Department of History and Civilization

Fire and Fuels: CO_2 and SO_2 Emissions in the Finnish Economy, 1800-2005

Jan Kunnas

Introduction

Thesis submitted for assessment with a view to obtaining the degree of Doctor of History and Civilization of the European University Institute

Florence, June 2009

EUROPEAN UNIVERSITY INSTITUTE

Department of History and Civilization

Fire and Fuels: CO_2 and SO_2 Emissions in the Finnish Economy, 1800 – 2005

Jan Kunnas

Supervisor: Giovanni Federico
External supervisor: Timo Myllyntaus

Examining Board:

Giovanni Federico
Bartolomé Yun Casalilla
Magnus Lindmark
Jan Luiten van Zanden

INDEX

ACKNOWLEDGMENTS

First, I need to express my gratitude to my external supervisor and long term colleague Dr. Timo Myllyntaus. Without him, I would not have started this thesis project in the first place. My greatest praise goes to my wife, Leena Karjalainen. Without her love, encouragement and editing assistance, I would never have finished the thesis. She took care of our wonderful daughters, Saimi and Elsa, and struggled with the Italian bureaucracy, while I stayed safe in the Academic bubble. Saimi made unquestionably the biggest sacrifices for my thesis, leaving her friends behind in Finland, and having to learn a new language in Scuola Materna. Elsa arrived during the process and brought a lot of joy with her. I would also like to thank my parents Solveig and Kalle Kunnas for the support they have provided me through my entire life and especially during this thesis project. To Päivi Karjalainen-Roikonen and Heikki Roikonen big hugs for being around and giving a helping hand whenever needed.

I would like to express my gratitude to my supervisor, Dr. Giovanni Federico, who trusted me enough to let me work in peace, and provided guidance when needed. Very special thanks go out to all my friends and colleagues in EUI and outside. I would like to thank Mia Kokkinen for proofreading, Arto Kokkinen for statistical advice, Harri Kiiskinen for discussions on quantitative science in general, Meri Vuohu for discussions on environmental history, and Samppa Rohkimainen and Ere Nokkala for discussions in general. Thanks for encouragement to James Williams and all other ICOHTEC-people over the years.

This research would not have been possible without the financial assistance from the Academy of Finland, European University Institute and Helsinki University Environmental Research Centre.

ABSTRACT

This thesis examines Finland's transition from a solar based energy system to a fossil fuel based one, and the environmental consequences of this transition. The period under examination is from the beginning of the 19th century to the present, covering Finland's transition from a proto-industrial agricultural society to a "post-industrial" society.

The theoretical starting point has been the environmental Kuznets curve hypothesis, which proposes that some pollution or measures of environmental degradation would follow an inverted U-curve related to incomes, increasing at low income levels and decreasing at high income levels. Based on the historical approach used in this thesis, two new explanations for the existence of an environmental Kuznets curve are added: 1) The severity of environmental degradation might itself create a turning point for the emissions, or in some cases fear of severe effects. 2) What at a first glance seems to be a genuine environmental improvement might just be a transformation of one environmental problem into another.

Some proponents of economic growth go as far as claiming that economic growth is a necessary condition for proper protection of the environment. This thesis turns the argument around, claiming that the causal connection goes in an opposite direction: proper environmental standards and conservation comprise a necessary condition for economic growth in the long run.

Finland industrialized by means of renewable, indigenous energy sources. The switch to imported fossil fuels in the 1960s led to exceptionally fast growth of carbon and sulphur dioxide emissions. The emissions of sulphur dioxide started to decline in the 1970s while the emission growth of carbon dioxide only slowed down. The initial decline of sulphur dioxide emissions was mainly a side-effect of changes in industrial processes rather than an outcome of a deliberate policy. Furthermore, anxiety about large and widespread damage to the forests was a major reason for active measures to decrease sulphur dioxide emissions since the mid-1980s. Thus the emissions themselves provoked their downturn.

Quantitative calculations on the use of natural resources provide valuable tools, which can give new insights to old questions and raise new questions. Burning cultivation of peatlands, which has been neglected in historical research, was found to be the greatest source of carbon dioxide in Finland during the whole of the nineteenth century and at the beginning of the twentieth century. Another neglected occupation, the production of potash might have consumed as much wood during the 19th century as the production of tar.

PAPERS INCLUDED IN THE THESIS

This thesis consists of an introductory review part, followed by five original research publications. The publications are referred to in the text by their roman numerals

I) Jan 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, 1820-1920," *Environment and History,* Vol. 11, No. 4, 2005, pp. 431-46.

II) Jan Kunnas, "Potash, Saltpetre and Tar: Production, Exports and Use of Wood in Finland in the 19th Century," *Scandinavian Journal of History,* Vol. 32, No. 3, 2007, pp. 281-311.

III) Jan Kunnas and Timo Myllyntaus, "The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland," *Scandinavian Economic History Review,* Vol. 55, No. 2, 2007, pp. 101- 27.

IV) Jan Kunnas and Timo Myllyntaus, "Anxiety and Technological Change – Explaining the Decline of Sulphur Dioxide Emissions in Finland since 1950."

V) Jan Kunnas and Timo Myllyntaus, "Postponed Leap in Carbon Dioxide Emissions: Impacts of Energy Efficiency, Fuel Choices and Industrial Structure on the Finnish Energy Economy, 1800 – 2005," Forthcoming *Global Environment.*

The author's contribution:
I) J. Kunnas planned and wrote the paper
II) J. Kunnas planned and wrote the paper
III) J. Kunnas and T. Myllyntaus planned and wrote the paper. Statistical analyses were done by J. Kunnas. Data on energy consumption from 1800 to 1998 from the project *Historical energy balance of Finland, 1800-1998* led by Timo Myllyntaus, and was updated by Jan Kunnas to take into consideration calculations done in Articles 1 & 2 and extended to the year 2003. Calculations of carbon dioxide and sulphur dioxide emissions from the energy consumption data by J. Kunnas.
IV) J. Kunnas planned the paper, J. Kunnas and T. Myllyntaus wrote the paper. Statistical analyses were done by J. Kunnas. Data was taken from Article 3, and additional data collected by J. Kunnas
V) J. Kunnas planned the paper, J. Kunnas and T. Myllyntaus wrote the paper. Statistical analyses were done by J. Kunnas. Data on energy consumption from 1800 to 1998 from the project *Historical energy balance of Finland, 1800-1998* led by Timo Myllyntaus unless otherwise stated in the text. Data on energy consumption updated by Jan Kunnas to take into consideration calculations done in Articles 1 & 2 and extended to the year 2005. Calculations of carbon dioxide emissions from the energy consumption data by Jan Kunnas.

1 INTRODUCTION

1.1 Fire and fuels

Fire has always had a pivotal importance in northern countries such as Finland. The first settlers, arriving at the end of the last Ice Age around ten thousand years ago, used fire to make clearings in the forests in order to attract game, and to provide heat against cold winters. Agriculture and animal husbandry were introduced to Finland around 5 000 years ago, and again the use of fire was indispensable. The pioneering cultivation method, slash-and-burn cultivation or swidden can be defined as a cultivation method of cutting down living trees to clear land, burning the biomass after it has dried, and planting a crop in the ashes. Afterwards cleared patches provided grazing grounds for the cattle. In the eventual transition to permanent fields, fire was again the most efficient tool for clearance of trees and shrubs.

Eventually peatlands were also set aflame for agricultural purposes. Peatland burning is mentioned in court protocols around 1640, but it might have been practiced in Finland as early as the fourteenth century. Both cultivation methods persisted in the country until the early 1900s.[1]

In addition, some of Finland's first export commodities had their origin in the flames. The first documented export of swidden rye from Finland to Sweden is from 1320. It was a popular seed as it did not contain any weeds. The earliest records of tar production date back to the 16th century, and it became Finland's most important export product in the 17th and 18th centuries. Tar was produced through dry distillation of resinous pine wood in tar-burning pits and kilns. It was commonly used for the impregnation of wood, ropes and textiles for protection against water and was thus essential for wooden fleets. The production of potash (an impure form

[1] Melander, K.R., ”Några uppgifter om äldre tiders kärrodling i vårt land,” *Historisk tidskrift för Finland.* Vol. 7, Helsingfors, 1922.

of potassium carbonate, K_2CO_3) started in Finland in 1672. Potash was an important industrial chemical prior to the 20th century and was, for example, used in glassworks, soap factories, textile and blast-furnace industries. It was mainly extracted from tree ash, although ash from other plants could also be used. In the late 1830s tar and potash alone contributed to one fifth of Finland's total exports.[2]

As Finland did not have domestic sources of coal and oil, but relatively good water resources, the initial industrialization in the 19th century was based on timber and water power. Timber was used as both a raw material and an energy source. As the forests were in overuse already at the beginning of the 19th century, an increased total consumption of timber was not possible. Firewood and raw timber needed for industrialization were made available by a stagnation of firewood consumption because space heating equipment and the insulation of buildings developed outstandingly, while slash-and-burn cultivation, tar burning, potash production and other wood consuming rural occupations also declined.[3] The wood burnt in open fires in smoky dwellings and forests was sanitized into fuel for efficient stoves, hungry steam boilers and other industrial machinery.

Finland's industry was from the very beginning exceptionally energy intensive and could easily eat all energy savings in other sectors. Thus the economy as a whole would eventually have reached the limits of the domestic energy sources available. The natural constraints of energy use were, however, stretched by imports of fossil fuels. Small amounts of coals and petroleum were imported already in the 19th century. Domestic peat remained, however, the most important fossil fuel into the 1920s. Finally in the 1960s, the consumption of fossil fuels exceeded the use of wood and other renewable domestic energy sources. Thus Finland's economy as a whole did not have any serious constraints to its energy use or attempts to limit it, except perhaps during the world wars and the energy

[2] Kuisma, J., *Tuli leivän antaa – Suomen ekohistoria.* Helsinki – Jyväskylä: Gummerus, 1997, p. 146; Rein, G., *Statistische Darstellung des Gross-Fürstenthums Finnland,* Helsingfors, 1839, pp. 48-53; Alho, P., ”Pohjois-Pohjanmaan metsien käytön kehitys ja sen vaikutus metsien tilaan,” *Acta Forestalia Fennica* 89, 1968; Virrankoski, P., ”Potaska suomalaisen talonpojan teollisuuden tuotteena,” *Scripta historica* XI, 1987, pp. 63–136.

[3] Myllyntaus, T. and Mattila, T. “Decline or Increase, the Standing Timber Stock in Finland, 1800-1997,” *Ecological Economics,* Vol. 41, No. 2, 2002, pp. 271-288.

crises in the 1970s. Finally in the 1980s the energy consumption in the industrial sector stagnated, but this could not turn the overall energy consumption into decline because of a continuing increase in the energy consumption in space heating and traffic. Consequently, in 2005 Finland had the largest energy consumption per capita among all EU member countries.[4] Over time the costs of breaking the natural constraints were discovered in the form of global climate change and acid rain.

1.2 Carbon dioxide and global climate change

Carbon dioxide is the most significant anthropogenic greenhouse gas contributing to global climate change. It represented 77% of the total anthropogenic greenhouse house gas emissions in 2004. Other important greenhouse gases are methane (CH4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine).[5]

The Swede Svante Arrhenius is often mentioned as the first one to warn about global warming as a consequence of increased atmospheric concentration of carbon dioxide. In a paper published in 1896, he calculated that a doubling of CO_2 in the atmosphere would increase global surface temperature by an average of five to six Celsius degrees. He did, however, not consider this a problem. On the contrary, he looked forward to better climates and abundant crops for the benefit of rapidly propagating mankind.[6]

[4] Eurostat. News release 126/2006.

[5] IPCC, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Geneva, Switzerland: IPCC, 2007.

[6] Arrhenius, S., "On the influence of carbonic acid in the air upon the temperature of the ground," *Phil. Mag*., Vol. 41, 1896; Arrhenius, S., *Worlds in the Making*. New York: Harper & Brothers, 1908, p. 63.

Forty years later, in 1938, G. S. Callendar downscaled the estimated effect of a doubling of CO_2 in the atmosphere to an increase in the mean temperature of two degrees Celsius. He also predicted a 0.4 degree Celsius increase in the global mean temperature in the 21st century and a 0.6º C increase in the 22nd century with the present rate of carbon dioxide production. 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 would delay the return of the deadly glaciers indefinitely.[7]

In a series of articles published in 1956 Gilbert Plass estimated that if the carbon dioxide content of the atmosphere doubles, the surface temperature would rise by 3.6 Celsius degrees.[8] Contrary to his predecessors, Plass regarded this as a problem.[9] Next year Roger Revelle and Hans E. Suess stated in an article about the carbon dioxide exchange between the atmosphere and ocean that the present rate of combustion of fossil fuels presents "…a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."[10]

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 (IPCC) to provide scientific advice on climate change.[11] 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. As a response to this need a large group of countries signed in 1992 *The United Nations Framework Convention on Climate Change,* which sets

[7] Callendar, G. S., "The artificial production of carbon dioxide and its influence on temperature," *Quarterly Journal of Royal Meteorological Society*, Vol. 64, 1938, pp. 223-237.
[8] Plass, G., "Infrared Radiation and the Atmosphere," *American Journal of Physics* 24, pp. 303-21; "Effect of Carbon Dioxide Variations on Climate," *American Journal of Physics* 24, 1956, pp. 376-387; "Carbon Dioxide and the Climate," *American Scientist* 44, 1956, pp. 302-316; "The Carbon Dioxide Theory of Climatic Change," *Tellus*, Vol. 8, No. 2, 1956, pp. 140-154.
[9] Plass, "Effect of Carbon Dioxide Variations on Climate."
[10] Revelle, R. and Suess, H., "Carbon dioxide exchange between atmosphere and ocean, and the question of an increase of atmospheric CO2 during the past decade," *Tellus*, Vol. 9, No. 18, 1957, pp. 18-27.
[11] IPCC, *16 Years of Scientific Assessment in Support of the Climate Convention.* 2004. www.ipcc.ch/about/anniversarybrochure.pdf (Downloaded 1 August 2007).

an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. Developed countries signing the Convention committed themselves to the aim of returning individually or jointly to their 1990 levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol.[12]

The Kyoto Protocol, which was adopted in 1997 and entered into force on 16 February 2005, shared the Convention's objective, principles and institutions, but significantly strengthened the Convention by committing the 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[13] by 5.2 percent below the 1990 levels between 2008 and 2012. The EU member states agreed to reduce their collective emissions by 8 percent 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.[14]

The last report from the Intergovernmental Panel on Climate Change published in 2007 states that:

> Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

For someone from the northern latitudes, the prospects of a warming climate might sound like an attractive prospect in the same way as for Arrhenius a hundred years earlier. Indeed, the potential for food production is projected to increase globally at a temperature increase between 1° to 3°C relative to 1980-1999, but above this it is projected to decrease. The blessings are, however, not equally distributed and even at these modest temperature changes food production is anticipated to decrease in

---

[12] United Nations, *The United Nations Framework Convention on Climate Change*, 1992. http://unfccc.int/resource/docs/convkp/conveng.pdf (Downloaded 8 June 2007).
[13] Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).
[14] United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, 1998. http://unfccc.int/resource/docs/convkp/kpeng.pdf (Downloaded 8 June 2007).

areas already facing food stress. In the same interval approximately 20% to 30% of the plant and animal species assessed so far are likely to be at an increased risk of extinction.[15]

Another question is that reaching such low temperature increases at the equilibrium might require substantial cuts in the emissions of greenhouse gases. The recent Global Carbon Budget 2007 report, however, shows that emissions are growing faster than even in the most fossil fuel intensive scenario of the latest IPCC Assessment Report.[16]

There are still large uncertainties in the required cuts due to missing knowledge about carbon cycle feedbacks. One thing is certain: the larger the emissions the larger the probabilities and effects of different adverse consequences like increases in droughts, heat waves and floods. By the 2080s, many millions more people than today are projected to experience floods every year as a result of risen sea level. In the worst cases anthropogenic warming could lead to abrupt or irreversible consequences. For example, Greenland's ice sheet loss alone could eventually bring a several meter increase in the sea level.[17]

A recent survey article, drawing on a workshop of 36 leading climate scientists, warns that: "Society may be lulled into a false sense of security by smooth projections of global change." The authors argue that in some regions anthropogenic forcing on the climate system could kick start abrupt and potentially irreversible changes. They list nine policy relevant global sub-systems which could pass critical thresholds within the next 100 years. Of these the Arctic sea-ice and the Greenland Ice Sheet are identified as the most sensitive systems with the smallest uncertainty. The extent of the Arctic sea-ice is already decreasing, but a total loss would devastate Arctic ecosystems. Melting of sea-ice accelerates global warming as a dark ocean surface absorbs more sun radiation than white ice. A summer ice-loss

---

[15] IPCC, *Climate Change 2007: Synthesis Report*.
[16] Global Carbon Project, *Carbon budget and trends 2007*, www.globalcarbonproject.org, [Last accessed 26 September 2008].
[17] IPCC, *Climate Change 2007: Synthesis Report*.

threshold, if not already passed, may be very close and a transition could occur within this century. For the Greenland Ice Sheet, the exact tipping point for disintegration of the ice sheet is unknown, but in a worst case scenario local warming of more than three degrees Celsius could cause the ice sheet to disappear within 300 years. This would result in a rise of sea level between two and seven meters. The remaining seven “tipping elements” are the collapse of the West Antarctic ice sheet, of the Atlantic thermohaline circulation or of the Indian summer monsoon, an increase in the El Nino Southern Oscillation, the disruption of the West African monsoon, and the dieback of the Amazon rainforest or of the Boreal Forest.[18]

1.3 Sulphur dioxide and acid rain

Sulphur dioxide (SO_2) together with nitrogen oxides is the major reason for acid rain damaging forests, crops and buildings, and making lakes and streams acidic and unsuitable for fish. Peak levels of SO_2 in the air can cause temporary breathing difficulties, especially for people with asthma, and longer-term exposures to high levels of SO_2 gas and particles cause respiratory illness and aggravate existing heart disease.

