Postponed Leap in Carbon Dioxide Emissions: The Impact of Energy Efficiency, Fuel Choices and Industrial Structure on the Finnish Economy, 1800-2005*

Jan Kunnas and Timo Myllyntaus

It is generally assumed that industrialization goes hand in hand with a steep increase in the use of energy. Renewable sources of energy, which are also usually indigenous energy sources, are as a rule considered to be insufficient for a major structural modernization of the economy.

The standard interpretation is that the first industrial revolution usually required a switch from renewable energy sources to fossil fuels, in the acceleration

phase at the latest. That was the case in Britain, Belgium, Switzerland, and Germany but also in industrial provinces in France and in many other countries as well.[1] It has been an axiom in economic history that a change of the energy system from renewable to non-renewable sources is an indispensable precondition for successful industrialization. Alternative routes of industrialization are seldom considered or researched.

The present article examines the growth and composition of energy consumption in Finland in the 19th and 20th centuries, focusing on energy-related carbon dioxide emissions. Contrary to some of our colleagues, we do not take muscle energy into consideration.[2] We believe that its inclusion would lead to a great deal of double counting, first of the energy used in the production of food and fodder, and then again of the muscle energy they feed. The problem is accentuated in countries like Finland, where fire was widely used in cultivation.

We argue here that, among European countries, Finland was odd man out because its industrialization process was based on renewable, indigenous energy sources. Norway was another such exception, but there the predominant indigenous source of energy was hydropower, whereas Finland relied on a combination of fuel wood, wood refuse, and hydropower. Only in the 1960s, in the mature phase of its industrialization, did the country switch from indigenous energy sources to imported fossil fuels. The transition from one energy system to another led to significant structural changes and environmental problems. Why did this transition take place so late in Finland? Why did imported fuels manage to replace indigenous sources in a very short time span? These are the pivotal questions in this article, which examines Finland's industrialization from the perspective of environmental history.

* We wish to thank all the participants in the "Historical energy balance of Finland, 1800-1998"-project. Versions of this paper have been presented on various ICOHTEC-conferences. We also wish to thank the anonymous referees and the journal editors for helpful comments.

[1] S. Pollard, *Peaceful Conquest: The Industrialization of Europe, 1760-1970*, Oxford University Press, Oxford 1981; H. Kiesewetter, *Industrielle Revolution in Deutschland: Regionen als Wachstumsmotoren* [Industrial revolution in Germany: Regions as motors of growth], Franz Steiner Verlag, Stuttgart 2004.

[2] See for example: B. Gales, A. Kander, P. Malanima, M. Rubio "North versus

We open our article with a brief historical overview illustrating how man-made climate, originally regarded as a source of "more equable and better climates", came to be perceived as a threat to the well-being of humanity. We subsequently present our case study of Finland by looking at energy consumption, sectoral energy consumption, fuel choices, and finally the related carbon dioxide emissions. The reason for this organisation is that we believe that overall energy consumption dictates available fuel choices and hence also the related carbon dioxide emissions. Furthermore, energy consumption levels and fuel choices in different sectors of the economy are not independent from one another.

Carbon dioxide: From promise of a better climate to threat to the well-being of humanity

The Swede Svante Arrhenius is often mentioned as the first person to predict that increased atmospheric concentration of carbon dioxide would lead to global warning. In an article published in 1896, he calculated that a doubling of CO_2 in the atmosphere would increase the global surface temperature by an average of five to six degrees Celsius. He did not, however, see this as a problem. On the contrary, in 1908 he wrote that with increased CO_2 "…we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the Earth will bring forth much more abundant crops than at present for the benefit of rapidly propagating mankind".[3] The research on carbon dioxide emissions was, in any case, only a sidetrack in Arrhenius' research. He was awarded the Nobel Prize in chemistry in 1903 for other merits.[4]

Forty years later, in 1938, G.S. Callendar downscaled the esti-

South: Energy Transition and Energy Intensity in Europe over 200 Years", in *European Review of Economic History*, 11, 2, 2007, pp. 219-253.

[3] S. Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground", in *Philosophical Magazine and Journal of Science*, 41, 1896, pp. 237-276; id., *Worlds in the Making*, Harper & Brothers, New York 1908, p. 63.

[4] E.T. Crawford, *Arrhenius: From Ionic Theory to the Greenhouse Effect*, Science History Publications, USA, 1996.

mated effect of a doubling of CO_2 in the atmosphere to a mean temperature increase of two degrees Celsius. He also predicted a 0.4 degree Celsius increase of the mean global temperature in the 21st century and a 0.6º C increase in the 22nd century at the current rate of carbon dioxide production (annual excess of CO_2 to air = 4 300 million tons). Just like Arrhenius, he saw this as a beneficial thing, as it would improve the conditions of agriculture at the northern margin of cultivation and indefinitely delay the return of the deadly glaciers. He closed his article with the statement: "As regards the reserves of fuel these would be sufficient to give at least ten times as much carbon dioxide as there is in the air at present."[5]

In a series of articles published in 1956, Gilbert Plass estimated that if the carbon dioxide content of the atmosphere doubles, surface temperature will rise by 3.6 degrees Celsius.[6] Contrary to his predecessors, Plass saw this as a problem: "It is interesting that two of the most important methods available at the present time for generating large amounts of power have serious disadvantages when used over long time intervals. The burning of fossil fuels increases the temperature of the earth from the carbon dioxide effect; the use of nuclear reactors increases the radioactivity of the earth. It is difficult to say which of these effects would be the less objectionable after several centuries of operation."[7]

The following year, Roger Revelle and Hans E. Suess wrote an article about the carbon dioxide exchange between the atmosphere and ocean where they argued that the present rate of combustion of fossil fuels can be regarded as "a large scale geophysical experiment

[5] G.S. Callendar, "The Artificial Production of Carbon Dioxide and its Influence on Temperature", in *Quarterly Journal of Royal Meteorological Society*, 64, 1938, pp. 223-237.

[6] G. Plass, "Infrared Radiation and the Atmosphere", in *American Journal of Physics*, 24, 1956, pp. 303-21; id., "Effect of Carbon Dioxide Variations on Climate", in *American Journal of Physics*, 24, 1956, pp. 376-387; id, "Carbon Dioxide and the Climate", in *American Scientist*, 44, 1956, pp. 302-316; id., "The Carbon Dioxide Theory of Climatic Change", in *Tellus*, VIII, 2, 1956, pp. 140-154.

[7] Id., "Effect of Carbon Dioxide Variations on Climate", in *American Journal of Physics*, 24, 1956, pp. 376-387.

of a kind that could not have happened in the past nor be reproduced in the future".[8]

In 1979, the first World Climate Conference organized by the World Meteorological Organization (WMO) appealed to the nations of the world "…to foresee and to prevent potential man-made changes in climate that might be adverse to the well-being of humanity". Finally, in 1988, the WMO and the United Nations Environment Programme jointly set up the Intergovernmental Panel on Climate Change to provide scientific advice on climate change.[9] Its First Assessment Report, released in 1990, stated that the threat of climate change was real, and a global treaty was needed to deal with it. To address the problem, in 1992 a large group of countries signed the United Nations Framework Convention on Climate Change, which established a general framework for intergovernmental efforts to face the challenge of climate change. Developed countries adhering to the Convention committed themselves to returning individually or jointly to their 1990 levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol.[10]

The Kyoto Protocol, which was adopted in 1997 and came into force on 16 February 2005, shared the Convention's objective, principles and institutions, but significantly strengthened the Convention by committing signatories to individual, legally-binding targets to limit or reduce their greenhouse gas emissions. Developed countries that had signed the Protocol agreed to a goal of reducing their aggregate emissions of the six main greenhouse gases[11] to 5.2 per cent below the 1990 levels between 2008 and 2012. The EU member states agreed to

[8] R. Revelle, H. Suess, "Carbon Dioxide Exchange between Atmosphere and Ocean, and the Question of an Increase of Atmospheric CO2 During the Past Decade", in *Tellus*, 9, 18, 1957, pp. 18-27.

[9] IPCC, 16 Years of Scientific Assessment in Support of the Climate Convention, 2004. www.ipcc.ch/about/anniversarybrochure.pdf (downloaded 1.8.2007).

[10] UNFCCC, The United Nations Framework Convention on Climate Change, 1992. http://unfccc.int/resource/docs/convkp/conveng.pdf (downloaded on 8.6.2007).

[11] Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF6).

reduce their collective emissions by 8 per cent in the same time span. In the internal redistribution among the EU's member states, Finland committed to drop its emissions back to the 1990 level.[12]

In 1896, at the time when Arrhenius first predicted the greenhouse effect, Finland's carbon dioxide emissions from fossil fuels amounted to 1.9 million tons. By 1938, forty years later, they had almost tripled, having risen to 5.6 million tons. In 1956, when Gilbert Plass first raised his concerns that carbon dioxide emissions might not be such a good thing, they had already increased to 10.5 million tons. By the 1979 Climate Conference, ninety-four years after Arrhenius' prediction, Finland's carbon dioxide emissions had multiplied 28-fold, attaining 53.5 million tons. At the time of the adoption of the Kyoto Protocol in 1997, Finland's emissions had already multiplied 30-fold since Arrhenius' prediction, reaching 58.9 million tons, and 36-fold by 2003, to 68.7 million tons. To gain an insight into the reasons behind this dramatic increase in emission level, we first need to take a step back. We will begin by investigating the general development of energy consumption, and then turn to sectoral energy consumption in the subsequent chapter.

