21		71.81	2.744
1898	22.56	21.06	4.42	16.64	43.62	84.49	19.2	8.4	0	112.06		76.64	2.652
1899	22.60	21.19	4.45	16.74	43.79	84.56	17.5	8.4	0	110.46		96.47	3.063
1900	22.77	21.34	4.48	16.86	44.12	84.70	22.3	8.3	0	115.41		96.6	3.221
1901	20.41	21.49	4.51	16.98	41.91	84.83	21.2	8.3	0.1	114.39		89.42	3.265
1902	20.42	21.58	4.53	17.05	42.00	84.70	25.8	8.3	0.1	118.86		93.43	3.514
1903	20.47	21.66	4.55	17.12	42.13	84.55	23.6	8.2	0.1	116.53		102.7	4.022
1904	20.32	21.82	4.58	17.24	42.14	84.67	22.9	8.2	0.1	115.86		108.4	4.045
1905	20.48	21.95	4.61	17.34	42.43	84.70	32.3	8.2	0.1	125.32		106.3	4.385
1906	20.67	22.11	4.64	17.47	42.78	84.85	33.2	8.1	0.2	126.37		118.8	4.456
1907	20.64	22.27	4.68	17.59	42.91	84.96	31.8	8.1	0.2	125.07		135.1	4.666
1908	20.82	22.47	4.72	17.76	43.29	85.25	27.4	8.1	0.2	120.93		143.6	5.961
1909	20.94	22.66	4.76	17.90	43.60	85.44	22.1	8	0.2	115.81		132.1	5.854
1910	21.02	22.84	4.80	18.04	43.86	85.61	38	8	0.2	131.89		136.6	5.752
1911	20.95	22.99	4.83	18.16	43.93	85.67	35.1	8	0.3	128.96		133.9	6.753
1912	22.43	23.15	4.86	18.29	45.58	85.77	32.9	7.9	0.3	126.88		147.8	6.2
1913	22.43	23.28	4.89	18.39	45.71	85.74	45.8	7.9	0.3	139.73		165.4	7.328
1914	22.61	23.44	4.92	18.52	46.05	85.81	49.4	8.3	0.3	143.87		156.6	5.853
1915	23.51	23.57	4.95	18.62	47.08	85.74	50.7	8.8	0.4	145.61		159.4	6.036
1916	24.08	23.74	4.99	18.76	47.82	91.82	59.1	9.8	0.3	161.08		167.6	6.693
1917	23.71	23.91	5.02	18.89	47.61	105.57	59.1	11	0.5	176.16		69.99	2.094
1918	23.62	23.95	5.03	18.92	47.57	105.23	56	11	0.5	172.75		82.53	1.177
1919	20.08	24.07	5.06	19.02	44.15	105.25	52.8	11	0.5	169.58		74.37	5.783
1920	21.10	24.30	5.10	19.20	45.40	85.70	48.4	11	0.5	145.54		102.7	6.462
1921	19.70	24.49	5.14	19.35	44.19	85.33	30.1	11	0.4	127.11		58.09	5.465
1922	19.67	24.62	5.17	19.45	44.28	84.70	31.3	12	0.1	127.90		101.4	6.6
1923	19.61	24.68	5.18	19.50	44.29	83.85	31.7	12	0.1	127.78		123.4	8.055
1924	19.76	24.79	5.21	19.59	44.55	83.17	38.4	13	0.1	134.25		148.6	9.424
1925	20.32	24.85	5.22	19.63	45.18	82.29	34.4	13	0.1	129.77		130.5	11.22
1926	19.78	24.93	5.23	19.69	44.71	81.45	34.7	13	0	129.64		126.1	12.33
1927	19.72	24.97	5.24	19.73	44.69	80.51	33.1	14	0	127.55		180.9	13.64
1928	19.76	25.03	5.26	19.77	44.79	79.62	32.9	14	0.1	126.86		161.3	16.87
1929	19.60	25.08	5.27	19.81	44.68	78.68	37.3	15	0.1	130.78		194	18.36
1930	18.90	25.16	5.28	19.87	44.05	77.83	33.7	15	0	126.69		185.5	22.42

Table F.1 (cont.) Energy, PJ

	draught animal energy	human energy	humene for work	humene for final consumption	total animate energy	fire-wood house-holds	fire-wood industry	fire-wood service	fire-wood power	total fire-wood	spent pulp-liquor	coal	oil
1931	19.01	25.23	5.26	19.97	44.24	76.95	28	16	0	120.58		185.1	24.09
1932	19.30	25.33	5.23	20.09	44.63	76.16	23.6	16	0	115.75		180.2	27.54
1933	19.16	25.40	5.21	20.20	44.56	75.28	26.7	16	0	118.49		187.4	29.47
1934	18.94	25.48	5.18	20.30	44.42	74.39	30.7	17	0.1	122.06		209.3	30.8
1935	17.60	25.54	5.15	20.39	43.14	73.45	31.5	17	0.1	122.29	0.00	217.6	35.21
1936	15.88	25.59	5.12	20.48	41.47	72.48	31.9	17	0.1	121.71	0.79	239.4	40.24
1937	14.82	25.65	5.09	20.57	40.47	71.53	32.8	17	0.1	121.36	1.21	276.3	45.95
1938	13.74	25.74	5.06	20.68	39.48	69.79	32.2	17	0.1	118.66	2.55	239	51.35
1939	12.61	25.86	5.04	20.82	38.47	140.26	34.2	32	0.1	206.93	3.25	268.5	59
1940	11.48	25.97	5.02	20.95	37.45	140.93	39.3	32	0.1	212.04	2.41	182	22.76
1941	10.54	26.10	5.00	21.10	36.63	141.70	58.4	31	0.2	231.23	2.25	156.5	5.697
1942	9.61	26.30	4.99	21.30	35.90	142.85	73.2	30	0.9	247.17	3.14	129.2	4.873
1943	8.77	26.55	4.99	21.55	35.31	144.27	68.9	29	0.4	242.95	2.65	155.3	5.135
1944	7.56	26.84	5.00	21.83	34.40	145.92	66.8	29	0.7	242.02	2.63	119.5	5.142
1945	6.83	27.13	5.01	22.12	33.96	210.00	73.7	42	0.7	326.34	4.89	24.27	7.532
1946	6.39	27.49	5.03	22.45	33.87	65.45	64.1	14	0.3	143.52	8.42	113.9	70.97
1947	5.99	27.79	5.04	22.75	33.78	65.26	44.3	13	0.5	123.26	12.91	158.7	125.1
1948	4.91	28.11	5.05	23.06	33.02	64.78	35	13	0.3	113.00	12.03	216.6	114.8
1949	4.43	28.35	5.05	23.30	32.78	64.06	30.9	12	0.3	107.81	10.89	185.5	108.7
1950	3.95	28.56	5.04	23.52	32.51	63.28	29.7	12	0.3	105.32	15.68	221	146.4
1951	3.42	28.78	5.03	23.75	32.20	60.74	26.1	12	0.3	98.85	19.99	241.2	185.3
1952	2.96	28.97	5.01	23.96	31.94	58.12	24.6	11	0.2	94.33	20.88	232.1	203
1953	2.36	29.13	4.99	24.14	31.48	55.38	22.7	11	0.2	89.28	24.30	176.9	221.7
1954	1.96	29.29	4.97	24.32	31.24	52.61	23	11	0.2	86.44	30.79	158	253.7
1955	1.60	29.50	4.96	24.54	31.09	49.89	22.3	10	0.4	82.77	35.47	179.4	319.1
1956	1.36	29.68	4.94	24.74	31.03	47.07	20.8	9.7	0.4	77.87	40.23	172.3	389.5
1957	1.26	29.86	4.92	24.95	31.12	44.23	20.6	9.1	0.3	74.23	43.80	163.3	371.6
1958	1.16	30.02	4.89	25.12	31.18	41.29	19.9	8.6	0.3	70.04	43.31	108.4	414
1959	1.07	30.13	4.86	25.27	31.21	38.27	17.2	8	0.5	63.99	48.67	106	355.1
1960	0.99	30.26	4.83	25.43	31.25	35.24	17.8	7.5	0.6	61.16	58.50	117.9	443.6
1961	0.91	30.42	4.80	25.62	31.33	32.22	18	6.9	0.8	57.88	63.50	108	439.9
1962	0.83	30.57	4.78	25.79	31.39	29.13	14.7	6.4	0.9	51.09	58.54	107	494
1963	0.85	30.74	4.75	25.99	31.58	26.04	13.2	5.8	0.9	46.00	65.73	104.7	543.4
1964	0.86	31.00	4.74	26.26	31.86	22.98	13.9	5.3	1.3	43.44	77.15	111.6	600.7
1965	0.84	31.29	4.73	26.56	32.14	19.88	12.8	4.7	1.4	38.81	83.10	94.8	638.7
1966	0.83	31.56	4.72	26.84	32.39	18.70	11.6	4.2	1	35.43	81.48	95.61	756.2
1967	0.81	31.75	4.69	27.05	32.56	17.46	10.9	3.6	0.5	32.56	87.41	80.93	713.5
1968	0.80	31.90	4.66	27.24	32.70	16.18	10	3.1	0.4	29.74	88.11	84.82	822.1
1969	0.78	32.16	4.65	27.52	32.94	14.94	9.83	2.5	0.6	27.90	94.97	76.96	926.6
1970	0.76	32.45	4.63	27.82	33.22	13.69	10.4	2	0.7	26.75	104.65	81.9	1038
1971	0.75	32.58	4.60	27.98	33.32	12.34	10.1	1.3	0.4	24.15	101.56	80.25	954.8
1972	0.73	32.61	4.55	28.07	33.35	10.96	10.6	1.1	0.5	23.20	107.25	67.24	957.3
1973	0.72	32.66	4.50	28.16	33.38	9.57	11.9	0.9	1	23.42	108.58	77.27	977.2
1974	0.70	32.77	4.46	28.31	33.47	8.20	12.9	0.7	0.9	22.72	116.52	92.66	926.8