The expression "acid rain" was first used by the Scottish chemist Robert Angus Smith in 1872.[19] At that time the problem was, however, considered to be local and confined to urban areas. As long as it was considered a local problem it could be dealt with by building higher smokestacks or by relocating polluting activities.

18 Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhuber, H. “Tipping elements in the Earth's climate system,” *PNAS*, Vol 105, No. 6, pp. 1786-1793.
19 Smith, R. A., *Air and rain. The beginnings of a chemical climatology*. London: Longmans, Green and co., 1872.

The combustion of fossil fuels generates more than 90% of all anthropogenic sulphur.[20] Thus along with a sharp increase in the use of fossil fuels, there was a strongly declining trend in the pH value of precipitation all around Europe in the 1950s and 1960s. The effects of this acid precipitation were most pronounced in countries, such as Sweden, where much of the ground is covered by thin layers of moraine or earth, with very little capacity to neutralise sulphuric acid. Still in the late 1960s sulphur dioxide was also in Sweden considered a local problem to be dealt with by constructing higher chimneys. This thought prevailed at least until Svante Odén raised the alarm in 1967 arguing that acidification could restrict the productivity of forests and cultivated land.[21]

Sweden could, however, not solve the problem alone, as the major part of the acid precipitation falling in Sweden originated from Britain or Central Europe. Thus, in order to get international recognition of the problem, Sweden published a report on the damage caused to soils and lakes because of sulphur in air and precipitation at the 1972 UN Conference on the Human Environment in Stockholm. As Norway and Finland, with similar vulnerable soils, joined the lobbying efforts, acid rain was finally recognized as an international problem in 1979 with the Geneva Convention on Long-range Transboundary Air Pollution. The convention was signed by the European Community (EC) and the governments of 33 countries including most European countries, the USA and Canada. It did, however, not include any concrete measures to reduce acid rain.[22]

In the same year an article was published about the deposition of air pollutants and their effects on forest ecosystems in the Solling mountain area in northern Germany. The results were popularized in three articles released in 1981 by the German news magazine *Der Spiegel.* They predicted that large areas of German

---

[20] Lefohn, A. S., Husar, J. D. and Husar, R. B. "Estimating historical anthropogenic global sulfur emission patterns for the period 1850-1990," *Atmospheric Environment*, Vol. 33, No. 21, 1999, pp. 3435-3444.

[21] Lundgren. L. J. *Acid Rain on the Agenda, A picture of a chain of events in Sweden 1966-1968.* Lund: Lund University Press, 1998.

22 United Nations Economic Commission for Europe, *The 1979 Geneva Convention on Long-range Transboundary Air Pollution.*, http://www.unece.org/env/lrtap/lrtap_h1.htm (Downloaded 24 October 2006).

forests would be dead within five years as a result of acidification.[23] In the following years the forest dieback (Waldsterben) and acid rain in general got large media attention all around Europe, making the public opinion favorable to emission reductions.[24] In this changed political climate the Nordic countries put forward a proposal for limiting the emissions of sulphur in spring 1983. After two years of negotiating a protocol requiring the signing countries to reduce their yearly emissions of sulphur by at least 30 percent from their 1980 levels by 1993 at the latest was signed in Helsinki in July 1985.[25]

1.4 Aims of the thesis

This thesis examines the environmental consequences of Finland's economic growth. The focus is on the transition from a solar based energy system to a fossil fuel based one, and the environmental consequences of this transition. Finland is a grateful subject in this sense. As a relatively late industrialized country, this transition took place up to hundreds of years later than in most European countries, which provides relatively good availability of historical documents. For example, the transition from burning of wood to coal took place in the capital of Finland around 500 years later than in London.[26]

The period under examination is from the beginning of the 19th century to the present covering Finland's transition from a proto-industrial agricultural society to a

---

23 Ulrich B., Mayer R., Khanna P. K., "Depositionen von Luftverunreiningungen und ihre Auswirkungen in Waldökosystem im Solling,". *Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächsischen Forstlichen Versuchanstalt. Band 58*. Frankfurt am Main: J. D. Sauerländer's Verland, 1979; Der Spiegel, Säuregen: "Da liegt was in der Luft" Der Spiegel No. 47, pp. 96-110; No. 48, pp. 188-200; No. 49, pp. 174-188, November 1981.
24 The Social Learning Group, *Learning to manage global environmental risks. Vol. 1*. Cambridge, Mass: MIT Press, 2001; Roll-Hansen, N., "Science, Politics, and the Mass Media: On Biased Communication of Environmental Issues," *Sci. Technol. Hum. Val.*, Vol. 19, No. 3, 1994.
25 United Nations Economic Commission for Europe, *The 1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent*. http://www.unece.org/env/lrtap/full%20text/1985.Sulphur.e.pdf (Downloaded 24 October 2006).
26 Brimblecombe, P., *The Big Smoke, A history of air pollution in London since medieval time*. London and New York: Routledge, 1988.

“post-industrial” society. The thesis concentrates on the growth and changes in the composition of energy consumption caused by this transition. During this period changes in the sectoral composition of the Finnish economy, agricultural practices and production processes have had profound consequences on the energy consumption and fuel mixes. The thesis is particularly focused on examining environmental consequences related to the growth in energy use and fuel choices, especially emissions of carbon and sulphur dioxide. In one of the studies nitrogen oxides are also taken into account.

The thesis belongs to the tradition of environmental history, a discipline that will be examined in Section 2.1. The main questions in this chapter are: what is environmental history, and does it differ from history in general? Finally, it is shown that environmental history resembles in many ways both economic history and ecological economics through its multidisciplinary approach and subjects of interests. In contrast to economic history, the use of quantitative methods remains, however, underutilized in environmental history.

Some theoretical questions related to the use of quantitative methods in history in general are provided in Section 2.2. What is quantitative history, or is in fact all history to some degree quantitative? Why did quantification as a method disappear in the 1980s from other historical disciplines than economic history?

Following a common tradition in economic history, the methods of economics and historical research are combined in this thesis.[27] Economics and economic history have still much to learn from each other. This issue will be touched upon in Section 2.3 on economics and economic history, which begins with the question whether there is anything new in “new economic history”. The section on economic history is concluded by elaborating on the lessons of economics to history, and whether economics could also learn something from history.

[27] For a classic example see: Fogel, R. W., *Railroads and American Economic Growth – Essays in Econometric History.* Baltimore and London: The John Hopkins Press, 1964.

1.5 Study design

The theoretical starting point for this study has been the environmental Kuznets curve hypothesis. This hypothesis proposes that some pollution or measures of resource or environmental degradation would follow an inverted U-curve related to incomes, increasing at low income levels and decreasing at high income levels. Using the hypothesis this study has been divided into three major parts, as illustrated in Figure 1 below:

1) In order to get an insight to the starting phase of economic growth when environmental pressure is supposed to grow, I have investigated the fate of peasant livelihoods at the turn of industrialization.

2) The calculations done in the first part are then used in the construction of long time series for several measures of environmental pressures in order to examine the overall development from the beginning of industrialization to the present.

3) In cases where a development path according to the Environmental Kuznets curve hypothesis is found, a closer look at the actual turning point is taken in order to track what lies behind the turn. Correspondingly, if no turning point is found, this will also be explained.

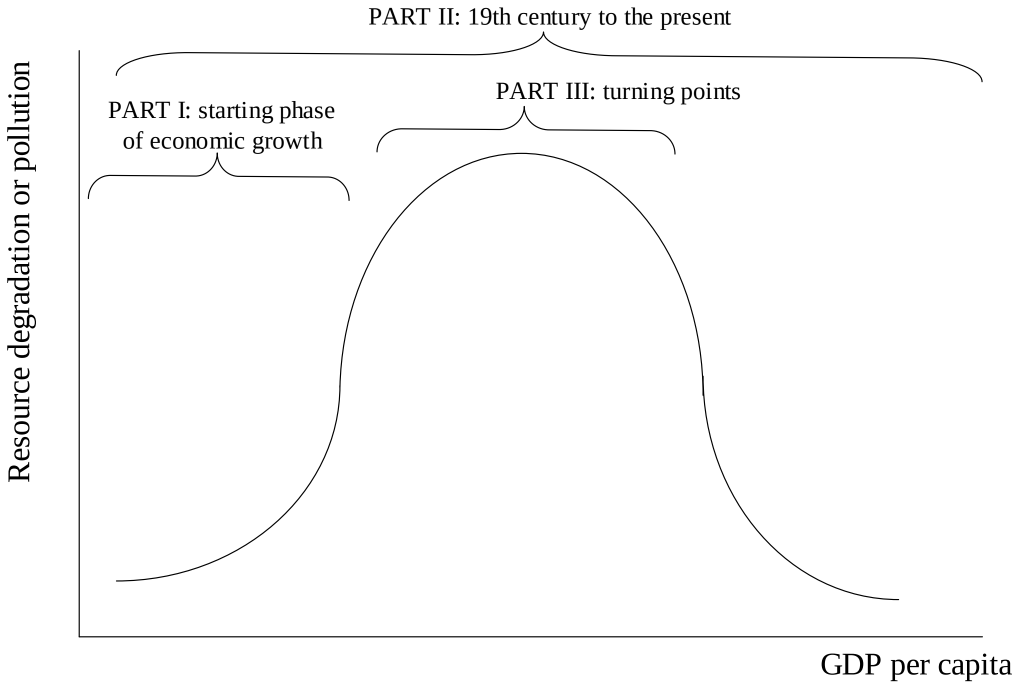


Figure 1. The structure of the study

2 DISCIPLINARY AND INTERDISCIPLINARY ASPECTS

2.1 Environmental history

Environmental history emerged as a distinctive academic discipline during the late 1960s or early 1970s. The American Society for Environmental History was founded in 1976, while its European equivalent was not set up until 1999. The expression *environmental history* is usually attributed to Roderick Nash, who used it in an article based on his presentation at the 1969 meeting of the Organization of American Historians.[28]

Some often mentioned early examples of environmental history are Alfred W. Crosby's *The Columbian Exchange: Biological and Cultural Consequences of 1492* (1972), Lynn White's article *The Historical Roots of Our Ecological Crisis* (1967), and Clarence Glackens's *Traces on the Rhodian Shore* (1967), a history of Western Civilization's conceptions of the environment from the earliest times to the eighteenth century. Including *Man's Role in Changing the Face of the Earth*, a voluminous anthology of essays on man's impact on the environment published in 1956, would push another decade backwards.[29]

[28] Nash, R., "The State of Environmental History," in Bass, H. J. (ed.) *The state of American history.* Organization of American Historians and Quadrangle Books, 1970, pp. 249-260. The usual reference is, however, an article published two years later: Nash, R. "American Environmental History: A New Teaching Frontier." *The Pacific Historical Review*, Vol. 41, No. 3, 1972, pp. 362-372.

[29] Crosby, A. W., *The Columbian Exchange: Biological and Cultural Consequences of 1492.* Westport, Conn.: Greenwood, 1972; White, L. Jr., "The Historical Roots of Our Ecological Crisis," *Science* 155, 1967, pp. 1203–7; Glacken, C. J., *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century.* Berkeley: University of California Press, 1967; Thomas, W. L. (ed.), *Man's Role in Changing the Face of the Earth. Chicago*, Ill.: University of Chicago Press, 1956.

Timo Myllyntaus and Mikko Saikku trace, however, the roots of environmental history back to the late 19th and early 20th centuries, to scholars like Frederick Jackson Turner, Walter Prescott Webb and James C. Malin, who "stressed the role played by the natural environment in the formation of American society". They identify a similar approach in their Finnish contemporaries, "the historian Väinö Voionmaa and the anthropologist Helmer Smeds, who claimed that natural conditions had profoundly shaped Finnish society."[30] A similar approach can be found in Fernand Braudel's voluminous history of the Mediterranean world published in 1949.[31] With this loose definition of environmental history, Ibn Khaldun (1332-1406) and his discussions about how environmental conditions shaped different peoples cannot either be ignored.[32]

Fernand Braudel's inclusion in environmental history proper has been contested, arguing that he tended to deploy environmental factors only as a backdrop of history.[33] Alfred W. Crosby, on the contrary, clearly considers Braudel to be environmental history proper, but deems Frederick Jackson Turner to be still only halfway. Crosby, however, lists several beginnings of environmental history in America from the 1920s and onwards "before it was finally well launched."[34]

Perhaps the whole search for a starting point is senseless. Taking an analogy from natural sciences, the search for a single point of creation, a.k.a. creationism, should be abandoned in favour of an evolutionary path towards present-day environmental history.

Finding a unique point of creation would also require an unambiguous definition of environmental history. There seems, however, to be at least as many definitions of

---

[30] Myllyntaus, T. and Saikku, M. (eds.), *Encountering the Past in Nature: Essays in Environmental history.* Athens: Ohio University Press, 2001, p. 3.

31 Braudel, F., *La Méditerranée et le Monde Méditerranéen à L'epoque de Philippe II*. Librairie Armand Colin, 1949. English translation: *The Mediterranean and the Mediterranean World in the Age of Philip II*. Harper&Row, 1972.

[32] Khaldūn, I., *The Muqaddimah: An Introduction to History*, 2d ed., Bollingen series. New Jersey: Princeton University Press, 1967.

[33] Beinart, W. "African history and environmental history," *African Affairs,* Vol. 99, No. 395, 2000, pp. 269-302.

[34] Crosby, A. W. "The Past and Present of Environmental History," *The American Historical Review,* Vol. 100, No. 4, 1995, pp. 1177 – 1189.

the concept of environmental history as there are scholars trying to define it. According to Verena Winiwarter, environmental history is concerned with two different endeavours:

1) The study of past perceptions of nature, of attitudes, traditions, etc.
2) Reconstruction of past environments, of their biological, geological, hydrological, pedological and atmospheric status.[35]

A more concise description is given by J. R. McNeill:"…the history of the mutual relations between humankind and the rest of nature."[36] It is also less inclusive as his requirement of mutual relations would drop early candidates like Turner or Ibn Khaldun, who only considered the impact of nature on humans and not the other way round. Neither does it include the second part of Winiwarter's list if the past environments are not created through human actions.

A recent encyclopedia of environmental history has a time scale of several billions of years and a geographical scale from local to global covering all continents. It includes topics from arts to technology and science to different religions, from people to zebra mussels and from domesticated plants and animals to nonliving resources.[37]

This same broad view is also apparent from a collection of short articles about future directions for the field in celebration of the tenth year of the journal Environmental History. The subjects suggested range from artificialization of our own bodies and the environment to the intersection between health, disease and the environment, and the environmental consequences of consumer behaviour or economic specialization. Several authors ask for detailed studies of the ecological footprint in different parts of the world. One writer wants research on ecosystem management while another suggests investigation of cities as urban ecosystems. The

---

[35] Winiwarter, V., "Approaches to Environmental History," in Laszlovszky, J. & Szabó, P. (eds.), *People and Nature in Historical Perspective.* Budapest: Central European University, Department of Medieval Studies & Archaeolingua, 2003, p. 5.
[36] McNeill, J. R., "Observations on the Nature and Culture of Environmental History," *History and Theory*, Vol. 42, No. 4, 2003, p.. 6.
[37] Krech, S., McNeill, J. R. and Merchant, C., *Encyclopedia of World Environmental History.* Routledge, 2004.

only recurring aspect seems to be emphasis on the importance of interdisciplinarity. Perhaps the most obvious intertwining disciplines are historical geography and historical ecology. Christine Meisner Rosen, however, tries to persuade readers about the urgent importance of engaging in research that integrates business and environmental history as it might “provide crucial insights into the origins of the mounting environmental and public-health crises that loom before us.”[38]

Elsewhere, in a special issue of the Journal of Social History on the future of social history, Stephen Mosley calls for a closer communication between social and environmental history to their mutual benefit.[39] A theme issue of Diplomatic History illustrates how an environmental perspective might reconfigure the diplomatic history of the past half-century or so.[40]

The very existence of environmental history as a separate field can also be questioned:

> …if the environment is everything from the microparticle to the universe, then all history, it may be argued, is collapsible to environmental history, which in turn ceases to be distinguishable from history as such.[41]

In my view, it is just a matter of perspective, whether the environment is just a background where “history” takes place, or whether the environment is one of the historical actors.