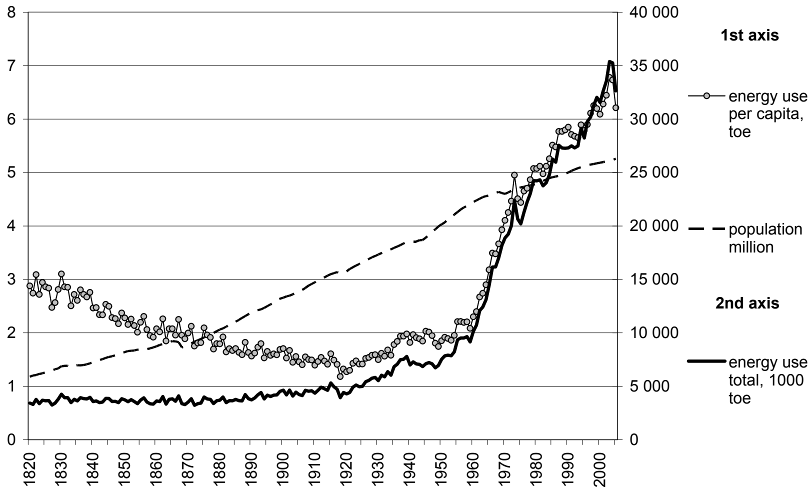
Energy consumption and efficiency

Despite rapid population growth, Finland's energy consumption grew at a modest rate in the 19th century. From 1820 to 1900, the country's population more than doubled, from 1.2 million to 2.7 million, while its energy consumption only increased by 35 per cent, from 3.4 to 4.6 million toe, as illustrated in Figure 1. Thus, Finland's energy consumption per capita declined from 2.9 toe in 1820 to 1.7 in 1900. The main reason for this trend was improved space heating efficiency, thanks to new stove technology tripling average thermal efficiency.[13] Another significant reason was a decrease in slash-and-

[12] United Nations, Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1998. *http://unfccc.int/resource/docs/convkp/kpeng.pdf* (downloaded on 8.6.2007).

[13] T. Myllyntaus, T. Mattila, "Decline or Increase, The Standing Timber Stock in Finland, 1800-1997", in *Ecological Economics*, 41, 2, 2002, pp. 271-288.

Figure 1. Population, primary energy consumption per capita and total energy use in Finland, 1820-2005



Sources: J. Kunnas, T. Myllyntaus, "The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland", in *Scandinavian Economic History Review*, 55, 2, 2007, pp. 101-127; Statistics Finland, Väkiluku sukupuolen mukaan 1750-2005, www.stat.fi (21.3.2006); Statistics Finland, Energy Statistics 2007, Helsinki 2007.

burn-cultivation and in the production of tar and pitch.[14] This decrease was partially counteracted by an increase in the burning of peatlands to clear land for cultivation, a practice that peaked in the 1890s and thereafter declined and was abandoned by 1940.[15] After

[14] T. Myllyntaus, M. Hares, J. Kunnas, "Sustainability in Danger? Slash-and-Burn Cultivation in Nineteenth-Century Finland and Twentieth-Century South-East Asia", in *Environmental History*, 7, 2, 2002, pp. 267-302.

[15] J. Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires: An Attempt to Compare the Energy Consumption in Slash-and-Burn Cultivation and Burning Cultivation of Peatlands in Finland in 1820-1920", in *Environment and History*, 11, 4, 2005, pp. 431-446.

a peak in the 1830s and a temporary upswing in the 1860s, Finnish peasants' total timber consumption started to decline, for various reasons. A notable change was that the demand for the peasants' protoindustrial products such as tar and potash diminished, and the profitability of their production hence fell markedly.[16]

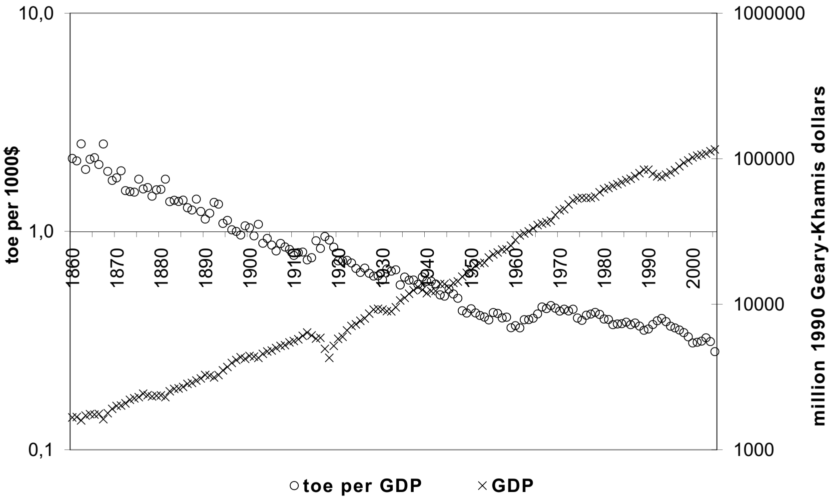
What makes Finland's slow growth in energy consumption in the 19th century and early 20th century phenomenal is the fact that the country's gross domestic product soared in the latter half of the 19th century. From 1860 to 1913 Finland's gross domestic product almost quadrupled, from 1675 million to 6408 million Geary-Khamis dollars. The annual 2.6 per cent GDP growth was, however, counteracted by a 2 per cent yearly decrease in the energy consumed per GDP dollar, as we can see in Figure 2. Thus, energy consumption grew by only half per cent a year and energy consumption per capita actually declined.

This "energyless" growth, however, did not continue after the First World War. Since the 1920s, Finland´s energy consumption per capita has been growing steadily, reaching the 1870s level by the 1950s, and tripling since then. During the interwar years, from 1920 to 1939, the GDP grew by almost 4 per cent a year, while the energy consumption per GDP decreased by only 1 per cent a year. Thus, as the GDP doubled, energy consumption grew from 4.2 to 7.8 million toe. After the Second World War, the GDP grew even faster: by 4.7 per cent a year from 1945 to 1959. It was counteracted by an annual decrease of 2 per cent in the energy-consumption-to-GDP ratio, resulting in a growth in energy consumption from 7.1 to 9.2 million toe. Energy consumption soared in the 1960s and early 1970s, as the effects of economic growth were intensified by decreasing energy efficiency. From 1960 to 1973 the GDP grew annually by 4.5 per cent, whereas the energy consumed per unit of GDP increased by 1.5 per cent per year; thus, energy consumption doubled from 10.2 million toe in 1960 to 22.7 million toe in 1973.

The first oil crisis, which started in 1973, determined stagna-

[16] J. Kunnas, "Potash, Saltpetre and Tar", in *Scandinavian Journal of History*, 32, 3, 2007, pp. 281-311.

Figure 2. GDP and energy consumption per unit of GDP in Finland, 1860-2005 (log)



Sources: J. Kunnas, T. Myllyntaus, "The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland", in *Scandinavian Economic History Review*, 55, 2, 2007, pp. 101-127; Statistics Finland, Energy Statistics 2007, Helsinki 2007; A. Maddison, *"Statistics on World Population, GDP and Per Capita GDP, 1-2006 AD*", http://www.ggdc.net/maddison/ (October 2008)

tion in GDP growth and consequently also a discontinuation in the growth of energy use. Around the second oil crisis, Finland experienced a brief period of GDP growth without increasing energy consumption from 1979 to 1982. Since then energy consumption has been growing, except for a brief decline during the recession at the beginning of the 1990s, surpassing 35 million toe in 2003.

Finland's rapid improvements in energy efficiency at the end of 19th century were achieved by means of relatively simple technology, although at that time to bring down energy consumption per 1000 $ of GDP from 2.16 toe in 1860 to 0.74 toe by 1913 was revolutionary indeed. By the end of the 1950s energy efficiency had further increased, halving the 1913 energy-to-GDP ratio. The closer we get to zero, the harder it becomes to bring about new revolutions, and indeed energy efficiency started to deteriorate again in the early 1960s. A common rule of thumb is that the time it takes to double the GDP can be calculated by dividing 70 by the growth rate. Thus, the 2.6 per cent GDP growth at the end of the 19th century corresponds to a doubling of the GDP every 27 years. A halving of the energy-to-GDP ratio in the same period would hence have been required to keep energy consumption constant. The almost 4 per cent yearly growth of the GDP during the interwar period would have required a halving of the energy-to-GDP ratio every 17th year, and every 15th after World War II. Even the moderate annual growth of 2.5 per cent from 1973 to 2003 would have required a halving of the energy-to-GDP ratio every 28th year.

Sectoral energy consumption

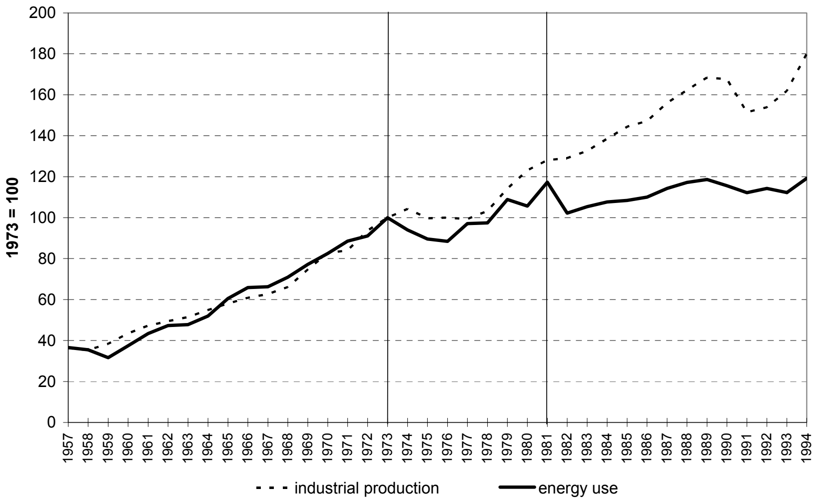
The primary motive for our interest in historical energy consumption is to understand how we got to the present situation as regards energy consumption and the related emissions. Hence, in the following section we focus on the three sectors that account for the largest share in Finland's present-day energy consumption. These are, in ascending order as regards their current energy consumption, industry, space heating, and traffic. Thus, we deal with agriculture, the second largest energy consumer in the 19th century after space heating, only through its connection with these three sectors. For a comprehensive review of declining energy consumption in agriculture in the 19th century, we refer the reader to the studies of Myllyntaus et al. and Kunnas.[17]

Industrial energy use

After a decline in industrial energy use at the end of the 1950s, Finland's industrial production and energy use grew at more or less

[17] Myllyntaus, Hares, Kunnas, "Sustainability in Danger?" cit.; Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires"cit.

