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Empirical study investigating the environmental and socio-economic impact of SF6 and its alternatives in medium voltage switchgear

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Empirical study investigating the environmental and socio-economic impact of SF6 and its alternatives in medium voltage switchgear

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Executive summary

The aim of this study is to better understand customer purchasing criteria for medium voltage (MV) switchgear, including the interplay of technical, economic as well as environmental aspects. This knowledge can be used to predict market development, in particular with regard to the emergence of SF6-free technologies. Since new alternatives to SF6 have not yet widely penetrated the market, empirical analysis cannot draw on observed adoption behaviour to elicit market acceptance of these alternatives. Therefore, a survey including stated preferences choice experiments (SPCE) was carried out among users of primary and secondary MV switchgear as well as intermediaries in different sectors (including utilities, renewable energy, and other private industry sectors). Respondents were selected to be company representatives with knowledge about switchgear and ideally involved in the switchgear procurement process. The survey was completed anonymously by a total of 443 respondents in five European countries.

SPCEs involve constructing hypothetic choice scenarios where alternatives (e.g., products, services) are described by a range of attributes (e.g., price, size, …). In this study, respondents were successively asked to choose one alternative from a set of MV switchgear alternatives. They were expected to make trade-offs between the attributes characterizing the different MV switchgear alternatives to select their most preferred alternative. This method allows notably to elicit customers' preferences and willingness to pay for different attributes of MV switchgear, including for instance compactness, global warming impact, and absence of F-gases. Furthermore, the declarative survey explicitly investigated barriers and drivers to adoption of SF6-free technologies as well as the role of policies and regulations to promote these technologies from the point of view of MV switchgear users.

Results from the survey suggest that customers for MV switchgear expect a decrease in use of SF6 technology in the near future. This decrease, however, is expected to be primarily driven by policies and regulations, rather than technological change or prices. Customers remain in fact uncertain which technology will most likely replace SF6. Technological alternatives are currently not attractive to many potential customers, mainly because these alternatives require too much space or are too expensive. Against this background, financial incentives (e.g. subsidies) for users of MV switchgear and a complete ban on SF6 are considered the two most useful policies to promote SF6-free MV switchgear by respondents.

At the same time, respondents express an interest in environmental aspects of different MV switchgear technologies. Eco-friendliness was in fact identified as one of the most important purchase criteria for MV switchgear. The fact that customers seem to care about environmental aspects when purchasing MV switchgear suggests that an environmental label for MV switchgear would be valorised if introduced on the market. Such a label could for instance feature an evaluation of the product's global warming impact or be used to certify F-gas free switchgear – two aspects for which respondents in the SPCE were willing to pay respectively 16% and 20% more compared to their usual purchase price.

Introduction

The current F-gas Regulation 517/2014 is expected to cut the EU's F-gas emissions by two thirds by 2030 compared with 2010 levels. One of the F-gases regulated is sulphur hexafluoride (SF6), which in Europe is mainly applied as an insulating and switching gas in high- and medium-voltage equipment. SF6 technology plays an important role for the reliability of power transmission and distribution networks in Europe, which constitutes the backbone of the infrastructure necessary to deliver the energy transition (T&D Europe, 2020). At the same time, SF6 is the most potent greenhouse gas evaluated by the Intergovernmental Panel on Climate Change (IPCC), with a global warming potential of 23,500 times that of CO2 over a 100-year period.[1]

By July 2020, as part of the current EU F-gas Regulation 517/2014 (Article 21), the European Commission shall publish a report on the existence of cost-effective and reliable alternatives to SF6 in medium-voltage (MV) switchgear. Based on this report, the Commission might suggest amendments to the current regulation which could in turn change the market for MV switchgear technology alternatives. Against this background, we wish to better understand customer purchasing criteria, including the interplay of technical, economic as well as environmental aspects. This knowledge can be used to predict market development, in particular with regard to the emergence of SF6-free technologies.

Since new alternatives to SF6 have not yet widely penetrated the market, empirical analysis cannot draw on observed adoption behaviour to elicit market acceptance of these alternatives. We therefore carried out a survey including stated preferences choice experiments (SPCE) among users of primary and secondary MV switchgear and intermediaries in different industries across five European countries. SPCEs allow notably to elicit customers' preferences and willingness to pay for different attributes of MV switchgear including, for example, environmental friendliness. Furthermore, the declarative survey explicitly investigates barriers and drivers to adoption of SF6-free technologies as well as the role of policies and regulations to promote these technologies from the point of view of MV switchgear users.