The lack of a unanimous description of environmental history has not held back its spread around the globe. Works on environmental history have been written for all continents, including the Antarctica.[42] The Environmental History Bibliography

---

[38] Bess, M. et al., “Anniversary forum: What's Next for Environmental History?” *Environmental history,* Vol. 10, No. 1, 2005, pp. 30-109.

39 Mosley, S., “Common Ground: Integrating Social and Environmental History*,” Journal of Social History,* Vol. 39, No. 3, 2006, pp. 915-933.

[40] Worster, D., “Environmentalism Goes Global,” *Diplomatic History,* Vol. 32, No. 4, 2008, pp. 639-641.

[41] Weiner, D. R. “A death-defying attempt to articulate a coherent definition of environmental history,” *Environmental History,* Vol. 10, No. 3, 2005.

[42] A theme number of *Environment and History* (Vol. 10, No. 4. 2004) provided overviews of environmental history practised in Africa, the Americas, Australia and New Zealand, China and

Database upheld by the Forest History Society contains over 40 000 annotated citations to books, articles, and dissertations published from 1633 to the present, and approximately 1 500 citations are added each year.[43]

Nevertheless, one common feature of environmental history is the prevailing belief that we can learn from history. Environmental history easily becomes a dismal science, as it is digging into past environmental problems showing that the history of humankind is a history of pollution and environmental decay. However, as already Voltaire knew, great errors of the past are very useful in many ways.[44] Digging into past environmental problems might prevent repeating them. In other cases, finding similarities between past problems and current ones might help solve the later ones. Sometimes hopeful insights from past success stories can also be found. To achieve these goals it is, however, necessary to go beyond a mere reconstruction of past events to an understanding of the underlying processes.

According to J. R. McNeill, environmental history resembles through its multidisciplinarity econometric history, "which also challenged historians to develop new and unfamiliar set of skills."[45] Here I mention just one, quantification. Scarce and partial sources are some of the major problems in most historical writing. This problem is emphasized in environmental history, as we often have to rely on records created long before current environmental thinking. So far the use of quantitative methods remains, however, underutilized in environmental history. Showing its strengths is thus the main contribution of my thesis to the field of environmental history.

One particular problem brought forth in this study is that in general, the use of raw materials with less economic value creates fewer legal disputes and court protocols

---

Europe as well as on the world scale. For an example from South-Asia see: David, A and Guha, R. (eds.) *Nature, Culture, Imperialism: Essays on the Environmental History of South Asia.* Delhi, India: Oxford University Press, 1995, and for Antarctica: Pyne, S. J., *The Ice: A Journey to Antarctica.* University of Iowa Press, 1986.

[43] http://www.foresthistory.org/Research/biblio.html (Updated: June 4, 2007)

[44] Voltaire, "On the Usefulness of History," in Stern, F. (ed.), *The Varieties of History: From Voltaire to the Present*. Macmillan, 1970, p. 46.

[45] McNeill, "Observations on the Nature and Culture," 9.

and other text sources for the use of historians. This can, however, give a misleading picture of historical events. I show how quantitative methods can be used to alleviate this problem. In fact, I go as far as to claim that leaving matters uncalculated because of scarce sources can be more misleading than to calculate despite this (I & II).[46]

Through its multidisciplinary approach and subjects of interests, environmental history also resembles ecological economics. And indeed in 2002 the flagship journal in ecological economics had a special issue on environmental history. According to Joan Martinez-Alier and Heinz Schandl, there were obvious reasons for this:

> Economic history, although it has a wider focus than strict economic theory, has mirrored the developments in economics. …As ecological economics grows, a corresponding ecological-economic history (or environmental history) will develop, of which many of the articles in this issue are excellent examples.[47]

[46] Compare to Söderberg, J. and Eggeby, E., *Kvantitativa metoder för ekonomisk och social historia.* Andra upplagan. Stockholm: Stockholms universitet, 1995, p. 6.
[47] Martinez-Alier, J. and Schandl, H.,"Introduction: Special Section: European Environmental History and Ecological Economics," *Ecological Economics,* Vol. 41, No. 2, 2002, pp. 175-176.

2.2 Quantitative history

There seems to be an immense gap between historians that use quantitative methods and those who avoid them. Allan G. Bogue claims, however, that the dichotomy into quantifiers and non-quantifiers is misleading: "When the literary historian notes that his poet subject lived in the country during most of his lifetime, he has resorted to quantification…"[48]

Similarly, Lee Benson points out that historians who use words like *typical*, *representative*, *significant*, *widesprea*d, *growing*, or *intense* are making quantitative statements whether or not they present figures to justify their assertions.[49] If we necessarily need to find some dichotomy, then there might be one between those who admit using quantitative statements and those who do not.

In the end the whole dichotomy is unnecessary and counterproductive. Roderick Floud stresses that ”qualitative“ and ”quantitative“ methods complement each other and both are needed:

> A major problem of the historian, whatever his interests, is that he is always faced with inadequate evidence; we never have enough to be sure that we are right in our interpretation or description. If in decrying the importance of quantification, the historian excludes all consideration of quantitative evidence, or relegates it to a subsidiary place, he is further reducing the already inadequate evidence that he has available.[50]

According to William O. Aydelotte, quantitative presentations formed the basis for substantial generalizations by an impressive group of historians from the 1930s to the 1960s. He also remarks that: "These results have often been achieved by fairly simple methods; for much historical research the quantitative procedures required

[48] Bogue, A. G., "Quantification in the 1980s," in Rabb, T. and Rotberg, R. (eds.) *The New History, the 1980s and Beyond: Studies in Interdisciplinary History.* Princeton, N.J: Princeton University Press, 1982, p. 140.
[49] Benson, L., "Research Problems in American Political Historiography," in Komarovsky. M. (ed.), *Common Frontiers of the Social Sciences*. Glencoe, Ill.: Free Press, 1957, p. 117.
[50] Floud, R., *An Introduction to Quantitative Methods for Historians.* London: Methuen, 1973, p. 3.

are not complex."[51] Later on, in the first two articles in this collection, I will show that considerable results can be achieved with simple spreadsheet calculations. Thus numbers are nothing to fear.

If we necessarily want to find a dividing point, one can perhaps be found between those who use sophisticated statistical methods and those who do not. The use of statistical methods in history itself is, however, not a new invention – the American historian Frederick Jackson Turner wrote already in 1904: "The method of the statistician as well as that of the critic of evidence is absolutely essential."[52]

Growing use of quantitative methods along with increasing computing capacity has greatly widened the range of materials that can be used in historical research and the possibility to ask new questions. Thus, for example, social historians were able to reconstruct the lives of ordinary people by aggregating the rather thin and stereotypic information contained in the records of the encounters between them and the public authorities:

> Old census manuscripts, tax registers, wills, advice books, inventories of estates, popular songs, city directories, statutes of mutual aid societies, building permits, records of marriages, baptisms, and deaths: all these and many other kinds of documents yielded evidence about the social structures, institutions, and life experiences of millions of ordinary people.[53]

Interestingly in the late 1970s and early 1980s, at the very same time as personal computers started to replace expensive and cumbersome machines working with punched cards or perforated paper tape or at best with magnetic tape, historians started to turn away from quantitative analysis.[54] Behind this abandonment seems to be a transformation from enthusiasm to disillusion. According to Jacques Revel, it was difficult to compare and combine different quantitative findings as many

---

[51] Aydelotte, W. O., "Quantification in History," *The American Historical Review*, Vol. 71, No. 3, 1966, pp. 803-825.
[52] Turner, F. J., "Problems in American History," reprinted in Turner, F. J., *The Significance of Sections in American History.* H. Holt and Company, 1932, p. 20.
[53] Sewell, W. H. Jr., *Logics of History: Social Theory and Social Transformation.* University of Chicago Press, 2005, p. 27.
[54] Ibid. 53.

statistics had been compiled in a chaotic manner, while the redundancy of the data collected led to a sense of diminishing returns. Another problem was that "…the dynamics of research turned the production of data itself into a goal, indeed a priority."[55]

Victoria E. Bonnell and Lynn Hunt mention, as a further reason for the disillusion, that numerous individual case studies came up with contradictory rather than the anticipated cumulative results:

> Social categories—artisans, merchants, women, Jews—turned out to vary from place to place and from epoch to epoch, sometimes from year to year. As a result, the quantitative methods that depended on social categories fell into disrepute almost as soon as they came into fairly widespread usage…[56]

As a result, some historians turned into microhistory, focusing on singular stories and places, while abandoning the search for the "big picture". Other joined the "cultural" or "linguistic turn", taking inspiration from feminism, literary critics and philosophers, and especially from anthropology.[57]

According to Jürgen Kocka, social history belonged, besides economic history and historical demography, to those sub-disciplines that have offered most opportunities for the application of analytical methods: Mass-data could be systematically collected and analyzed by using advanced statistical methods, sharply defined concepts, sophisticated models and rigid procedures for testing them. He adds, however, that it was never valid to over-estimate the potentials of social-scientific history, as it was always obvious that neither history at large nor social history as a whole could be turned into a rigid "science". Nevertheless, he thinks that these endeavours have been given up too early: "Counting is certainly not everything, but sometimes it helps. Giving it up altogether means a step back."[58]

---

[55] Revel, J., "Introduction," in Revel, J. & Hunt, L. (eds.), *Histories: French Constructions of the Past.* New York: New Press, 1995, p. 44.
[56] Bonnell, V. E and Hunt, L. A. (eds.), *Beyond the Cultural Turn: New Directions in the Study of Society and Culture.* University of California Press, 1999, p. 7.
[57] Ibid.
58 Kocka, J., "Losses, Gains and Opportunities: Social History Today," *Journal of Social History,* Vol. 37 No. 1, 2003, pp. 21-28.

The quantitative approach has, however, not disappeared altogether from social history. For example, the Social Science History Association states in its constitution as one of its objectives to foster the retrieval and archiving of quantitative historical data for general scholarly use and its processing in data series of wide applicability.[59]

Finally, it is in place to mention, although briefly, that quantification in history is not an entirely American or West European phenomenon. For example, in the former Soviet Union quantification has had an important role in historical research from the late 1960s. A collection of articles of Soviet quantitative history also clearly shows that it is not just a copy of “western” quantitative history, but clearly a tradition on its own (with roots than can be traced at least to the 1910s) with several distinctive features, and even disagreements with the “western” tradition, especially with the American tradition with both methodological differences and different emphasis.[60]

At least for students of economics or economic history, the best known representative of quantitative history from the Soviet Union is Nikolai Dmyitriyevich Kondratieff (1892 – 1938). Based on study of nineteenth century price behaviour, he argued that capitalistic economies have 50 to 60 year-long cycles of economic booms and depressions. Such business cycles are now called long waves, or Kondratiev waves after him.[61]

[59] Social Science History Association, http://www.ssha.org/about-ssha/constitution/
[60] Rowney, D. K. (ed.), *Soviet Quantitative History.* Beverly Hills, London, New Delhi: Sage Publications, 1984.
[61] Kondratiev, N. D. ”Die langen Wellen der Konjunktur,” *Archiv für Sozialwissenschaft und Sozialpolitik,* Vol 56, No. 3, 1926, pp. 573-609 and ”The Long Waves in Economic Life,” *Review of Economic Statistics,* Vol 17, No. 6, 1935, pp 105-115.

2.3 Economics and Economic History

As I have above demonstrated, all history is to some degree quantitative – and this is even clearer for economic history. The use of quantitative data and quantification can be traced back at least to the political arithmeticians such as Gregory King and John Graunt in the seventeenth century.[62] Thus naming the "revolution" that took place in economic history in the 1960s as *quantitative economic history* is somewhat misleading. The label c*liometrics* is equally misleading, as *Clio* refers to the muse of history and metrics refers to quantitative measurement. Similarly, *econometric history* is too restrictive as it refers to one single economic method. Thus, I think that the label *New Economic History* is the most accurate to describe the changes happening in economic history in the 1960s, although it makes labelling the next revolution quite difficult.

New Economic History indeed brought along something new under the sun – the use of the theoretical and statistical tools of modern economics on the historical past. With a rigid theory guiding the collection of data, economic history managed to avoid the pitfall of quantitative social history: collecting data without any criteria.

The exact timing of the revolution varies from author to author and whether the origins of the revolution or when the revolution was in full bloom are traced. Some mention as the starting point the publication of "The Economics of Slavery in the Ante-Bellum South," by Alfred Conrad and John Meyer in 1958.[63] Peter D. McClelland adds several other candidates from the period 1955 to 1957 to the list.[64] An even earlier candidate is the book *The process of economic growth* from 1952 by Walt Whitman Rostow.[65] Simon Kuznets started to work on his own revolution as

[62] Lee, C. H., *The Quantitative Approach to Economic History.* New York: St. Martin's Press, 1977, p. 1.
[63] Conrad, A. H. and Meyer, J. R., "The Economics of Slavery in the Ante Bellum South," *The Journal of Political Economy*, Vol. 66, No. 2, 1958, pp. 95-130.
[64] McClelland, P. D., *Causal Explanation and Model Building in History, Economics, and the New Economic History*. Ithaca, N.Y: Cornell University Press, 1975, p. 176.
[65] Rostow, W. W., *The Process of Economic Growth.* New York: W. W. Norton, 1952.

early as 1949, with the work that was culminating in the publication of *Modern Economic Growth: Rate, Structure and Spread* in 1966.[66]

Perhaps this creationist approach is again unfruitful and an evolutionary approach should again be taken. R. M. Hartwell divides the appearance of the "new economic history" to three stages. In his chronology it appeared in the United States "in the 1950's, flourished in the 1960's, and dominated by 1970". For Britain he dates the appearance to the 1960s. According to J. W. Drukker, academic history research (also) outside of the United States was dominated by a rigorous quantitative analytic approach, which he considers as the characteristics of the "new economic history, by the end of the 1970s.[67] According to Hartwell, this new economic history was actually a return to the economic history of the pre-1914 era, characterized as well by a close relationship with economics. The difference being that in the pre-1914 era the direction of influences was mainly going from economic history to economics, while in the post 1950s era the direction of this one-way street was from economics to economic history.[68]

D. N. McCloskey lamented already in 1976 that, "the new historical economist has neglected the task of persuading the others of the worth of history in economics".[69] Thirty years or so later this suggestion is still pitifully relevant; during my Masters studies in economics at the University of Helsinki in the late 1990s, I was in the last class having an obligatory course in economic history. My modest hope is that this collection of articles could demonstrate at least to some degree that there are indeed lanes in both directions; from history to economics and from economics to history. Historical methods can be used to test economic theories, and economic methods can be applied to test historical questions.

[66] Drukker, J. W., *The Revolution that Bit Its Own Tail: How Economic History Changed Our Ideas.* Aksant, 2006, p. 178.
[67] Ibid. 107.
[68] Hartwell, R. M., "Good Old Economic History," *The Journal of Economic History*, Vol. 33, No. 1, 1973, pp. 28-40.
[69] McCloskey, D. N., "Does the Past Have Useful Economics?" *Journal of Economic Literature*, Vol. 14, No. 2, 1976, pp. 434-461.

The lesson from economics and especially from economic history to history in general is not to fear numbers. Here, I follow the advice of D. N. McCloskey: “The attempt to produce a number is usually illuminating, even when no number is in the end producible.”[70] This is a good piece of advice also to economists, who seldom produce the statistical data they use themselves.

Zvi Griliches warned already in the seventies about the danger arising from the separation between the producers and analyzers of data, as the analyzers do not feel responsible for it and are thus uninterested in the sources of data and their errors. In the articles dealing with sulphur dioxide, I present one example of problems that might arise from this separation. This is not to say that everyone should produce all data by themselves. Some extra caution is, however, needed when using data compiled by others.[71]

[70] McCloskey, D. N., *Econometric History.* Houndmills, Basingstoke, Hampshire: Macmillan Education, 1987, p. 41.
[71] Griliches, Z., “Errors in variables and other unobservables,” *Econometrica*, Vol. 42, No. 6, 1974, pp. 971–98.

3 THEORETICAL BACKGROUND

3.1 Environmental Kuznets curve hypothesis

The environmental Kuznets curve hypothesis proposes that some pollution or measures of resource or environmental degradation would follow an inverted U-curve related to incomes, increasing at low income levels and decreasing at high income levels. Such a relation was found for some measures of pollution and environmental degradation in the early 1990s, and was popularized in the 1992 World Development Report.[72] Theodore Panayotou coined the concept "Environmental Kuznets curve" (EKC), after the similar theory of income distribution proposed by Simon Kuznets in 1955.[73]

Figure 2 illustrates the assumed relationship between gross domestic product [per capita] and environmental degradation, pollution or resource depletion. Point A illustrates a pre-industrial economy with a low level of per capita income, where one might expect rather pristine environmental conditions relatively unaffected by economic activities. Along with industrialization and economic growth, increasing use of natural resources and emission of pollutants causes escalating environmental degradation. After a peak in environmental degradation (B), the declining part of the curve is finally reached. In the final stage complementary reasons, like growing ability and willingness to pay for a better environment, cleaner technologies and a

---

[72] Grossman, G. M., Krueger, A.B.,"Environmental Impacts of the North American Free Trade Agreement," *NBER. Working paper 3914.* Princeton, 1991; Shafik, N. and Bandyopadhyay, S., *Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence.* Background Paper for World Development Report 1992. Washington D.C: World Bank, 1992; Selden, T. M. and Song, D., "Environmental quality and development: is there a Kuznets curve for air pollution estimates?" *Journal of Environmental Economics and Management*, vol. 27, 1994, pp. 147–162; World Bank, *World development report 1992.* World Bank, 1992, pp. 39-41.