Figure 3. Industrial production and industrial energy use in Finland, 1957-1994



Sources: R. Hjerppe, *Finland's historical national accounts 1860-1994*, Jyväskylän yliopisto, Historian laitos, Jyväskylä 1996; T. Myllyntaus (ed.), *Historical energy balance of Finland, 1800-1998*, unpublished manuscript.

the same pace until the first oil crisis, as illustrated in Figure 3. From 1960 to 1973, industrial production grew by an average of 6.3 per cent a year, industrial energy use by 7.2 per cent a year. As industry used around half of the total energy consumed in Finland in the 1960s, this difference in growth pace accounts for most of the increase in energy consumption per GDP unit.

The impact of the oil crises on Finnish industry was alleviated by Finland's bilateral trade with the Soviet Union. Finland imported most of its oil from its eastern neighbour, and the higher the rise in the price of oil, the larger the amount of manufactured commodities Finland

[18] M. Kuisma, *Kylmä sota, kuuma öljy: Neste, Suomi ja kaksi Eurooppaa 1948-1979*, WSOY, Porvoo-Helsinki 1997.

had to export in exchange.[18] Nevertheless, the period from the beginning of the first oil crisis in 1973 to the end of the second oil crisis in 1981 witnessed a divergence of the paths of industrial production and energy consumption. From 1973 to 1981, industrial production grew by 32 per cent, industrial energy consumption only by 17 per cent. From 1981 to 1994, industrial production grew by 39 per cent, while industrial energy consumption remained more or less constant. Increased energy efficiency obviously played a role in this trend. A more important factor, however, was a change in the industrial structure. From 1973 to 1981, industrial output in the energy-intensive wood-processing and paper industry grew by 7 per cent, by 40 per cent in the electrical industry, and by 56 per cent in the metal-processing and engineering industry. The difference was even more remarkable from 1981 to 1994, when industrial output grew by 48 per cent in the wood and paper industry and by 56 per cent in the metal-processing and engineering industry, while the output in the electrical industry witnessed a phenomenal increase of 263 per cent.[19]

The different growth speeds of individual sectors had a significant influence on overall energy efficiency. For example, in 1993 the forest industry consumed 10 TJ for every million Finnish marks of added value, and the chemical industry 7 TJ. The metal-processing and engineering industry consumed 2 TJ per million Fmk, less than agriculture.[20] In 1991 energy constituted 35% of the value added in the production of pulp and paper, but only 2 per cent in the manufacture of electrical and optical equipment.[21]

Statistics on industrial activity cover all industrial establishments only from 1995 onwards. Earlier statistics only took account of enterprises with 5 or more employees. We hence examine the period from 1995 onwards separately. From 1995 to 2004, added value increased

[19] Statistics Finland, Statistical Yearbook of Finland 2006, Helsinki 2006.

[20] I. Mäenpää, *Kansantalous, energia ja päästöt*, Tilastokeskus, Helsinki 1998, pp. 9-13.

[21] A. Aittomäki, T. Kalema, P. Sarkomaa, “Energian säästö”, in *Kestävän kehityksen edellytykset Suomessa. Imatran Voima OY:n 60-vuotisjuhlajulkaisu*, I. Kurki-Suonio, M. Heikkilä (eds), Kustannusosakeyhtiö Tammi, Helsinki 1994, p. 686.

by 44 per cent in the industry, industrial energy consumption by only 27 per cent. Again, this slower growth can be explained by a faster growth of added value in sectors with lower energy intensity. During the same period, the industrial output in the wood-processing and paper industry grew by 35 per cent, the output in the metal-processing and engineering industry doubled, and the output in the electrical industry almost quadrupled.[22] The fact that an industrial action that closed down the factories for one and a half months caused a 7 per cent decrease in the final consumption of energy in the entire manufacturing sector in 2005 compared to 2004 bears witness to the magnitude of the forest industry's share in industrial energy consumption.[23]

Space heating

Space heating was by far the biggest consumer of energy in 19th-century Finland, accounting for between 60 and 80 per cent of the country's global energy consumption, as shown in Figure 4. It maintained this position long into the 20th century, despite the heating revolution described earlier and Finland's industrialization in the 19th century. Finally, in the early 1950s, energy consumption in the manufacturing sector surpassed consumption for heating. Space heating, however, remained the second largest sector of energy consumption. In 1981, for example, 24 per cent of all the energy consumed in Finland was used for the heating of residential, commercial, and public buildings, another 6 per cent for the heating of industrial spaces, and 2 per cent for that of agricultural buildings.[24]

Wood remained the only fuel used for space heating until the very end of the 19th century. At this time, coal was introduced in some large coastal towns in a small number of blocks of flats with central

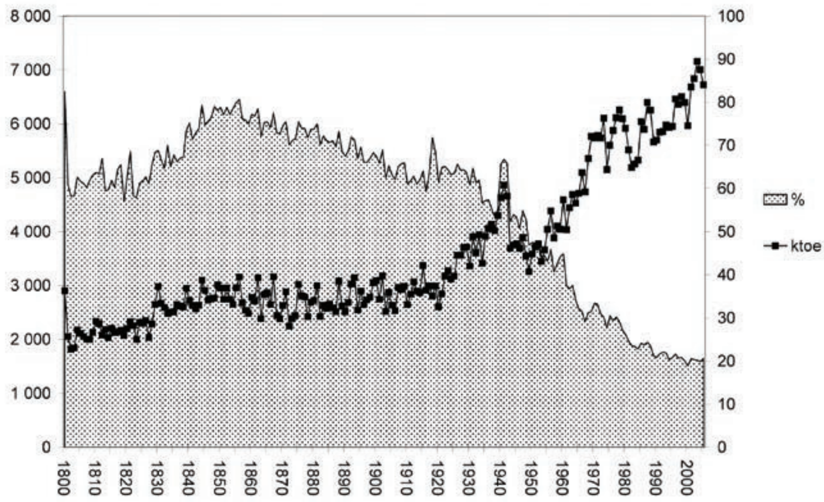
[22] J. Autio (ed.), *Kymmenvuotiskatsaus 2005: Teemana yritystoiminta*, Tilastokeskus, Helsinki 2005.

[23] Statistics Finland, Energy Statistics 2006, Helsinki 2006.

[24] M. Lappalainen (ed.), *Energiakäsikirja*, Suomen Arkkitehtiliitto ja Rakennuskirja Oy, Helsinki 1983, p. 11.

[25] T. Myllyntaus, *Electrifying Finland. The Transfer of a New Technology into a Late Industrialising Economy*, Macmillan & ETLA, London 1991, pp. xvi, 21, 407.

Figure 4. Total energy consumption for the heating of residential, commercial, and public buildings in Finland, and percentage of total energy consumption, 1800-2005.



Sources: (1800-1969) Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.; (1970-2005) Statistics Finland, Energy Statistics 2006, Helsinki 2006.

heating.[25] Small quantities of peat were also used. At the eve of the Second World War, wood still provided around three fourths of the total energy used for heating, and even more during the war period.

Despite continuing increases in energy efficiency, from 1950 to 2003 energy consumption for space heating doubled. In the aftermath of the oil crisis of the 1970s the *specific consumption* per cubic metre of heated space decreased by almost 30 per cent. This trend, however, had already come to an end by the early 1980s, as increased room temperatures and ventilation ate up the effects of advances in *construction engineering*.[26] Furthermore, the demand for larger resi-

[26] Energiansäästötoimikunta *Energiansäästötoimikunnan mietintö*, Kauppa-ja teollisuusministeriö, Helsinki 1995, p. 17.

dential space was given a higher priority than saving energy in space heating. Residential space per capita increased from 14.3 square metres in 1960 to 18.9 in 1970, 24.8 in 1985, and all of 38 in 2005.[27]

The 1950s witnessed another "heating revolution"; the introduction of combined heat and power generation (CHP), which had a major effect on the efficiency of electricity production. When electricity is generated separately, the utilisation rate of fuel energy is a mere 40-50 per cent, while when electricity is produced in "combined heat and power" plants 80-90 per cent of the energy value of fuel can be utilized. Thus, the increased production of electricity in CHP-plants managed at least to some degree to offset a decrease of energy efficiency due to the increasing use of electricity for heating from the 1970s onward. District heating increased by a factor of 7 from 1970 to 2005, and electricity used in space heating grew by a factor of 17. Nowadays district heating provides around half of the energy for heating, and three fourths of this heat is produced by CHP-plants. Oil heating has a share of one fifth and electric heating provides one seventh.[28]

Motorised road traffic

As we have not taken into account animate power or the wind power used by sail ships, in our calculations energy consumption for transportation remains at zero until 1833, when Nils Ludvig Arppe acquired the first steamship in Finland, Ilmarinen. Railroad traffic with steam-driven trains started in 1862, when Finland's first railroad was opened. The share of traffic in Finland's energy consumption, however, remained low for the rest of the century: 0.1 per cent in 1857, 1 per cent in 1879, and still only around 3 per cent at the turn of the century.

