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Windfall Gains or Eco-Innovation?

'Green' Evolution in the Swedish Innovation System

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Extended abstract

In theory, innovation processes lie behind evolution of national systems as they create *interacting dynamics* among organizations. Institutions and policies are considered means for influencing these interactive dynamics, such as shifting innovative focus from traditional to environmentally oriented production, more environmentally friendly types of energy use, or environmental protection measures, products or services. Institutions and policies are thus considered drivers of change in technologies, processes, markets, raw materials or organizational forms--innovation in a Schumpeterian sense. Shifts in energy sources among organizations from fossil to non-fossil sources in the Swedish innovation system therefore call for explanations in terms of changed institutions and policies and their resulting eco-innovations. This paper looks closer into climate gas emission and the shift to non-fossil energy in Sweden; what types of organizations are behind the shift to non-fossil energy use, what are the relative effects on emissions, to what extent can these interactive dynamics be considered eco-innovations, and if so, can they be related to specific institutions and policies?

Quantitative analysis of evolving innovation processes in national systems is not always possible due to lack of reliable and multi-level time-series data sets. This is also true for eco-innovations (‘green' innovations). In the Swedish case, there are detailed data sets at national, regional, organizational and employee levels, making possible the estimation of evolutionary models. Register data can be merged with time series on environmental energy consumption and emissions. Data allow for a detailed analysis of environmentally oriented innovation since at least 2003. Analyses in this paper are based on time-series of data on the recent shift from fossil to non-fossil energy sources in the Swedish innovation system, as well as data on emissions, and potentially innovation promoting parameters at organizational and employee levels. Methods are quantitative, Cox regression is used.

Previous investigations of the energy use of Swedish organizations reveal a clear shift from fossil to non-fossil energy use. This is described both in terms of cumulative energy use and effects on emissions of carbon dioxide. Data provides us with information for conclusions on why energy sources change and in interaction with what organizational parameters. For example, wood fuel and solid waste increase as sources of energy while fossil oil is decreasing during the years 2003 to 2010. This result is in line with national industrial and environmental policies and presented as institutionally and policy related ‘green innovation'. But a quantitative analysis contests such a conclusion and it is noticed that the shift to non-fossil sources of energy has not lead to verifiable decreases in green-house gas emissions. Public ownership is the single most important contributor to green innovation into non-fossil energy use. Still, CO_2 emissions are not fundamentally reduced by this low-tech shift, since they do not affect end-of-pipe reductions.

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Introduction

In theory, innovation processes lie behind evolution of national systems as they create interacting dynamics among organizations. Institutions and policies are considered means for influencing these interactive dynamics, such as shifting innovative focus from traditional to environmentally oriented production, more environmentally friendly types of energy use, or environmental protection measures, products or services. Institutions and policies are thus considered drivers of change in technologies, processes, markets, raw materials or organizational forms--innovation in a Schumpeterian sense. Shifts in energy sources among organizations from fossil to non-fossil sources in the Swedish innovation system therefore call for explanations in terms of changed institutions and policies and their resulting eco-innovations. This paper looks closer into climate gas emission and the shift to non-fossil energy in Sweden;

- what types of organizations are behind the shift to non-fossil energy use, what are the relative effects on emissions, to what extent can these interactive dynamics be considered eco-innovations, and
- if so, can they be related to specific institutions and policies?

Background

From most points of view, not least from the political perspective, a "greening" of production by means of innovation is highly desirable. Most countries wish to excel in being increasingly "green" in technologies, processes and products, logistics, raw materials, waste handling and so forth. From a social scientist's perspective, however, the dominating problem is how to be able to investigate what has actually been accomplished and what the likely prospects are in this area. First of all, many of us already have problems in defining a "greening" of innovation. Second, the problem is one of data: are there any ways we can estimate the development in our innovation systems regarding green versus conventional innovations? Only on the basis of existing data we might, thirdly, consider measuring, modelling, estimating, explaining, and perhaps even forecasting, such greening of innovation in our systems.

In order to study and assess development in this area, one has to have reliable data stretching sufficiently far back in time. One may, of course, initially make a general mapping of both the environmental orientation of the production of goods and services over the whole economy or its sectors and branches. But the grading system is critical for such data gathering. For example, is an environmentally oriented improvement of traditional production and processes measurable with the same scales as the production of recycling services? One may also ask which economically, as opposed to environmentally motivated, modifications in existing production processes, for example energy saving, may qualify as "green" innovation. Can any production or process be considered "green" or "conventional" by the fact that they affect the environment more or less? These questions point to the problems in defining "environmentally sound", "green" or "eco-efficient" production. It also means that the measurement of "green" innovation, or "eco-innovations" in technologies, products or processes become difficult or controversial. This does not mean, however, that such attempts should be avoided. Instead, it means that one should focus, as social scientist, on what is measurable, what has actually been measured, and start off with the questions that can be answered.

