Long run decomposition of CO2 emissions in several European countries: 1850-2000[*]

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ABSTRACT
The present piece is no more than an advance of work in progress relating decomposition of CO_2 emissions in several European countries in the very long run. A newly set of CO_2 emissions is constructed for several European countries from 1850 to the year 2000. It is possible then to analyse the comparative trends in the long run of several indicators -emissions per capita, pollution intensity of energy, pollution intensity of the economy-. The main difference of our approach is that we include all forms of energy used in the past, not only modern forms as most common analysis of this type. Finally, a Divisia index perfect decomposition analysis is used in order to be able to scrutinize the differences in the total emissions. Population differences across countries take the Lion's share indicating that further decomposition analysis is needed at the per capita level if we are to understand the forces behind the different trend in the evolution of CO_2 emissions.

Introduction

There has been rising popularity in using decomposition analysis to study changes in energy demand and related indicators, such as the aggregate energy intensity and energy-related carbon dioxide emissions. Seven papers of the top ten of the most highly cited papers published in *Energy Economics* in the period 1979–1999, including the top three, dealt with energy decomposition analysis. In fact, decomposition analysis, particularly Divisia index based decomposition, has been applied to a wide array of fields: the aggregate energy intensity for industry, national energy consumption, aggregate energy index measure, total energy-related carbon dioxide, carbon dioxide per unit of GDP, etc (for an excellent summary of works in the area see Ang, 2004). Most of the works, however, dealt typically with a single country or region over time

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(generally short periods of time, ranging from a 20 years to a decade) or with cross country examinations of benchmark years.

The present work offers an enquiry into the emissions of CO2 over a period of 150 years (1850-2000) for a number of European countries (in this first advance only Spain, Italy and Sweden, soon the Netherlands will also be included, and it is expected to be able to produce the data for the United Kindgom and Germany up to the same standards). This paper make use of brand new data compiled by the members of the Energy Growth and Pollution-Network (EGP-network), which so far was mostly used for the analysis of long term trends energy consumption and energy intensities (see Kander,2002; Malanima, 2006; Gales et al 2005; Rubio, 2005). Although alternative historical series of CO_2 emissions exists (see CDIAC) and have been used in scholarly articles with similar aim to this one (Lanne and Liski, 2004), we felt obliged to re-construct the figures of CO_2 emissions using these new energy series for at least two reasons: first because the historical series of energy consumption were not fully reliable, and secondly, because once the data for the different countries were compiled, the series need to be calculated (both energy and emissions wise) in a consistent manner. We believe such aim has been achieved and the new series are far more reliable and consistent among them than any of the previous. Having said so, it is also relevant to point out that the CDIAC series are entirely consistent with the ones presented here for the period 1950 to the present, however the further back in time the more distant our estimates appear from the CDIAC's CO_2 published emissions.

An additional feature of our work is that it takes into consideration all forms of energy, not only modern ones. The research carried out by the EGP-Netork, pioneered by Malanima, 1996 and Kander,2002, demonstrates that including traditional forms of energy transforms our perception of the relationship between economy and energy inputs. Even when traditional energy carriers are considered "clean" energies, for their emissions are not currently accounted, as it is discussed below, they should be taken into account for the elaboration of long run series of pollution intensity of energy and other indicators, which otherwise will be missing the crucial contribution of traditional energies.

In this advance of work we firstly present the time series of several CO2 indicators for three countries, Italy, Spain and Sweden. We look at total emissions, emissions per capita, pollution intensity of energy (decarbonisation), and pollution intensity of these three economies. In a second section the cross correlations between some of the variables are scrutinised. The aim is to find out whether it is possible to consume more energy per capita and produce more output per capita at lower levels of emissions and if so how it was achieved.

Finally, a Divisia index perfect decomposition analysis is used in order to be able to scrutinize the differences in the total emissions where the population differences across countries take the Lion's share indicating that further decomposition analysis is needed at the per capita level if we are to understand the forces behind the different trend in the evolution of CO2 emissions.