The 20th century witnessed an increase of motorised road transport. Since a regular lorry in the 1920s could carry loads two or three times heavier than horse-drawn carts, lorries gradually displaced horse transport. By 1938 coaches provided more passenger kilometres than trains.

[27] Tilastokeskus, Asuminen www.stat.fi (20.9.2007).
[28] Energy Statistics 2006.

In the transportation of goods this transition took a longer time. In 1938, waterway transport accounted for more than half of all tonne-kilometres in domestic goods transport, mainly due to timber rafting, while railroads provided 40 per cent, and road transport only 7 per cent. As waterway transport decreased, the share of railroad transport rose to around half of the total in the 1950s and early 1960s. In the end, road transport won this battle as well. In 1970, road traffic's share of the total goods transport was 56 per cent, followed by rail traffic with 26 per cent and water transport with 18 per cent.[29] In 2006, 73 per cent of all freight transport in Finland was by road, equalling the average share of road transport in EU27.[30] Today passenger cars account for 80 per cent of all passenger transport, which explains why Finland has the third highest amount of passenger kilometres in road traffic per capita in the EU, surpassed only by Italy and Luxembourg.[31]

The increased role of road traffic in Finland's transportation system has had a major effect on energy efficiency in transportation. This effect has been accentuated by the transition of passenger road traffic from public transport to passenger cars, which took place during the 1960s. In 2001 the average energy consumption of passenger cars per passenger-kilometre was double that of a bus and triple that of an electric train. The average highway energy consumption of a delivery lorry was 1.6 MJ per tonne-kilometre, that of a full trailer 0.58 MJ, that of a diesel train 0.46 MJ, and that of an electric train 0.23 MJ per tonne-kilometre.[32]

Finland acquired its first automobiles at the turn of the century. After the 1918 civil war, and until 1920, motoring was in theory

[29] E. Pihkala, "Liikenteen uusi vallankumous", in *Suomen taloushistoria 2 – Teollistuva Suomi*, J. Ahvenainen, E. Pihkala, V. Rasila (eds), Kustannusosakeyhtiö Tammi, Helsinki 1982, pp. 440-452; J. Ahvenainen, Y. Kaukiainen, M. Viitaniemi, "Liikenne", in ibid., pp. 279-293.

[30] Eurostat, News Release 49/2008-10 April 2008: Transport in the EU27. http://epp.eurostat.ec.europa.eu (accessed 12.1.2009).

[31] Environment and Natural Resources 2008, Statistics Finland, Helsinki 2008.

[32] K. Mäkelä, Unit emissions of vehicles in Finland, h*ttp://lipasto.vtt.fi/yksikkopaastot/indexe.htm* (accessed on 6.12.2007).

strictly controlled due to fuel scarcity and security reasons. With the economic growth of the interwar years the number of cars rapidly increased. Another reason for this fast increase was Prohibition (1919-32), which induced alcohol smugglers to buy cars for quick delivery of their highly demanded wares.[33] In 1922 there were roughly 2000 cars in the country (0.6 per 1000 people), while in 1929 there already were 35000 (10 per 1000), and 52 000 (14 per 1000) at the eve of the Second World War in 1939.[34]

The number of cars seems to halve in 1941, while energy consumption doubles, as we can see in Figure 5. The reason for the former datum is that a large number of automobiles were in the use of the army during the war years and immediately thereafter, or remained unused due to fuel regulation, and were thus not included in car registration statistics.[35] One reason for the huge increase in energy consumption was that automobiles had to be converted to be fuelled by wood instead of oil, causing a decrease in fuel efficiency and loading capacity.[36]

Along with the increase in the quantity of cars, road traffic's share of the total energy consumption in traffic increased fast. In 1945 automobile traffic consumed 10 per cent of all energy in Finland, out of which road traffic's share was 30 per cent. From 1945 to 1960 the number of automobiles grew by a factor of 10, while the energy consumption in road traffic tripled. Traffic's share of the total energy consumption remained at 10 per cent, but the share of road traffic doubled to 60 per cent. In 1960, road traffic consumed only 6 per cent of all energy in Finland, while its share in 1945 had been 3 per cent.

From 1960 to 1973 the number of automobiles quadrupled, while energy consumption in road traffic grew at an only slightly slower rate, increasing from 600 to 2100 ktoe. In the same period the car-

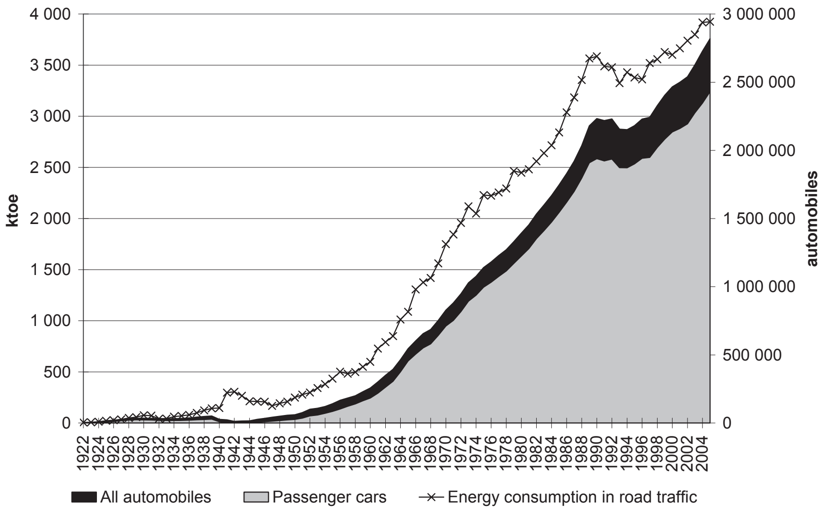
[33] R. Ahtokari, *Pirtua, pirtua... Kieltolaki Suomessa 1.6.1919-5.4.1932*, WSOY, Porvoo, Helsinki 1972, p. 120.

[34] Statistical Yearbook of Finland 2006

[35] Statistical Yearbook of Finland 2006: CD-rom chart liike_14.

[36] R. Boijer, H. Roste, *Puukaasu autoissa*, Kustannusosakeyhtiö Otava, Helsinki 1940.

Figure 5. Number of automobiles and energy consumption in road traffic in Finland, 1922-2005



Sources: Statistics Finland, Statistical Yearbook of Finland 2006, Helsinki 2006; Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.

to-people ratio increased from 58 to 220/1000. In 1973, road traffic accounted for 10 per cent of the total energy consumption and 88 per cent of the total energy consumption in traffic. The oil crises did not significantly affect road traffic. Energy consumption in this sector did drop slightly from 1973 to 1974, but by 1975 the 1973 level had already been surpassed, while the 1980s crisis only caused a few years of slowdown in growth speed. From 1991 to 1993 Finland faced an economic depression that was the most serious slump any industrial society had experienced since the Second World War. This depression caused a dramatic stagnation in the growth of energy consumption in road traffic that lasted for close to a decade. The 1990 level was surpassed only in 1999. By 2005, energy consumption in road traffic had grown by another 9 per cent, peaking at 3900 toe, or 91 per cent of the total energy consumption in traffic.

By 2005, the car-to-people ratio had multiplied ninefold since 1960, to 536 cars per thousand people, and the total amount of cars elevenfold, to 2,8 millions. Behind this manifold increase in the number of automobiles was a move from public transportation to passenger cars. In 1945 passenger cars accounted for 24 per cent of all automobiles. By 1960 their share had increased to 71 per cent, and by 1970 to 86 per cent. This change in the mode of transportation has eaten up all efficiency gains and contributed to a sixfold increase in the energy consumption of road traffic since 1960, and a doubling of its percentage share of all energy consumption, to 12%.[37]

Fuel choices

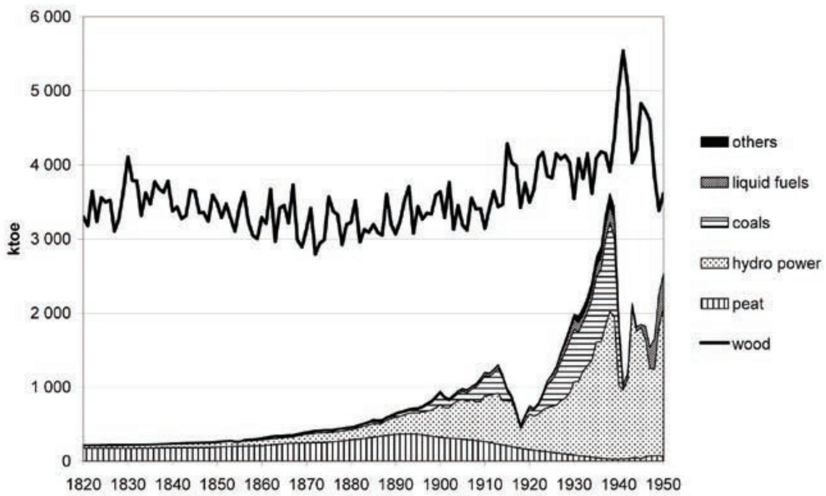
Wood provided 84 per cent of all energy in 1820, while peat contributed 4 per cent, as indicated in Figure 6. The remaining percentage mainly consisted of water power and some wind energy, and a negligible amount of coal. All of the peat consumption came from the burning of peatlands to clear land for cultivation. Small amounts of peat were used as fuel from the mid 19th century onward, but this use remained negligible until the early 20th century. Thus, the peak of peat consumption at the end of 19th century was mainly caused by the expansion of agriculture in peatlands cleared by means of burning.[38] By 1860 the share of peat had increased to 6 per cent, while the use of other fossil fuels (coal and some oil) was less than half per cent. 81 per cent of the total energy was derived from wood, while other renewable resources (mostly hydropower, but also some wind mills) had a share of 3 per cent.[39]

[37] Statistical Yearbook of Finland 2006. Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.

