

SWITCHGEAR AND SF6 GAS

INDEX

1	Why use SF6?	1
1.1	Relevant characteristics for its application in switchgear	1
1.2	Basic design requirement. Gastight enclosure	1
1.3	Environmental impacts	4
1.3.1	<i>Impact of the SF6 switchgear in the greenhouse effect ..</i>	4
2	Responsible use of the SF6	5
2.1	Assuming the responsibility to minimise emissions	5
2.1.1	<i>Design</i>	5
2.1.2	<i>Manufacturing</i>	6
2.1.3	<i>Installation</i>	6
2.1.4	<i>Operation and maintenance</i>	6
2.1.5	<i>End of life recycling policy</i>	7
2.2	Voluntary actions / Agreements	7
2.3	Evaluation of emissions	8
3	Summary and conclusions	9
4	Glossary	11
5	Bibliography	12

Annex 1. INVENTORY METHODOLOGY

Annex 2. EXAMPLES OF CALCULATIONS

Annex 3. EXAMPLES OF COMPARISON WITH OTHER ACTIVITIES

SWITCHGEAR AND SF6 GAS

1 WHY USE SF6?

1.1 Relevant characteristics for its application in switchgear

Since 1960, SF6 has been used as arc quenching and insulating medium for high and medium voltage switchgear systems. The favourable electrotechnical, chemical and physical characteristics of the gas have considerably influenced the development of the switchgear technology.

SF6 is an alternative to other conventional insulating and quenching media such as e.g. oil, and air. The use of SF6 gas considerably increases, in some applications, the efficient utilisation of resources in energy transmission and distribution with respect to technology, finances and personnel [1]. At the same time SF6 in comparison to oil reduces the risk of hazard (e.g. fire, explosion) to personnel and environment.

An overall evaluation considering all ecological, economic, safety and technological aspects has proven that SF6 is still an excellent choice as insulating medium [2]. The existing SF6 technology in the field of energy transmission and distribution is the result of decades of optimisation and contributes essentially to the further development of the economically efficient power distribution.

1.2 Basic design requirement. Gas-tight enclosure

SF6 is used in different types of electrical switchgear:

- Modern, state of the art, High Voltage and Extra High Voltage switching devices (e.g. circuit breakers) use SF6 as an arc-quenching medium, almost exclusively. More integrated solutions, like the Gas Insulated Switchgear (GIS) use the gas not only as arc-quenching medium but as insulation as well.
- In the Medium Voltage range circuit breakers, switches, etc., using different quenching media including SF6, are normally installed inside a metal enclosure (traditional metal-enclosed switchgear). Another design is the SF6 insulated metal-enclosed switchgear, where the SF6 gas provide the main insulation of the equipment. Vacuum or SF6 interrupters can be used. A particular case, broadly used in the public secondary network, is the SF6 insulated Ring Main Unit (RMU). In this type of equipment switching devices are contained in a single enclosure, where the SF6 gas ensures simultaneously two tasks: general insulation and arc-quenching. It gives to the equipment a great simplicity, compactness, reliability and safety.

In all these types of equipment there is a common design requirement. Gas-tight enclosure is a functional and essential requirement, for obvious reasons.

Although the International Standard IEC 60694 still describes three different types of pressure systems when qualifying the tightness of the enclosure, nowadays switchgear design is based on only two of these pressure systems:

- Closed pressure systems, which can be re-filled periodically. IEC 60694 allows two standardised relative leakage rates of 1% and 3% per year. The present generation of switchgear is according to the 1% criteria.
- Sealed pressure systems are designed and manufactured to have no emission. Therefore they do not need to be refilled during the expected operating life (generally 20 to 40 years).

In High Voltage Switchgear, both economical and functional/operational reasons make the SF6 usage as arc-quenching medium the only practical choice.

At Medium Voltage level most frequently used quenching systems are SF6 and vacuum. Air or oil switching devices are still also available, although they can present some disadvantages or limitations: economical in some cases, functional in other cases (performance, expected service life, maintenance requirements, risk of fire, etc.).

In the case of SF6 insulated switchgear the combination of the outstanding characteristics of the gas with the gas-tight metal enclosure, following features are available.

- Low operating energy for the switching devices.
- No risk of fire.
- Not toxic hazard. (See IEC 61634, Annex C) [3]
- Independence of the installation site altitude, allowing the use of standard products at altitudes higher than 1000 m above sea level.
- High protection against ambient conditions resulting in two very important properties:
 - Contaminant conductive deposits can not build up to degrade solid insulators, so preventing one of the most frequent causes of serious failures.
 - Electrical contacts are protected against chemical corrosion that can reduce their performance, and potentially lead also to a final failure of the equipment.
- The level of partial discharges will not increase during operation. Therefore deterioration of insulation material by radiation and chemical reactions due to

partial discharges will not occur. As a result the full dielectric properties will remain practically on the level of new equipment over the total service life time. In fact the dielectric withstand capability of all live-parts of the switchgear is not prone to ageing.

Due to all these features a number of benefits for the installation can be listed:

- Very limited space required for installation.
- Favourable ergonomic conditions, due to the small volume and relatively light weight.
- Easy choice of optimal installation site (independent to prevailing environmental local conditions, close to the electrical load demand, etc..). SF6 insulated switchgear are used, for example, in places subjected to hazard of flooding, or underground.
- Recommended use in severe climatic conditions (sea shore, heavy industrial pollution, etc.)

Additionally some operational benefits can be achieved, for example:

- Extremely low probability of failure, due to the good performance level, and the protection of the insulating system from any degrading influence.
- Low maintenance, for the same above mentioned reasons.
- Long service life.
- Low operating energy, making easy to implement remote control and/or automation schemes. This -in turn- can contribute to a fast restoration of the service after a fault in the network.

Further, several socio-economic benefits are derived:

- Moderate consumption of material resources (plastic, metals, etc.) [2].
- Relatively low cost of first installation and operation.
- High continuity of service.
- Low visual impact, which makes easier the social acceptance of the installations.
- Safety for the public and property, due to the low probability of serious failures, limitation of fire hazard, etc.

- Efficient design of the power supply system. In fact the location of the equipment optimally with respect to the local demand, reduces the losses of energy with a double result: better technical and economical performance of the network and less energy generation with its environmental side-effects [1].

1.3 Environmental impacts

The reduction of the size of the switchgear, compared to conventional designs (open type and metal-enclosed air-insulated switchgear) allows a reduction of material required. In general the reductions are usually very important not only in structural materials but also in solid insulating materials and electric conductive active parts.

In the other hand the use of SF6 switchgear, requiring less dimensions of busbars and electric conductive active parts of the switching devices will reduce the energy losses by Joule effect in the switchgear itself. At the same time, the possibility of installing the compact equipment closer to the load demand, makes the network itself more efficient reducing the losses. This is, therefore, an indirect reduction of energy use by the application of SF6 switchgear in the network.

From the point of view of the local environment, the Technical Report IEC 61634 [3] shows that no significant air toxicity hazard is derived by the use of SF6. Additionally the gas can not contaminate the soil and the water. At the end of life the small amount of solid decomposition-products can be easily transformed into natural occurring substances that can be disposed without hazard to the environment.

SF6 does not contribute to the ozone layer depletion, because it does not contain chlorine. [3] [4]

Special attention is paid to the impact on the Greenhouse effect due to the high global warming potential of the gas.

1.3.1 Impact of the SF6 switchgear in the greenhouse effect

Extensive inquiries and data provided by CAPIEL HV have established a reliable information [5] [6] about the situation in the European Union (15 countries).

- SF6 banked in switchgear in service about 4.000 t. in 1995.
- Quantity of SF6 purchased by manufacturers to produce new switchgear about 1.000 t (more than 2/3 of this quantity is used to fill switchgear exported out of the EU).

- The emission during manufacturing process, erection on site and commissioning (within the EU) was estimated to amount 90 t. (ECCP Report)
- On the other hand emission from switchgear in service was evaluated by the utilities to be 120 t.
- Therefore the total emissions in 1995 were 210 t.

In the same base year of 1995 the corresponding situation in the world was estimated as follows [7]:

- Total SF6 banked in switchgear in service 27.500 t.
- Emission world-wide related to switchgear about 2.700 t.

The atmospheric measurement carried out in 1995 showed a worldwide total emission of 6200 t of SF6 that year [8].

Based on the above data, and the available information about the emissions of the other Greenhouse gases (expressed in CO2 equivalent), the contribution to the Greenhouse effect of SF6 emissions related to electrical switchgear was in 1995 only about 0,1%. [6] [7]. A contribution of this size is considered negligible. (See also Annex 2 and Annex 3).

2 RESPONSIBLE USE OF THE SF6

Nowadays within R&D of electrical systems new tools dealing specifically with environmental objectives are available providing a more rational and scientific approach.

Specific analyses within R&D are devoted to improve safety, reliability and environmental efficiency.

2.1 Assuming the responsibility to minimise emissions

2.1.1 Design

Improved designs processes already implemented by the industry and supported by CAPIEL are focusing on the aspects such as the following examples:

- to reduce the environmental impact of processes by applying the best available technology compatible with available resources.
- to use the principles of risks assessment, such as per Failure Modes and Effects Analysis, or equivalent.

- to apply principles of Design for Environment.