Long run CO_2 emissions in Europe

Over the last two centuries, the energy system has changed, shifting from traditional energy sources such as wood, water, and the muscle power of human beings and animals, to modern sources such as coal, oil, and electricity[1]. Energy consumption in the Western world has grown at an exponential rate, for several reasons including

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[1] P. Malanima, *Between two energy systems. Energy consumption in Europe 1600-1800,* M. Prak (ed.), *Early modern capitalism.* Economic and social change change in Europe, 1400-1800, London –New York, Routledge, 2001; *Tra due sistemi energetici. I consumi di energia in Europa fra il 1600 e il 1800* in "Meridiana", n. 30, 1997; Energia e crescita nell'Europa preindustriale, Roma, La Nuova Italia Scientifica, 1996;

demographic growth, changes in the economic structure, the rise of motorization and electrification, and the general economic situation. In the long run, the agricultural sector has lost ground to the industry, transportation, and service sectors. Today, Europe is one the most industrialized regions in the world.

Not only did energy consumption increase both in absolute and relative terms; the relative importance of energy sources changed as well. From a world dominated by traditional forms of energy until the end of the 19th century (see Gales et al, 2005), to an energy basked fully dominated by fossil fuels at the end of the 20th century. This change in the structure of the energy system involved not only a transition from renewable to non-renewable energy sources, but also the replacing of coal with oil, especially from the 1950's onward. Yet the composition of the basket varied considerably across countries, not only because the time of adoption of new technologies varied, but also because of choices made depending upon relative prices, policies, resource endowment and path dependency.

The passage from an economy based on firewood to one based on fossil fuels had significant consequences. The rise in fossil fuel consumption has immensely increased carbon dioxide (CO_2) emissions, giving rise to one of the most serious environmental problems of our time: global warming. Compared to other gases, carbon dioxide is not a very potent greenhouse gas, but due to the magnitude of its emissions it presently accounts for about half of the anthropogenic contribution to the greenhouse effect.

Panel 1 provide the CO_2 long term series for Italy, Spain and Sweden. As we can see in Figure 1.1, there was a steep rise in all three countries after World War II, with an steeper increase in the country with the larger population, Italy, followed by Spain and Sweden. Nevertheless, after the oil crisis all three countries reduced their emissions, only temporarily in the cases of Italy and Spain, but in absolute terms in the case of Sweden. Figure 1.2 allows a fairer contrast, taking into account the different population sizes of the three countries at stake. In per capita terms the story is quite different. For most part of the last 150 years Swedish were responsible for the larger emissions per capita of the three countries, followed by Italy and Spain, which were at very similar levels until the Italian take off of the 1950s. It is remarkable, however that the Swedish ended the 20th century with the lowest emissions per capita of the three countries, an achievement obtained only in the last decade, but consequence of the long term decline in CO_2 emissions per capita observable in Sweden from 1979.

Changes in the composition of the energy basket have an important effect on CO_2 emissions, because different energy carriers emit CO2 to varying degrees. Perhaps the single most important transition in gobal energy systems is that of increasing energy quality.[2]. As an indicator of energetic quality, one can use the carbon intensity of energy, which is also used here as an indicator of relative environmental quality.

Cesare Marchetti introduced the notion that the historical transitions from fuelwood to coal, to oil, and to gas in primary energy supply can be conveniently summarized as a gradual transition from fuels with low H/C ratios to fuels with high H/C ratios. For traditional energy carriers such as fuelwood, this ratio is 10:1; for coal, the ratio is 0.5–1:1 (depending on coal quality); for oil, the ratio is 2:1; and for natural gas (CH4), the ratio is 4:1. That is, the more hydrogen relative to carbon, the more energy is obtainable with less emissions. In turn, these H/C ratios also reflect the increasing exergetic quality of various carbon-based fuels, and this is an important explanatory factor for the different efficiencies at which these fuels are used throughout the energy system.