Our results suggest that customers for MV switchgear expect a decrease in the use of SF6 technology in the near future. This decrease, however, is expected to be primarily driven by policies and regulation, rather than technological change. Customers remain in fact uncertain which technology will most likely replace SF6-based switchgear. Technological alternatives are currently not attractive to many potential customers, mainly because these alternatives require too much space or are too expensive. At the same time, respondents express an interest in environmental aspects of different MV switchgear technologies. Eco-friendliness was in fact identified as one of the most important purchase criteria for MV switchgear. Moreover, the findings from the SPCE suggest that customers are on average willing to pay a

[1]https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

20% higher purchase price for MV switchgear options that have a low global warming impact (GWI) compared to options with a high GWI and a 16% higher purchase price for options that cannot leak F-gases.

Methodology

The design of the declarative survey and SPCE was guided by repeated discussions with industry experts as well as 12 semi-structured interviews that were conducted with French and German professionals that had a leading role in their company's switchgear procurement process Survey respondents were required to be company representatives with knowledge about switchgear and ideally involved in the switchgear procurement process.

SPCE involve constructing hypothetic choice scenarios where alternatives (e.g. products, services) are described by a range of attributes (e.g., price, environmental impact, size, …). Respondents are successively asked to choose one alternative from a set of product alternatives. They are expected to make trade-offs between the attributes characterizing the different alternatives to select their most preferred alternative. This allows estimating the willingness to pay for multiple attributes. The attribute levels in each choice scenario are determined by a computer algorithm to maximize the amount of information gathered. While SPCE and other experimental methods to elicit customer valuation are most frequently targeted at private individuals or households, these methods have been successfully applied with representatives from companies or municipalities. (E.g., Klinke, 2018; Olsthoorn et al., 2019; Klinke et al., 2017; Polzin et al., 2016; Schulz et al., 2013; Roucan-Kane et al., 2013).

In our SPCE, respondents were asked to make eight choices between two different switchgear options each.[2] (I.e., in choice scenario 1, the respondent sees two switchgear options and has to indicate which out of the two option he would purchase on behalf of his company. In choice situation 2, the respondent sees two options that are different from the ones in scenario 1 and again has to indicate which out of the two option he would purchase on behalf of his company. The same goes for choice scenarios 3 to 8.) In each choice scenario, after having chosen one of the two switchgear option, respondents were further asked to indicate on a scale from 1 ("very unlikely") to 4 ("very likely") how likely they thought their company would be to actually purchase the preferred option if it was available on the market.

Depending on the respondent's profile, the choice situations displayed were framed to feature primary or secondary switchgear. (E.g.: *"On the following pages, we will describe eight scenarios, each with two different options for secondary MV switchgear. In each scenario, we would like to know which option you would choose if you were making a purchase on behalf of your company and these were your only options."*[3]*).*

[2] The choice experiment contained a total of 24 choice scenarios. Respondents were randomly assigned to one out of 3 different blocks with 8 predefined choice scenarios.

[3] Framing for respondents more familiar with secondary switchgear. For respondents more familiar with primary switchgear, the word "secondary" was replaced by "primary". Otherwise, the choice experiment remained

The switchgear options in our SPCE were characterized by the following attributes and attribute levels:

- Purchase price: the purchase price of switchgear could be the same or 5%, 10%, 15%, 25% or 35% higher compared to the price of MW switchgear most frequently purchased.
- Global warming impact (GWI): the life cycle global warming impact classified as low, medium, or high.
- Health and safety: possible leakage of F-gases in the event of an accident (yes/no).
- Volume/dimensions: the switchgear could be 10% smaller, the same size, 10% larger or 20% larger compared to the volume/dimension of MV switchgear most frequently purchased.
- Warranty period: the warranty period for each switchgear could be 2 years, 5 years, or 10 years.

In addition, respondents were asked to assume that all options only differed in these attributes and were conform with any required technical specifications as well as with the relevant laws and standards currently in place. The exact framing used to explain the choice experiments to respondents is presented in Figure A1 in Appendix A. Two examples for choice scenarios are presented in Figure A2 in the Appendix A.