The following ones are some examples of typical design measures adopted by the industry:

- Promotion of the sealed pressure system concept, where possible, mainly for Medium Voltage application.
- Use of hermetically tight welded enclosures or certified quality casting, as appropriate.
- Reduction of the quantity of SF6 gas per unit.
- Use of static and dynamic sealing high quality materials.
- Use of dynamic sealing redundant systems.
- Provision of means designed for a proper recovery operations.

2.1.2 Manufacturing

The principles of responsible environmental management based on such as ISO 14001 are in the process of being adopted by the industry. This will cover aspects such as:

- waste prevention and minimisation
- control of emissions in air and in the water
- energy management in the production processes
- health and safety in the working environment

2.1.3 Installation

The installation phase is performed by qualified personnel properly equipped in order to fulfil the same quality and environmental procedures applied to the manufacturing processes.

2.1.4 Operation and maintenance

The adoption of tools such as Failure Modes and Effects Analysis or Reliability Analysis minimise the need for monitoring and maintenance for modern electrical systems. For SF6 switchgear two classes are available today: sealed and closed pressure systems. For the first one no need for any refilling is required during the whole life cycle; consequently no monitoring or maintenance is needed. In the second case each

compartment can be equipped with density monitoring devices alerting and ultimately preventing gas losses. In case of repair, the maintenance operations including SF6 handling and operational procedures shall be in accordance with IEC 61634 requirements.

2.1.5 End of life recycling policy

Electrical systems are generally composed by metallic and insulating materials easily recyclable with associated economic advantages. It is consequently an economic opportunity to recover and recycle most of the used components. As SF6 is an expensive gas and is characterised by an high degree of stability it is convenient to recover the gas and reuse, adopting the same procedures as in the manufacturing phases. The procedures and the criteria for the reuse of the SF6 gas are given by IEC 60480 (now in revision) and Cigre guide [9]. In addition to this CAPIEL HV favors the following actions:

- To inform users in an appropriate way on the mass content of SF6, relevant pressure system - according to IEC 60694 - and that the material used, including SF6, are recyclable.
- to provide users with a list of entities adequately prepared to perform an environmentally compatible recovering and recycling of the SF6.
- these recycling centres must be properly instructed and equipped.

2.2 Voluntary Actions / Agreements

Since the time the high warming potential of the SF6 became known, the European electrical industry has taken voluntary actions to reduce emission as much as technically possible.

The agreed reduction measures are as follows:

- Manufacturers of switchgear:
 1. Permanent improvement in switchgear design: minimising the amount of SF6 per unit; maximising gas tightness of enclosures thus minimising leakage in service; simplifying handling in service.
 2. Reduction of emission during development, manufacture and testing (improved processes).
 3. Improved procedures on site for initial filling, where necessary.
 4. Use of "sealed-for-life" technique, where possible (mainly in MV equipment).

- Users of switchgear:
 1. Improved filling procedures on site.
 2. Use of sealed pressure systems, where available.
 3. Better monitoring in service (for closed pressure systems).
 4. Target older existing equipment with known leakage problem for repair/replacement.
 5. Improved maintenance procedures, including RCM (Reliability Centered Maintenance)
 6. Improved end-of-life recovery and recycling (in co-operation with specialised disposal/recycling entities).

The application of the above listed Voluntary Actions, according to estimation made by CAPIEL HV, would produce a reduction of about 7% of the emissions of SF6 in 2010 compared to 1995. This reduction is achievable in spite of an expected increase of 50% in SF6 banked in switchgear in service up to a total of 6.000 t in the E.U. [7] [10]

The final report of the WG Industry - work item fluorinated gases - to the ECCP makes some general recommendations. One of them is to "examine the appropriateness of Selected Voluntary Agreements", that are considered to be an appropriate policy instrument in a number of sectors, of which e.g. switchgear is mentioned. One of the ways to use such agreements is "to support one or more of other measures being implemented". Then the recommendation quotes the "voluntary action undertaken by the Switchgear Industry, that is found to be very suitable to support such a policy mix".

2.3 Evaluation of emissions

Conscious of their responsibility with respect to the environment sustainability, the manufacturers of switchgear (associated in CAPIEL HV) co-operate and will keep co-operating with European and National Authorities with the aim to effectively comply with the obligations adopted in relation with the Kyoto Protocol.

The member companies members of CAPIEL HV are now applying an Inventory system (see annex 1) to quantify and to verify the emissions based on a Mass Balance Methodology, as given by IPCC Tier 3 b. [11]

3 SUMMARY AND CONCLUSIONS

Measurements in the atmosphere showed that total annual SF6 emission from all applications, electrical and not electrical, has been reduced since 1995 due to the growing awareness of the high global warming potential of SF6.

CAPIEL HV manufacturers have contributed to that reduction. Their products are increasingly designed and manufactured in a way that reduces the content of SF6 and minimise leakage to a negligible level. Improved handling systems additionally reduce the losses during the entire service life of the switchgear. Sealed pressure systems generally used on the medium voltage level, do not require any additional gas filling for the entire product life. The typical leakage rate of such current products is less than 0.1% per year.

This very low emission and handling losses makes that the use of SF6 in switchgear has insignificant impact on the greenhouse effect.

The use of electricity as the source of energy for domestic, social and industrial purposes is not only a growing need, but a development engine as well. The improvement of the reliability and the quality of electricity at competitive prices is a must to fulfil the requirements of all users, in an open market.

The switchgear technology developed by the CAPIEL HV manufacturers, in the field of the electrical network, increasingly meets these requirements, taking seriously into account, as part of the heritage for future generations, the environment sustainability.

The choice to use SF6 in electrical switchgear takes into account the most demanding requirements of the electricity users and the environment.

In co-operation with SF6 producers, professional institutions and competent authorities, major manufacturers and users of SF6 switchgear have researched the entire cycle of use of SF6, from manufacture to recycling. They have found that the environmental impact of the use of SF6 in the electrical industry is negligible and controlled, and they commit themselves to continuously minimise it.

CAPIEL HV and EURELECTRIC jointly committed themselves with the European Climate Change Programme to ensure that, despite a considerable increase in switchgear population, the emissions will be reduced in comparison with the 1995 levels [10].

That commitment is being implemented by different actions:

- National Voluntary Agreements
- Optimisation of designs, manufacturing and testing processes and handling processes during installation and maintenance operations.
- To work closely with users and recycling companies to ensure appropriate environmentally conscious SF6 recycling or disposal, when the switchgear has been permanently withdrawn from use.

The switchgear industry, represented by CAPIEL HV, acts therefore in an exemplary fashion, acknowledged by environmental authorities and institutions;

thereby their voluntary agreement for the monitoring system of the SF6 related to their switchgear has been positively recognised by the Final Report on Fluorinated Gases of the European Climate Change Programme [10] to the Enterprise Directorate-General of the European Commission.

CAPIEL HV members are engaged not only to help the Member States to fulfil the commitment of the European Union in the Kyoto Protocol regarding the reductions of the emissions of the greenhouse gases. They are also committed to look further at other impacts of processes, materials and operation of the switchgear.

All these efforts have been undertaken to preserve the environment, as SF6 technology provides acknowledged benefits in terms of safety, compactness and reliability of electrical supply.

4 **GLOSSARY**

SF6	Sulphur hexafluoride
CO2	Carbon dioxide
EMS	Environmental Management Systems
LCA	Life Cycle Assessment
GHG	Greenhouse gas
GWP	Global Warming Potential
FMEA	Failure Mode and Effects Analysis
CB	Circuit breaker
RCM	Reliability Centered Maintenance
ISO	International Standard Organisation
IEC	International Electrotechnical Commission
CAPIEL	Co-ordinating Committee for the Associations of Manufacturers of Industrial Electrical Switchgear and Controlgear in the European Union.
CAPIEL HV	Branch of CAPIEL in the field of HV and MV
HV	High voltage
MV	Medium voltage
ECCP	European Climate Change Program
IPCC	Intergovernmental Panel on Climate Change

5 BIBLIOGRAPHY

- [1] H.Krähling, S.Krömer
Electricity Supply, using SF6-Technology
Life Cycle Assessment
Solvay Germany, May 1999
- [2] N.Bernard, S. Theoleyre, G.Valentin
How to use a greenhouse gas while being environmentally friendly:
SF6 case in medium voltage distribution
CIRED 2001
- [3] High-Voltage Switchgear and Controlgear. Use and Handling of Sulphur Hexafluoride (SF6) in High Voltage Switchgear and Controlgear (IEC 61634 - Edition 1995-04).
- [4] Sulphur Hexafluoride leaflet (Solvay Fluor and Derivate. 1999).
- [5] CAPIEL presentation to ECCP (Nov. 2.000).
- [6] CAPIEL statement on switchgear and the Greenhouse Effect (June 1998).
- [7] SF6 Management and Handling by Switchgear Manufacturers and Users. As overview of the situation in the European Union. (EPA Conference: SF6 and the Environment Emissions Reduction Strategies. San Diego. Nov. 2000).
- [8] M. Maiss, C.A. Brenninkmaijer. "A reversed trend in emission of SF6 into the atmosphere?" 2nd Int. Symp. On Non-CO2 Greenhouse Gasses, Noordwijkerhout, The Netherlands, 8-10 September 1999.
- [9] SF6 Recycling guide. Re-used of SF6 gas in electrical power equipment and final disposal. Cigre SC23, 1997.
- [10] Final Report on the European Climate Change Programme. Working Group Industry. Work item fluorinated gases Ecofys, Environs, June 2001.
- [11] Methodology to Quantify Emission of SF6 for SF6 Switchgear Production and Use (CAPIEL, 2001).
- [12] Greenpeace Switzerland "Energy and Food" 1994
- [13] K. Andersson T. Ohisson – "Life Cycle Assessment of Bread Produced on Different Scales", Int. Jour. LCA 4 (1), pg. 25-40 – 1999.

