Historical global emission trends of the Kyoto gases HFCs, PFCs, and SF_6

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INTRODUCTION

Recently, emissions of the so-called 'new' greenhouse gases HFCs, PFCs, and SF_6 are being considered by policymakers with more attention, since they are incorporated in the greenhouse gas commitments of the Kyoto Protocol to the United Nations' Framework Convention on Climate Change (UNFCCC). Global estimates of historical emissions of these F gases have only been compiled recently (AFEAS, 1999; Harnisch et al., 1998; Maiss and Brenninkmeijer, 1998).

However, more detailed emissions estimates at regional and country levels have not yet been made. In order to produce a credible reference dataset for these gases, global emissions inventories have been compiled for these gases as part of EDGAR 3.0, based on national statistics and available production or sales statistics of these compounds and emission factors from recent literature (Olivier et al., 1999; 2000). The compilation of this global database (which provides global annual emissions of greenhouse gases, both per region/country and on a 1^o x 1^o grid) is a joint project of RIVM and TNO in the Netherlands. The work is linked into and part of the *Global Emissions Inventory Activity* of IGBP/IGAC.

MAGNITUDE OF INDUSTRIAL PROCESS SOURCES

Greenhouse gas emissions from industrial processes are presently about 3% of global total CO_2-eq. emissions (see Figure 1). However, this trend is increasing (as illustrated in Figure 3, which shows the trend in global total greenhouse gas emissions from 1980 to 1997).

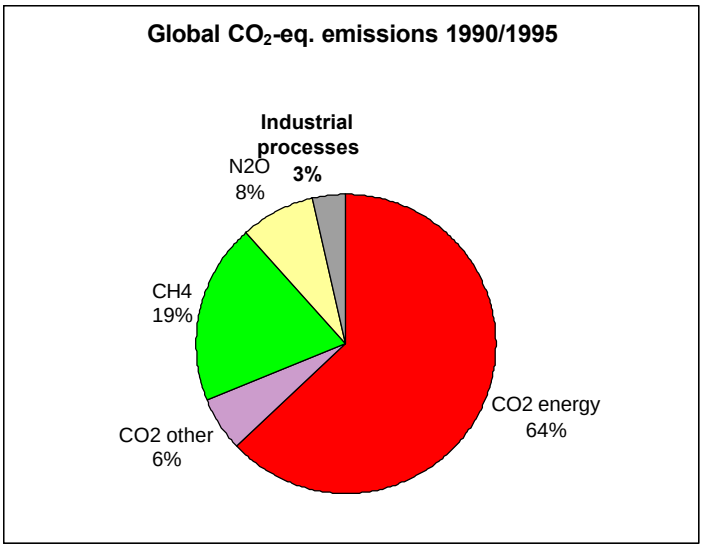


Figure 1. Global CO_2-eq. emissions in 1990 (F gases: 1995). (Source: EDGAR 3.0)

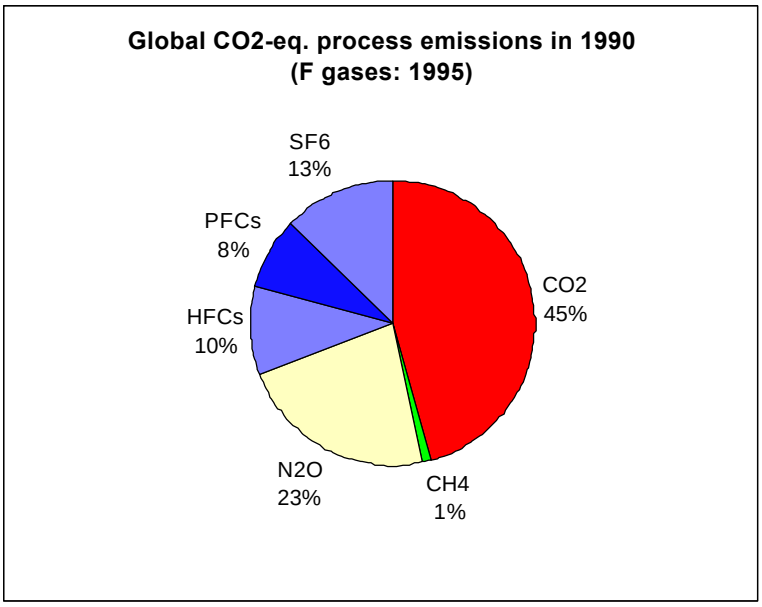


Figure 2. Global CO_2-eq. emissions of industrial process sources in 1990 (F gases: 1995). (Source: EDGAR 3.0)