To analyse the data from the SPCE, we apply a mixed logit model. Unlike standard conditional logit models, the mixed logit model allows for unobserved respondent-specific preference heterogeneity (Revelt and Train, 1998). In the mixed logit model, for a sample of *N* respondents and a series of *T* choice sets (in our case T=8) with *J* alternatives (in our case J=2), the utility that respondent n gains from choosing alternative j in the choice set t can be described as:

$$U_{njt} = \beta_n X_{njt} + \varepsilon_{njt}, n = 1,2, \dots, N, \quad j = 1,2, \quad t = 1,2, \dots, T$$

where X_{njt} is a vector of switchgear attributes that are included in our SPCE with a vector of parameters β_n. The error term ε_{njt} is assumed to follow an extreme-value Gumbel distribution. The mixed logit model defines β_n as a vector of random parameters which varies among respondents. We assume β_n to follow a normal distribution.

We employ simulation methods to estimate the parameters. By comparing the estimated parameter for the price attribute and the estimated parameters for other switchgear attributes, we deduce respondents' willingness to pay for the switchgear attributes. More precisely, the marginal willingness-to-pay (WTP) for an attribute x can be estimated as:

$$\widehat{WTP_x} = -\frac{\hat{\beta}_x}{\hat{\beta}_p}$$

identical. Respondents equally familiar with primary and secondary switchgear were randomly assigned to either framing. Lastly, for respondents unaware of the distinction between primary and secondary switchgear, the notions "primary" or "secondary" were dropped from the framing.

where $\hat{\beta}_x$ is the estimated random parameter associated with attribute x, and $\hat{\beta}_p$ is the estimated price parameter.

The remaining parts of the survey more directly elicited respondents' acceptance of the proposed solutions (e.g. intention to invest in SF6-free technology) and investigated barriers and drivers to technology and label acceptance as well as respondents' knowledge of and attitude towards different policies. Results from these parts of the survey are presented in form of descriptive statistics.

Survey implementation

The declarative survey and choice experiment were targeted at customers of MV switchgear in France, Germany, Poland, Spain and the UK. Respondents were selected to be company representatives with knowledge about switchgear and ideally involved in the switchgear procurement process. To participate in the SPCE, respondents were moreover required to know the approximate price of switchgear commonly used by their company.

The survey was translated by a professional translation company from English to French, German, Polish and Spanish. The translations were then proof-read by industry experts to assure that the vocabulary used was appropriate and consistent. The survey was fielded between November 2019 and February 2020 using the online survey platform Qualtrics. Survey invitations were sent directly by the researchers and contained a single, non-reusable survey link.

Approximately 46000 e-mail invitations were sent out in several waves[4]. Respondents received up to two reminders before their survey link expired. In total, 443 respondents completed the survey. This corresponds to a response rate of approximately 1%, all countries considered. It is noteworthy that the response rate was higher in Germany compared to the other countries (approximately 5%). Out of the 443 respondents, 324 indicated having an approximate knowledge of the price of switchgear used by their company and thus participated in the SPCE.

The survey started with screening questions to determine whether respondents were qualified to participate and what type of MV switchgear they were dealing with most frequently in the course of their work. Respondents who indicated in the first survey question that they had not been dealing with MV switchgear in the course of their work over the past three years were excluded from the survey. Respondents who indicated that they knew the approximate price of switchgear used by their company then completed the SPCE. If respondents did not know the approximate price of MV switchgear commonly used by their company, they did not participate in the choice experiment but were nevertheless invited to

[4] Approximately 21000 in France, 4000 in Germany, 1600 in Poland, 9000 in Spain and 10000 in the UK.

complete the other parts of the declarative survey for which no knowledge of prices was required.

The SPCE was followed by questions on technology adoption (e.g., intention to invest in SF6-free technology, drivers and barriers for investment in SF6-free technology) and policies and regulations (e.g., respondent's knowledge of EU policies to reduce F-gas emissions). Finally, respondents were asked to provide information regarding their company (e.g., sector, number of employees) and themselves (e.g., role within company).

Characteristics of survey respondents

The vast majority of respondents came from France (113), Germany (214) and Spain (85), few respondents from the UK (25) and Poland (6). 87% of respondents indicated that their company purchased MV switchgear, either for they own use, for use by subsidiaries, or for resale. The remaining 13% did not purchase MV switchgear, but installed or maintained it, recommended it to customers, or dealt with it in other ways. This repartition is very similar across countries.

