COMMON REVIEW by Eurelectric, E.DSO and GEODE of Öko-Recherche Briefing Paper ‘SF_6 and alternatives in electrical switchgear and related equipment’ (March 2020)

April 2020

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1. Executive Summary

Eurelectric, E.DSO and GEODE are supportive of the European Commission efforts to reduce SF_6 emissions in electrical switchgear and related equipment under Article 21.4 of Regulation (EU) No 517/2014.

Society requires a reduction in greenhouse gasses and has multiple choices as to how it allocates resources to greenhouse gas reduction investments, so that it is important that such resources are targeted at areas which produce the greatest return, as otherwise such investments would have been more effectively deployed elsewhere.

Eurelectric members are keen to consider non-SF_6 switchgear but unfortunately the alternative non-SF_6 MV switchgear is not as suitable or as available in the timeline and relative prices suggested in the Briefing Paper.

The Briefing Paper covers SF_6 switchgear over a wide range of voltages (MV to HV), but it is generally agreed that any application of non-SF_6 switchgear in the near term is only likely to be technically feasible in 'greenfield' stations up to no more than 36kV.

Within this range there are two types of Switchgear, that are used in primary substations which generally contains circuit breakers, and where there is some experience in using non-SF_6 switchgear such as AIS, and secondary substations where Ring Main Units which use load break switches and fuses predominate.

Economically it would be difficult to justify the requirement to use non-SF_6 in new MV secondary substations[1] - this is because the 'sealed for life' containment in this switchgear already has very low emission rates of no more than 0.1%pa, and the quantities in each switch are so small (0.7 – 2.5kg). [2]This means the abatement costs - the cost per kg of SF_6 removed - would be excessively high, and this point was also confirmed in the earlier 2011 F-Gas report.

There are also technical difficulties which are referred to in the body of the report.

In primary MV switchgear the quantities of SF_6 per bay are slightly higher (2.5 – 3.5 kg)[3] and, because of glands used for maintenance, the emission rates are somewhat higher (0.5 – 1% pa). However, there is more experience with non-SF_6 switchgear (such as AIS) although it may be more bulky and with a smaller range of suppliers. Nevertheless, the abatement costs may still be excessive.

There are number of options which could be undertaken to incentivise the use of non-SF_6 switchgear where technically feasible and cost effective, especially if these situations could be decided individually by the utility, as this leaves scope for utility to select the locations and applications which should meet these criteria (see section 3.4 below). Obviously, there are other alternative proposals that could also be suitable. Eurelectric, E.DSO and GEODE would welcome the opportunity to discuss such solutions with the European Commission so that a real progress could be made on the introduction of non-SF_6 solutions not only in trial projects but in business as usual.

[1] cf Article 21.4 of Regulation (EU) No 517/2014
[2] Ecofys, 'Concept for SF6-free transmission and distribution of electrical energy – Final report', 2018, p. 41
[3] Ecofys, 'Concept for SF6-free transmission and distribution of electrical energy – Final report', 2018, p. 41

2. General overview

2.1 Introduction

Eurelectric, E.DSO and GEODE are supportive of global efforts to reduce the release of greenhouse gases to the environment. As part of that overall goal, Eurelectric, E.DSO and GEODE members have welcomed the on-going development by switchgear manufacturers of designs of distribution and transmission switchgear which do not contain sulphur hexafluoride (SF_6) gas and are safe and practicable for use on the European distribution and transmission networks.

Whilst such designs may have the future potential to reduce SF_6 emission, the question arises whether these alternatives already exist and have reached market maturity so that they can be applied in the electricity systems. Eurelectric, E.DSO and GEODE welcome the European Commission to assess this question for the area of secondary medium voltage (MV) switchgear, as foreseen in Article 21.4 of Regulation (EU) No 517/2014.

The consultants engaged by the European Commission not only analysed the secondary MV switchgear, but also the situation both for primary MV and high voltage (HV) switchgear. This is worthwhile because sooner or later provisions for these areas may also be considered for adoption. Yet, for the time being, the Secondary MV should be the focus, and specific policy recommendations for this area developed.

Eurelectric, E.DSO and GEODE strongly support efforts to reduce SF_6 in switchgear and have no lack of willingness to support viable alternatives. With this view in mind, the associations examined the Öko-Recherche Briefing Paper ***'SF6 and alternatives in electrical switchgear and related equipment'*** (March 2020), referred hereafter to as the '***Briefing Paper'***.

The 'Briefing Paper' identifies important questions which must be answered conclusively before new policy proposals can be recommended. However from the analysis below it is apparent that certain aspects of the Briefing Paper require further development - in particular there is a need for greater clarification and completeness in a number of specific areas (see Appendix 1).

The Eurelectric, E.DSO and GEODE's review depicts our most important remarks and amendment proposals on the Briefing Paper.

2.2 Summary of overview

The Briefing Paper covers a variety of SF6 switchgear from MV to EHV, and in particular discusses approaches to MV switchgear in both primary and secondary substations, as well as switchgear at other voltage levels. Much of the analysis is based on the German grid[4] and an assumption made that the grids in the rest of the EU are similar, which is not the case.

However**, under Article 21.4 of the Regulation (EU) No 517/2014 the scope of any SF_6 reductions assessment is only to apply to new MV secondary switchgear.**

[4] Ecofys, 'Concept for SF6-free transmission and distribution of electrical energy – Final report' (2018), Section 1.1 Page I: 'The report focusses on switchgear, measuring transformers and electrical lines in the medium- (1 ≤ 52kV) and high-voltage (>52kV) in Germany.' This report is referred hereafter to as 'Ecofys report' or 'Ecofys final report'.

'Article 21
'Review'

4. No later than 1 July 2020, the Commission shall publish a report assessing whether cost-effective, technically feasible, energy-efficient and reliable alternatives exist, which make the replacement of fluorinated greenhouse gases possible in new medium-voltage secondary switchgear and new small single split air-conditioning systems and shall submit, if appropriate, a legislative proposal to the European Parliament and to the Council to amend the list set out in Annex III.'

In relation to MV:

- Throughout the document, overly optimistic assessments are made on SF_6 alternatives and their industrialization times (marketing and associated after-sales service), without supporting evidence. Given that the use of SF_6 is currently critical for the continued secure and safe supply of electricity in the EU, it is essential that decisions on SF_6 are based on evidence of what can be achieved rather than proposals of what might be achievable in the future.

- Rather than state timeframes by which alternatives might be available, it would be more appropriate to set out the criteria by which alternatives will be judged for suitability and the steps that still need to be taken to meet these criteria. This varies considerably for different SF_6 applications and dependant on the specific station design there are few MV or HV applications that currently have viable alternatives. It is uncertain when there will be viable alternatives.

- Solutions for the different application areas should be more clearly distinguished in the 'Briefing Paper', as the issues for each are distinct. Unfortunately, a clear distinction is not made between primary and secondary medium voltage (MV) distribution, e.g. circuit breakers are rarely used in the secondary MV level. [5] In the secondary substations, standard RMUs are very often designed as a combination of load-breaking switch and fuses, which do not require protection relays or electric drives. In practice there are huge differences in the availability of alternatives to SF_6 between these applications areas. This is even more important as the scope of Article 21.4 of the Regulation (EU) No 517/2014 is limited to new Secondary MV switchgear.

- Furthermore, the definition of medium voltage used is inappropriate and not in line with similar EU legislation such as the EcoDesign Transformer Directive[6] (see below page 15). This leads to an assumption that switchgear in the range 36 – 52kV should be banned simply because it falls into this range, even though no technical alternatives were identified in the

[5] The T&D Europe (2020) report from which the information in table 1 was taken says that, on a European level, the repartition for secondary switchgear is 80 % switches and 20 % circuit breakers (see T&D Europe (2020), table 3). As an example, in the public distribution grids in Germany, the share of switches in secondary switchgear is even higher (> 90 %).
[6] COMMISSION REGULATION (EU) 2019/1783 of 1 October 2019 amending Regulation (EU) No 548/2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers

report. It is important to be clear on the definitions of MV as Article 21.4 of Regulation (EU) No 517/2014 refers to new MV secondary switchgear.

- An assessment of the successful development of alternatives to SF_6 over a complete industrial cycle (from design, marketing, maintenance, operation to end of life and recycling) is missing. This is essential for a full understanding of the feasibility of non-SF_6 solutions in the timeframes proposed.

- Alternatives, especially at HV, are frequently specific to a small number or even one single manufacturer. Mandatory use of one single alternative would present significant issues for competitiveness and security of supply. This needs to be highlighted in the Öko-Recherche report for further consideration.

- Costs and performance for alternatives presented in the Öko-Recherche report do not have public domain references. This raises concern on the actual cost and feasibility of the alternatives that have been included so far. The presentation of information from manufacturers should be transparent and distinguished between both voltage categories and low current and high current categories. The distinction between current ratings is as significant as the voltage categories.

In relation to HV:

- The Öko-Recherche report notes that, in the field of HV applications, the alternative solutions for industrial processes <245 kV are currently the subject of experiments with utilities with a number of pilot projects being trialled. However, the report understates what this means – namely, that the long-term viability and feasibility of these solutions still remains to be evaluated, from a technical, economic, environmental and health & safety (toxicity aspect on large volumes) points of view. Until a full assessment of these fundamental factors are completed, it is not possible to draw a conclusion safely on alternative solutions for HV applications. This issue did not receive enough emphasis in the Öko Recherche report.