[73] Panayotou, T., *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development*. Working Paper. Geneva: International Labor Office, Technology and Environment Programme, 1993; Kuznets, S., "Economic growth and income inequality," *American Economic Review*, vol. 45, no. 1, 1955, pp. 1-28.

shift to information and service-based activities are expected to result in reduced environmental degradation.[74]

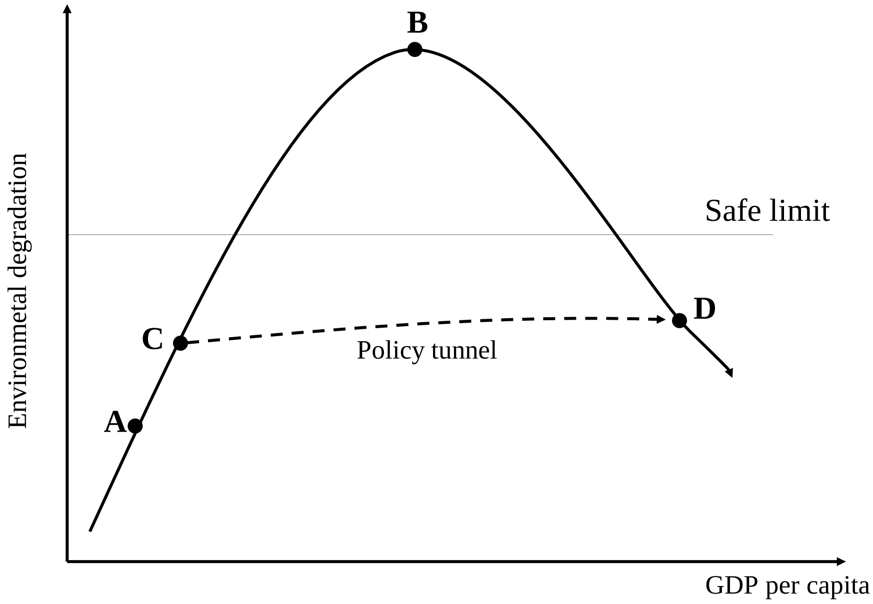


Figure 2. The environmental Kuznets curve with a policy tunnel.

Based on Munasinghe, M., "Is environmental degradation and inevitable consequence of economic growth: tunnelling through the environmental Kuznets curve." *Ecological Economics*, vol. 29, No. 1, 1999, pp. 89-109.

Mohan Munasinghe argues (in a gerschenkronian way) that developing countries could learn from past experiences of the industrialized world by adopting measures, which would permit them to "tunnel" through the EKC.[75] In Figure 1 above it means that developing countries could go through a policy tunnel from point C straight to point D, a society combining high per capita income with low levels of environmental degradation, without passing through point B associated with a high

[74] Munasinghe, M, "Is environmental degradation an inevitable consequence of economic growth: tunnelling through the environmental Kuznets curve," *Ecological Economics*, Vol. 29, No. 1, 1999, pp. 89-109.

[75] Alexander Gerschenkron argues that backward countries could skip several (rostowian) stages of economic growth which advanced countries have gone through by adopting their advanced technology. Gerschenkron, A., *Economic Backwardness in Historical Perspective: A Book of Essays*. Cambridge, MA: Belknap Press of Harvard University Press, 1962.

peak in environmental degradation. This new point should preferably be under some safe limit beyond which environmental damage could become irreversible.[76] David Pearce warns that if environmental losses are irreversible, no amount of income growth will restore those losses. As an example of such irreversibility he uses global climate change.[77]

The standard parametric EKC regression is given by:

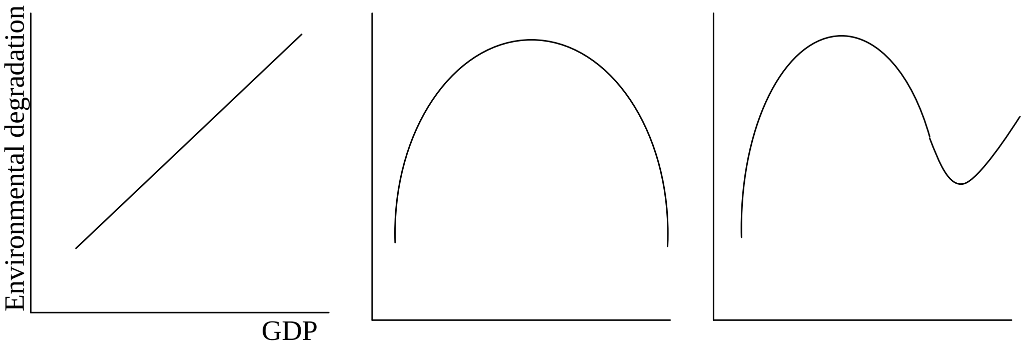
(1) $Y_{it} = \beta_1 G_{it} + \beta_2 G^2_{it} + \beta_3 G^3_{it} + \epsilon_{it}$

where Y_{it} denotes the measure environmental degradation, pollution or resource depletion of interest in region *i* and period *t*. G_{it} denotes gross domestic product or gross domestic product per capita, and ϵ_{it} is an error term. Sometimes the cubic GDP is not included. Usually a number of additional variables, like population density and measures of trade openness or political freedom are added.

Some possible outcomes from the regression are illustrated in Figure 3 below. If all β's are positive, we get an ever rising curve (a). In the picture it is illustrated as a linear curve (β_2=0 and β_3=0). If β_1 is positive, but at least β_2 is negative, we get the so called inverted U-curve (b). For a meaningful EKC relationship the turning point should also occur at a reasonably low income level. A positive β_3 will eventually turn the curve up again at higher income levels generating a so-called N-curve (c). Obviously a decreasing line/curve or a U-curve is also possible.

[76] Munasinghe, "Is environmental degradation an inevitable consequence of economic growth."
[77] Pearce, D., *Investing in Environmental Wealth for Poverty Reduction.* New York: United Nations Development Programme, 2005.

$\beta_1 > 1, \beta_2 \geq 0, \beta_3 \geq 0$ $\beta_1 > 1, \beta_2 < 0, \beta_3 \leq 0$ $\beta_1 > 1, \beta_2 < 0, \beta_3 > 0$



(a) (b) (c)

Figure 3. Possible regression outcomes, an ever increasing curve, inverted U-curve and N-curve.

According to Anton Naiman and Geoff Antrobus:

> The main divergence in the EKC literature is between optimists, who take the EKC as implying that economic growth is ultimately good for the environment; and critics, who point to a number to a number of flaws evident in deriving the EKC or advocate caution in interpreting its causes and implications.[78]

Theodore Panayotou has drawn one of the most explicit conclusions on the EKC hypothesis, which he undoubtedly supports:

…if economic growth is good for the environment, the policies that stimulate growth such as trade liberalization, economic restructuring and price reform ought also to be good for the environment. This in turn would tend to suggest that the environment needs no particular attention, either in terms of domestic environmental policy or international pressure or assistance; resources can best be focused on achieving rapid economic growth to move quickly through the environmentally unfavorable stage of development to the environmentally favorable range of the Kuznets curve.[79]

[78] Naiman, A. and Antrobus, G., "The Environmental Kuznets Curve: a Literature Survey," *South African Journal of Economics,* Vol. 73, No. 1, 2005, pp. 105-120.
[79] Panayotou, "Empirical Tests and Policy Analysis of Environmental Degradation."

Gene M. Grossman and Alan Krueger are more cautious regarding the implications of the EKC:

> …even for those dimensions of environmental quality where growth seems to have been associated with improving conditions, there is no reason to believe that the process has been an automatic one…"[80]

Recently an increasing amount of criticism has been raised on the methods used for deriving an EKC. For example, Elbert Dijkgraaf and Herman Vollebergh cast doubts on the validity of panel estimations assuming homogeneity across countries.[81] Tom Verbeke and Marc de Clercq show that with stochastically trending series, regression analysis spuriously confirms the EKC hypothesis in 40% of the cases.[82] Martin Wagner argues that the use of nonlinear transformations of integrated regressors and cross-sectional dependence in panel data fundamentally invalidates the use of widely applied time series and panel unit root and cointegration techniques.[83]

Following the growing critique towards the commonly used methods in the EKC literature, the popularity of semi-parametric and non-parametric regressions has increased. They leave the functional form unspecified and thus avoid the risk of choosing an inadequate parametric function.[84] In this thesis, I have taken a different approach resorting to historical methods. Historical methods can be used to check a result gained through econometrical methods and vice versa. By extending the data series used we can diminish the statistical problems related to short time series, and also avoid giving too much weight to small fluctuations.

---

80 Grossman, G. M. and Krueger, A.B., "Economic growth and the environment," *Quarterly Journal of Economics*, Vol. 110, No. 2, 1995, pp. 353–377.
81 Dijkgraaf, E. and Vollebergh, H., "A Test for Parameter Homogeneity in CO2 Panel EKC Estimations," *Environmental & Resource Economics,* Vol. 32, No. 2, 2005, pp. 229–239.
82 Verbeke, T. and De Clercq, M., "The EKC: Some really disturbing Monte Carlo evidence," *Environmental Modelling & Software,* Vol. 21, No. 10, pp 1447-1454.
83 Wagner, M., "The carbon Kuznets curve: A cloudy picture emitted by bad econometrics?" *Resource and Energy Economics,* Vol. 30, No. 3, 2008, pp. 388-408.
84 Ordás Criado, C., "Temporal and Spatial Homogeneity in Air Pollutants Panel EKC Estimations: Two Nonparametric Tests Applied to Spanish Provinces," *Environ. Resource. Econ. Vol. 40, No. 2,* 2008, pp. 265–283. See also: Bertinelli, L. and Strobl, E., "The Environmental Kuznets Curve semi-parametrically revisited," *Economics Letters,* Vol. 88, 2005, pp. 350-357.

In my opinion historical methods are especially strong in finding the direction of causation where a correlationship has been established. Most EKC papers assume a unidirectional relationship between income and pollution, with income causing environmental degradation and not vice versa. This assumption has, however, been challenged. The direction of causation can be examined using time series econometric techniques like the Granger Causality test.[85] This test can, however, only detect the direction of short run temporal movements, which is not so relevant regarding the long run concept underlying the EKC concept.

3.3.1 The first EKC study and its revisions and critics

The first EKC study appeared in 1991 in the NBER working papers as a part of a study on the environmental impacts of the North American Free Trade Agreement. The authors, Grossman and Krueger used measures of three air pollutants in a cross-section of urban areas located in 19 to 42 countries in a variety of developing and developed countries for the period 1977 to 1988. As explanatory variables they included functions of per capita GDP in the country where the site is located, characteristics of the site, measurement methods and a time trend. They found that ambient levels of both sulphur dioxide and smoke in the air increased with per capita GDP at low levels of national income, but decreased with per capita GDP at higher levels of income after a peak at around $5 000, measured in 1985 U.S. dollars. After $16 000 sulphur dioxide levels started to rise again, but as there were only two countries in their sample (the United States and Canada) with per capita incomes in excess of this, they argued that this should probably not be viewed as strong evidence for a renewed positive relationship between national product and SO_2 pollution at high income levels. For the mass of suspended particles found in a

[85] See for example: Coondoo, D., Dinda, S., "Causality between income and emission: a country group-specific econometric analysis," *Ecological Economics,* Vol. 40, No. 3, 2002, pp 351-367; Soytas, U., Sari, R. and Ewing, B. T., "Energy consumption, income, and carbon emissions in the United States," *Ecological Economics*, Vol. 62, No. 3-4, 2008, pp. 482-489.

given volume of air, the relationship between pollution and GDP was monotonically decreasing.[86]

The data they used came from the Global Environmental Monitoring System (GEMS), a project set up by the WHO and the United Nations Environment Programme with the goal to monitor the concentrations of several pollutants in a cross-section of urban areas using standardized methods of measurement. The participating cities are located in a variety of developing and developed countries and had been chosen to be fairly representative of the geographic conditions that exist in different regions of the world. As the same data have been used in a large number of EKC studies, it might be illuminating to go briefly through some of them, to see how the changes in the dataset, explanatory variables and statistical methods have affected the results.

Grossman and Krueger returned to the subject in 1995, and compared to their earlier paper, the major change was the inclusion of some data on water quality from the GEMS/Water project. Their model was following:

$$(2)\ Y_{it} = \beta_1 G_{it} + \beta_2 G^2_{it} + \beta_3 G^3_{it} + \beta_4 \underline{G}_{it-} + \beta_5 \underline{G}^2_{it-} + \beta_6 \underline{G}^3_{it-} + \beta_7 X_{it'} + \epsilon_{it}$$

where Y_{it} is a measure of water or air pollution in station *i* in year *t*, G_{it} is GDP per capita in year *t* in the country in which station *i* is located, $\underline{G}_{it}$ is the average GDP per capita over the prior three years, X_{it} is a vector of other covariates (like water temperature, measure equipment or the location of the measure station), and ϵ_{it} is an error term.

For air pollution measures their results were more or less the same as in their earlier paper, as they had the same pollutants and essentially replicated the 1991 paper. Regarding the oxygen regime in rivers they found an inverted U-shaped relationship between income and three measures of environmental damage, with turning points around $7 500. For one direct measure of environmental quality, dissolved oxygen,

[86] Grossman and Krueger, "Environmental Impacts of the North American Free Trade Agreement."

they found a U-shaped relationship, indicating improving conditions with income growth. Increases in per capita GDP were associated with roughly constant levels of fecal coliform until an income level of about $8 000, thereafter fecal contamination fell sharply with income. Total coliforms, however, were found first to rise with income, then fall, and then again rise sharply by $10 000. For heavy metals they found a statistically significant relationship between concentrations of pollution and current and lagged GDP only for lead, cadmium, and arsenic. For lead the relationship was mostly downward sloping, for cadmium flat and for arsenic it resembled an inverted U, with a peak at $4 900.[87]

Mariano Torras and James K. Boyce used in their own analysis the same GEMS dataset as Grossman and Krueger although with a three year longer time span. The starting point for their analysis was their hypothesis that a more equitable distribution of power contributes to improvements in environmental quality, by enhancing the influence on the policy of those who bear the costs of pollution, relative to the influence of those who benefit from pollution-generating activities. They found that literacy, political rights and civil liberties had particularly strong effects on environmental quality in low-income countries. The statistical significance of the income effects generally diminished when inequality variables were included. The most striking cases were those of smoke and heavy particles, where the income effects receded into statistical insignificance. Considering per capita income values up to $15 000 they saw evidence of an inverted U-curve. However, considering values of income greater than that they see quite a different story. They point out that beyond a trough around this income level several pollutants increase:

> Grossman and Krueger do not comment on these subsequent upturns, which are apparent for eight of the 12 pollution variables for which they found support for the environmental Kuznets curve hypothesis. These upturns can hardly be called irrelevant; the income levels at which they occur are not terribly high – indeed many industrialized countries have already exceeded them.[88]

---

[87] Grossman and Krueger, "Economic growth and the environment."

[88] Torras, M. and Boyce, J. K., "Income, inequality, and pollution: a reassessment of the environmental Kuznets Curve," *Ecological Economics*, Vol. 25, No. 2, 1998, pp. 147–160.

Actually, in their 1991 paper, Grossman and Krueger commented on the upturn for sulphur levels, although in a dismissive manner. Thus we can see that different researchers might draw divergent conclusions from the same data.[89]

In 2002, William T. Harbaugh, Arik Levinson and David M. Wilson re-examined Grossman and Krueger's findings. First they replicated the regression made by Grossman and Krueger using a revised dataset for the period 1977 to 1988, but incorporating corrections and additions made to the original dataset. Even then, using the same observations and econometric specifications, the changes in the outcomes were substantial for the concentrations of sulphur dioxide. Rather than increasing and then peaking at $4 000 as with the original data, the predicted pollution-income path declined initially, and then started to increase at about $7 000. Then it started to decline again at about $14 000 at a level where concentrations started to increase again with the original data. For the other air pollutants studied (total suspended particulates and smoke) there were fewer corrections to the original data, and therefore the regression results did not change that much. Finally they tested the sensitivity of the pollution-income relationship to the functional forms and econometric specifications used, to the inclusion of additional covariates besides income, and to the nations, cities and years sampled. The reduced-form relationships typically estimated in the EKC literature are not driven by any particular economic model, thus there is little theoretical guidance for the correction specification. Their conclusion was that the evidence for an inverted U is much less robust than previously thought:

> …the locations of the turning points, as well as their very existence, are sensitive both to slight variations in the data and to reasonable permutations of the econometric specification.[90]

[89] Grossman and Krueger, "Environmental Impacts of the North American Free Trade Agreement."
[90] Harbaugh, T., Levinson, A. and Wilson, D. M., "Reexamining the Empirical Evidence for an Environmental Kuznets Curve," *The Review of Economics and Statistics*, Vol. 84, No. 3, 2002, pp. 541-551.

