

Update on global SF₆ emissions trends from electrical equipment – Edition 1.1

Ecofys Emission Scenario Initiative on Sulphur
Hexafluoride for Electric Industry (ESI-SF₆)

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Executive Summary

The Emission Scenario Initiative on Sulphur Hexafluoride for Electric Industry aims to provide scenarios for the short and long-term SF₆ emissions from high and medium voltage electrical equipment at the global level. It shows emission scenarios for the three life cycle phases, manufacturing, use and decommissioning of equipment for the period between 2005 and 2030. A “business-as-usual” scenario (BAU scenario) and an additional action scenario are based on a forecast of market trends, global energy demand, population development and regional GDP growth. The underlying data is based on a global data collection, literature research and interviews among industry experts.

Key findings:

- **Global emissions from electrical equipment can be reduced by 30 % compared to 2005, despite a strong increase in global electricity demand until 2030**
- **Relative emissions would accordingly decrease from 5.0 % in 2005 to 0.8 %¹ in 2030 per metric tonne of banked SF₆**
- **With a reduction of 30 % by 2030 the global electrical equipment industry has ambitious objectives that contribute significantly to the effort of stabilizing the global warming at an average global temperature increase of 2°C as agreed in the Copenhagen accord. The 2°C path implicates to freeze global CO₂ concentration in the atmosphere at 450 ppm until 2050. This can be achieved by a global emission reduction of 12,1% until 2030 with respect to 2005².**
- **The success of voluntary agreements shows that this could be one flexible and efficient tool beside future regulations to achieve environmental improvements on a global scale. Through these voluntary agreements, the electrical industry proactively contributes to global emission reductions. As a consequence, SF₆ emissions will continue to remain very low in the future**

¹ A sensitivity analysis for the bank development showed that by varying the annual bank growth by ± 25 % the relative emissions per metric tonne of banked SF₆ only vary by 0.007%.

² Joeri Rogelj, Julia Nabel, Claudine Chen, William Hare, Kathleen Markmann, Malte Meinshausen, Michiel Schaeffer, Kirsten Macey, Niklas Höhne 2010: Copenhagen Accord pledges are paltry, Nature Vol 464, p. 1126-1128

The report clearly shows that if existing emission reduction actions based on state-of-the-art techniques are applied on a global level, today's global emissions from electrical equipment could be reduced by 30 % until 2030, despite a global increase in electricity demand and a significant SF₆ bank growth in developing countries.

Such reduction measures are primarily standard technologies close to best available techniques that are already currently widely applied in OECD countries. Europe and Japan in particular, have already achieved significant emission reductions during the past 15-20 years. Therefore, in Europe and Japan no major improvements in the emissions limitation can be expected in absolute terms, in the coming years. However, a decrease of the emission rate per ton of SF₆ installed can be still expected as old equipment at end of life is replaced by state of the art equipment having less SF₆ volume, as well as lower leakage rates.

Compared to the SF₆ emission scenarios presented in the SRES report³ from 1999, projected emissions from electrical equipment shown in this study are only a minor part of global total SF₆ emissions. Comparing the two best emission paths from both scenarios, SF₆ emissions from electrical equipment calculated in this study only represent 16,4% of global total SF₆ emissions shown in SRES.

Helping countries in transition and developing countries to rapidly implement adequate reduction measures to reach the same level of consciousness and professional management of SF₆ as in Europe, Japan and lately also in the USA therefore becomes a key task for both industry and policy makers in the coming years. Major improvements can than be expected in countries in transition and in developing countries, by extending the use of state-of-the-art technology.

If emissions remain uncontrolled in countries in transition and in developing countries, the scenario calculations show that global SF₆ emissions are projected to rise significantly from 1,600 t SF₆ to 2,800 t SF₆ under the BAU scenario until 2030. 70 % of the projected growth in electricity demand takes place in non-OECD countries, where important parts of the OECD countries exports are allocated. By selling state of the art equipment and by producing within non-OECD countries state-of-the-art equipment using state-of-the-art manufacturing process, the OECD manufacturing sector will assist them in making a significant contribution on their emissions evolution. State-of-the-art equipment usually generally involves the necessary technical support and training to implement the technical and organizational measures that facilitate the achievement of low emission levels by 2030.

³ Special Report on Emission Scenarios [3]

Upon examining the context, the electrical equipment industry has been a front-runner in recent years. Through applying several voluntary reduction programmes, considerable emission reductions were achieved already in the past although no or much less ambitious regulations were in place.

Through the large economic growth in developing countries, the electrical industry needs to face new challenges to further reduce SF₆ emissions from the application of high and medium voltage switchgear. SF₆ technology globally remains an important part of interconnected electricity grids in particular with regard to growing importance of renewable energy supply. It fulfils important criteria like compactness, cost effectiveness and long distance transportation, being currently the only available technology to do so for high voltage levels. It is therefore very important for the producers and users of SF₆ electrical equipment to keep the proactive spirit of the recent past to achieve the given reduction potentials in countries in transition and in developing countries.

1 Introduction

The following report aims to provide scenarios for the short and long-term SF₆ emissions from high and medium voltage electrical equipment at the global level. Emission scenarios will be presented for all life cycle phases, manufacturing, use and decommissioning of equipment for the period between 2005 and 2030..

Additionally Annex 3 presents an approach to a possible scenario beyond 2030 up to 2100. After 2030 the uncertainties for the future development are very high. Therefore the Figures given in Annex 3 should be used as an indication for potential future emissions from electrical equipment only.

1.1 SF₆ and climate change

Due to growing concerns over the potential effects of anthropogenic climate change due to greenhouse gas emissions into the atmosphere, increasing attention is given to specific greenhouse gases, their emission sources as well as their future emission development and emission reduction options.

SF₆ (sulphur hexafluoride), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are usually referred to as fluorinated greenhouse gases or F-gases. PFCs and HFCs were introduced as the “environmental-friendly alternative” to ozone depleting substances like chlorofluorocarbons (CFCs) in the mid nineteen nineties, while SF₆ in HV equipment has been in use since the early nineteen sixties. These chlorofluorocarbons (mostly used as refrigerants) are controlled under the international Montreal Protocol that looks to phase out ozone depleting substances by 2040. However, further scientific research on F-gases has revealed their contribution to climate change. They have high global warming potentials (GWP) ranging from 140 (HFC-152a) to 23,900 (SF₆).⁴ This is the reason why F-gases, beside CO₂, N₂O and CH₄ are regulated under the Kyoto-Protocol (see chapter 3.1).

Global Warming Potential (GWP) of SF₆

Recent research concluded that the GWP for a 100 years time horizon of SF₆ is 22.800 [1]. This value will be used for future climate change actions under the UNFCCC after 2012. However, annual emission reporting under the UNFCCC is still using the value of 23,900 for SF₆.⁵ Therefore, this value is also used for emission calculation in this study to ensure consistency with past emission projections.

⁴ GWP is a measure to compare gases' effects on global warming in relation to the same mass of carbon dioxide, which is indexed at 1.

⁵ http://unfccc.int/ghg_data/items/3825.php

SF₆ is a non-flammable man-made gas with excellent dielectric and arc-quenching properties. It also occurs naturally in common granitic rocks and fluorite minerals from which it is released extremely slowly through weathering processes [2]. With its high GWP of 23,900 and an atmospheric lifetime of 3,200 years it is the greenhouse gas with the highest specific potential impact on the global climate system. It is completely inert, nontoxic and has very good dielectric⁶ and quenching⁷ properties. Therefore, it is used in various products and industrial processes such as in electrical equipment, as a cover gas for magnesium die-casting, in degassing of aluminium, in semiconductor manufacturing, in sound-insulating glazing⁸ and historically in high performance sports shoes. “Use” can mean both open use, where the gas is emitted, as e.g. magnesium die-casting, as well as closed use, where the gas is contained inside products, e.g. banked in electrical equipment.

1.2 Project objectives

Emission scenarios play an important role by informing policy makers about the need for future policy action. The most important scientific source for policy makers is the IPCC report that provides a regular update on the global climate system. The underlying scenarios of the IPCC only consider aggregated SF₆ emissions from all different emission sources until 2100 [3]. The unique scenario that assesses electrical equipment emissions in particular, only projects emissions until the year 2020 [4].

This report aims at providing short to long-term scenarios covering a business-as-usual and an additional action scenario on a global level. In particular, the study shows the emission development for the entire life cycle of high voltage (HV) and medium voltage (MV) electrical equipment for the period between 2005 and 2030 and gives an indication for the period from 2030 to 2100. The year 2030 was selected because solid global data for electricity demand and economic growth is only available until 2030. For this purpose, major stakeholders from the electrical equipment industry and electricity suppliers were invited to deliver technical expertise to support the development of regional scenarios for 14 major market regions.

As an introduction to transmission and distribution of electricity, Chapter 2 provides a brief overview of the main electrical equipment categories used in T&D networks and describes how emissions occur during each life cycle phase of the equipment. In addition, Chapter 2 also offers a comprehensive overview on handling practices for electrical equipment already used by the industry to reduce life cycle emissions. Information about handling practices was collected through a detailed questionnaire that was distributed among industry representatives in the different market regions.

⁶ The ability to withstand the applied voltage.

⁷ The ability to extinguish an electrical arc.

⁸ Forbidden in the EU as of July 4th 2007 (Regulation (EC) No 842/2006)

Chapter 3 provides the latest information on global climate change policy. Particular focus is placed on recent developments of policies that affect the use of SF₆ in electrical equipment.

The scenario development is presented in chapter 4. It shows the global SF₆ emission development from electrical equipment for the periods 2005- 2030. For this period, the emission calculation is presented for each of the three life cycle phases; manufacturing, use and disposal of equipment. To classify the scenarios, they will be compared with existing emission scenarios from SRES [3], US EPA [4] and the ECOFYS report for CAPIEL from 2005 [5].

Additionally, chapter 4 contains information about projected amounts of SF₆ consumed by electrical equipment manufacturers; shows the development of SF₆ banked in electrical equipment and estimates the amount of SF₆ that needs to be decommissioned in the future.

A similar approach is followed in Annex 3 to estimate evolution of emission in the period 2030-2100.

Chapter 5 summarizes the previous chapters and provides conclusions for policy relevant storylines, for future evolution and mitigation of SF₆ emissions. In addition, the need for further research in future key market regions is identified.

2 SF₆ Electrical Equipment

Chapter 2 provides a short introduction on electricity transmission and distribution. It provides a brief overview of the main electrical equipment categories used in T&D networks and describes how emissions occur during each life cycle phase of the equipment. Chapter 2 also provides further information about the handling practices for electrical equipment helping to reduce SF₆ emissions in the different life cycle phases.

2.1 Power Transmission and Distribution

According to IEA's World Energy Outlook 2009, 19,756 TWh of electricity was consumed worldwide in 2007. World electricity demand is projected to grow at an annual rate of 2.7 % in the period 2007-2015, slowing to 2.4 % per year on average in the period 2015-2030, as economies mature and as electricity becomes more efficient [6]. Interconnected power networks play an important role for a safe and sustainable electricity supply throughout the world.

A power system consists of electricity generation, transmission and distribution. Transmission relates to transferring power over long distances and is usually associated with voltage levels above 52kV to minimise energy losses during transport. Distribution is associated with shorter distances at voltage levels below 110kV. Transmission and distribution networks consist of overhead lines or cables, in addition to other components such as switchgears and transformers. Switchgear is used to protect electrical equipment against overload and short circuit currents ("circuit breaking") and to connect / disconnect networks ("load-breaking"). Figure 1 shows the use of switchgear in a power network.

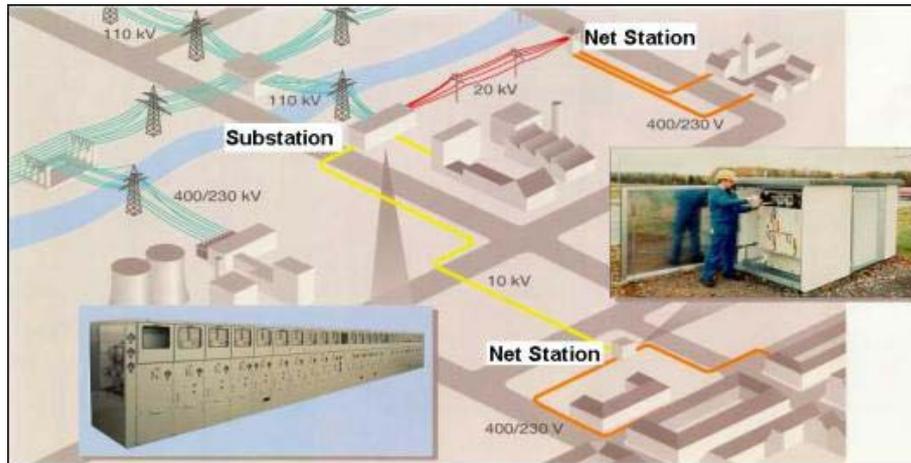


Figure 1: Gas insulated switchgear in the power distribution network

2.2 Equipment Categories

For a simplified assessment of the emission development in this survey only, “Sealed Pressure Systems” and “Closed Pressure Systems” have been taken into account, as defined in IEC standards [7]. A third category, defined in IEC standard as “controlled pressure systems”, is not taken into account, as this type of product is no longer manufactured.

Sealed pressure systems are defined as: “volume for which no further gas processing is required during its expected operating life”

All modern switchgear between 1 and 52 kV are allocated to this category. Typical new (state-of-the-art) medium voltage equipment is of the sealed pressure type. The category “Sealed Pressure Systems” includes gas insulated circuit breakers and gas insulated metal or insulation enclosed switchgear. Sealed pressure equipment has been in service since the early 1980’s in OECD countries. It has an enclosure designed to remain unopened during the lifetime of the equipment. Maintenance inside the gas compartment during the expected lifetime of about 40 years is not required under normal circumstances. The design leads to very low leakage rates during operation – presently less than 0.1 % annually [8]. Gas handling only takes place during manufacture and decommissioning. The amount of SF₆ contained varies widely with the specific application, but 0.25-10 kg per gas compartment can be considered as a typical range.

Closed Pressure Systems are defined as: “volume which is replenished only periodically by manual connection to an external gas source.”