When presenting empirical research results based on necessarily controversial definitions and measurements, it is therefore critical to emphasise what these results are *not* saying as much as what they *are* saying. In particular, any results on the ratio between green and traditional sectors or innovations of the economy have only to be presented with detailed definitions on whether they depict the greening by new products, new processes or innovations.

The innovation system is, in this case, simply understood as all changes in values from one year to the next in the registered variables of activities of all organisations included in the merged official time-series data set. The basic unit of the innovation system is, therefore, change in activities, rather than the population of organisations and individuals as agents of change. A change in orientation from traditional to environmentally oriented production, more environmentally friendly types of energy use or larger amounts of environmental protection measures among organisations that are considered "greener" innovations in the Schumpeterian sense of change in technologies, processes, markets, raw materials or organisational forms. Considering change as the fundamental unit in a system makes it natural to model the evolution of changes and interactions between them over time. Our focus is, therefore, to study such evolution of greener innovations in the Swedish innovation system. This, of course, requires time-series data from which changes in organisational activities can be extracted, modelled and analysed. The aim of this article is thus to make some initial explorations in this direction.

Swedish National Register Data

Data sets can have different structures and be more or less suitable for testing different kinds of models that can help us to understand the dynamics of an innovation system. The best form of data covers the whole population of cases – individuals as well as organisations – in the system, and variables should, of course, be those that are included in the model. When dynamics are in focus, a time-series data structure is essential. It is always critical that data are of high quality, i.e. the values of the variables should correspond to actual conditions. Other types than such total sets of data are often based on samples of the organisational population in which the larger organisations of the population are completely covered, while smaller organisations are randomly selected. This is the case with other interesting data sets, such as the Eurostat CIS data set, which provides comparable data for European Union member states on innovation, including environmentally oriented innovations.

In this case, where we focus on Swedish environmental innovation as changing environmentally significant activities of organisations, there is one data set option that one must consider superior to all the rest, namely the national register data of all organisations in Sweden in a time-series structure (Swedish Statistics' so-called FAD data set). This data set can also be merged and expanded with variables available at an organisational level, such as environmental product data and data on the industrial use of various types of energy sources and environmental protection measures (apart from electric energy). There is also data on use of various types of energy sources among Swedish organizations and their emissions (see table 1).

FAD is compiled from yearly Labour Market Register Data ("RAMS") – information from organisational and sub-unit level as well as employee level. All organisations, their sub-units (separate plants etc., with their own addresses) and all with case identification employees are included on these three levels. FAD is, therefore, a time series of these RAMS data and is therefore demographic in character. It means that by using FAD you may study "births" and "deaths" of organisations and their sub-units as well as mergers and splits over a period of several years, depending on the variables. Data quality issues are addressed systematically. Interestingly, RAMS data also includes figures of all education data on all employees. For example, in this study, data on number of employees having at least an undergraduate education in at least one course is used for company level aggregation, as is the number of employees with an environmental education of any type. The company-level aggregates are then used in the further analysis of company and organisation behaviour in terms of energy use.[1]

//Table 1 around here//

In a separate file, the so-called Coal File ("Kolfilen"), data on both energy use and emissions of various kinds are given for industrial organization in Sweden, both private, state or municipally owned or administered. Among the energy types coded we find e.g. solid fossils (coal and coke), liquid fossils (oil), fossil gas, gasoline, non-fossil solids and non-fossil liquid gas, solid waste, and wood fuel (for details, see figure 2 below). This implies that types of fuels are easily grouped into fossil and non-fossil fuels. In addition there are also emission data included, such as emissions of carbon dioxide and a series of other gases (SCB 2010). Omitted are of course other energy users than industry, such as households. The production of electric power by power plants is not deducted from the consumption (and we realise that energy is never "consumed", but still use this term.)

In describing its data, SCB states that time-series data sets have been created in a way that makes temporal comparisons possible. Each year the entire data set is checked to ensure that the variables are reliable over time (SCB, 2008). The classifications made in the time-series data SCB provides for the period 2003–2011 are shown in the figure 1 below.