Table F.1 (cont.) Energy, PJ

	draught animal energy	human energy	humene for work	humene for final consump-tion	total animate energy	fire-wood house-holds	fire-wood industry	fire-wood service	fire-wood power	total fire-wood	spent pulp-liquor	coal	oil
1975	0.69	32.88	4.42	28.46	33.57	6.81	10.9	0.4	1	19.08	107.37	84.87	962.9
1976	0.67	32.98	4.38	28.60	33.65	10.89	11.2	0.4	0.6	23.09	104.43	91.65	1005
1977	0.65	33.09	4.34	28.75	33.74	14.98	12.6	0.4	0.3	28.30	91.34	62.59	995.3
1978	0.64	33.14	4.29	28.85	33.78	19.06	13.6	0.5	0.8	33.90	104.49	54.65	873.5
1979	0.81	33.20	4.24	28.96	34.01	23.15	13.8	0.6	1	38.54	113.66	80.04	1014
1980	0.80	33.24	4.19	29.05	34.04	27.23	14.4	0.6	2.4	44.59	107.07	74.24	880.8
1981	0.78	33.24	4.24	29.01	34.02	33.32	17.2	0.6	4.1	55.16	105.30	59.08	707.6
1982	0.76	33.25	4.28	28.96	34.01	35.53	19.3	0.6	5.8	61.25	92.72	73.71	675.2
1983	0.75	33.24	4.33	28.91	33.99	38.29	23.1	0.6	9.4	71.38	115.46	93.21	626.3
1984	0.73	33.27	4.38	28.89	34.01	41.40	23.4	0.6	13	78.17	119.43	115.7	547.2
1985	0.72	33.32	4.43	28.89	34.03	41.68	22.8	0.7	15	80.52	114.34	147.6	602
1986	0.70	33.39	4.49	28.91	34.10	39.74	22.3	0.7	17	79.59	117.37	133.8	682.5
1987	0.69	33.51	4.55	28.96	34.19	35.25	21	0.7	18	74.67	123.94	113.8	562.1
1988	0.67	33.67	4.62	29.05	34.34	35.25	20.5	0.7	18	99.81	131.38	118.8	603.9
1989	0.65	33.92	4.70	29.22	34.58	35.25	21.2	0.7	17	94.52	125.00	120.5	529
1990	0.64	34.16	4.78	29.38	34.80	35.03	21	0.7	17	129.64	100.25	112.1	521.1
1991	0.65	34.37	4.76	29.61	35.02					150.8	103.66	106.7	496.8
1992	0.65	34.56	4.74	29.82	35.21					196.7	61.70	96.5	493.2
1993	0.65	34.77	4.72	30.05	35.42					164	108.19	96.8	490.8
1994	0.65	35.06	4.71	30.35	35.71					217.3	66.23	100.1	506.2
1995	0.65	35.14	4.67	30.47	35.79					187.8	113.95	98.5	510.5
1996	0.65	35.17	4.63	30.54	35.82					199.6	112.18	110.3	515.7
1997	0.65	35.18	4.58	30.60	35.83					204	120.25	94.2	509
1998	0.65	35.21	4.53	30.67	35.86					212.9	119.70	94.1	496.1
1999	0.65	35.24	4.49	30.75	35.89					212.7	122.56	90.7	494.1
2000	0.65	35.32	4.45	30.87	35.97					204.9	141.50	92.9	471.7

Table F.1 (cont.) Energy, PJ

	peat	gas	gross district heating	el(S)	el(E)	(fossel+fwel)/totel	energy (S)	energy (E)	total population	energy (S)/cap	energy (E)/ cap
1800							110.55	110.55	2336303	47.317	47.32
1801							110.82	110.82	2343952	47.278	47.28
1802							110.44	110.44	2361216	46.774	46.77
1803							111.35	111.35	2377619	46.831	46.83
1804							111.25	111.25	2392814	46.493	46.49
1805							111.7	111.7	2411039	46.331	46.33
1806							112.01	112.01	2417734	46.329	46.33
1807							111.17	111.17	2428599	45.776	45.78
1808							110.35	110.35	2416592	45.664	45.66
1809							106.74	106.74	2394101	44.585	44.58
1810							106.18	106.18	2396351	44.311	44.31
1811							106.52	106.52	2411382	44.173	44.17
1812							106.83	106.83	2418780	44.168	44.17
1813							106.59	106.59	2423949	43.972	43.97
1814							106.53	106.53	2438241	43.689	43.69

Table F.1(cont.) Energy, PJ

	peat	gas	gross district heating	el(S)	el(E)	(fossel+fwel)/ totel	energy (S)	energy (E)	total population	energy (S)/cap	energy (E)/ cap
1815							107.48	107.48	2465066	43.602	43.6
1816							109.66	109.66	2497484	43.908	43.91
1817							110.12	110.12	2521442	43.674	43.67
1818							110.67	110.67	2546411	43.462	43.46
1819							111.3	111.3	2561780	43.446	43.45
1820							111.85	111.85	2584690	43.274	43.27
1821							111.73	111.73	2610870	42.793	42.79
1822							112.09	112.09	2646314	42.356	42.36
1823							113.55	113.55	2689031	42.229	42.23
1824							114.39	114.39	2726877	41.949	41.95
1825							115.25	115.25	2771252	41.587	41.59
1826							115.8	115.8	2804926	41.286	41.29
1827							115.49	115.49	2827719	40.842	40.84
1828							115.68	115.68	2846788	40.636	40.64
1829							114.54	114.54	2863132	40.005	40
1830							115.12	115.12	2888082	39.859	39.86
1831							114.93	114.93	2901039	39.617	39.62
1832							114.96	114.96	2922801	39.332	39.33
1833							115.36	115.36	2959141	38.983	38.98
1834							115.5	115.5	2983055	38.718	38.72
1835							116.98	116.98	3025439	38.667	38.67
1836							117.54	117.54	3059356	38.42	38.42
1837							117.43	117.43	3076184	38.174	38.17
1838							117.43	117.43	3090262	38	38
1839							117.79	117.79	3106459	37.919	37.92
1840							118.35	118.35	3138887	37.705	37.71
1841							118.77	118.77	3173160	37.429	37.43
1842							119.65	119.65	3206776	37.311	37.31
1843							119.5	119.5	3236632	36.922	36.92
1844							119.24	119.24	3275133	36.408	36.41
1845							119.63	119.63	3316536	36.07	36.07
1846							120.63	120.63	3342927	36.086	36.09
1847							120.7	120.7	3362072	35.899	35.9
1848							121.77	121.77	3397454	35.842	35.84
1849							121.78	121.78	3441286	35.389	35.39
1850							123.39	123.39	3482541	35.43	35.43
1851							124.8	124.8	3516647	35.489	35.49
1852							125.36	125.36	3540409	35.408	35.41
1853							125.49	125.49	3563316	35.216	35.22
1854							127.47	127.47	3608124	35.329	35.33
1855							129.48	129.48	3641011	35.561	35.56
1856							131.02	131.02	3672988	35.671	35.67
1857							132.55	132.55	3687601	35.945	35.94
1858							133.69	133.69	3734240	35.802	35.8
1859							137.25	137.25	3787735	36.235	36.24

Table F.1 (cont.) Energy, PJ

	peat	**gas**	**gross district heating**	**el(S)**	**el(E)**	**(fossel+fwel)/ totel**	**energy (S)**	**energy (E)**	**total population**	**energy (S)/cap**	**energy (E)/ cap**
1860							139.04	139.04	3859728	36.022	36.02
1861							142.24	142.24	3917339	36.309	36.31
1862							144.7	144.7	3965899	36.487	36.49
1863							145.47	145.47	4022564	36.164	36.16
1864							148	148	4070061	36.364	36.36
1865							149.17	149.17	4114141	36.258	36.26
1866							150.65	150.65	4160677	36.207	36.21
1867							150.45	150.45	4195681	35.859	35.86
1868							151.51	151.51	4173080	36.307	36.31
1869							150.52	150.52	4158757	36.194	36.19
1870							152.99	152.99	4168525	36.701	36.7
1871							153.9	153.9	4204177	36.607	36.61
1872							162.01	162.01	4250412	38.117	38.12
1873							162.56	162.56	4297972	37.823	37.82
1874							161.78	161.78	4341559	37.263	37.26
1875							168.69	168.69	4383291	38.485	38.49
1876							171.78	171.78	4429713	38.778	38.78
1877							173.01	173.01	4484542	38.579	38.58
1878							169.29	169.29	4531863	37.355	37.35
1879							170.49	170.49	4578901	37.234	37.23
1880							178.17	178.17	4565668	39.024	39.02
1881							176.93	176.93	4572245	38.697	38.7
1882							180.58	180.58	4579115	39.435	39.44
1883							183.35	183.35	4603595	39.827	39.83
1884							185.76	185.76	4644448	39.996	40
1885						0.82	189.3	189.3	4682769	40.424	40.42
1886						0.792	187.25	187.25	4717189	39.695	39.69
1887						0.764	187.39	187.39	4734901	39.577	39.58
1888						0.736	190.65	190.65	4748257	40.151	40.15
1889						0.708	197.84	197.84	4774409	41.437	41.44
1890				0.02	0.489	0.68	200.02	200.17	4784981	41.802	41.83
1891				0.041	1.016	0.652	202.46	202.8	4802751	42.154	42.22
1892				0.058	1.426	0.624	201.8	202.07	4806865	41.981	42.04
1893				0.079	1.923	0.596	202.02	202.77	4824150	41.877	42.03
1894				0.1	2.424	0.568	213.76	214.76	4873183	43.864	44.07
1895				0.133	3.193	0.54	215.16	216.57	4919260	43.738	44.02
1896	0.15			0.185	4.386	0.512	220.38	222.43	4962568	44.409	44.82
1897	0.15			0.225	5.283	0.484	230.25	232.86	5009632	45.961	46.48
1898	0.15			0.296	6.906	0.456	235.28	238.88	5062918	46.472	47.18
1899	0.15			0.382	8.829	0.428	254.15	258.98	5097402	49.858	50.81
1900	0.15			0.49	11.2	0.4	259.8	266.23	5136441	50.58	51.83
1901	0.64			0.616	13.75	0.3917	250	257.98	5175228	48.306	49.85
1902	0.64			0.772	16.75	0.3833	258.92	268.77	5198752	49.804	51.7
1903	0.64			0.902	19.04	0.375	266.57	277.9	5221291	51.054	53.22
1904	0.64			1.127	23.11	0.3667	271.75	285.67	5260811	51.655	54.3