[38] Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires" cit.

[39] The standard way to calculate the primary energy produced by wind and waterpower is to use the average operating efficiency rate of a modern conventional thermal power plant, which is 33 %. Historically this method is not sound, as the efficiency changed considerably over time. That is why have calculated the primary energy content equalling the energy produced by wind and waterpower using the average thermal efficiency of each point in time. Thus, in principle the efficiency changed every year.

Figure 6. Consumption of primary energy in Finland, 1922-1950



Sources: Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.; T. Myllyntaus, T. Mattila "Decline or Increase, the Standing Timber Stock in Finland, 1800-1997", in *Ecological Economics*, 41, 2, 2002, pp. 271-288; M. Tommila, *Avaintekijä puu Suomen teollisuuden raaka-aineena ja energianlähteenä 1845-1913*, Master's thesis in Finnish history, University of Helsinki, 2000; Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires" cit., pp. 431-446; J. Kunnas, "Potash, Saltpetre and Tar", in *Scandinavian Journal of History*, 32, 3, 2007, pp. 281-311.

As Finland did not have domestic sources of coal and oil, but relatively good water resources, Finland's initial industrialization was based on wood and water power. Thus, from 1860 to 1900 the use of firewood in industry multiplied fivefold, from 85 to 420 ktoe, and that of waterpower ninefold, from 41 to 386 ktoe. Together, firewood and waterpower provided for 87 per cent of all industrial energy needs. Fossil fuels, including peat, provided only 11 per cent of total consumption in 1900, which can be compared to 43 per cent in Italy, 45 per cent in Sweden, 55 per cent in Spain and 94 per cent in the Netherlands.[40] In the United States, oil and coal provided half of the primary energy consumed in the 1890s.[41]

Although the industrial use of wood-derived energy in Finland increased rapidly, in 1920 the total use of energy from wood was more or less the same as in 1820, as we can see in Figure 6 above. This was mainly due to improvements in space heating technology and the insulation of buildings. In 1920 the same amount of heat could be produced using only a third of the firewood needed in 1800.

We would venture to claim that without this heating revolution Finland's wood-based industrialization in the late 19th century would not have been possible, since the Finnish industry, besides consuming firewood in considerable quantities, needed wood as a raw material. This is reflected in Figure 7 below, which shows that throughout the 19th century the total drain of wood in the country's forests was higher than regrowth. Thus, without decreasing consumption of wood in other sectors there would not have been any reserves for a wood-based industrialization. Timber consumption by slash-and-burn cultivation decreased throughout the 19th century, as did the production of tar and potash after peaking in the 1830s. This can be seen as a consequence of the rising value of timber and the new work opportunities offered by the rapid growth of the forest industry. The overexploitation of forests was halted in the early 20th century just as the forest growth rate was increasing thanks to a favourable warm climatic period, a more favourable tree age structure as a result of extensive cutting of forests some decades previously, and improved forestry practises. During the interwar period, however, the drain of wood was again higher than growth.[42]

In 1938, on the eve of the Second World War, waterpower pro-

[40] This comparison is based on Gales, Kander, Malanima, Rubio, "North versus South" cit., pp. 219-253. We have, however, excluded muscle energy from their total energy use statistics to allow comparability with our own figures.

[41] R.S.J. Tol, S.W. Pacala, R. Socolow, *Understanding Long-Term Energy Use and Carbon Dioxide Emissions in the USA*, FEEM Working Paper n. 107.06. (August 2006). Available at SSRN: http://ssrn.com/abstract=927741

[42] Myllyntaus, Mattila, "Decline or Increase" cit.; Kunnas, "Potash, Saltpetre and Tar" cit., pp. 281-311.

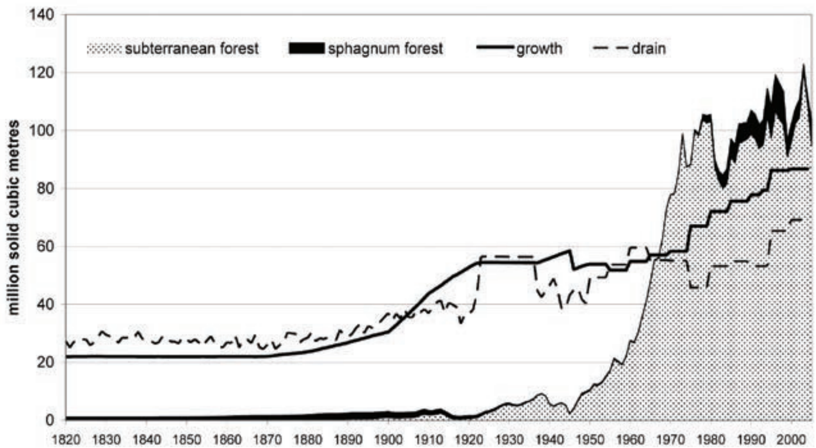
vided 26 per cent of the total energy used in Finland, while the share of coal was 16 per cent and that of oil 3 per cent. The country, however, still had a mostly timber-based economy, as firewood and wood refuse still provided 52 per cent of all energy, and wood was also the primary industrial non-energy input. The consumption of wood-derived energy peaked during the World War II period, just as it had during the First World War, when it had had to substitute for fossil fuels that were no longer available. The very sub-optimality of wood for certain purposes further increased the demand. For one thing, the fuel efficiency of a combustion chamber designed for burning coal or oil decreases when wood is used. Also, due to acute fuel shortage wood felled the same year had to be used instead of well-dried one, and this further diminished fuel efficiency. Thus, whereas it was earlier estimated that six cubic metres of stacked wood could provide the energy equivalent of one metric ton of coal, now as much as ten cubic metres was needed. The demand for fuel wood was further accentuated by a shortage of water for hydropower plants, caused by dry summers and low water contents in snow. On top of that, the winters of 1939-1942 were the coldest in over one hundred years.[43]

Following the example of Rolf Peter Sieferle, in Figure 7 below we have calculated the role of fossil fuels as substitutes for wood.[44] To do this, we have compared the growth of, and drain on, Finland's forests with the consumption of coal and other fossil fuels – what Sieferle nicknamed the "subterranean forest" – expressed as energy-content equivalents of cubic metres of firewood. We have calculated and graphed in the same way the consumption of domestic peat, which we call here the "sphagnum forest", after the principal peat-

[43] N. Osara, "Polttoaineiden ja puutalouden säännöstely Suomessa toisen maailmansodan aikana ja sen jälkeen", in *Silva Fennica*, 3, 4, 1969, pp. 251-284; H. Lindroos, *Puuta mottiin – puuhuoltoa sodan varjossa, 1939-1947*, Teollisuuden metsänhoitajat, Rauma 1993, pp. 27-28.

[44] R.P. Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, White Horse Press, Cambridge and The Isle of Harris 2001. See also F. Krausmann, H. Schandl, R.P. Sieferle, "Socio-Ecological Regime Transitions in Austria and the United Kingdom", in *Ecological Economics*, 65, 1, 2008, pp. 187-201.

Figure 7. The growth of, and drain on, Finland's forestland and the extra "timber" provided by the "subterranean forest" and "sphagnum forest", 1820-2005



Sources: Myllyntaus, *Historical Energy Balance of Finland, 1800-1998* cit.; Myllyntaus, Mattila "Decline or Increase, the Standing Timber Stock in Finland, 1800-1997" cit., pp. 271-288; Tommila, *Avaintekijä puu Suomen teollisuuden raaka-aineena ja energianlähteenä 1845-1913* cit.; Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires" cit., pp. 431-446; Kunnas, "Potash, Saltpetre and Tar" cit., pp. 281-311; Statistics Finland, Statistical Yearbook of Finland 2006, Helsinki 2006.

creating moss. During the 19th century the use of these additional "forests" oscillated between four and ten per cent that of wood. Most of this came from the clearing of peatlands for agriculture by means of burning. The consumption of the subterranean forest surpassed that of the sphagnum forest in the early 20th century. During the interwar period these two sources accounted for at most one third of the energy content of the total drain on wood.

With the resuming of the forest industry after the Second World War, the total drain on wood caught up with total growth by 1955, increasing the need for fuel energy from other sources. Conveniently, the average import prices of fossil fuels decreased from 1950 onwards. From 1957 to 1970 the deflated price of imported coal dropped to one third and that of crude oil halved.[45] Thus in the 1960s the energy share of the subterranean forest surpassed that of the forest above the ground; over half a century late, as in most industrialized countries the combustion of fossil fuels already equalled biomass combustion as early as 1900.[46]

From 1950 to 1969 energy consumption increased by 140 per cent, and 92 per cent of this increase was sustained by fossil fuels, as shown in Figure 8. Thus, in 1960 the use of fossil fuels surpassed that of wood, and in 1965 it surpassed the total use of renewable energy. Finland had entered the fossil-fuel age. Despite the first oil crisis in 1973, the share of fossil fuels in the energy mix kept increasing until 1977, when they provided 70 per cent of all energy – 72 per cent if we include peat, the use of which increased in the seventies as a response to the crisis. Finland's first four nuclear plants were connected to the national grid in the period from February 1977 to November 1980.[47] The first three were commissioned before the oil crisis, but the commissioning of the fourth was officially announced in August 1974,[48] so in its case the crisis may have been at least a further argument for its construction. The 1970s also brought an increased share of electricity imports. A natural gas pipeline from the Soviet Union to Finland was opened in 1974 and the burning of consumer waste started in 1975. The role of the latter, however, has remained minimal so far.