By combining environmental product data with FAD one can obtain a data set from which it is possible to make authoritative conclusions about the total number and variety of environmental product-oriented organisations in Sweden, its regions and branches. It is also possible to add individual-level variables, such as: age of the individual, type of education, level of education level, employment status, region where the individual lives, labour mobility, occupational code, sex, wage, number of employees, and so on. To some extent, hypotheses of networking effects on eco-innovation (Hörte and Halila 2008, Halila and Rundquist 2011) can be tested on this kind of data. Public organisations are also included in the data set. This means that publicly and privately owned organisations can be compared in various branches. A comparison between activities of private and public organisations is often interesting from a public policy point of view, and will, of course, be presented as a background to change modelling and analysis of time-series information of transitions to non-fossil energy.

To make analyses comparable with international research, and also from a descriptive point of view, it would also be advantageous to be able to define and operationalise "eco-innovation" on the basis of variables in this data set. "Eco-innovation" has been defined by Arundel and Kemp (2009: 5) as something much wider than environmental products only:

> *the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.*

In particular, in this paper, we will look closer into the reduction of pollution aspect of eco-innovation, and the factors affecting this aspect of greener innovation (ibid, Figge and Hahn 2004).

Energy Use and CO2 Emissions

Among the datasets mentioned in table 1 above, one cover energy use and emissions (the Swedish Statistics' "coal file"). The sample made in this data set is less than two thousands enterprises each year but covers all the largest organizations in Sweden and a structured sample of the rest in terms of both branch ("SNI") and sector (private, public, etc., see table 1). Data from the "coal file" can be used to explore fundamental trends in Swedish energy use (for a description of the data set, see SCB 2010). The data set includes organizations involved in agriculture, fisheries, wood processing, industry, construction, transports, public organizations, housing, and private services. An overview of the energy use by these different types of organizations is given in figure 1.

//Figure 1 around here//

At least three important conclusions can be drawn from the figure 1. One is that wood fuels have rapidly been increasing as share as source of energy, in particular in the years 2003-2010, as well as solid waste to a somewhat lesser extent continuously throughout the period of investigation. These two types of non-fossil energy are behind the shift from fossil to non-fossil energy during these years, as a consequence of the reduction of fossil oil and solid fossils. However, fossil gases are second largest in terms of energy consumption. “Green innovation”, therefore, is in the case of Sweden a matter of replacing fossil oil and solids with wood and waste, in combination with an increasing use of fossil gas. If the two groups of sources, fossil and non-fossil, are compared, we can see that the shift around 2006 becomes very clear (se figure 2).

//Figure 2 around here//

Figure 2 describes the shift from fossil to non-fossil fuel as source of energy among Swedish organizations in the simplest graphic form. The fossil fuels decrease as the non-fossil fuels increase as energy source. Taken together, energy consumption, in total, declines the last years of the period measured, which is in line with what Statistics Sweden reports (SCB

2010). Our question is then if this also implies a “greening” of Swedish industry and other organizations in the sense that CO_2 emission decline as a consequence of this shift. Looking at the figure 3, we understand that this is not the case.

//Figure 4 around here//

The shift from fossil to non-fossil energy in Sweden has had the consequence that non-fossil users are responsible for increasing CO_2 emissions (figure 4). The shift 2006-2007 is dramatic and mirrors the consumption figure. As the emissions mirror consumption, the increasing CO_2 emissions arise as a consequence of increasing consumption of the energy from primarily wood fuels, but also solid waste, while especially fossil oil is declining as the origin of carbon dioxide. The gap between fossil and non-fossil energy closes as a consequence of increasing total consumption in particular in 2010.

Survival analysis of “eco-innovations”

Survival analysis is a statistical technique, in which we are concerned about the time duration until a specific event occurs. It is thus a technique that requires time-series data of the type we have at hand here. The event can be, for example, when an organization changes from fossil to non-fossil fuel. Typical to the survival analysis of time-series, some cases never reach the analysed variable value (the event of changing into non-fossil energy), and are therefore ‘censored’. Since such a variable with censored cases does not follow a normal distribution, a times-series, event history or survival analysis is required. In this paper we will use a Cox regression, since it produces prediction at survival time t as a function of baseline survival taken to the power of an expression that contains predictors we wish to include as co-variates or factors behind the shift to non-fossil energy sources.