Switchgear above 52 kV is assigned to Closed Pressure Systems. This category contains gas insulated circuit breakers, gas insulated metal enclosed switchgear, gas insulated lines and outdoor gas-insulated instrument transformers. For equipment designed since the mid-nineties, maintenance including gas handling for closed pressure systems is commonly required only after 20 to 25 years. Topping-up of SF₆ can be required once or twice during the lifetime, depending on the leakage rate. Design-related leakage rates for new equipment are ≤ 0.5 % p.a. [7]. Operation pressure is in the range of 0.2-0.8 MPa absolute pressure. The high operating pressure requires transport of the equipment at a lower pressure level and increasing this to the operating pressure at the site of installation. Gas amounts can vary between a few kg and up to several hundreds kg SF₆ per gas compartment. Switchgear dimensions and subsequently also the SF₆ amount per piece of equipment have significantly decreased over time, both for sealed and closed pressure systems (see Figure 22).

2.3 Life Cycle SF₆ Emissions

Manufacturing

In the manufacturing phase, the components are produced and assembled. Depending on the type of equipment, several test phases for gas tightness are carried out on components and assembled equipment. Sealed pressure equipment is usually filled and tested at the production site and is, in normal operation, only reopened for dismantling at decommissioning after gas recovery. Closed pressure systems are filled for testing at the production site. The gas is then recovered and the equipment is filled with SF₆ or N₂ at a pressure slightly above atmospheric for shipping. At the installation site, they are then topped up (if filled with SF₆ before) or evacuated (if filled with N₂ before) and then filled to the rated SF₆ pressure. During the manufacturing process, emissions can occur whenever gas is handled; this is predominantly during, filling, topping up and gas recovery before shipping.

Use

During the use phase, no gas handling is required for sealed equipment. Closed pressure equipment installed since the mid 1990s is designed to require maintenance including gas-handling only after 20-25 years. Prior to opening for internal inspection and/or maintenance, the SF₆ is recovered almost 100% depending on the evacuation equipment used [9]. The maintenance is then carried out and afterwards, once the compartment is closed again, it is filled up to rated pressure. Older equipment may not be designed for high tightness and might require additional gas refilling. Emissions in the use-phase include the design-related leakage of gas from the equipment, increased leakage of defective equipment, losses during gas handling and emissions because of single events e.g. internal arc faults. For this study, the emission rate during use-phase includes all of these sources of emission.

Decommissioning

In the decommissioning phase of equipment, SF₆ is recovered. Afterwards it can be reused either on-site or at gas manufacturer or it is disposed of, according to local or international regulations on waste management. Gas reuse is presently more common than disposal. The gas supplier commonly carries out reuse of SF₆. The empty equipment is dismantled and the materials are predominantly recycled, as a number of valuable raw materials such as stainless steel, aluminium and copper are present. As full recovery of the gas is not possible (even when state-of-the-art gas handling equipment is utilised), some emissions also occur during decommissioning, but remain typically between 2 % and 0.4% of the name plate capacity, depending on the SF₆ rated filling pressure of the equipment, the performance of the evacuation

equipment and if the operation is carried out by qualified staff with the appropriate equipment. According to the recently issued Technical Report IEC/TR 62271-303 [9] the SF₆ residual pressure in the gas compartment should be lower than 2 kPa before flooding with air. The emission factor is defined as, “the ratio between the SF₆ residual pressure and the SF₆ rated filling pressure”.

2.4 Handling practices

According to the European F-Gases Regulation (EC) No 842/2006 [10] and Regulation (EC) No 305/2008 [11], the European industry (manufacturers, recycling companies, maintenance providers, utilities etc.) is obliged to provide for training, examination and certification of all personnel involved in the recovery of SF₆ from high voltage switchgear. For the purposes of Regulation (EC) No 305/2008 “high voltage switchgear” means switching devices intended for use in connection with generation, transmission, distribution and conversion of electric energy at rated voltages above 1 kV. Another important part of proper handling is the clear identification of equipment that contains SF₆. Regulation (EC) 1494/2007 [12] therefore obliges the correct labelling of such equipment in Europe. A similar regulation does not currently exist anywhere else in the world (see also chapter 3). However, international standards (IEC) require to indicate in the nameplate the quantity and pressure of the gas contained.

According to the manufacturers interviewed in Europe, Japan, Korea and the USA, the staff who fill HV-equipment with SF₆ on-site (when taking equipment into operation) or carrying out maintenance involving SF₆ handling, are always trained. Some companies organize internal trainings for production staff for SF₆ gas handling procedures, which covers the proper use of gas carts, safe handling of pressurized equipment and safe handling of SF₆ arc by-products. Training sessions also include; how to operate air evacuation and gas recovery equipment, how to fill up SF₆ in equipment and how to check for leakage in factory and on site. The objectives of this training are to minimize the SF₆ emissions continuously during testing, production, construction on site and commissioning, operating, service and dismantling.

Apart from training, continual improvement on SF₆ monitoring can also be observed. Manufacturers prepare periodical meetings to raise environmental awareness on the SF₆ impact on climate change and all main international industry associations (i.e. T&D Europe, JEMA, NEMA, CIGRE), have established special SF₆ working groups over the last 15 years.

The first efforts to reduce SF₆ emissions from electrical equipment started around 1995 in Europe and Japan, when the high potential climate impact of SF₆ was first acknowledged. North American efforts started some years later, with the introduction of the SF₆ emission reduction partnership for electric equipment. Table 1 gives

an overview of the past measures taken to reduce SF₆ emissions during manufacturing processes and future planned activities. .

Table 1: Measures taken by manufacturers to minimize SF₆ emissions from electrical equipment

SF₆ Reduction measures during manufacturing and installation
<ul style="list-style-type: none">• use of automated gas handling equipment to minimize leakage threats during evacuation and filling• improvements in equipment design for electrical equipment filled with SF₆• reduction of the SF₆ mass in the gas filled compartments -with the same functionality and same or higher rating data• routine tightness tests of components and / or gas filled compartments without SF₆ (i.e. with helium) as integral tightness routine test• installation of SF₆ flow meters at all feeder and tapping points• implementation and continuous improvement of a SF₆ mass balance system• Improved awareness and training of personnel involved in production processes• installation of monitoring and leak detection equipment in the manufacturing system• revision of joints to improve gas tightness• recovery of SF₆ left in the flexible connections between the filling and making the vacuum• reduction of treatment time during repair of leaking products• testing gas-tightness with helium rather than SF₆;• use of more efficient recovery compressors (announced down to 2 kPa)• usage of flow meters to check the quantity of gas used in the products and detect leakages in the network and monthly calculation of emissions are planned

3 Global SF₆ Policy

This chapter provides an overview on global and national climate change policy related to SF₆ emissions from electrical equipment.

3.1 Introduction to Climate change policy

Climate change is a global problem. In 1997, the industrialized countries accepted emission reduction targets for six greenhouse gases at the third conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto. The agreed target is an average reduction of 5 % from 1990 levels by the year 2012. This agreement subsequently became known as the Kyoto-Protocol and came into effect on February 16, 2005. Despite non-ratification by the USA, it is widely seen as an important step to limit global greenhouse gas emissions to levels which “avoid dangerous anthropogenic interference with the climate system” – the key objective laid down in the UN framework convention in 1992. Carbon dioxide (CO₂) is the major greenhouse gas, with emissions occurring mainly from fossil fuel use for the generation of heat and power. However, the Kyoto-Protocol also concerns nitrous oxide (N₂O), methane (CH₄) and the entire set of fluorinated greenhouse gases, including hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF₆).

3.2 Regulations concerning SF₆

The Kyoto Protocol has been ratified by 184 countries. 37 countries of those 184 have committed themselves to a reduction of four greenhouse gases (carbon dioxide, methane, nitrous oxide and sulphur hexafluoride) and two groups of greenhouse gases (hydrofluorocarbons (HFC) and perfluorocarbons (PFC), in relation to their 1990 emission levels, in accordance with Annex B of the Protocol. The six greenhouse gases are translated into their CO₂ equivalents to determine the reduction of emissions.

F-Gases only account for approximately 1.1 % of the total global greenhouse gas emissions (see Figure 2). This might be one reason that other than the European Union, no other country has so far introduced a regulation dedicated to F-Gases. Looking at the total reported F-Gas emission data from Annex I, countries of the

UNFCCC, the SF₆ emissions from electrical equipment contributes to 8.0 % of the total F-Gas emissions of those countries in 2007⁹.

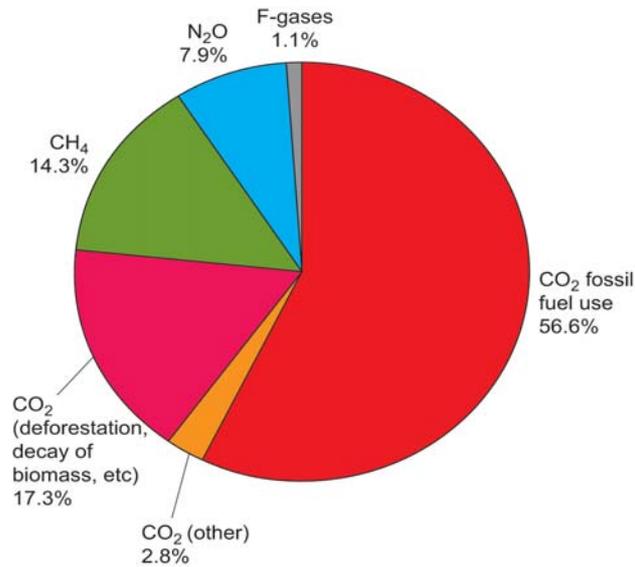


Figure 2: Distribution of global total greenhouse gas emissions over individual greenhouse gases in 2004 [13]

The objective of the European regulation, (Regulation (EC) No 842/2006) is to reduce emissions of the fluorinated greenhouse gases considered under the Kyoto Protocol. It addresses the containment, use, recovery and destruction of fluorinated greenhouse gases in addition to the labelling and disposal of products and equipment containing those gases. It also regulates the reporting of information on F-Gases; the control of uses referred to in Article 8 and the placing on the market, prohibitions of the products and equipment referred to in Article 9 and Annex II. Another important part is the training and certification of personnel from companies involved in activities provided for by this regulation.

The F-Gas regulation has no binding reduction targets on F-Gases but the above-mentioned set of measures is nevertheless, expected to achieve significant reductions. Estimations by the European commission, state a reduction potential of 21 Mt CO₂ eq. by 2012 through containment measures and further 6 Mt CO₂ eq. through prohibitions and use bans by 2012 [14]. The Commission does not state specific estimates for SF₆ emissions from electrical equipment.

The European F-Gas regulation affects electrical equipment using SF₆ in two different ways. Article 4 regulates the recovery of SF₆ from high voltage switchgear above 1 kV (see also chapter 2.4) and Article 6 demands reporting of produced amounts of

⁹

http://unfccc.int/di/DetailledByParty/Event.do?jsessionid=5A2B0A801213B4F89F0E3EA380D6EE5F_diprod01?event=go#

SF₆ in Europe, including import and export.¹⁰ The reporting is controlled under Regulation (EC) No 1493/2007 [15].

Although other countries do not have a regulatory framework on SF₆ or F-Gases in place, several countries undertake efforts to limit their GHG emissions and influence F-Gas emissions. Table 2 provides an overview of actual developments in the most important market regions assessed in this report.

Table 2: Selected regional policy activities for GHG reductions

Policy overview:
<ul style="list-style-type: none">• Europe has several regulations for the reduction of greenhouse gases in place. Reduction targets are:<ul style="list-style-type: none">- 20 % from 1990 levels by 2020- Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases has an effect on SF₆ emissions from electrical equipment. It regulates the recovery of SF₆ (Article 4) and includes mandatory data reporting of SF₆ producers (see page 14)• Japan has no GHG regulation in place but in case of electrical equipment the industry accepted voluntary reporting of SF₆ emissions to the Japanese government. Utilities and manufacturers report their SF₆ emissions on an annual basis.• US Congress has proposed a GHG regulation for the USA¹¹. The objectives are:<ul style="list-style-type: none">- 17% reduction in 2020- 80% reduction in 2050- California has proposed a regulation to limit SF₆ emissions during the use phase to 1% annual emission rate by 2020• In South Africa a GHG regulation is under preparation, considering economic instruments like: taxes, tariffs, etc.[16] The objectives are:<ul style="list-style-type: none">- stop growing GHG emissions between 2020 and 2025- start declining in absolute terms between 2030 and 2035- No specific measures for SF₆• Australia is planning to introduce a Carbon Pollution Reduction Scheme. Among other measures the package comprises a cap and trade system

¹⁰ Reported figures can be downloaded at:
http://ec.europa.eu/environment/climat/fluor/reporting_en.htm

¹¹ American Clean Energy and Security Act of 2009

- Importers and exporters of SF₆ might be obligated to hold a so called obligation transfer number¹²

- Canada regulations since 2005 in place¹³. The objectives are:
 - 20 % from 2006 levels by 2020
 - 60 - 70 % by 2050
 - No specific measures for SF₆ on national level, but the province of Ontario recently enacted a law to create a new emission trade system that includes SF₆¹⁴
- China's National Climate Change Program [17]
 - 40%-45 % reduction per achieved Chinese Yuan from 2005 levels by 2020
 - No specific measures for SF₆
- Brazil: National Plan of Climate Change [18]
 - No specific GHG reduction targets
 - No specific measures for SF₆
- Korea: No GHG regulation in place
- India: No GHG regulation in place

An important option to further limit SF₆ emissions from electrical equipment are voluntary agreements between industry and governments. Through these voluntary agreements, the electrical equipment industry has always been a frontrunner by extending its achievements beyond the necessary regulations. A detailed overview of voluntary agreements in different countries can be found at Wartmann and Harnisch [5]. A recent example has been signed in 2008 in Spain between AFBEL-SERCOBE (National Association of manufacturers), REE (Transmission Network Electrical Utility), UNESA (National Association of Distribution companies) and the Ministry of Environment. It covers all lifecycle phases and gives a reduction target of 330,000 t CO₂ equivalent in five years (2008-2012).

¹² Carbon Pollution Reduction Scheme

<http://www.climatechange.gov.au/government/initiatives/cprs.aspx>

¹³ <http://climatechange.gc.ca>

¹⁴ http://www.ontla.on.ca/bills/bills-files/39_Parliament/Session1/b185rep.pdf

4 Emission Development 2005-2030

The following chapter contains emission scenarios for 2005 to 2030. For this period, a “business-as-usual” scenario and an additional action scenario is calculated. The scenarios aim to provide a comprehensive overview of the development of SF₆ emissions from the electrical equipment and electrical industry on the global climate system.

