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Abstract

This paper provides global and individual country estimates of sulfur emissions from 1991-2000. Raw estimates are obtained in two ways. For countries and years with published data I compile that data from the available sources. For the remaining countries and for missing years for countries with some published data, I use either the decomposition model estimated by Stern (2002), the first differences environmental Kuznets curve model estimated by Stern and Common (2001), or a simple extrapolation, depending on the availability of data to interpolate or extrapolate estimates. The results are combined with estimates from the ASL database for earlier years to develop continuous time series from 1850 to 2000. Finally, I discuss the main movements in global and regional emissions in the 1990s and compare the results to other studies. Global emissions peaked in 1989 or 1991 and declined rapidly thereafter. The locus of emissions shifted towards East and South Asia, but even this region peaked in 1996. Our estimates tend to be lower than other published studies and show a much more rapid decline reflecting the view that technological progress in reducing sulfur based pollution has been rapid and is beginning to diffuse worldwide.

Keywords

Sulfur, emissions, time-series, global, estimates

1. Introduction

Data on sulfur emissions are important for analyzing and understanding three important environmental problems: local air pollution and smog, acid rain and dry deposition, and global climate change. In the latter case, sulfate aerosols derived from emissions have a cooling effect on a continental scale due to the reflection and absorption of radiation by the aerosol particles. The additional information provided by the most recent temperature data is critical to the power of tests to detect and attribute climate change (Kaufmann and Stern, 1997). Exploiting these data requires up to date data on the variables that may be causing changes in climate. Hence, developing up to date time series and spatial data sets of sulfur emissions is vital to the investigation of global change.

ASL and Associates (ASL and Associates, 1997; Lefohn *et al*., 1999) produced a data base of sulfur emissions for individual countries for the period 1850-1990 which has been used in a number of climate studies (e.g. Stern and Kaufmann, 2000). I refer to this source in the following as “ASL”. These estimates were superior to all previous estimates published in the academic literature and by national and international agencies (e.g. Cullis and Hirschler, 1980; Dignon and Hameed, 1989; Hameed and Dignon, 1992; Kato, 1996; Möller, 1984; Spiro *et al.*, 1992; Varhelyi, 1985) in terms of their spatial and temporal resolution and extent. However, the cut-off point of 1990 is an impediment for continued use of these estimates in climate change research.

Smith *et al*. (2001) developed estimates of global sulfur emissions from 1980-2000. But they do not provide data for individual countries, only regions (gridded data is available for 1990) and estimates are only given for five year intervals. Also, by comparison with Carmichael *et al*. (2002) and other sources of information on developments in Asia, they underestimate the control of sulfur emissions in East Asia and particularly in China. Olivier and Berdowski (2001) provide country by country estimates for 1990 and 1995 for all countries in the World. These are used to develop some of the estimates in this paper and are referred to as “Edgar”.

This paper aims to provide global and individual country estimates of sulfur emissions for each year from 1991 to 2000. Estimates are obtained in two ways. For countries with published data I compile the data from the available sources. For the remaining countries, depending on the availability of data, I use the decomposition model estimated by Stern (2002), the first differences environmental Kuznets curve model estimated by Stern and Common (2001), or simple extrapolation of the growth rate of emissions in the 1980s into the 1990s. Time series are also provided for the period from 1850 to 1990 based on these estimates and the ASL database. The preferred series uses the individually published estimates for years before 1990 where these are available in North America, Europe, and Asia. For earlier years the growth rates in the ASL database are used. Finally the main movements in emissions in the 1990s are discussed and the estimates in this study compared to those of other studies.

2. Estimating Emissions for the 1990s

i. Compiling Published Estimates

Published estimates are available in time series form for around 70 countries in Europe, the former Soviet Union, North America, East and South Asia, and Australia. These are used in preference to any other estimates. For the remaining countries Olivier and Berdowski (2001) (Edgar) have computed estimates for 1990 and 1995. These were used occasionally where mentioned. The sources are described in Appendix I. The Asian source is referred to in the following as Carmichael *et al*., the source for Europe (including the former Soviet Union) and Canada is referred to as EMEP, and the US and Australian sources are referred to as EPA and AGO respectively. Husain (1994) provides an estimate of emissions from the oil fires in Kuwait in 1991. All published estimates are first converted to the common unit of metric tonnes (Gg) of sulfur per annum. The remainder of this section describes the three methods used to estimate emissions in countries without published data and the data used to generate those estimates. In the online database all model estimates and interpolated or extrapolated data appear in italics, while all previously published data appear in normal font.

ii. Estimating Emissions in the Remaining Countries and Years

Appendix III lists the methods used in each country and year. These methods were used to determine the growth rate of emissions. When used to interpolate estimates, for example between the 1990 and 1995 Edgar estimates, the rates were adjusted by subtracting or adding a constant to each year so that the final period level was predicted correctly. This is equivalent to adjusting the rate of technological change, which is assumed before adjustment to simply be the average rate in the previous period.

a. Decomposition Method

The decomposition model described in Stern (2002) is used to estimate emissions. This model estimates sulfur emissions S in country i and year t using the following function of economic outputs y and inputs x:

$$S_{it} = \gamma_i A_t \prod_{j=1}^{J} y_{jit}^{\alpha_j} \left(\sum_{k}^{K} \beta_k x_{it} \right) \varepsilon_{it} \qquad (1)$$

where the α's, β's, γ's, and A’s are regression coefficients to be estimated using a nonlinear panel data estimation and ε is a random error term. The outputs are value added in services, manufacturing, non-manufacturing industry, and agriculture in country i. Only primary energy inputs were considered and categorized as: coal, oil, natural gas, hydroelectric power and nuclear energy inputs. The α_j coefficients sum to zero. γ_i represents a country specific effect and A_t a time specific effect. I estimate the changes in emissions over the 1990s assuming that the residual in 1990 was zero. This is necessary for the countries not in the Stern (2002) study because we do not have an estimate of the country specific effect. But I also used this approach when I did have an estimate of the country specific effect because of revisions to the data and differences in the data used. The data required to produce estimates of emissions using this model include, for each country, the shares of the different industries in gross domestic product and the quantities of different fuels used. I assume the rate of change in the time specific effect, ΔA_t, in the prediction period is the same as the mean over the estimation period. More details including the parameter values of the model are given in Stern (2002).