Table F.1 (cont.) Energy, PJ

	peat	**gas**	**gross district heating**	**el(S)**	**el(E)**	**(fossel+fwel)/ totel**	**energy (S)**	**energy (E)**	**total population**	**energy (S)/cap**	**energy (E)/ cap**
1905	0.64			1.318	26.24	0.3584	279.94	295.93	5294885	52.87	55.89
1906	0.57			1.536	29.64	0.35	293.94	312.21	5337055	55.076	58.5
1907	0.57			1.866	34.9	0.3417	309.58	331.32	5377713	57.567	61.61
1908	0.57			2.301	41.65	0.3334	315.9	342.13	5429600	58.181	63.01
1909	0.57			2.631	46.04	0.325	299.71	329.01	5476441	54.727	60.08
1910	0.57			3.22	54.42	0.3167	320.9	355.88	5522403	58.108	64.44
1911	0.62			3.674	59.88	0.3084	316.71	355.59	5561799	56.944	63.93
1912	0.56			4	62.79	0.3	329.84	370.99	5604192	58.855	66.2
1913	0.87			5.215	78.23	0.2718	362.8	415.97	5638583	64.343	73.77
1914	0.53			5.311	75.86	0.288	356.74	406.97	5679607	62.81	71.65
1915	1.11			6.499	88.2	0.2697	363.93	423.6	5712740	63.706	74.15
1916	1.49			7.874	101.2	0.2416	390.7	461.51	5757566	67.859	80.16
1917	2.53			8.347	101.4	0.2891	304.33	370.44	5800847	52.462	63.86
1918	5.05			8.765	100.2	0.2554	315.6	383.67	5813850	54.284	65.99
1919	4.53			8.74	93.65	0.257	304.91	367.99	5847037	52.148	62.94
1920	5.58			9.379	93.79	0.2658	312.61	374.58	5904489	52.945	63.44
1921	2.58			7.926	75.3	0.2325	243.53	295.23	5954316	40.899	49.58
1922	1.58			9.659	86.93	0.2252	289.28	349.14	5987520	48.313	58.31
1923	1.82			10.75	91.37	0.2333	313.55	375.36	6005759	52.208	62.5
1924	1.22			12.66	101.3	0.2332	347.78	415.73	6036118	57.616	68.87
1925	1.22			13.22	99.17	0.2633	327.61	390.93	6053562	54.119	64.58
1926	0.86			14.42	100.9	0.2551	324.33	388.79	6074368	53.393	64
1927	1.08			15.81	102.8	0.2493	379.77	445.05	6087923	62.382	73.1
1928	0.77			15.87	95.24	0.259	362.33	421.14	6105190	59.348	68.98
1929	0.66			17.88	98.35	0.2573	401.76	461.52	6120080	65.646	75.41
1930	0.65			18.44	92.19	0.2631	392.87	447.21	6142191	63.962	72.81
1931	0.5			18.34	90.31	0.2729	387.85	440.18	6162446	62.938	71.43
1932	0.51			17.65	85.6	0.2834	381.25	429.94	6190364	61.588	69.45
1933	0.42			19.24	91.86	0.2967	393.85	444.92	6211566	63.405	71.63
1934	0.44			21.71	102	0.3017	422.15	478.25	6233090	67.728	76.73
1935	0.45			24.82	114.8	0.317	435.62	497.07	6250506	69.694	79.52
1936	0.45			26.64	121.2	0.3023	462.63	528.62	6266888	73.821	84.35
1937	0.5			28.8	128.9	0.3075	505.73	575.04	6284722	80.47	91.5
1938	0.37			30.96	136.2	0.2939	473.26	547.59	6310214	74.999	86.78
1939	0.33			32.4	142.6	0.2894	599.54	677.82	6341303	94.545	106.9
1940	1.11			30.96	136.2	0.2798	480.09	555.9	6371432	75.351	87.25
1941	3.6			32.76	144.1	0.2625	460.03	542.18	6406474	71.808	84.63
1942	9.24			35.28	155.2	0.2486	456.04	546.17	6458200	70.614	84.57
1943	14.2			39.6	174.2	0.2325	485.9	589.23	6522827	74.492	90.33
1944	11.2			44.64	196.4	0.2067	450.32	570.73	6597348	68.258	86.51
1945	15.2			48.6	213.8	0.2173	450.25	579.58	6673749	67.465	86.84
1946	11.2			51.12	224.9	0.2237	421.57	556.49	6763685	62.328	82.28
1947	6.33			48.6	213.8	0.2308	497.51	624.62	6842046	72.714	91.29
1948	5.28			50.76	223.3	0.2254	534.07	667.75	6924888	77.124	96.43
1949	1.37			57.6	253.4	0.2229	491.74	643.92	6986181	70.387	92.17

Table F.1 (cont.) Energy, PJ

	peat	**gas**	**gross district heating**	**el(S)**	**el(E)**	**(fossel+fwel)/ totel**	**energy (S)**	**energy (E)**	**total population**	**energy (S)/cap**	**energy (E)/ cap**
1950	1.09			65.52	288.3	0.2091	573.75	749.93	7041829	81.477	106.5
1951	1.69			69.12	297.9	0.2184	633.21	812.04	7098740	89.201	114.4
1952	1.81			73.44	309.9	0.2021	642.71	831.39	7150606	89.882	116.3
1953	1.32			79.56	328.6	0.1985	608.8	808.38	7192316	84.646	112.4
1954	1.18			85.68	346.1	0.2105	628.99	834.64	7234664	86.942	115.4
1955	1.27			89.28	352.7	0.2044	720.05	929.6	7290112	98.77	127.5
1956	1.33			96.12	371	0.2009	789.14	1008.8	7338991	107.53	137.5
1957	1.59			103	388.2	0.209	766.99	992.57	7388611	103.81	134.3
1958	1.42			107.3	394.8	0.1954	754.62	985.96	7429675	101.57	132.7
1959	2.18			114.1	409.7	0.2131	696.9	929.48	7462823	93.383	124.5
1960	1.5			122	427.1	0.2	811.6	1055.7	7497967	108.24	140.8
1961	1.06			134.3	461.9	0.2244	805.74	1059.9	7542028	106.83	140.5
1962	0.64			143.3	484.3	0.2097	855.82	1125.3	7581148	112.89	148.4
1963	0.88			146.5	486.4	0.2173	906.95	1173	7627507	118.91	153.8
1964	0.59			162.7	530.5	0.2199	992.34	1279.2	7695200	128.96	166.2
1965	0.36			173.9	556.4	0.2356	1020.9	1313.3	7772506	131.34	169
1966	0.36			178.2	559.5	0.2401	1136.9	1426.6	7843088	144.95	181.9
1967	0.36			191.9	591	0.2408	1093	1396	7892774	138.48	176.9
1968	0			208.8	630.6	0.2498	1214.1	1530.5	7934996	153.01	192.9
1969	0			222.5	658.5	0.2795	1319.6	1633.8	8004377	164.87	204.1
1970	0			232.9	675.5	0.3151	1444.5	1747.6	8081229	178.74	216.3
1971	0			245.5	707.1	0.2182	1386	1746.9	8115426	170.79	215.3
1972	0			262.8	751.6	0.2499	1385.5	1752.2	8129160	170.44	215.5
1973	0			283.7	805.7	0.2059	1445.1	1859.6	8144428	177.43	228.3
1974	0			275	775.6	0.2102	1409.4	1804.8	8176691	172.37	220.7
1975	0			286.2	801.4	0.1357	1455.2	1900.4	8208442	177.28	231.5
1976	0			310.3	862.7	0.1801	1511.8	1964.6	8236179	183.55	238.5
1977	0			307.8	849.5	0.1843	1462.4	1904.3	8267116	176.89	230.3
1978	0			321.5	880.9	0.1222	1382.5	1873.5	8284437	166.88	226.2
1979	0			337.7	918.5	0.1362	1572	2073.7	8303010	189.33	249.8
1980	0			338.4	913.7	0.1138	1440.6	1950.5	8317937	173.2	234.5
1981	0.36			348.8	934.9	0.0526	1292	1847.2	8323033	155.23	221.9
1982	0.65			358.2	952.8	0.0543	1276.7	1839	8327484	153.31	220.8
1983	0.4		0	398.9	1053	0.0397	1323.8	1952.1	8330573	158.91	234.3
1984	1.5		6.5	432	1132	0.0359	1319	1993.7	8342621	158.1	239
1985	3.2	3.2	11.1	470.9	1224	0.0512	1442.7	2157.6	8358139	172.61	258.1
1986	4.4	8.3	18.4	464.4	1198	0.0521	1518.7	2214.2	8381515	181.19	264.2
1987	6.3	11.2	21	493.2	1263	0.046	1417.7	2151.7	8414083	168.49	255.7
1988	5.6	14.4	23.5	496.8	1262	0.04	1508.7	2243.1	8458888	178.35	265.2
1989	6.3	19.3	23.2	496.8	1252	0.05	1424.3	2141.7	8527036	167.04	251.2

Table F.1 (cont.) Energy, PJ

	peat	**gas**	**gross district heating**	**el(S)**	**el(E)**	**(fossel+fwel)/ totel**	**energy (S)**	**energy (E)**	**total population**	**energy (S)/cap**	**energy (E)/ cap**
1990	10	24	23.7	503.8	1260	0.0359	1441.3	2170.3	8590630	167.78	252.6
1991		25.7	25.6	508	1271	0.0472	1428.3	2154.8	8644119	165.23	249.3
1992		28.9	24.9	503	1258	0.0551	1412.4	2125.9	8692013	162.5	244.6
1993		31.8	26	506	1266	0.0617	1427.8	2140.5	8745109	163.27	244.8
1994		28.5	24.9	499.1	1248	0.0722	1442	2137.2	8816381	163.56	242.4
1995		28.4	24.9	512.8	1283	0.069	1477.2	2193.8	8837496	167.15	248.2
1996		28.5	24.4	511.9	1280	0.0979	1488.4	2181.5	8844499	168.28	246.7
1997		29.8	25.3	513.1	1283	0.0694	1495.9	2212.6	8847625	169.07	250.1
1998		32.6	26.5	518	1295	0.0689	1500	2223.8	8854322	169.41	251.2
1999		30.1	25.7	514.6	1287	0.0654	1492.7	2214.6	8861426	168.45	249.9
2000		29	26.7	516.1	1291	0.0654	1485	2208.9	8882792	167.17	248.7

Table F.2 Physical energy intensities (MJ/SEK), constant prices, 1910-12 price level

	energy (S)	**energy (E)**	**energy intensity (S)**	**energy Intensity (E)**	**household energy (S)**	**energy (S, -h)**	**energy intensity (-h, S)**
1800	110.55	110.55	276.8	276.8	83.63	26.91	84.03
1801	110.82	110.82	286.1	286.1	83.38	27.43	88.71
1802	110.44	110.44	272.3	272.3	83.47	26.97	82.88
1803	111.35	111.35	275.1	275.1	83.53	27.82	85.72
1804	111.25	111.25	276.7	276.7	83.53	27.72	86.11
1805	111.70	111.70	267.1	267.1	83.64	28.07	83.51
1806	112.01	112.01	271.1	271.1	83.33	28.68	86.5
1807	111.17	111.17	277.8	277.8	83.17	28	87.7
1808	110.35	110.35	285.5	285.5	82.22	28.13	92.24
1809	106.74	106.74	279.3	279.3	80.93	25.81	84.96
1810	106.18	106.18	257	257	80.48	25.71	77.47
1811	106.52	106.52	249.8	249.8	80.45	26.07	75.78
1812	106.83	106.83	262.1	262.1	80.16	26.67	81.82
1813	106.59	106.59	266.3	266.3	79.79	26.79	84.01
1814	106.53	106.53	252.9	252.9	79.72	26.8	79.23
1815	107.48	107.48	241	241	80.06	27.43	76.01
1816	109.66	109.66	241	241	80.56	29.1	78.97
1817	110.12	110.12	245.8	245.8	80.77	29.35	81.27
1818	110.67	110.67	256.1	256.1	81.01	29.66	85.81
1819	111.30	111.30	254.7	254.7	80.93	30.37	86.82
1820	111.85	111.85	241.8	241.8	81.08	30.77	82.47
1821	111.73	111.73	232.4	232.4	81.33	30.4	78.07
1822	112.09	112.09	228.7	228.7	81.84	30.24	76.12
1823	113.55	113.55	226.9	226.9	82.57	30.98	76.29
1824	114.39	114.39	219.1	219.1	83.13	31.26	73.42
1825	115.25	115.25	219.3	219.3	83.87	31.38	73.34
1826	115.80	115.80	219.7	219.7	84.27	31.54	73.62
1827	115.49	115.49	223.3	223.3	84.33	31.16	74.52
1828	115.68	115.68	211.6	211.6	84.27	31.42	70.5
1829	114.54	114.54	206	206	84.12	30.42	66.98
1830	115.12	115.12	210.1	210.1	84.21	30.91	69.4
1831	114.93	114.93	210.2	210.2	83.95	30.98	69.77
1832	114.96	114.96	209.9	209.9	83.93	31.03	69.84
1833	115.36	115.36	199.7	199.7	84.32	31.04	65.82
1834	115.50	115.50	196.4	196.4	84.34	31.16	64.79
1835	116.98	116.98	195.1	195.1	84.87	32.12	65.44
1836	117.54	117.54	192.3	192.3	85.14	32.4	64.64
1837	117.43	117.43	192	192	84.93	32.5	64.88
1838	117.43	117.43	197.8	197.8	84.63	32.8	67.81
1839	117.79	117.79	191.4	191.4	84.39	33.4	66.32
1840	118.35	118.35	186.7	186.7	84.58	33.78	64.9
1841	118.77	118.77	187.6	187.6	84.8	33.97	65.51
1842	119.65	119.65	193.8	193.8	84.99	34.66	68.93
1843	119.50	119.50	188.3	188.3	85.06	34.44	66.43
1844	119.24	119.24	178	178	85.35	33.89	61.54