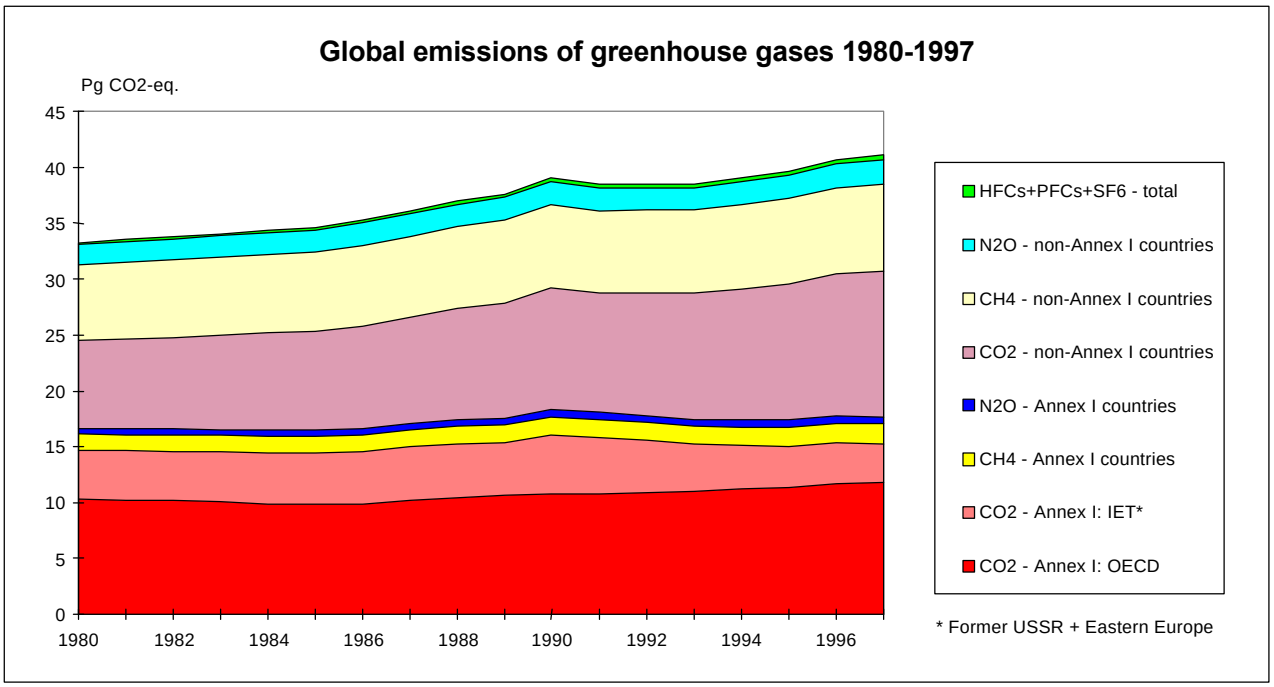


Figure 3. Trend in greenhouse gas emissions, 1980-1997, of the six 'Kyoto' gases in Annex I countries and other regions (in CO_2-eq.) (Sources: EDGAR, 1996 [CO_2, HFCs]; BP, 1998 [CO_2]; World Bank, 1998; FAO, 1998 [CH_4, N_2O]; IMAGE 2.0, 1994 [CH_4, N_2O]; own estimates [1997 CH_4, N_2O, HFCs, PFCs, SF_6])

If we look more closely at global industrial emissions of CO_2, CH_4, N_2O, and the 'new' gases HFCs, PFCs, and SF_6, we see that almost half of them stem from CO_2 emissions related to cement (clinker) production, about one-quarter can be attributed to adipic acid and nitric acid production, and one-third stem from the three F gases, each with roughly equal contribution of about 10% (Figure 2). Thus we may conclude that, at the *global* level *presently,* industrial process emissions account only for a very minor share (3%), and the new gases account for about 1%. However, particular countries' share in the national total may be quite different of course, depending on whether particular sources are present.

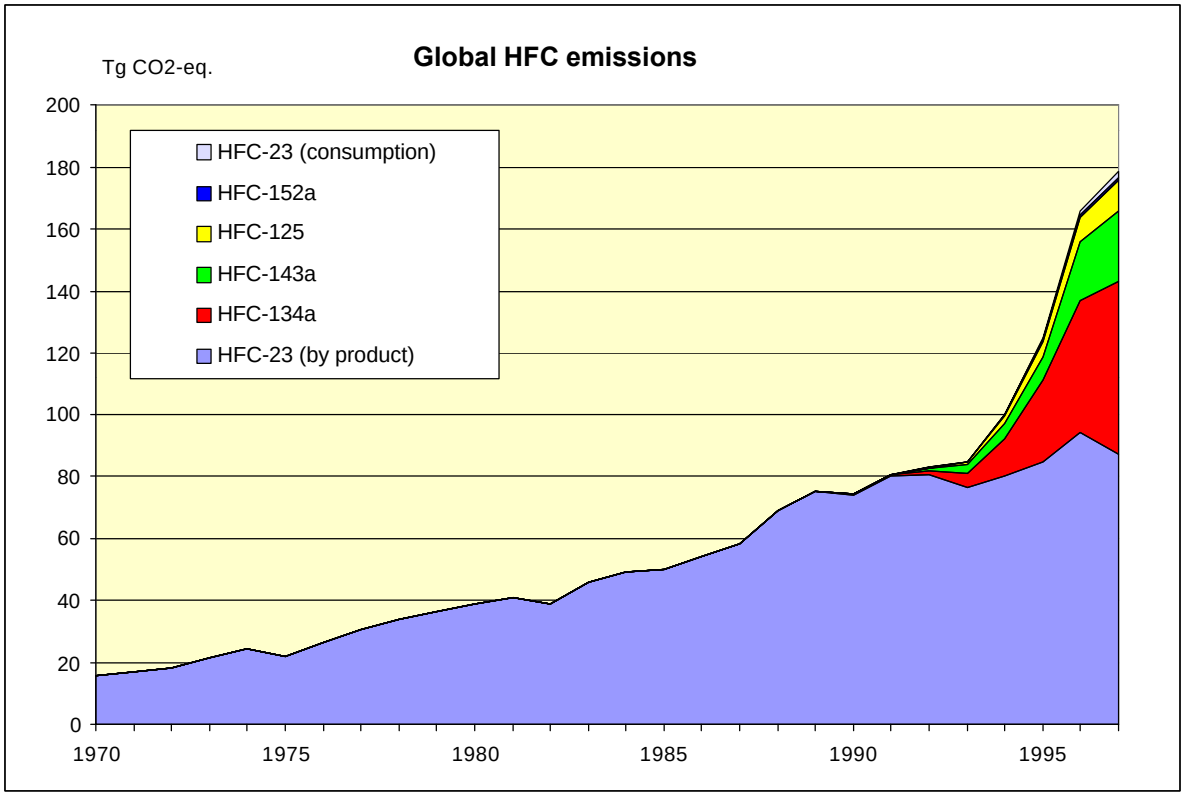
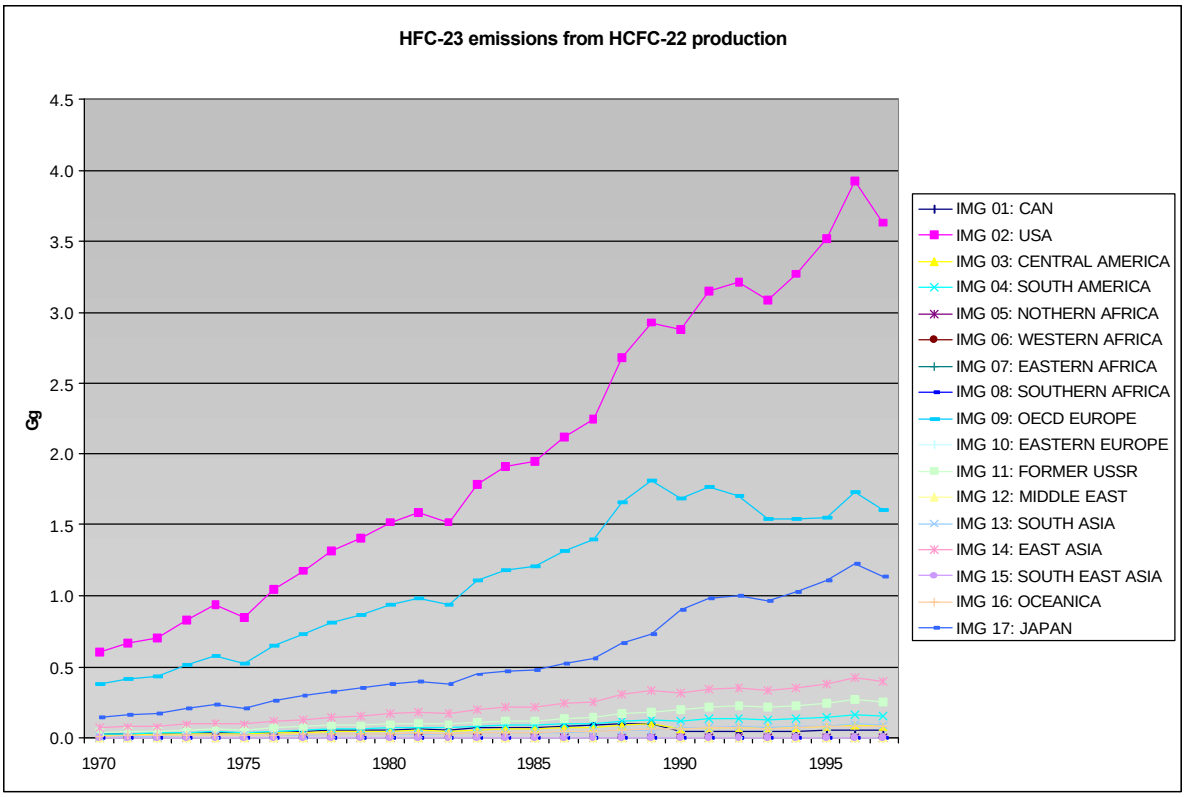