b. First Differences EKC Method

When insufficient data was available to estimate (1), I used the fixed effects global estimate of the environmental Kuznets curve (EKC) in first differences estimated by Stern (2002). An environmental Kuznets curve is a quadratic in logarithms relating emissions or concentrations of a pollutant to national income. Such a model also includes country and time specific effects with the latter representing technological progress in reducing emissions. I chose the estimate from Stern (2002) as it only includes data from 1973 to 1990. Stern and Common (2001) show that in a global EKC model covering the period from 1960 to 1990 the time specific effect is increasing before the oil price shock in 1973 and decreasing afterwards. Assuming that the rate of technological progress is the sample mean, the rate of change of sulfur emissions in year t and country i is given by:

$$\Delta \ln(S_{it}/P_{it}) = -0.01158 + 1.5729\, \Delta \ln GDP_{it}/P_{it} - 0.05722\, \Delta((\ln GDP_{it}/P_{it})^2) \qquad (2)$$

where GDP/P is in 1985 US dollars per capita adjusted for purchasing power parity (PPP dollars).

c. Growth Rate Method

In cases where the data to estimate even model (2) were not available I used the mean growth rate of sulfur emissions in the previous decade in the country in question to estimate the growth in emissions. In other cases where data for some years was available values were interpolated using a simple linear curve.

iii. Data for the Models

Estimates of GDP per capita in PPP dollars are available for some countries from a consistent set of estimates for 1990-96 provided by an online version of the World Development Indicators (IBRD, various years) or an online version of the Penn World Table (Summers and Heston, 1991) for years up to 1992. Where available these estimates are used and otherwise International Financial Statistics (IFS) data is used to estimate changes in income per capita. Estimates of PPP GDP per capita for 1997-2000 are updated using IFS data or growth rates of GNP per capita from the World Development Report. Occasionally interpolations of growth rates were used. In all cases PPP data are deflated into 1985 PPP dollars using the US GDP deflator. Data on the structure of economic output are from the World Bank Development Report (IBRD, various years) and an online version of the World Development Indicators. Energy data is from OECD (International Energy Agency, various years). The data source for population is International

Financial Statistics (IMF, various issues) and in some cases the same World Bank sources that were used for the economic output structure.

Appendix II describes the treatment of countries that split apart or merged or faced other boundary changes, as well treatment of the Russian Federation and Turkey, countries that cross the Europe-Asia boundary.

3. Estimates for 1850-2000

Though the focus in this paper is on the estimates for 1991-2000, I also provide estimates for the period 1850-1990. The primary source for this period is the ASL database. However, our preference is for alternative published estimates (Streets *et al.*, 2000 or as reported by governments) where they are available. This is because individual country estimates take account of more detailed data than used by ASL. This is a point essentially conceded by LeFohn *et al*. (1999). For example, ASL assume that the sulfur content of fuels is constant in each country over time, with the exception of the US. ASL estimates for many developing countries do not include emissions from oil burning and therefore are lower than other estimates. Additionally, Streets *et al*. (2000) show that their estimates for Asia are congruent with official estimates for those countries and previous estimates for the region by for example Kato (1996).

Our aim is to produce continuous and reasonably smooth time series of emissions for each country for use in global climate modeling. We achieve this with the following methods:

a. There are numerous periods of missing data for specific countries in the ASL database and I interpolate using a simple linear function.

b. For the countries with alternative published data we use the growth rates of emissions implied in the ASL database to extrapolate estimates backward from the first year with such estimates. For the other countries we use unmodified ASL data.

c. I also extrapolated estimates for each country back in time to 1850. For this computation we first extrapolate estimates for 1850 for those countries with estimates for 1851 but not 1850 using the growth rate from 1851 to 1852.

d. Then I group the data into the following regions:
W. Europe, E. Europe and the Soviet Union, Middle East and North Africa, Asia, Africa, Oceania, Anglo America, Latin America.

The composition of the regions is described in Appendix IV. The extrapolations for each country with initial data missing for years after 1850 were based on the growth rate of the aggregate emissions for the region. This problem was solved iteratively in Microsoft Excel.

4. Trends and Developments in Emissions

The estimates are available at:

http://www.rpi.edu/~sternd/datasite.html

Figure 1 presents the global and regional totals for the full 1850-2000 period. Maximum emissions were reached in 1991 at 68.7 million tonnes. But this is due to the Kuwait oil fires which contributed more than 4 million tonnes of sulfur. Excluding this source the peak is in 1989 at 68.3 million tonnes. An initial peak occurred in 1980 at 66.8 million tonnes. The recession following that year and the beginning of a secular decline in Western Europe (North America peaks in 1973) lead to a decline in total global emissions in the first half of the 1980s. Emissions then recovered to the slightly higher high in 1989 mainly on the back of rising emissions in Asia (Figure 4).

After 1989 a precipitous decline sets in, only punctuated by the Kuwait oil fires, as the Soviet Union and Eastern European economies collapse. Figure 2 presents a close up view of the 1990s showing the relentless fall over the decade. Asia peaks in 1996 and starts to add to the decline.

The effects of the Asian crisis in 1997 obviously have an impact, but changes in China appear to be more deep-seated (Stern, 2003).

Thus after going through a topping out period in the 1970s and 1980s the direction of change has reversed on a decadal scale. At the regional level, the 1990s continue the process of change already evident in the previous 140 years. In 1850 Europe accounted for 87% of non-shipping emissions (Figure 3). The locus of emissions shifted first to North America, then the share of Eastern Europe and the Soviet Union increased followed by the rise of Asia as a substantial emitter. In the 1990s Asia became the largest source area. Chinese emissions overtook US emissions in 1987 to make China the largest single emitter. Chinese emissions peak in 1996 and then fall. Figure 3 also shows that emissions in the minor regions – Africa, South America, Middle East, and Oceania are also an increasing share of global emissions and this trend accelerated in the 1990s. In fact since 1996 Asia's share of global emissions started to decline.