- The Öko-Recherche report suggests that SF_6 alternatives will be available within four to five years, whilst it is not possible to make a judgement on this given current knowledge. The Öko-Recherche report should make a more balanced presentation of the current level of knowledge on alternatives and the further steps that need to be taken to understand their feasibility.

- The Öko-Recherche report makes no reference to the results already obtained with existing HV installations in minimising SF_6 emissions by introducing strengthened maintenance policies and procedures (the ultimate goal being to keep the SF_6 emission equal or below that of the initial design i.e. generally 1%).

- The Öko-Recherche report does not give context on the scale of the variation between different applications of switchgear at different currents but at the same voltage rating. These technical details are fundamental to the feasibility of alternatives in different applications.

2.3 Assessment of the proposals

The basis of any decision on future use of SF_6 in switchgear was to be assessed against the following four criteria **for new MV secondary switchgear** (Article 21.4 of Regulation (EU) No 517/2014):

- **(A) Cost Effectiveness**
- **(B) Technical Feasibility**
- **(C) Availability of Reliable Alternatives**
- **(D) Energy Efficiency**

Toxicology is also an additional and significant criterion which has to be taken into account. This is discussed under point **(E) Toxicology.**

A more detailed assessment of the Öko-Recherche 'Briefing Paper' is provided in the Technical review (see page 8 and the following pages), with individual comments provided in Appendix 1. You will find below a summary of the main outcomes of this assessment as well as recommendations.

(A) Cost Effectiveness

Secondary MV switchgear using SF_6 is virtually all 'sealed for life' with emissions of less than 0.1% pa on small quantities of SF_6 (0.7 – 2.5kg), so that it can yield very little reduction in SF_6 quantities as the emissions are already so low, and there is professional disposal of SF_6 at end of life.

Whilst secondary MV switchgear is highest in the number of installations, with one such secondary MV switchgear for every 250 customers, the overall quantity of SF_6 involved is less than 10% of the SF_6 used in switchgear overall.

This means that the costs of any savings in emissions involve tiny savings in SF_6 (<0.1% pa on quantities of 0.7 – 2.5kg per unit), involving large numbers of more expensive (up to 30% as stated in the Briefing Paper) switchgear units (in practice the extra cost could be yet higher and there is no information provided as to where the costs estimates referenced in the Briefing Paper were sourced).

Additionally, the banning of **new** secondary MV switchgear creates difficulties and often huge costs for the replacement of existing MV Switchgear in the majority of legacy small substations. First, alternative switchgear technologies have to be type tested for the use in these MV packaged substations. One major problem is that products need more space than SF_6 switchgear. This is why in many existing places the alternative solutions are not used – they wouldn't physically fit. This is a problem especially in urban areas where alternative places are difficult to find. Furthermore, it is not expedient to replace simple RMUs with circuit breaker systems with electrical drive and protection systems.

The cost increases of up to 30% provided in the Briefing Paper were not referenced in the main Ecofys report and details of how they were derived were not provided. However, the figures used only referred to the purchase cost of the equipment itself, and failed to include other associated costs – such as installation - which could be expected to be significantly larger.

Furthermore, in the EU 2011 Assessment of Fluorinated Gases[7], it was recommended that MV switchgear should NOT be banned as the abatement costs at €347/t CO_2 Equivalent were considered excessively high (see also page 9 for further details). A simple assessment now of the equipment costs for non-SF_6 switchgear suggests that the costs are now actually higher per tonne than in 2011.

The above analysis would indicate that it will not be cost effective to invest large amounts of money in an MV SF_6 ban, only to produce such very small reductions in emissions i.e. there is no real gain in such a ban as effectively there are so little emissions saved.

In order to demonstrate the cost effectiveness of the switchgear, the extra life cycle cost in relation to the emissions reduced would have needed to have been calculated. However, this calculation of cost effectiveness was not provided. Life cycle cost along the value chain (from manufacturing, operation and end-of-life) is required to measure impact and in the comparison of alternative technologies (which may have higher initial costs) so that a correct assessment of the potential feasibility of all solutions is made on the basis of total cost of ownership over the technical/economic lifecycle.

(B) Technical Feasibility and (C) Availability of Reliable Alternatives

It was evident from the Ecofys report and Briefing Paper that there was no technical agreement amongst experts as to the technical merits of non-SF_6 switchgear, although there was clarity that non-SF_6 switchgear would be more expensive and could have different dimensions than SF_6 switchgear.

This would create problems for retrofitting in existing legacy stations if similarly dimensioned non-SF_6 switchgear which had been type-tested for this application needed to be installed, requiring costly and disruptive work which would affect customers. This issue was not addressed, although significant.

It was also generally agreed that there was no immediate potential to consider the use of non-SF_6 at voltages above 36kV, and no examples of available solutions in the range 36 -52kV were provided, yet it was proposed to ban switchgear in this voltage range despite no alternatives being presented.[8]

From the information presented in the Öko Briefing Paper, the technical feasibility of using non-SF_6 in new MV secondary substations was not established (see Technical review and Appendix 1 for a more detailed analysis).

It was also clear from the examples provided and the discussions in the Ecofys Final Report that many of the proposed alternatives to SF_6 were at a very early stage and had no established track record to

[7] Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases, Final report prepared for the European Commission in the context of Service Contract No 070307 / 2009 / 548866 / SER / C4, referred hereafter as to '2011 EU Fluorinated Gases study' or '2011 report'.

[8] Switchgear at above 24kV is Primary Switchgear so is **outside the scope of Article 21.4 of Regulation (EU) No 517/2014**. Also the description of Medium Voltage as voltages up to 52kV is inappropriate for technical issue such as switchgear, as no switchgear solutions were proposed for non-SF_6 switchgear above 36kV. Additionally, the EU EcoDesign Directive used 36kV to distinguish between transformer types on voltage, and IEC 60038 defines Voltages in Table 3 as from 1kV to 35kV, and in Table 4 from above 35kV to 245kV. Accordingly, any proposals should be related to a voltage range such as '***1- 35kV nominal***' rather than using generic 'Medium Voltage'.

prove their reliability (older types of switchgear proposed, such as AIS, was larger than SF_6 switchgear and unsuitable where space was at a premium).

There is an insufficient quantity of non-SF_6 MV switchgear in service for long enough to provide a track record of 'proven reliability' and insufficient data on reliability was provided in the Öko-Recherche Briefing Paper.

Some proposed alternatives were only available from a small number of manufacturers and should there be a ban on MV SF_6 switchgear it was not shown that the market would be able to switch production lines to provide such switchgear.

The proposed timescales mentioned of two or in some cases five years were wholly inadequate as evidenced from the EcoDesign Transformer Directive which demonstrated the timescales required for change in an area that was more mature and far simpler to implement. Tenders and specification changes alone would take at least two years and moving an industry to a new technology is best done gradually, with time to pilot changes and correct mistakes.

The T&D Report[9] of March 2020 did not indicate short time scales such as this and it is not clear how these proposed timescales were developed.

If such timescales, which are critical to any consideration of implementation are to be presented, then there must be strong supporting evidence that these are achievable. Yet this is completely absent in the Briefing Paper, and no such timescales were mentioned in the Ecofys Report. **Where is the supporting evidence for these timescales?**

Consequently the current availability of reliable alternatives was not demonstrated in the Öko-Recherche Briefing paper (see Technical review and Appendix 1 for a more detailed analysis).

(D) Energy Efficiency is not a differentiator between SF_6 and Non-SF_6 switchgear so is not a relevant criterion for assessing a ban on SF_6 in Switchgear.

In relation to **(E) Toxicology**[10] there is insufficient knowledge of the toxicology associated with non-SF_6 gas as studies on targeted quantities (according to Reach Regulation) have not yet been carried out. This aspect should be assessed to avoid potential issues on proposed deployment of later problems in service or on removal at end of life.

2.4 Conclusions & Recommendation for the current use and development of non-SF_6 switchgear

Assessing the cost effectiveness of non-SF_6 solutions is very difficult – some areas may become cost effective for some solutions but not others. Similarly assessing a track record of reliable operation requires large quantities of non-SF_6 switchgear to have been manufactured and installed.

[9] T&D Europe, 'Technical report on alternative to SF6 gas in medium voltage & high voltage electrical equipment', March 2020.

[10] Additionally EU should have a standard or a "Green Stamp" to support the correct decision about the alternative gas for SF6. The decision about the alternative gas for SF_6 cannot be left to the discretion of the manufacturers or clients.

There are number of options which could be undertaken to incentivise the use of non-SF_6 switchgear where technically feasible and cost effective, especially if these situations could be decided individually by the utility, as this leaves scope for utility to select the locations and applications which should meet these criteria. In the Ecofys report a number of market-based solutions were proposed including taxation, levies, deposits and tariffs and it could be possible to create such market solutions using these financial tools. Alternatively it might be possible to put a cost on SF_6 emissions so that the impact of SF_6 is now transparent and explicit to society and accordingly the cost of commensurate solutions could then be assessed.

These are further discussed in the section 3.4 below.

Obviously, there are other alternative proposals that could also be suitable. Eurelectric, E.DSO and GEODE would welcome the opportunity to discuss such solutions with the European Commission so that a real progress could be made on the introduction of non-SF_6 solutions not only in trial projects but in business as usual.