This report makes use of information about future global electricity demand projections according to the latest publication of the World Energy Outlook 2009 [6], which is a key driver for the expansion of electricity grids and therefore also for SF₆ emissions from electrical equipment. Accordingly, global SF₆ consumption from the electrical equipment industry and the global bank development are also shown.

Global Electricity Demand

An important driver for future SF₆ use in transmission and distribution equipment is the future global electricity demand. The emission scenario design is based on IEAs World Energy Outlook 2009¹⁵. The global electricity demand is projected to grow at an annual rate of 2.7 % in the period, 2007 to 2015, slowing to 2,4 % per year on average in the period, 2015-2030. Over 70% of the growth takes place in non-OECD countries. In the OECD, electricity demand is projected to rise by just 1.1 % annually between 2007 and 2030.

Total global electric capacity additions amount to 4,800 GW until 2030, of which about 1,522 GW are added in the period to 2015. The total cumulative investment in the power sector over the period 2007 to 2030 is projected \$ 13.7 trillion¹⁶, of which \$ 6.5 trillion is required for transmission and distribution networks.

¹⁵ <http://www.worldenergyoutlook.org/2009.asp>

¹⁶ year-2008 dollars

4.1 Data Collection Process

Emissions estimates and projections from electrical equipment are based on an assessment of expected technology shifts and an evaluation of respective emission factors in the 14 market regions shown in Table 3.

Table 3: Regional Scope of the study

Assessed regions:	
<ul style="list-style-type: none"> • EU-27 • North America • Japan • India • Korea • China • Russia • Saudi Arabia 	<ul style="list-style-type: none"> • Brazil • South Africa • Central Europe (Non EU) • South East Asia • Indonesia • Oceania

Therefore, a detailed questionnaire was developed and distributed among experts from JEMA, NEMA and T&D Europe. The Japan Electrical Manufacturers' Association (JEMA) consists of major Japanese companies in the electrical industry, including power and industrial systems, home appliances and related industries. NEMA is the trade association for the electrical manufacturing industry in the USA. The member companies of NEMA manufacture products used in the generation, transmission and distribution, control, and end-use of electricity. T&D Europe is the European association of the electricity transmission and distribution equipment and services industry. It represents all relevant European national associations.

The survey resulted in a solid data basis for existing banks, applied technologies and technology shifts in Europe, Japan and North America.

The questionnaire was sent to industry experts in other market regions with a very low response quota. As a result the emission projections of the remaining 11 market regions are primarily based on assumptions that have been intensively discussed with industry experts and market representatives from the above mentioned associations. The SF₆ emission development in the 14 regions can be seen in Figure 17 and Figure 19.

However, the report gives a very clear picture of the current state of the electrical equipment industry and the end users of electrical equipment on a global level. It also aims to indicate what action needs to be taken to further reduce SF₆ emissions from the entire life cycle of electrical equipment essential to today's global society.

4.2 Scenario Design

Chapter 4.3 shows a “business-as-usual” scenario (“BAU Scenario”) and an additional action scenario (“Additional Action Scenario”) for period 2005-2030. Both scenarios are based on a forecast of market trends, global energy demand, population development and regional GDP growth. Life cycle emissions are calculated by using an emission-factor approach that applies annual emission factors per life cycle phase. Relevant activity data per life cycle phase is SF₆ consumption by equipment manufacturers, banked SF₆ quantities in transmission and distribution networks and the annual share of SF₆ banked in equipment that is recovered during decommissioning.

BAU Scenario

By 2005, Europe and Japan had already reached low emission levels over the entire life cycle of electrical equipment, due to voluntary actions launched since the mid-1990s. Manufacturers and end users of SF₆ insulated electrical equipment have succeeded in significantly improving the technical standards according to which the equipment is produced, serviced, maintained and decommissioned.

Emission rates during **manufacturing** are below 3 % (see chapter 4.3.1) and are expected to reach a minimum of 2.0 % until 2015. Apart from design-related leakages, emissions from the **use-phase** are also caused during gas handling and by defective equipment. The data collection for Japan showed that annual emissions during use phase have already reached a level below 1.0 %. In Europe, these emissions still remain slightly above 1.0 %, but this is expected to decrease further in the coming years [5]. According to an opinion shared among experts, the emission rate during **decommissioning** of equipment in Europe is around 0.8 % for the mix of closed and sealed electrical equipment [9]. At present, figures from Japan are not available. However, it is assumed that handling processes are comparable to Europe and emissions from decommissioning are estimated to not exceed 0.8 %. However, due to a different share between HV and MV equipment, the global annual BAT emission rate for decommissioning is 0.9 %.

North America still offers considerably higher potential for emission reduction than Europe and Japan. Due to a growing awareness of climate change in the USA, it is estimated that North America will pick up quickly in the coming years. Other well-developed world regions like Korea, Saudi Arabia, South Africa and Oceania are also expected to be at an acceptable emission level as of 2005. The electrical equipment industry in these regions is represented, mainly by European and Japanese companies, which already have high tightness standards in place. However, in order to reach European and Japanese standards, additional action still needs to be taken.

It is estimated that currently, countries in transition (i.e. China, India and Brazil) and developing countries show the highest life cycle emissions from electrical equipment. In particular, emission rates from the use-phase and from decommissioning seem considerably higher than in the developed world. This is mainly a result of the lack of trained handling and maintenance personnel and a lack of established handling procedures. Emission rates from manufacture are assumed closer to the European and Japanese average, because manufacturing in developing countries is mainly executed from western companies.

As a result, the **BAU Scenario** shows the global emission development under the assumption that in developing countries, emission rates from manufacture and disposal of electrical equipment remain constant at the 2005 level over the given timeframe. Emissions from the use phase decline slightly until 2030, depending on the year of installation, assuming that older equipment with higher leakage rates is progressively decommissioned.

Emission rates from developed countries that already have voluntary actions established in the mid nineteen nineties follow their trend from the recent past in the BAU scenario.

Additional Action Scenario

The additional-action scenario is based on the trend of voluntary action aiming for a reduction of SF₆ emissions, and on past experience with the implementation of “voluntary-action” measures in Europe and Japan. Under this scenario it is expected that Europe and Japan will reach best possible emission rates in all three life cycle phases until 2020. Experiences from the recent past in OECD countries have shown that significant improvements can be achieved in a period of 15 to 20 years. Therefore, for all other countries, it is estimated that BAT emissions rates can be reached, at the latest, by 2030. Table 4 shows annual emission rates per life cycle phase for best available techniques (BAT). The emission rates are weighted emission factors for both, HV and MV electrical equipment, applying a global average use share of 30/70 for MV and HV equipment. In some regions, i.e. in Japan and the USA, HV equipment is more significant and reaches a share of 90 %. In other regions like Europe, MV equipment is in the process of becoming more significant and the share of MV equipment reaches approx. 40 %. To facilitate calculations, a global average share of 30/70 for MV/HV is applied to all markets.

Table 4: Weighted BAT annual emission rates¹⁷

Manufacturing	Use-phase	Decommissioning
2.0 %	0.4 %	0.9 %

The decommissioning of electrical equipment will become very important in the coming years. The additional action scenarios show two different scenarios for the decommissioning phase. The first scenario assumes that all (100 %) of the equipment reaches proper recycling facilities at end of life. The second scenario shows how emissions evolve in a situation where only 80 % of the equipment is recycled properly and the remaining 20 % is vented into the atmosphere.

The additional action scenario sets the BAT emission rates as a target for the entire electrical equipment industry. Although this target seems very ambitious, the experience from Europe and Japan showed that this is achievable. Figure 9 (page 35), Figure 10 (page 37) and Figure 11 (page 39) shows that by achieving this target by 2030 and beyond, emissions from the global electrical equipment industry can be reduced by 30 % against 2005 levels, even if the global energy demand and related SF₆ banks grow significantly.

4.2.1 Reduction measures under the Additional Action Scenario

Chapter 2.4 described handling practices applied by equipment manufacturers. However, several reduction measures can be applied throughout the entire life cycle of electrical equipment. The following section shows selected reduction measures, which are already implemented in most of the developed world. By applying those reduction measures in developing countries, a significant reduction potential can be achieved as the emission development under the Additional Action Scenario shows. (see chapter 4.3 ff.)

Reduction measures during manufacturing

Instead of using individual gas bottles for each work place in the production and shuttling bottles back and forth through the production site, a central supply system helps to significantly reduce emissions and allows the process to be thoroughly monitored through flow meters at the workstations. Such a system consists of a single gas tank and a pipe-system to the single working stations.

¹⁷ According to expert interviews

Gas bottles are usually equipped with self-closing valves, but when tubes are used for filling, a certain amount of gas remains in the tube and is released after the tube is disconnected from the filled application. These emissions can also be avoided by equipping the tubes with self-closing couplings/valves or through process changes, such as evacuation of the tube after the filling process and recovery of the SF₆ from the resulting gas/air-mix.

Reduction measures during the use-phase

Leakage of closed pressure equipment can be monitored with either density or temperature compensated pressure sensors. When the pressure level falls below the operating pressure, an alarm is given. State-of-the-art monitoring techniques enable the detection of leaking compartments at an early stage, allowing for timely action for repair or replacement. Today, all closed pressure equipment is equipped with density/pressure sensors and most of the older units have been re-equipped in OECD countries.

Even with high awareness and good training, opening closed pressure equipment as part of maintenance will always lead to emissions. Therefore, reducing the frequency of maintenance for closed pressure equipment to the minimum will lead to emission reductions. In recent years, a strong tendency can be observed towards decreasing the fixed maintenance frequencies or carrying out maintenance only if gas quality checks indicate it to be necessary, in OECD countries (reliability centered/condition based maintenance)

End of life emission reduction measures

Creating a cost-efficient and reliable decommissioning structure is an important option. When greater numbers of equipment are expected to be taken out of operation after 2045, a decommissioning infrastructure with clear competences and logistics, sufficient numbers of trained staff and up-to-date equipment has to be in place. Awareness of the user will contribute significantly to avoid emissions, by making the equipment reaching its end of life to be processed by accredited disposal entities.

Reduction measures for all life cycle phases

Training is a significant option, that is already widely applied in OECD countries, for all phases of the life-cycle, as it ensures that staff are able to properly carry out all provisions for emission prevention and reduction. This includes not only the proper handling of the equipment, but also the awareness that SF₆ is a greenhouse gas and emissions need to be kept to a minimum. The industry from OECD countries is already taking training very seriously and has implemented several training measures [19].

Monitoring and book keeping of handled, installed or consumed gas amounts does not directly lead to emission reductions, but it does allow for the identification of reduction potential and controlling the effects of implemented reduction measures. It also raises awareness and responsibility for emission development can then be assigned (e.g. to staff at single working stations in manufacturing).

Labelling of equipment, i.e. the indication on the equipment that SF₆ is contained and the amount of the substance in kg, also has no direct impact on emission reduction. The main purpose of this is to create awareness in those handling the equipment and to identify the equipment for correct decommissioning. Most new products in the OECD countries actually show a separate label applied since April 1st 2008 indicating that SF₆ must not be released into the atmosphere.

Most of the above mentioned reduction measures are commercially available on a global level and can be implemented at a relatively low cost (below 20 US dollar per tonne abated CO₂ equ.). More detailed information about reduction costs is available via [5].

4.2.2 Activity data projections

SF₆ consumption by manufacturers:

Annual SF₆ consumption has been estimated from results of the data collection with the questionnaire, literature data and expert estimates. The main SF₆ consuming regions of the electrical equipment industry are Europe, Japan and China followed by North America. It is assumed that approximately 80 % of the SF₆ consumption for high and medium voltage electrical equipment is consumed in these regions. However, detailed data is only available for Europe, Japan, the USA and Korea. Europe's SF₆ consumption in 2005 is estimated at approximately 1,200t [5]. The data collection showed that Japan consumed around 600t in 2005. According to the National emission inventory of the USA, their annual SF₆ consumption for manufacture amounted to 300t in 2005 and the Korean manufacturers consumed 278t.

According to expert estimates, at least five large electrical equipment manufacturers exist in China and each of these manufacturers account for an annual SF₆ consumption of 200-600t. For the SF₆ consumption projections in this report, a conservative estimate of 1.500t SF₆ was estimated for the annual SF₆ consumption of Chinese manufacturers. It is assumed that in other regions no significant SF₆ consumption for manufacturing takes place. If electrical equipment is manufactured in other countries the production site usually belongs to one of the leading European, Japanese or US companies and the SF₆ consumption is already included in their figures.

Consumption projections for the five electrical equipment producing regions are calculated according to annual market growth expectations until 2013 [20]. From 2013 onwards, SF₆ consumption for manufacture is correlated with annual GDP growth projections and electricity demand projections, according to the World Energy Outlook 2009, which leads to a global annual average growth rate for SF₆ consumption of 2 %. Figure 3 shows that annual SF₆ consumption peaks around 2045 and slowly decreases in the following years, due to market saturation, and reduced SF₆ quantities in the equipment. An example for the decreases of SF₆ quantities per unit of electrical equipment over the last 40 years is shown in Annex 2, figure 24.

The development of annual SF₆ consumption for the long-term is associated with high uncertainties. Chapter 4.4 provides a sensitivity analysis for the SF₆ consumption development. As the amount of annual consumption is integral to the emission projections, chapter 4.4 shows the emission development for the situations that the annual amount of SF₆ consumption is 25 % above or 25 % below the following figures.