The Cox regression is developed for purposes of biostatistics, such as the analysis of survival among cancer patients in relation to treatment. This means that survival in relation to an illness condition may correspond to, with respect to our data, either the event of innovating into non-fossil sources of energy or the reverse event, analysed in the next step below. However, the Cox regression is not only used to actually study survival and hazard ratios among patients, but is also used in analysis of clinical trials examining time to disease resolution (i.e. in the study of the "survival of the disease" or its symptoms), something which perhaps is a more easily acceptable analogy for the analysis of a "pathological" use of fossil energy. In a Cox regression, the hazard ratio represents the hazard that a treated patient will resolve symptoms *before* a control patient. The relation of the hazard rate in the two groups is called the hazard ratio. Stated the analogous way, for any randomly selected pair of organisations using fossil energy, one from the 'treatment' group (in our case an organization that was affected earlier by a specific conditions likely to enhance the likelihood of earlier transition to non-fossil use), and one from the control group of fossil user organisations (without such conditions). The hazard ratio in our case is therefore the ratio of the 'hazard' that the *time* to 'healing' (an advantageous transition to non-fossil use) *is less* in the nation from the group of organizations affected by a hypothesized factor than in the organizations of the control group.

Survival of fossil use among organisations can be analysed using Swedish Statistics' coal file, merged with data on employee education programs and levels, provided in the

Swedish Statistics labour market data base (“RAMS”), if aggregated at organisation level and tied using organizational number as key (see table 1). That way, data both on the organizations’ ownership, degree of market orientation, energy consumption, economic added value, operational profit, and revenues, can be combined with the factor of general level of education of their employees and degree to which employees have any kind of (at least undergraduate) environmental program education. The effect of all these factors on the “survival of fossil energy use” can then be made using Cox regression, and also separately for various types of industrial branches. The model used here lists the hypothesized variables that affect the likelihood of survival of fossil use among Swedish industrial organisations. The column B first indicates the direction of how these factors influence the event of non-survival of fossil energy use; minuses indicate that these factors negatively affect the likelihood of the event of transition to democracy. The column Exp (B) gives the predicted change in the hazard for each unit increase in the covariate (the factor). When the Exp (B) value is 1.0, the covariate makes no difference in predicting the event of transition to non-fossil energy. The more the hazard ratio exceeds 1.0, the greater the relative hazard of ‘death’ of fossil energy use--related to a change in a factor or covariate. An Exp (B) value of 1.1 for any the covariates would mean that a positive value of the factor in question would be associated with a 0.1 (10%) increase in the hazard rate for an innovation into use of non-fossil energy. The further the hazard ratio is below 1.0, then the greater the covariate’s contribution to decreasing the hazard of “death”, in this case decrease in the ‘hazard’ of innovation into non-fossil energy use. We test hypotheses of effects of employees’ education, the number of environmentally educated to all educated at undergraduate level, on green innovations and the time lags for such effects, along with consumption levels, turnover, value added, and operating profits as indicators of economic situation of the organisations. We are also interested in the fact that some organisations are public, while others are private.

Survival Analysis of Fossil Energy

A survival analysis is first made on the already described set of industrial organisations, their energy use, a set of economic variables (the "coal file") combined with aggregated values of numbers of employees with environmental education and at least undergraduate education, as well as the ratio between them (the "RAMS" files).

//Table 2 around here//

The Cox regression shows, first, that neither private ownership, value added of the organization, nor the number of environmentally educated employees significantly affect the likelihood of survival of the fossil energy use ($p>0.05$). Since energy consumption, net turnover and operational profit all have Exp (B) values of 1, we can say with statistical accuracy that these factors do not influence the survival of the fossil energy use at all. The factor environmentally educated has a slightly lower Exp (B) value than 1, indicating that, in fact, the employment of environmentally educated personnel increases the chances of survival of *non-fossil* use among Swedish organisations. This is an unexpected result. Maybe, these organisations have been in situations in which environmentally trained employees are needed in order to investigate future energy sources. The last factor in the model, with a strong detrimental effect on the survival of fossil energy use is public ownership, however, i.e. publically owned organizations are more likely to innovate from fossil to non-fossil energy. The Exp (B) of slightly more than 2 implies that public organizations have 68 per cent higher probability of reaching the non-fossil energy use than the private ones (the probability equals the hazard ratio Exp(B) divided by 1 + the same hazard ratio).

Survival of Non-fossil Energy

Similarly, we may look at the reverse analysis, i.e. a Cox regression in which the survival of non-fossil, rather than fossil, energy use is analysed with the same set of co-variates.

//Table 3 around here//

In this analysis, we look at the factors influencing the reversal from non-fossil to fossil energy use in Swedish organisations 2003-2011. In this analysis, net turnover, value added, and operational profit are not statistically significant factors for explaining why organisations fail to maintain their non-fossil energy use. Energy consumption and the number of employees with at least an undergraduate education have a hazard ratio of 1, indicating statistical significance of their non-influence on the survival. Organisations with a higher number of environmentally educated and privately owned organizations are somewhat more likely to stick to the non-fossil use. A statistically significant larger effect is again only found among public organisations as opposed to private, where the Exp (B) value is only .515, indicating that being public rather than private organisation enhances the probability to instead introduce fossil fuels as energy source with 34 percent.