3. TECHNICAL REVIEW of Öko-Recherche Briefing Paper

‘SF_6 alternatives in electrical switchgear and related equipment’ (March 2020)

3.1 Overview

The basis of any decision on future use of SF_6 in switchgear was to be assessed against the following four criteria **for new MV secondary switchgear** (Article 21.4 of Regulation (EU) No 517/2014):

- **(A) Cost Effectiveness**
- **(B) Technical Feasibility**
- **(C) Availability of Reliable Alternatives**
- **(D) Energy Efficiency**

Toxicology is also a significant criterion which has to be taken into account. This is discussed under point **(E) Toxicology.**

SF_6 Switchgear is used both in network utilities, generation stations (including wind/solar) and by large industry, so that ultimately the costs and consequences of failure are borne by the end customer, society itself.

Society requires a reduction in greenhouse gasses and has multiple choices as to how it allocates resources to greenhouse gas reduction investments, so that it is important that such resources are targeted at areas which produce the greatest return, as otherwise such investments would have been more effectively deployed elsewhere.

An assessment of Öko-Recherche 'Briefing Paper' is provided below under each of the above headings with individual comments provided in Appendix 1.

3.2 Assessment

(A) COST EFFECTIVENESS

'Cost Effectiveness' is an assessment of the relative cost of achieving an outcome compared to the cost of alternatives which may achieve similar results but at lower cost.

In this case the outcome is a reduction in SF_6 emissions (in terms of CO_2 Equivalent) compared to the investment costs per kg required, which can then be compared with other costs per kg of CO_2 Equivalent.

This approach was initially followed by Öko-Recherche in the initial 2011 EU Fluorinated Gases study where an assessment was made of the relative costs per kg CO_2 Equivalent that would be provided by various measures, and where it became apparent that these costs associated with greenhouse gas reduction provided by banning MV switchgear would be inordinately high – far higher than for alternative investments which would reduce greenhouse gas more significantly for a much lower cost.

Accordingly**, the 2011 report stated that the banning of MV SF_6 switchgear was not recommended as it was not cost effective:**

Apart from the recommended bans described above, bans are not recommended for the following applications and reasons:

- *Because of low effectiveness for refrigerated vans, domestic refrigeration, rail and maritime transport, centrifugal chillers, and medium voltage secondary switchgear. A strict regulatory* *instrument such as a ban would need to be justified with a substantial contribution to the EU's emission reduction targets. This is unlikely, given the limited potential of these options;*

- ***Because of low efficiency and high mitigation costs for rail transport, MV secondary switchgear and heat pumps; Chapter 8 Options for further EU action 296;***
- *Due to limited availability of alternatives for HFC- 227ea in fire protection, by 2030.' (p.295, 296).*

The reasons why it was not worthwhile to ban MV SF_6 switchgear were as follows, and have not changed in any significant way:

- MV switchgear has the greatest number of installations, is 'sealed for life' with 0.1% emissions pa, but with each installation having a very small amount of SF_6 – typically 0.7- 2.5kg, so that in total it has about 10% of installed switchgear SF_6.
    - MV pole mounted reclosers have even less SF_6 – typically 0.7kg (but were not covered in the report).
    - This means that the extra costs associated with banning new MV secondary switchgear only produce a very small impact for a high investment, so that the cost per kg then becomes very high.
- A new MV secondary switchgear ban provides little scope for greenhouse gas reduction – in Table 8.10 of 2011 report it indicated that out of overall possible reductions of 62,125 kt CO_2 Eq in 2030, the most that MV switchgear could offer was 97kt CO_2Eq – about 0.15%.
- MV secondary switchgear is normally of a 'sealed for life' type with emission rates of 0.1% per annum, which is about 3% over 30 years. With between 0.7 – 2.5kg contained in each MV switchgear these amounts to 0.021 – 0.075kg SF_6 or 0.504 – 1,800kg CO_2 Equivalent. Additionally it is seen from the Ecofys report[11] that the emissions from production are very small and emissions from disposals are negligible.

In the 2011 Report the costs associated with an MV switchgear ban were given as €347/t EqCO_2, whereas other areas such as refrigeration had abatement costs of less than €30/t EqCO_2.

The Final Report '*Concept for SF_6-Free Transmission and Distribution of electrical energy'* by Öko-Recherche (2018) and associated '*Briefing Paper 'SF$_6$ and alternatives in electrical switchgear and related equipment'* (March 2020) **do not address the cost effectiveness of a ban on MV switchgear and instead just give indicative costs for the extra cost of non-SF_6 switchgear itself, but without relating this to the associated savings in SF_6 emissions**.

In the Briefing Paper (p.4) it mentions that ***'…manufacturer representatives reported additional investment costs after industrialisation in the range between 5% to 20%, with some conditional exceptions down to 0% and up to 30%'***, and in the Final Report it provides little extra information on costs other than to say that at a workshop participants considered that '***At present, the costs for alternatives are higher but are not considered prohibitive***' and ***'…that manufacturers largely abstained from discussions on costs[12]'.***

[11] Ecofys Report (2018) Section 5.3, Figure 21, page 42
[12] See Section 8.3.2 p75 Final Report

There are also additional costs that were mentioned in the Final Report but were not quantified:

*'An essential criterion when designing electrical equipment is a compact design. In urban areas, the installation of electrical equipment often depends upon space-saving construction. Furthermore, cost constraints are a factor, especially at the lower voltage levels. This applies equally to the **installation costs** and the **construction costs**, which are defined not least of all by the dimensions of the installation' (p.8).*

Maintenance costs for SF_6 switchgear were mentioned as higher than for non-SF_6 but this would not apply to the majority of 'sealed for life' MV SF_6 switchgear, but these costs were not quantified. There was also disagreement on the cost increases associated with the equipment costs of non-SF_6 with some users suggesting extra equipment costs of 30-50% for secondary distribution and 10-25% for primary, with manufacturers indicating that costs might decrease over time to about 10% extra (p.68 Final Report).

The Briefing Paper suggests 5-20/30% (p.4) for MV switchgear although not consistent with figures in Ecofys Final Report, but the experience[13] of Eurelectric. E.DSO and GEODE members is that the costs in practice have been considerably higher.

Costs are a difficult area, but this does not mean that assessments can be made on a qualitative basis as to whether an investment is cost effective or not.

To assess whether banning SF_6 switchgear would be cost effective requires a whole of life costing approach to establish the full impact of the associated costs, coupled with an assessment of the SF_6 emissions that would accrue. This has not been done.

Accordingly, the information provided in these reports is not sufficient to meet the criteria on 'Cost Effectiveness' as set out in the EU requirements as there is insufficient cost information provided on which to make an assessment of whether the reduction in SF_6 emissions produced by a ban on secondary MV SF_6 switchgear would be justified by the associated costs (equipment costs up to 30%, installation costs, design costs, legacy costs).

Note 1: For a simple 10% increase in the cost of an MV ring Main Unit costing €5,000, the emissions reduction would be 0.1% pa or 3% over 30 years. Emissions on disposal are negligible (see below Figure Z1 p(ii) Final Report) and on production are less than a sixth of the ongoing emissions.

[13] For example, see GEODE report which has been passed separately to Öko-Recherche.

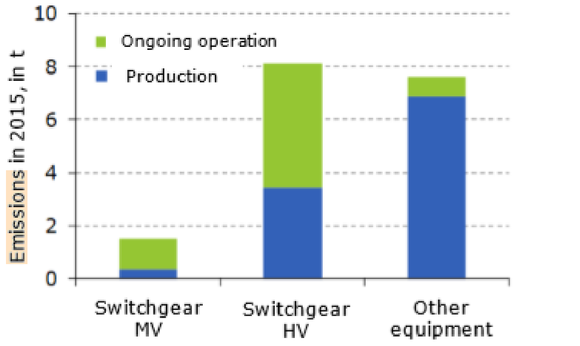

Figure Z1: SF_6 emissions from production and operation; emissions from disposal are negligible (2015).
Source: Own research based on [SOLVAY et al., 2005; UBA, 2016]

This means that for MV RMU's containing 0.7 – 2.5kg SF_6 with lifetime emissions of 0.021 – 0.075kg SF_6 or 504 – 1,800kg CO_2 Eq (say 1,150kg CO_2 Equivalent) the cost of abatement (if there were no further costs whatsoever) would be €500 or €0.43 /kg CO_2 Equivalent corresponding to €430/t Co2Eq.

In the 2011 report it was considered that €347 /t CO_2 Equivalent was excessively high for abatement costs for MV switchgear, and this figure is higher again.

Note 2: GEODE have done assessments of the economic and technical feasibility of replacement of existing SF_6 switchgear to reduce emissions and shown that it is not cost effective – details of this assessment have been separately passed to Öko-Recherche.

Note 3: Competition in the market for non-SF_6 alternatives

Some of the non-SF_6 solutions are proprietary and will limit competition in the market. Additionally, in the event on any ban on SF_6 the availability of non-SF_6 switchgear will be low, driving up prices to customers and delaying delivery.

(B) TECHNICAL FEASIBILITY AND (C) AVAILABILITY OF RELIABLE ALTERNATIVES

The nature of a distribution network is that it consists of very large numbers of assets with long life-times and whose installation costs and value in service are far greater than their equipment costs.

In a transmission network, similar considerations apply although the number of the assets is far less their criticality is far greater, and the consequences of failure on large numbers of customers are more severe.

Accordingly, in choosing equipment which is very expensive and disruptive to install the 'sine qua non' is that the equipment must be ***proven*** (not *expected*) to work reliably when installed for its full 40-year lifetime.