3.3.2 Carbon Kuznets curves

Douglas Holtz-Eakin and Thomas M. Selden investigated the reduced-form relationship between national CO_2 emissions per capita and real GDP per capita for a sample of 130 countries over the period 1951 to 1986. Using a quadratic polynomial model with fixed country and year-specific effects they found an out-of-sample EKC, with a turning point equal to $35 500 per capita in 1986 US dollars, indicating a monotonically increasing relation between carbon dioxide emissions and income. For the logarithmic specification model the turning point was even higher, above $8 million![91]

Nemat Shafik also found an upward sloping relationship for CO_2 from his panel data for the period 1960 to 1990. As an explanation for the exponential increase found in carbon emissions per capita he presented the classic free rider problem:

> There are no major local costs associated with carbon emissions – all the costs in terms of climate change are borne by the rest of the world – and the local benefits in the near term are small in most cases.[92]

Heil and Selden used a second order polynomial in income per capita with several specification tests to study panel data from 135 countries over the period 1951 to 1992. They found a monotonous increasing relationship between CO_2 emissions and income per capita in both levels model and logarithmic model. Similar results have also been reported by Tucker, Carlsson and Lundström, and Azomahou, Laisney and Nguyen Van.[93]

---

[91] Holtz-Eakin, D. & Selden, T., "Stoking the Fires? CO2 Emissions and Economic Growth," *Journal of Public Economics*, vol. 57, No. 1, 1995, pp. 85-101.

[92] Shafik, N., "Economic Development and Environmental Quality: An Econometric Analysis," *Oxford Economic Papers*, vol. 46, 1994, pp. 757 - 773.

[93] Heil, M. and Selden, M., "Carbon Emissions and Economic Development: Future Trajectories Based on Historical Experience," *Environment and Development Economics*, Vol. 6, 2001; Tucker, M., "Carbon Dioxide Emissions and Global GDP." *Ecological Economics*, Vol. 15, No. 3, 1995, pp. 215-223; Carlsson, F. & Lundström, S., "Political and Economic Freedom and the Environment: The case of CO2 Emissions," *Working Papers in Economics, No 29*, Gothenburg University: Department of Economics, 2001; Azomahou, T., Laisney, F. and Nguyen Van, P., "Economic development and CO2 emissions: A nonparametric panel approach," *Journal of Public Economics*, Vol. 90, No. 6-7, 2006, pp. 1347-1363.

Dipankor Coondoo and Soumyananda Dinda made an empirical analysis at the level of country-groups, separately for the country-groups of Africa, America (North and South combined), Asia, Europe and the World taken as a whole. Evidence for turning points was found only for Europe. These estimated turning points were observed at within the sample income levels, although they were increasing monotonically over time, suggesting that even the rich countries of Europe find it hard to bring down their CO_2 emission levels.[94]

So far all the carbon studies presented have been based on panel data including several countries; another and increasingly popular way is to study individual countries. Catia Cialani explores the emissions of CO_2 in Italy during 1861 to 2002. She finds a positive relationship between economic growth and CO_2: "...following the trend, the maximum emission of CO_2 per capita in Italy would be reached when the GDP per capita will be about $26 900.[95]

Carlos Ordás Criado examined a balanced panel of 48 Spanish provinces on four pollutant emissions covering the period 1990 to 2002 using a non-parametric approach. He found that the global pollutants methane (CH_4) and carbon dioxide (CO_2) were increasing with GDP in most of the provinces while the local pollutants carbon monoxide (CO) and non-methanic volatile organic compounds (NMVOC) were stabilised or decreasing. Both global pollutants were found to be structurally stabile, i.e. the regions tend to keep their relative position when cross-sectional income-emissions relationships (IER) were estimated for different years. This indicates that no offsetting force is at work to change the underlying dynamic of the IER.[96]

Swedish carbon dioxide emissions follow an inverted U-trajectory related to income. Magnus Lindmark, however, argues that there are no indications that

---

[94] Coondoo, D. and Dinda, S., "Carbon dioxide emission and income: A temporal analysis of cross-country distributional patterns," *Ecological Economics*, Vol. 65, No. 2, 2008, pp. 375-385.

[95] Cialani, C., "Economic Growth and environmental quality," *Management of Environmental Quality*, Vol. 18 No. 5, 2007, pp. 568-577.

[96] Ordás Criado, C., "Temporal and Spatial Homogeneity in Air Pollutants Panel EKC Estimations: Two Nonparametric Tests Applied to Spanish Provinces," *Environ. Resource. Econ.*, Vol. 40, No. 2, 2008, pp. 265–283.

environmental motives have played a direct role for lowered CO_2 emissions in Sweden prior to the 1990s. As the first indication of evolving environmental preferences concerning CO_2 he mentions the introduction of the CO_2 tax in 1991. Instead, other changes have impacted upon the carbon dioxide emissions. Some of them, like the nuclear power program and energy taxes, originate from more traditional political agendas like economic concerns and national security.[97]

Lindmark and Astrid Kander add that the Swedish emission decline cannot be explained by outsourcing of environmental problems to less developed countries, as Sweden was a net exporter of energy in goods between 1955 and 2000. They argue that internal forces, like efficiency improvements, changed consumption patterns and transformation of the energy system, have been crucial for the relative environmental improvement in Sweden, while foreign trade has played no role.[98]

Jan Kunnas and Timo Myllyntaus argue that in the case of cumulative pollutants, like carbon dioxide, focusing on yearly emissions and pollution trajectories can be utterly misleading. They base their argument on a comparison of cumulative carbon dioxide emissions in the period 1870 to 2003 for four European countries. Switzerland with its linear emission-income relation had clearly the smallest cumulative emissions; followed by Finland whose emission development path does not either have a downward slope at high income levels as suggested by the EKC hypothesis. Sweden had the second largest cumulative emissions after Denmark, even though its emissions were following an inverted U-curve related to income.[99]

---

[97] Lindmark, M., "An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997," *Ecological Economics,* Vol. 42, No. 1-2, 2002, pp. 333-347.

[98] Kander, A. and Lindmark, M., "Foreign trade and declining pollution in Sweden: a decomposition analysis of long-term structural and technological effects," *Energy Policy,* Vol. 34, No. 13, 2002, pp. 1590-1599.

[99] Kunnas, J. and Myllyntaus, T., "Forerunners and Policy Tunnels," in Jesień, L., (ed.) *European Union Policies in the Making*. Kraków: Tischner European University, 2008, pp. 249-263.

3.3.3 Sulphur Kuznets curves

An article by David I. Stern provides an illuminating overview of sulphur EKC studies from 1993 to 2001. He presents ten studies, all of which found some evidence for an inverted U-shaped relation between sulphur dioxide emissions or concentrations in the atmosphere and GDP per capita. There is, however, large variation in the turning point: $3 000 - $101 000 per capita for emissions and $4 500 – 15 000 for concentrations. The two highest turning points for emissions were out of sample implying a monotonic emissions-income relation. Stern himself argues that emissions are monotonic in income, and that reductions in emissions are time-related rather than income-related.[100]

Using the database compiled by David I. Stern, for the above mentioned papers, Anil Markandya, Alexander Golub and Suzette Pedroso-Galinato examined the linkage between per capita GDP and sulphur emissions for 12 Western European countries. They found an inverted U-shaped relationship on both the aggregate and country levels. In addition, they discovered that environmental legislation may make the EKC to become flatter and it can also shift the turning point of the curve either to left or right.[101]

David Maddison explored the extent to which accounting for transboundary pollution flows and the spatial nature of the data alters the widely held belief that there exists an EKC for sulphur. He argued that there is no EKC for sulphur emissions in Europe, just a spatial lag – countries' environmental quality tracks that

[100] Stern, D. I., "The Rise and Fall of the Environmental Kuznets Curve," *World Development*, Vol. 32, No. 8, 2004, pp. 1419-1439; Stern, D. I., "Reversal of the trend in global anthropogenic sulphur emissions," *Global Environ. Change*, Vol. 16, No. 2, 2006, pp. 207-220.
[101] Stern D. I., "Global sulfur emissions from 1850 to 2000," *Chemosphere*, Vol.58, No. 2, 2005, pp. 163-175; Markandya, A., Golub, A., Pedroso-Galinato, S., "Empirical Analysis of National Income and SO2 Emissions in Selected European Countries," *Environ. Resour. Econ.*, Vol. 35, No. 3, 2006, pp. 221-257.

of their neighbours. Furthermore, he believed that similar results might also be found for other pollutants.[102]

Yue Yaguchi, Tetsushi Sonobe and Keijiro Otsuka made a comparative study of SO_2 and CO_2 emissions between Japan and China, finding clear evidence for the EKC hypothesis only for SO_2 in Japan. Their estimation results on Japan show that the local governments do not react to CO_2 emissions, which cause global externalities, whereas they do react to SO_2 emissions, which cause local externalities.[103]

3.3.4 Widening EKC perspectives

Since the initial articles, the relation between gross domestic product or GDP per capita and an increasing number of different measures of environmental pollution or degradation and measures of environmental concern have been examined. Below, I mention only a few recent examples of the wide range of subjects taken into consideration.

Phu Nguyen Van and Théophile Azomahou used a panel data set of 59 developing countries over the 1972 to 1994 period to study the deforestation process using both parametric and semiparametric models. Their data sample provided no evidence of an EKC, although this is in concordance with the EKC hypothesis as it only suggests a decline in environmental degradation at high income levels. They also found that failures of political institutions may worsen the deforestation process in developing countries.[104]

---

[102] Maddison, D., “Modelling sulphur emissions in Europe: a spatial econometric approach,” *Oxford Economic Papers,* Vol. 59, 2007, pp. 726–743.
[103] Yaguchi, Y., Sonobe, T. and Otsuka, K., “Beyond the Environmental Kuznets Curve: a comparative study of SO_2 and CO_2 emissions between Japan and China,” *Environment and Development Economics,* Vol. 12, No. 3, 2007, pp. 445-470.
[104] Van Phu, N. and Azomahou, T., “Nonlinearities and heterogeneity in environmental quality: An empirical analysis of deforestation,” *Journal of Development Economics,* Vol. 84, No. 1, 2007, pp. 291-309.

Joshua Frank found mixed evidence concerning animal welfare, "with some measures indicating a turning point while other measures showing no sign of peaking/improving animal welfare".[105] Marco Bagliani, Giangiacomo Bravo and Silvana Dalmazzone did not find any evidence of a de-linking between GDP and the ecological footprint indicator.[106] They argue that the absence of EKC in their results may derive from the fact "that consumption-based indicators like the ecological footprint account for the displacement of environmental damage away from high income countries."[107] Jill L. Caviglia-Harris, Dustin Chambers and James R. Kahn argue that energy consumption and related emissions of carbon dioxide emissions are the main reason for the lack of an EKC relationship for the Ecological Footprint measure. They found that energy use component in the Footprint would have to be cut by a full 50% before a traditional EKC is found.[108]

3.3.5 Explanations for the EKC

Following Soumyananda Dinda's comprehensive survey article citing close to two hundred EKC papers, at least five distinct explanations for the EKC can be listed. To keep the list short, I have dropped some overlapping explanations, and some that explain only increasing emissions at low level of incomes, as they are quite obvious. On the other hand, I have added some complementary explanations and counterarguments:

---

[105] Frank, J., "Is there an "animal welfare Kuznets curve?" *Ecological Economics*, Vol. 66, No. 2-3, 2008, pp. 478-491.

[106] The ecological footprint of a specified population or economy can be defined as the area of ecologically productive land that would be required on a continuous basis to provide the energy and material resources consumed, and to absorb all the wastes discharged. It should be noted that the Footprint is not all inclusive, but instead focus on the renewable natural capital requirements of the economy. (Wackernagel, M. and Rees, W., *Our Ecological Footprint, Reducing Human Impact on the Earth.* Gabriola Island, BC and Stony Creek, CT.: New Society Publishers. Sixth printing 1998, pp. 52-53, 63 & 75.)

[107] Bagliani, M., Bravo, G. and Dalmazzone, S., "A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator," *Ecological Economics,* Vol. 65, No. 3, 2008, pp. 650-661.

[108] Caviglia-Harris, J.L., Chambers, D., Kahn, J. R., "Taking the "U" out of Kuznets," *Ecological Economics*, Vol. 68, No. 4, 2009, pp. 1149-1159.

1) *Income elasticity of environmental quality demand*: when a country achieves a sufficiently high standard of living, people attach increasing value to environmental amenities.

   This explanation is criticized by Bengt Kriström and Pere Riera. According to them, there is little support for the assumption that environmental commodities would be luxury goods. In their own estimations of the income elasticity of environmental improvements for a number of European datasets, it was consistently found to be less than one, with few exceptions. In other words, demand increased less than proportionately with income.[109] Even more crushing, Hanno Sandvik found that the public concern over climate change is negatively related both to measures of national wealth and to a measure for responsibility for global warming.[110]

2) *Scale, composition and, technological effects*:
   a. *Scale effect:* Increasing output requires more input and thus more natural resources are used and as a by-product more wastes and emissions a generated.
   b. *Composition effect*: Environmental degradation tends to increase as the structure of the economy changes from rural to urban or from agricultural to industrial, but it starts to fall with another structural change from energy intensive industry to services and knowledge based technology intensive industry.
   c. *Technological effect:* Because a wealthy nation can afford to spend more on R & D, technological development occurs with economic growth and dirty and obsolete technologies are replaced by upgraded new and cleaner technology.

   David Stern, however, shows that, at least for the abatement of sulphur dioxide, income is not the only or the most important factor determining to what degree best practice technology is adopted.[111]

The EKC suggests that the negative impact on the environment of the scale effect will eventually be outweighed by the positive impact of the composition and technique effects. In the last article included in the thesis, I show, however, that the composition

[109] Kriström, B. and Riera, P., "Is the income elasticity of environmental improvements less than one?" *Environmental & Resource Economics*, Vol. 7, No. 1, 1996, pp. 45-55.
[110] Sandvik, H. "Public concern over global warming correlates negatively with national wealth," *Climatic Change*, Vol. 90, No. 3, 2008, pp. *333-341*.
[111] Stern, D. I., "Beyond the environmental Kuznets curve: Diffusion of sulphur-emissions-abating technology," *Journal of Environment and Development,* Vol. 14, No. 1, 2005, pp. 101-124.

effect does not work if the technology intensive industry is added on top of the energy intensive industry instead of replacing it (V).

3) *International trade:*
    a. *Displacement Hypothesis:* Changes in the structure of production in developed economies are not accompanied by equivalent changes in the structure of consumption; therefore, the EKC actually records displacement of dirty industries to less developed countries. Or as Dale S. Rothman puts it, the increased ability of consumers in wealthy nations to distance themselves from the environmental degradation associated with their consumption[112]
    b. *Pollution Haven Hypothesis* has fundamentally the same implications, referring to the possibility that multinational firms, particularly those engaged in highly polluting activities, relocate to countries with lower environmental standards.[113]

4) *Market mechanism:* An endogenous "self-regulatory market mechanism" for those natural resources that are traded in markets might prevent environmental degradation from continuing with income.
    a. *Role of price:* Efficiency in the use of natural resources increases as markets for environmental resources develop and prices begin to reflect the value of natural resources.
    b. *Role of economic agents:* Market agents can also play an important role in creating pressures for environmental protection. For example, bankers may refuse to advance credit because of the environmental liabilities; consumers may avoid products known to be heavy polluters and heavy emissions may give a signal to investors about inefficient production activities.
    c. Giuseppe Di Vita adds that low levels of income involve high values of *discount rate* that are obstacles to the adoption of a pollution abatement policy. The discount rate measures individuals' preferences for benefits now rather than benefits later.[114] While people in rich countries typically have discount

[112] Rothman, D. S., "Environmental Kuznets curves – real progress or passing the buck? A case for consumption-based approaches," *Ecological Economics*, Vol. 25, No. 2, 1998, pp. 177-194.
[113] For a critique of the pollution haven hypothesis see: Letchumanan, R. and Kodama, F., "Reconciling the conflict between the 'pollution-haven' hypothesis and an emerging trajectory of international technology transfer," *Research Policy*, Vol. 29, No. 1, 2000, pp. 59–79.
[114] Di Vita, G., "Is the discount rate relevant in explaining the Environmental Kuznets Curve?" *Journal of Policy Modeling*, Vol. 30, No 2, 2008, pp. 191-207.

rates well below 10%, evidence from the developing world suggests discount rates of 30% to 150%, and even higher.[115]

5) *Regulation:* With economic growth, economies advance their social institutions that are essential to enforce environmental regulation: environmental standards, laws, proper allocation of property rights and informal regulation pursued by NGOs and social groups.

Based on the historical approach used in this thesis, I add two more explanations:

6) The *severity of environmental degradation* might itself create a turning point for the emissions, or in some cases fear of severe effects (III).[116] This proposition gets further proof in the fourth study in this collection, where it is argued that the anxiety about large and widespread damage to forests was a major reason for active measures to decrease sulphur dioxide emissions in Finland since the mid-1980s (IV).