Discussion

Results from our survival analysis of energy use among Swedish industrial organizations 2003-2011 on the basis of register data, show that neither energy consumption, economic indicators of the organisations, nor the education levels in general play important roles for why these organisations innovate in the direction to or from the use of non-fossil sources. The Cox regressions cannot find more than one distinct co-variate affecting the likelihood of greener or non-greener innovation in this respect than public versus private ownership. Public ownership to an organization both drastically increases the chances for fossil energy users to become later non-fossil energy users fast. Public ownership also drastically reduces the hazard or risk that an organisation already using non-fossil energy instead rapidly starts using fossil energy. One reason why the public ownership is critical to greener energy innovation is probably a matter of which industrial sector it belongs. Public organisations are more likely to be involved in transition to non-fossil energy use, obviously. Exactly why this is the case is not easy to reveal, using the register data from Statistics Sweden referred to here. What we can see in descriptive statistics (figure 5), that typically public organisations primarily use wood fuels, at least until 2010, while private also use fossil gases to a substantial degree. Private organisation, more than public, shifted from fossil oil to fossil gases. This is why the ownership factor plays such a crucial role in the survival analyses of fossil vs. non-fossil energy in Sweden. More specific sector studies can be made using other data sets from Sweden statistics, but is not dealt with here.

The result that public ownership is a critical factor suggests that the shift to non-fossil use in practice to a large part is a question of using wood fuels instead of fossil oil. Unfortunately this shift does not affect SO_2 emissions. The shift is not of high-tech character, but rather a market innovation, if using Schumpeter's definition (1947). The storms Per and Gudrun in 2005 and 2007 helped in this respect. But these were wind-fall gains, rather than effects of eco-innovations, institutions or policies. Emissions are not much affected.

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Figure 1. Total energy use (apart from electricity) by Swedish organizations 2003-2011 (tera-joules)