Considerations of equipment costs are a distant second – the equipment must meet the '**proven reliability** 'criteria, and only then does cost come into play.

To ensure security of supply to customers, any switchgear used must have been installed in sufficient volume, for a sufficient period, in the environment in which it is to be installed, so that it has an operational history that can prove its reliability.

In order to gain the necessary experience required, Grid operators together with manufacturers should continue to continue collecting experience in the operation of the alternatives so enabling the possibility of their future deployment/wide-spread usage.

Many things can affect reliability but may take a long time to initially present and then to become critical e.g. partial discharge.

The 'Briefing Paper' reviews alternative MV Switchgear up to 36kV and comments on its background:

Table 2: Examples of alternative medium voltage switchgear (secondary and primary distribution)

Rated Voltage	Type of application	Solution for insulation Solution for load breaking / circuit breaking	Status / comment
Up to 24 kV	Secondarydistribution	Air vacuum interrupter / vacuum breaker	Commercial product (applied for more than 5 years)
		Alternative gas using synthetic substances vacuum	Type tested and demonstrated with end users (less than 5 years).
		Alternative gas using natural substances Vacuum	Pilot presented in 2019 (12 kV).
		AIS load break switch with alternative gas (natural substances) at enhanced pressure in combination with vacuum interrupter	Commercial launch anticipated in 2020, GIS using same concept announced for 2021
36 kV		Various. Partly design extensions of existing 24 kV solutions.	Piloting / demonstration anticipated within 2 years
12 kV	Primarydistribution	Alternative gas (natural substances) at enhanced pressure	12 kV pilot presented in 2019, next panel type to be presented in 2020
Up to 24 kV		AIS load break switch with alternative gas (natural substances) at enhanced pressure in combination with vacuum interrupter	Commercial launch anticipated in 2020, GIS using same concept announced for 2021
Up to 24 kV		Alternative gas blended with synthetic substances, design comparable to SF_6	Type tested, piloting and demonstration running for several years.
36 kV		GIS alternative gas (natural substances, enhanced pressure) Vacuum	Type testing and piloting ongoing, to be finalised in 2020
Up to 36 kV		Various AIS vacuum breaker	Variety of commercial products (applied for more than 5 years), larger footprint than SF_6

(a) Medium Voltage is taken by Öko-Recherche as generally referring to 'up to and including 52kV'.

However when dealing with whether or not alternative switchgear is available at different voltage levels it is inappropriate to define Medium Voltage so loosely and then to propose a ban on 'MV Switchgear; when the definition used for 'Medium Voltage' casually includes 52kV - in fact Table 2 above only extends to 36kV whereas the Öko-Recherche definition of MV is up to 52kV[14].

This is problematic as:

(i) It is proposed to ban SF_6 in MV switchgear yet the report does not assess the availability of replacement switchgear above 36kV, e.g. generally 52kV rated equipment (as used in Ireland).

(ii) It is not consistent with the EU EcoDesign Transformer Directive which splits transformers into two voltage classes – up to 36kV and above 36kV.

(iii) As switchgear is internationally traded and Medium Voltage is not well defined it would be better to use IEC 60038 Section 4.3 Table 3 which covers nominal voltages up to 35kV and which is also compatible line with *'ANSi/IEEE 1585-2002 which refers to : Medium Voltage (1-35kV)*' and '*IEEE Std 1623-2004 refers to: Devices rated to medium voltage (1kV – 35kV)'*

(b) No evidence supporting 'proven reliability'

It is proposed that in addition to traditional existing solutions without SF_6 (AIS switchgear & solid insulated switchgear (up to 24kV)) that there are also new varieties of alternative SF_6 switchgear which may be suitable as substitutes for SF_6 switchgear up to 36kV, yet most of the varieties featured are commented as having experience of *'less than 5 years'*, '*launch anticipated in 2020*','*pilot presented in 2019*','*…demonstration running for several years', 'to be finalised in 2020'* etc. (see Table 2 above).

The only ones featured with at least five years were:

- **24kV Secondary Distribution**: Air-vacuum Interrupter/vacuum breaker

Comment Final Report (p.49): '*According to various manufacturers, vacuum load break switch designs are 30 – 100% more complex and more expensive than SF_6 load break switches which have a very simple structure'*.

Comment Briefing Paper (p.2): '*In the current market for new secondary distribution (RMU), AIS does not play any role of importance'*

- **Up to 36kV: Various AIS Vacuum Breaker**: (applied for more than 5 years)- larger than SF_6

Comment Final Report (p.49): '*AIS for primary distribution are produced by most manufacturers and are a good option when minimum space requirements are not a main criterion*.' Solid-insulated

[14] Moreover, there is a significant technological gap between 12kV and 24kV, so that these two voltage levels should be assessed separately.

switchgear is also mentioned as being as/more compact and based on variants of existing switchgear but with no details of volumes installed or length.

Comment Briefing Paper: '*Solid Insulated Switchgear solutions for secondary distribution have been commercially available for decades. The footprint of products up to 24kV currently marketed is equal to the solutions using SF_6. Market share all over Europe is in the lower single digit percentage… In some member states and regions, however final users adopted this technology and hence the market share locally is much highe*r'

Utilities first look for the ability of the switchgear to perform as required in the environment where they are installed (e.g. very cold/hot, humid) and for proven ability to do so reliably.

Given the above, the price the utility is willing to pay for the switchgear is whatever it costs to meet these criteria, as the cost of the switchgear itself is only a small fraction of the cost of failure or replacement on failure.

Type tests on switchgear are taken for granted – these are a minimum requirement that any manufactured switchgear would be expected to meet.

Reliability in operation, as evidenced by significant volumes working for long enough for failures to be able to develop and become evident, is what is required by utilities.

Each utility literally has about one Ring Main Unit for every 250 customers, so that as units are replaced or new ones installed there is likely to be large amount of equipment which will either provide reliable or faulty.

If faulty they can either fail, give rise to an outage and then be replaced, or they can fail functionally, where because of an inherent fault they are not considered safe to operate and all switching operations with them is then disallowed en masse. This means that any planned work or fault repairs on the system can then only be carried out by switching the remaining un-faulted units, with customers on faulty units having to be left without supply until switching on these units can be carried out de-energised.

Either way, the costs associated with installing switchgear which is not fully reliable is very high and lasts for many years, and utilities have experience with failures of such units.

As experience with non-SF_6 switchgear is limited in comparison with that of SF_6 Switchgear, further time and installed volumes are required to prove the operation of such units in the field.

(c) Issues of Size

For environmental reasons (minimising size and maximising public acceptability) most utilities use 'packaged MV/LV substation' which feature a modularised combination of transformer, MV Ring Main Unit and LV panel, all mounted on a chassis and contained in metal housing.

If MV SF_6 switchgear is banned this would mean that:

(i) All existing MV/LV substations would need to be redesigned, tendered and type tested so that a new design of MV/LV substation was available.

(ii) Similarly, for indoor MV/LV substations the layout would have to be configured so as to accommodate the new footprint of SF_6 free equipment, which generally has a different L x B x W than SF_6 switchgear

(iii) MV SF_6 switchgear in existing substations would have to be replaced with non-MV SF_6 switchgear[15] which would not be possible unless the non-SF_6 switchgear had smaller dimensions than existing switchgear (which is generally not the case) and a type test could prove that it was compatible with each legacy design.

In the case of MV/LV packaged substations these are installed on sites matching the dimension of the module – land outside this curtilage is not owned by the utility and generally belongs to private households on either side. Acquiring extra land e.g. extra 0.5m would be very expensive as the substation cabling is fixed in place so that alternative sites are not feasible without extensive street-works. This means that the opportunity cost to the utility of such land would be very high – up to the cost of acquiring a substation site elsewhere and cabling to it. These costs would be a multiple of the entire cost of the modular substation.

In packaged substations, which comprise the majority of locations for MV secondary switchgear, the combination of equipment installed in the cabinet (Transformer & Switchgear) is type tested as a unit to ensure that the combination of equipment in the cabinet can operate correctly in case of fault, as such units are located in public areas. This would mean that each variety of existing packaged substation designs would have to be type tested with the new non-SF_6 switchgear to prove its correct operation. This is very slow and excessively costly for the small volumes that may be required in practice for each design.

In indoor substations it is more likely that the siting equipment would need to be reconfigured in order to accommodate larger non-SF_6 equipment and this would involve several days' labour plus standby supply whilst the substation is out of commission. This would amount to considerable costs in labour and civils where such work was required.

Consequently a critical issue for utilities is any consequent requirement to install non-SF_6 equipment in existing locations, as replacement to existing switchgear, where the costs associated become very significant.

(d) Distinction between Primary and Secondary MV Switchgear:

Whilst secondary distribution stations are about 500kVA in size, primary distribution stations involve transformer capacities of up to about 2 x 15MVA and typically transformation from above 24kV down to 20/10kV. Unlike secondary substations which use load break switches and transformer fuses, primary substation employs circuit breakers each in their own bay.

[15] The use of primary switchgears with circuit breakers as an RMU is conceivable, but in addition to the significant additional costs it has the disadvantage that protection relays must be used. These must be maintained in regular intervals. In addition, the fault response time with circuit breakers is significantly slower than with fuses. This means that using circuit breakers instead of fuses would result in a complete revision of the current protection scheme.

Space is very important in these stations particularly if they are indoor, as all the 10/20/33kV switchgear will have been set out to maximise the number of outlets that can fit into the switch-room. This means that it is not possible to replace one circuit breaker with one with slightly different dimensions – even down to mm as the switchgear has been assembled side by side.