- [14] A. Carlsson, M. Faist ETH “Energy Use in Food Sector” Zurich 2000
- [15] ABB Internal Report AS/TR – 030/00 “LCA of PASS M0” – October 2000.
- [16] <http://www.arbld.unimelb.edu.au/envjust/papers/allpapers/lenzen/home.htm>

ANNEX 1 - INVENTORY METHODOLOGY

Introduction

The Inventory Methodology is developed to meet the demands of UNFCCC (United Nations Framework Convention on Climate Change) to report on:

- Banked SF6, considered as potential emission
- Emission of SF6 in a year.

Authorities in each country, which have committed itself to the UNFCCC, shall report these figures. EU-15, and its Member States have this obligation.

Chain Management

General

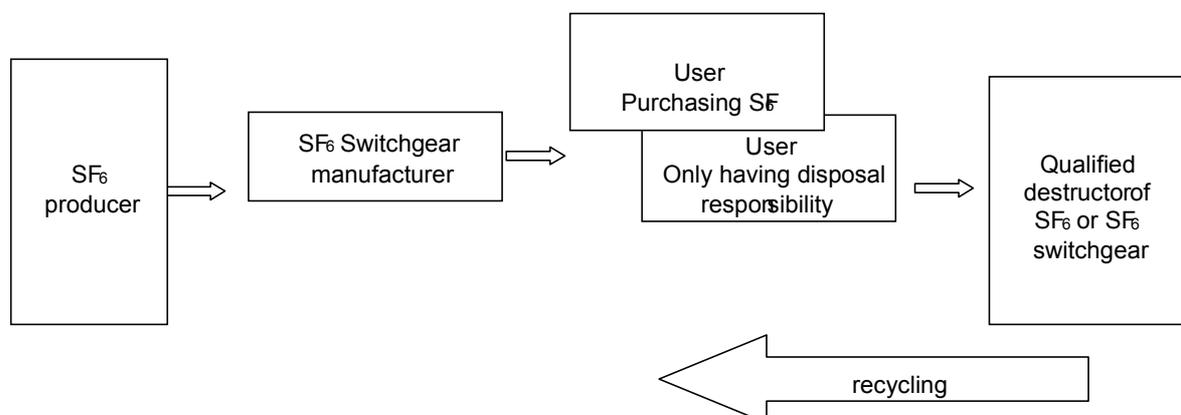
To comply with the UNFCCC demands, the total chain of use of SF6 has to be covered, from production of SF6, via application in switchgear, the operation in the electrical network, its use and maintenance, to the end of life of the switchgear and the return/destruction of the SF6.

Only when this chain is completely covered, it can be assured that no SF6 is “lost” without knowing where and how.

Players

During the life cycle of SF6 applied in the Electrical Industry, a number of players may have some responsibility for the SF6 in various stages of its application.

They are summarised in its essence as in the figure.



Transfer of ownership

General

To ensure a clear responsibility in any stage of the process of handling SF6, the principles of ownership and transfer of ownership have been introduced.

Ownership implicates that an entity, which handles SF6, has the responsibility for monitoring the SF6 he has banked/stocked, as well as for monitoring its emission, as long as he is owner of the gas.

As soon as he hands over, sells, or does any other transaction with the SF6 gas, he transfers the ownership.

This is an important step, which shall be properly documented, both at intake as well as at transfer to a new owner.

End of Life, Recycling

This applies also at the end of life of the electrical equipment, or of the SF6 removed from the product. It is clear that the owner of the switchgear has the responsibility of the proper use and disposal of the product and of the SF6 inside. At the destruction stage of the installation, SF6 shall be recovered from the switchgear before qualified personnel or entities dismantle it. This operation shall be properly documented.

Emission data

Due to Member States' obligation to provide figures within the UNFCCC framework, one can expect that during its time of SF6 ownership, an entity is responsible to make figures available on:

- SF6 banked/stocked on 31 December of year X
- Change in banked/stocked in year X
- SF6 emitted in year X

National authorities will have to decide which entities have to do this reporting, taking into consideration the importance of the emissions. This may take a form of estimation.

For this reporting a number of decision models is available, known as Tier 1, 2, or 3 according to IPCC (Intergovernmental Panel on Climate Change). It can be expected that authorities will decide for a Tier 3 method, when substantial amounts are banked/stocked and handled in a country. Consequently, they will transfer the responsibility to the owner and user of the SF6 accordingly.

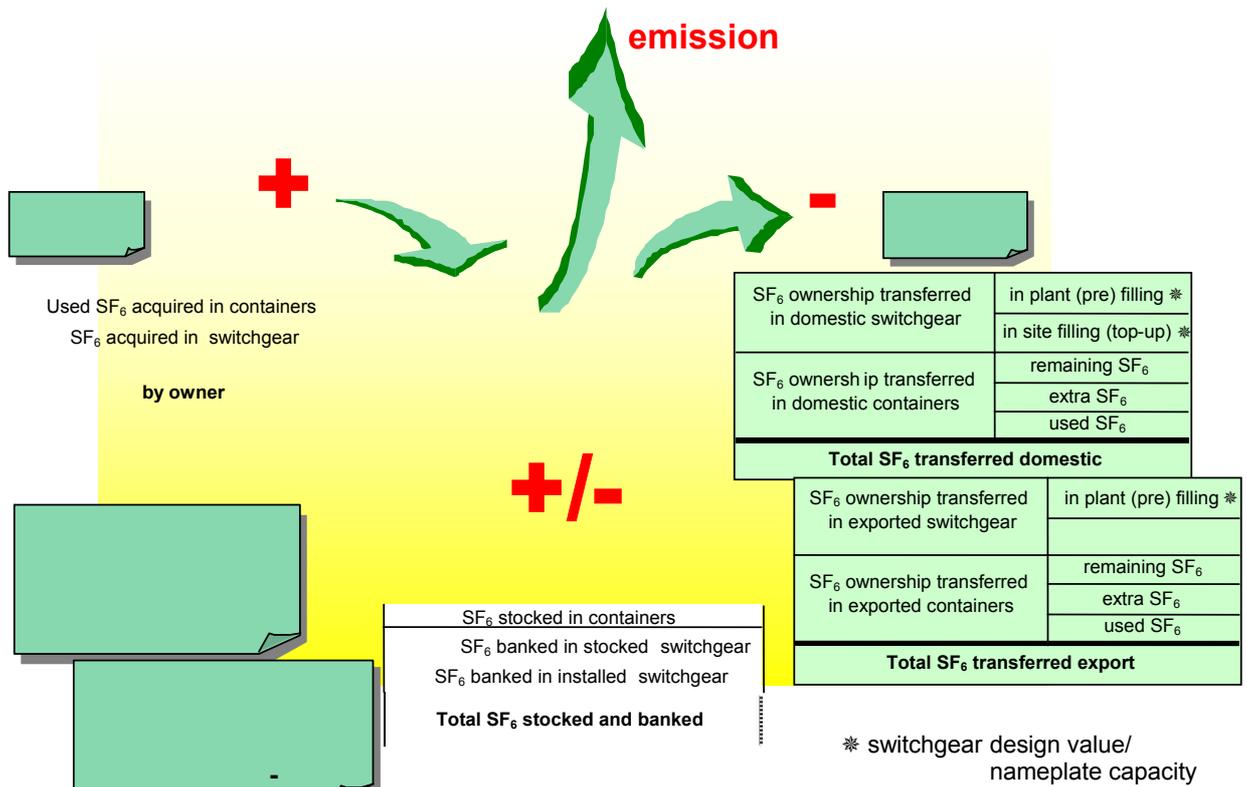
Inventory Methodology

Principle

The Capiel Inventory Methodology meets the demands for a comprehensive system, and covers all sorts of use of SF6 in the electrical sector, from the moment of acquiring the SF6 till the end of life of the equipment and covers all aspects of the required data.

It is based on a Mass Balance Methodology, as given by IPCC Tier 3b, comparing the input and output of SF6 on a year basis. In fact, it is the only practical way to determine emissions with a reasonable precision. Evaluated emissions resulting from this are on the conservative side, as non-identified transactions are counted as emission.

The principle is shown on the flow diagram.



Being implemented on a geographical basis, consolidation of the information collected from inside a given country will provide total emission from the country with no distortion due to international trade. Manufacturer or user associations, similarly to the other type of statistical declarations can easily implement this collection.

Concerned entities

Concerned entities are either those bodies that purchase SF₆, in practice switchgear manufacturers, users (such as utilities) and servicing companies maintaining large high voltage electrical systems, or otherwise qualified waste destruction or recycling companies.