Table F.2 (cont.) Physical energy intensities (MJ/SEK), constant prices, 1910-12 price level

	energy (S)	**energy (E)**	**energy intensity (S)**	**energy intensity (E)**	**household energy (S)**	**energy (S, -h)**	**energy intensity (-h, S)**
1845	119.63	119.63	172.8	172.8	85.69	33.93	59.43
1846	120.63	120.63	178.1	178.1	85.64	35	62.95
1847	120.70	120.70	174.5	174.5	85.38	35.31	62.05
1848	121.77	121.77	169.2	169.2	85.53	36.24	60.93
1849	121.78	121.78	161.1	161.1	85.87	35.91	57.18
1850	123.39	123.39	160.3	160.3	86.13	37.26	58.19
1851	124.80	124.80	162.9	162.9	86.63	38.18	60.07
1852	125.36	125.36	164.8	164.8	86.86	38.5	61.13
1853	125.49	125.49	162.1	162.1	87.07	38.41	59.84
1854	127.47	127.47	160.4	160.4	87.81	39.66	60.05
1855	129.48	129.48	154.6	154.6	88.25	41.23	58.87
1856	131.02	131.02	156.1	156.1	88.66	42.36	60.4
1857	132.55	132.55	154.7	154.7	88.65	43.9	61.18
1858	133.69	133.69	149.2	149.2	89.4	44.29	58.68
1859	137.25	137.25	145.3	145.3	90.31	46.94	58.67
1860	139.04	139.04	142.3	142.3	91.64	47.39	57.11
1861	142.24	142.24	143.5	143.5	92.62	49.61	58.93
1862	144.70	144.70	148.8	148.8	93.38	51.32	62.39
1863	145.47	145.47	142.1	142.1	94.32	51.16	58.82
1864	148.00	148.00	140.3	140.3	95.03	52.98	58.96
1865	149.17	149.17	137.9	137.9	95.65	53.52	58.08
1866	150.65	150.65	138.8	138.8	96.32	54.33	58.77
1867	150.45	150.45	137.2	137.2	96.72	53.74	57.29
1868	151.51	151.51	153.9	153.9	95.78	55.73	67.39
1869	150.52	150.52	140.8	140.8	95.04	55.48	61.18
1870	152.99	152.99	127	127	94.85	58.14	56.07
1871	153.90	153.90	118.2	118.2	94.56	59.34	52.34
1872	162.01	162.01	119.8	119.8	98.64	63.37	53.76
1873	162.56	162.56	116.4	116.4	98.07	64.49	52.82
1874	161.78	161.78	110.5	110.5	96.7	65.08	50.67
1875	168.69	168.69	119.1	119.1	99.89	68.81	55.67
1876	171.78	171.78	111.5	111.5	100.8	71.02	52.41
1877	173.01	173.01	113.8	113.8	100.5	72.5	54.27
1878	169.29	169.29	114.7	114.7	97.41	71.88	55.74
1879	170.49	170.49	109.2	109.2	97.15	73.34	53.49
1880	178.17	178.17	115.2	115.2	100.5	77.64	57.19
1881	176.93	176.93	110.3	110.3	98.85	78.08	55.39
1882	180.58	180.58	115.5	115.5	99.88	80.7	58.91
1883	183.35	183.35	109.3	109.3	100.4	82.96	56.06
1884	185.76	185.76	115.1	115.1	100.7	85.09	60.14
1885	189.30	189.30	111.4	111.4	101.5	87.76	58.69
1886	187.25	187.25	109	109	99.39	87.86	58.17
1887	187.39	187.39	111.7	111.7	98.42	88.97	60.49
1888	190.65	190.65	109.4	109.4	99.07	91.58	59.71
1889	197.84	197.84	110.8	110.8	101.7	96.13	61.08

Table F.2 (cont.) Physical energy intensities (MJ/SEK), constant prices, 1910-12 price level

	energy (S)	**energy (E)**	**energy intensity (S)**	**energy Intensity (E)**	**household energy (S)**	**energy (S, -h)**	**energy intensity (-h, S)**
1890	200.02	200.17	110.2	110.3	101.7	98.31	61.41
1891	202.46	202.80	106.1	106.3	101.8	100.6	59.55
1892	201.80	202.07	106.3	106.5	100.4	101.4	60.4
1893	202.02	202.77	103.6	104	99.35	102.7	59.26
1894	213.76	214.76	107.1	107.6	103.9	109.8	61.93
1895	215.16	216.57	102.2	102.9	103.4	111.7	59.46
1896	220.38	222.43	100.1	101	104.7	115.7	58.62
1897	230.25	232.86	99.87	101	108.1	122.2	58.96
1898	235.28	238.88	98.71	100.2	109.1	126.1	58.76
1899	254.15	258.98	103.9	105.8	116.5	137.7	62.32
1900	259.80	266.23	104.4	107	117.6	142.2	63.33
1901	250.00	257.98	98.96	102.1	111.8	138.2	60.72
1902	258.92	268.77	103.1	107	114.3	144.6	64.09
1903	266.57	277.90	101.1	105.4	116.2	150.3	63.03
1904	271.75	285.67	100.2	105.4	117	154.8	63.19
1905	279.94	295.93	104.8	110.8	118.9	161	66.77
1906	293.94	312.21	101.4	107.7	123.3	170.7	64.94
1907	309.58	331.32	100.4	107.5	128.1	181.5	64.43
1908	315.90	342.13	104.9	113.6	128.9	187	68.28
1909	299.71	329.01	98.04	107.6	120.7	179.1	64.41
1910	320.90	355.88	100.1	111	127.4	193.5	66.19
1911	316.71	355.59	96.17	108	124	192.7	64.17
1912	329.84	370.99	96.87	109	127.3	202.6	64.97
1913	362.80	415.97	98.8	113.3	138.1	224.7	66.5
1914	356.74	406.97	96.06	109.6	135.7	221	64.63
1915	363.93	423.60	96.33	112.1	138.5	225.5	64.79
1916	390.70	461.51	98.21	116	148.6	242.1	65.89
1917	304.33	370.44	81.74	99.5	115.7	188.6	55.16
1918	315.60	383.67	90.86	110.4	120	195.6	61.55
1919	304.91	367.99	83.95	101.3	115.9	189	56.74
1920	312.61	374.58	81.05	97.12	118.8	193.8	54.63
1921	243.53	295.23	66.84	81.03	92.57	151	45.25
1922	289.28	349.14	71.71	86.55	109.9	179.3	48.3
1923	313.55	375.36	75.28	90.11	119.1	194.4	50.68
1924	347.78	415.73	78.96	94.39	132.1	215.6	52.98
1925	327.61	390.93	72.89	86.98	124.5	203.2	48.91
1926	324.33	388.79	68.1	81.63	123.2	201.1	45.56
1927	379.77	445.05	77.89	91.28	144.2	235.6	52.06
1928	362.33	421.14	72.13	83.84	137.6	224.8	48.14
1929	401.76	461.52	74.63	85.74	152.5	249.2	49.56
1930	392.87	447.21	70.15	79.85	149.1	243.7	46.45
1931	387.85	440.18	71.07	80.66	147.2	240.7	47.23
1932	381.25	429.94	72.51	81.77	144.7	236.6	48.42
1933	393.85	444.92	72.64	82.06	149.4	244.4	48.35
1934	422.15	478.25	72.34	81.95	160.1	262	47.81

Table F.2 (cont.) Physical energy intensities (MJ/SEK), constant prices, 1910-12 price level

	energy (S)	**energy (E)**	**energy intensity (S)**	**energy intensity (E)**	**household energy (S)**	**energy (S, -h)**	**energy intensity (-h, S)**
1935	435.62	497.07	70.72	80.7	165.2	270.4	46.57
1936	462.63	528.62	71.87	82.12	175.4	287.2	47.23
1937	505.73	575.04	76.31	86.77	191.2	314.5	50.1
1938	473.26	547.59	68.93	79.75	178.5	294.8	45.27
1939	599.54	677.82	80.78	91.32	225.4	374.1	52.84
1940	480.09	555.90	70.67	81.83	180	300.1	46.71
1941	460.03	542.18	68.94	81.25	172	288.1	45.73
1942	456.04	546.17	67.74	81.13	170	286.1	44.96
1943	485.90	589.23	68.68	83.28	180.6	305.3	45.53
1944	450.32	570.73	61.18	77.53	166.9	283.5	40.59
1945	450.25	579.58	59.86	77.05	166.3	283.9	39.87
1946	421.57	556.49	49.68	65.59	155.3	266.3	32.93
1947	497.51	624.62	53.92	67.7	182.7	314.8	35.75
1948	534.07	667.75	56.57	70.73	195.6	338.5	37.62
1949	491.74	643.92	50.47	66.08	179.5	312.2	33.67
1950	573.75	749.93	57.27	74.86	208.9	364.9	38.32
1951	633.21	812.04	60.2	77.2	229.8	403.4	40.36
1952	642.71	831.39	60.86	78.73	232.6	410.1	40.94
1953	608.80	808.38	55.81	74.1	219.6	389.2	37.62
1954	628.99	834.64	55.51	73.66	226.2	402.8	37.49
1955	720.05	929.60	61.68	79.63	265	455.1	41.11
1956	789.14	1008.83	65.26	83.43	284.1	505.1	44.05
1957	766.99	992.57	60.74	78.6	276.1	490.9	40.97
1958	754.62	985.96	59.49	77.72	271.7	483	40.19
1959	696.90	929.48	53.42	71.25	250.9	446	36.12
1960	811.60	1055.68	59.61	77.54	292.2	519.4	40.3
1961	805.74	1059.88	56.02	73.69	290.1	515.7	37.82
1962	855.82	1125.33	56.42	74.19	308.1	547.7	38.04
1963	906.95	1173.02	56.71	73.34	326.5	580.4	38.17
1964	992.34	1279.21	57.13	73.64	357.2	635.1	38.38
1965	1020.86	1313.27	55.99	72.02	367.5	653.3	37.58
1966	1136.86	1426.64	60.64	76.1	409.3	727.6	40.71
1967	1093.01	1396.00	57.02	72.83	393.5	699.5	38.28
1968	1214.12	1530.53	60.83	76.68	437.1	777	40.81
1969	1319.65	1633.85	64.39	79.72	475.1	844.6	43.21
1970	1444.47	1747.59	66.92	80.97	519.8	924.7	44.84
1971	1386.04	1746.89	62.44	78.69	509.6	876.5	41.34
1972	1385.51	1752.19	62.84	79.47	518.9	866.6	41.21
1973	1445.10	1859.60	63.02	81.09	517.7	927.4	42.37
1974	1409.44	1804.80	56.79	72.72	467	942.4	39.69
1975	1455.18	1900.42	57.85	75.55	491.6	963.5	40.05
1976	1511.77	1964.64	59.9	77.84	528.6	983.2	40.75
1977	1462.37	1904.28	59.24	77.14	523.9	938.5	39.82
1978	1382.53	1873.55	57.69	78.18	536.1	846.4	37.06
1979	1571.98	2073.69	63.08	83.21	538.4	1034	43.48