Table 1 lists the peak year of emissions in each region. The first four regions were each the World's largest emitter in their peak year. Asia is still the largest emitter in 2000 – none of the other four regions has yet emerged as a new focus of pollution.

Figure 4 presents regional estimates for just the 1980s and 1990s in order to show more detail of the regional changes. Emissions in Western Europe are now less than in South America and about the same as in the Middle East. In fact the UK now has lower emissions than in 1850 when it emitted more than half the global total. British emissions have been declining since 1956.

Emissions in Oceania are dominated by Australia and are showing a relentless increase despite Australia's developed country status. Australia does not have near neighbors and most power stations etc are in the narrow strip of development along the south east coasts between the arid interior and the ocean in either a westerly or easterly air flow. The damage from pollution seen in North America, Europe, and East Asia will be much less evident.

Developments in both Australia and China contradict the environmental Kuznets curve theory that proposes that emissions are a quadratic function of national income per capita. Emissions should be rising in developing countries and falling in developed countries. There is extensive other evidence to refute this idea first made popular in the early 1990s (Stern, 2003).

The reversal in emissions in Figure 1 might be thought to have negative implications for future climate change. That is, if sulfate aerosols will decline in future (and have already declined) their effect in offsetting future warming may be less than had previously been expected. In fact this is one key factor behind higher rates of temperature increase in the 21st century predicted in the most recent IPCC Report (Schneider, 2001). Zhang (2002) documents the relative contributions of the decrease in carbon and sulfur emissions in China to potential global warming.

In the period from 1950 to 1990 rising sulfur emissions likely helped mask the effects of increased radiative forcing from greenhouse gases on the global climate. Figure 5 clearly demonstrates that when sulfur emissions rose fast northern hemisphere temperatures stalled and when the increase in emissions slows temperature rises. Of course many other factors and complex dynamics are involved but this basic pattern is very apparent. Stern and Kaufmann (2000) showed that the difference between the underlying trends or signals in northern and southern hemisphere temperatures is very closely correlated with sulfur emissions.

5. Comparison with Other Studies

Table 2 compares our global estimates with other estimates for the 1990s. Our estimates are clearly lower than others and decline faster. First, comparing our estimate for 1990 with Lefohn *et al*. (1999) (ASL), we find that our estimate is 93% of the ASL estimate. This is despite our inclusion of emissions from shipping which are not included by Lefohn *et al*. This is because the official totals produced by governments and used in our estimate are almost always smaller than the ASL estimates. Even in the case of the US the ASL estimate for 1990 is 2 million tonnes higher. There is no reason to believe that the US EPA estimate is inaccurate to that degree. The reason for the discrepancy would be in underestimation by Lefohn *et al*. (1999) of the degree of sulfur pollution controls.

Table 3 presents alternative regional estimates for 1990. Turkey is included in Smith *et al*.'s (2001) Western Europe total, while I have included it in the Middle East for the other three estimates. North Africa is included in the Middle East in the all the estimates apart from Smith *et al*. In Asia, Streets *et al*. (2000) estimate for China is 3.1 million tonnes lower than ASL's. This explains much of the difference in Asia. There are both positive and negative differences in Eastern Europe in the estimates for individual countries, which in sum lead to a lower estimate in the present study. For the remaining regions we either use the ASL estimate or in the case of Oceania reported emissions for Australia happen to coincide with ASL's estimate.

Olivier and Berdowski's (2001) estimate is highest. They include a number of emissions sources that are omitted from the other databases. Excluding non-industrial emissions their estimate for 1990 is 72.8, which is very close to Smith et al. (2001) and Lefohn *et al*. (1999).

The most significant difference between our estimate and Smith *et al*. (2001) is the estimate for China, which they place at 13 million tonnes. Again, we favor the regional focus of the Streets *et al*. (2000) estimate. Smith *et al*. (2001) estimate emissions for Latin America at 2.1 million tonnes higher than our estimate. Smith *et al*. (2001) project strongly rising emissions in Asia through 2000. Possibly their estimate of sulfur retention before the 1990s is too low as well. They note that the only adjustment they make for emissions control in developing Asia is a 3% retention due to coal washing in China.

Olivier and Berdowski's (2001) regional estimates are largely congruent with ASL except in North America where they are very close to Smith et al. and in Eastern and Western Europe where they are higher than all three other estimates. In particular the estimate for the Soviet Union is much higher than ASL's.

Going forward from 1990 we show a decline in emissions of 13% to 1995. Olivier and Berdowski (2001) indicate a decline of 7% and Smith *et al*. (2001) only 7%. Both the official estimates we use, the Streets *et al* (2000) estimates for Asia, and our own model estimates all predict rapid adoption of strategies to reduce sulfur emissions that the other sources do not seem to be taking into account. Between 1995 and 2000 we predict another 10% fall in emissions while Smith *et al*. (2001) predict an increase.

6. Conclusions

This study has developed continuous time series of sulfur emissions for the period from 1850-2000 for most countries in the world. Despite inherent uncertainties, these data should be useful in global change research.

This study has also revealed that changes in the pattern of global sulfur emissions were more dramatic than previously believed (e.g. Smith *et al*., 2001). Emissions shifted southward and eastward on a global basis but East Asia is already seeing a declining trend in emissions. Global emissions are now falling at a rate of 2.2% per annum. If these trends continue they will have important implications both physically for the problems of acid rain and deposition and global warming and potentially politically for how they will shape attitudes about environmental problems. Both of these issues have been discussed above but the latter point deserves further comment.