- Emission of SF₆ during manufacturing, commissioning, modification and maintenance processes, as well as compensation of leakage (by topping up), requires purchasing of SF₆ gas; therefore it will be assessed by the declaring entities.
- Emission occurring, but not compensated for during the operating life, will be consolidated at the end of life during the destruction process and assessed by the waste destruction/recycling companies as the difference between the quantity acc. the design value (nameplate capacity) and the quantity of gas processed. Consequently users do not have to declare sealed for life switchgear (sealed pressure system according to IEC 60694), since it is not refilled during its operating life. They are only committed to initiate the end of life recycling process through qualified recovery channels.
- Variation of the banked quantity of SF₆ in switchgear can be determined from switchgear manufacturers' declaration (delivery) and destruction company declaration (removal), on a country level.

Data concerning the total quantity of SF₆ banked in switchgear can be obtained by enquiry from manufacturers, utilities or from National Associations on a country level.

Methodology

The Capiel Inventory Methodology, as described in detail in the annex, is covering all aspects of the required data providing.

It shall be considered as a guide, allowing each entity to define relevant procedures to be implemented according to each situation.

From the Inventory it is easy to facilitate reporting, by filling in only essential transactions and data into the grey cells of the spreadsheet. The calculation of the banked/stocked as well as emitted SF₆ is subsequently done by the spreadsheet system.

Every entity is free to do this in this simplified way as long as he can comply with the request for transparency from the authorities. It shall be noted that by using the more detailed system, the user will find it easier to ensure the completeness of the data provided, and will enable him to demonstrate the correctness of the data provided to the authorities.

Annex: SF6 Inventory Methodology, detailed description

ANNEX

SF6 Inventory Methodology (detailed description)

Introduction.

Kyoto.

The Kyoto protocol (December 1997), signed by, amongst others, the EU and its member states, implicates that emission of SF6 shall be monitored by the member states.

The UNFCCC (United Nations Framework Convention on Climate Change) states that a number of validation requirements shall be fulfilled in the emission inventory:

- completeness
- consistency
- comparability
- transparency

To ensure these aspects, in particular comparability between the countries, they shall report according to sector definitions and formats, as indicated in the Revised IPCC guidelines (Intergovernmental Panel on Climate Change guidelines, Revised 1996, Reference Manual, Vol.3).

Further UNFCCC guidelines for a Common Reporting Format, to ensure comparability and transparency, are currently under development.

The IPCC guidelines describe 2 methods for determining the emission:

- Method 1, which is a simplified method, based on the principle: consumption = emission, to be used when small emissions have to be reported, or when more detailed information is not available.
- Method 2, which quantifies in a rather accurate way the emission, in particular to be used when substantial amounts have to be reported.

More recently IPCC, in the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Chapter 3.5 Industrial Processes, Electrical Equipment, published September 2000, has refined the method 2, into Tier 2a and 2b and has made three variants of an even more accurate approach, Tier 3a, 3b and 3c.

The Basics of the three methods are:

- Tier 1, Potential Approach, the same as the original method 1.
- Tier 2a, Life-Cycle Emission Factor Approach, to be used when only limited data are available on annual sales to SF6 switchgear manufacturers and users (see note on Annex page 4).
- Tier 2b, IPCC Default Emission Factors, to be used if countries only have information on the total charges of installed and retiring equipment.
- Tier 3, Mass Balance Approach, split into:
 - Tier 3a, Emissions by Life Cycle Stage of Equipment, at the facility level, for each phase of the life cycle.
 - Tier 3b, Manufacturer and Utility Level Mass-Balance Method, to be used when data for estimating emissions from life cycle stages are unavailable.
 - Tier 3c, Country Level Mass-Balance Method, to be used when no annual surveys of SF6 using facilities can be made.

The attached decision tree, which is part of the IPCC Good Practice Guidance, gives more details on the individual tiers and applicability (fig. 1, Annex page 4).

It shall be noted that the decision on the method ultimately to be used is at the authorities, which will largely be influenced by the quantities, as well as by their policies on the approach to implement the Kyoto protocol.

Quantification system

The Capiel inventory methodology for a monitoring system of SF6 emission is based on the IPCC Tier 3b approach, and is the preferred system to be used by those entities who purchase SF6, in practice switchgear manufacturers, users (such as utilities) and servicing companies maintaining large HV electrical systems or otherwise qualified waste destruction or recycling companies (table 1, Annex page 7, available as well as MS Excel spread sheet).

It shall be noted that the responsibility for the monitoring and recording by the owner is given by the fact that he owns the SF6 at a certain stage. As soon as a transfer of ownership has taken place, the responsibility for the monitoring and

recording is transferred as well. Two examples are given, one for a large utility and another for manufacturers (see Annex pages 11-15).

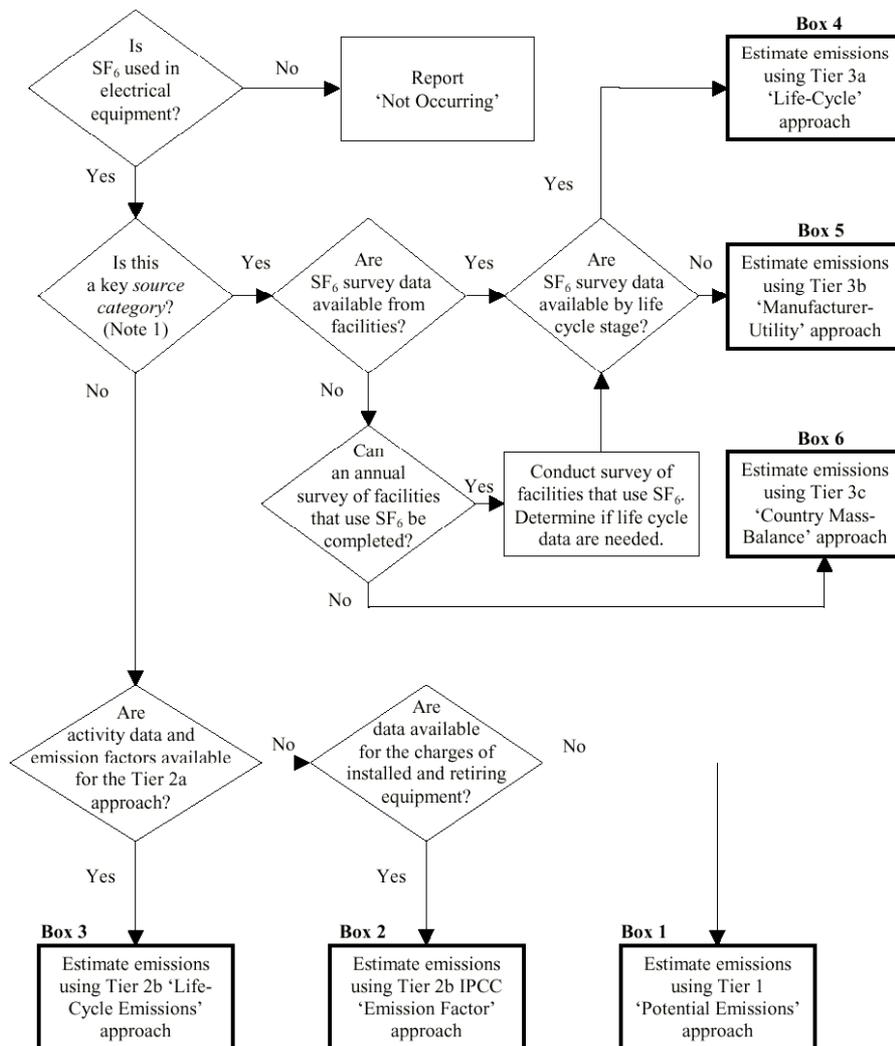
The monitoring of sealed for life switchgear (sealed pressure system acc. to IEC 60694) is superfluous. Emission occurring, but not compensated for during the operating life, will be consolidated at the end of life during the destruction process and assessed by the waste destruction/recycling companies as the difference between design quantity (nameplate capacity) and the quantity of gas processed.

Consequently users do not have to declare sealed for life switchgear, since it is not refilled during its operating life. They are only committed to initiate the end of life recycling process through qualified recovery channels.

Variation of the banked quantity of SF₆ in switchgear can be determined from switchgear manufacturers' declaration (delivery) and destruction company declaration (removal), on a country level.

It further shall be noted that the inventory methodology shall be used in such a way that data are verifiable, in order to fulfil the requirement of transparency as indicated above.

Figure 3.7 Decision Tree for SF₆ from Electrical Equipment



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Note: on the IPCC decision tree, in Box 3 Tier 2a erroneously has been named Tier 2b.

fig. 1

Manual/Explanation

General

The purpose of the methodology is to enable an entity, manufacturer (M) or user (U), eventually laboratories or service companies, further called owner, to fulfil the obligation of an authority to quantify the “emission” of SF6 under his responsibility in a certain year, by the mass balance method.

Transfer of ownership of the SF6 implicates a transfer of responsibility for the recording of the SF6 and consequently for the quantification of the “emission”. It is therefore essential that these transfers are recorded and documented properly.

It is suggested that, in case an entity decides to do the recording at sub-entity level, only the aggregated amount in the country will be reported.