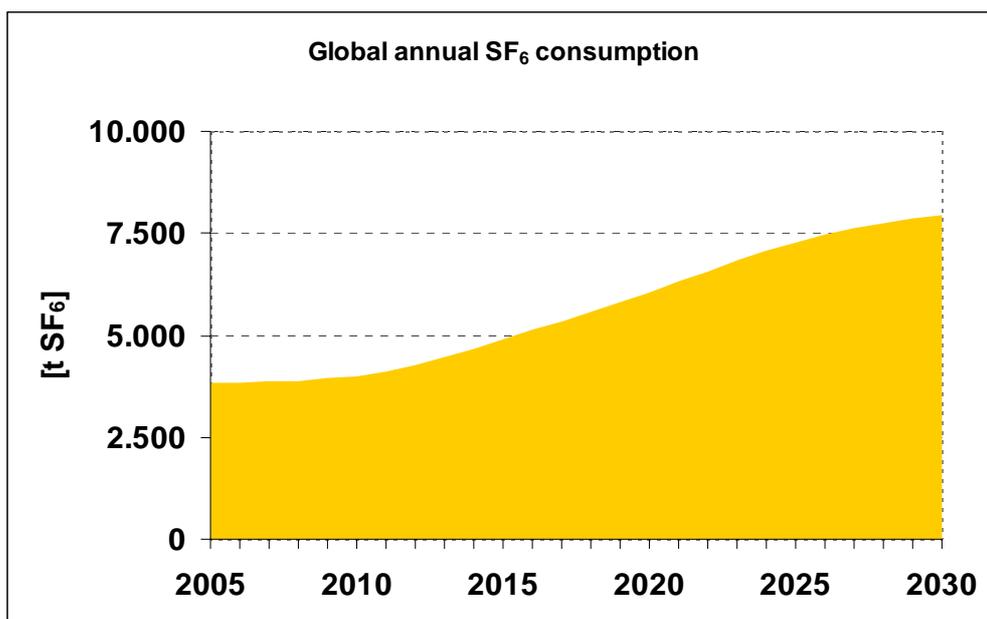


Figure 3: Global annual SF₆ consumption projections for electrical equipment production 2005-2030

Bank development:

It is very difficult to get exact figures on the global amount of banked SF₆ in transmission and distribution networks. Reliable reported data is available only for Europe, Japan, the USA and Korea. The calculation for missing bank data in 2005 is based on a correlated coefficient for SF₆ per installed GW electric capacity per respective region (see Figure 4).

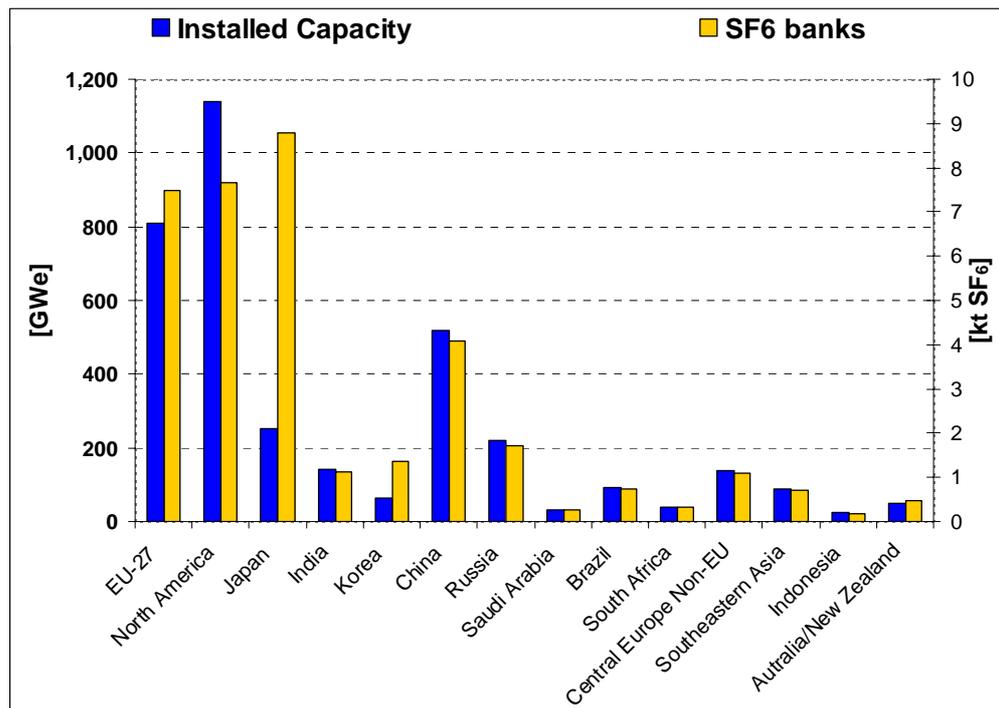


Figure 4: Global installed electrical capacity and banked SF₆ in 2005

The annual bank increase until 2030 is calculated by adding the annual SF₆ consumption of the industry and subtracting the annual decommissioned amount of SF₆. This leads to the bank increase as shown in Figure 5. Due to the enormous increase in electricity demand in non-OECD countries, the total amount of banked SF₆ in transmission and distribution grids will be more than four times higher in 2030 than today, resulting in a total bank amount of 150 kt of SF₆.

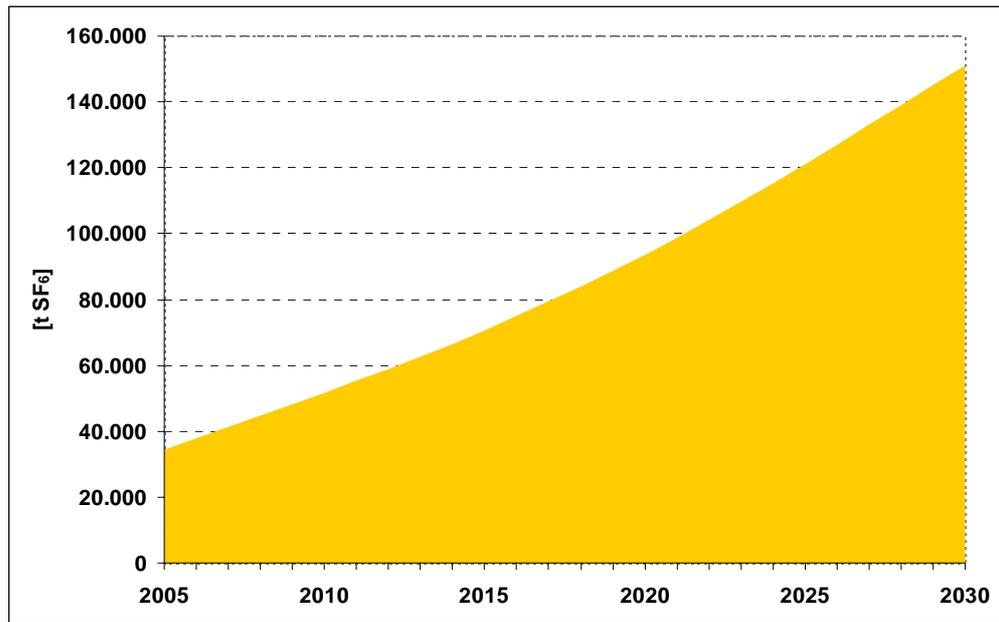


Figure 5: Projected aggregated SF₆ bank development 2005-2030

Annual share of decommissioned SF₆ banks:

The annual share of banked SF₆ that is going to be disposed is estimated from results of the data collection, literature data and expert estimates. Equipment lifetimes are between 30-50 years on average, depending on the equipment category. At present decommissioning of old and defective equipment occurs only in small quantities, because, in comparison to today, 30 years ago, those installed quantities were very small. Figures for Europe show that the annual share of decommissioned SF₆ will remain below 2.0 % until 2020 [5]. According to a recent report on the recovery of F-gases in the EU-27, recovered amounts of SF₆ from electrical equipment are ten times higher than the above-mentioned 2 % of the bank in 2005 [21]. However, this amount seems very high and for the purpose of this study, a conservative value of 2 %, according to Wartmann 2005, is applied.

After 2020, the decommissioning of equipment increases to a maximum annual share of 3.0 %. Due to missing data for other developed regions, the European figures are also used for Japan, Korea, Saudi Arabia, South Africa and Oceania.

For North America, an annual share of decommissioned SF₆ of 2.0 % is currently estimated. Particularly in the USA, much of the older equipment has been replaced with up-to-date technology that demonstrates greater efficiency. The annual share of 3.0 % is estimated to be reached in 2015 in North America. In developing countries, the annual share of decommissioned equipment is estimated to remain on a very low

level of 0.5 % until 2045, as most of the equipment in these countries has only recently been installed.

In consideration that the average lifetime of the equipment is 40 years, decommissioning becomes increasingly relevant after 2045. From 2045 onwards, in our projections, the annual amount of decommissioned SF₆ equals the amount of produced equipment 40 years before. This leads to a stabilization of decommissioned amounts from approximately 2075 onwards, because 30 years before production quantities peaked and started to slowly decrease. This leads to a further decrease after 2100.

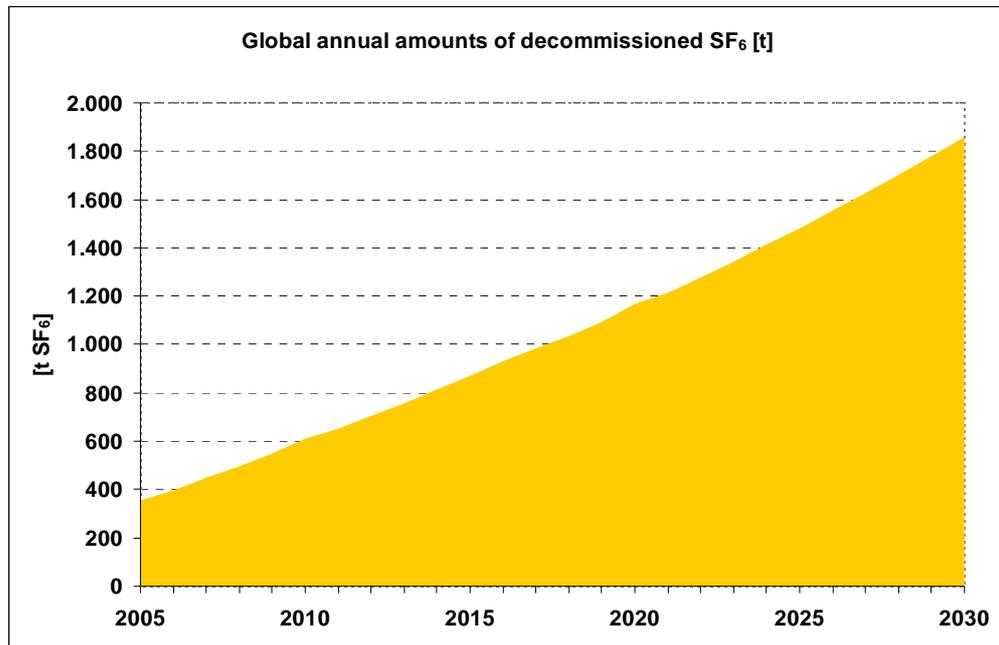


Figure 6: : Global annual decommissioned SF₆ projections 2005-2030

4.3 Emission Development 2005-2030

The following chapters show detailed figures for each life cycle phase, both for the BAU scenario and the additional action scenario. As Figure 7 shows, the additional action scenario offers a large reduction potential for the period up to 2030. 2030 emissions can be reduced by 30 % compared to 2005 levels, despite a significant bank increase if BAT standards are applied in all three life cycle phases of high and medium voltage electrical equipment.

In contrast if global SF₆ emissions from electrical equipment remain uncontrolled, they are projected to rise significantly by 60 % from about 1,700 t in 2005 to about 2,800 t in 2030 under the BAU scenario. Figure 7 shows that a global emissions increase takes place in correlation with global bank growth as shown in chapter 4.2.

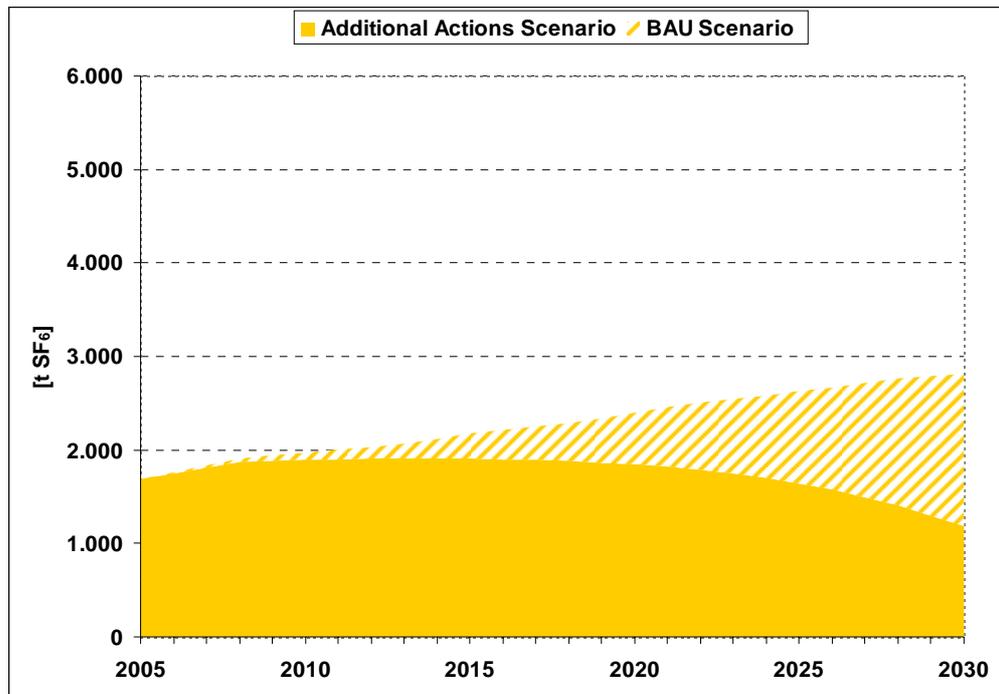


Figure 7: Global annual SF₆ emissions from electrical equipment 2005-2030

Clearly, the strong increase in emissions in the BAU scenario is not in correlation with the global necessity to reduce GHG emissions in order to reduce man-made climate change as much as possible. In the other hand, the estimated reduction of emissions in the additional action scenario, exceeds the required global reduction of GHG to achieve the goal of 450 ppm of CO₂ equipment in 2050. In such a way the contribution of the electrical industry to limit climate change would be positive.

4.3.1 Emissions during manufacturing

During the last 15 years, the manufacturing processes of the main global electrical equipment manufacturers have significantly improved in reducing SF₆ emissions. As a result, emission rates of the manufacturing phase declined in Europe from 8 % to 3 % between 1995 and 2003 [5]. Emission rates for manufacture also declined significantly in Japan during the last years (see Figure 8). In 1995, emission factors for manufacture reached almost 30 % in Japan. However, due to voluntary reduction measures the Japanese switchgear industry reached an annual emission rate of only 2.3 % in 2008. The emission reductions in Europe are also a result of voluntary programs from the recent past. In 2008, the emission rate for manufacture had already reached 2.2 %.