If any unit had to be replaced with non-SF_6 Switchgear that wasn't absolutely identical then the whole busbar would need to be replaced which would be inordinately expensive. This expense would arise not only for the purchase of multiple circuit breakers but because it is not generally possible to simply rewire a switchboard in an existing station as the station loads are substantial and must continue to be fed.

Accordingly, it is more practical in such situations to bring in a modular switch room completely equipped with new switchgear and associated protection relays, develop a new concreter plinth, dig new cable trenches and then joint and divert each MV cables from the old board to the new board. As typically there will be at least 10 such breakers per station the cost involved are around €200,000+ for 10/20kV switchgear and higher if above 20kV.

Inevitably any costs associated with retrofitting non-SF_6 switchgear in existing stations are likely to be several orders of magnitude greater than the costs of using non-SF_6 in brand new substations, and this point has just been highlighted here as it was not evident in earlier reports.

(e) Time to ensure commercial availability of alternatives

Aside from time and experience requirements already referred to, any changes to switchgear require changes in specifications, of the switchgear itself and changes to designs in which the switchgear is used, including type tests of the substations. Additionally, any projects already in train either need to continue or be altered, although altering projects in train has consequences for customers in terms of both cost and delay.

The period of two/five years suggested is completely inadequate for both utilities and manufacturers. If any ban were to take place of MV SF_6 switchgear it would take several years for manufacturers to gear up to produce the alternative SF_6 switchgear in the quantities required, as the nature of such a ban is that every utility in Europe would need such switchgear at the same time. Consequently, factories would have to be expanded and retooled and existing stocks of SF_6 switchgear reduced as it would be unsaleable after the ban.

The sort of realistic time scale would be a minimum of 5+ to 10+ years (depending on the type of switchgear and assuming that it was economically justifiable to use non-SF_6 switchgear at MV, given that only 10% of SF_6 in switchgear is used at MV and with so little content of SF_6 per units (0.7 – 2.5kg) and such low emission rates (0.1%) it would be difficult to justify).

(f) Switchgear of 52kV – 145kV

Experience of suitable non-SF_6 switchgear is even more limited at 52kV and above, and functional requirements are higher and the consequences of any reliability issues greater. Alternatives to SF_6 gas in GIS requires switchgear with larger dimensions with greater cost increases (20 – 30%) (per p.5 Briefing Paper).

In the Briefing Paper it is clear that experience with non-SF_6 switchgear is very limited and that there is no proven track record of reliability*, as illustrated below:*

'According to manufacturers, several hundred bays have already been ordered. Implementation of different technology approaches is expected in the next two years' (p.5)

'… Live tank breakers have been presented and piloted successfully by several manufacturers'

The above comments clearly indicate that such switchgear is simply at a stage where utilities are carrying out initial pilots on the use of such switchgear – no utility would move to use such switchgear on a 'Business as Usual' basis until such trials had proven reliability, which would take several years.

All of the earlier points made for MV switchgear also apply at HV, so that usage at HV is even more difficult to justify.

(g) Switchgear above 145KV and related equipment

As the Briefing Paper notes any equipment discussed is only at an early stage in trials.

MV instrument transformers *'contain only very low residues of SF_6' (p.5).* The point that replacement of SF_6 *'may be possible for a limited number of applications (lower insulation levels) in the next 5 years'* is just that - a possibility that something might happen, but is not a justification of technical feasibility and action on SF_6 MV instrument transformers.

(h) Niche Areas where no replacement of SF_6 is likely to be available

Examples provided (p.6) included *'..extreme currents and temperatures'*.

Consideration of 'niche areas' using derogation:

- This and earlier comments about 'niche' requirements for SF_6 switchgear could more generally be addressed by a derogation system based on similar principles to those in the EcoDesign Transformer Directive.
- This would avoid need to attempt to identify every possible exception e.g. requirements in nuclear power plants.

(i) Limited number of manufacturers

Depending on the technology, the number of manufactures available to offer solutions varies, and this could result in reduced competition and higher prices due to the time to develop alternative technologies. This is particularly applicable to replacement of SF_6 gases.

(j) Sustainability

The possibility of a future ban on other gasses which might replace SF_6 and which could have fluoroketone in their composition is not addressed, nor is the toxicology of alternative SF_6 solutions (please see section E for further details on the toxicology aspect).

From the above it is clear that neither the case for non-SF_6 being (B) Technically Feasible or (C) Reliably Available, has been made.

In particular the requirements for 'proven reliability' are not met with many alternatives being in the early pilot stage. Where some established alternatives are available, such as AIS, they are unsuitable due to size, and the issue of how to approach replacement of existing SF_6 switchgear in existing station when only non-SF_6 switchgear is available (which will not fit) has not been addressed.

(D) Energy Efficiency

Energy Efficiency is not an issue that has required consideration in either the Final Report or in the Briefing Paper as there is little or no difference in the energy efficiency of SF_6 and non-SF_6 switchgear, as electrical losses in the switchgear depend on the conductivity of the busbars, which is the same in SF_6 and non-SF_6 installations.

A comment on operational efficiency was made on page 4 of the Briefing Paper to state that '*Differences of Operational efficiency of existing switchgear and new alternatives are negligible'.*

(E) Toxicology[16] studies

The report also proposes fluorinated substances as alternatives to SF_6 (fluoronitriles or fluoroketones). These solutions, even if they have a lower emission-rate than SF_6, should not be compared to natural and non-toxic substances as their harmlessness has not been established yet, especially because

[16] T&D Technical guide to validate alternative gas for SF_6 in electrical equipment" should not be enough to help DSO to choose the right alternative gas for SF_6. In terms of environmental, health and safety aspects, DSO will have to validate the solution based in a complex list of environmental, safety and toxicity data (DSO will have the capacity to validate each of these parameters?):

1. "GWP over 100 years
2. ODP
3. LC50 4h (on animals)
4. TLV-TWA based on tests performed on animals for each pure gas
5. CMR classification based on each pure gas
6. Flammability
7. Eyes, hands, body protection required for handling and breathing
8. Odour, colour if easy to detect its presence
9. Reactivity with other gases, materials, liquids, life stock
10. Density (relative to air)
11. Solubility in water
12. Persistency and degradability (abiotic and biotic)
13. Bioaccumulation (BCF)
14. Ecological information "

secondary substations are installed close to living areas and even into them (buildings, residential areas, hospitals…).

From a DSO's perspective, SF_6 is a stable gas without any recycling or re-use problem. The toxicity of some decomposition products related to switching function is already fully monitored. According to DSOs' experts, recycling matters have not been evaluated yet for alternatives manufactured gases. Toxicology analysis must be mentioned for some manufactured gases, both at initial state and after decomposition. The table below relates the studies carried out so far according REACH regulation:

	Annex			
	VII > 1 t C5F10O C4F7N	VIII > 10 t	IX > 100 t HFO 1234ze	X > 1000 t SF6
In vitro gene mutation study in bacteria (Ames)	X	X	X	X
In vitro cytogenicity study in mammalian cells or in vitro micronucleus study		X	X	X
In vitro gene mutation study in mammalian cells, if a negative result in Annex VII		X	X	X
In vivo somatic cell genotoxicity			X	X
Second in vivo somatic cell test				X
Potential for germ cell mutagenicity			X	X

Table 3: Mutagenicity requirements according REACH regulation and situation of SF_6 and alternative gases

Studies on molecules such as Fluoronitriles and Fluroketone, have been limited to 1t volume. Studies must be carried out for all targeted quantities to avoid these substances to be forbidden in the latter. Then, the absence of risks for population living on the vicinity to that equipment must absolutely be demonstrated. The report must explicitly mention these requirements.

Moreover, toxicology studies are not mentioned either on the HV part of the report.

Only solutions for which positive toxicity studies have been released would be trialled by DSOs. It is unwise to conclude that operating pilots for a short-time period should be considered as mature and reliable solutions taking into account that toxicology studies are not yet completed enough and fragmented.

It is **not possible** to conclude that operating pilots for a short-time period should be considered as mature and reliable solutions taking into account that toxicology studies are not yet completed enough and fragmented, and doing this prematurely would not be in accordance with Safety legislation. Therefore, further assessment is needed to ensure health and security requirements are met.

3.3 Conclusions

Proposals to ban the use of SF_6 in switchgear had to be assessed against the following four criteria as per Article 21.4 of Regulation (EU) No 517/2014.

- **(A) Cost Effectiveness**
- **(B) Technical Feasibility**
- **(C) Availability of Reliable Alternatives**
- **(D) Energy Efficiency**

(E) Toxicology is also a significant additional criterion.

In the above analysis it was shown that **no case to demonstrate cost effectiveness had been made** and that all indications were that it would **not** be cost effective, as was already established in the earlier 2011 Report. In fact it appears that the costs per tonne of CO_2 Equivalent could actually be larger, even if based only on the cost of the equipment itself.

In relation to technical feasibility it was not established that non-SF_6 MV switchgear was technically feasible – examples were given of relatively unproven products which were at early stage in development and the issue of how to retrofit existing substations with non-SF_6 MV switchgear following a ban on SF_6 MV switchgear was not addressed (also MV should be defined as up to 36kV, not to include 52kV).

In relation to reliability there were no statistics offered demonstrating a track record of proven performance in the field of enough units for a long enough period to establish the required level of performance.