Figure 4. Trend in global HFC emissions per compound. (Source: EDGAR 3.0)

RESULTS FOR HFCS: SOURCES, DOMINANT REGIONS, TRENDS

As Figure 4 clearly shows, HFC-23 emissions as byproducts from HCFC-22 manufacture were the only source of HFC emissions until the early '90s, when HFCs were introduced on the market as a substitute for CFCs and halons, whose use was phased out under the Montreal Protocol for the protection of the ozone layer. Although only global production figures for HFC-134a are currently reported, estimates of emissions of other HFCs based on extrapolation of reported consumption by a few countries clearly show that their contribution in terms of CO_2-eq. is now of the same order as the HFC-134a emissions. Both production and use of HFCs is dominated by industrialised countries, in particular OECD countries (Fig. 5).



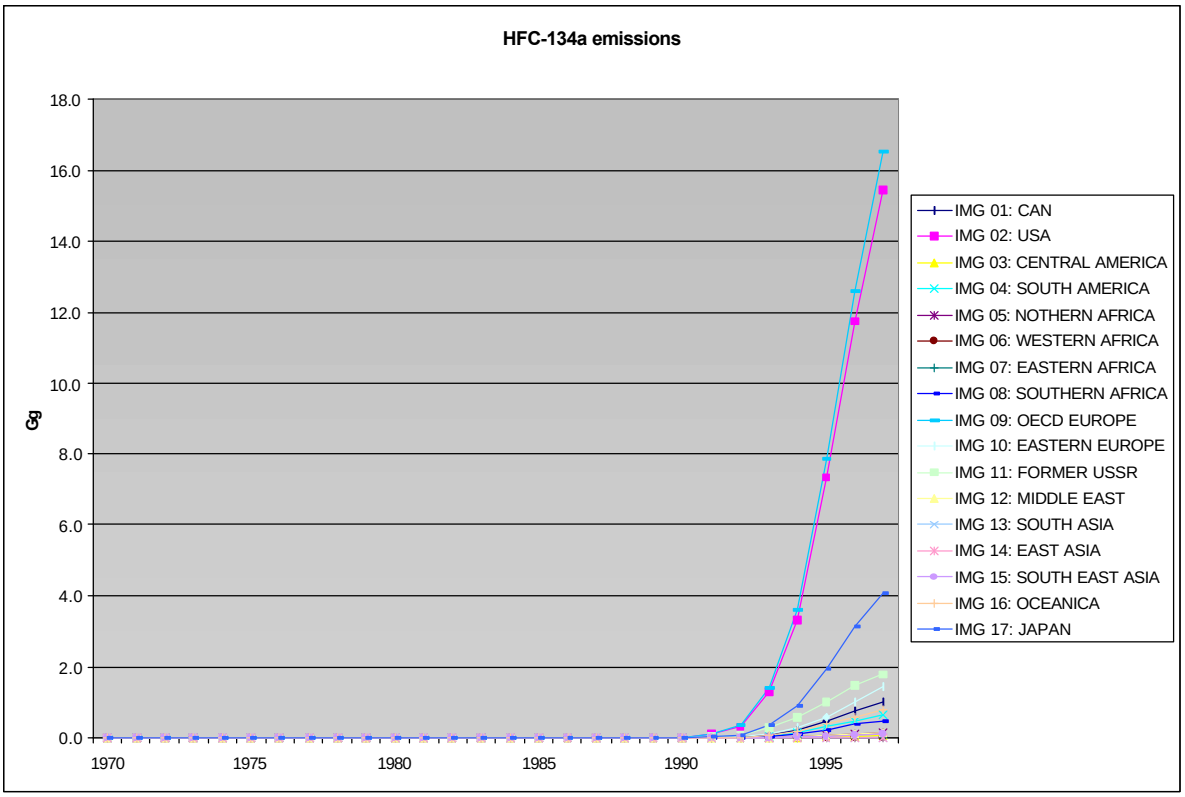


Figure 5. (a) Regional trends in HFC-23 emissions from HCFC-22 production. (b) Regional trends in HFC-134a emissions. (Source: EDGAR 3.0)