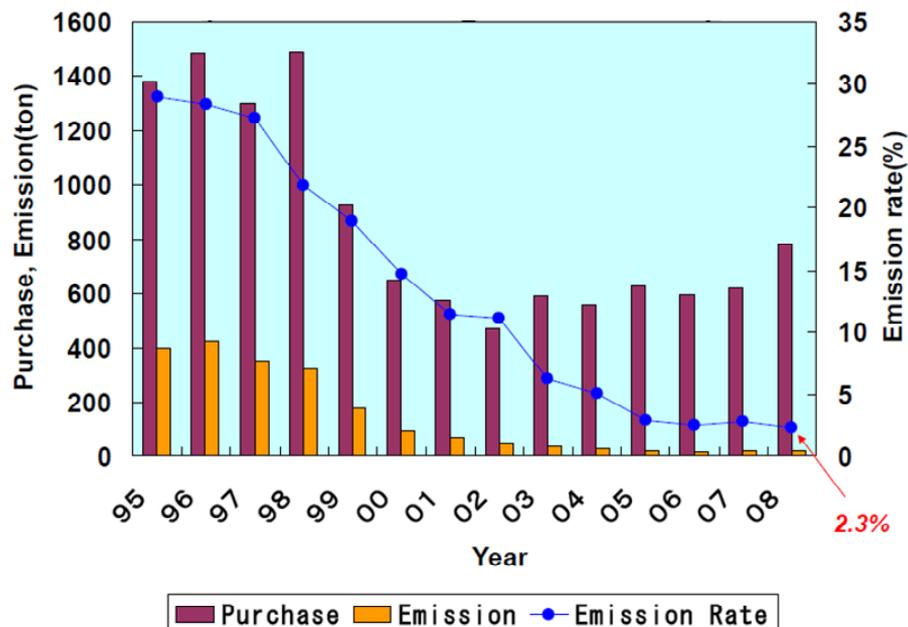


Figure 8: Emission development from manufacturing and installation in Japan (JEMA, 2009)

Europe and Japan are still the front-runners in terms of emission rates, but the USA are also picking up. However, emission rates for manufacture in 2008 are still reported at a level of 10 % in the national emission inventory of the USA, even if single manufactures already reach lower emission rates.

Historically, Japan and Europe supply most of the global demand for electrical equipment. Manufacturing in most other regions only plays a minor role and if production sites are located in those regions, they usually belong to Japanese or European companies. For those regions with production sites from western companies, an annual emission factor of 5.0 % is estimated.

This is different for China. Due to the growing energy demand in China and the rapid growth of the switchgear industry in recent years, (see chapter 4.2) several Chinese manufacturers have entered the market and it is expected that the Chinese electrical equipment industry will reach a market share of 50 % of the total global market in the coming years. As of today no awareness for SF₆ emissions during the manufacturing process exists in China, an annual emission rate of 15 % is assumed.

Annual emissions can be calculated by applying the afore-mentioned emission factors on the projected SF₆ consumption of electrical equipment manufacturers, as described in chapter 4.2.

Figure 9 shows the emission development for both the BAU scenario and the additional action scenario between 2005 and 2030. It becomes clear that emissions from manufacture will increase by more than 200 % of today's amount in the BAU scenario. If additional actions are implemented globally and the target emission rate as shown in Table 4 is reached, emission can be reduced by 80 % in 2030 compared to the BAU Scenario. Emissions would then fall below today's level.

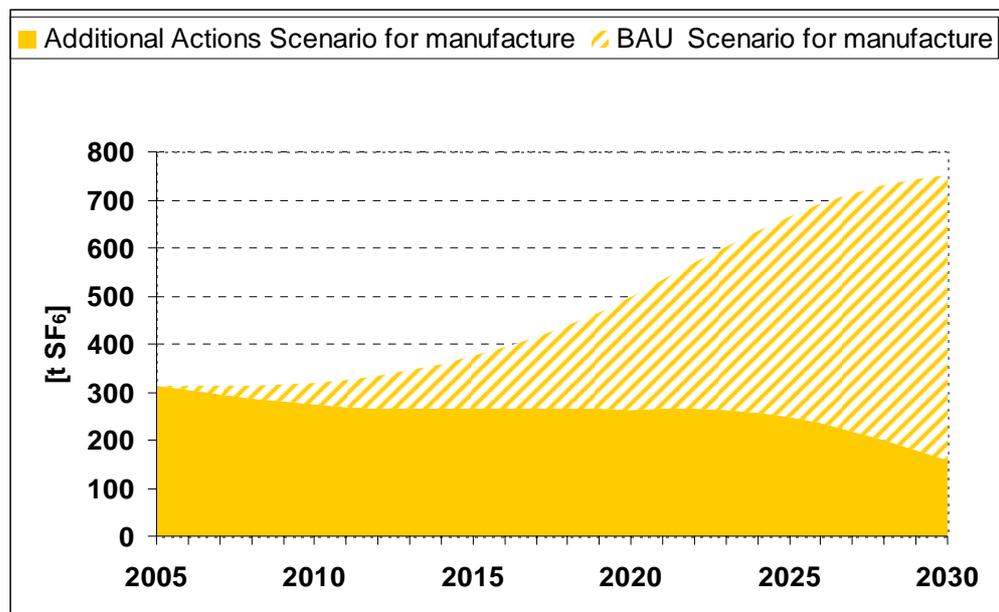


Figure 9: Global annual SF₆ emissions from manufacture 2005-2030

4.3.2 Emissions from the use-phase

As already described above, the data collection showed that the annual emission rates during use phase have already reached a level below 1.0 % in Japan. In Europe, the emission rates still remain slightly above 1.0 %, but are expected to decrease further in the coming years [5]. In North America, emissions from the use phase are still relatively high because of a high share of old equipment not designed for high tightness in the grids. According to the national greenhouse gas (GHG) inventory of the USA, emissions during use phase are slightly above 10%¹⁸ of the installed bank. However, several utilities in the USA participate in a voluntary reduction programme initiated by US EPA. The participating companies achieved an emission reduction from 15.2 % in 1999 to 5.5 % in 2007 [22].

Current emission rates for developing countries are estimated at a level of 5 % annually because although new equipment designed for high tightness is used in the grid, gas handling practices and individual staff awareness have not yet reached western standards.

Figure 10 shows that emissions during the use phase only increase slowly in the BAU scenario. The increase is smaller than the bank development shown in Figure 5, according to decreasing emission factors caused by progressively decommissioned old equipment that is replaced by new equipment designed for high tightness (see chapter 4.2).

When taking additional action, especially in developing countries, emissions from the use phase can be reduced to a level that is 25 % below today's global emissions from the use phase in 2030 compared to the BAU-Scenario.

¹⁸http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/usa_2009_crf_13apr.zip

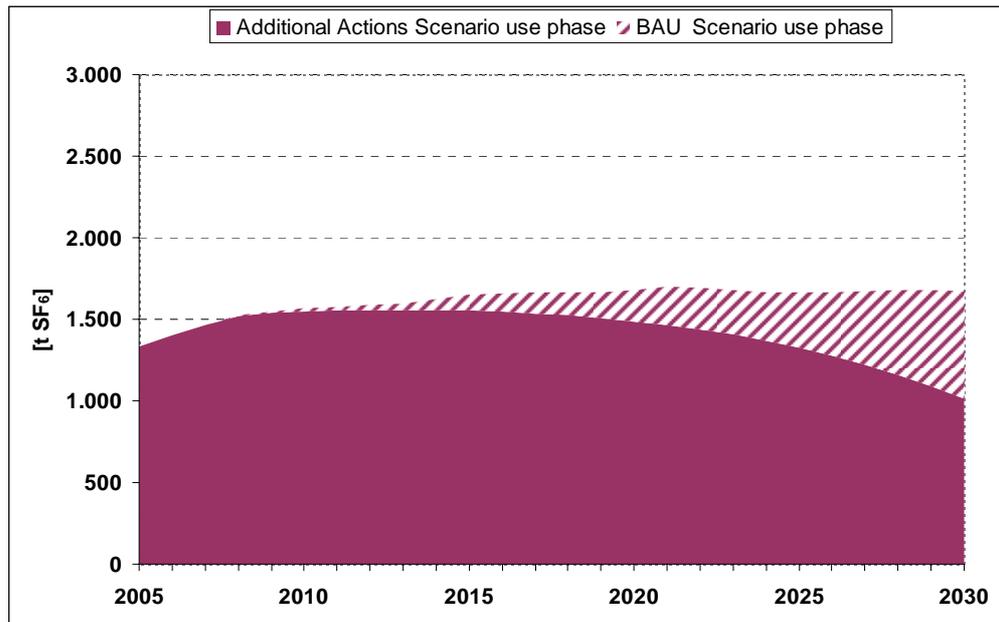


Figure 10: Global annual SF₆ emissions from the use-phase 2005-2030

4.3.3 Emissions from decommissioning

The emission rates for gas recovery in decommissioning have two drivers: the rate of correct decommissioning, i.e. where the gas is recovered instead of releasing it into the atmosphere (venting), and the amount of gas emitted during recovery for technical reasons.

Due to a lower level of awareness, in Europe a significant share of venting is assumed to have taken place in the 1990s. Based on information from the European manufacturers and users side the total emission rate for recovery in decommissioning was assumed to be 70 % of the SF₆ contained in decommissioned equipment in 1995. For 2003, an emission rate of 2 % has been determined for decommissioning in Europe due to increased awareness [5]. This emission rate reflects 100 % of equipment being decommissioned properly with a technically minimized gas loss of 2 % during gas recovery. Table 5 shows the best handling practices for gas recovery according to IEC/TR 62271-303.

Table 5: Recovering and reclaiming of SF₆ from any compartment of controlled and/or closed pressure systems [9]

Step		Procedure
1	Prepare SF ₆ handling equipment	Check that the SF ₆ reclaiming is properly working, the filters and pre-filters are still active, and the gas connections are clean and dry, hoses are evacuated and no leaks on connection fittings exist to avoid contamination. Check the validity of the calibration of instruments subject to calibration
2	Connect filters	Connect the pre-filter between the gas-filled compartment and the compressor and the filter between the compressor and the storage container
3	SF ₆ recovery	Connect the gas-filled compartment. Use the main compressor stage as soon as the SF ₆ residual pressure in the compartment approaches the pressure in the storage container. Use a safety valve and a calibrated gauge to avoid overfilling of the storage container (see NOTE)
4	Minimise residual SF ₆ content	Connect the auxiliary compressor stage when the SF ₆ residual pressure in the compartment approaches 100 kPa and leave it running until a pressure lower than 2 kPa is reached
5	Documentation	Record at least the manufacturer and serial number and/or the identification of the gas compartment, the reading and the date for further reference
6	Flooding with air	Disconnect the compressor and let the air enter slowly into the gas compartment.
7	Open the gas compartment	Carefully open the gas compartment. Apply safety rules according to 5.1
8	Remove solid by-products and adsorbers when present	Immediately use vacuum cleaner or wipe with a clean lint free rag to collect the solid by-products, if present. Place adsorber materials in a plastic bag. Seal the plastic bag with tape and tag it
9	Neutralisation, if required	If solid by-products were collected, use 10 % by weight soda solution or equivalent to wash and neutralise all parts and then wash with clean water, according to Table 6
<p>NOTE In the case of liquid storage the weight of the storage container is controlled in order to avoid overfilling. The filling factor is smaller than 0,8 kg/l for safety reasons.</p>		

These assumptions are also applied for Japan, Korea, Saudi Arabia, South Africa and Oceania. For North America, an emission factor of 5 % has been assumed for 2005. For the remaining regions, an emission factor of 70 % is applied. However, the high emission factor for developing countries in the remaining regions will have only a minor effect on the annual emissions, as the share of decommissioned equipment in these countries will remain very small until 2045 (see chapter 4.2).

Figure 11 shows the emission development until 2030, under the assumption that 100% of the disposed equipment reaches adequate recycling facilities at end of life as described in chapter 4.2.1. Figure 12 shows how emissions evolve in the case that only 80 % of the equipment is treated in a proper way at end of life and the remaining 20 % is vented into the atmosphere. Figure 12 shows that even in the additional action scenario, emissions increase by 350 % if a share of 20 % is not treated correctly after end of life. This clearly shows how important an efficient and interconnected global recycling system for SF₆ insulated electrical equipment is, to reduce emissions at the end of life. In this sense, awareness of users become essential to assure that 100% of the decommissioned equipment is correctly disposed of.

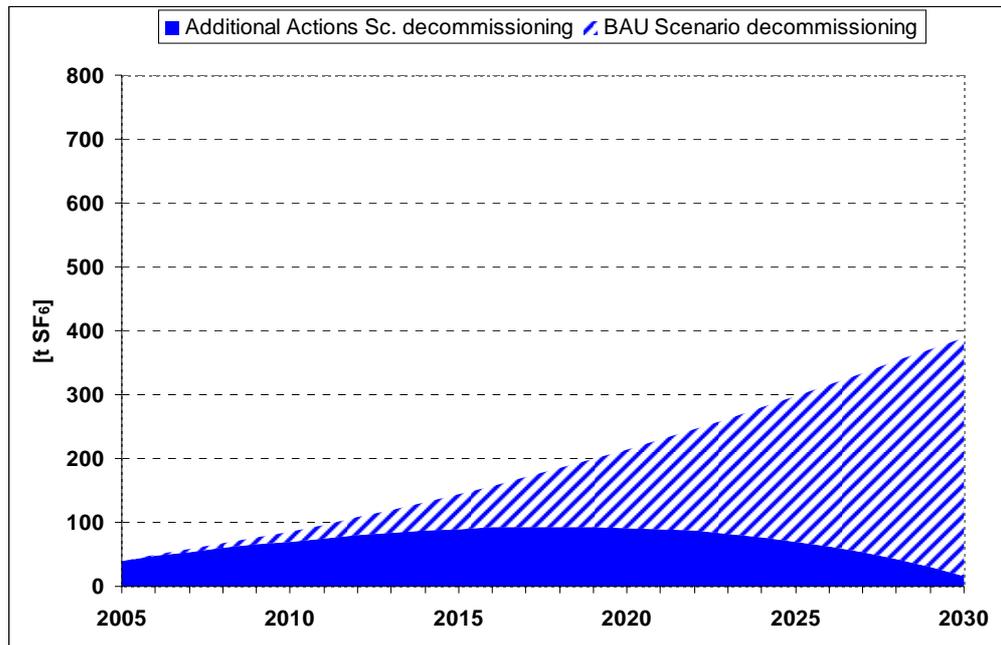


Figure 11: Global annual SF₆ emissions from decommissioning 2005-2030 (recycling quota 100 %)