Success in reducing emissions and concentrations of pollutants such as sulfur dioxide in the developed countries in the 1970s and 1980s helped generate the idea of the environmental Kuznets curve in the early 1990s. The concept that pollution first rose and then fell with increasing income strengthened pre-existing beliefs that developing countries were “too poor to be green” (Martinez-Alier, 1995) and that the only way to attain a decent environment in most countries is to become rich (Beckerman, 1992). These views have also permeated media and policy debates (Stern, 2003). The fact that emissions of some pollutants are already falling in East Asia, particularly in China, partly as a result of explicit environmental policies (Dasgupta *et al*., 1992; Stern, 2003), will eventually have to result in a change in these attitudes.

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Appendix I: Sources of Published Data

The countries and sources of the published data are as follows:

East and South Asia. Streets *et al*. (2000) report data for 23 countries in East and South Asia: Bangladesh, Bhutan, Brunei, Cambodia, PRC, Hong Kong, India, Indonesia, Japan, North Korea, South Korea, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, and Vietnam. The data are reported in Gg of SO_2. The period of the data is 1990-97. Carmichael *et al.* (2002) update this data for 2000 and also include data on emissions from ships in Asia. These data are available online at:

http://www.cgrer.uiowa.edu/people/carmichael/ACESS/Emission-data_main.html

Data for emissions from ships in Asian waters for 1988, 1990, 1993, 94, and 95 are available in Streets, Guttikunda, and Carmichael (2000). Earlier figures that appear in a chart in Carmichael *et al*. (2002) were supplied by David Streets.

Europe. Estimates for Eastern and Western Europe and the former Soviet Union countries are from the EMEP website: http://www.emep.int/emis_tables/tab1.html.

Data for 1980-99 are available for the following 33 countries: Armenia, Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Latvia, Lithuania, Luxembourg, Moldova, Monaco, Netherlands, Norway, Poland, Russian Federation, Slovakia, Slovenia, Sweden, Switzerland, Turkey, United Kingdom, Yugoslavia.

Most Western European countries have a complete data set as does the Russian Federation and many other eastern European and former Soviet Union countries. A few countries just have missing data for 1999. Coverage in others is variable, from a few missing years to only a few years of observations. The latter are small emitters.

Canada. Canadian data for 1980-99 are also reported on the site providing the European estimates.

United States Data for 1940-98 are available from US EPA (2000). The US EPA reports emissions in short tons of sulfur dioxide. We apply a conversion factor of 908 kilograms to a short ton. Data for 1989-2001 and 1980 and 1985 are available from:

http://www.epa.gov/ttn/chief/trends/index.html

Earlier years are adjusted to conform to these estimates.

Australia. Estimates for 1990-2000 are from on Australian Greenhouse Office (2002).

Shipping Carmichael et al. (2002) provide estimates of emissions from shipping in Asian waters. Estimates for the world as a whole are provided by Smith *et al*. (2001).

Global Olivier and Berdowski (2001) provide estimates for all countries for 1990 and 1995. These are used for the countries not mentioned above. These data are available online at:

http://arch.rivm.nl/env/int/coredata/edgar/data32_so2.html

For years from 1850 to 1990 data are available from the ASL database described by LeFohn *et al*. (1999). The growth rates implied by this database are used for all observations where the other published estimates described above are not available.

Appendix II: Boundary Changes and Related Issues

Our general approach is to make borders as comparable as possible to those of the present day. Therefore where countries have merged - for example Germany we report the figures for the merged country for all years. Where countries have split we report separate figures as far back as possible. This section also reports on methods of interpolation in these countries not reported above.

Korea

The ASL database gives separate figures for North and South Korea from 1947.

Pakistan

Bangladesh and Pakistan are treated as separate countries starting in 1972 and a single country before that date. Pakistan is included in India for years before 1948.

Yugoslavia

Estimates are primarily based on EMEP data. We interpolate values for Croatia for 1981-89 and for Bosnia and Macedonia for 1980-89 as a constant proportion of Yugoslavia's (Serbia and Montenegro) EMEP emissions. In the 1990s for Bosnia-Hercegovina we use the Edgar estimate for 1995 and interpolate the other values in the missing years based on the rate of change in the former Yugoslavia as a whole. For Macedonia we use Edgar estimates for 1990 and 1995 and EMEP for 1997 and the same method of interpolation. For 1998 and 1999 we use the first differences EKC method. We report estimates for these countries separately from 1980 on. Emissions for Serbia for 1851 to 1912 are attributed to Yugoslavia.

USSR

For 1990 and 1995 we use the Edgar estimates for those republics/countries without EMEP estimates (Tajikistan, Turkmenistan, Kazakhstan, Azerbaijan, Uzbekistan). To interpolate between 1990 and 1995 we use the growth rates method and to extrapolate beyond 1995 we use the decomposition model. For Ukraine we estimate emissions for 1998-2000 using the decomposition model. EMEP data for Russia only cover European Russia. To estimate Asian

Russia or Siberia in 1990 we subtract the estimates for all the other Republics including European Russia from the ASL total. For years from 1991-1999 we assume that the rate of change in Siberia is the same as in European Russia. For years between 1980 and 1990 we use the growth rates in the ASL database to derive the total for the Soviet Union and then compute a figure for the Asian USSR by subtracting the observed EMEP data from this total. The Asian USSR includes Siberian Russia, the 5 Central Asian Republics and Azerbaijan. Georgia and Armenia are in Asia but are not included in this figure.

Czechoslovakia

From 1980 we report the Czech Republic and Slovakia separately and as a single country before 1980. Estimates for Slovakia for 1981-4 were interpolated from the EMEP data using an exponential growth rate.

Vietnam, Germany, and Yemen

Are each reported as a single country in all years.

Turkey

As is the case for Russia, EMEP data for Turkey only cover the European portion (Smith *et al.*, 2001). We use the ASL estimate of total Turkish emissions for 1990 and compute the figure for Asian Turkey by subtracting the EMEP figure. Emissions in the Asian portion then are estimated over time using the decomposition method.