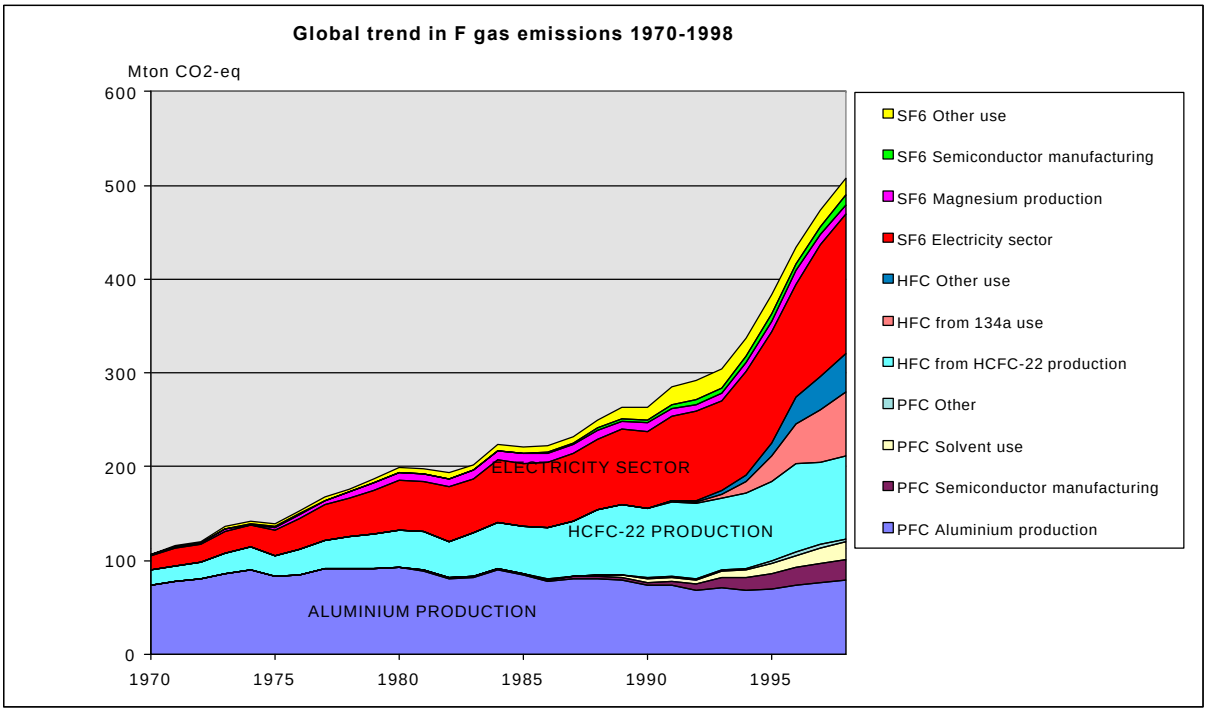
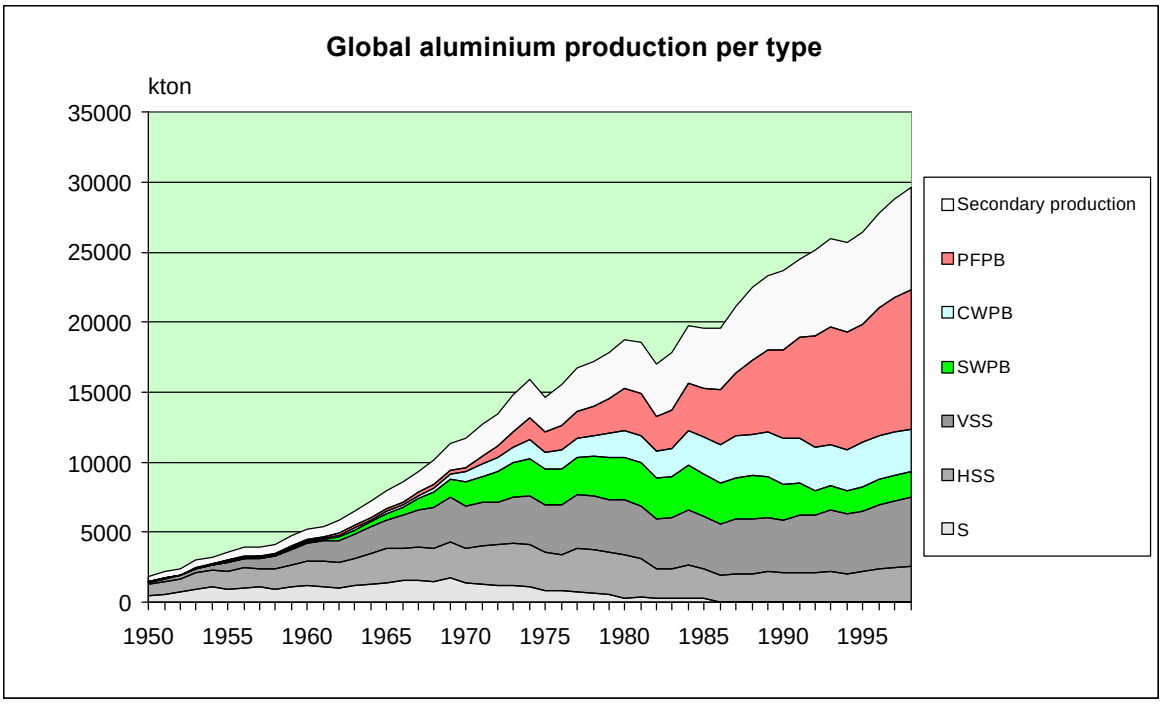