Table F.2 (cont.) Physical energy intensities (MJ/SEK), constant prices, 1910-12 price level

	energy (S)	**energy (E)**	**energy intensity (S)**	**energy intensity (E)**	**household energy (S)**	**energy (S, -h)**	**energy intensity (-h, S)**
1980	1440.63	1950.45	56.6	76.64	528.6	912	37.56
1981	1291.99	1847.19	50.88	72.74	516.6	775.4	32.07
1982	1276.70	1839.04	49.17	70.82	500.2	776.5	31.42
1983	1323.84	1952.05	49.68	73.25	484.7	839.2	33.1
1984	1318.98	1993.66	47.43	71.69	490.3	828.7	31.31
1985	1442.74	2157.61	50.95	76.2	525.3	917.4	34.02
1986	1518.67	2214.17	52.3	76.25	517.6	1001	36.16
1987	1417.67	2151.69	47.21	71.65	531.4	886.2	30.93
1988	1508.65	2243.12	48.98	72.83	510.5	998.1	33.96
1989	1424.33	2141.71	44.96	67.6	504.7	919.7	30.38
1990	1441.31	2170.35	45.04	67.82	503.9	937.4	30.65
1991	1428.30	2154.78	45.27	68.3	523.3	905	30.14
1992	1412.44	2125.86	45.51	68.5	524	888.4	30.48
1993	1427.82	2140.49	46.64	69.92	526.2	901.6	31.4
1994	1442.04	2137.19	44.88	66.52	526.8	915.2	30.12
1995	1477.20	2193.85	44.23	65.69	533.3	943.9	29.75
1996	1488.35	2181.51	43.82	64.23	546.6	941.8	29.13
1997	1495.86	2212.56	43.05	63.68			29
1998	1499.98	2223.84	41.84	62.04	513.5	986.5	28.74
1999	1492.74	2214.63	40.71	60.4			
2000	1484.96	2208.95	38.48	57.24			

Table F. 3 Energy prices, SEK/MJ

	firewood price	alternative firewood price (higher energy content)	muscle price	coal price	oil price	electricity price	gas price	distric heating price
1800	0.16	0.12	4.63686	0.2852				
1801	0.17	0.13	4.30847	0.2856				
1802	0.14	0.11	3.95381	0.2983				
1803	0.14	0.11	3.84873	0.298				
1804	0.14	0.11	4.17712	0.2856				
1805	0.15	0.12	4.00636	0.2954				
1806	0.16	0.12	4.8339	0.3303				
1807	0.18	0.14	4.95212	0.3111				
1808	0.25	0.19	6.63347	0.2951				
1809	0.28	0.22	5.39873	0.3543				
1810	0.30	0.23	4.99153	0.348				
1811	0.32	0.25	7.05381	0.4889				
1812	0.33	0.25	9.16864	0.5926				
1813	0.34	0.26	8.81398	0.669				
1814	0.33	0.25	7.57924	0.6741				
1815	0.32	0.25	6.7911	0.6844				
1816	0.31	0.24	8.27542	0.7556				
1817	0.31	0.24	8.26229	0.6593				
1818	0.31	0.24	9.57585	0.6519				
1819	0.32	0.25	9.74661	0.8213				
1820	0.33	0.25	7.19831	0.9203				
1821	0.33	0.25	6.6072	0.8738				
1822	0.33	0.25	7.06695	0.8711				
1823	0.34	0.26	5.88475	1.0412				
1824	0.34	0.26	5.93729	0.8763				
1825	0.35	0.27	6.00297	0.8105				
1826	0.36	0.27	10.0881	0.7822				
1827	0.36	0.28	7.1589	0.8433				
1828	0.39	0.30	6.2	0.7639				
1829	0.39	0.30	6.75169	0.6939				
1830	0.39	0.30	7.23771	0.7548				
1831	0.38	0.30	9.62839	0.7283				
1832	0.41	0.31	7.30339	0.6734				
1833	0.42	0.33	6.22627	0.5743				
1834	0.42	0.32	7.10636	0.5952				
1835	0.41	0.32	7.08008	0.6185				
1836	0.42	0.33	7.48729	0.6361				
1837	0.43	0.33	8.43305	0.6844				
1838	0.43	0.33	8.94534	0.7005				
1839	0.44	0.34	7.78941	0.6456				
1840	0.45	0.34	7.1589	0.6472				
1841	0.46	0.35	7.01441	0.617				
1842	0.45	0.35	7.81568	0.6111				
1843	0.44	0.34	7.51356	0.5566				
1844	0.45	0.35	5.8322	0.6312				

Table F. 3 (cont.) Energy prices, SEK/MJ

	firewood price	**alternative firewood price (higher energy content)**	**muscle price**	**coal price**	**oil price**	**electricity price**	**gas price**	**distric heating price**
1845	0.44	0.34	8.38051	0.5206				
1846	0.46	0.35	9.91737	0.4902				
1847	0.48	0.37	9.20805	0.5758				
1848	0.51	0.40	7.27712	0.5038				
1849	0.52	0.40	6.69915	0.4917				
1850	0.51	0.40	7.55297	0.4711				
1851	0.49	0.38	9.12924	0.4294				
1852	0.51	0.39	8.95847	0.4438				
1853	0.54	0.42	10.3114	0.5692				
1854	0.62	0.48	9.47076	0.6339				
1855	0.72	0.55	11.9534	0.6014				
1856	0.76	0.58	12.8729	0.5145				
1857	0.62	0.48	11.4017	0.506				
1858	0.60	0.46	8.87966	0.4959				
1859	0.63	0.49	9.05042	0.4969				
1860	0.67	0.52	10.1801	0.5466				
1861	0.65	0.50	10.9945	0.5405				
1862	0.65	0.50	10.0881	0.4812				
1863	0.63	0.49	9.64153	0.495				
1864	0.63	0.48	8.40678	0.5474				
1865	0.64	0.49	8.49873	0.5532				
1866	0.63	0.49	10.1932	0.5493				
1867	0.60	0.46	12.9254	0.5748				
1868	0.58	0.45	14.0814	0.5122				
1869	0.58	0.44	9.53644	0.5149				
1870	0.66	0.51	9.52331	0.5045				
1871	0.75	0.57	10.0093	0.5214				
1872	0.94	0.73	11.0076	0.8426				
1873	0.97	0.74	12.597	1.1119				
1874	0.95	0.73	13.3983	0.9159				
1875	0.79	0.60	11.5725	0.7067				
1876	0.86	0.66	11.9008	0.5816				
1877	0.76	0.59	11.914	0.5411				
1878	0.74	0.57	10.6136	0.5035				
1879	0.74	0.57	10.1144	0.4666				
1880	0.81	0.62	11.2441	0.4761				
1881	0.80	0.62	11.2178	0.4773				
1882	0.75	0.58	9.91737	0.4863				
1883	0.75	0.57	9.68093	0.4976				
1884	0.73	0.56	9.39195	0.4946				
1885	0.68	0.52	8.81398	0.4761	4.693022			
1886	0.62	0.48	8.49873	0.4761	4.348607			
1887	0.64	0.50	7.22458	0.4428	4.004193			
1888	0.69	0.53	8.59068	0.4403	4.171908			
1889	0.71	0.55	8.97161	0.5351	3.962264			

Table F. 3 (cont.)Energy prices, SEK/MJ

	firewood price	**alternative firewood price (higher energy content)**	**muscle price**	**coal price**	**oil price**	**electricity price**	**gas price**	**distric heating price**
1890	0.69	0.53	9.06356	0.6773	3.530997			
1891	0.67	0.52	10.5216	0.6594	3.26445			
1892	0.66	0.51	9.39195	0.6257	3.075771	177.8458		
1893	0.66	0.51	9.1161	0.5637	2.824199	126.6912		
1894	0.65	0.50	7.98644	0.5653	2.785265	128.6035		
1895	0.65	0.50	8.44619	0.4934	3.560946	123.8227		
1896	0.68	0.53	9.05042	0.4282	3.519018	117.8467		
1897	0.78	0.60	10.1538	0.5352	3.144654	112.5878		
1898	0.89	0.69	9.93051	0.5621	2.833184	110.4365		
1899	0.83	0.64	10.3114	0.6764	2.93501	100.6358		
1900	0.70	0.54	10.1932	0.948	3.012878	91.31329		
1901	0.67	0.52	10.3114	0.6144	3.045822	91.31329		
1902	0.73	0.56	10.1013	0.6038	2.970949	91.07425		
1903	0.73	0.56	10.0225	0.5893	3.063792	88.92289		
1904	0.73	0.56	10.0881	0.5843	3.093741	79.36129		
1905	0.77	0.60	10.2064	0.5318	2.833184	73.14624		
1906	0.80	0.62	10.4559	0.5863	2.614555	71.95104		
1907	0.91	0.70	11.2178	0.6803	2.698413	72.19008		
1908	0.89	0.69	11.3097	0.6849	3.069781	71.95104		
1909	0.83	0.64	10.7712	0.5222	3.069781	65.01888		
1910	0.82	0.63	10.5085	0.5576	2.914046	57.84768		
1911	0.86	0.66	11.2835	0.6075	3.057294	57.3696		
1912	0.93	0.71	11.4542	0.8361	3.972163	55.45728		
1913	0.99	0.76	9.99153	0.7306	4.8379	55.21824		
1914	1.00	0.77	15	0.8055	5.188088	54.74016		
1915	1.18	0.91	17.161	1.3548	5.870894	54.9792		
1916	1.74	1.34	18.2203	2.2476	8.082741	61.67232		
1917	3.05	2.34	21.1864	4.6491	12.51116	79.12225		
1918	2.80	2.15	27.9661	9.2831	27.95381	115.6954		
1919	5.49	4.22	26.9237	6.0334	20.32896	118.3248		
1920	3.06	2.36	29.1949	7.1443	20.33182	100.6358		
1921	2.34	1.80	16.7712	1.243	15.88005	100.8749		
1922	2.48	1.91	11.8983	1.0483	10.2756	94.65985		
1923	2.62	2.01	12.4407	1.1073	10.02232	76.25376		
1924	2.33	1.79	16.9237	0.9183	10.37116	58.88889		
1925	2.03	1.56	14.3051	0.7121	11.66099	59.16667		
1926	2.08	1.60	14.4237	0.7718	10.75346	61.94444		
1927	2.05	1.57	16.0593	0.7687	9.642695	57.5		
1928	1.93	1.49	14.0508	0.6803	8.528529	55.27778		
1929	1.91	1.47	12.4492	0.7686	9.317044	54.44444		