Others

We added Cape of Good Hope to the ASL estimates for South Africa between 1926 and 1935. French Equatorial Africa is attributed to Gabon during 1950-57. French-Indo China refers to Laos. Emissions for French West Africa are attributed to Senegal. Estimates for the Leeward Islands are attributed to Antigua and Barbuda. Rhodesia-Nyasaland are split between Zimbabwe and Malawi from 1950 to 1963 (mostly attributed to Zimbabwe, but allowing for exponential growth in emissions in this period in Malawi). The various states of Malaysia which appear separately in the ASL database are reported as a single country. Japan includes the Ryuku Islands when these are listed separately by ASL. Newfoundland data are included in Canada when they are listed separately by ASL. Rwanda and Burundi are reported as separate countries from 1962 onwards.

Shipping

Data for shipping in Asian waters were subtracted from the estimates of Smith *et al*. (2001) for global shipping to derive an estimate for shipping in the rest of the World.

Appendix III: Methods Used to Estimate Emissions

In this section we note which of the three methods was used to estimate emissions in each country in each year. When not otherwise specified, the data for that country and those years is from the published sources.

i. Decomposition Method

1991-2000 Algeria, Asian Turkey Bahrain, Argentina, Bolivia, Brazil, Cameroon, Chile, Colombia, Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Gabon, Ghana, Guatemala, Honduras, Jamaica, Jordan, Kenya, Mexico, Morocco, Mozambique, Namibia, New Zealand, Nigeria, Panama, Paraguay, Peru, Saudi Arabia, Senegal, South Africa, Tanzania, Trinidad and Tobago, Tunisia, UAE, Uruguay, Venezuela, Yemen, Zaire, Zambia, Zimbabwe

1994-2000 Lebanon

1995-2000 Romania

1996-2000 Azerbaijan, Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan

1997-2000 Spain

1998-99 Bangladesh, China, Hong Kong, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Thailand, Vietnam

1998-2000 Ukraine

1999-2000 Greece, Portugal

2000 Armenia, Austria, Belarus, Belgium, Bosnia And Herzegovina , Bulgaria, Canada, Croatia, Czechoslovakia, Denmark, Estonia, European Turkey, Finland, France, Georgia, Germany, Hungary, Ireland, Italy, Kyrgyzstan, Latvia, Lithuania, Moldova, Netherlands, Norway, Poland, Serbia Montenegro, Slovakia, Slovenia , Sweden, United Kingdom

ii. First Differences EKC Method

1959-2000 Guyana

1960-64 and 1980-2000 Togo

1961-2000 Cape Verde

1962-2000 Rwanda and Burundi - emissions in 1961 for the joint territory in the ASL database are allocated to the two countries according to relative GDPs.

1972-2000 Haiti

1979-2000 Uganda

1982-88 Liberia

1983-2000 Antigua and Barbuda

1984-2000 Angola

1985-2000 The Bahamas

1988-2000 Oman

1989-2000 Congo

1991-93 Lebanon

1991-2000 Albania, Barbados, Botswana, Fiji, Israel, Madagascar, Malawi, Malta, Mauritania, Mauritius, Niger, Papua, New Guinea, Qatar, Sierra Leone, Sudan, Surinam, Swaziland, Syria

1998-99 Bhutan, Cambodia, Laos, Mongolia

1998-2000 Macedonia

1999-2000 Iceland, Luxembourg

2000 Czech Republic, European Russia, Siberia, Switzerland

iii. Growth Rates Method

1956-1960 Cape Verde

1969-2000 Gibraltar

1973-2000 Faeroe Islands

1976-1999 Bermuda

1977-2000 Saint Pierre and Miquelon

1984-2000 Guam using a moving average of the ten-year growth rate

1984-89 1991-94 1996-2000 Macao - 1990 and 1995 use Edgar estimates.

1985-2000 Greenland

1989 1991-94 1996-2000 Liberia - 1990 and 1995 use Edgar estimates.

1991-1994 Azerbaijan, Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan

1991-2000 Afghanistan, Benin, Burkina Faso, Central African Republic, Chad, Cuba, Djibouti, Eritrea, Guinea, Guinea-Bissau, Iraq, Libya, Mali, Martinique, Netherlands Antilles and Aruba, New Caledonia, Puerto Rico, Reunion, Somalia, US Virgin Islands - 1995 uses ratio of1995 and 1990 Edgar estimates when ASL data is available. When ASL data is not available we use the actual Edgar estimates for 1990 and 1995.

1995-2000 Liechtenstein

1998-1999 Brunei, North Korea, Taiwan

1999-2000 Yugoslavia (Serbia and Montenegro)

1999-2000 Monaco

2000 Cyprus

Appendix IV: Regions

The regions include the following countries:

W. Europe: Austria, Belgium, Cyprus, Denmark, Faeroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, United Kingdom.

E. Europe and the Former Soviet Union: Albania, Armenia, Asian USSR, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Czechoslovakia, Estonia, European Russia, FYR Macedonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Serbia, Serbia-Montenegro, Siberia, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine, USSR, Uzbekistan, Yugoslavia.

Middle East and North Africa: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, UAE, Yemen.

Asia: Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Laos, Macau, Malaysia, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam.

Africa: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Rwanda-Urundi, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe.

Oceania: Australia, Fiji, Guam, New Caledonia, New Zealand, PNG.

Anglo America: Bahamas, Bermuda, Canada, Greenland, Puerto Rico, St Pierre et Miquelon, USA, US Virgin Islands.

Latin America: Antigua and Barbuda, Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rep., Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles and Aruba, Nicaragua, Panama, Paraguay, Peru, Surinam, Trinidad, Uruguay, Venezuela.