Figure 6. Global trend in F gas emissions, 1970-1998, per source category. (Source: EDGAR 3.0)

RESULTS FOR PFCS: SOURCES, DOMINANT REGIONS, TRENDS

Figure 6 shows the trend in global emissions of F gases per major source category. It clearly shows that PFC emissions are dominated by emissions as byproducts from primary aluminium production. However, since the early '90s, semiconductor manufacturing ('chips') and special solvent applications are starting to make up an increasing share of global PFC emissions. In contrast, emissions from aluminium production (mainly CF_4 and some C_2F_6, plus little C_3F_8) tend to decrease – even with increasing production statistics. This is due to the fact that modern smelter techniques like Prebake, in particular the Point-Feed type, have much lower emission factors for PFCs than the older Söderberg types (Fig. 7.a). A large proportion of the Söderberg type smelters are located in the countries of the former USSR. As illustrated in Figure 7.b, replacement or modernisation of smelters of this type would result in a substantial reduction of PFC emissions from this source.



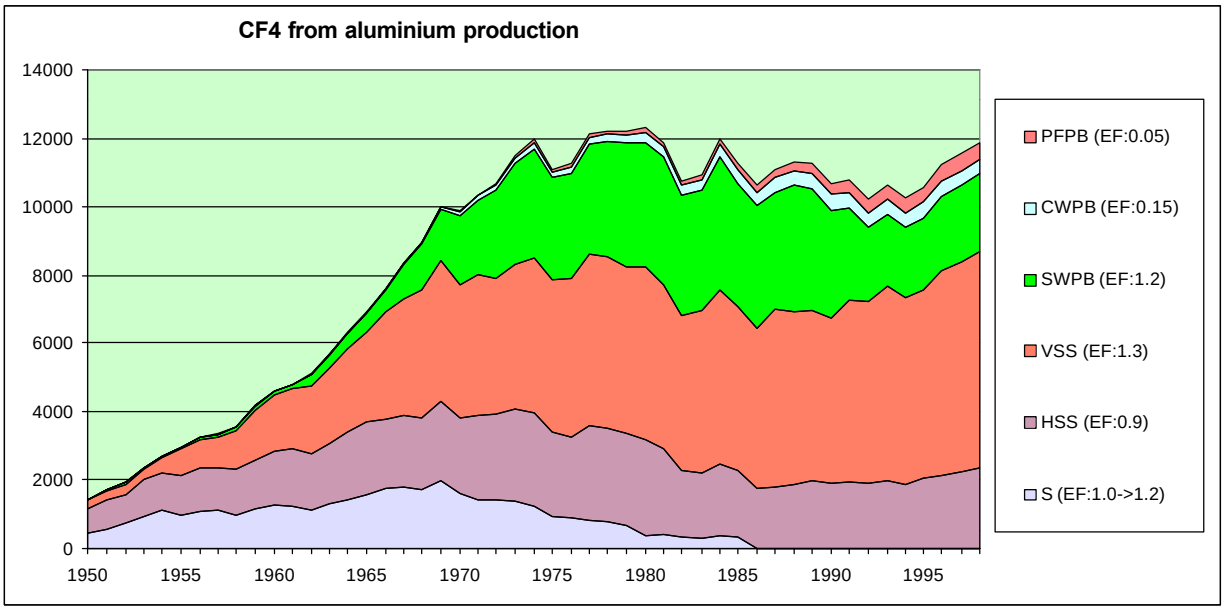
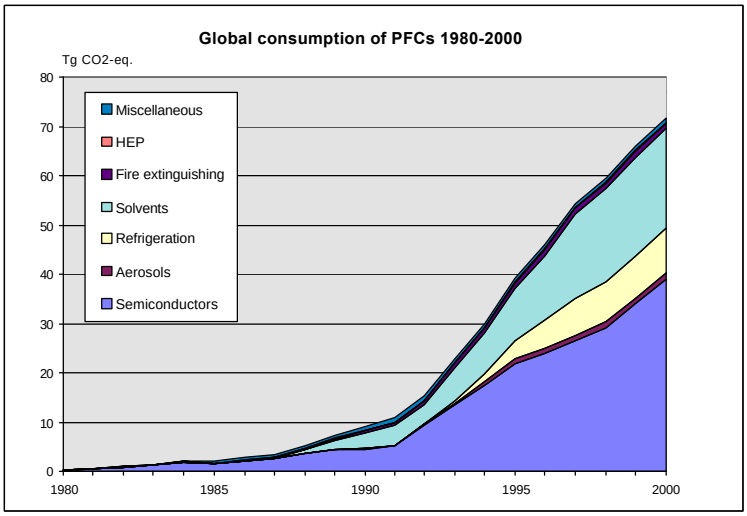
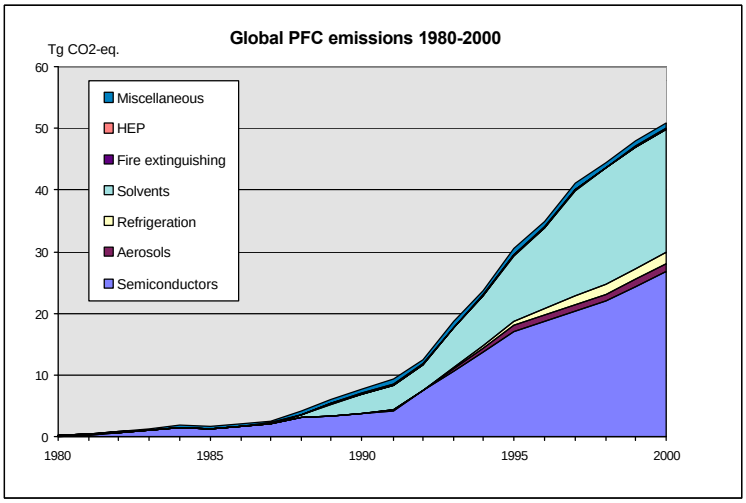


Figure 7. (a) Trend in global production of aluminium per type of process. (b) Trend in global emissions of CF_4 per type of process. (Source: EDGAR 3.0)