A simple explanation for Finland's late transition from an energy system based on indigenous energy sources to one largely dependent on fossil fuels is that the country's vast wood resources allowed it to

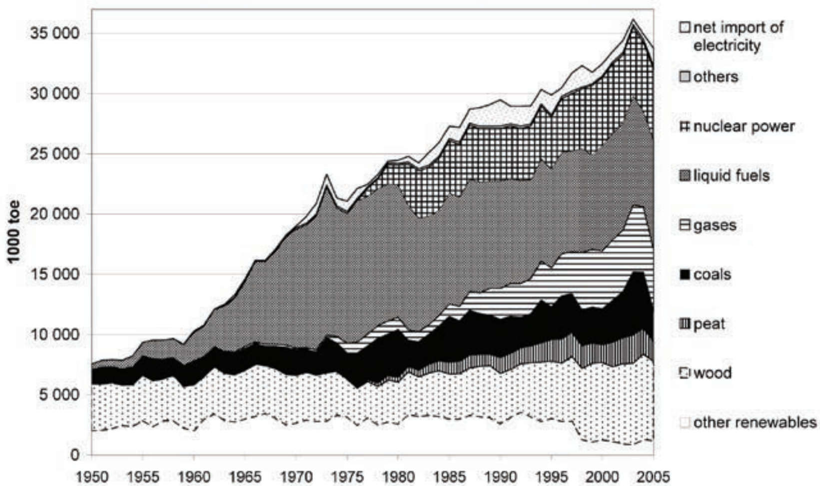
[45] T. Myllyntaus (ed.), *Energian hinta 1800-1998, Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 12*, Edita, Helsinki 1999.

[46] V. Smil, *Energy in Nature and Society: General Energetics of Complex Systems*, MIT Press, Cambridge (MA) 2008, p. 375.

[47] J. Auer, N. Teerimäki, *Puoli vuosisataa Imatran Voimaa, Imatran Voima Oy:n synty ja kehitys 1980-luvulle*, Kirjapaino F.G. Lönnberg, Helsinki 1982; Teollisuuden Voima Oy, Olkiluoto, Nuclear power plant units 1 and 2, TVO 2007 http://www.tvo.fi/uploads/tekninenesite-Eng(1).pdf (22.08.2007).

[48] M. Sunell, "Suomalainen ydinvoimapoikkeus", in *Ydinvoima, valta ja vastarinta*, Matti Kojo (ed.), Like, Helsinki 2004, pp. 179-207.

Figure 8. Consumption of primary energy in Finland, 1950-2005



Sources: Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.; Statistics Finland, Energy Statistics 2007, Helsinki 2007.

postpone the transition. To obtain a comprehensive picture, however, we have also taken into account relative prices and political considerations. Throughout the 19th century, in Finland firewood was cheaper than coal. As a result of developing mining technology and decreasing overseas transportation costs, coal began to compete in price with indigenous firewood from the turn of the century onward, at least in coastal towns. Inland transportation costs divided the country into a coal and a wood zone, whose size depended on the relative prices of coal and firewood. Eventually firewood lost the battle and coal has remained the cheapest fuel since the Second World War. Actually for a short period, from the end of the 1950s to the beginning of the 1970s, heavy fuel oil could compete with coal in price. However, for political considerations – the safeguarding of employment – firewood was preferred until the end of 1950s. For example, from the Second World War to 1961 it was forbidden to transport coke and anthracite inland from the coast.[49]

In the 1960s, increasing and diversified timber demand in the forest industry caused a U-turn in Finland´s firewood policy. Suddenly there was no more need for political measures favouring firewood; on the contrary, the burning of wood was deemed irresponsible. The deepest change in attitude was that towards birch, which as late as the 1950s Finnish foresters still regarded as a weed. This change was caused by an acute scarcity of birch stocks resulting from new pulping technology allowing the making of pulp from this species, as well as considerable demand for birch in the expanding plywood industry.[50]

The redirection of wood to the forest industry was, however, counteracted by the burning of waste liquor in the pulp industry in order to recycle valuable chemicals used in the pulping process. In the production of pulp, only about 50 per cent of the wood fibers actually ends up in the pulp. The rest goes into the waste liquor, which can be used as fuel. Thus the change of policy toward wood energy was in practice a redirection of wood from direct use as fuel to an indirect use in waste liquor furnaces. This supports our initial assumption that energy consumption and fuel choices in different sectors of the economy are not independent from one another.

An increasing amount of fossil fuels was also needed for the production of electricity, as the technological and political feasibility of further hydropower plants ended in the 1960s. Furthermore, the increased use of central heating speeded up the ongoing transfer from wood-derived energy to fossil fuels.

Carbon dioxide emissions

We have calculated the level of carbon dioxide emissions from fuel use by multiplying fuel consumption by specific emissions per consumed fuel unit. For this calculation method, we refer the reader

[49] Myllyntaus, *Energian hinta 1800-1998* cit.

[50] I. Björn, *Kaikki irti metsästä*, Suomen historiallinen seura, Helsinki 1999, p. 117; P. Schybergson, *Med rötter i skogen, Schaumann 1883-1983*, vol. 2, Frenckellska Tryckeri Ab, Helsingfors 1983, p. 265.

to its detailed description by Kunnas and Myllyntaus.[51] As there are no economically feasible methods of removing carbon from emissions, the whole carbon content of burned fuels is released into the air. Carbon dioxide emissions from 1998 onward are obtained from official statistics.[52] The results are presented in Figure 9 below and in Appendix I.

Since wood is carbon-neutral, until the beginning on the 1920s peat was the principal source of carbon dioxide.[53] The share of peat declined with the end of the burning of peatlands, and did not regain importance until after the oil crises. As peat declined, coal rose to become the largest source of carbon dioxide, until the 1960s, when liquid fuels took the pole position. The oil crises did not end the prevalence of fossil fuels. Increasing oil prices merely increased the attractiveness of natural gas, coal and peat. The first emits less carbon dioxide than oil, the last twice as much. The 1970s also witnessed an increased share of electricity imports, and nuclear power was added to energy sources, with four nuclear plants connected to the national grid between 1977 and 1980. Neither the importing of electricity nor the nuclear plants, however, have brought down the emissions of carbon dioxide, although they have flattened the upward slope of the carbon dioxide emission curve.[54]

Christian Pfister has described the shift from the moderate use of

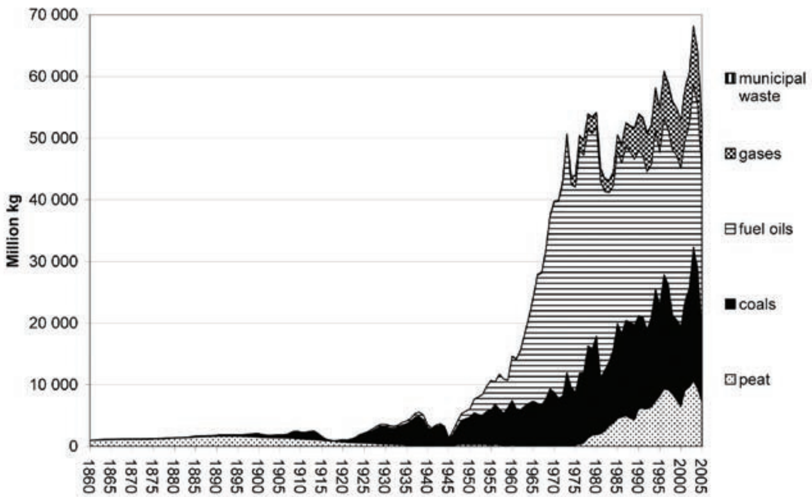
[51] Tilastokeskus, Energia ja päästöt, Hiilidioksidi-, typenoksidi- ja rikkidioksidipäästöt Suomessa 1980-1993, SVT Ympäristö 1996:2. For details see J. Kunnas, T. Myllyntaus, "The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland", in *Scandinavian Economic History Review*, 55, 2, 2007, pp. 101-127.

[52] Energy Statistics 2007, Statistics Finland, Helsinki 2007.

[53] Wood-based fuels contain carbon that has been bound from carbon dioxide in the air through photosynthesis. Therefore, no net emissions are created through wood combustion if the wood burned is compensated for by growing the same volume of trees, which will bind the same amount of carbon dioxide. For further discussion on this issue, see Kunnas, Myllyntaus, "The Environmental Kuznets Curve Hypothesis" cit., and Myllyntaus, Mattila "Decline or Increase" cit., pp. 271-288.

[54] If the electricity imported had been produced in Finland, assuming an amount of carbon dioxide emissions per MWh equivalent to that produced in average electricity generation, the country's overall emissions during the 1990s would have been around 4-11% higher.