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Figure 1. Global and Regional Sulfur Emissions 1850-2000

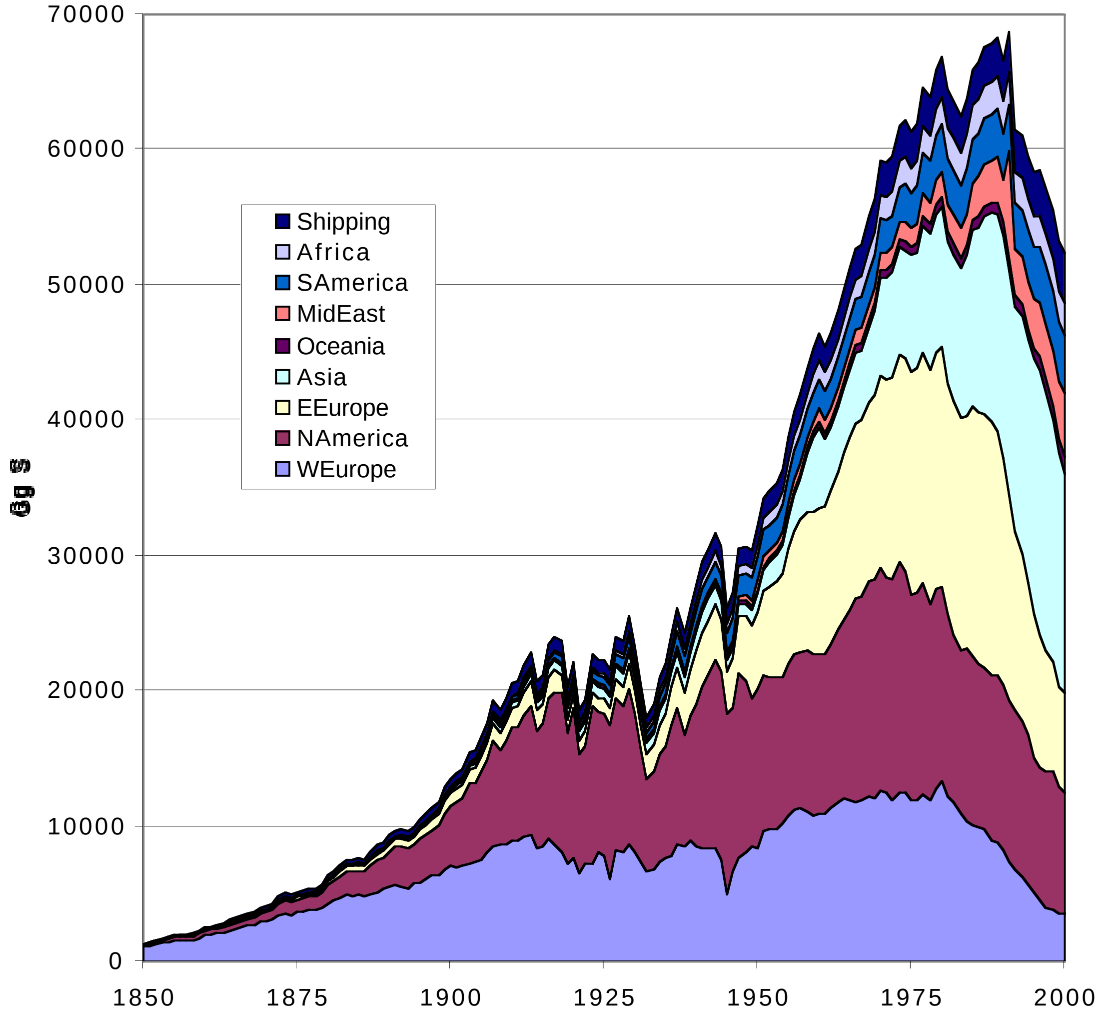

Figure 2. Global and Regional Sulfur Emissions 1990-2000

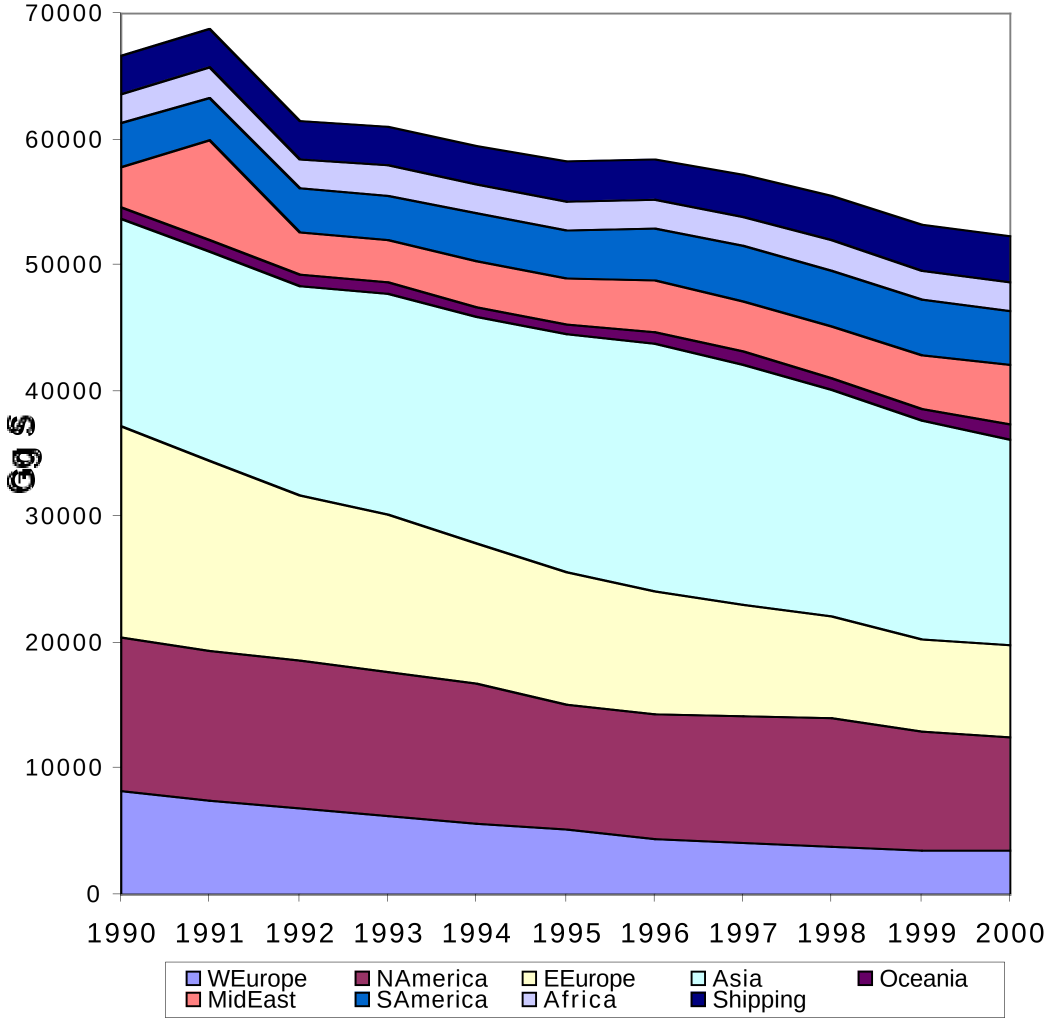

Figure 3. Shares of Global Sulfur Emissions

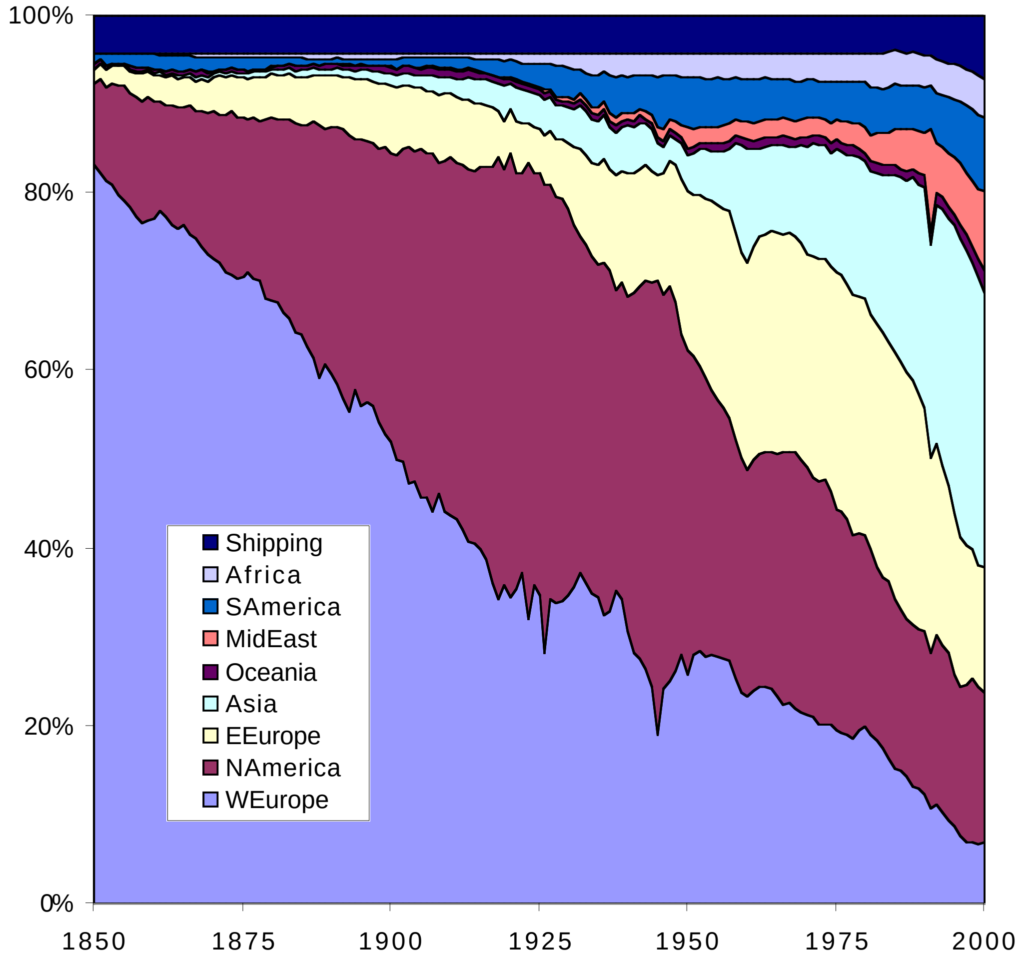

Figure 4. Regional Trends in the 1980s and 1990s

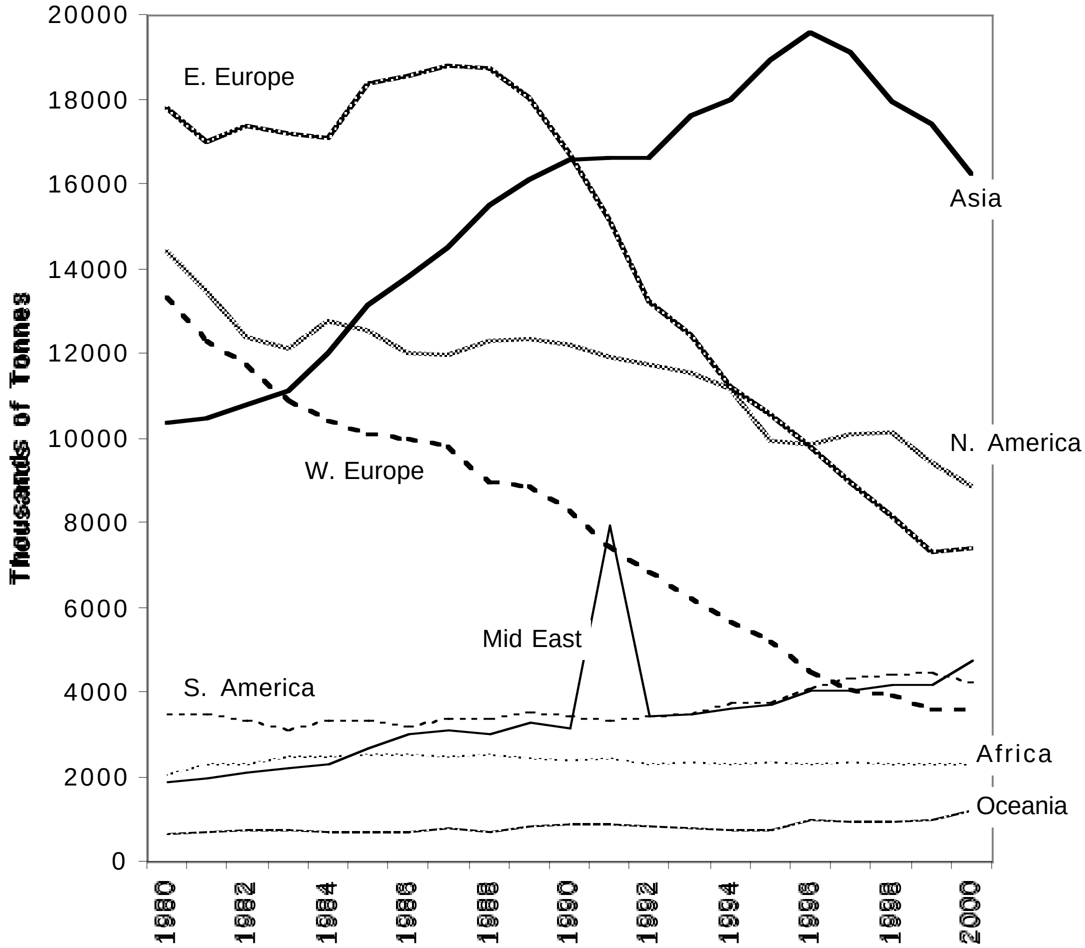

Figure 5. Northern Hemisphere Temperature and Radiative Forcing Due to Anthropogenic Sulfur Emissions.