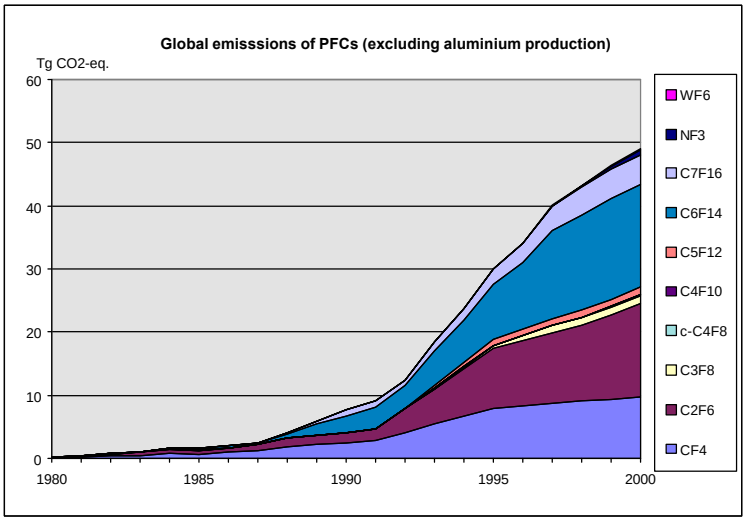


Figure 8. (a) Trend in global PFC consumption, 1980-2000. (b) Trend in global emissions of PFCs, 1980-2000, by source (excluding aluminium production). (c) Global emissions of PFCs, 1980-2000, by compound (excluding aluminium production). (Source: EDGAR 3.0)

Figure 8.a shows global consumption of PFCs per application, which boosted in the early '90s. Key users are the semiconductor manufacturing industry, which is dominated by the USA and Japan, and specialised solvent use, in particular in Japan. The third largest consumption category is refrigeration. Since most of the compounds are used in semiconductor manufacturing and as solvent is being emitted, these are by far the largest emission sources here (Fig. 8.b). Three specific PFCs dominate emissions: CF_4, C_2F_6, and C_6F_{14} (Fig. 8.c), the first two mainly from chip production, the latter from solvent use.