Table F. 3 (cont.) Energy prices, SEK/MJ

	firewood price	**alternative firewood price (higher energy content)**	**muscle price**	**coal price**	**oil price**	**electricity price**	**gas price**	**distric heating price**
1930	1.80	1.39	11.5339	0.7487	8.245763	53.88889		
1931	1.77	1.36	10.7288	0.6964	5.361662	53.33333		
1932	1.66	1.28	10.6441	0.68	5.688746	54.72222		
1933	1.59	1.22	10.3729	0.6775	6.003025	54.72222		
1934	1.58	1.22	11.4492	0.7222	5.806242	53.88889		
1935	1.65	1.27	11.5	0.7701	5.545395	54.44444		
1936	1.73	1.33	12.5932	0.8535	5.330494	54.16667		
1937	1.86	1.43	14.4831	1.1863	5.212504	53.61111		
1938	2.05	1.58	13.7203	1.0677	5.392153	53.05556		
1939	2.96	2.27	11.9661	1.6271	5.75237	52.22222		
1940	3.55	2.73	18.2203	1.8208	11.19616	55		
1941	3.93	3.02	21.8559	2.2357	19.94189	54.44444		
1942	4.14	3.19	21.1864	2.4161	29.25977	53.88889		
1943	4.05	3.11	19.5424	2.412	28.54264	51.94444		
1944	3.90	3.00	19.7881	2.4831	27.31998	48.33333		
1945	3.83	2.94	19.2712	2.5829	19.76237	50		
1946	3.75	2.89	19.2712	2.8395	6.560143	48.05556		
1947	4.16	3.20	20.7203	3.0096	5.691959	43.88889		
1948	4.53	3.48	22.8475	3.2525	8.003686	44.72222		
1949	4.67	3.59	22.2373	3.412	8.41655	39.44444		
1950	8.55	6.58	21.1441	3.2117	8.306914	36.94444		
1951	8.97	6.90	29.0339	4.675	8.198896	37.5		
1952	7.42	5.71	31.1949	4.5223	8.267813	40.27778		
1953	5.95	4.58	27.3305	3.8055	8.214107	42.22222		
1954	6.36	4.89	26.8475	3.7201	7.831988	40.55556		
1955	6.76	5.20	30.1102	4.4303	7.41348	38.88889		
1956	6.49	4.99	29.8983	5.3425	7.582575	41.11111		
1957	6.43	4.95	24.6949	5.4425	9.252104	43.05556		
1958	5.82	4.48	28.161	4.6049	8.840217	45.83333		
1959	5.70	4.38	33.2034	3.9224	9.193929	48.88889		
1960	6.36	4.89	34.322	3.7263	8.415523	47.77778		
1961	7.79	5.99	31.0932	3.7692	8.504352	47.77778		
1962	7.79	5.99	32.9068	4.0352	8.906025	41.94444		
1963	7.64	5.88	35.0763	4.3125	9.13078	42.77778		
1964	7.91	6.09	35.6017	4.5164	9.321277	36.66667		
1965	8.09	6.23	38.1356	4.1706	9.384778	35.55556		
1966	8.72	6.70	40.2034	4.2357	9.653152	33.88889		
1967	9.15	7.04	41.6102	3.9085	10.48141	32.77778		
1968	9.49	7.30	43.322	3.7576	10.12711	31.11111		
1969	9.99	7.69	42.0932	4.0374	9.699771	28.61111		
1970	10.66	8.20	45.074	5.4466	9.81063	30.55556		

Table F. 3 (cont.) Energy prices, SEK/MJ

	firewood price	**alternative firewood price (higher energy content)**	**muscle price**	**coal price**	**oil price**	**electricity price**	**gas price**	**distric heating price**
1971	9.93	7.64	50.2567	6.8616	11.55876	31.66667		
1972	16.94	13.03	54.3401	7.1791	12.06236	33.61111		
1973	20.75	15.96	57.167	6.9214	13.35647	33.33333		
1974	20.08	15.45	62.0356	9.0649	17.75045	38.58333		
1975	17.75	13.65	69.5741	11.885	18.42621	43.52778		
1976	18.66	14.35	77.4268	12.872	21.20574	41.55556		
1977	32.33	24.87	89.9909	13.295	22.00948	49.72222		
1978	42.64	32.80	95.4878	13.516	25.65065	54.91667		
1979	42.84	32.95	101.613	13.424	34.02602	63.80556		
1980	47.44	36.49	116.376	17.423	45.41354	67.16667		
1981	57.53	44.26	133.837	20.898	61.10673	72.31912		
1982	65.36	50.27	150.363	24.35	72.15539	75.29114		
1983	65.05	50.04	167.82	21.696	79.68135	77.66876		69.96
1984	67.11	51.62	187.372	21.097	91.23458	79.84824		72.58
1985	69.17	53.21	201.221	24.288	93.20958	83.81093		72.37
1986	69.02	53.10	215.652	23.695	72.83081	87.57548		68.81
1987	73.89	56.84	222.402	22.991	75.68609	91.14191		68.38
1988	79.37	61.05	234.622	23.937	77.66374	95.30273		75.00
1989	84.99	65.38	248.122	26.97	93.8656	99.66169		75.00
1990	97.96	75.36	266.045	27.739	121.7693	107.3889	45.70	83.07
1991	100.49	77.31	278.381	32.503	121.125	121.7184	40.95	92.14
1992	86.58	66.61	264.066	31.59	116.2088	126.951	37.11	94.38
1993	92.95	71.51	265.928	32.997	139.8827	131.9391	43.64	86.44
1994	103.73	79.80	270.467	33.718	141.6714	136.2914	40.76	84.59
1995	117.20	90.16	274.424	34.65	141.43	140.8393	41.31	80.37
1996	114.34	87.96	255.338	35.547	148.8626	153.2117	46.25	80.24
1997	119.11	91.63	256.269	36.876	157.3581	162.4054	47.44	88.68
1998	119.43	91.88	259.178	47.108	151.8572	167.4423	33.73	95.31
1999	118.48	91.14	263.019	45.13	158.0651	159.9113	48.58	78.17
2000	0.00	0.00	263.019	46.449	193.2077	157.2217	85.78	80.00

Table F.4 Economic energy intensity (ratio without unit)

	energy volumes, million SEK, current prices	**consumers' surplus, million SEK, current prices**	**energy deflator, 1910/12=1**	**augmented energy volume, million SEK, constant prices, 1910-12 price level**	**economic- energy intensity**
1800	111.1	160.9	0.445	608.9	1.525
1801	104.6	151.3	0.417	612.0	1.580
1802	98.0	141.3	0.388	614.7	1.516
1803	94.5	136.8	0.371	621.2	1.535
1804	102.9	149.1	0.402	625.7	1.556
1805	99.9	144.7	0.387	630.5	1.508
1806	119.6	173.9	0.461	635.2	1.537
1807	123.3	179.2	0.472	638.5	1.596
1808	163.4	238.3	0.625	640.7	1.657
1809	139.3	201.0	0.535	634.4	1.660
1810	132.4	189.9	0.506	634.6	1.536
1811	181.7	262.8	0.691	641.1	1.503
1812	233.2	338.8	0.883	646.3	1.586
1813	225.9	327.9	0.853	647.5	1.618
1814	199.0	287.5	0.749	647.9	1.538
1815	181.0	261.2	0.676	652.7	1.464
1816	218.3	316.6	0.804	663.2	1.458
1817	219.2	318.1	0.802	668.4	1.492
1818	252.3	367.3	0.916	674.8	1.561
1819	258.7	376.7	0.933	679.5	1.555
1820	198.4	286.9	0.711	680.8	1.472
1821	185.5	267.4	0.661	683.7	1.422
1822	198.3	286.5	0.701	689.7	1.408
1823	170.6	245.3	0.597	694.7	1.388
1824	173.8	249.7	0.604	699.7	1.340
1825	177.1	254.4	0.610	705.2	1.342
1826	283.9	412.9	0.971	716.0	1.358
1827	210.1	303.3	0.715	716.1	1.385
1828	186.5	267.8	0.632	717.3	1.312
1829	203.3	292.2	0.687	719.1	1.293
1830	217.4	313.2	0.730	725.2	1.324
1831	281.0	407.7	0.940	730.5	1.336
1832	220.3	317.7	0.734	731.3	1.335
1833	194.6	278.8	0.643	733.8	1.270
1834	220.4	316.8	0.725	739.5	1.258
1835	221.4	318.4	0.721	746.7	1.246
1836	233.8	336.8	0.756	752.3	1.231
1837	261.5	377.7	0.843	756.4	1.237
1838	276.9	400.6	0.889	760.1	1.280
1839	246.3	355.1	0.787	761.9	1.238

Table F.4 (cont.) Economic energy intensity (ratio without unit)

	energy volumes, million SEK, current prices	**consumers' surplus, million SEK, current prices**	**energy deflator, 1910/12=1**	**augmented energy volume, million SEK, constant prices, 1910-12 price level**	**economic- energy intensity**
1840	230.9	331.9	0.733	765.6	1.208
1841	229.1	329.1	0.722	771.4	1.219
1842	254.5	366.7	0.795	779.6	1.263
1843	246.9	355.4	0.766	784.0	1.235
1844	199.4	285.2	0.614	786.6	1.174
1845	276.5	399.5	0.844	798.5	1.153
1846	323.3	469.1	0.979	807.0	1.192
1847	305.1	441.8	0.919	810.7	1.172
1848	252.2	362.6	0.751	816.0	1.134
1849	238.9	342.1	0.705	821.3	1.086
1850	268.0	385.2	0.783	831.4	1.080
1851	318.5	460.3	0.922	842.2	1.099
1852	314.2	454.3	0.903	848.4	1.115
1853	359.9	522.1	1.028	855.3	1.105
1854	339.6	491.4	0.960	863.6	1.087
1855	427.6	619.7	1.197	872.8	1.042
1856	467.8	677.0	1.297	880.5	1.049
1857	426.2	614.6	1.173	884.8	1.033
1858	338.3	487.3	0.922	893.0	0.996
1859	346.9	501.2	0.933	906.9	0.960
1860	392.2	567.6	1.041	919.9	0.941
1861	427.6	619.8	1.120	932.6	0.941
1862	400.1	578.9	1.034	944.4	0.971
1863	388.1	561.2	0.994	952.4	0.930
1864	349.7	504.9	0.883	964.8	0.914
1865	354.2	511.7	0.891	969.6	0.896
1866	416.5	604.0	1.043	976.2	0.899
1867	513.7	748.2	1.284	980.1	0.894
1868	550.3	803.9	1.378	980.2	0.995
1869	386.8	561.0	0.972	972.5	0.909
1870	387.3	562.7	0.970	977.1	0.811
1871	416.9	604.8	1.029	990.3	0.761
1872	477.4	697.1	1.147	1021.0	0.755
1873	565.7	825.7	1.336	1039.0	0.744
1874	593.6	865.5	1.403	1037.3	0.709
1875	534.6	777.1	1.229	1064.2	0.752
1876	536.7	783.5	1.221	1078.5	0.700
1877	544.9	793.3	1.233	1082.2	0.712
1878	489.5	711.7	1.101	1088.3	0.737
1879	470.0	682.9	1.050	1095.1	0.701
1880	519.3	758.1	1.149	1109.1	0.717
1881	521.0	758.3	1.158	1101.7	0.687
1882	476.2	693.5	1.044	1117.0	0.715
1883	467.0	682.4	1.016	1128.5	0.673
1884	457.7	669.1	0.989	1136.1	0.704