Figure 9. Carbon dioxide emissions from the use of fossil fuels in Finland, 1860 to 2005

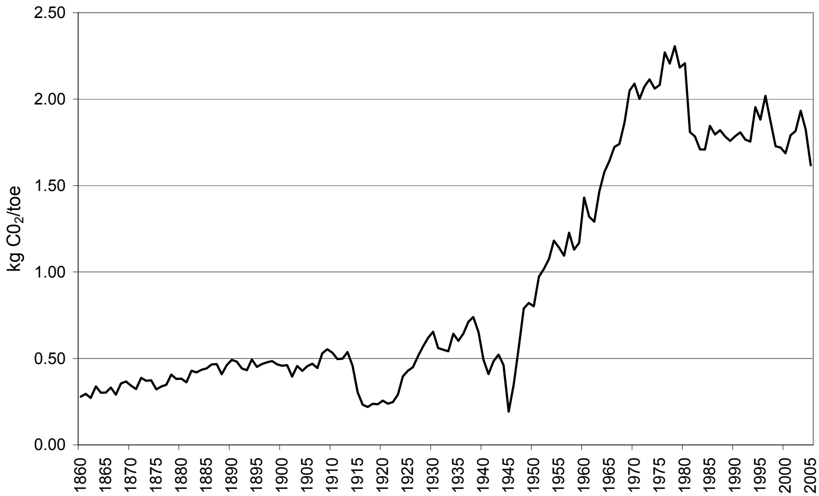


Sources: Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.; Myllyntaus, Mattila "Decline or Increase" cit., pp. 271-288; Tommila, *Avaintekijä puu Suomen teollisuuden raaka-aineena ja energianlähteenä 1845-1913* cit.; Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires" cit., pp. 431-446; Kunnas, "Potash, Saltpetre and Tar" cit., pp. 281-311; Statistics Finland, Energy Statistics 2007, Helsinki 2007.

energy to the extensive use of fossil fuels, and a simultaneous change from sustainability to mass consumption, as the "syndrome of the 1950s".[55] Finland's development seems to support this notion. The country's growth of carbon dioxide emissions soared from a mere 0.4 per cent per year in the 1870-1950 period to 5.2 per cent in the 1950s. We could also speak of a "syndrome of the 1960s", as the an-

[55] C. Pfister, "The 'Syndrome of the 1950s' in Switzerland. Cheap Energy, Mass Consumption, and the Environment", in *Getting and Spending, European and American Consumer Societies in the Twentieth Century*, S. Strasse, C. McGovern, M. Judt (eds), Cambridge University Press, New York 1998, pp. 359-377.

Figure 10. Carbon dioxide emissions per unit of energy used in Finland 1860-2005



Sources: Kunnas, Myllyntaus, "The Environmental Kuznets Curve Hypothesis" cit., pp. 101-127; Statistics Finland, Energy Statistics 2007, Helsinki 2007.

nual emission growth doubled to 10.6 per cent in this period! Sweden and Denmark also experienced considerably higher emission rates in the 1960s than in the 1950s. Unlike these countries, in the early 1970s Finland continued to grow at a phenomenal rate. After the oil crisis, however, its average annual growth rate dropped to a mere 2.7 per cent a year throughout the rest of the decade.[56]

From 1860 to 1913, carbon dioxide emissions per amount of ener-

[56] J. Kunnas, T. Myllyntaus, "Forerunners and Policy Tunnels", in *European Union Policies in the Making*, Leszek Jesień (ed.) Tischner European University, Kraków 2008, pp. 249-263; A. Kander, *Economic Growth, Energy Consumption and CO_2 Emissions in Sweden 1800-2000*, Doctoral thesis, Lund Studies in Economic History 19, Almqvist & Wiksell International, Lund 2002.

Figure 11. Carbon dioxide emissions per GDP, 1860-2005

Sources: Kunnas, Myllyntaus, "The Environmental Kuznets Curve Hypothesis" cit., pp. 101-127; Statistics Finland, Energy Statistics 2007, Helsinki 2007; A. Maddison, "Statistics on World Population, GDP and Per Capita GDP, 1-2006 AD", http://www.ggdc.net/maddison/ (October 2008).

gy consumed doubled. The First World War halved carbon emissions, bringing them back to their 1860 level, but during the interwar period the emissions per used energy unit resumed their upward trend, to drop again during the Second World War. The prewar peak (0.74 kg CO_2 per toe in 1938) was surpassed in 1948 and doubled in 1963. The absolute peak, 2.3 kg CO_2 per toe, was attained in 1978.

Altogether, the development of energy consumption per unit of GDP and carbon dioxide emissions per unit of energy have cancelled out one another, as illustrated in Figure 11. Thus, from 1860 to 2003 the GDP and carbon dioxide emissions have grown at more or less the same pace: respectively, by a factor of 66 and 69. On a global level, Finland´s decreasing carbon intensity in the late 19th century is exceptional. According to Magnus Lindmark, the average global carbon intensity increased slightly during this period, and Astrid Kander´s calculations show a steep rise in carbon intensity in neighbouring Sweden.[57]

The improving of carbon dioxide efficiency in Finland since 1980 appears to have gone hand in hand with an increase in the eco-efficiency of the Finnish economy. Neither trend, however, has been strong enough to counterbalance the effects of GDP growth and to determine a substantial decline in carbon dioxide emissions. Evidently technological development alone cannot achieve this: changes in consumption patterns are definitely also needed.[58]

Discussion and conclusions

In this paper, we have traced Finland's transition from an energy system based on renewable indigenous energy sources to a fossil-fuel based one. The period under examination encompasses more than two centuries, from 1800 to 2005. The development of energy use during this long period can be divided into two main phases. The first, from 1800 to the First World War, was characterized by a close to zero growth in total energy use and a declining per capita energy use. What makes this slow growth phenomenal is the fact that the country's gross domestic product soared in the latter half of the 19th century. The main reason for this anomaly was improvement in space heating efficiency thanks to new stove technology tripling average thermal efficiency. Other significant reasons for Finland's declining energy consumption per capita was a decrease in slash-and-burn-cultivation and in the production of tar, pitch

[57] M. Lindmark, "Patterns of Historical CO_2 Intensity Transitions Among High and Low-Income Countries," in *Explorations in Economic History*, 41, 2004, pp. 426-447; Kander, *Economic Growth, Energy Consumption and CO_2 Emissions in Sweden* cit.

[58] J. Hoffrén, "Measuring the Eco-efficiency of the Finnish Economy," Third Biennial Conference of the European Society for Ecological Economics, Vienna, 3-6 May 2000, www.wu-wien.ac.at/project/esee2000/PapersPDF/I84.pdf (January 2009).

and potash. The second phase, from the First World War to the present, has been characterized by a steady growth in total energy use. The most notable deviation was a decline in energy use during the Second World War, while events like the oil crises or the economic recession of the 1990s were little more than hiccups in an otherwise steady growth.

Finland industrialized by means of renewable, indigenous energy sources. This is a fairly exceptional development path. Why did the transition from an energy system based on indigenous energy sources to one largely dependent on fossil fuels take place so late in Finland? The simple answer, as we have remarked above, is the country's ample wood resources, which made it possible to postpone the transition. A more complex explanation would have to take into account relative prices and political considerations. The latter mainly concerned the choice of whether to burn wood in order to produce energy or use it as a raw material in the manufacturing of paper, pulp and wood products. New technology developed in the 1960s made it possible to use birch, as well as other woods, in chemical pulping and this raised the price of birch, which had traditionally been used mainly for energy production. When concern for a growing scarcity of timber began to arise in the 1960s, the wood-processing industry used the purchasing of wood at stump price[59] and other instruments to obtain more timber for its factories. Also, the government's pro-firewood policy lost its former strong political support. As a result of various factors, relative prices stopped to favour the use of wood for energy production, and fossil fuels consequently got the upper hand in the Finnish energy economy.

Finland´s postponed switch to imported fossil fuels in the 1960s led to an exceptionally fast growth of carbon dioxide emissions. At the same time, the average import prices of fossil fuels decreased

[59] An arrangement that is peculiar to Finland. The buyer takes care of both the logging and the transport of the timber to the road, making selling easy for forest owners. At the same time this practice increases forest companies' control over forest resources.

from 1950s onwards. Thus, the country's increasing dependency on imported fuels did not harm its economic growth, at least not until the oil crises of the 1970s. The difference between total growth and drain in Finland's present day forests is in theory large enough to replace around one fifth of the present day fossil-fuel use. This is, however, a theoretical maximum restricted by both economic and environmental considerations.

The growth of carbon dioxide emissions slowed down during the 1970s. This favourable development was attributed to various concomitant reasons, such as changes in the industrial structure, the increase of electricity imports and the construction of nuclear power plants. Environmental considerations probably did not play any kind of role before the 1990s, although Gilbert Plass had raised his concerns about the negative effects of carbon effects as early as 1956. Despite this slowdown, Finland's carbon dioxide emissions have increased almost sevenfold since Plass first voiced his concerns. Thus, Finland's present-day situation as regards carbon dioxide emissions can hardly stand as an example for latecomers to follow.

Some lessons can be found in Finland's 19th-century "energyless" growth. If present-day developing countries followed a similar development path, this could buy us time in the struggle against global climate change. If developed countries used this time to lower their energy consumption and develop as environmental friendly means as possible to provide for their remaining energy needs, there may be hopes to win this gigantic battle for the future of humankind. The achieving of this goal would require technology transfer to developing countries. This transfer should not regard high-tech only; as we have seen, Finland's initial "energyless" growth was achieved thanks to a technology which can be considered quite primitive from a present-day perspective, although it was revolutionary at the time.[60]

Another lesson is that, if we want a significant decline in energy

[60] This idea is developed further in Kunnas and Myllyntaus, "Forerunners and Policy Tunnels" cit.

consumption and the related carbon dioxide emissions, we cannot focus on just one sector of the economy. The declining use of wood energy in heating and agriculture in the 19th century only paved the way for an increasing use of wood in the industrial sector. In the late 20th century, ever increasing energy consumption in heating and road traffic ate up whatever improvements in efficiency had been achieved in other sectors. The EU´s recent decision to give free emission permits to the most energy-intensive industry under the European Union Emissions Trading Scheme gives little hope for a change in this trend.