Maintenance and service activities, executed by third parties or not, will have emission equals consumption, since no SF6 will be added other than compensating handling losses or leakages in the (recent) past (no new products or new installation), and is accordingly covered by the methodology.

It should be understood that the “emissions” resulting of this methodology can vary considerably over the years, since quantities of SF6 which are in process are considered as emission, as long as they have not been filled into switchgear, recorded as stock, or as quantity being delivered to a new owner or exported for any purpose.

An example is the amount of SF6 used in an SF6 switchgear manufacturers plant for temporary filling of the switchgear for testing purposes. Another example is the amount of SF6 taken from stock by a switchgear user, for maintenance purposes onsite, in excess of the amount required by the design value of the switchgear, and not (yet) returned to - and recorded as - stock.

The reader therefore shall be aware that any lack of outgoing transaction recording will lead to an overestimation of emission, the worst giving emission equals acquisition as it is described under Tier 1 of IPCC.

The chart (fig. 2, Annex page 6) shows the logic structure to determine the flow and emission of SF6 within a country and the SF6 exported. It should not be understood as actual project related flow chart.

Banked and stocked SF6 do mark different stages of application: banked, inside switchgear prior to, or after its final commissioning on site, stocked for any stage in the process of handling SF6 prior to being banked, or after having been removed from switchgear.

In the Excel spreadsheet (table 1, Annex page 7, available as well as MS Excel file) which quantifies the emission, the grey cells have to be filled, either directly when these data are available, or by filling the white cells referring to the grey.

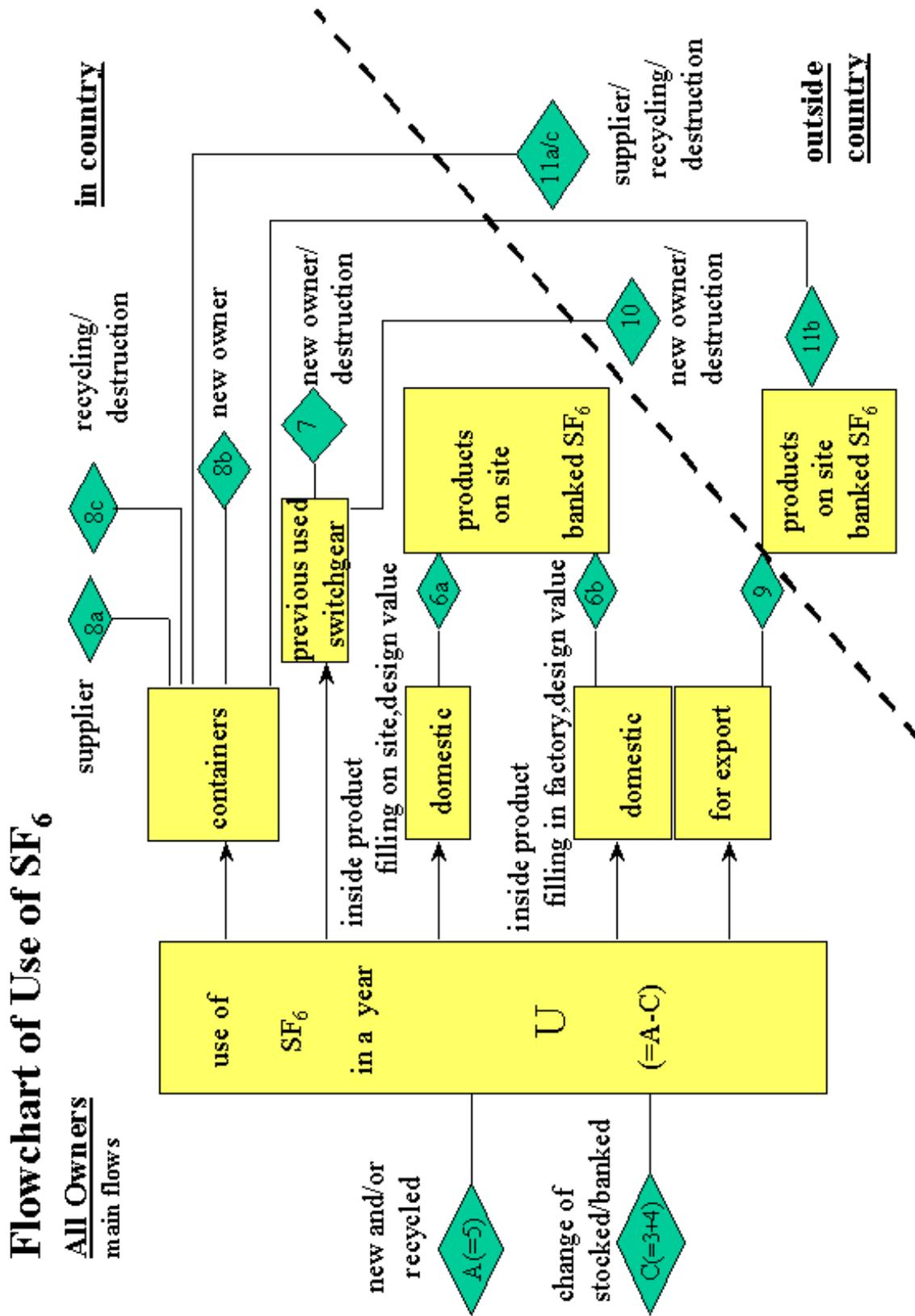


fig. 2

Inventory methodology of SF6 emission

Entity X		End of year	n-1	n
new SF6 stocked in containers		1a		
used SF6 stocked in containers		1b		
total SF6 stocked in containers, actual figure		1 Act		
total SF6 stocked in containers, calculated		$1 = 1a+1b \text{ or } 1Act$	0	0
SF6 banked in stocked switchgear, not yet installed		2a		
SF6 banked in stocked switchgear, retired from installed		2b		
SF6 banked in installed switchgear*		2c		0
total SF6 banked in switchgear, actual figure		2 Act		
total SF6 banked in switchgear, calculated		$2 = 2a+2b+2c \text{ or } 2Act$	0	0
Total quantity Q of SF6 stocked and banked at owner		Q = 1+2	0	0
change in new SF6 stocked in container		$3a = 1an - 1an-1$		0
change in used SF6 stocked in container		$3b = 1bn - 1bn-1$		0
change in total SF6 stocked in containers,calculated		$3 = 3a+3b \text{ or } 1Actn-1Actn-1$		0
change in SF6 banked in stocked switchgear, not yet installed		$4a = 2an - 2an-1$		0
change in SF6 banked in stocked switchgear, retired from installed		$4b = 2bn - 2bn-1$		0
change in SF6 banked in installed switchgear*		$4c = 2cn - 2cn-1$		
change in total SF6 banked in switchgear, calculated		$4 = 4a+4b+4c \text{ or } 2Actn-2Actn-1$		0
Change C in stocked and banked SF6		C = 3+4		0
New SF6 acquired in containers		5a		
Used SF6 acquired in containers		5b		
SF6 acquired in new switchgear		5c		
Used SF6 acquired inside retired equipment		5d		
Total SF6 acquired A by owner		A = 5a+5b+5c+5d		0
Total SF6 U used by owner		U = A - C		0
SF6 ownership transferred in new switchgear, domestic	in plant (pre)filling*	6a		
	on site filling (top-up)*	6b		
SF6 transferred in used switchgear, domestic		7		
SF6 ownership transferred in containers, domestic	remaining SF6	8a		
	extra SF6	8b		
	used SF6	8c		
Total SF6 transferred, domestic Tdom, actual figure		T_{dom} Act		
Total SF6 transferred, domestic Tdom,calculated		T_{dom} = T_{dom} Act or 6a+6b+7+8a+8b+8c		0
SF6 ownership transferred in new switchgear, exported	in plant (pre)filling*	9		
		10		
SF6 transferred in used switchgear, exported		11a		
SF6 ownership transferred in containers, exported	remaining SF6	11a		
	extra SF6	11b		
	used SF6	11c		
Total SF6 transferred, exported Texp, actual figure		T_{exp} Act		
Total SF6 transferred, exported Texp, calculated		T_{exp} = T_{exp} Act or 9+10+11a+11b+11c		0
Total SF6 ownership transferred		T_{tot} = T_{dom} + T_{exp}		0
Total SF6 emitted by owner in the owner's country		E = U - T_{tot}		0

* Switchgear* : design value/name plate capacity

Grey cells may be filled directly. In their absence the White cells shall be filled, which then have priority over the Grey cells
Yellow, Blue and Purple cells are calculated by the system

table 1

Explanation to the various terms

- M/U 1 Stocked quantity of SF6, recorded at the owner, on 31/12 of the year. This can be in various forms:
- a) New SF6 in containers.
 - 1b) Used SF6, recovered from switchgear and made suitable for re-use (IEC 60480 gas), or (temporarily) stocked for further processing or disposal.
- 2 Banked quantity of SF6, inside switchgear, on 31/12 of the year:
- U 2a) Inside new switchgear, as supplied by a manufacturer, not yet installed on site, and (temporarily) stocked at the owner.
- (M)/U 2b) Inside retired switchgear, temporarily stocked, prior to: re-installing at (another) site, selling to a new owner or final disposal. The actual amount of SF6 shall be recorded.
- U 2c) Inside switchgear installed on site, on 31/12 of the year. Calculation is on the basis of design values/nameplate capacities of the installed switchgear.
- M/U Q Total amount of SF6 recorded at the owner (Q=1+2), on 31/12.
- M/U 3 Change in the year in total amount of SF6 stocked in containers at he owner:
- 3a) Change in recorded stock (1a) of new SF6, in containers.
 - 3b) Change in recorded stock (1b) of used SF6, in containers.
- 4 Change in total amount of SF6, banked inside switchgear:
- U 4a) Change in SF6 banked inside new switchgear, stocked at the owner, not yet installed.
- (M)/U 4b) Change in SF6 banked in switchgear retired from installed, stocked at the owner. In general this indicates a temporary stage.
- U 4c) Change in recorded SF6 banked in switchgear installed on site, design value. This results from newly installed, and retired switchgear.
The recovered SF6 from, or still inside the switchgear taken out of service is recorded as used stocked SF6 (1b) and/or in retired switchgear (2b).