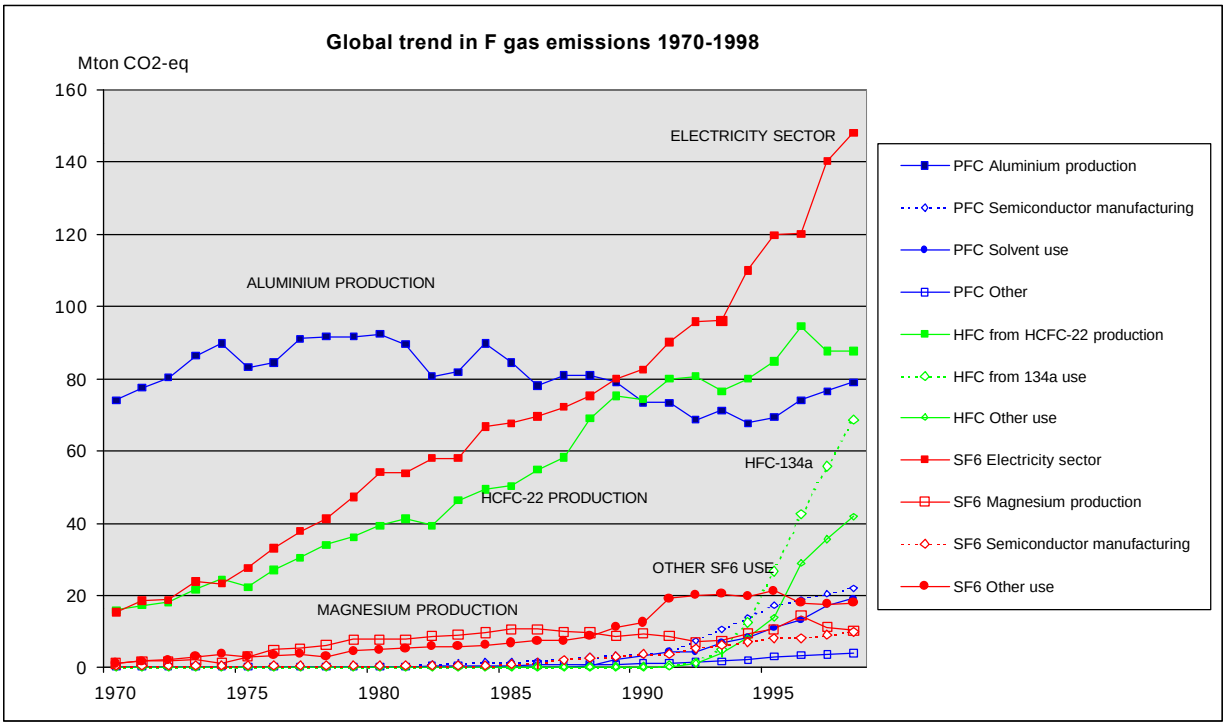


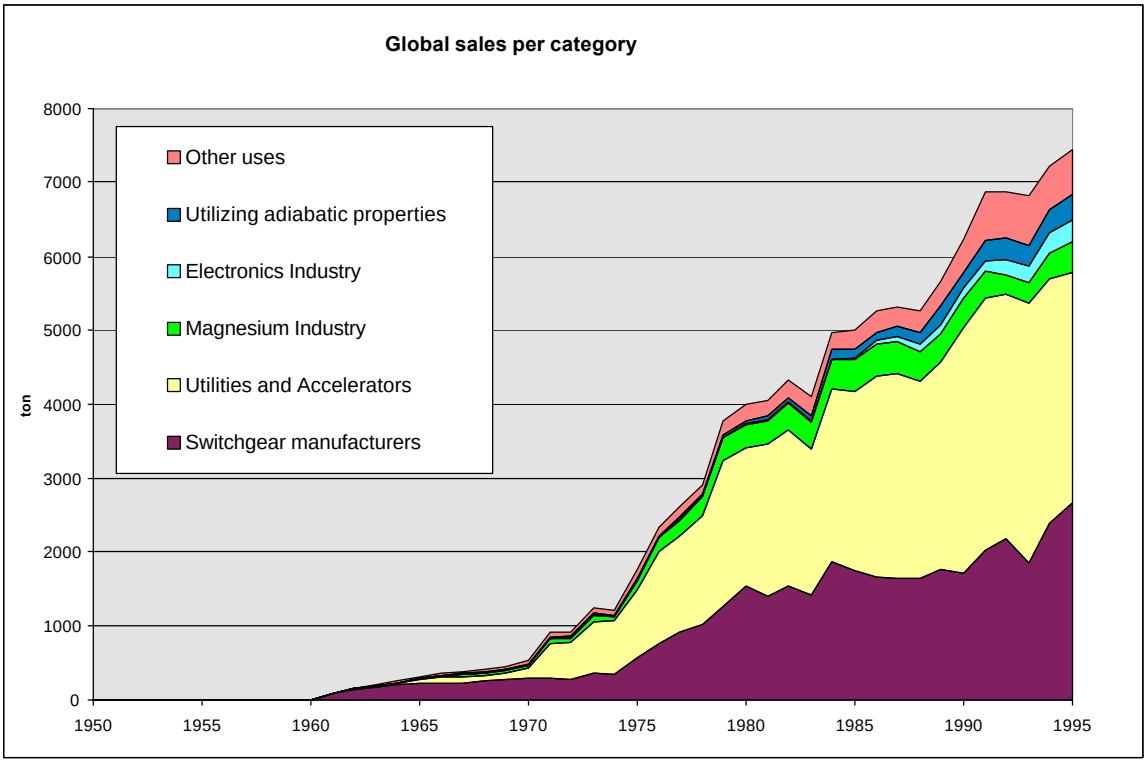
Figure 9. Global trend in F gas emissions, 1970-1998, of individual source categories. (Source: EDGAR 3.0)

RESULTS FOR SF_6: SOURCES, DOMINANT REGIONS, TRENDS

Figure 9 shows the trend in global emissions of F gases per major source category in another fashion than Fig. 6. It clearly shows that SF_6 emissions from the electricity sector are becoming the largest source of F gases of all sources considered here, overtaking aluminium production's number one position around 1990. HFC-23 emissions as byproducts of HCFC-22 manufacture follow SF_6 from electricity applications closely, but tend to grow less strongly after around 1990.

The fourth- and fifth-largest sources in Fig. 9 are SF_6 emissions from magnesium production and 'other SF_6 use.' However, in 1995, their positions are taken over by HFC emissions associated with HFC usage.

These SF_6 source categories are also presented in Fig. 10, where both consumption and emissions are presented at the global level. Based on sales statistics, about 75% of SF_6 emissions in the '90s stem from electrical equipment (either manufacture or use). This includes a significant amount that is allocated to this sector, but whose allocation is questioned in the literature. (Such questions revolve around whether this equipment is resold to other use categories, e.g., the magnesium production sector.)



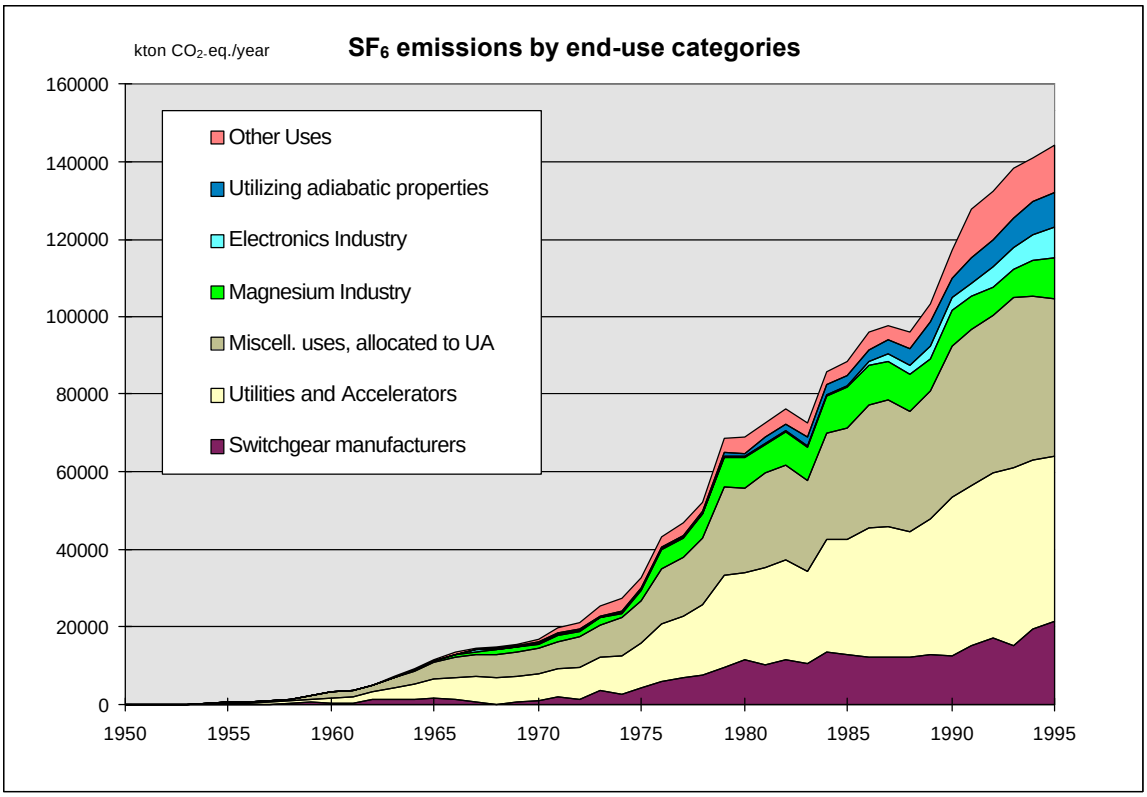
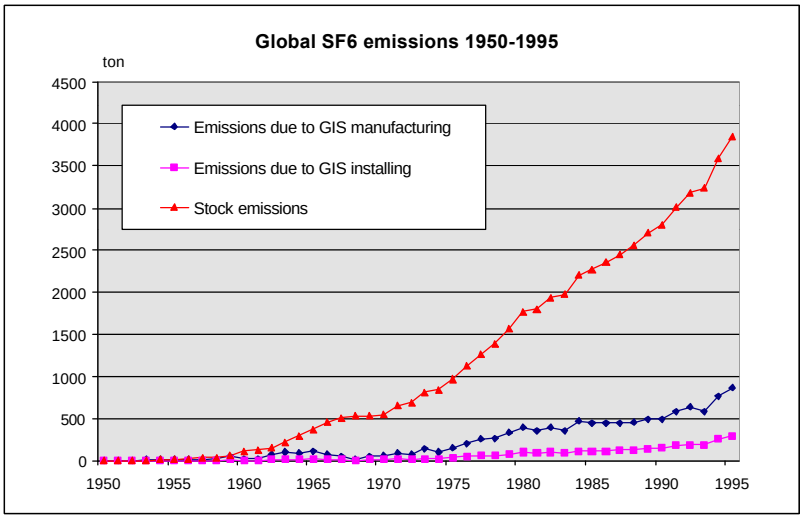
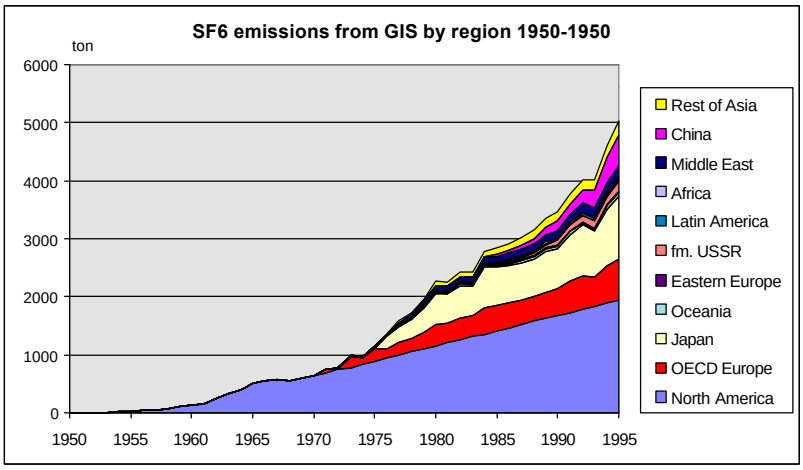