Although some authors point that that the secular trend toward ever higher H/C ratios

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[2] This sections relies heavily in Gruble (2004).

has come to a standstill since the mid-1970s, basically resulting from limited growth of natural gas and the continued heavy reliance on coal (Gulber, 2004), our findings are slightly more optimistic. Figure 1.3 plots the pollution intensity of modern energy carriers, that is CO2 emissions per unit of modern energy consumed. While the decarbonisation is clear with the replacement of coal by oil and later by natural gas and other forms of energies not producing CO2 (such as hydroelectric, nuclear and renewables), the trend has not flatten out completely in Sweden, and in Italy and Spain it only stopped declining in the last decade of the 20th century. If rather than considering the pollution intensity of modern energy carriers we include in the denominator all forms of energy used in order to include human and animal force, direct water and wind power as much as firewood, the decarbonisation does not appear anymore as a long run phenomenon. Surely this has to do with the fact that current standards of CO2 accounting do not include the emissions from firewood or other form of biomass. Most international protocols including that of the Intergovernmental Panel on Climate Change (IPCC) consider biomass emissions to be neutral. The IPCC views biomass emissions as part of the natural carbon balance and states that such emissions do not add to atmospheric concentrations of carbon dioxide. In fact, the Energy Information Administration (EIA) 1605(b) reporting instructions contain a footnote[3] citing the IPCC guidance and stating that "reporters may wish to use an emission factor of zero for wood, wood waste, and other biomass fuels."[4] Energy-rich biomass carbon – derived from wood chips, bark, sawdust and pulping liquors recovered from the harvesting and manufacturing processes – is atmospheric carbon dioxide that is transformed and sequestered by trees during their growth. When these biomass fuels are burned, the CO_2 that is emitted is in fact the atmospheric carbon dioxide that has been sequestered

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[3] EIA 1605(b) long form reporting instructions, Appendix B, footnote "d."

[4] See also "Emissions of Greenhouse Gases in the United States 2000," EIA, November 2001, document number DOE/EIA-0573 (2000)

during growth, and it becomes part of the natural carbon cycle that includes trees, air and other normal CO_2 emissions. This cycle is a closed-loop: new tree growth keeps absorbing atmospheric carbon dioxide; hence, there is no net contribution to the atmospheric CO_2 level. It is not clear, however, whether in historical terms the loop was sustained, since the degree of deforestation of the past 200 years may not guarantee the neutrality of firewood emissions. Nevertheless, following the international standards, Figure 1.4 does not include the emissions from firewood, challenging the decarbonisation trend by its absence in the long run, but making even clearer the trend towards a lower carbon intensity of the energy used in Sweden.

Finally, the relationship with economic output is also shown in Figure 1.5. The amount of CO2 emitted by dollar produced was always higher in Sweden for most of the past 150 years. Yet the continuous reduction in emissions in Sweden from the oil crisis of the 1970 has led the Swedish economy to be the less pollutant intensive of the three. While Italy and Spain reduced their emissions per dollar produced from the end of the oil crisis, these two economies did not manage to keep the down trend. As a consequence, the pollution intensity of their economies was only able to go down to the levels of the 1950s, but not further reduction was achieved towards the end of the 20th century.

As much as the time series are informative of the time breaks, cross correlations provide different information about the association among the variables that are important at the time of understanding the levels of CO2 emissions of a country. These cross correlations are shown in Panel 2.

For instance, Figure 2.2 tells us that it is possible to achieve higher levels of income per capita at lower levels of pollution per capita, as the data for Sweden show, while for Spain and Italy more income per capita always resulted in more pollution per capita.

Figure 2.1 and 2.3 illustrate an interesting point: at low levels of energy consumption the amount of emissions grew a lot in order to gain a little more energy into the system, at larger levels of energy consumption it has been possible to increase energy consumption without proportional increases in emissions. This is particularly true in the case of Sweden whose citizens were able to achieve much higher levels of energy consumption per capita than Italy and Spain, and doing so with lower emissions per unit of energy used than either of them.