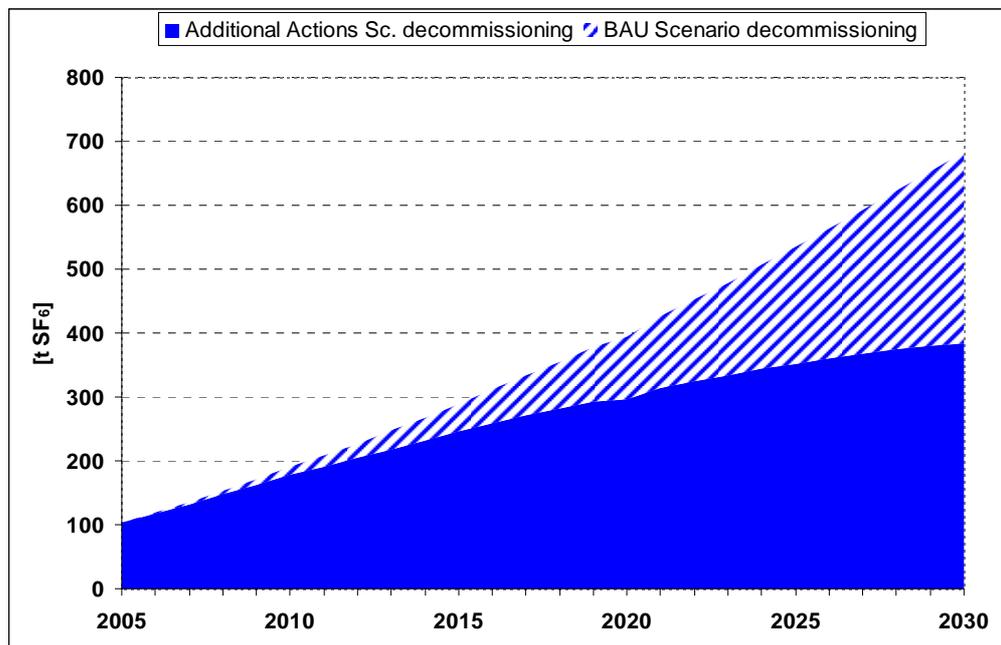


Figure 12: Global annual SF₆ emissions from decommissioning 2005-2030 (recycling quota 80 %)

Even if emissions from decommissioning under the BAU-scenario only play a minor role in comparison to the total life-cycle of electrical equipment, a significant emis-

sion reduction can be achieved in the additional action scenario if all disposed system reach an appropriate recycling facility and today's emissions can be halved by 2030. The impact of increasing amounts of equipment that requires decommissioning is more substantial after 2045, when globally bigger shares of electrical equipment require decommissioning (see Annex 3).

4.4 Sensitivity analysis for annual SF₆ consumption

As already described in chapter 4.2.2, the development of annual SF₆ consumption for the long-term is associated with high uncertainties. To demonstrate the sensitivity of annual SF₆ consumption by the electrical equipment industry, the emission figures above, are recalculated on the premise that annual SF₆ consumption is either 25 % above or 25 % below the above shown figures. Figure 13 shows the global total SF₆ emission development from electrical equipment for the different consumption scenarios in the period 2005-2030. All figures are created assuming that 100 % of the equipment reaches proper recycling facilities at end of life.

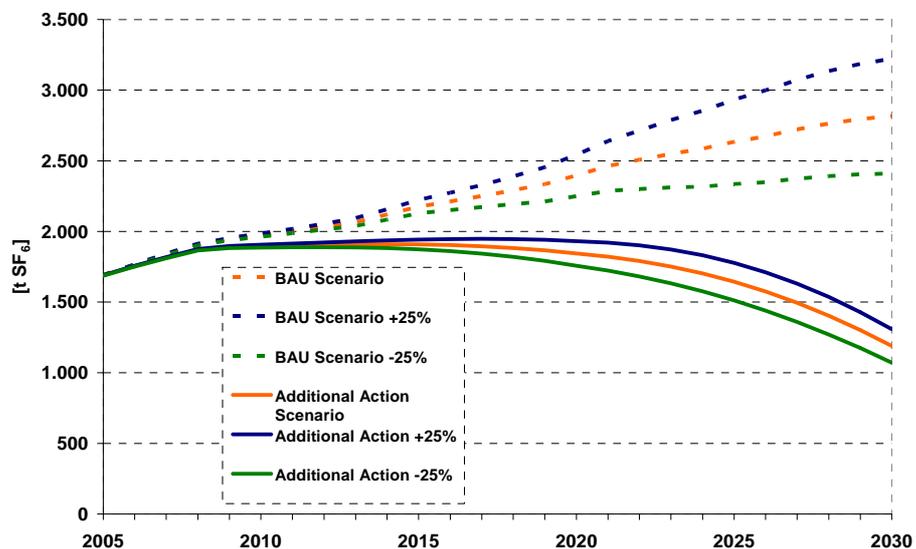


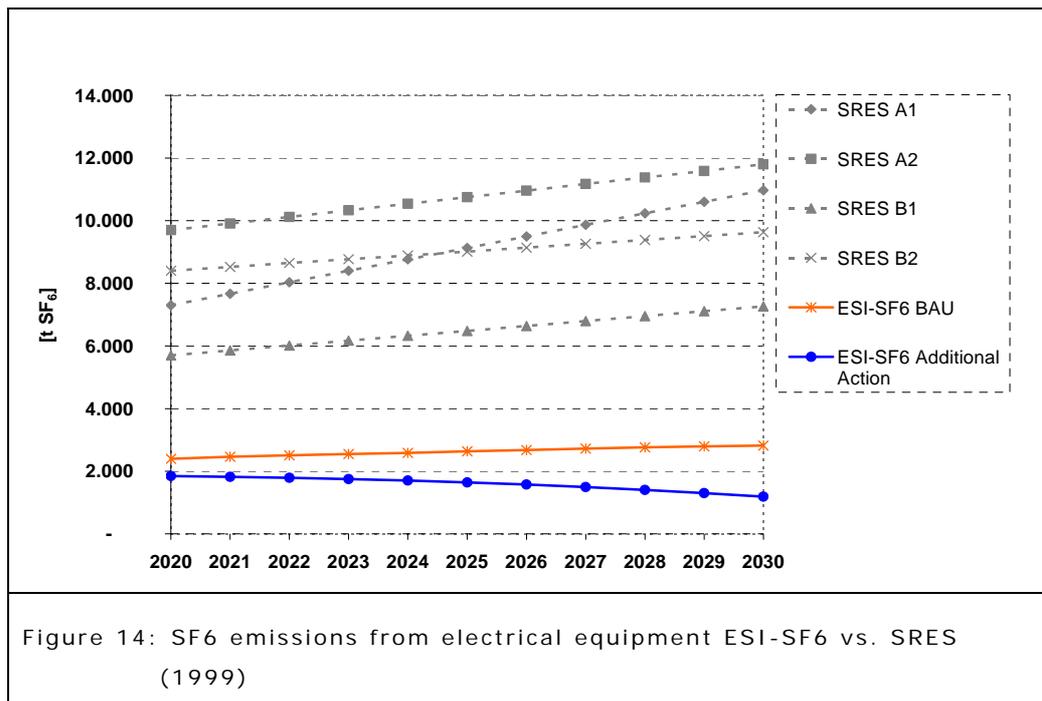
Figure 13: Sensitivity analysis for global total SF₆ emissions from electrical equipment 2005-2030

Figure 13 clearly shows that the sensitivity of the annual SF₆ consumption remains relatively small. Through changing the annual SF₆ consumption by 25 %, the total emission development only changes by approximately 15 % under the BAU scenario. The influence of the annual amount of consumed SF₆ becomes even less important under the additional action scenario, as an increase in the implementation of additional actions reduces the emissions sensitivity to SF₆ gas consumption. Emissions in 2030 then vary by only. ±10 %.

4.5 SF₆ emissions and the IPCC scenario process

The latest emission scenarios for SF₆ stem from the Special report on Emission scenarios (SRES) prepared by the IPCC in 2000. They show the global SF₆ emission development only on an aggregated basis, meaning that SF₆ emissions from various sources like the semiconductor industry, magnesium industry, electrical equipment industry and military applications are shown all together. In 2003, the IPCC decided to develop new emission scenarios until 2012/2013. These scenarios shall present the global greenhouse gas emission development for the “near term” until about 2035 and the long term until 2100.

The new IPCC scenario process is run much more decentralised than the IPCC SRES process. The IPCC has only a facilitating role of the work of a range of modelling groups. The report at hand wants to provide the relevant emission scenarios for SF₆ emissions from electrical equipment. Figure 14 below shows the result of this study in comparison to the SRES scenarios¹⁹.



It becomes clear that emissions from electrical equipment, depending on what scenarios are used for comparison, are only responsible for 10.0 % to 38.7 % of global total SF₆ emissions. This underlines the need of further research also for other emission sources than electrical equipment.

¹⁹ A detailed scenario description of the SRES scenarios can be found on page 48.

5 Conclusions

The aim of this report is to provide detailed information on the future development of SF₆ emissions from high and medium voltage electrical equipment at the global level. This chapter summarizes the global emission projections and compares the results with other emission scenarios from the recent past.

Emission Projections

The scenario calculations show that global SF₆ emissions are projected to rise by almost 100 % under the BAU scenario until 2030. The increase between 2005 and 2030 is mainly a result of the significant increase in the global electricity demand during this period, which then leads to the significant expansion of transmission and distribution networks, especially in developing countries. In 2030, the electricity demand is predicted to stabilize but emissions will continue to increase under the BAU scenario due to further growing banks and growing numbers of equipment that reaches end of life and has to be decommissioned. (see Figure 15). The immense SF₆ emission increase under the BAU scenario clearly needs to be addressed in order to contribute to global efforts on reducing climate change. As the additional action scenario shows, that if the already existing reduction measures, as used e.g. in Japan and the EU, were applied at a global level, this would be sufficient to avoid emission increases and even allow emission reductions compared to 2005.

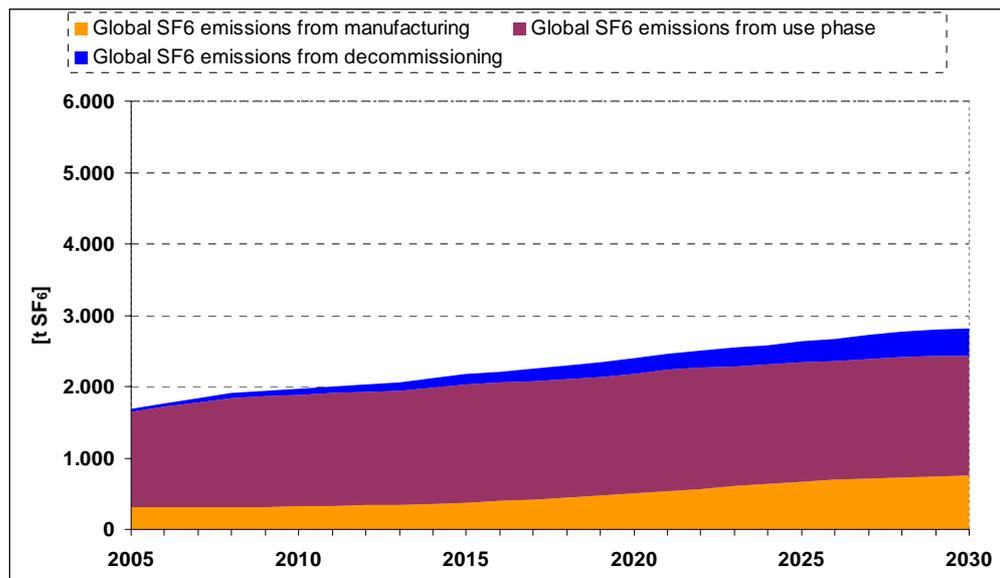


Figure 15: Global annual SF₆ emissions from electrical equipment 2005-2030 under the BAU scenario

Figure 16 shows the emission development under the assumption that the global electrical equipment and electricity industry applies worldwide BAT standards for manufacturing, use and decommissioning of electrical equipment.

The regional assessment identifies an overall reduction potential of 65 %, if developing countries achieve western emission standards and the USA also follows the recent trend of decreasing emissions. If appropriate measures are applied globally, the current global emissions from electrical equipment can already be reduced by 30 % until 2030, despite the projected increases in global electricity demand and significant bank growth.

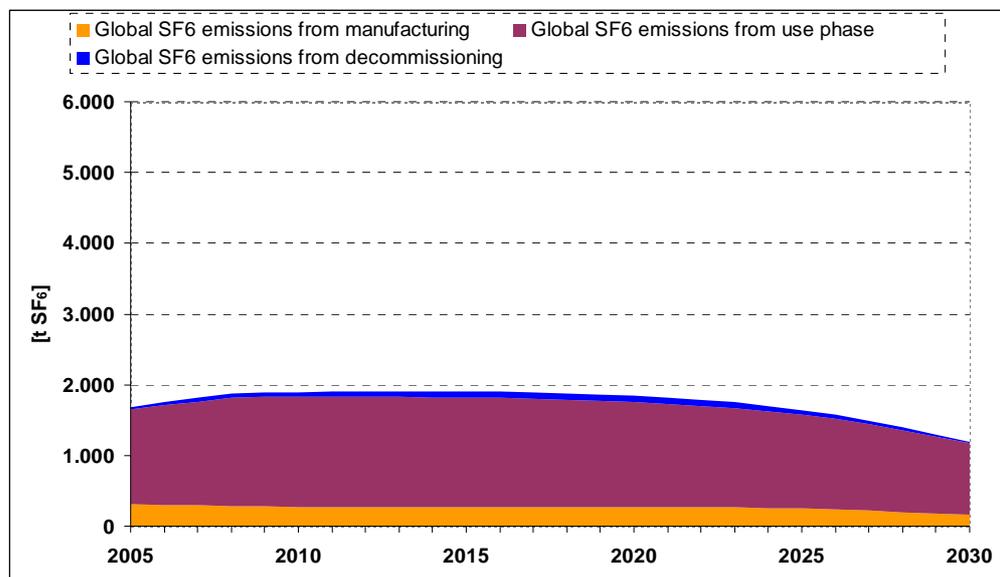


Figure 16: Global annual SF₆ emissions from electrical equipment 2005-2030 under the additional scenario

The emission development under the additional action scenario might be perceived as an ambitious target for the global electrical equipment industry. However, the record of emission reductions achieved in Europe and particularly in Japan, demonstrates that by implementing voluntary emission reduction programs, significant emission reductions are achievable over a period of less than 15 years. Through these voluntary agreements, the electrical equipment industry has always been a frontrunner by extending its achievements beyond the necessary regulations. It is of great importance to maintain this spirit and raise awareness for the need for action with the global electrical equipment industry and for users of SF₆ equipment to support the implementation of appropriate reduction measures, especially in major developing countries like China, India, Russia, Brazil or Mexico.