Appendix I: Carbon dioxide emissions from the use of fossil fuels in Finland, 1800 to 2005. Unit: Million Kg

year	coals	peat	total	year	petroleum	coals	peat	Total
1800	0	806	806	**1850**	0	4	876	880
1801	0	806	806	**1851**	0	8	889	897
1802	0	806	806	**1852**	0	9	897	906
1803	0	806	806	**1853**	0	11	905	916
1804	0	806	806	**1854**	0	7	913	920
1805	0	806	806	**1855**	0	1	921	922
1806	0	806	806	**1856**	0	7	929	936
1807	0	806	806	**1857**	0	22	936	959
1808	0	806	806	**1858**	0	28	944	972
1809	0	806	806	**1859**	0	38	951	990
1810	0	806	806	**1860**	0	46	959	1 004
1811	0	806	806	**1861**	0	57	986	1 043
1812	0	806	806	**1862**	0	75	1 013	1 088
1813	0	806	806	**1863**	0	79	1 039	1 119
1814	0	806	806	**1864**	0	68	1 065	1 133
1815	0	806	806	**1865**	0	57	1 091	1 148
1816	0	806	806	**1866**	0	67	1 116	1 184
1817	0	806	806	**1867**	0	64	1 121	1 185
1818	0	806	806	**1868**	1	67	1 126	1 193
1819	0	806	806	**1869**	1	70	1 131	1 202
1820	0	812	812	**1870**	2	71	1 135	1 208
1821	0	811	811	**1871**	3	88	1 140	1 231
1822	0	810	810	**1872**	3	87	1 153	1 243
1823	0	809	809	**1873**	4	77	1 166	1 246
1824	0	808	808	**1874**	5	92	1 178	1 275
1825	0	806	806	**1875**	5	90	1 190	1 286
1826	0	805	805	**1876**	5	76	1 203	1 284
1827	0	804	804	**1877**	7	87	1 215	1 310
1828	0	803	803	**1878**	8	102	1 262	1 372
1829	0	802	802	**1879**	6	87	1 297	1 391
1830	0	801	801	**1880**	7	73	1 331	1 412
1831	0	800	800	**1881**	10	80	1 356	1 446
1832	0	804	804	**1882**	10	89	1 384	1 483
1833	0	808	808	**1883**	12	99	1 417	1 527
1834	0	812	812	**1884**	13	107	1 455	1 575
1835	1	816	817	**1885**	18	154	1 493	1 664
1836	1	820	821	**1886**	17	145	1 535	1 697
1837	1	824	825	**1887**	18	107	1 567	1 691
1838	1	828	829	**1888**	20	102	1 597	1 720
1839	1	832	833	**1889**	24	111	1 627	1 761
1840	2	835	837	**1890**	27	150	1 652	1 829
1841	2	839	841	**1891**	29	171	1 687	1 886
1842	4	839	843	**1892**	30	163	1 691	1 884
1843	5	839	843	**1893**	34	149	1 695	1 878
1844	2	838	840	**1894**	34	161	1 698	1 892
1845	2	838	840	**1895**	35	182	1 665	1 882
1846	4	838	842	**1896**	43	206	1 630	1 879
1847	4	837	841	**1897**	49	332	1 596	1 977
1848	6	850	856	**1898**	53	408	1 559	2 020
1849	5	863	868	**1899**	58	506	1 523	2 086

year	Petro-leum	gases	peat	coals	Total
1900	60	0	1 489	551	2 100
1901	62	0	1 450	411	1 923
1902	66	0	1 433	321	1 820
1903	68	0	1 414	357	1 839
1904	76	0	1 394	413	1 883
1905	88	0	1 370	442	1 900
1906	90	0	1 346	479	1 915
1907	93	0	1 317	615	2 025
1908	102	0	1 287	967	2 356
1909	106	0	1 255	1 139	2 500
1910	109	0	1 222	982	2 313
1911	114	0	1 174	995	2 283
1912	120	0	1 126	1 185	2 430
1913	124	0	1 077	1 343	2 544
1914	108	0	1 026	993	2 127
1915	96	0	977	524	1 597
1916	108	0	929	106	1 143
1917	103	0	868	57	1 029
1918	50	0	807	74	931
1919	75	0	753	199	1 027
1920	100	0	698	288	1 085
1921	67	0	666	312	1 045
1922	84	0	637	485	1 206
1923	108	0	602	776	1 486
1924	147	0	569	1 241	1 957
1925	190	0	539	1 413	2 142
1926	213	0	504	1 721	2 438
1927	261	0	474	2 115	2 849
1928	325	0	443	2 500	3 269
1929	357	0	415	2 835	3 607
1930	415	0	374	2 827	3 616
1931	392	0	338	2 656	3 385
1932	290	0	306	2 643	3 239
1933	302	0	275	2 873	3 450
1934	377	0	247	3 257	3 881
1935	425	0	204	3 489	4 118
1936	493	0	174	3 886	4 554
1937	600	0	146	4 575	5 322
1938	694	0	114	4 756	5 564
1939	753	0	108	4 204	5 065
1940	440	0	94	2 945	3 479
1941	223	0	99	2 655	2 976
1942	253	0	96	3 083	3 432
1943	223	0	124	3 337	3 684
1944	182	0	114	2 910	3 206
1945	121	0	116	1 126	1 363
1946	556	0	155	1 819	2 530
1947	846	0	242	2 904	3 992
1948	1 101	0	310	3 887	5 298
1949	1 232	0	339	4 134	5 705

year	Petro-leum	gases	peat	municipal waste	coals	Total
1950	1 288	0	281	0	4 488	6 056
1951	2 180	0	295	0	5 153	7 628
1952	2 871	0	300	0	4 865	8 037
1953	3 349	0	311	0	4 738	8 398
1954	4 055	0	255	0	5 428	9 738
1955	4 807	0	192	0	5 704	10 702
1956	3 666	0	272	0	6 522	10 460
1957	5 665	0	251	0	5 799	11 715
1958	5 532	0	157	0	5 227	10 917
1959	4 416	0	185	0	6 111	10 712
1960	7 168	38	217	0	7 214	14 637
1961	8 014	53	197	0	5 926	14 189
1962	9 585	73	178	0	5 765	15 602
1963	11 705	88	170	0	6 348	18 310
1964	13 928	102	168	0	6 813	21 010
1965	16 692	125	167	0	7 135	24 119
1966	20 757	146	138	0	6 855	27 896
1967	21 419	152	122	0	6 587	28 280
1968	24 096	155	116	0	7 614	31 981
1969	28 012	163	122	0	9 215	37 513
1970	30 873	179	98	0	8 664	39 814
1971	31 888	211	98	0	7 705	39 902
1972	34 512	477	107	0	8 095	43 192
1973	38 295	414	174	0	11 758	50 641
1974	32 840	1 456	192	0	9 408	43 897
1975	33 328	1 884	192	32	8 531	43 967
1976	36 178	2 267	353	123	11 485	50 405
1977	35 244	2 330	572	148	11 423	49 718
1978	35 060	2 431	1 336	155	14 966	53 948
1979	34 937	2 542	1 800	148	14 014	53 442
1980	33 722	2 395	1 877	155	16 046	54 195
1981	31 706	2 069	2 064	194	9 092	45 125
1982	28 957	1 919	2 560	194	9 823	43 452
1983	27 487	1 860	3 342	161	10 352	43 203
1984	26 524	2 103	3 820	136	11 916	44 499
1985	28 019	2 457	4 526	129	15 389	50 521
1986	27 662	2 906	4 767	161	13 559	49 056
1987	28 169	3 762	4 995	129	15 440	52 495
1988	27 630	4 045	4 566	174	15 574	51 989
1989	26 880	4 960	4 343	174	15 347	51 704
1990	26 856	5 740	6 148	194	15 017	53 955
1991	26 192	5 927	6 201	252	14 762	53 335
1992	25 761	6 121	6 081	232	12 700	50 896
1993	24 719	6 212	6 420	194	14 558	52 103
1994	25 714	6 821	7 336	136	18 161	58 167
1995	24 806	6 989	8 177	136	14 724	54 832
1996	25 313	7 426	9 325	299	18 498	60 862
1997	25 072	7 300	9 167	302	17 116	58 957
1998	26 800	7 600	8 500	300	12 800	56 000
1999	26 700	7 600	7 500	300	13 000	55 100
2000	25 700	7 800	6 500	300	12 900	53 200
2001	26 100	8 400	9 100	300	14 500	58 400
2002	26 500	8 400	9 600	300	16 100	60 900
2003	26 500	9 300	10 600	400	21 700	68 500
2004	26 500	8 900	9 300	400	19 400	64 500
2005	26 000	8 200	7 200	400	11 200	53 000

Sources: Myllyntaus, *Historical energy balance of Finland, 1800-1998* cit.; Myllyntaus, Mattila "Decline or Increase" cit., pp. 271-288; Tommila, *Avaintekijä puu Suomen teollisuuden raaka-aineena ja energianlähteenä 1845-1913* cit.; Kunnas, "A Dense and Sickly Mist from Thousands of Bog Fires" cit., pp. 431-446; Kunnas, "Potash, Saltpetre and Tar" cit., pp. 281-311; Statistics Finland, Energy Statistics 2007, Helsinki 2007.