Energy efficiency is not a differentiator between SF_6 and Non-SF_6 switchgear so is not a relevant criterion for assessing a ban on SF_6 in Switchgear.

In relation to Toxicology there is insufficient knowledge of the toxicology associated with non-SF_6 gas.

3.4 Recommendations for the current use and development of non-SF_6 switchgear

Justifying a ban on MV SF_6 switchgear is difficult as any assessment is complicated and there is little experience with non-SF_6 switchgear, particularly in terms of reliability, as there are not enough units installed to provide the required reassurance on performance.

There are number of options which could be undertaken to incentivise the use of non-SF_6 switchgear where technically feasible and cost effective, especially if these situations could be decided individually by the utility, as this leaves scope for utility to select the locations and applications which should meet these criteria. In the Ecofys report a number of market-based solutions were proposed including taxation, levies, deposits and tariffs and it could be possible to create such market solutions using these financial tools. Alternatively it might be possible to put a cost on SF_6 emissions so that the impact of SF6 is now transparent and explicit to society and accordingly the cost of commensurate solutions can be assessed.

Obviously, there are other alternative proposals that could also be suitable and Eurelectric, E.DSO and GEODE would welcome the opportunity to discuss such solutions with the European

Commission so that real progress could be made on the introduction of non-SF_6 solutions not only in trial projects but in business as usual.

4. APPENDIX 1 - Particular comments on items within the briefing paper

Note: To facilitate the reading and / or taking into account of the remarks, the OKO report has been numbered in the distributed version.

General

The scope of the report goes beyond what is called for in Article 21.4 of Regulation (EU) No 517/2014 (possible ban on new MV SF_6 switchgear in secondary substations) and does not draw a clear distinction between primary and secondary substations, and the voltage range covered in the scope of 'Medium Voltage' is too indiscriminate e.g. secondary substations do not go above 24kV.

Furthermore the report is very short (just 7 pages long) and does not go into enough detail to bring out the potential difficulties faced by the European network operators or embrace the content of the Energy Networks Association (GEODE) impact Assessment Report on costs (for example) which will have a significant impact on European customers.

1. Introduction

Line nº 10:

''Sulphur hexafluoride (SF_6) has been used as an insulating and circuit breaking medium in switchgear for decades.'

It is also effective in arc interruption and has an important role in providing insulation for a point of isolation in a compact arrangement.

Line nº 12:

'…it's use in switchgear can produce toxic products…'

Such toxic products are **only** produced when SF_6 breaks down during a severe short circuit. These products are then absorbed by molecular sieves within the sealed container containing the SF_6 gas, and do not escape to the atmosphere. Only in the event of a fault severe enough to rupture the tank would these products escape into the atmosphere, and this would be a very rare occurrence.

2. Status of alternatives to SF_6 in different types of equipment

2.1 Different types of Switchgear

Line nº 20 – 25

(a) Voltage Classification:

The classification shown 1kV – 52kV and 52kV – 230kV and > 230kV is inappropriate and should instead correspond with IEC 60038 which covers in Table 3 1- 35kV, Table 4 > 36kV – 245kV and >245 kV in Table 5.

The ranges above, of 1kV – 35kV and >35kV are also in line with the voltage band used in the EU EcoDesign Transformer Directive.

Given the technology gap between <12kV and >12kV, the more appropriate ranges would be 1kV - 12kV, 12kV - 24kV, 24kV - 36kV and > 36kV.

Including 52kV when considering proposals for Switchgear is inappropriate when the possible solutions for non-SF_6 Switchgear in the range 1kV to 35kV are not applicable at 52kV.

(b) Requirement for additional factors other than voltage for correct classification:

Voltage cannot only be the only discriminant/selection technical criteria when describing switchgear. It's very important to also add the nominal and short-circuit withstand and opening currents since these technical parameters have a huge impact on the size & volume and even the size of the market for any given switchgear.

(c) For example a 24 kV secondary distribution circuit-breaker with a rated current of 630-2500 A (16 kA to 31.5 kA) cannot at all be compared with a 24 kV generator circuit breaker designed for a rated current of 28 kA and a short-circuit current of 210 kA. The first apparatus can be found in many secondary distribution substations whereas the second apparatus can only be found in power generating plants with power greater than 1000 MW.Other electrical functional requirements need also to be considered when assessing switchgear e.g.
   - current interrupting,
   - switch-disconnector and
   - earthing switch

   As an example, in France, the switch disconnector function is essential and mandatory as it allows the insulation and separation of an electrical circuit. Following this, operators are then able to intervene safely. As a matter of fact, the vacuum switching function alone cannot provide this capability.

Section 2.2 Medium voltage switchgear – general

Line n° 30 – 32

'Primary distribution is generally implemented in controlled environments such as substations of regulated or industrial network operators in closed buildings, such devices are integrated directly into the networks of the final users.'

Primary circuit breakers are actually owned and operated by the network operator and are not integrated into the networks of the final users.

Line n° 30 – 32

'Secondary power distribution refers to the switchgear at the interface between medium voltage distribution networks and the (medium voltage-low voltage) distribution transformers, located in cabinets near the user's premises.'

For clarity, not all MV/LV distribution transformers are located in cabinets as there are a variety of approaches used in different countries with large groups of legacy installations of small size or in difficult to access areas such as basements or underground vaults. Configurations of equipment may also be quite different with some interconnections by cables between separate items of plant but others involving direct connection of the switchgear to the Transformer via tank to tank connections to accommodate circuits in oil.

Distribution transformers may be located in indoor or outdoor environments. In the case of larger industrial users, they will generally be located near their premises. In the case of domestic users, they will supply consumers in the locality via LV service main cables.

Line n° 33 – 35

'The dominating application of secondary power distribution are ring main units (RMU), in different configurations, integrated in MV/LV transformer cabinets in regulated public networks.

The RMU may not be located within a cabinet – it could be separate from the Transformer and cabled, or it could be bolted to the Transformer directly but not be within a cabinet. These arrangements would mean that the impact on low temperature on operation would be more significant.

Line n° 46

(a) Table Layout:

The table is hard to understand and has associated qualitative indications (low, medium, high) which are not explained, especially when it comes to make a distinction in between technologies (AIS, GIS, SIS). Elements of comparison should be given for equivalent functionalities (i.e. for an HV switchyard in a power plant, a GIS installation contains 2600 kg of SF_6 when an AIS equivalent switchyard will contain 70 kg only located in the breakers).

Note: Other electrical functions of switchgear should be included, such as current interrupting, switch-disconnector and earthing switch as they are mandatory in some Member States (e.g. France).

(b) Table obscures variations between countries:

Additionally, as an illustration of media per segment it obscures the quite different practices in different countries e.g.

Table 1 – Circuit breaker Breaking medium for public sector – in UK at MV more of a 50/50 split between SF_6 and vacuum, so both entries would be "medium"; In Ireland virtually 100% SF_6.

Table 1 bottom row - Circuit Breaker Breaking Medium (SF_6 low /Vacuum High) - The UK position is quite different to this. The predominant breaking medium for non-oil secondary circuit breakers is SF_6. The use of vacuum interrupters in ground mounted secondary circuit breakers is very low. In Ireland SF_6 would also predominate.

(c) Table is unclear on use of MV Switchgear at Primary and Secondary level:

In most MV networks (e.g. in Germany), short-circuit protection for MV cables and overhead lines is provided by the **primary** substation. **For this purpose, circuit breakers are required.**
Table 1 depicts, for the **secondary** MV level, the shares of different insulation media and breaking media for **switches** on the one hand and for **circuit breakers** on the other hand.

It says that the share of vacuum technology is already high among the circuit breakers. This is correct but it neglects the information that circuit breakers are rarely used in the secondary MV level.[17] In the **secondary** substations, **standard RMUs** are very often designed as a combination of **load-breaking**

[17] The T&D Europe (2020) report from which the information in table 1 was taken says that, on a European level, the repartition for secondary switchgear is 80 % switches and 20 % circuit breakers (see T&D Europe (2020), table 3). In the public distribution grids in Germany, the share of switches in secondary switchgear is even higher (> 90 %).

switch and fuses, which do not require protection relays or electric drives. The MV/LV transformers connected to the secondary substation are protected by fast-acting fuses.[18]

This technology is much more cost-effective than circuit breakers. Yet, **for the secondary MV, RMUs (load-breaking switch/fuse) with alternative gases are barely available** (in opposition to the situation for primary switchgear). This is why, up to now, grid operators primarily use SF_6 products for secondary switchgear.

Note: The use of primary switchgears with circuit breakers as an RMU is conceivable, but in addition to the significant additional costs it has the disadvantage that protection relays must be used. These must be maintained in regular intervals. In addition, the fault response time with circuit breakers is significantly slower than with fuses. This means that using circuit breakers instead of fuses would result in a complete revision of the current protection scheme

Line n^o^ 53

'*In the current market for new secondary distribution (RMU), AIS does not play any role of importance*.'

This wording is also applicable to SIS due to the configuration of the equipment i.e. there is no like-for-like alternatives to SF_6 RMUs.

Line n^o^ 60 - 62

'The footprint of products up to 24 kV currently marketed is equal to solutions using SF_6.'

Regarding SIS, do not agree with wording '*is equal to solutions using SF_6*'. There are SIS products which are larger.

Line n^o^ 67

'In summary, SF_6-free alternatives <u>have always</u> been used in primary distribution…'

It would be more correct to state that '*SF_6-free alternatives are <u>commonly</u> used in primary distribution*' because older Primary Substations were comparatively large and could accommodate AIS Switchgear. In contrast such space is not available in packaged secondary substations.