Comparison to projections from other studies

To further reinforce the scenario calculations, Figure 24 and Figure 26 show the SF₆ emission scenarios calculated by the US EPA from 2005 [4]. When comparing US EPA's scenarios with the calculated BAU scenario, a similar growth trend can be identified. Our recent calculations show that emissions are approximately the same in 2020 and will rise by a further 10 Mt CO₂ eq. until 2030.

To gain a comprehensive impression of how our calculations can be seen in respect to the total emissions of all SF₆ emitting appliances and processes, Figure 27 illustrates the SF₆ scenarios from the IPCC Special Report on Emissions Scenarios (SRES scenarios) from 1999, which show emission projections until 2100 [3]. The ESI-SF₆ BAU emissions in 2100 account for 20 % to 100 % of the SF₆ emissions calculated in the SRES scenarios for that year. Thereby it becomes obvious that the global electrical equipment industry is a major source of SF₆ emissions. Taking this into account, a clear need to assess all relevant SF₆ emissions sources separately is identified. If only aggregated SF₆ emissions from different emissions sources are considered, this might lead to an incorrect picture of the different SF₆ emitting sectors. A clear picture is however, highly relevant when aiming to identify a need for action for single sectors.

With regard to the ongoing IPCC scenario process, which aims to provide updated emission scenarios for all major greenhouse gases, it is recommended that the presented emission scenarios of this report are used as an important data source for future emissions estimates under the umbrella of the IPCC. Furthermore, future efforts should also be focused on generating a solid database from developing countries with a strong economic growth such as China and India because these countries will predominantly determine future emission development from high and medium voltage electrical switchgear.

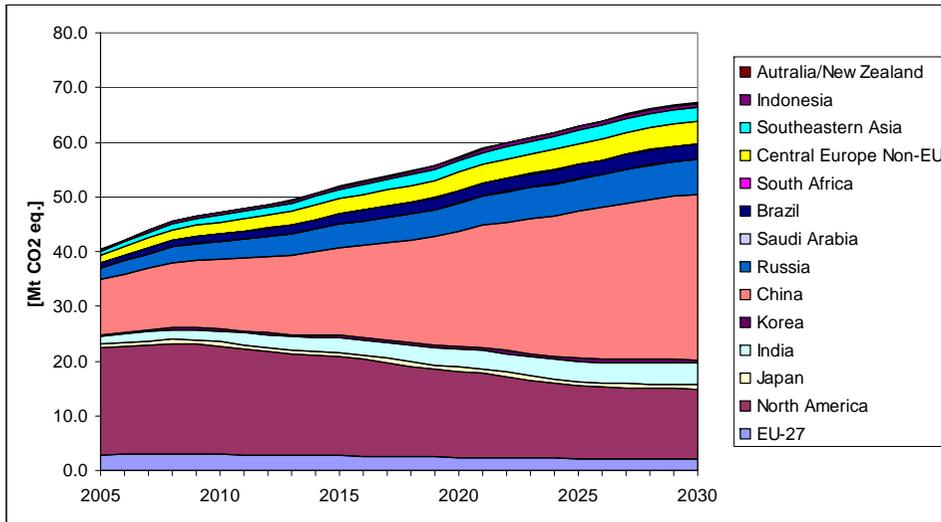


Figure 17: Regional annual SF₆ emissions from electrical equipment under the BAU scenario 2005-2030

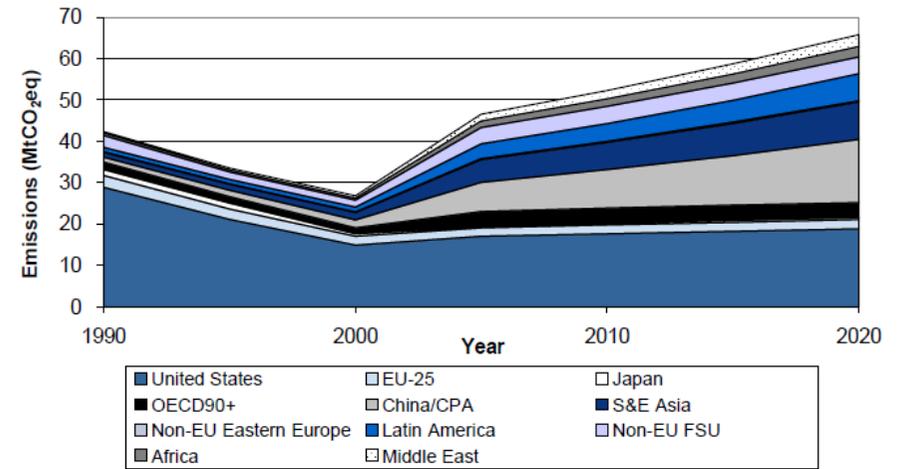


Figure 18: US EPA No-action scenario for SF₆ emissions from electrical equipment 1990-2020 (US EPA 2006)

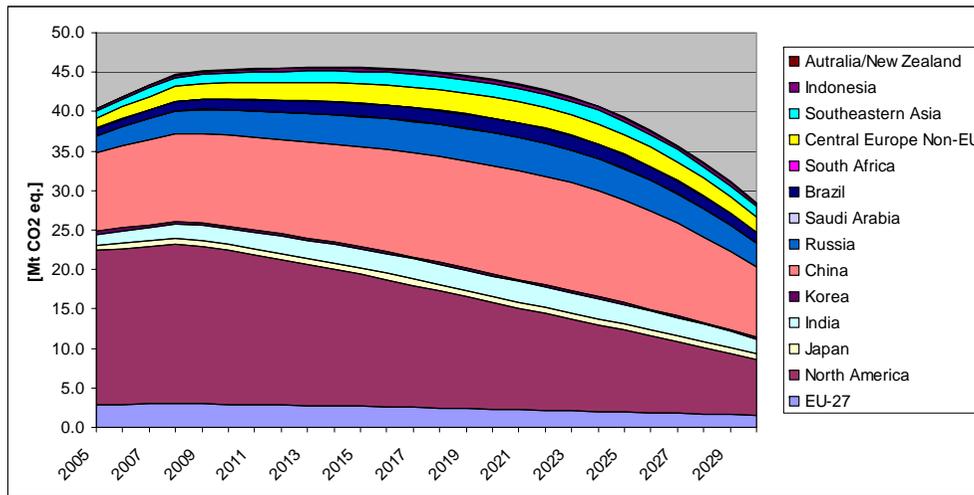


Figure 19: Regional annual SF₆ emissions from electrical equipment under the additional action scenario 2005-2030

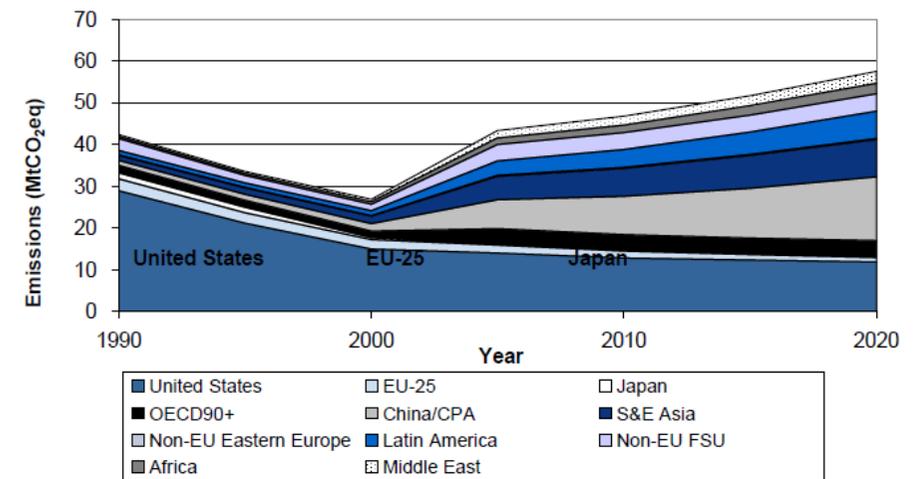


Figure 20: US EPA Technology Adoption scenario for SF₆ emissions from electrical equipment 1990-2020 (US EPA 2006)

IPCC - SRES SF₆-Emissions Scenario²⁰

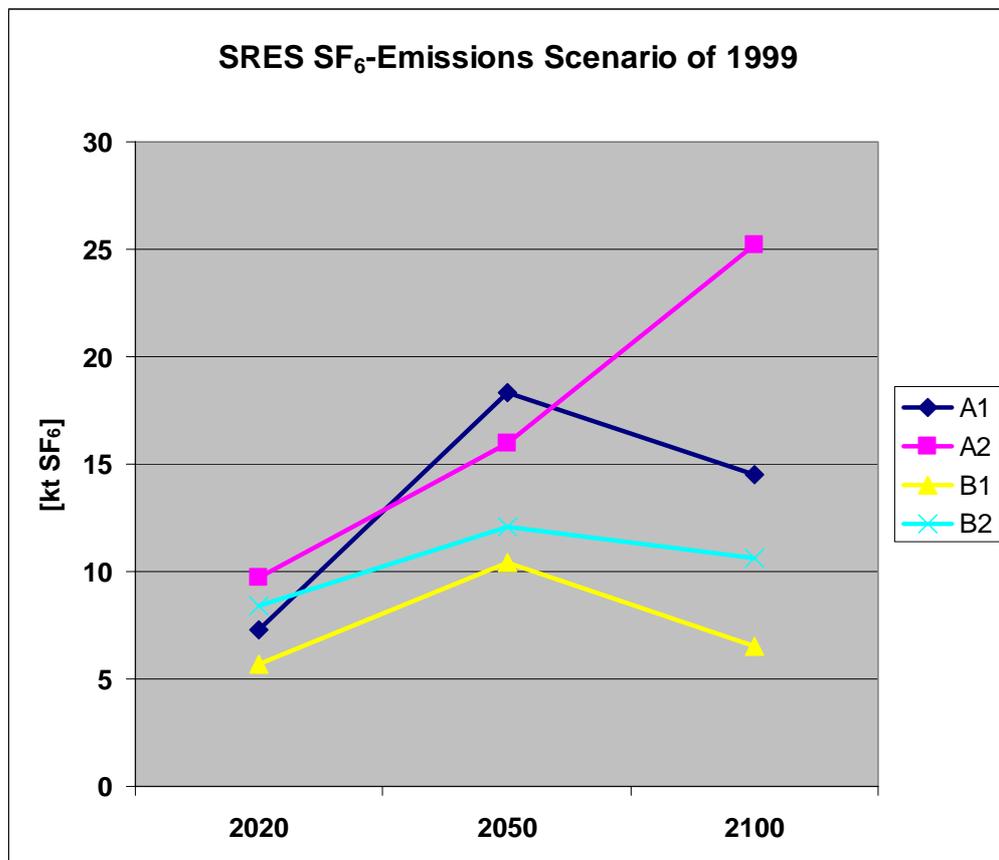


Figure 21: SRES SF₆ emission scenario (Fenhann, 1999)

Scenario description

- **The A1 storyline** and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.
- **The A2 storyline** and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines.

²⁰ <http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0>

- **The B1 storyline** and scenario family describes a convergent world with the same low population growth as A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- **The B2 storyline** and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. Although the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

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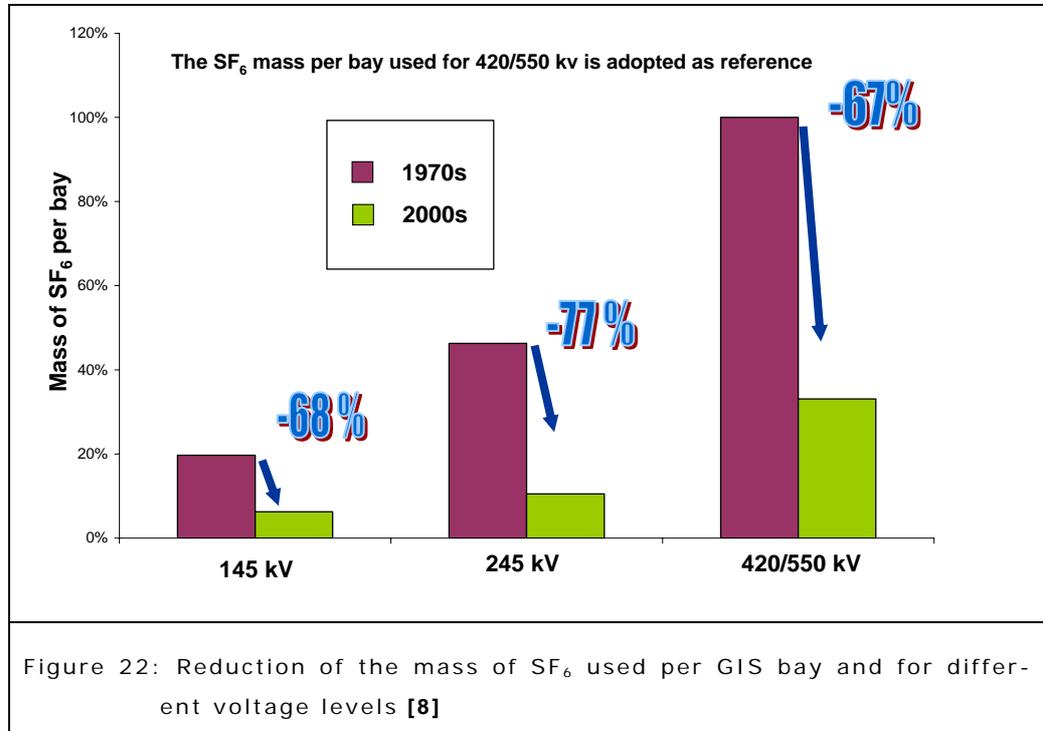
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Annex 1: Abbreviations

CIGRE	International Council on large electric systems
CO ₂ eq.	CO ₂ equivalent
ESI-SF ₆	Ecofys Emission Scenario Initiative on Sulphur Hexafluoride
GHG	Greenhouse gas
GDP	Gross Domestic Product
GWP	Global Warming Potential
HV	High voltage
JEMA	Japanese electrical manufacturers association
kt	kilo (1000) metric tonnes
MV	Medium voltage
NEMA	National electrical manufacturers association (USA)
OECD	Organisation for Economic Co-operation and Development
t	metric tonnes
T&D Europe	European Association of the Electricity Transmission and Distribution Equipment and Services Industry
UNFCCC	United Nations Framework Convention on Climate Change

Annex 2: Additional figures



Annex 3: Emission Development 2030-2100

Estimating long-term global SF₆ emissions from electrical equipment carries a number of uncertainties, because several questions can not be easily answered at present. One of the main questions will be, how the global electrical equipment industry will be positioned when the electrification of the global society reaches saturation and when this saturation will occur.