Table F.4 (cont.) Economic energy intensity (ratio without unit)

	energy volumes, million SEK, current prices	**consumers' surplus, million SEK, current prices**	**energy deflator, 1910/12=1**	**augmented energy volume, million SEK, constant prices, 1910/12 years' price level**	**economic- energy intensity**
1885	445.2	637.9	0.934	1146.5	0.675
1886	429.2	614.9	0.898	1148.7	0.669
1887	369.3	528.3	0.775	1143.5	0.681
1888	428.4	617.6	0.896	1154.9	0.663
1889	459.8	660.1	0.941	1171.5	0.656
1890	473.0	689.5	0.966	1189.9	0.656
1891	533.1	755.3	1.079	1194.8	0.626
1892	494.2	678.1	0.978	1190.0	0.627
1893	479.1	648.0	0.937	1193.7	0.612
1894	444.7	598.9	0.849	1218.7	0.611
1895	471.7	626.9	0.880	1236.9	0.588
1896	501.5	663.6	0.917	1258.3	0.571
1897	571.4	752.0	1.014	1291.6	0.560
1898	583.5	773.8	1.010	1328.5	0.557
1899	640.9	858.5	1.067	1390.2	0.568
1900	670.5	904.5	1.086	1434.3	0.576
1901	613.2	821.1	1.020	1384.1	0.548
1902	623.9	835.3	1.004	1426.1	0.568
1903	647.1	861.4	1.008	1464.3	0.555
1904	659.5	875.5	0.993	1510.5	0.557
1905	670.9	904.0	0.974	1582.0	0.592
1906	714.9	963.8	0.999	1642.6	0.567
1907	799.1	1080.1	1.065	1720.6	0.558
1908	865.3	1185.3	1.092	1825.8	0.606
1909	815.2	1106.9	1.011	1842.3	0.603
1910	827.0	1154.3	0.963	2000.2	0.624
1911	884.6	1261.6	0.996	2092.3	0.635
1912	969.8	1341.2	1.043	2153.0	0.632
1913	999.9	1456.8	0.977	2434.5	0.663
1914	1246.1	1737.8	1.220	2378.6	0.641
1915	1525.0	2076.7	1.378	2545.4	0.674
1916	1921.8	2578.6	1.585	2768.1	0.696
1917	2238.9	3111.8	2.081	2484.9	0.667
1918	3514.9	4634.9	3.194	2476.7	0.713
1919	3111.4	4677.0	2.918	2582.7	0.711
1920	3692.5	4869.9	3.246	2565.7	0.665
1921	1982.6	3452.4	2.080	2524.4	0.693
1922	1836.3	3408.5	1.642	3070.2	0.761
1923	1819.6	3214.9	1.496	3238.5	0.777
1924	1981.3	3321.1	1.464	3505.7	0.796

Table F.4 (cont.) Economic energy intensity (ratio without unit)

	energy volumes, million SEK, current prices	**consumers' surplus, million SEK, current prices**	**energy deflator, 1910/12=1**	**augmented energy volume, million SEK, constant prices, 1910-12 price level**	**economic-economic energy intensity (augmented energy volume/GDP#)**
1925	1853.6	3222.3	1.383	3522.3	0.784
1926	1951.3	3522.8	1.401	3746.1	0.787
1927	2072.7	3649.5	1.392	3949.9	0.810
1928	1927.3	3444.8	1.280	4020.3	0.800
1929	2009.7	3658.9	1.237	4382.5	0.814
1930	1980.2	3657.6	1.191	4513.5	0.806
1931	1861.2	3421.7	1.120	4478.3	0.821
1932	1859.2	3404.2	1.130	4417.0	0.840
1933	1940.6	3565.1	1.118	4645.7	0.857
1934	2130.7	3909.1	1.139	4997.1	0.856
1935	2337.4	4308.5	1.151	5403.0	0.877
1936	2509.9	4697.4	1.164	5819.5	0.904
1937	2821.5	5213.4	1.228	6164.0	0.930
1938	2850.4	5432.5	1.196	6528.6	0.951
1939	3203.1	6021.6	1.238	7064.4	0.952
1940	3400.7	6133.0	1.512	5999.9	0.883
1941	3641.9	6430.0	1.632	5893.8	0.883
1942	3813.4	6829.6	1.656	6153.1	0.914
1943	3997.5	7368.2	1.593	6846.0	0.968
1944	4015.9	7698.5	1.514	7456.3	1.013
1945	4279.5	8182.5	1.538	7771.9	1.033
1946	4735.8	9818.5	1.555	9022.2	1.063
1947	4320.4	8681.2	1.249	10038.0	1.088
1948	4869.3	9775.7	1.379	10273.0	1.088
1949	4878.1	9897.9	1.352	10582.2	1.086
1950	5266.4	10917.7	1.251	12565.6	1.254
1951	6726.4	12554.7	1.429	12870.7	1.224
1952	7240.2	13829.5	1.521	13358.6	1.265
1953	7048.4	14256.6	1.484	13980.4	1.282
1954	7043.7	14143.4	1.413	14525.7	1.282
1955	7810.9	15001.7	1.409	15592.8	1.336
1956	8996.6	17298.6	1.461	17416.6	1.440
1957	9648.0	18829.2	1.525	18172.5	1.439
1958	10041.8	19448.6	1.645	17281.1	1.362
1959	10099.7	19495.3	1.718	16572.8	1.270
1960	10946.8	20936.0	1.672	18419.9	1.353
1961	11172.7	21431.0	1.623	19487.4	1.355
1962	11755.8	21627.5	1.559	20655.8	1.362
1963	12601.1	22714.9	1.580	21552.0	1.347
1964	13087.1	22939.7	1.505	23093.9	1.329

Table F.4 (cont.) Economic energy intensity (ratio without unit)

	energy volumes, million SEK, current prices	**consumers' surplus, million SEK, current prices**	**energy deflator, 1910/12=1**	**augmented energy volume, million SEK, constant prices, 1910/12 years' price level**	**economic- energy intensity**
1965	13555.6	23295.5	1.514	23427.6	1.285
1966	14883.6	24821.2	1.485	25737.6	1.373
1967	15245.4	25133.6	1.515	25670.2	1.339
1968	16322.9	26362.8	1.482	27717.3	1.389
1969	16689.5	26371.7	1.412	29403.8	1.435
1970	18566.8	28594.0	1.495	30289.2	1.403
1971	21064.9	32344.5	1.742	29408.5	1.325
1972	22250.0	34041.7	2.468	21896.7	0.993
1973	25193.4	37948.2	2.559	23701.5	1.034
1974	30408.5	44512.0	3.205	22419.7	0.903
1975	34704.6	51004.7	3.446	23836.5	0.948
1976	38769.8	55446.4	3.955	22824.1	0.904
1977	41636.4	59536.4	4.159	23273.8	0.943
1978	46164.8	66247.0	4.668	23100.1	0.964
1979	63695.5	88241.7	5.510	26433.2	1.061
1980	72194.1	97944.3	6.547	24859.4	0.977
1981	80892.6	109091.3	7.818	23238.5	0.915
1982	90507.1	119782.4	8.839	22751.8	0.876
1983	98371.9	129262.4	9.536	22826.4	0.857
1984	104184.5	135973.2	10.388	22100.2	0.795
1985	117651.6	152024.3	10.778	23936.9	0.845
1986	112702.4	145210.7	9.791	25195.7	0.868
1987	109284.7	142631.6	10.301	23422.0	0.780
1988	119750.5	152539.4	10.673	24402.5	0.792
1989	125500.1	158011.5	12.077	22445.8	0.708
1990	150335.0	184385.5	12.077	26478.4	0.827
1991	158610.4	192965.2	12.077	27824.1	0.882
1992	159828.7	192762.7	12.077	27971.9	0.901
1993	170737.5	204434.7	12.077	29710.6	0.971
1994	179151.6	209464.7	12.260	30289.8	0.943
1995	184260.1	214176.8	12.603	30208.5	0.905
1996	196255.3	225075.7	13.573	29710.7	0.875
1997	207077.2	235507.4	14.154	29871.7	0.860
1998	208249.6	234431.2	14.282	29598.1	0.826
1999	206809.5	229462.5	14.112	29507.2	0.805
2000	220426.8	240637.0	15.037	29263.8	0.758

Table F.5 CO_2 emissions (million ton) and CO_2 intensities (kg/SEK)

	CO_2 emissions from fossil fuel (million ton)	**CO_2 emissions from forests (min) (million ton)**	**net CO_2 emissions (million ton)**	**fossil CO_2 intensity (kg/SEK)**	**combined CO_2 intensity (kg/SEK)**
1800	0.022	0.516	0.538	0.054	1.347
1801	0.032	0.516	0.549	0.083	1.416
1802	0.020	0.516	0.537	0.050	1.324
1803	0.032	0.516	0.549	0.080	1.356
1804	0.039	0.516	0.556	0.098	1.382
1805	0.027	0.516	0.544	0.066	1.301
1806	0.052	0.516	0.569	0.127	1.377
1807	0.063	0.516	0.580	0.159	1.449
1808	0.085	0.516	0.602	0.220	1.556
1809	0.073	0.516	0.589	0.190	1.541
1810	0.051	3.511	3.562	0.124	8.623
1811	0.034	3.511	3.545	0.081	8.315
1812	0.041	3.511	3.552	0.100	8.714
1813	0.034	3.511	3.545	0.086	8.857
1814	0.031	3.511	3.542	0.073	8.408
1815	0.045	3.511	3.556	0.100	7.973
1816	0.053	3.511	3.564	0.116	7.833
1817	0.051	3.511	3.562	0.113	7.951
1818	0.036	3.511	3.547	0.084	8.208
1819	0.043	3.511	3.554	0.099	8.135
1820	0.042	5.153	5.195	0.091	11.232
1821	0.042	5.153	5.195	0.088	10.808
1822	0.043	5.153	5.196	0.088	10.604
1823	0.046	5.153	5.200	0.092	10.390
1824	0.047	5.153	5.200	0.090	9.962
1825	0.038	5.153	5.191	0.072	9.880
1826	0.047	5.153	5.201	0.090	9.865
1827	0.056	5.153	5.210	0.109	10.074
1828	0.041	5.153	5.194	0.074	9.500
1829	0.041	5.153	5.194	0.074	9.340
1830	0.060	4.137	4.198	0.110	7.662
1831	0.044	4.137	4.182	0.081	7.648
1832	0.045	4.137	4.182	0.082	7.636
1833	0.046	4.137	4.184	0.080	7.243
1834	0.063	4.137	4.200	0.106	7.143
1835	0.079	4.137	4.216	0.132	7.033
1836	0.071	4.137	4.208	0.115	6.883
1837	0.064	4.137	4.201	0.105	6.870
1838	0.079	4.137	4.217	0.134	7.102
1839	0.087	4.137	4.224	0.142	6.864

Table F.5 (cont.) CO_2 emissions (million ton) and CO_2 intensities (kg/SEK)