Line n^o^ 70 - 73

'*There are however a number of limiting factors, in particular in secondary distribution, that restricted choice of switchgear type including...initial investment…space constraints…maintenance … environmental…'*.

The ability of these products to provide a Point Of Isolation (POI) as required under many utilitiy's safety rules is not mentioned e.g. such requirements may be mandated under a particular utility's safety rules (e.g. current UK rules). Equipment can be made compact by having the physical gap serving as the Point Of Isolation (POI) in gases that are good insulators (such as SF_6). In air the gap would be bigger making it difficult to keep the footprint compact. However, if the Vacuum Interrupter

[18] VDE FNN TH „Leitfaden zum Einsatz von Schutzsystemen in elektrischen Netzen" – Chapter 11.4 and 12.3.

is intended for POI duty, this would not meet POI requirements e.g. this approach is not currently allowed in UK.

Section 2.3 Assessment of new alternatives for medium voltage switchgear

Line nº 85 Table 2

There is a significant difference in the availability and experience with 24kV and 12kV Switchgear using non-SF_6 solutions and the Table should be split to show the differences between 12kV and 24kV.

Currently many utilities are buying 24kV rated equipment even when the network is currently operating at 10kV because this facilitates subsequent conversion to 20kV which can accommodate more renewables and better cater for the electrification of heat and transport.

Footnote 8 Briefing Paper: *'From a climate policy perspective end of life emissions of SF_6 are a crucial aspect. So far, only marginal shares of the existing SF_6 asset base have reached end of life. Very little evidence-based data on end of life emissions are available. Estimates cover a range from 1% to 40% of emissions from scrapped equipment. In the worst case, 40% of the 1500 t SF_6 annually filled into new equipment by European manufacturers (in MV and HV) will be released to the atmosphere at some moment in time. This corresponds to 1.5 Mt CO_2 eq annually. The environmental impact of these emissions is potentially a multiple of current emissions in manufacturing and operation of electrical switchgear (MV and HV) in Europe.'*

This suggests that there is massive scope for a saving SF_6 from end of life emissions, far greater than all the emissions during life cycle, yet this area has received little attention in the Report. It is also not clear how such end of life emissions would occur given the stringent requirements on SF_6 disposal and the recording of the quantities involved. It is surprising that greater attention wasn't paid to this area given the potential scale of emissions which could be saved.

Line nº 91 – 95

'…manufacturer representatives reported additional investment costs after industrialisation in the range between 5% to 20%, with some conditional exceptions down to 0% and up to 30%.'

There is considerable uncertainty over equipment price increases e.g. In the UK, manufacturers reported an expected 10-30% increase in cost.

In fact one Eurelectric utility has reported the cost of some alternative non-SF_6 solutions as being up to 100% higher than traditional SF_6 solutions.

However, the equipment price increase is minor compared to other costs which may be associated and which are described above in the response by Eurelectric, E.DSO and GEODE.

Line nº 103 – 104

'Thus, the costs at this stage of the life cycle is lower than for systems using SF_6 or alternative gas blends using synthetic substances[19]. However, it is not possible to reliably quantify this potential cost advantage'

Detailed international rules covering the handling of non-SF_6 gas in case of fault incidents or end of life, are currently unavailable but may involve extra costs, particularly if there are disposal issues or interaction with existing materials.

Line nº 105 - 118

In the end of chapter 2.3, the briefing paper lists some **obstacles** (called "additional steps") currently preventing a higher market penetration of alternative products. Eurelectric, E.DSO and GEODE appreciate that the authors make references to these obstacles. However, **Eurelectric, E.DSO and GEODE do not share the conclusion** saying that a period of "*around 2 years for applications in primary distribution (MV switchgear in substations) and the most common RMU configurations*" would be needed

In summary, for applications in the secondary MV, a period of two years is too short.

Even if products were available on the market two years from now, it would take at least another 2-5 years before they were available for deployment on the networks.

This is due to the steps which have to be accomplished by the network operators: First, they have to carry out a tendering procedure and, after comparing different offers[20] and prequalification procedures, conclude a contract with the supplier. Before the systems can be purchased, all the necessary tests must be carried out; e. g., factory-fabricated station buildings (according to EN 62272-202) require proof of arc fault safety, in combination with the installed switchgear. Due to the change in technology and the changing behaviour under fault conditions, these have to be re-performed in individual laboratory tests.

This also assumes that all the associated EN Standards covering this switchgear have been suitably amended and updated.

Thus, **between commercial availability of a product** and its **installation** a **considerable time gap** has to be taken into account.

Line nº 105 - 108

'Commercial availability of alternatives and, thus, potential market penetration will be affected by several additional steps:

[19] End-of-life treatment of gas blends with synthetic substances requires similar procedures like SF_6.

[20] It would not suffice to have only product offered by one supplier since this would bear the danger of monopoly prices. A competitive market is needed.

- *In particular in secondary distribution (RMUs), specific application configurations need to be developed and type-tested'*

Not alone would this type testing be required for all new substation configurations as the combination of RMU and Trafo in a cabinet forms a unique unit which must be tested as a combination. This would also apply to a requirement for Type Testing of legacy substations where new types of non-SF_6 MV Switchgear are required to be installed e.g. repair or refurbishment.

In addition, there are also national variations e.g. in markets like the UK an SF_6-free RMU that could be close coupled to the transformer would be required to be developed and type tested.

Note: Legacy and current standard UK 11 kV distribution substations have a curtilage of 3 m x 3 m and use outdoor rated ring main units (RMUs) with an average footprint of 0.75 m2. The small footprint is achieved by coupling the transformer to the RMU and LV PENDA (LV switchgear). Non-SF_6 alternatives currently on the market require cable connection to the transformer which generally requires greater space. Non-SF_6 switchgear available at the present time is generally rated for indoor use only.

Line n^o 105 – 108

'Pilot installations for voltages up to 145kV have been successfully implemented and operated using the different gases and gas blends. According to manufacturers, sever hundred bays already have been ordered. Implementation of different technology approaches is expected in the next two years.'

Some of the findings are potentially misleading. It is correct that pilot installations for voltages "*up to 145 kV*" have been successfully implemented and operated using alternatives to SF_6, and several hundred bays have already been ordered. But it should be stated more precisely that these are primarily applications in the 72.5 kV level.

2.4 Assessment of new alternatives for high voltage switchgear

Switchgear for Voltages between 52 and 145kV

Line n^o 124 – 130

It's worth mentioning that only one gas blend (g3) is available. This is important since if no other competitor emerges, the end users will face a monopolistic market.

The indicated 20% to 30% cost increase used in the evaluation is unsupported by evidence (where are these values sourced and how were they calculated?).

Furthermore, non-SF_6 technologies have only recently have been proposed to utilities and consequently applied in pilot/experimental phases and for limited power capacity range with costs significantly higher than current SF_6 solutions.

In addition, the reliability of equipment using alternative gas solutions on a large scale hasn't been validated with sufficient time-experience.

Line n^o 136 – 153

With regard to switchgear for voltages higher than 145 kV, the briefing paper correctly states that SF_6-free switchgear is under development.

However, the development and on-site testing of SF_6-free assets above 145 kV needs to be considered **separately**. Although, in a very limited number, some SF_6-free **passive components are already in the on-site testing phase** (e. g. bus ducts, bushings, AIS voltage transformers), the development of SF_6-free **switching elements** (circuit breakers, disconnectors, earthing switches) still **represent a major challenge**.

According to manufacturer statements, the development of e. g. 420 kV equipment might take up to 7 years from now. Their development needs to be followed by a similarly long introduction phase.

For the HV and EHV level the introduction of alternative technologies **will take more time than indicated in the briefing paper**: After the development period (which is estimated to take up to 5 years in the paper), it will take again **several years until a sufficient number of products will be offered** by different suppliers. Only when this process has triggered a functioning competitive market, grid operators will be able to order the new products in large scale. From the tendering procedure for a new HV or EHV switchgear installation until its start into operation, a period of up to 7 years is realistic. Thus, from now onwards, it will take 10-15 years until alternative solutions will enter into general use in these voltage levels.

For any given solution & technology, it would be important to carry out a full Life Cycle Costing analysis on the overall impact on CO_2 taking into account not only “future technology optimization” (i.e. taking into account only the cost) but also the global carbon print (i.e. raw materials, energy needed to produce the new switchgears, etc..).

Line n° 137 – 140

Just as a reminder, g3 was first introduced in 2014 and there is no other known competitor for voltages above 220 kV and short-circuit currents up to 63 kA.

The proposed time scales mentioned - “2 to 5 years development period” – are not credible for a transition to non-SF_6 Switchgear on a ‘businesses as usual’ basis.

The development period just to produce a prototype model that can be installed as a pilot would itself alone be 2-5 years – this would still be many years from commercial availability.

It is concerning that such timescales, which are not appropriate or realistic, are being proposed and would indicate a lack of appreciation of the issues in this area.

Again, is the given time line (2 to 5 years depending on the voltage level but also on the current level) the result of a consensus between a small number of different manufacturers?

However, solutions without competition are not really an option for end users.

Section 2.5 Related equipment

Line n° 154 – 157

The text states that instrument transformers contain only low quantities of SF_6 (residues from the manufacturing process) and epoxy is used as insulation medium. That is correct for MV, but does not apply in all cases. In the HV and EHV levels there are also instrument transformers which use SF_6 as insulation medium and thus are completely filled with SF_6.