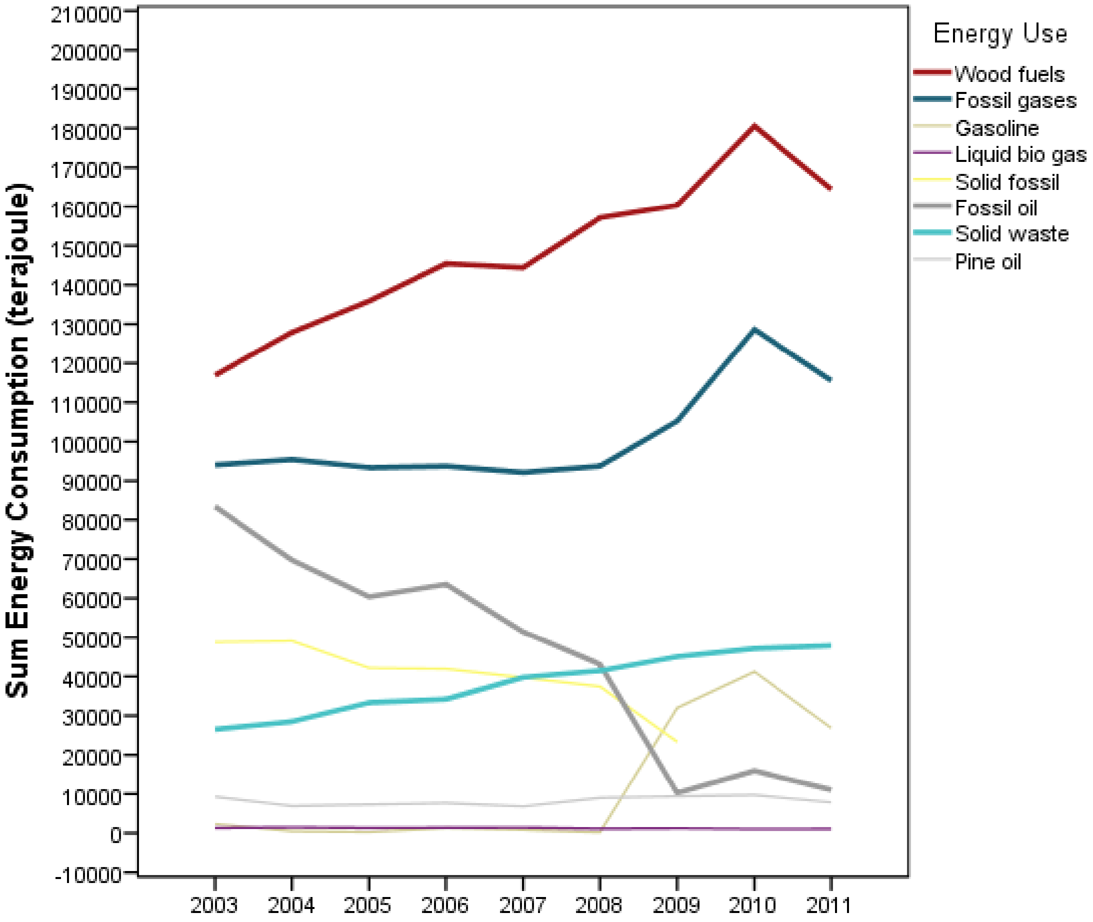

Figure 3. Fossil vs. non-fossil use of energy among Swedish organizations (sums in terajoules)