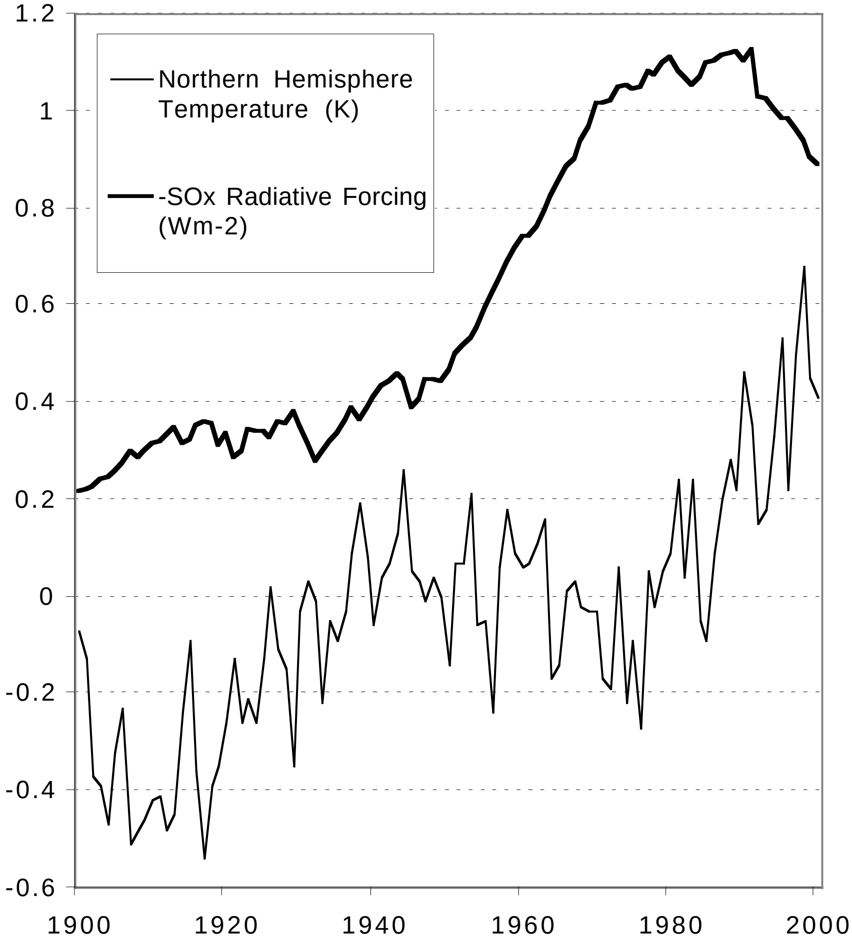

Table 1. Peak Shares in Global Emissions		
Region	**Peak Percentage**	**Year of Peak**
Western Europe	1850	87.0%
North America	1923	53.6%
Eastern Europe	1986	29.1%
Asia	1996	35.5%
South America	1999	9.0%
Middle East (does not include Kuwait oil fires in 1991)	2000	9.8%
Africa	2000	4.7%
Oceania	2000	2.5%
Note – these figures do not include emissions from shipping.		

Table 2. Alternative Estimates of Global Sulfur Emissions in the 1990s (Gg S)

Year	Lefohn et al.	Olivier and Berdowski	Smith et al.	Present Study
1990	71.5	77.1	72.0	66.7
1991				68.7
1992				61.4
1993				61.0
1994				59.5
1995		70.9	67.0	58.3
1996				58.5
1997				57.3
1998				55.5
1999				53.3
2000			68.0	52.4

Table 3. Regional Estimates 1990

Region	Lefohn et al.	Present Study	Smith et al.	Olivier and Berdowski – Industrial Emissions
W. Europe	9.1	8.3	9.1	11.2
E. Europe	18.2	16.7	17	20
N. America	14.0	12.2	11.7	11.8
S. America	3.4	3.4	5.5	3.8
Asia	20.4	16.6	19.9	19.8
Africa	2.3	2.3	3.0	2.5
Middle East	3.2	3.2	1.2	3.0
Oceania	0.9	0.9	0.9	0.7