Instrument transformers – may have to develop different technology due to space considerations, with an impact on cost and technical performance.

Section 3 End users' perspective on SF_6 free alternatives

***Line n°* 162- 165**

- ***'Utility Sector: …'***

General comment - Several SF_6-free solutions, particularly those utilising alternative gases, have only been in service for a few years and therefore the longevity of the products is unproven, which presents a risk to network operators.

The wide range of alternative gases offered also has cost and training implications for network operators; each gas type needs a dedicated gas cart and fittings available, and operators need to be trained in gas handling and familiar with the equipment for each type.

Additionally, only a limited number of manufacturers have been able to propose alternatives to SF_6 switchgear Ring Main Units at 24kVand for 145kV Circuit Breakers.

Line n° 169 – 175

AIS is seen as part of the solution since an AIS Substation has less SF_6 than an equivalent GIS, because SF_6 is only present in the breaker itself, whilst using GIS technology SF_6 is present in the whole switchyard i.e. for the same functionalities a GIS switchyard contains approximately 40 to 50 times more SF_6 than in an AIS switchyard.

However, GIS results in a much more compact substation than AIS, suitable for use in urban areas, or to redevelop existing AIS stations to accommodate Renewable Generation/ Extra load where the existing Substation must remain operational whilst a new substation is developed on the same site.

There is probably scope for greater use of AIS in Wind/Solar farms which tend to be developed on uncrowded greenfield sites.

Line n° 170 – 171

'In the industrial sector, however, alternatives like AIS have always been part of the solutions'

The sentence should be completed by adding the words '*always been part of the solution* ***when space allowed'*****.**

Line n° 175 – 179

This paragraph takes a one-sided optimistic view of non-SF_6 alternatives and is not sufficiently developed.

Depending on the application and the main technical criteria (voltage & current) there is a need for a table giving the details below in order to better assess whether non-SF_6 is a viable alternative:

- the different alternative solutions i.e. the media proposed and status (patented/unpatented);
- the number of manufacturers for each solution;

* the relative costs (i.e. ratio between new and traditional solutions)
* The relative volumes and sizes between new and traditional solutions
* the development stage (prototype / on site tests / industrial product) and numbers in use for what period of time
* the specific constraints & required skills (when compared with SF_6 handling) and whether there may be any health (toxicological) issues

In the absence of such detail it is not possible to make a reasoned assessment of non-SF_6 as a potentially viable solution.

Line n^o 180 – 184

The "niche sectors" are mainly in MV (< 50 kV) and not in high voltages (> 220 kV) applications. Even if there was an exception for these applications Eurelectric. E.DSO and GEODE members, as end users, fear that the banning of SF_6 (or coercive and complex regulations) might lead main manufacturers to also abandon these very small market segments

The availability of competition has not been covered yet is of concern to users, particularly when there is an availability of alternatives e.g. g3

Line n^o 186 – 188

Untitled Table…
'greenfield'
'Dominating part of total market potential in MV'

This is an optimistic statement and it is not currently clear whether this has a 'positive potential evaluation' and as outlined in the paper a proper Life Cycle economic analysis and proven experience is required before wide scale deployment.

' Complete Retrofit '
'Only solutions with the same or smaller footprint offer a realistic alternative. Manufacturers are addressing this aspect (no fundamental obstacle)'

This is still at an early stage in development in many cases e.g. Manufactures are beginning to engage with UK network operators to develop an SF_6-free solution to replace existing close-coupled RMUs, but this is still at a very early stage in development.

Untitled Table…
' Partial retrofit/extension
Depending on the specific situation, identical footprint is not always a strict precondition. Nevertheless, manufacturers are addressing this aspect (no fundamental obstacle) '

Whilst in theory it may be possible to develop solutions for retrofit/extension it is unlikely that this will occur due to commercial and practical reasons (e.g. test requirements):

(a) There will be a wide variety of substation designs so that the development of switchgear which will meet these requirements would involve smaller volumes and higher costs which would be

unlikely to be recouped through sales volumes i.e. not attractive from manufacturers to develop

(b) In many cases, particularly where the switchgear is in some form of cabin /container the combination woof the new retrofit switchgear and the container would need to be type tested together which would be very expensive and require inordinately high resources from both the utilities and manufacturers.

As a simple example, where the busbars of the existing SF_6 switchboard are outside the gas zone (e.g. presented as a bushing) then with development, a joggle arrangement might feasibly enable the connection of an alternative product to the board. However, where the switchboard busbars are contained within the gas zone, the board could not be extended with another product without creating an additional gas zone with a termination bushing to connect onto (hence adding additional SF_6 filled equipment to the site)

4 Conclusions

Lines n°206 - 209*:*

The first sentences give the impression (for a reader who does not know precisely the market and the field of electrical equipment) of solutions which are either already available or will become available in the short term. This is more likely for low voltage and low current applications…but not true for all applications. To avoid any confusion in the interpretation, the conclusion should be distinguished according to the voltage and current levels.

Furthermore, the sentence: '*In primary distribution, SF_6 free solutions always have had a significant market share*. 'should be continued to state*'* ***In secondary distribution SF_6 is more commonly used due to space restrictions.'***

Lines n°210 to 217*:*

'In recent years, the technological development of SF_6 free switchgear in GIS design for medium voltage switchgear in secondary distribution has made very good progress, providing alternative technologies that are comparable in many ways to SF_6 GIS systems.'

However, 95% of all secondary switchgear presently in service contains SF_6 (cf '*T&D Europe Technical report on alternative to SF_6 gas in medium voltage & high voltage electrical equipment',* 5/3/20).

SF_6 free switchgear in GIS Design for MV has only recently been proposed to utilities, with limited pilots in specific power ranges. The experiences have been that costs are significantly higher than for SF_6 solutions.

In regard to the use of non-SF_6 gas as an alternative, there have been no large-scale trials and hence limited experience of performance.

Lines n°213 to 217*:*

'The time period required for alternatives to be ready for large scale application depends, among others, on the level of voltage and application area. It may be quite short for standard applications in primary distribution (MV switchgear in substations) and the most common RMU configurations

(secondary distribution). It is foreseen that SF_6 free switchgear can become technically feasible and associated with reasonable investments for nearly all segments of MV applications within 2 to 4 years.'
The time line displayed of solutions available (with the same level of performance when compared with existing solutions) within 2 to 5 years is not realistic from an industrial point of view, taking into account the experiences acquired on the equipment's currently available (especially in HV switchgear).

How was this 2-4 year timescale established and what does it refer to?

In Table 2 nearly all the examples presented were either '*undeveloped*', '*at trial or pilot stage*' or had '*less than 5 years*' experience in the market.

Others that had longer experience and were more developed, such as AIS, were unsuitable for use where space is at a premium, which is generally where SF_6 switchgear is deployed.

There is a complete underestimation of the time-scales required to develop and produce prototype switchgear, trial it in the field to identify problems and then to scale up production to meet market demands.

As can be seen from the EcoDesign Transformer Directive, which involved relatively minor changes to Transformer designs that already been proven, this took 10 years, with manufacturers having to changeover production to different materials and meet a single deadline for all EU utilities

Lines n°218 to 220:

'…result in an initial cost increase of up to 20%, raising to 30% in exceptional cases, compared to systems using SF_6.'

This 20 -30% increases seems to be referring to purchase price only and not whole life cycle cost. The Life Cycle Costs and rankings given in Energy Networks Association (GEODE) Impact Assessment Report are very considerably higher and do not appear to have been considered. Another Eurelectric utility has seen costs 100% higher than for conventional SF_6.

The EU cost assessment methodology requires use of Life Cycle costing in economic assessments and this has evidently not been the case here.

Furthermore, such cost comparisons are only of relevance if there are suitable non-SF_6 technically acceptable, which can be substituted, and which are commercially available.

For specific MV applications and for HV applications issues of cost are not applicable because there are no suitable alternatives.

There is a clear need for manufacturers and users site references to establish a proof track record of such proposed alternatives.

The costs related to the treatment of the equipment at the end of life is not known and depends on the amount of SF_6 and the presence of by-products. In addition, gas blends will also generate extra costs at the end of life (g3 for example is made with GWP gas and also generates toxic by-products). These factors need to be incorporated into an economic analysis of alternatives.

Lines n°221 to 225:

Again, there is a huge gap between a prototype or pre-production switchgear (at least 5 years in applications > 225 kV) and a fully proven commercial product.

There are indeed manufacturers' solutions, currently being tested in HV and MV, but no experimentation to date that address voltage levels> 245 kV / 40 or 63 kA or high ICCs in MV (reference to niche applications).

Eurelectric E.DSO and GEODE would also suggest the development (with the help of the manufacturers)and introduction of proactive maintenance policies for industrial operators (network utilities and producer), to control / reduce SF_6 releases and strengthen the service life and tightness of existing installations, which would be an important step in minimising the impact of SF_6 in a practical way.

Lines n°224 to 225: Derogation

'At all voltage levels some exceptional applications exist, where adequate alternatives are not yet readily available. These applications have to be evaluated on a case by case basis'.

This and earlier comments about niche requirements for SF_6 Switchgear could more generally be addressed by a Derogation System based on similar principles to those in the EcoDesign Transformer Directive.

This would avoid need to attempt to identify every possible exception e.g. requirements in nuclear power plants, availability of national requirements such as UK outdoor rated close coupled RMU's.