For its part Firgure 2.4 shows that an economy does not need to be intensely pollutant to improve the income of its citizens. Of the three countries analysed, the richer ones –the Swedish- had the less pollutant economy. Even Italy and Spain were able to move towards higher levels of income, keeping or even reducing the pollution intensity of their economies. In other words, the three countrie analysed were able to produce more dollars per capita at a lower level of CO2 emissions per dollar produced. Yet the trend is not systematic: at lower income levels –from 1000 to 4000 dollars per capita- the trend was clearly upwards, implying that only with higher emissions per dollar produced was possible to increase the production per capita at the early levels of industrialisation.

In order to gain some further insights into the causes of these variations between countries the literature make use of different methods of decomposition analysis. As it was noted in the introduction, decomposition has been applied to almost every field of energy economics. We look into the specificity of cross-country decomposition in the following section.

Decomposing CO2 emission: a log-mean weight Divisia method

Cross-country decomposition studies allow analysts and decision-makers to have a better understanding of the underlying causes of variation in an aggregate between countries. There are, however, some specific problems in cross-country decomposition that do not normally arise in decomposition of changes of an aggregate over time in a country. These problems were addressed by Zhang and Ang, 2001.Cross-country decomposition is often characterized by large variations in explanatory factors, such as GDP and fuel shares in energy consumption, which arise from inherent differences between the countries compared. In such a situation, application of the conventional decomposition methods could lead to a large residual which makes result interpretation very difficult. To overcome such a problem, Zhang and Ang, 2001 proposed some perfect decomposition methods that may be used. Application of such methods does not leave a residual.

A review of decomposition methodology in energy studies can be found in Ang, 1995.. Various decomposition methods have been proposed, generally given in either the additive or multiplicative form. The analysis and discussions in our paper are based on the additive form, i.e. decomposition of the difference in total CO2 emissions between two world regions into contributions from various pre-defined explanatory factors. Following Zhang and Ang, 2001, we define the following variables for a region:

E Total energy consumption of all fuel types
Ei Energy consumption of fuel type i
C Total CO2 emissions from all fuel types
Ci CO2 emissions from fuel type i
Y GDP
P Population

The CO2 emissions from a region can be written as

$$C = \Sigma_i C_i = \Sigma_i (E_i/E)(C_i/E_i)(E/Y)(Y/P)P = \Sigma_i S_i F_i IGP$$

where *Si*=*Ei*/*E* is the consumption share of fuel type *i*, *Fi*=*Ci*/*Ei* the CO2 emission coefficient for fuel type *i*, *I*=*E*/*Y* the aggregate energy intensity, and *G*=*Y*/*P* the GDP per capita or income. The decomposed components of a change in *C* that are associated with these factors are respectively referred to as fuel share effect Δ*C*fsh, emission coefficient effect Δ*C*emc, intensity effect Δ*C*int., income effect ΔCypc.and population effect Δpop.

Let subscripts 1 and 2 denote variables for the two regions being compared. The difference in emission level between the regions can be expressed as

$$\begin{aligned}\Delta C &= C_1 - C_2 = \Sigma_i S_{i1} F_{i1} I_1 G_1 P_1 - \Sigma_i S_{i2} F_{i2} I_2 G_2 P_2 \\ &= \Delta C_{\text{fsh}} + \Delta C_{\text{emc}} + \Delta C_{\text{int}} + \Delta C_{\text{ypc}} + \Delta C_{\text{pop}} + \Delta C_{\text{rsd}}\end{aligned}$$

where Δ*C*rsd is a residual term which does not exist if decomposition is perfect. For convenience, the choices of regions 1 and 2 are made in such a way that Δ*C* is a positive number. The different effects (Δ*C*fsh, Δ*C*int, ΔCypc and Δpop) can be calculated in different ways, but in order to obtain a perfect decomposition Zhang and Ang, 2001, signalled that the preferred method should be a logarithmic mean weight Divisia method. Using such method the formulae for the calculation of Δ*C*fsh can be written as:

$$\Delta C_{\text{fsh}} = \Sigma_i \frac{C_{i1} - C_{i2}}{\ln(C_{i1}/C_{i2})} \ln \frac{S_{i1}}{S_{i2}}$$

For other effects, the formulae are simply given by exchanging *Si j* with the respective variables.