In the following figures, it is assumed that market saturation will be reached around 2030. The CAPIEL report from 2005 showed that the European electrical equipment market reaches saturation around the year 2010. Due to lack of similar information from other market regions, it is assumed that markets in the rest of the world and especially in developing countries will reach saturation when the enormous capacity additions for electricity production are installed in 2030 (see chapter 4.2.2). At this point of time industry's SF₆ consumption peaks and will then slowly decline until 2100.

Global SF₆ emissions from electrical equipment are projected to rise with the same speed from 2030 to 2070, due to further bank growth and significant amounts of SF₆ that have to be decommissioned. Figure 13 shows that emissions under the Additional Action scenario also increase slightly after 2030, but will be only slightly above 2005 levels, despite the SF₆ bank that will still be growing until 2070.

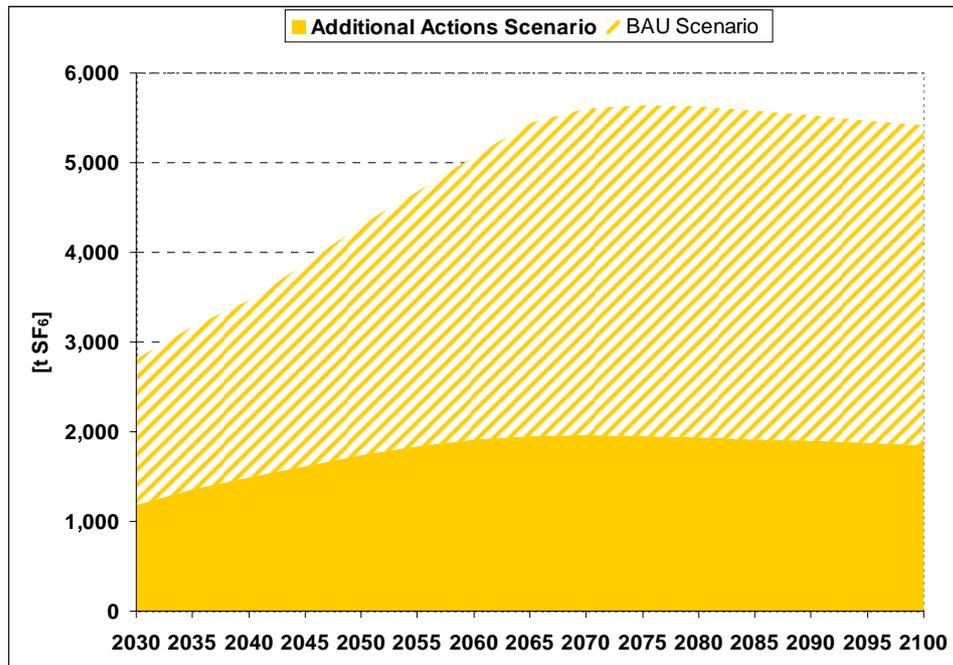


Figure 23: Global SF₆ emissions from electrical equipment 2030-2100

Emissions during manufacturing 2030-2100

Figure 14 shows the emission development from manufacturing between 2030 and 2100. When applying annual emission factors for manufacturing to the global SF₆ consumption, as shown in Figure 3, the annual emissions from manufacturing decline slightly until 2100 under the BAU scenario due to decreasing amounts of annual SF₆ consumption (see chapter 4.2.2).

If BAT standards for manufacturing can be achieved until 2030, emissions under the additional action scenario will remain stable at those 2030 levels until 2100. Under the Additional Action Scenario, manufacturing emissions contribute to approximately 8 % of the global total annual SF₆ emissions from electrical equipment.

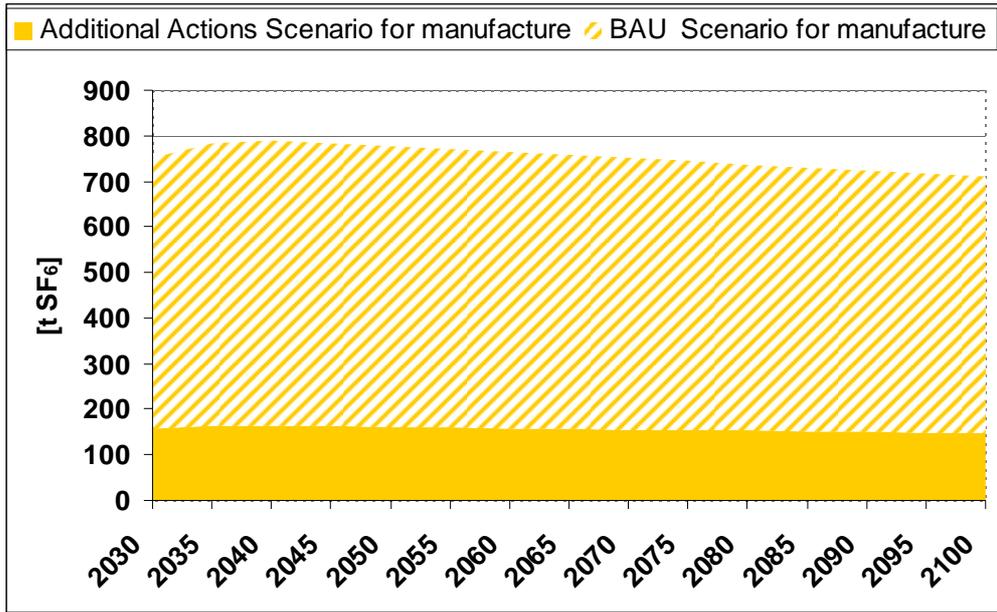


Figure 24: Global annual SF₆ emissions from manufacture 2030-2100

Emissions from use phase 2030-2100

Figure 15 shows the projected emission development from the use-phase of electrical equipment from 2030-2100. It is assumed that global banked SF₆ in electrical equipment will peak around the year 2060 (see chapter 4.2.2). Accordingly, emissions under the BAU scenario will continue to grow until 2060. In line with growing SF₆ banks, emissions from the use phase increase again even under the additional action scenario. The increase occurs because it has been assumed that after 2030, no further improvements in the SF₆ technology are achievable, because best available techniques (i.e. standards for manufacturing, use and decommissioning of electrical equipment) will reach their optimum in 2030. Certainly, research on further improvements of the SF₆ technology will not simply stop after 2030, but from today's perspective, those results are very difficult to predict for the long-term.

The reduction potential under the Additional action scenario for the period 2030-2100 is about 40 %. However, in both scenarios emissions from the use phase are responsible for the largest share of total emissions, ranging from 60 % to 80 %.

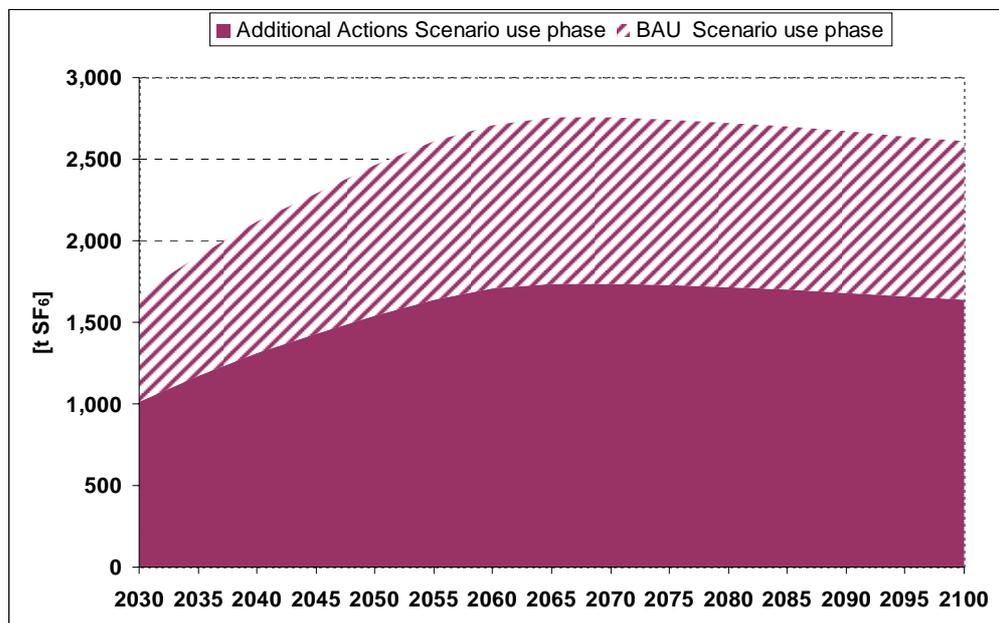


Figure 25: Global annual SF₆ emissions from the use-phase 2030-2100

Emissions from decommissioning 2030-2100

Decommissioning of electrical equipment – which is then replaced by new equipment - is becoming increasingly relevant after 2045. Globally, the steadily increasing amounts of SF₆ that have been installed from 2005 onwards are then disposed of. This leads to a significant increase in emissions under the BAU scenario, as shown in Figure 16. Accordingly, emissions under the BAU scenario in 2100 will be 5 times higher than in 2030 if all equipment reaches the proper recycling facilities at end of life.

A rather small increase of approximately 50t SF₆ in the period after 2045 can also be noticed in the additional action scenario. However, if the recycling industry reaches the BAT target of a 0.9 % emission rate from decommissioning, these emissions will continue to play a minor role also on the long-term, always assuming that 100 % are treated properly at end of life.

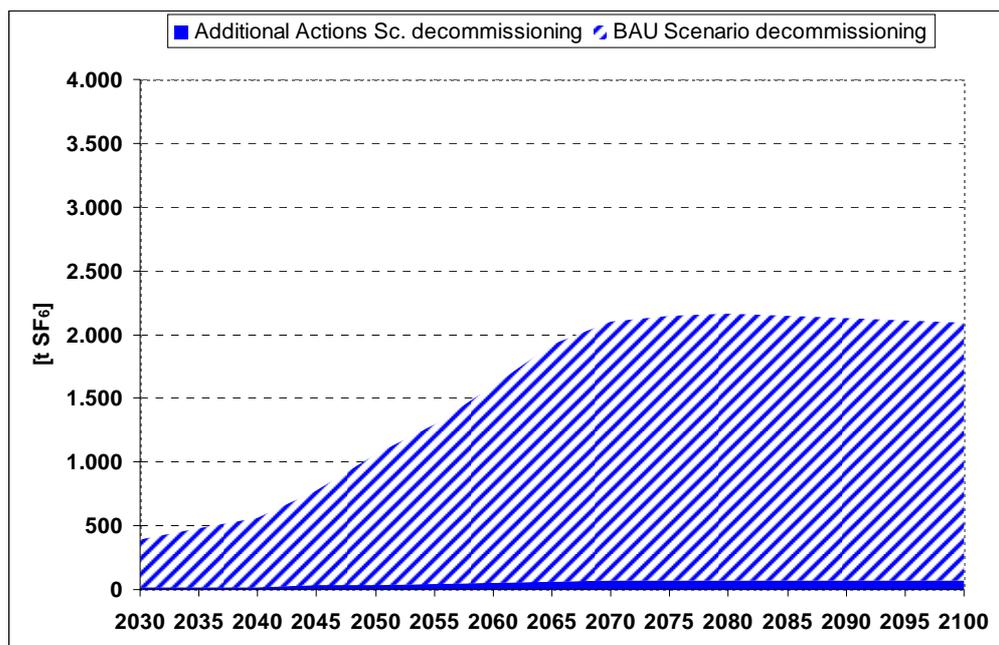


Figure 26: Global annual SF₆ emissions from decommissioning 2030-2100 (recycling quota 100 %)

Figure 27 shows that emissions in both scenarios increase significantly if only 80 % of the disposed equipment reaches proper recycling facilities at end of life. Emissions under the BAU scenario only increase by 150 %. Emissions under the additional action scenario will dramatically increase and lay more than 20 times above the projected emissions in the scenario where all equipment is properly recycled at end of life.

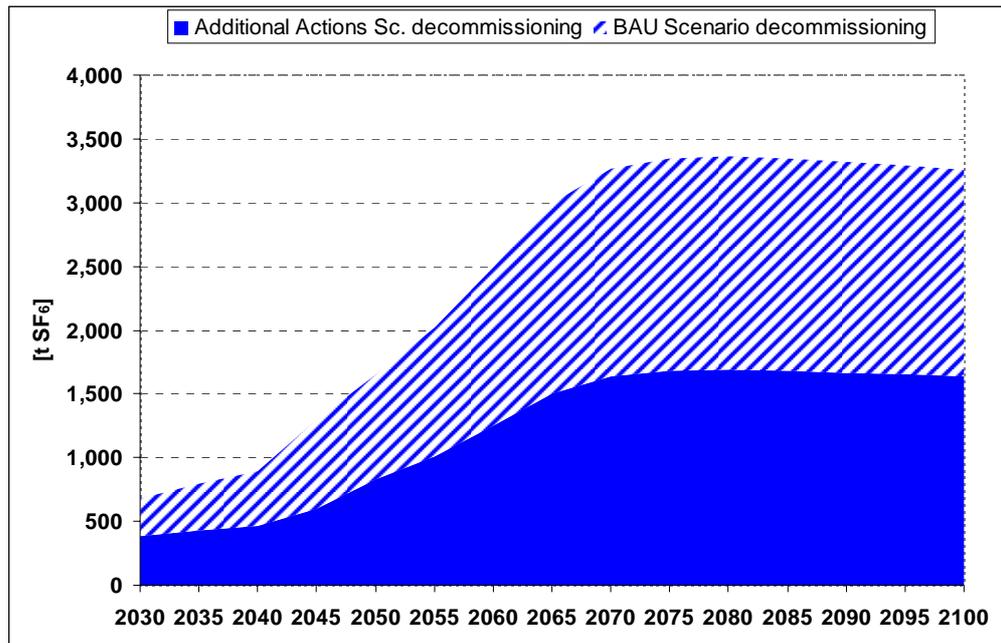


Figure 27: Global annual SF₆ emissions from decommissioning 2030-2100 (recycling quota 80 %)