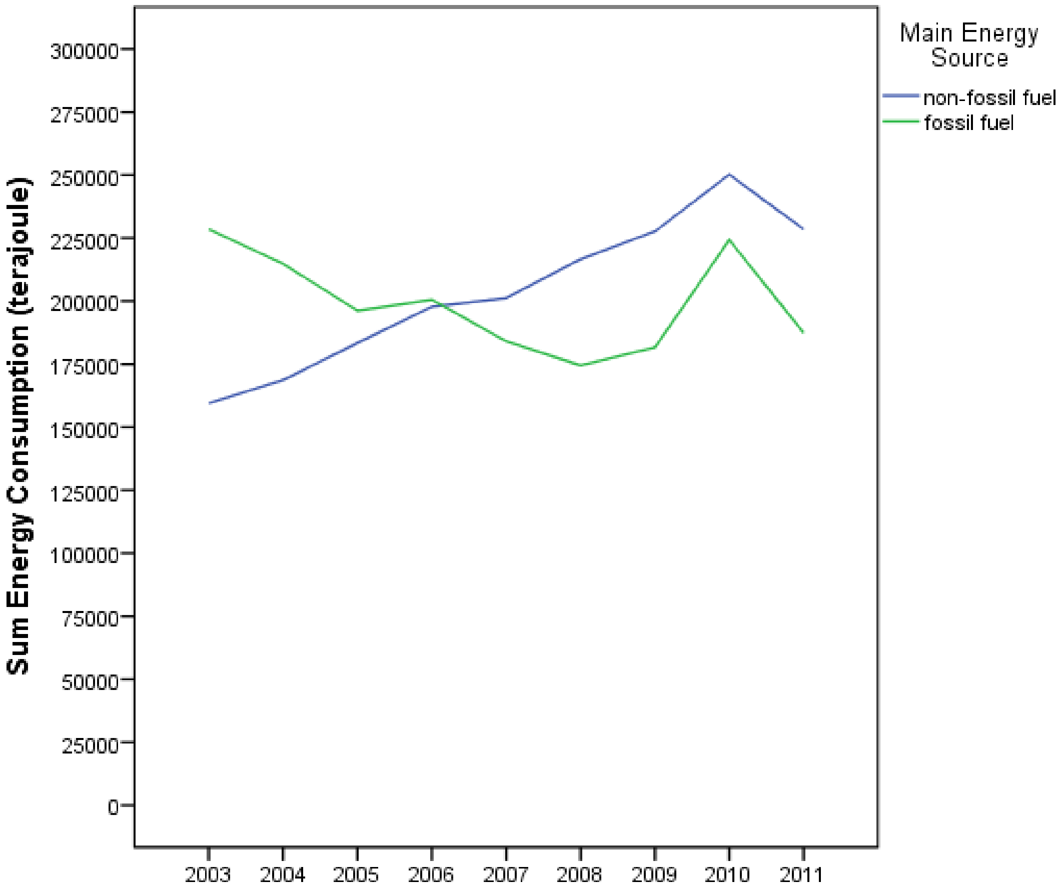

Figure 4. Emissions of CO_2 among energy users in Sweden

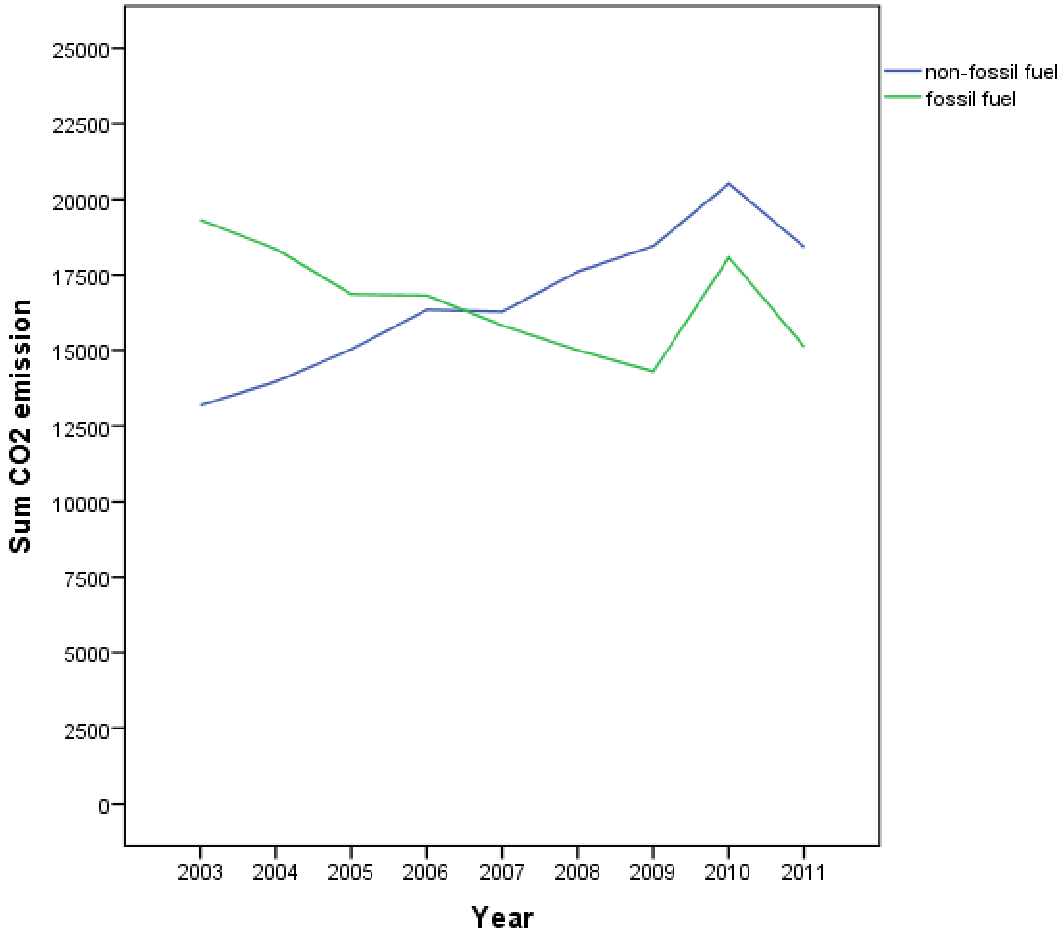

Figure 5. Emissions of CO_2 among public and private energy users in Sweden

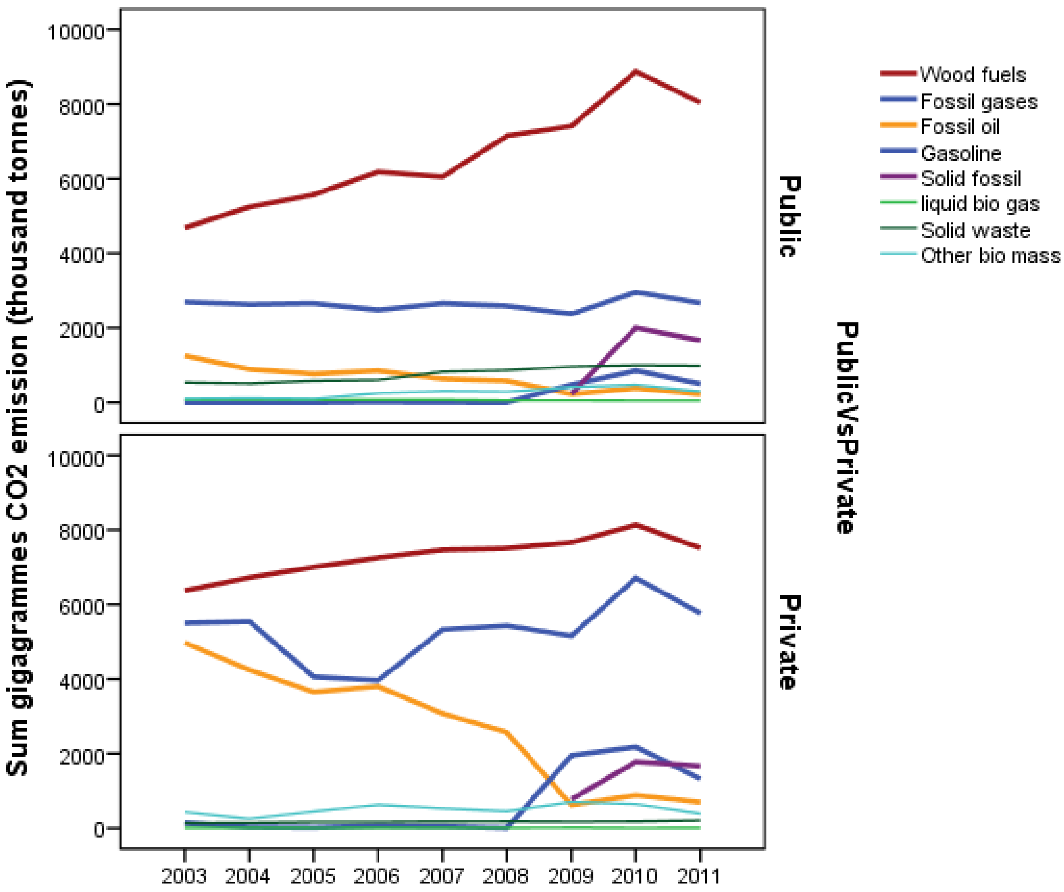

Table 1. Number of cases in two mergable Swedish register databases 2003–2011 on individual employees and all registered organizations.

	Employee data (RAMS)	Energy Use and Emission data ("The Coal file")
Year	**No. Employees**	**No. Organizations**
2003	4,095,047	1,456
2004	4,173,085	1,431
2005	4,184,556	1,336
2006	4,290,877	1,386
2007	4,401,126	1,368
2008	4,417,583	1,431
2009	4,291,088	2,414
2010	4,402,789	2,402
2011	4,459,310	2,412

Table 2. Survival of Fossil Energy Use in Swedish Industry: a Cox Regression

	B	SE	Wald	df	Sig.	Exp(B)	95,0% CI for Exp(B) Lower	Upper
Energy consumption	.000	.000	413.688	1	.000	1.000	1.000	1.000
PublicVsPrivate			140.442	2	.000			
PublicVsPrivate (public)	.700	.185	14.360	1	.000	2.013	1.402	2.890
PublicVsPrivate (private)	.349	.184	3.588	1	.058	1.417	.988	2.033
Net turnover	.000	.000	32.361	1	.000	1.000	1.000	1.000
Value added	.000	.000	.046	1	.831	1.000	1.000	1.000
Operating profit	.000	.000	7.277	1	.007	1.000	1.000	1.000
No. empl. with at least undergraduate educ	-.002	.000	80.749	1	.000	.998	.997	.998
No. empl. with Environmental educ	-.006	.015	.145	1	.704	.994	.965	1.024

Note: The model reduces the -2loglikelyhood from 87520.35 to 86543.37, a statistically significant change at 99% level (chi-sq.). Public vs. private organisation is included as categorical variable.

Table 3. Survival of Non-Fossil Energy Use in Swedish Industry: a Cox regression