Note that the decomposition method offered by Zhang and Ang is indicated for answering the question: what is the driving force behind the different CO2 emission levels between any two countries in Figure 1.1? The answer according to the results of the log-mean weighted Divisia method plotted in Figure 3.1: the driving force for the differences observed in Figure 1.1 between Sweden and Spain is the different population size, with a little contribution of the fuel share in the last ten years of the 20th century. While the result may look obvious, it is important just to corroborate the power of the decomposition method. We know that the main difference between these three countries is their population size: 40 million Spaniards pollute in aggregate much more than the barely 9 million Swedes. Population differences across countries take the Lion's share indicating that further decomposition analysis is needed at the per capita level if we are to understand the forces behind the different trend in the evolution of CO_2 emissions.

Further work in this direction is underway, and it will presented in Session 49 at Helsinki EHA meeting.

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PANEL 1: TIME SERIES COMPARISONS OF CO_2 INDICATORS FOR ITALY, SPAIN AND SWEDEN 1850-2000

Figure 1.1 Total CO_2 emissions1850-2000

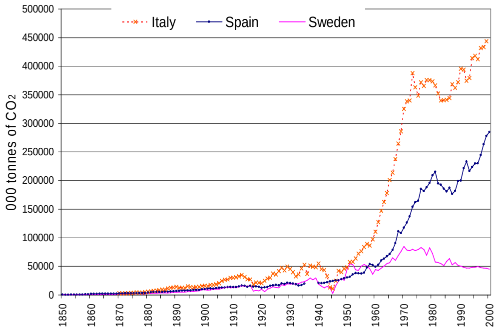


Figure 1.2 CO_2 per capita 1850-2000

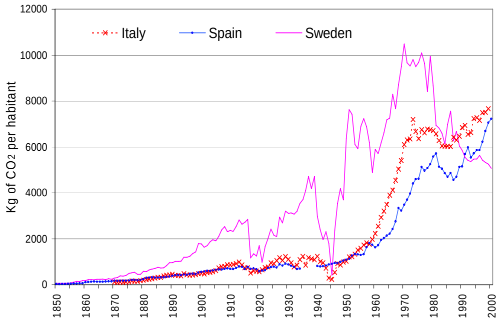
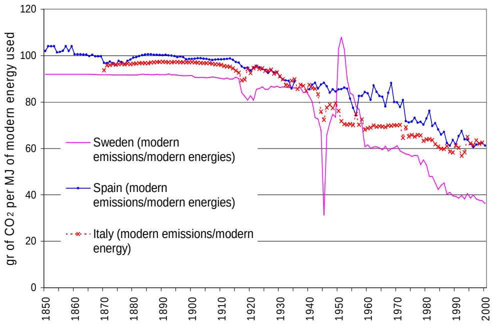
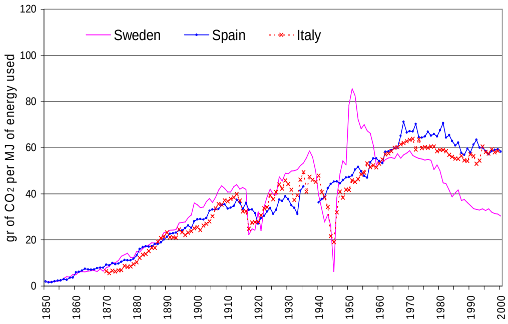


Figure 1.3 Pollution intensity of **modern** energies
1850-2000 (CO_2/E)
(CO_2 emissions per unit of modern nergy consumed)