Among those working for companies purchasing MV switchgear, more than half (52%) indicated having a leading role in the switchgear purchasing process, while 39% indicated being involved (see Figure 1). In Germany, the share of respondents indicating having a leading role is higher (62%) compared to France (39%) and Spain (43%).[5] Moreover, out of all 443 respondents, 73% indicated that they knew the approximate price of switchgear used by their company (see Figure 2). This share was again highest in Germany (80%), followed by Spain (71%) and France (64%).

Across all countries, most survey respondents described themselves as (electrical) project managers (see Figure 3). In Germany, their share among all respondents was particularly high (42%, compared to 22% in France and 16% in Spain). In France, more respondents identified as electrical site managers compared to the other countries while in Spain, more respondents identified as commissioning engineers or managers. Finally, a vast majority of respondents (86%), indicated having more than 10 years of industry experience. Overall, **survey respondents appear qualified to provide information on MV switchgear use in their companies and insights in the switchgear purchasing process.**

[5] Because of the low number of respondents in Poland and the UK, we do not provide country specific analyses for these two countries.

Figure 1: To what extent are you involved in the purchase of MV switchgear at your company?

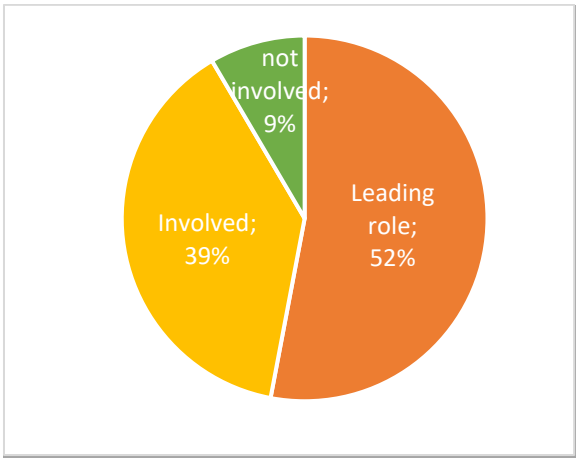


Figure 2: Do you know the approximate price of MV switchgear your company is dealing with?

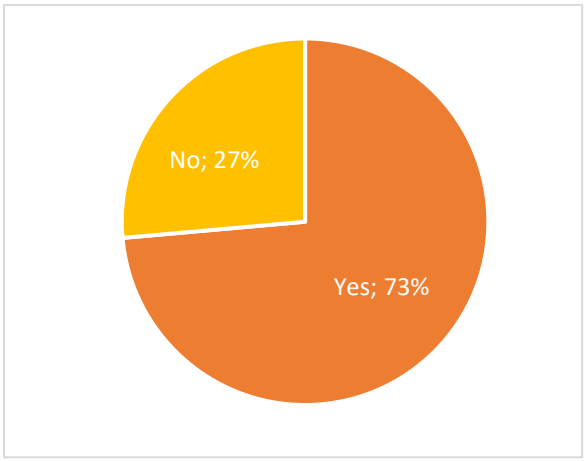
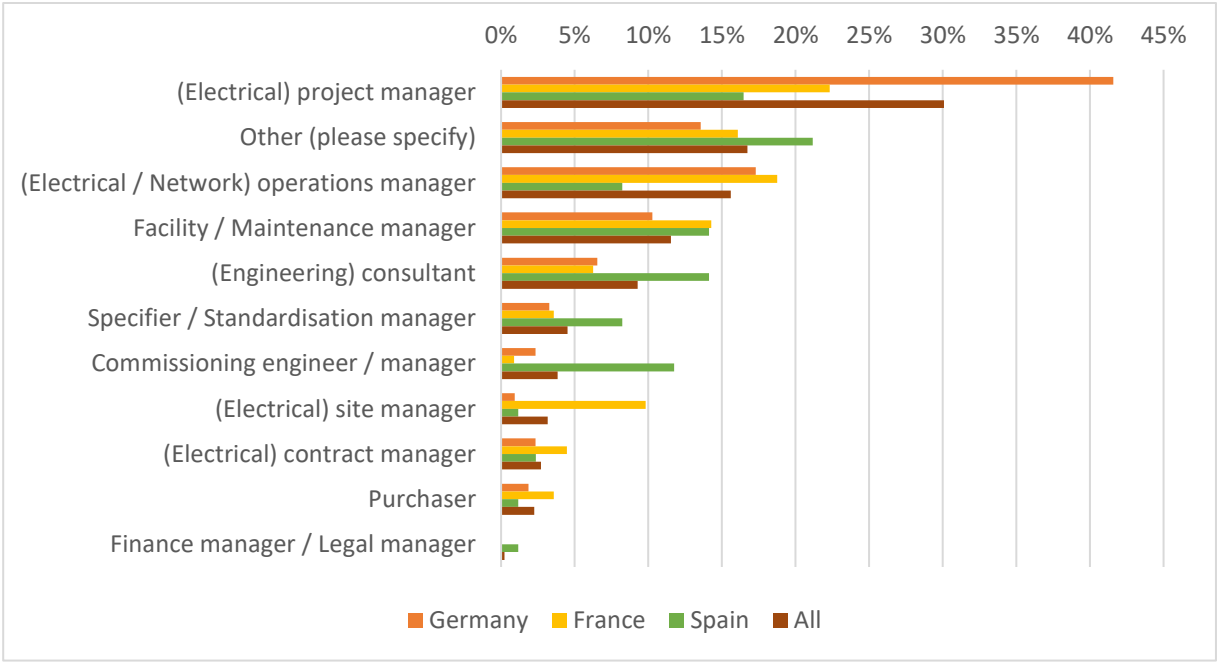