7) Finally, what at a first glance seems to be an environmental improvement might just be a transformation of one environmental problem into another. What in an ahistorical perspective seems to be one single environmental Kuznets curve are in fact several sequential curves. A genuine environmental improvement occurs in this case, only if the new problem created can be considered smaller than the preceding one. One example of such transformation is the Finnish pulp industry's transfer from water pollution into air pollution through burning of waste liquor (IV).

---

[115] Pearce, *Investing in Environmental Wealth for Poverty Reduction.*
[116] See also: Yandle, B., "Environmental turning points, institutions, and the race to the top.," *Independent Review*, Vol. 9, No. 2, 2004.

4 RESULTS AND DISCUSSION

4.1 Starting phase of economic growth

The first two studies examine the starting phase of economic growth when environmental pressure is supposed to increase.

The first study compares the biomass consumption of slash-and-burn cultivation to that of burning cultivation of peatlands. Finland has been chosen as a case study because it is one of the Western countries where the use of fire in agriculture lasted longest. In historical research about fire-clearance husbandry the focus has been on burning of forests, while swamps and other peatlands have been neglected.[117] I claim that this neglect is not acceptable, as according to my calculations, the amount of biomass measured by energy value burned on peatlands surpassed the amount burned in slash-and-burn cultivation after the mid-nineteenth century. A comparison with other sources of carbon dioxide (Figure 4), also shows that burning cultivation of peatlands was by far the greatest source of carbon dioxide in Finland during the entire nineteenth century and at the beginning of the twentieth century (I).

[117] Pyne, S. J., *Vestal Fire – An Environmental History, Told through Fire, of Europe and Europe´s Encounter with the World.* Seattle and London: University of Washington Press, 1997; *Suomen maatalouden historia I-III.* Helsinki: Suomalaisen Kirjallisuuden Seura, 2003 – 2004.

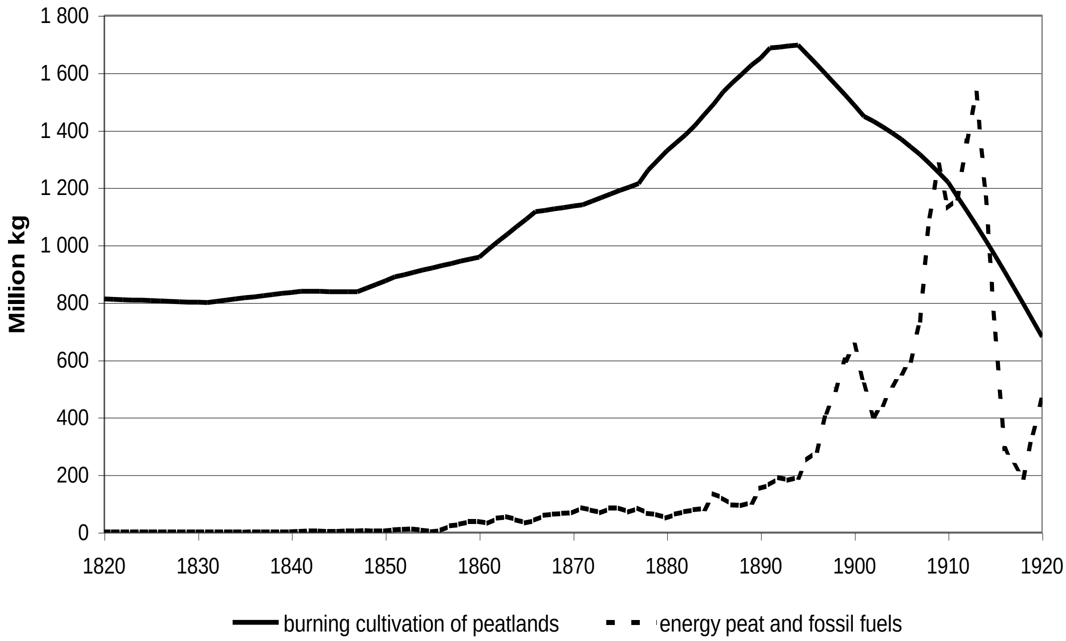


Figure 4. Carbon dioxide emissions from burning cultivation of peatlands vs. emissions from energy peat and fossil fuels 1820 – 1920

Source: Kunnas, J., "A Dense and Sickly Mist from Thousands of Bog Fires." *Environment and History*, Vol. 11 No. 4, 2005, pp. 431-46.

The remaining question is: To what degree can the results from Finland be generalized to other peat-rich countries? Burning cultivation of peatlands has been practiced all over Europe and North America, and was by no means a Finnish curiosity. In these and other peat-rich countries, the inclusion of the emissions from burning cultivation could substantially alter historical carbon dioxide emission estimates.

Deforestation caused by slash-and-burn cultivation is commonly used as an example of the environmental degradation caused by poverty. This study, however, shows, on the one hand, that possible alternatives to slash-and-burn cultivation can cause as large or even bigger environmental problems. On the other hand, the decline of slash-and-burn cultivation did not diminish the pressure on the forests, as the timber saved was used in saw mills and the paper industry. Furthermore, Timo Myllyntaus, Minna Hares and Jan Kunnas claim that slash-and-burn agriculture can, under certain circumstances, be considered sustainable.[118]

The second study compares the wood consumption in the production of potash, saltpetre and pine wood tar in 19th century Finland. This study also provides surprising results, as my calculations indicate that under its high period the production of potash might have consumed more wood than tar burning (Figure 5). Despite its short glory, it can thus not be neglected if we want to achieve a comprehensive picture of protoindustrial forest utilization. In the 19th century the cumulative wood consumption in the production of potash might have been higher or at least on the same level as in the production of tar. In the 1830s the combined wood consumption in the production of tar, potash and saltpetre reached the level of slash-and-burn cultivation (II).

The production of saltpetre consumed only a fraction of that used in the production of tar or potash. Its production might nevertheless have had considerable environmental impacts; it used the manure from domestic animals, which could have been used as a fertilizer, and thus in some part postponed the transfer to permanent field cultivation. Thus it prolonged at least in some degree burning cultivation of peatlands.

[118] Myllyntaus, T., Hares, M., and Kunnas, J., ”Sustainability in Danger? Slash-and-Burn Cultivation in Nineteenth-Century Finland and Twentieth-Century Southeast Asia,” *Environmental History,* Vol. 7, No. 2, 2002, pp. 267-302.

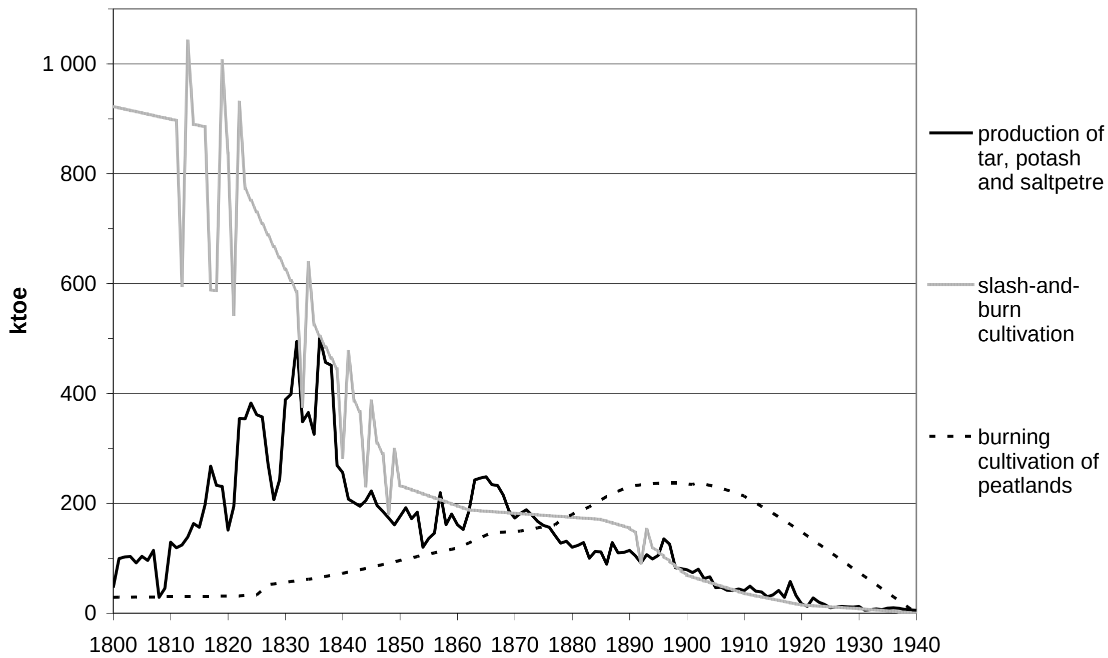


Figure 5. Energy consumption in the production of tar, potash and saltpetre compared to that in slash-and-burn cultivation and burning cultivation of peatlands 1800 – 1940

Source: Kunnas, J., ”Potash, Saltpetre and Tar,” *Scandinavian Journal of History,* Vol. 32, No. 3, 2007, pp. 281 – 311. & “A Dense and Sickly Mist from Thousands of Bog Fires.” *Environment and History*, Vol. 11 No. 4, 2005, pp. 431-46.

4.2 From the 19th century to the present

The second part of the study examines the overall development of major air pollutants from industrialization to the present. The calculations done in the first part of the study are here used in the construction of long time series for several measures of environmental pressure in order to examine the overall development from industrialization to the present. Most notably, we have a 200-year long time series of carbon dioxide and sulphur dioxide emissions stretching from 1800 to the present.

I test whether the major energy related air pollution emissions follow an inverted U-curve related to income, as predicted by the 'environmental Kuznets curve' hypothesis. The carbon dioxide emissions from Finnish energy production increased at the beginning of the period under study according to the EKC hypothesis, but a steady decline of these emissions at high income levels could not be found – only stagnation. Genuine support for the EKC hypothesis was only found for sulphur dioxide emissions and, with some reservations, for nitrogen oxides as well (III).

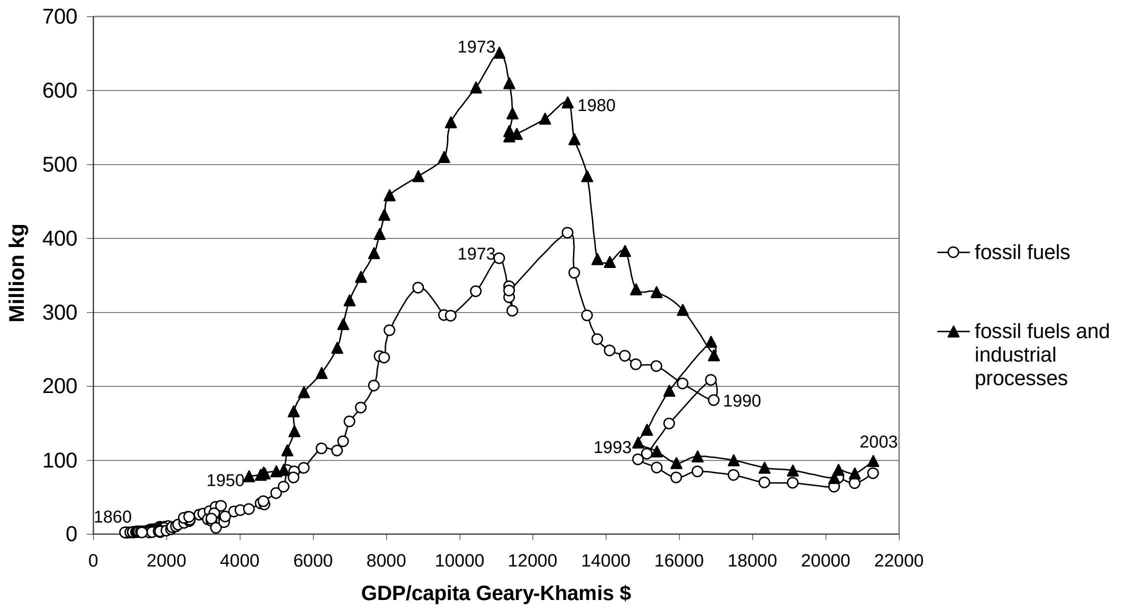


Figure 6. Relation between sulphur dioxide emissions and GDP in Finland, 1860 – 2003
Sources: see Kunnas J. & Myllyntaus, T., "The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland." Scandinavian Economic History Review, Vol. 55 No. 2, 2007, pp. 101 - 127.

Finally some problems related to the interpretation of the EKC were brought up. First, it is questionable whether economic growth has an automatic tendency to diminish environmental damage at high-income levels. A limitation of the reduced-form approach used is that it is unclear why the estimated relationship between pollution and income exists. The driving force behind the turn-around of sulphur dioxide from industrial processes in the 1970s seems to be a by-product of technological changes dictated by economic reasons. The reason behind the concern surrounding acidification also seems to be mainly economic: in Sweden and Norway a concern about commercially valuable fish stocks and in Finland about the raw material base for the forest industry. In a sense, the environmental concern leading to emission reductions was caused by environmental deterioration itself. In this way the turning point of emissions might have been created by the emissions themselves and not by a change in preferences as a result of income growth.

The single biggest question left aside in this part is related to the changes in carbon bonded in Finnish forest ecosystems. The general assumption is that the growing standing stock has been a carbon sink since the mid-1960s. In the study it was, however, pointed out that the result might change dramatically if the change of the carbon in decaying wood was also taken into account, as studies show that old growth forests in general have a much larger amount of dead wood than present-day economy forests.[119] Answering this question would, however, have required a thesis on its own, or perhaps even a whole research project.

4.3 Turning points?

The goal of part three of the study is to take a closer look at the reason between the divergent paths of carbon dioxide and sulphur dioxide emissions. Why did the emissions of sulphur dioxide start to decline in Finland and other industrialized countries in the 1970s, but emissions of carbon dioxide did not?

In the first study in this part the linkage between per capita GDP and sulphur dioxide emissions for one single country, in this case Finland, is examined. The narrow approach together with a combination of a historical and economic approach enables to cut deeper into the controversial environmental Kuznets curve hypothesis. The main reasons for a downturn in sulphur emissions were found to be:

[119] Rouvinen, S., Kuuluvainen, T. & Karjalainen L., “Coarse Woody Debris in Old Pinus Sylvestris Dominated Forests Along a Geographic and Human Impact Gradient in Boreal Fennoscandia,” *Canadian Journal of Forest Research*, Vol. 32, No. 12, 2002, pp. 2184 - 2200; Sippola, A. L., Siitonen, J. & Kallio, R., “Amount and Quality of Coarse Woody Debris in Natural and Managed Coniferous Forests Near the Timberline in Finnish Lapland,” *Scandinavian Journal of Forest Research*, Vol. 13, No. 2, 1998, pp. 204-214.

technological development and anxiety about possible environmental damage and economic costs related to that. The role of economic growth creating a downturn was noticed being small or nonexistent (IV).

The decline of emissions in the 1970s was mainly a side-effect of changes in industrial processes rather than an outcome of a deliberate policy. Furthermore, anxiety about large and widespread damage to the forests was a major reason for active measures to decrease sulphur dioxide emissions since the mid-1980s. Thus the emissions themselves provoked their downturn. Although the risks facing Finnish forests might have been overestimated, without active measures the emissions would have eventually reached a level in which the forests would have been seriously damaged. This again would have caused serious losses to the Finnish economy.

From an environmental point of view it does not matter whether the emission decline is a result of environmental considerations or a by-product of economically dictated technological change, or whether the engine of change is increased wealth or public reactions against emissions themselves. However, there is a big difference in the policy implications, for example, regarding carbon dioxide emissions. For future development of carbon dioxide emissions, the story of declining sulphur dioxide emissions in the 1970s inspires hope that reduction of emissions could be part of normal technological development. By speeding up this kind of development, environmental concerns and policy measures can accelerate the development creating at best a win-win situation according to the Porter Hypothesis, which claims that environmental protection can benefit competitiveness.[120]

If again the environmental damage has to become severe enough to create pressure to reduce the emissions, then in the case of carbon dioxide the prospects are grim indeed. Another option is that, as in the case of sulphur dioxide, the anxiety about

---

[120] Porter M., "America's green strategy," *Sci. Am.* Vol. 264, No. 4, 1991, p. 96; Porter M. and van der Linde, C., "Toward a new conception of the environment – competitiveness relationship," *J. Econ. Perspect.* Vol. 9, No. 4, 1995, pp. 97-118.

possible serious damage in the future can be enough to create the downturn in emissions.

The second study in this part examines the growth and composition of energy consumption in Finland in the 19th and 20th centuries, focusing on energy-related carbon dioxide emissions. This study argues that among European countries, Finland was an 'odd-man out' because it industrialized by means of renewable, indigenous energy sources. Only in the 1960s in the mature phase of industrialization, the country switched from indigenous energy sources, fuel wood, wood refuse and hydropower, to imported fossil fuels. The reasons for this late transition from an energy system based on indigenous energy sources to one largely depending on fossil fuels are Finland's large wood resources and reasonable hydropower potential, which made it possible to postpone the transition (V).