Figure 10. (a) Trend in global sales of SF_6 per source category. (b) Trend in global emissions of SF_6 per category. (Source: EDGAR 3.0)

When taking a closer look at the SF_6 emissions from the electrical equipment in Fig. 11, we can observe that stock emissions are by far the largest subcategory here. The USA's large share (50%) of the emissions in this sector has two causes: a large amount of heavy leaking old equipment and the (mis?-)allocation of the questioned amounts. Three-quarters of the emissions of this sector are estimated to stem from OECD countries.





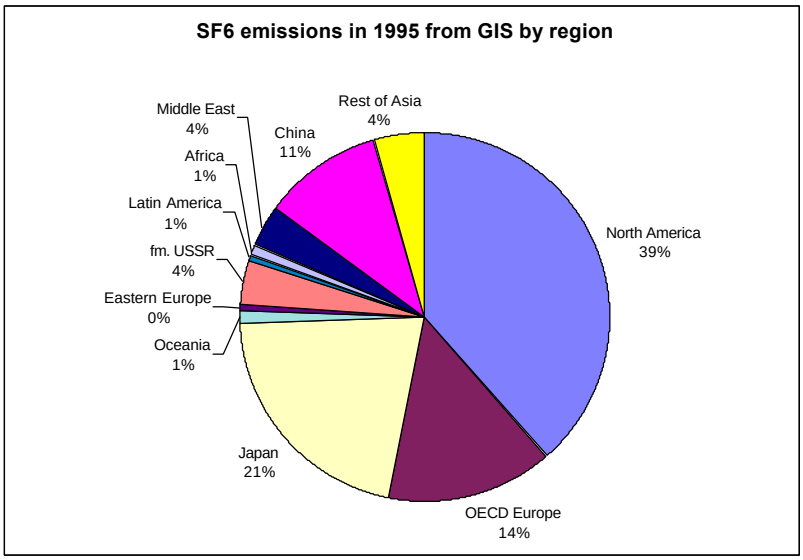


Figure 11. SF_6 emissions from the electricity sector. (a) Trend in global SF_6 emissions sector per category. (b) Trend in regional SF_6 emissions. (c) Estimate of regional shares in SF_6 emissions in 1995. (Source: EDGAR 3.0)

REFERENCES

AFEAS (1999) Production, Sales and Atmospheric Release of Fluorocarbons Through 1997. Alternative Fluorocarbons Environmental Acceptability Study (AFEAS).

Harnisch, J., I.S. Wing, H.D. Jacoby, and R.G. Prinn (1999) Primary Aluminum Production: Climate Policy, Emissions and Costs. MIT, Massachusetts, USA, December 1998. MIT Global Change Joint Program Report no. 44.

Maiss, M., and C.A.M. Brenninkmeijer (1998) Atmospheric SF_6: trends, sources and prospects. *Environ. Sci. Techn.* **32**, 3077-3086.

Olivier, J.G.J, A.F. Bouwman, J.J.M. Berdowski, C. Veldt, J.P.J. Bloos, A.J.H. Visschedijk, C.W.M. van der Maas, P.Y.J. Zandveld (1999) Sectoral emission inventories of greenhouse gases for 1990 on a per country basis as well as on 1^o x 1^o. *Environmental Science & Policy* **2**, 241-264.

Olivier, J.G.J., J.J.M. Berdowski, J.A.H.W. Peters, J. Bakker, A.J.H. Visschedijk, and J.-P.J. Bloos (2000) Applications of EDGAR. Including a Description of EDGAR 3.0: Reference Database with Trend Data for 1970-1995. RIVM, Bilthoven. RIVM report no. 773301 001/NOP report no. 410200 051.