- M/U C Change in recorded total amount (Q) of SF6 at the owner, in a certain year (amount on 31/12 minus amount on 31/12 of the previous year).
- M/U 5 Acquired new (IEC 60376 gas), or used SF6, recovered from switchgear, made suitable for re-use (IEC 60480 gas) from a variety of sources: SF6 supplier, switchgear supplier in container, or inside switchgear.
Only SF6 acquired from a previous owner, and consequently transferred in ownership shall be recorded here. Changes in stock are covered at C.
The amount A (=5) represents the total inflow of SF6.
- 5a) New SF6, acquired in containers.
- 5b) Used SF6, acquired in containers.
- 5c) SF6, acquired inside new switchgear.
- 5d) Used SF6, acquired inside retired switchgear.
- M/U U: The total amount of SF6 used/handled in a certain year, $U=A-C$
- 6 Total amount of SF6, and ownership transferred in new switchgear, in the country of the owner, design value/name plate capacity.
- M 6a) SF6 filled into switchgear by the switchgear manufacturer prior to shipment and shipped with the switchgear, for installation in the country. The user will record this as acquired (5c).
- M/U 6b) SF6 (supplied in container) for first filling or topping up of the switchgear after its installation onsite in the country. This quantity is determined by the design value/name plate capacity and can/will be smaller than the quantity delivered to site in containers.
- M 7 Amount of SF6, in the country, inside used switchgear, transferred to a new owner, i.e. a new user or destructor.
- M/U 8 Amount of SF6 within the country, in a container.
- 8a) Remaining in a container, after use in the factory or on site, (re-)delivered to the manufacturer of the SF6 .
- 8b) Supply to another domestic owner, for (later) use.
- 8c) Amount of used SF6 for further handling by another domestic company for re-use, recycling or destruction

- M 9 SF6 filled into switchgear by the switchgear manufacturer, prior to shipment and shipped with the switchgear, for (re-) export, design value.
This amount shall be recorded as intake/acquired at the receiving side.
- M/U 10 SF6 inside used switchgear, exported to another user or to a destructor.
- M/(U) 11 SF6 exported in containers and ownership transferred:
- 11a) Remaining in a container, after use in the factory or on site, (re-) delivered to the manufacturer of the SF6.
- 11b) Amount of SF6, exported in containers, for filling of switchgear or for other purposes (such as reselling to others).
- 11c) Amount of used SF6, exported to the SF6 manufacturer, a recycler or a destructor.
- M/U E Total emitted by owner in the owner's country is: Amount of SF6 used (U), (which equals the amount acquired (A) minus the change in stocked and banked (C)), minus the amount transferred to a new owner (Ttot)

Example 1 (see table 2)

Utility U – declaration for year 2000

At the beginning of the year (ref stock 1999 – 12 – 31) situation was:

- Total installed: 300 t (design value) [2c - 1999]
- 3 t in switchgear not yet installed [2a - 1999]
- 4 t new SF6 in container [1a - 1999]
- 3 t old gas, not usable [1b - 1999]

At the end of the year 2000 the situation was:

- Total installed: 307 t (design value) [2c] being the result of:
 - Sealed: 2 t removed [-2 in 4c] and transferred to recuperator [+2 in 7] and 4 t new installed [+4 in 4c] (1 from stock [-1 in 4a] and 3 t purchased [+3 in 5c])

- HV GIS:
 - 1 installation of 5 t nominal out of service [-5 in 4c], 4 t recovered and stocked in containers [+4 in 3b]
 - 1 installation of 5 t nominal out of service [-5 in 4c], 4 t recovered in containers and transferred to recuperator [+4 in 8c]
 - 3 new installations of 5 t nominal installed [+ 3*5 in 4c] delivered ready to operate by manufacturers [+ 3*5 in 5c]
- 2 t in switchgear not yet installed [2a] (1 t being installed, already covered in 4a)
- 8 t new SF6 in container [1a] (net increase of 4 t due to extra buying)
- 4 t of used gas [1b] (3 t of old gas, not usable transferred [-3 in 3b] to recuperator [+3 in 8C] and 4 t back from HV GIS, already covered in 8c)
- The Utility purchased during the year 11 t of new SF6 in container [5a] for maintenance purposes

The corresponding table gives a total emission by U in its country of 9 tons.

Inventory methodology of SF6 emission

Example 1:Utility U

	End of year	1999	2000	2000 detailed
new SF6 stocked in containers	1a	4	8	8
used SF6 stocked in containers	1b	3	4	4
total SF6 stocked in containers, actual figure	1 Act			
total SF6 stocked in containers, calculated	1 = 1a+1b or 1Act	7	12	
SF6 banked in stocked switchgear, not yet installed	2a	3	2	2
SF6 banked in stocked switchgear, retired from installed	2b			
SF6 banked in installed switchgear*	2c	300	307	307
total SF6 banked in switchgear, actual figure	2 Act			
total SF6 banked in switchgear, calculated	2= 2a+2b+2c or 2Act	303	309	
Total quantity Q of SF6 stocked and banked at owner	Q= 1+2	310	321	
change in new SF6 stocked in container	3a=1an-1an-1		4	
change in used SF6 stocked in container	3b=1bn-1bn-1		1	
change in total SF6 stocked in containers,calculated	3= 3a+3b or 1Actn-1Actn-1		5	
change in SF6 banked in stocked switchgear, not yet installed	4a=2an-2an-1		-1	
change in SF6 banked in stocked switchgear, retired from installed	4b=2bn-2bn-1		0	
change in SF6 banked in installed switchgear*	4c=2cn-2cn-1		7	4-2-5-5+3*5
change in total SF6 banked in switchgear, calculated	4= 4a+4b+4c or 2Actn-2Actn-1		6	
Change C in stocked and banked SF6	C=3+4		11	
New SF6 acquired in containers	5a		11	11
Used SF6 acquired in containers	5b			
SF6 acquired in new switchgear	5c		18	3+3*5
Used SF6 acquired inside retired equipment	5d			
Total SF6 acquired A by owner	A=5a+5b+5c+5d		29	
Total SF6 U used by owner	U=A-C		18	
SF6 ownership transferred in new switchgear, domestic	in plant (pre)filling*	6a		
	on site filling (top-up)*	6b		
SF6 transferred in used switchgear, domestic	7		2	2
SF6 ownership transferred in containers, domestic	remaining SF6	8a		
	extra SF6	8b		
	used SF6	8c	1	4+3
Total SF6 transferred, domestic Tdom, actual figure	T_{dom Act}			
Total SF6 transferred, domestic Tdom,calculated	T_{dom} =T_{dom Act} or 6a+6b+7+8a+8b+8c		9	
SF6 ownership transferred in new switchgear, exported	in plant (pre)filling*	9		
SF6 transferred in used switchgear, exported	remaining SF6	11a		
	extra SF6	11b		
	used SF6	11c		
Total SF6 transferred, exported Texp, actual figure	T_{exp Act}			
Total SF6 transferred, exported Texp, calculated	T_{exp} =T_{exp Act} or 9+10+11a+11b+11c		0	
Total SF6 ownership transferred	T_{tot} = T_{dom} + T_{exp}		9	
Total SF6 emitted by owner in the owner's country	E = U-T_{tot}		9	

* Switchgear* : design value/name plate capacity

Grey cells may be filled directly. In their absence the White cells shall be filled, which then have priority over the Grey cells

Yellow, Blue and Purple cells are calculated by the system

table 2

Example 2 (see tables 3 and 4)

Manufacturer M – declaration for year 2000

M has 3 facilities:

- site M1 producing sealed MV products
- site M2 producing HV GIS
- site M3 testing facility

M's stock of SF6 (new gas in container) was at the beginning of the year (ref stock 31/12/1999):

- 0 t at M1 [1a – 1999]
- t at M2 [1a – 1999]
- 2 t at M3 [1a – 1999]

and was at the end of the year 2000

- 4 t at M1 [1a – 2000] and [+4 in 3a]
- 0 t at M2 [1a – 2000] and [-5 in 3a]
- 2 t at M3 [1a – 2000] and [0 in 3a]

M purchased during the year in total 104 t new SF6 in container, and 6 t of used SF6 in container for re-use in HV GIS and split as follow:

- 21 t at M1 [+ 21 in 5a]
- 88 t at M2 [+ 82 in 5a] and [+6 in 5b]
- 1 t at M3 [+ 1 in 5a]

The gas was used as follows:

- M1: 15 000 units with a design value quantity of 1 kg each. 5000 pieces for the domestic market [+5 in 6a] and 10 000 for exportation [+ 10 in 9]. SF6 remaining in container was exported to the producer of the SF6 [+1 in 11a].
- M2: Total design value quantity according to project delivery was 80 t, 20 t for domestic market and 60 t for export. Products are 10 % filled in plant [+ 2 in 6a and +6 in 9] and the filling is completed on site [+ 18 in 6b].
 - Domestic: 22 t were allocated to commissioning department. From these 22 t, 2 t were sold to the user [+ 2 in 8b] for maintenance purposes.
 - Export: 60 t were allocated to commissioning department. No quantities were returned [+ 60 in 11b].