The switch to fossil fuels led to exceptionally fast growth of carbon dioxide emissions in the 1960s, as we can see from Figure 7. The growth of carbon dioxide emissions slowed down, however, in the 1970s. The major reasons for this are a change in the industrial structure, an increased share of electricity import and nuclear power. Environmental considerations probably did not have any kind of role before the 1990s, although Gilbert Plass raised his concerns about the negative consequences of carbon dioxide emissions already in 1956. Despite this slowdown, Finland's carbon dioxide emissions have been almost seven-fold since Plass expressed his concerns. Finland's present-day development concerning carbon dioxide emissions cannot thus act as an example for latecomers to follow.[121]

[121] Plass, "Effect of Carbon Dioxide Variations on Climate."

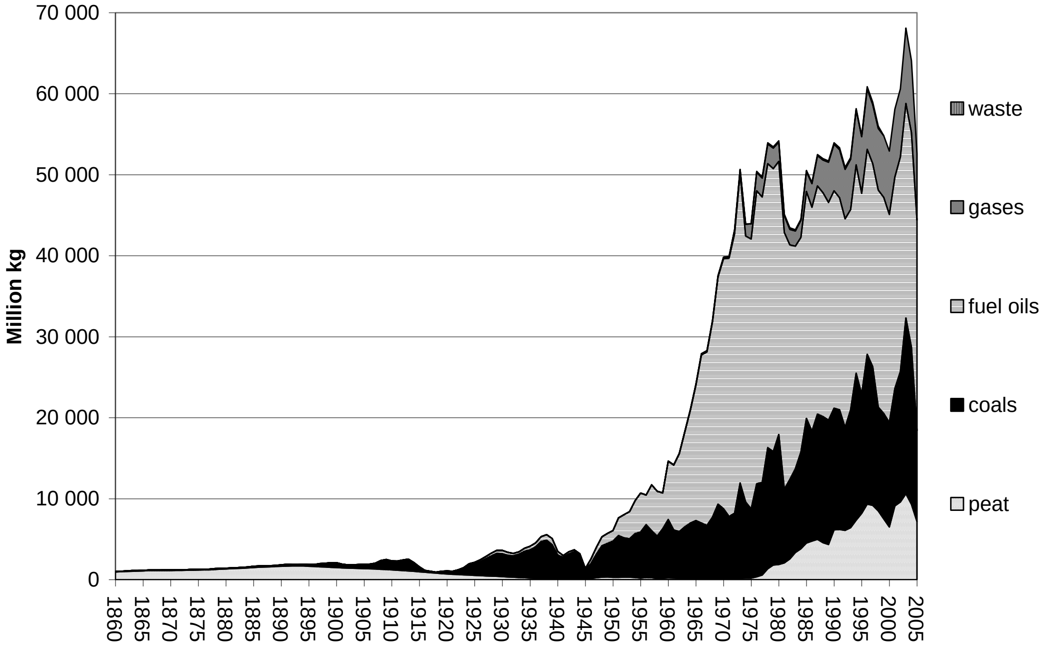


Figure 7. Carbon dioxide emissions from the use of fossil fuels in Finland, 1860 - 2005

Source: Kunnas, J. and Myllyntaus, T., "Postponed Leap in Carbon Dioxide Emissions: Impacts of Energy Efficiency, Fuel Choices and Industrial Structure on the Finnish Energy Economy, 1800 – 2005,"Unpublished manuscript.

5. CONCLUSIONS

I have traced Finland's transition from a solar based energy system to a fossil fuel based one. The period under examination ranges for more than two centuries, from 1800 to 2005. In such a long period the development of energy use can be generalized into two distinctive periods.

The first period from 1800 to the First World War is characterized by a close to zero growth in total energy use (0.2% a year from 1820 to 1913) and a declining per capita energy use. What makes this slow growth phenomenal is the fact that its gross domestic product soared in the latter half of the 19th century. From 1860 to 1913 Finland's gross domestic product almost quadrupled. The main reason for this development was improvement in space heating efficiency because of new stove technology tripling the average thermal efficiency (III, V). Another significant reason for the declining energy consumption per capita was a decrease in the wood burned in slash-and-burn-cultivation. This decrease was partially counteracted by an increase in burning cultivation of peatlands; this cultivation practice peaked in the 1890s and thereafter withered away by 1940 (I).

The second period from the First World War to the present is characterized by a steady growth in total energy use (2% a year). The most notable deviation is a decline in energy use during the Second World War, while events like the oil crises or the economic recession of the 1990s are reduced to mere hick-ups in the growth (III, V).

Finland industrialized by means of renewable, indigenous energy sources. Not until the 1960s did it switch to imported fossil fuels. This switch led to exceptionally fast growth of carbon and sulphur dioxide emissions (IV, V).

The emissions of sulphur dioxide started to decline in the 1970s while the emission growth of carbon dioxide only slowed down. The initial decline of sulphur dioxide emissions was mainly a side-effect of changes in industrial processes rather than an outcome of a deliberate policy. Furthermore, anxiety about large and widespread damage to the forests was a major reason for active measures to decrease sulphur dioxide emissions since the mid-1980s. Thus the emissions themselves provoked their downturn. Although the risks facing Finland’s forests might have been overestimated, without active measures the emissions would have eventually reached a level in which the forests would have been seriously damaged. This again would have caused serious injury to the Finnish economy (III, IV, V).

Some proponents of economic growth go as far as claiming that economic growth is a necessary condition for proper protection of the environment and in the long run it is also probably a sufficient condition.[122] This thesis turns the argument around. I claim that the causal connection goes in an opposite direction: proper environmental standards and conservation comprise a necessary condition for economic growth in the long run (III, IV).

From a policy perspective Finland's industrialization in the 19th century without increasing its total use of energy and related carbon dioxide emissions is of particular interest (III, V). If the present-day developing countries could repeat Finland's “energy-less” growth which continued until the First World War, this could buy valuable time in the battle against climate change. If the developed countries would again use this time to lower their energy consumption and develop as environmentally friendly means as possible to provide the remaining needs for energy, there would be hopes to win this gigantic battle for the future of humankind. The accomplishment of this goal requires technology transfer to developing countries. This should, however, not focus on high-tech only; it should be remembered that Finland's initial energy-less growth was achieved by a technology

[122] Beckerman W., *Small is stupid: Blowing the whistle on the greens.* London: Duckworth, 1995.

which can be considered quite primitive from the present-day perspective, although it was revolutionary indeed at the time.[123]

I argue that quantitative calculations on the use of natural resources provide valuable tools, which can give new insights to old questions and raise new questions. The first two studies put forth the methodological question whether it is more misleading to leave matters uncalculated because of scarce sources to rely on or calculating despite this, suggesting that it can be the first one. Burning cultivation of peatlands, which has been neglected in historical research, was by far the greatest source of carbon dioxide in Finland during the whole of the nineteenth century and at the beginning of the twentieth century (I). Another neglected occupation, the production of potash might have consumed as much wood during the 19th century as the production of tar (II).

I also show how methods of historical research can be used to test economic theory (III, IV, V). So far, in my understanding, it has been mostly the other way round; economic tools have been used to provide answers to historical questions. Based on the historical approach used in this thesis, I add two new explanations for the existence of an Environmental Kuznets curve:

1) The *severity of environmental degradation* might itself create a turning point for the emissions, or in some cases fear of severe effects (III, IV).

2) What at a first glance seems to be an environmental improvement might just be a transformation of one environmental problem into another. What in an ahistorical perspective seems to be one single environmental Kuznets curve are in fact several sequential curves (IV).

[123] This idea is developed further in: Kunnas and Myllyntaus, ”Forerunners and Policy Tunnels.”

6. CONSIDERATIONS FOR FUTURE RESEARCH

In this thesis, I have presented several supplementary reasons for the divergent paths of carbon dioxide and sulphur dioxide emissions since the 1970s. One key difference between carbon dioxide emissions and sulphur dioxide emissions is the scale of effects. In regional pollution problems, such as acidification, caused mainly by emissions of sulphur dioxide, the decisions by the countries within that region are sufficient. For global environmental problems, the decisions of all countries are, at least in principle, necessary. How to overcome this problem is without doubt one of the major questions for humankind, and I sincerely believe that historians could have a number of insights to this.

Further insights could probably be gained by adding the successful dealing with ozone depleting substances to the comparison. Similarly to climate change, the depletion of the ozone layer was a global problem needing a global solution. Acidification and the depletion of ozone layer also have several similarities. Their effects were immediate and easy to understand in contrast to the, so far, slow process of global warming caused by emissions of greenhouse gases. The effects of acidification, like dying forests or declining stocks of commercially valuable fish stocks, and the loss of a "protective shield" and skin cancer linked to the depletion of the ozone layer, were easy to envision. In both cases a few countries first made unilateral cuts. Their example together with active lobbying eventually led to successful international treaties. Cass R. Sunstein argues that in the end the actual costs for replacing ozone depleting substances were also much lower than at first anticipated, which made it easier for less eager countries to follow.[124]

I believe that more understanding could be acquired by going through different official estimates by governmental bodies and working groups and unofficial estimates by NGOs and representatives of business interests about the costs to

[124] Sunstein, C. R., *Worst-Case Scenarios.* Cambridge, Mass. : Harvard University Press, 2007.

control emissions of sulphur dioxide and to replace ozone depletive substances. Some relevant question would be:

1) How and why the estimates have evolved over time?
2) Do various interest groups estimate costs differently, and why?
3) How do the cost estimates vary between countries, and why?

Making an analogy from the successes with dealing with acid rain and the ozone depletion, I claim that unilateral measures to curb climate change could provide an example for later comers to follow, allowing them to tunnel through the peak emissions.[125] In the case of ozone depleting substances the United States took the lead without waiting for actions by the European Community, the forerunner of the European Union. Thus it managed by its own example to overcome the scepticism and opposition of regulatory measures by the EC, which eventually followed the example.[126] This time is it the European Union's turn to take the lead?

Another important question would be what we can learn from a successful technology transfer related to the reduction of sulphur dioxide emissions and ozone depletive substances that could be useful in the global struggle to curb emissions of greenhouse gases. The EU's goal of keeping the rise in global temperatures below 2°C compared to the pre-industrial level, which would require global emissions to be reduced by up to 50% compared to 1990 by 2050, will not be achieved by measures in industrialized countries alone.[127] Thus we need active measures to guarantee a transfer of suitable technology to developing countries. This should, however, not focus on high-tech only. As shown in this thesis, Finland's initial energy-less economic growth in the 19th century was achieved by a technology which can be considered primitive from the present-day perspective.

125 Kunnas and Myllyntaus, "Forerunners and Policy Tunnels."
126 Sunstein, *Worst-Case Scenarios.*
127 Commission of the European Communities, *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond.* COM/2007/0002 final. http://eur-lex.europa.eu/en/index.htm [Last accessed 5 November 2007]

BIBLIOGRAHPY

Alho, P., ”Pohjois-Pohjanmaan metsien käytön kehitys ja sen vaikutus metsien tilaan,” *Acta Forestalia Fennica* 89, 1968.

Arrhenius, S., “On the influence of carbonic acid in the air upon the temperature of the ground,” *Phil. Mag.*, Vol. 41, 1896.

Arrhenius, S., *Worlds in the Making*. New York: Harper & Brothers, 1908.

Aydelotte, W. O., “Quantification in History,” *The American Historical Review,* Vol. 71, No. 3, 1966, pp. 803-825. [http://www.jstor.org/stable/1846023]

Azomahou, T., Laisney, F. and Nguyen Van, P., “Economic development and CO2 emissions: A nonparametric panel approach,” *Journal of Public Economics,* Vol. 90, No. 6-7, 2006, pp. 1347-1363..

Bagliani, M., Bravo, G. and Dalmazzone, S., “A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator,” *Ecological Economics*, Vol. 65, No. 3, 2008, pp. 650-661.

Beckerman W., *Small is stupid: Blowing the whistle on the greens*. London: Duckworth, 1995.

Beinart, W. “African history and environmental history,” *African Affairs,* Vol. 99, No. 395, 2000, pp. 269-302.

Benson, L., “Research Problems in American Political Historiography,” In Komarovsky. M. (ed.), *Common Frontiers of the Social Sciences*. Glencoe, Ill.: Free Press, 1957, pp 113-183.

Bertinelli, L. and Strobl, E. “The Environmental Kuznets Curve semi-parametrically revisited,” *Economics Letters,* Vol. 88, 2005, pp. 350-357.

Bess, M., Giles-Vernick, T., Gugliotta, A., Guha, R., Hall, M., Igler, D., Jones, S. D., Lekan, T., Lewis, M., Marks, R. B., McCann, J. C., McCarthy, T., McNeill, J. R., Nash, L., Pauly, P. J., Pyne, S., Ritvo, H., Meisner Rosen, C., Russell, E., Sabin, P., Cazaux Sackman, D., Schneider, D. W., Sluyter, A., Soluri, J., Stroud, E., Sutter, P. S., Tsutsui, W. M., van Dam, P., van Sittert, L., “Anniversary forum: What's Next for Environmental History?” *Environmental history,* Vol. 10, No. 1, 2005, pp. 30-109.

Bogue, A. G., “Quantification in the 1980s,” In Rabb, T. and Rotberg, R. (eds.), *The New History, the 1980s and Beyond: Studies in Interdisciplinary History.* Princeton, N.J: Princeton University Press, 1982, pp. 115-175.

Bonnell, V. E and Hunt, L. A. (eds.), *Beyond the Cultural Turn: New Directions in the Study of Society and Culture*. University of California Press, 1999.

Braudel, F., *La Méditerranée et le Monde Méditerranéen à L'epoque de Philippe II.* Librairie Armand Colin, 1949.

Braudel, F., *The Mediterranean and the Mediterranean World in the Age of Philip II.* Harper&Row, 1972.

Brimblecombe, P., *The Big Smoke, A history of air pollution in London since medieval time*. London and New York: Routledge, 1988.

Callendar, G. S., “The artificial production of carbon dioxide and its influence on temperature,” *Quarterly Journal of Royal Meteorological Society,* Vol. 64, 1938, pp. 223-237.

Caviglia-Harris, J.L., Chambers, D., Kahn, J. R., "Taking the "U" out of Kuznets," *Ecological Economics*, Vol. 68, No. 4, 2009, pp. 1149-1159

Cialani, C., "Economic Growth and environmental quality," *Management of Environmental Quality*, Vol. 18, No. 5, 2007, pp. 568-577.

Commission of the European Communities, *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond*. COM/2007/0002 final. http://eur-lex.europa.eu/en/index.htm [Last accessed 5 November 2007]

Conrad, A. H. and Meyer, J. R., "The Economics of Slavery in the Ante Bellum South," *The Journal of Political Economy*, Vol. 66, No. 2, 1958, pp. 95-130. [http://www.jstor.org/stable/1827270]

Coondoo, D. and Dinda, S., "Carbon dioxide emission and income: A temporal analysis of cross-country distributional patterns," *Ecological Economics*, Vol. 65, No. 2, 2008, pp. 375-385.

Coondoo, D., Dinda, S., "Causality between income and emission: a country group-specific econometric analysis," *Ecological Economics*, Vol. 40, No. 3, 2002, pp 351-367.

Crosby, A. W., "The Past and Present of Environmental History," *The American Historical Review*, Vol. 100, No. 4, 1995, pp. 1177 – 1189. [http://www.jstor.org/stable/2168206]

Crosby, A. W., *The Columbian Exchange: Biological and Cultural Consequences of 1492*. Westport, Conn.: Greenwood, 1972.

David, A and Guha, R. (eds.), *Nature, Culture, Imperialism: Essays on the Environmental History of South Asia*. Delhi, India: Oxford University Press, 1995

Der Spiegel, Säuregen: "Da liegt was in der Luft" *Der Spiegel* No. 47, pp. 96-110; No. 48, pp. 188-200; No. 49, pp. 174-188, November 1981.

Di Vita, G., "Is the discount rate relevant in explaining the Environmental Kuznets Curve?" *Journal of Policy Modeling*, Vol. 30, No 2, 2008, pp. 191-207.

Dijkgraaf, E. and Vollebergh, H. "A Test for Parameter Homogeneity in CO2 Panel EKC Estimations," *Environmental & Resource Economics*, Vol. 32, No. 2, 2005, pp. 229–239.

Drukker, J. W., *The Revolution that Bit Its Own Tail: How Economic History Changed Our Ideas*. Aksant, 2006.

Floud, R., *An Introduction to Quantitative Methods for Historians*. London: Methuen, 1973.

Fogel, R. W., *Railroads and American Economic Growth – Essays in Econometric History*. Baltimore and London: The John Hopkins Press, 1964.

Frank, J. "Is there an "animal welfare Kuznets curve?" *Ecological Economics*, Vol. 66, No. 2-3, 2008, pp. 478-491.

Gerschenkron, A., *Economic Backwardness in Historical Perspective: A Book of Essays*. Cambridge, MA: Belknap Press of Harvard University Press, 1962.

Glacken, C. J., *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century*. Berkeley: University of California Press, 1967. 763 pp..

Global Carbon Project, *Carbon budget and trends 2007*, www.globalcarbonproject.org, [Last accessed 26 September 2008].