	B	SE	Wald	df	Sig.	Exp(B)	95,0% CI for Exp(B)	
							Lower	Upper
Energy consumption	.000	.000	4.491	1	.034	1.000	1.000	1.000
PublicVsPrivate			379.541	2	.000			
PublicVsPrivate (public)	-.664	.080	68.991	1	.000	.515	.440	.602
PublicVsPrivate (private)	-.187	.078	5.773	1	.016	.829	.712	.966
Net turnover	.000	.000	.035	1	.851	1.000	1.000	1.000
Value added	.000	.000	.495	1	.482	1.000	1.000	1.000
Operating profit	.000	.000	.001	1	.981	1.000	1.000	1.000
No. empl. with at least undergraduate educ	.000	.000	20.403	1	.000	1.000	1.000	1.000
No. empl. with Environmental educ	-.075	.012	36.019	1	.000	.928	.905	.951

Note: The model reduces the -2loglikelyhood from 160823.42 to 160187.89, a statistically significant change at 99% level (chi-sq.). Public vs. private organisation is included as categorical variable.

Notes:

[1] In the documentation from Swedish Statistics (SCB), the quality of RAMS is discussed in "Årlig regional sysselsättningsstatistik 1988:7", "Kvalitetsdeklaration av den årliga regionala sysselsättningsstatistiken 1991:1" (SCB) (in Swedish). SCB notes that the greatest effort is devoted to finding the correct sub-unit for the employees. It is primarily on that particular point that quality problems may arise. Employers with more than one organisational sub-unit have been given sub-unit control figure since 1985 from the tax authorities. These control figures should be tied to the address of the sub-unit and be included in the organisational registry data set. If the data entry is incomplete or incorrect, this may, of course, lead to quality problems. However, the organisations are contacted in order to extract the correct data.