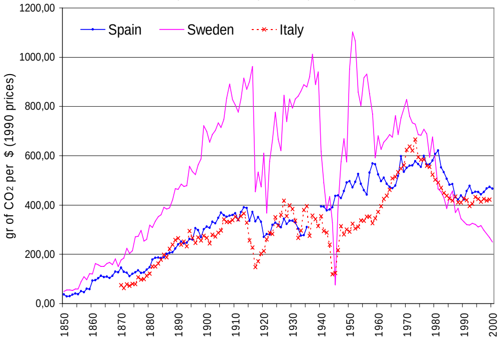
Notes: Modern energies refers to fossil fuels, hydroelectricity, nuclear
and other forms of energetic production poper of the 20th century (district heating, pulp liquour)

Figure 1.4 Pollution intensity of **all forms** of energy
1850-2000 (CO_2/E)
(CO_2 emissions per unit of energy consumed)



Notes: all forms of energy include modern energy plus traditional forms of energy used before modern indutrialisation
traditional forms of energy include human and animal force, direct water and wind power.
No emissions are associated with traditional energies, see text.

Figure 1.5 Pollution intensity of the economy 1850-2000
(CO_2/GDP)
(CO_2 emissions per dollar produced)



PANEL 2: CROSS-CORRELATION OF CO_2 INDICATORS FOR FOR ITALY, SPAIN AND SWEDEN 1850-2000

Figure 2.1 Total CO2 emissions vs total energy consumed 1850-2000

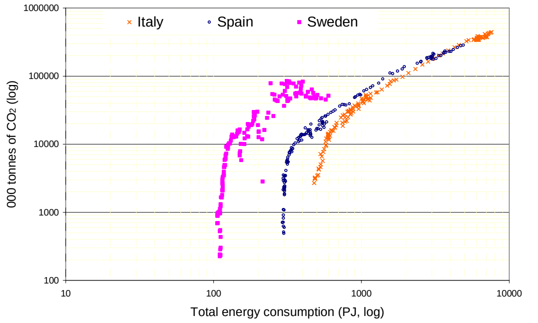


Figure 2.2 Pollution per capita vs income per capita 1850-2000

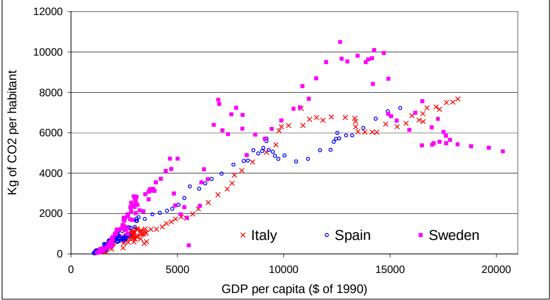


Figure 2.3 Pollution intensity of energy (CO_2/E) vs energy per capita

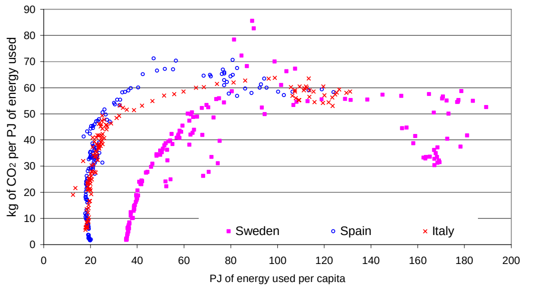
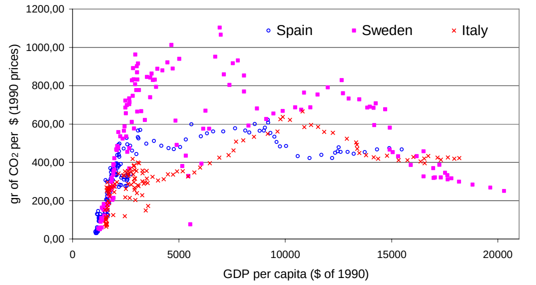


Figure 2.4 Pollution intensity of the economy (CO2/GDP) vs income per capita



Notes: all forms of energy included, that is modern energy plus traditional forms of energy used before modern indutrialisation traditional forms of energy include human and animal force, direct water and wind power. No emissions are associated with these, see text.

Figure 3.1

Divisia decomposition of the total difference of CO2 emissions between Sweden and Spain