- M3: has no production

The corresponding table gives a total emission by M in its country of 7 tons.

Inventory methodology of SF6 emission

Example 2: Manufacturer total

	End of year	1999	2000	2000 detailed		
				M1	M2	M3
new SF6 stocked in containers	1a	7	6	4	0	2
used SF6 stocked in containers	1b					
total SF6 stocked in containers, actual figure	1 Act					
total SF6 stocked in containers, calculated	$1 = 1a+1b \text{ or } 1Act$	7	6			
SF6 banked in stocked switchgear, not yet installed	2a					
SF6 banked in stocked switchgear, retired from installed	2b					
SF6 banked in installed switchgear*	2c		0			
total SF6 banked in switchgear, actual figure	2 Act					
total SF6 banked in switchgear, calculated	$2 = 2a+2b+2c \text{ or } 2Act$	0	0			
Total quantity Q of SF6 stocked and banked at owner	Q= 1+2	7	6			
change in new SF6 stocked in container	$3a=1a_n-1a_{n-1}$		-1	4	-5	0
change in used SF6 stocked in container	$3b=1b_n-1b_{n-1}$		0			
change in total SF6 stocked in containers,calculated	$3 = 3a+3b \text{ or } 1Act_n-1Act_{n-1}$		-1			
change in SF6 banked in stocked switchgear, not yet installed	$4a=2a_n-2a_{n-1}$		0			
change in SF6 banked in stocked switchgear, retired from installed	$4b=2b_n-2b_{n-1}$		0			
change in SF6 banked in installed switchgear*	$4c=2c_n-2c_{n-1}$					
change in total SF6 banked in switchgear, calculated	$4 = 4a+4b+4c \text{ or } 2Act_n-2Act_{n-1}$		0			
Change C in stocked and banked SF6	C=3+4		-1			
New SF6 acquired in containers	5a		104	21	82	1
Used SF6 acquired in containers	5b		6		6	
SF6 acquired in new switchgear	5c					
Used SF6 acquired inside retired equipment	5d					
Total SF6 acquired A by owner	A=5a+5b+5c+5d		110			
Total SF6 U used by owner	U=A-C		111			
SF6 ownership transferred in new switchgear, domestic	in plant (pre)filling*	6a	7	5	2	
	on site filling (top-up)*	6b	18		18	
SF6 transferred in used switchgear, domestic	7					
SF6 ownership transferred in containers, domestic	remaining SF6	8a				
	extra SF6	8b	2		2	
	used SF6	8c				
Total SF6 transferred, domestic Tdom, actual figure	T_{dom} Act					
Total SF6 transferred, domestic Tdom,calculated	T_{dom} =T_{dom} Act or 6a+6b+7+8a+8b+8c		27			
SF6 ownership transferred in new switchgear, exported	in plant (pre)filling*	9	16	10	6	
SF6 transferred in used switchgear, exported	10					
SF6 ownership transferred in containers, exported	remaining SF6	11a	1	1		
	extra SF6	11b	60		60	
	used SF6	11c				
Total SF6 transferred, exported Texp, actual figure	T_{exp} Act					
Total SF6 transferred, exported Texp, calculated	T_{exp} =T_{exp} Act or 9+10+11a+11b+11c		77			
Total SF6 ownership transferred	T_{tot} = T_{dom} + T_{exp}		104			
Total SF6 emitted by owner in the owner's country	E = U-T_{tot}		7			

* Switchgear* : design value

Grey cells may be filled directly. In their absence the White cells shall be filled, which then have priority over the Grey cells

Yellow, Blue and Purple cells are calculated by the system

table 3

Inventory methodology of SF6 emission

Example 2: Manufacturer M2

	End of year	1999	2000
new SF6 stocked in containers	1a	5	
used SF6 stocked in containers	1b		
total SF6 stocked in containers, actual figure	1 Act		
total SF6 stocked in containers, calculated	1 = 1a+1b or 1Act	5	0
SF6 banked in stocked switchgear, not yet installed	2a		
SF6 banked in stocked switchgear, retired from installed	2b		
SF6 banked in installed switchgear*	2c		0
total SF6 banked in switchgear, actual figure	2 Act		
total SF6 banked in switchgear, calculated	2= 2a+2b+2c or 2Act	0	0
Total quantity Q of SF6 stocked and banked at owner	Q= 1+2	5	0
change in new SF6 stocked in container	3a=1an-1an-1		-5
change in used SF6 stocked in container	3b=1bn-1bn-1		0
change in total SF6 stocked in containers,calculated	3= 3a+3b or 1Actn-1Actn-1		-5
change in SF6 banked in stocked switchgear, not yet installed	4a=2an-2an-1		0
change in SF6 banked in stocked switchgear, retired from installed	4b=2bn-2bn-1		0
change in SF6 banked in installed switchgear*	4c=2cn-2cn-1		
change in total SF6 banked in switchgear, calculated	4= 4a+4b+4c or 2Actn-2Actn-1		0
Change C in stocked and banked SF6	C=3+4		-5
New SF6 acquired in containers	5a		82
Used SF6 acquired in containers	5b		6
SF6 acquired in new switchgear	5c		
Used SF6 acquired inside retired equipment	5d		
Total SF6 acquired A by owner	A=5a+5b+5c+5d		88
Total SF6 U used by owner	U=A-C		93
SF6 ownership transferred in new switchgear, domestic	in plant (pre)filling*	6a	2
	on site filling (top-up)*	6b	18
SF6 transferred in used switchgear, domestic		7	
SF6 ownership transferred in containers, domestic	remaining SF6	8a	
	extra SF6	8b	2
	used SF6	8c	
Total SF6 transferred, domestic Tdom, actual figure		T_{dom Act}	
Total SF6 transferred, domestic Tdom,calculated		T_{dom} =T_{dom Act} or 6a+6b+7+8a+8b+8c	22
SF6 ownership transferred in new switchgear, exported	in plant (pre)filling*	9	6
SF6 transferred in used switchgear, exported		10	
SF6 ownership transferred in containers, exported	remaining SF6	11a	
	extra SF6	11b	60
	used SF6	11c	
Total SF6 transferred, exported Texp, actual figure		T_{exp Act}	
Total SF6 transferred, exported Texp, calculated		T_{exp} =T_{exp Act} or 9+10+11a+11b+11c	66
Total SF6 ownership transferred		T_{tot} = T_{dom} + T_{exp}	88
Total SF6 emitted by owner in the owner's country		E = U-T_{tot}	5

* Switchgear* : design value

Grey cells may be filled directly. In their absence the White cells shall be filled, which then have priority over the Grey cells
Yellow, Blue and Purple cells are calculated by the system

table 4

ANNEX 2 - EXAMPLES OF CALCULATIONS

Medium Voltage example

The global warming associated with the operation of any electrical SF6 switching device is the result of two main contributors:

- The CO2 eq. emitted during the fuel combustion to generate the electric energy lost in the switching device by Joule effect.
- The CO2 eq. corresponding to accumulated emission of SF6.

As an example the figures below correspond to a typical M.V. SF6 circuit breaker.

Expected service life	20 years
Running time per year	8,760 hours
Rated current	1,250 A
Rated voltage	24 kV
Load ratio	80%
Content of SF6	282 g.
Leakage rate per year	0,45 %
Current path resistance per phase	3.25 E-5

Taking into account the current electricity generation mix in the European Union and the currently accepted value for the GWP of the SF6, following calculation parameters are used:

CO2 eq. emitted per kWh generated	0.51 kg.
GWP of the SF6 gas	23,900

The result of the calculations are the following:

CO2 eq. emitted to compensate Joule losses .	8,712 kg.
CO2 eq. to the total SF6 losses	607 kg.

It is clear that Joule losses in 20 years are by far the dominant contributor to the GWP, derived from the operation of the CB accounting for more than 93% of the total. Therefore, less than 7% is attributable to SF6 emissions.

In order to give an idea on how the SF6 technology is potentially contributing to the global warming with reference to other human activities or consumer goods, it is very interesting to consider the following table. The potential impact of the operation of the CB is allocated to each family (the hypothesis is that a MV CB distributes energy to 500 families).

Service / life support		Kg CO2 eq.
SF6 losses in MV CB per year and family		0.07
Cultivation of 1 kg of apples	[12]	≅ 0.3
Production and distribution of 1 kg of bread	[13]	0.63 ÷ 1
100 km trip by car (two carried persons)		≅ 12
1 McDonalds sandwich	[14]	0.55
1 kg of lamb	[12]	45

Order of magnitude of absolute contribution to the GWP

In the other hand, it is to note that the ratio CO2 eq. per citizen and year is about 12,000 kg./year in the EU.