Griliches, Z., “Errors in variables and other unobservables,” *Econometrica*, Vol. 42, No. 6, 1974, pp. 971–98.
Grossman, G. M. and Krueger, A.B., “Economic growth and the environment,” *Quarterly Journal of Economics*, Vol. 110, No. 2, 1995, pp. 353–377.
Grossman, G. M., Krueger, A.B.,”Environmental Impacts of the North American Free Trade Agreement,” *NBER. Working paper 3914*. Princeton, 1991.
Harbaugh, T., Levinson, A. and Wilson, D. M., “Reexamining the Empirical Evidence for an Environmental Kuznets Curve,” *The Review of Economics and Statistics*, Vol. 84, No. 3, 2002, pp. 541-551.
Hartwell, R. M., “Good Old Economic History,” *The Journal of Economic History*, Vol. 33, No. 1, 1973, pp. 28-40. [http://www.jstor.org/stable/2117139]
Heil, M. and Selden, M., “Carbon Emissions and Economic Development: Future Trajectories Based on Historical Experience,” *Environment and Development Economics*, Vol. 6, 2001.
Holtz-Eakin, D. & Selden, T., “Stoking the Fires? CO2 Emissions and Economic Growth,” *Journal of Public Economics*, vol. 57, No. 1, 1995, pp. 85-101.
IPCC, *16 Years of Scientific Assessment in Support of the Climate Convention.* 2004. www.ipcc.ch/about/anniversarybrochure.pdf [Downloaded 1 August 2007].
IPCC, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. Geneva, Switzerland: IPCC, 2007.
Kander, A. and Lindmark, M. “Foreign trade and declining pollution in Sweden: a decomposition analysis of long-term structural and technological effects,” *Energy Policy*, vol. 34, no. 13, 2002, pp. 1590-1599.
Khaldūn, I., *The Muqaddimah: An Introduction to History*, 2d ed., Bollingen series. New Jersey: Princeton University Press, 1967.
Kocka, J., “Losses, Gains and Opportunities: Social History Today,” *Journal of Social History*, Vol. 37, No. 1, 2003, pp. 21-28.
Kondratiev, N. D., ”Die langen Wellen der Konjunktur,” *Archiv für Sozialwissenschaft und Sozialpolitik*, Vol 56, No. 3, 1926, pp. 573-609.
Kondratiev, N. D., ”The Long Waves in Economic Life,” *Review of Economic Statistics*, Vol 17, No. 6, 1935, pp 105-115.
Krech, S., McNeill, J. R. and Merchant, C., *Encyclopedia of World Environmental History*. Routledge, 2004.
Kriström, B. and Riera, P., “Is the income elasticity of environmental improvements less than one?” *Environmental & Resource Economics*, Vol. 7, No. 1, 1996, pp 45-55.
Kuisma, J., *Tuli leivän antaa – Suomen ekohistoria*. Helsinki – Jyväskylä: Gummerus, 1997.
Kunnas, J. and Myllyntaus, T., ”Forerunners and Policy Tunnels,” in Jesień, L., (ed.) *European Union Policies in the Making*. Kraków: Tischner European University, 2008, pp. 249-263.
Kuznets, S., “Economic growth and income inequality,” *American Economic Review*, Vol. 45, No. 1, 1955, pp. 1-28.
Lee, C. H., *The Quantitative Approach to Economic History*. New York: St. Martin's Press, 1977.

Lefohn, A. S., Husar, J. D. and Husar, R. B. “Estimating historical anthropogenic global sulfur emission patterns for the period 1850-1990,“ *Atmospheric Environment,* Vol 33, No. 21, 1999, pp. 3435-3444.
Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhuber, H. “Tipping elements in the Earth's climate system,” *PNAS*, Vol. 105, No. 6, pp. 1786-1793. [http://www.pnas.org/content/105/6/1786.full.pdf]
Letchumanan, R. and Kodama, F., “Reconciling the conflict between the ‘pollution-haven’ hypothesis and an emerging trajectory of international technology transfer,” *Research Policy,* Vol. 29, No.1, 2000, pp. 59–79.
Lindmark, M. “An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997,” *Ecological Economics*, Vol. 42, No. 1-2, 2002, pp. 333-347.
Lundgren. L. J., *Acid Rain on the Agenda, A picture of a chain of events in Sweden 1966-1968*. Lund: Lund University Press, 1998.
Maddison, D., “Modelling sulphur emissions in Europe: a spatial econometric approach,” *Oxford Economic Papers,* Vol. 59, 2007, pp. 726–743.
Markandya, A., Golub, A., Pedroso-Galinato, S., “Empirical Analysis of National Income and SO2 Emissions in Selected European Countries,” *Environ. Resour. Econ*., Vol. 35, No. 3, 2006, pp. 221-257.
Martinez-Alier, J. and Schandl, H.,”Introduction: Special Section: European Environmental History and Ecological Economics,” *Ecological Economics*, Vol. 41, No. 2, 2002, pp. 175-176.
McClelland, P. D., *Causal Explanation and Model Building in History, Economics, and the New Economic History*. Ithaca, N.Y: Cornell University Press, 1975.
McCloskey, D. N., “Does the Past Have Useful Economics?” *Journal of Economic Literature,* Vol. 14, No. 2, 1976, pp. 434-461. [http://www.jstor.org/stable/2722462]
McCloskey, D. N., *Econometric History*. Houndmills, Basingstoke, Hampshire: Macmillan Education, 1987.
McNeill, J. R., “Observations on the Nature and Culture of Environmental History,” *History and Theory,* Vol. 42, No. 4, 2003, pp. 5-43.
Melander, K.R., ”Några uppgifter om äldre tiders kärrodling i vårt land,” *Historisk tidskrift för Finland*. Vol. 7, Helsingfors, 1922.
Mosley, S., “Common Ground: Integrating Social and Environmental History,” *Journal of Social History,* Vol. 39, No. 3, 2006, pp. 915-933.
Munasinghe, M, “Is environmental degradation an inevitable consequence of economic growth: tunnelling through the environmental Kuznets curve,” *Ecological Economics,* Vol. 29, No. 1, 1999, pp. 89-109.
Myllyntaus, T. and Mattila, T. “Decline or Increase, the Standing Timber Stock in Finland, 1800-1997,” *Ecological Economics,* Vol. 41, No. 2, 2002, pp. 271-288.
Myllyntaus, T. and Saikku, M. (eds.), *Encountering the Past in Nature: Essays in Environmental history*. Athens: Ohio University Press, 2001.
Myllyntaus, T., Hares, M., and Kunnas, J., ”Sustainability in Danger? Slash-and-Burn Cultivation in Nineteenth-Century Finland and Twentieth-Century Southeast Asia,” *Environmental History,* Vol. 7 No. 2, 2002, pp. 267-302.
Naiman, A. and Antrobus, G., “The Environmental Kuznets Curve: a Literature Survey,” *South African Journal of Economics,* Vol. 73, No. 1, 2005, pp. 105-120.

Nash, R. “American Environmental History: A New Teaching Frontier.” *The Pacific Historical Review*, Vol. 41, No. 3, 1972, pp. 362-372. [http://www.jstor.org/stable/3637864]
Nash, R., “The State of Environmental History,” in Bass, H. J. (ed.), *The state of American history*. Organization of American Historians and Quadrangle Books, 1970, pp. 249-260.
Ordás Criado, C., “Temporal and Spatial Homogeneity in Air Pollutants Panel EKC Estimations: Two Nonparametric Tests Applied to Spanish Provinces,” *Environ. Resource. Econ.* Vol. 40, No. 2, 2008, pp. 265–283.
Ordás Criado, C., “Temporal and Spatial Homogeneity in Air Pollutants Panel EKC Estimations: Two Nonparametric Tests Applied to Spanish Provinces,” *Environ. Resource. Econ.*, Vol. 40, No. 2, 2008, pp. 265–283.
Panayotou, T., *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development.* Working Paper. Geneva: International Labor Office, Technology and Environment Programme, 1993.
Pearce, D., *Investing in Environmental Wealth for Poverty Reduction*. New York: United Nations Development Programme, 2005.
Plass, G., “Carbon Dioxide and the Climate,” *American Scientist* 44, 1956, pp. 302-316.
Plass, G., “Effect of Carbon Dioxide Variations on Climate,” *American Journal of Physics* 24, 1956, pp. 376-387.
Plass, G., “Infrared Radiation and the Atmosphere,” *American Journal of Physics* 24, pp. 303-21.
Plass, G., “The Carbon Dioxide Theory of Climatic Change,” *Tellus,* Vol. 8, No. 2, 1956, pp. 140-154.
Porter, M., “America’s green strategy,” *Sci. Am.,* Vol. 264, No. 4, 1991, p. 96.
Porter, M., and van der Linde C., “Toward a new conception of the environment – competitiveness relationship,” *J. Econ. Perspect.,* Vol. 9, No. 4, 1995, pp. 97-118.
Pyne, S. J., *Vestal Fire – An Environmental History, Told through Fire, of Europe and Europe´s Encounter with the World.* Seattle and London: University of Washington Press, 1997.
Pyne, S. J., *The Ice: A Journey to Antarctica*. University of Iowa Press, 1986.
Rein, G., *Statistische Darstellung des Gross-Fürstenthums Finnland*, Helsingfors, 1839.
Revel, J., “Introduction,” in Revel, J. & Hunt, L. (eds.), *Histories: French Constructions of the Past*. New York: New Press, 1995.
Revelle, R. and Suess, H., “Carbon dioxide exchange between atmosphere and ocean, and the question of an increase of atmospheric CO2 during the past decade,” *Tellus*, Vol. 9, No. 18, 1957, pp. 18-27.
Roll-Hansen, N., “Science, Politics, and the Mass Media: On Biased Communication of Environmental Issues,” *Sci. Technol. Hum. Val.,* Vol, 19, No. 3, 1994.
Rostow, W. W., *The Process of Economic Growth*. New York: W. W. Norton, 1952.
Rothman, D. S., “Environmental Kuznets curves – real progress or passing the buck? A case for consumption-based approaches,” *Ecological Economics*, Vol. 25, No. 2, 1998, pp. 177-194.
Rouvinen, S., Kuuluvainen, T. & Karjalainen L., “Coarse Woody Debris in Old Pinus Sylvestris Dominated Forests Along a Geographic and Human Impact Gradient in Boreal Fennoscandia,” *Canadian Journal of Forest Research*, Vol. 32, No. 12, 2002, pp. 2184 - 2200.

Rowney, D. K. (ed.), *Soviet Quantitative History*. Beverly Hills, London, New Delhi: Sage Publications, 1984.
Sandvik, H. “Public concern over global warming correlates negatively with national wealth,” *Climatic Change*, Vol. 90, No. 3, 2008, pp 333-341.
Selden, T. M. and Song, D., “Environmental quality and development: is there a Kuznets curve for air pollution estimates?” *Journal of Environmental Economics and Management*, Vol. 27, 1994, pp. 147–162.
Sewell, W. H. Jr., *Logics of History: Social Theory and Social Transformation.* University of Chicago Press, 2005, p. 27.
Shafik, N. and Bandyopadhyay, S., *Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence*. Background Paper for World Development Report 1992. Washington D.C: World Bank, 1992.
Shafik, N., “Economic Development and Environmental Quality: An Econometric Analysis,” *Oxford Economic Papers*, Vol. 46, 1994, pp. 757 - 773.
Sippola, A. L., Siitonen, J. & Kallio, R., “Amount and Quality of Coarse Woody Debris in Natural and Managed Coniferous Forests Near the Timberline in Finnish Lapland,” *Scandinavian Journal of Forest Research*, Vol. 13, No. 2, 1998, pp. 204-214.
Smith, R. A., *Air and rain. The beginnings of a chemical climatology*. London: Longmans, Green and co., 1872.
Soytas, U., Sari, R. and Ewing, B. T., “Energy consumption, income, and carbon emissions in the United States,” *Ecological Economics*, Vol. 62, No. 3-4, 2008, pp. 482-489.
Stern D. I., “Global sulfur emissions from 1850 to 2000,” *Chemosphere*, Vol.58, No. 2, 2005, pp. 163-175.
Stern, D. I., “Beyond the environmental Kuznets curve: Diffusion of sulphur-emissions-abating technology,” *Journal of Environment and Development*, Vol. 14, No. 1, 2005, pp. 101-124.
Stern, D. I., “Reversal of the trend in global anthropogenic sulphur emissions,” *Global Environ. Change*, Vol. 16, No. 2, 2006, pp. 207-220.
Stern, D. I., “The Rise and Fall of the Environmental Kuznets Curve,” *World Development*, Vol. 32, No. 8, 2004, pp. 1419-1439.
Sunstein, C. R., *Worst-Case Scenarios*. Cambridge, Mass. : Harvard University Press, 2007.
Suomen maatalouden historia I-III. Helsinki: Suomalaisen Kirjallisuuden Seura, 2003 – 2004.
Söderberg, J. and Eggeby, E., *Kvantitativa metoder för ekonomisk och social historia. Andra upplagan*. Stockholm: Stockholms universitet, 1995.
The Social Learning Group, *Learning to manage global environmental risks. Vol. 1.* Cambridge, Mass: MIT Press, 2001.
Thomas, W. L. (ed.), *Man's Role in Changing the Face of the Earth*. Chicago, Ill.: University of Chicago Press, 1956.
Torras, M. and Boyce, J. K., “Income, inequality, and pollution: a reassessment of the environmental Kuznets Curve,” *Ecological Economics*, Vol. 25, No. 2, 1998, pp. 147–160.
Tucker, M., “Carbon Dioxide Emissions and Global GDP,” *Ecological Economics*, Vol. 15, No. 3, 1995, pp. 215-223.

Carlsson, F. & Lundström, S., “Political and Economic Freedom and the Environment: The case of CO_2 Emissions,” *Working Papers in Economics*, No 29. Gothenburg University: Department of Economics, 2001.
Turner, F. J., “Problems in American History,” Reprinted in Turner, F. J., *The Significance of Sections in American History*. H. Holt and Company, 1932.
Ulrich B., Mayer R., Khanna P. K., “Depositionen von Luftverunreiningungen und ihre Auswirkungen in Waldökosystem im Solling,“ *Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächsischen Forstlichen Versuchanstalt. Band 58.* Frankfurt am Main: J. D. Sauerländer’s Verland, 1979. [In German with English summary]
United Nations Economic Commission for Europe, *The 1979 Geneva Convention on Long-range Transboundary Air Pollution.* United Nations Economic Commission for Europe, http://www.unece.org/env/lrtap/lrtap_h1.htm [Downloaded 24 October 2006].
United Nations Economic Commission for Europe, *The 1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent.* http://www.unece.org/env/lrtap/full%20text/1985.Sulphur.e.pdf [Downloaded 24 October 2006].
United Nations, *The United Nations Framework Convention on Climate Change*, 1992. http://unfccc.int/resource/docs/convkp/conveng.pdf [Downloaded 8 June 2007].
United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, 1998. http://unfccc.int/resource/docs/convkp/kpeng.pdf [Downloaded 8 June 2007].
Wackernagel, M. and Rees, W., *Our Ecological Footprint, Reducing Human Impact on the Earth*. Gabriola Island, BC and Stony Creek, CT.: New Society Publishers. Sixth printing 1998.
Wagner, M. “The carbon Kuznets curve: A cloudy picture emitted by bad econometrics?” *Resource and Energy Economics*, Vol. 30, No. 3, 2008, pp. 388-408.
Van Phu, N. and Azomahou, T., “Nonlinearities and heterogeneity in environmental quality: An empirical analysis of deforestation,” *Journal of Development Economics*, Vol. 84, No. 1, 2007, pp. 291-309.
Weiner, D. R., “A death-defying attempt to articulate a coherent definition of environmental history,” *Environmental History*, Vol. 10, No. 3, 2005.
Verbeke, T. and De Clercq, M. “The EKC: Some really disturbing Monte Carlo evidence,” *Environmental Modelling & Software*, Vol. 21, No. 10, pp 1447-1454.
White, L. Jr., "The Historical Roots of Our Ecological Crisis," *Science* 155, 1967, pp. 1203–7.
Winiwarter, V., “Approaches to Environmental History,” in Laszlovszky, J. & Szabó, P. (eds.), *People and Nature in Historical Perspective*. Budapest: Central European University, Department of Medieval Studies & Archaeolingua, 2003.
Virrankoski, P., ”Potaska suomalaisen talonpojan teollisuuden tuotteena,” *Scripta historica* XI, 1987, pp. 63–136.
Voltaire, “On the Usefulness of History,” in Stern, F. (ed.), *The Varieties of History: From Voltaire to the Present*. Macmillan, 1970, pp. 44-45.
World Bank, *World development report 1992*. World Bank, 1992.
Worster, D., “Environmentalism Goes Global,” *Diplomatic History*, Vol. 32, No. 4, 2008, pp. 639-641.

Yaguchi, Y., Sonobe, T. and Otsuka, K., “Beyond the Environmental Kuznets Curve: a comparative study of SO2 and CO2 emissions between Japan and China,” *Environment and Development Economics*, Vol. 12, No. 3, 2007, pp. 445-470.

Yandle, B., ”Environmental turning points, institutions, and the race to the top,” Independent Review, Vol. 9, No. 2, 2004.