	CO_2 emissions from fossil fuel (million ton)	**CO_2 emissions from forests (min) (million ton)**	**net CO_2 emissions (million ton)**	**fossil CO_2 intensity (kg/SEK)**	**combined CO_2 intensity (kg/SEK)**
1840	0.089	5.886	5.975	0.141	9.425
1841	0.091	5.886	5.977	0.144	9.441
1842	0.123	5.886	6.009	0.199	9.732
1843	0.103	5.886	5.989	0.162	9.436
1844	0.102	5.886	5.988	0.152	8.940
1845	0.131	5.886	6.017	0.189	8.692
1846	0.124	5.886	6.009	0.183	8.874
1847	0.113	5.886	5.998	0.163	8.672
1848	0.167	5.886	6.053	0.232	8.408
1849	0.186	5.886	6.072	0.246	8.032
1850	0.225	6.576	6.802	0.293	8.835
1851	0.238	6.576	6.814	0.310	8.895
1852	0.238	6.576	6.815	0.313	8.958
1853	0.233	6.576	6.810	0.302	8.798
1854	0.284	6.576	6.860	0.357	8.633
1855	0.300	6.576	6.877	0.359	8.211
1856	0.432	6.576	7.008	0.514	8.350
1857	0.545	6.576	7.121	0.636	8.314
1858	0.524	6.576	7.101	0.585	7.924
1859	0.692	6.576	7.268	0.733	7.697
1860	0.688	5.407	6.095	0.704	6.238
1861	0.883	5.407	6.289	0.890	6.344
1862	0.902	5.407	6.308	0.927	6.487
1863	0.896	5.407	6.302	0.875	6.156
1864	0.952	5.407	6.358	0.902	6.026
1865	0.989	5.407	6.396	0.914	5.912
1866	1.021	5.407	6.428	0.940	5.921
1867	0.953	5.407	6.359	0.869	5.798
1868	1.118	5.407	6.524	1.135	6.626
1869	0.976	5.407	6.383	0.913	5.969
1870	1.224	12.506	13.730	1.017	11.401
1871	1.305	12.506	13.811	1.002	10.608
1872	1.653	12.506	14.159	1.223	10.472
1873	1.640	12.506	14.146	1.174	10.125
1874	1.793	12.506	14.299	1.225	9.769
1875	2.172	12.506	14.678	1.534	10.367
1876	2.330	12.506	14.836	1.513	9.634
1877	2.456	12.506	14.962	1.615	9.839
1878	2.083	12.506	14.589	1.411	9.884
1879	2.100	12.506	14.606	1.345	9.354

Table F.5 (cont.) CO$_2$ emissions (million ton) and CO$_2$ intensities (kg/SEK)

	CO$_2$ emissions from fossil fuel (million ton)	**CO$_2$ emissions from forests (min) (million ton)**	**net CO$_2$ emissions (million ton)**	**fossil CO$_2$ intensity (kg/SEK)**	**combined CO$_2$ intensity (kg/SEK)**
1880	2.689	13.542	16.231	1.738	10.491
1881	2.611	13.542	16.153	1.628	10.072
1882	2.950	13.542	16.492	1.887	10.551
1883	3.143	13.542	16.685	1.874	9.949
1884	3.297	13.542	16.839	2.043	10.435
1885	3.555	13.542	17.097	2.092	10.062
1886	3.479	13.542	17.021	2.025	9.907
1887	3.536	13.542	17.078	2.107	10.176
1888	3.933	13.542	17.475	2.257	10.030
1889	4.590	13.542	18.132	2.572	10.159
1890	4.624	14.578	19.202	2.548	10.579
1891	4.899	14.578	19.477	2.568	10.211
1892	4.900	14.578	19.478	2.582	10.264
1893	4.944	14.578	19.522	2.535	10.011
1894	5.867	14.578	20.445	2.941	10.248
1895	5.921	14.578	20.499	2.812	9.736
1896	6.123	14.578	20.701	2.781	9.401
1897	6.831	14.578	21.409	2.963	9.286
1898	7.270	14.578	21.848	3.050	9.166
1899	9.133	14.578	23.711	3.732	9.689
1900	9.160	4.218	13.378	3.680	5.375
1901	8.496	4.218	12.714	3.363	5.033
1902	8.881	4.218	13.099	3.537	5.216
1903	9.777	4.218	13.995	3.708	5.308
1904	10.307	4.218	14.525	3.802	5.358
1905	10.145	4.218	14.363	3.797	5.376
1906	11.305	4.218	15.523	3.901	5.356
1907	12.867	4.218	17.085	4.174	5.542
1908	13.746	4.218	17.964	4.563	5.963
1909	12.676	4.218	16.894	4.147	5.527
1910	13.091	4.218	17.309	4.084	5.400
1911	12.932	4.218	17.150	3.927	5.208
1912	14.226	4.218	18.444	4.178	5.417
1913	15.931	4.218	20.149	4.338	5.487
1914	15.003	4.218	19.221	4.040	5.176
1915	15.537	4.218	19.755	4.113	5.229
1916	16.375	4.218	20.593	4.116	5.176
1917	6.777	4.218	10.995	1.820	2.953
1918	7.859	4.218	12.077	2.263	3.477
1919	7.368	4.218	11.586	2.029	3.190

Table F.5 (cont.) CO_2 emissions (million ton) and CO_2 intensities (kg/SEK)

	CO_2 emissions from fossil fuel (million ton)	**CO_2 emissions from forests (min) (million ton)**	**net CO_2 emissions (million ton)**	**fossil CO_2 intensity (kg/SEK)**	**combined CO_2 intensity (kg/SEK)**
1920	10.057	4.218	14.275	2.608	3.701
1921	5.831	4.218	10.049	1.600	2.758
1922	10.003	4.218	14.221	2.480	3.525
1923	12.139	4.218	16.357	2.914	3.927
1924	14.637	4.218	18.855	3.323	4.281
1925	13.039	4.218	17.257	2.901	3.839
1926	12.810	4.218	17.028	2.690	3.575
1927	17.998	-10.049	7.948	3.691	1.630
1928	16.476	-10.049	6.427	3.280	1.279
1929	19.651	-10.049	9.602	3.651	1.784
1930	19.141	-10.049	9.092	3.418	1.623
1931	19.319	-10.049	9.270	3.540	1.699
1932	19.070	-10.049	9.021	3.627	1.716
1933	19.906	-10.049	9.857	3.671	1.818
1934	22.055	-10.049	12.005	3.779	2.057
1935	23.238	-10.049	13.189	3.773	2.141
1936	25.733	-10.049	15.684	3.997	2.436
1937	29.640	-10.049	19.590	4.472	2.956
1938	26.469	-10.049	16.419	3.855	2.391
1939	29.894	-10.049	19.845	4.028	2.674
1940	19.039	-10.049	8.990	2.803	1.323
1941	15.395	-10.049	5.345	2.307	0.801
1942	12.665	-10.049	2.616	1.881	0.389
1943	15.103	-10.049	5.054	2.135	0.714
1944	11.800	-10.049	1.751	1.603	0.238
1945	2.822	-10.049	-7.227	0.375	-0.961
1946	16.090	-10.049	6.041	1.896	0.712
1947	24.180	-16.369	7.811	2.621	0.847
1948	28.992	-16.369	12.624	3.071	1.337
1949	25.803	-16.369	9.434	2.648	0.968
1950	44.967	-16.369	28.598	4.489	2.855
1951	54.185	-16.369	37.816	5.152	3.595
1952	53.105	-16.369	36.736	5.029	3.479
1953	43.985	-16.369	27.616	4.032	2.532
1954	42.886	-16.369	26.517	3.785	2.340
1955	50.369	-16.369	34.000	4.315	2.913
1956	53.089	-16.369	36.720	4.390	3.037
1957	50.826	-16.369	34.457	4.025	2.729
1958	46.063	-22.404	23.660	3.631	1.865
1959	36.531	-22.404	14.128	2.800	1.083

Table F.5 (cont.) CO_2 emissions (million ton) and CO_2 intensities (kg/SEK)

	CO_2 emissions from fossil fuel (million ton)	**CO_2 emissions from forests (min) (million ton)**	**net CO_2 emissions (million ton)**	**fossil CO_2 intensity (kg/SEK)**	**combined CO_2 intensity (kg/SEK)**
1960	44.271	-22.404	21.868	3.252	1.606
1961	42.998	-22.404	20.594	2.989	1.432
1962	46.899	-22.404	24.496	3.092	1.615
1963	50.388	-22.404	27.984	3.150	1.750
1964	55.264	-22.404	32.860	3.181	1.892
1965	56.419	-22.404	34.015	3.094	1.866
1966	65.165	-1.036	64.129	3.476	3.421
1967	60.569	-1.036	59.533	3.160	3.106
1968	68.988	-1.036	67.952	3.456	3.404
1969	75.986	-1.036	74.950	3.707	3.657
1970	84.748	-5.712	79.036	3.926	3.662
1971	78.442	-5.712	72.730	3.534	3.276
1972	77.427	-5.712	71.715	3.512	3.253
1973	79.924	-5.712	74.212	3.485	3.236
1974	77.644	-5.712	71.932	3.128	2.898
1975	79.474	-21.756	57.718	3.159	2.294
1976	83.127	-21.756	61.371	3.294	2.432
1977	79.662	-21.756	57.906	3.227	2.346
1978	69.777	-21.756	48.021	2.912	2.004
1979	82.604	-21.756	60.848	3.315	2.442
1980	72.119	-34.395	37.724	2.834	1.482
1981	57.788	-34.395	23.393	2.276	0.921
1982	56.767	-34.395	22.372	2.186	0.862
1983	54.955	-34.395	20.560	2.062	0.772
1984	51.150	-34.395	16.755	1.839	0.603
1985	58.391	-34.395	23.996	2.062	0.847
1986	63.352	-6.838	56.515	2.182	1.946
1987	52.691	-6.838	45.854	1.755	1.527
1988	56.518	-6.838	49.680	1.835	1.613
1989	51.459	-6.838	44.621	1.624	1.408
1990	50.318	-6.838	43.480	1.572	1.359
1991	48.017	-6.838	41.179	1.522	1.305
1992	46.995	-6.838	40.158	1.514	1.294
1993	47.005	-6.838	40.168	1.535	1.312
1994	48.264	-6.838	41.426	1.502	1.289
1995	48.426	-6.838	41.589	1.450	1.245

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Astrid Kander

Economic growth, energy consumption and CO_2 emissions in Sweden 1800-2000

Large transformations of technologies have occurred in the Swedish economy during the last two centuries, resulting in higher income, better quality of products and changing composition of GDP. An agrarian society has given way to an industrial society and lately to a post-industrial phase. The energy supply systems have changed, from traditional energy carriers, such as firewood and muscle energy to modern carriers like coal, oil and electricity, with effects on CO_2 emissions. Not only the energy supply has gone through fundamental changes, but also forest management, which affects the net emissions of CO_2. The interrelations of growth, energy and CO_2 are analyzed in this thesis, which uses standard calculations, relative price analyses and energy quality factors, to determine the relative effects of structural and technical changes, including changes in energy carrier composition to explain the long term delinking of energy consumption, CO_2 emissions and economic growth that takes place.

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