High voltage bays example

In this case the environmental evaluation is conducted comparing two substation solutions providing the same service. The first solution is constituted of an innovative system that contain more SF6 than the older. The results are that reducing contact points and length of the current path it is possible to achieve a GWP performance improvement.

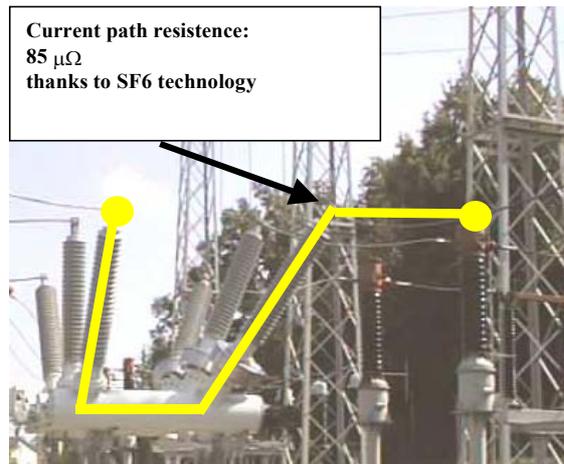


Figure - Solution 1 containing 36 kg of SF6

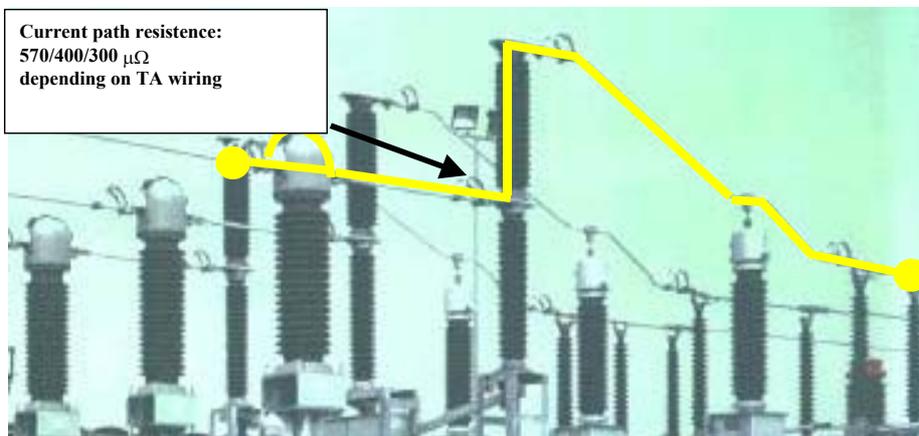


Figure - Solution 2 containing 28.5 kg of SF6

The assumption were the following:

	HV system in accordance with 60517
Product expected life time [years]	25 years
Running time per year [h]	8760 hours (24 hours/day)
Rated current (In [A])	Specified according to IEC 60694
Rated voltage (Vn [V])	Specified according to IEC 60694
SF6 percent losses during usage	0,3%
Current path resistance	1. for system 1 85 $\mu\Omega$ 2. for system 2 - 400 $\mu\Omega$ from 400A to 800 ^a - 300 $\mu\Omega$ over 800 ^a

And the results are shown below.

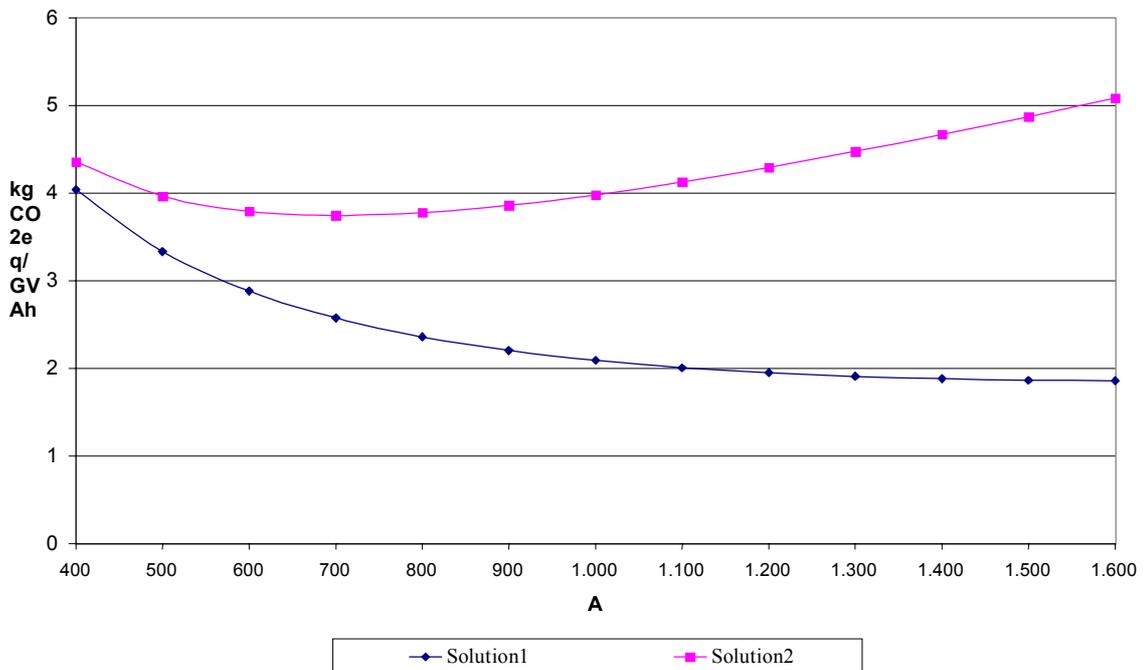


Figure – Potential saving in GWP with smart SF6 usage [15]

It is to be noted that at 1000 A of rated current, the solution 1 (36 kg SF6) with higher content of SF6 has 50% lower GWP impact than solution 2 with lower SF6 content (28.5 kg)

ANNEX 3 - EXAMPLES OF COMPARISON WITH OTHER ACTIVITIES

Basic data

- SF6 GWP = 23.900
- 1 l. petrol produce 2.65 kg. CO2 (1)
- Average consumption of an European car: 0.9 litre/10 km. (1)
- Average use of an European car: 15.000 km./year (1)
- 1 hour of a TV colour produce 0.29 kg. of CO2 by the energy consumed (2)
- Production and distribution of 1 kg. of bread produce between 0.63 and 1 kg. of CO2 (3).

- (1) Volvo Car Corporation and the Swedish Petroleum Institute.
(2) International Equity and Greenhouse gas Emissions [16]
(3) "Lyfe Cycle assessment of Bread produced on different scales", int. Jour LCA pag. 24-40 1999 [13]

Examples - Calculations

One Medium Voltage Ring Main Unit (RMU) contains approximately 3 kg. of SF6. Each RMU gives switching and protection functions to one Medium Voltage / Low Voltage Transformer Substation that provides electricity to 100 families (approx.).

The leakage on its entire life are as follows:

- In service, less than 0.1% per year; that gives less than 3.5% in all his life (35 years approx.).
- During manufacturing, dismantling and recycling less than 7.5% in total (Capiel target). That gives a total loss of less than 11% in all his life:

3 kg. x 11% = 330 gr. in 35 years.

Considering its GWP it can be calculated the CO2 equivalent amount:

330 gr. x 23900 = 7887 kg. of CO2 equiv. in 35 years

Making an average per year of life goes to:

$7887 \div 35 = 225.34$ kg. CO2 eq./year

- Comparison with a car

The 7887 kg. of CO2 eq. produced by an RMU in 35 years are equivalent to:

$(7887 \text{ kg.} \div 2.65 \text{ Kg/l}) \div 0.09 \text{ l/km.} = 33069.2 \text{ km.}$ run by one car in 35 years.

or

$33069.2 \div 35 = 944.8$ km. run by one car by 1 year.

or

$944.8 \div 365 = 2.6$ km. run by one car by 1 day.

So the contribution to the greenhouse effect of an RMU that provides electricity to 100 families is equivalent to 2.6 km./day of a car of one of those families.

- Comparison with a TV colour.

The 7887 of CO₂ eq. produced by an RMU in 35 years are equivalent to:

$7877 \text{ kg.} \div 0.29 \text{ kg/hour} = 27196.6$ hours of TV colour in 35 years

or

$27196.6 \div 35 = 777$ hours of TV colour by 1 year

or

$777 \div 365 = 2$ hours 8 min. of TV colour by 1 day.

So the contribution to the greenhouse effect of an RMU that provides electricity to 100 families is equivalent to 2 h. 8 m. per day watching TV, one of those families.

- Comparison with bread

The 7887 kg. of CO₂ eq. produced by an RMU in 35 years are equivalent to:

$7887 \div 0.63 \text{ kg./kg. of bread} = 12519$ kg. of bread in 35 years.

or

$12519 \div 35 = 357.7$ kg. of bread by 1 year

or

$357.7 \div 365 = 0.98$ kg. of bread by 1 day; approximately the consumption of 2 families.

So the contribution to the greenhouse effect of an RMU that provides electricity to 100 families is equivalent to less than one kilo of bread, consumed daily by two of those families.