Figure 3: How would you best describe your role within your company?



Regarding the profile of respondents' companies, we observe that the majority of respondents work for companies that are in the power and utility sector or have customers for MV switchgear in the power and utility sector (see Figures 4a and 4b). Companies in the renewable energy sector or with customers in the renewable energy sector are also frequent in our data. 42% of respondents further identify their company as a distribution network operator or electrical distribution company (see Figure 5). It is possible, that the power and utility as well as the renewable energy sector are overrepresented in our study. Therefore, when analysing the SPCE and declarative survey questions on technology adoption and policies, we test if results differ between companies active in the power and utility sector or the renewable energy sector and companies active in other sectors.

Moreover, the majority of respondents in our sample are from companies with more than 250 employees (see Figure 6). When analysing the SPCE and declarative survey questions on technology adoption and policies, we also test if results differ between companies with more than 250 employees and smaller companies.

Users of primary and secondary switchgear are approximately equally represented in our sample of respondents (see Figure 7). Across all countries, 9% of respondents did not know if their company was dealing mainly with primary switchgear, secondary switchgear, or both (France: 22%, Germany: 3%, Spain: 5%). For these respondents, subsequent questions in the declarative survey and the SPCE did not distinguish between primary and secondary MV switchgear.

Figure 4a: To what industry(ies) or sector(s) do your customers for MV switchgear and related services mainly belong? (Multiple answers possible)

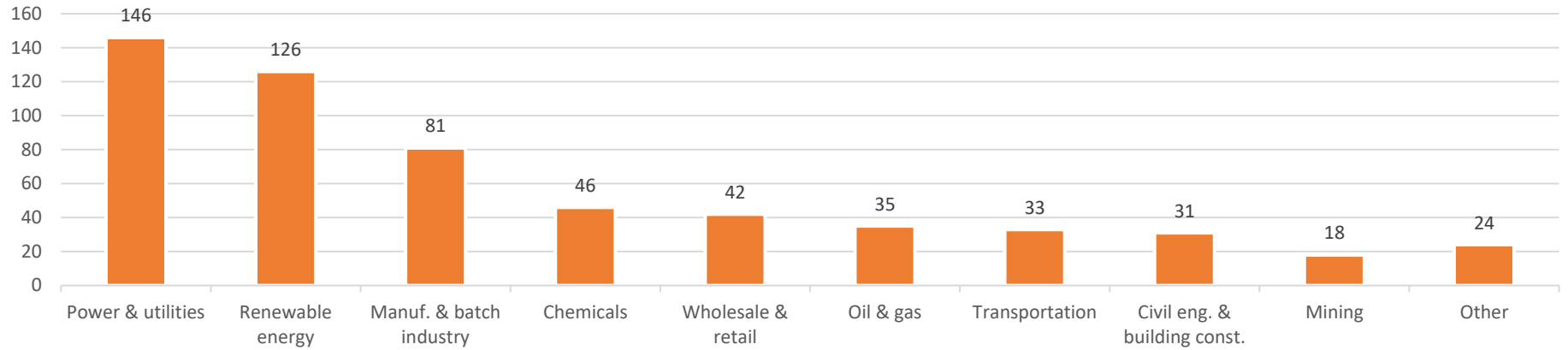


Figure 4b: To what industry(ies) or sector(s) does your company belong? (Multiple answers possible)

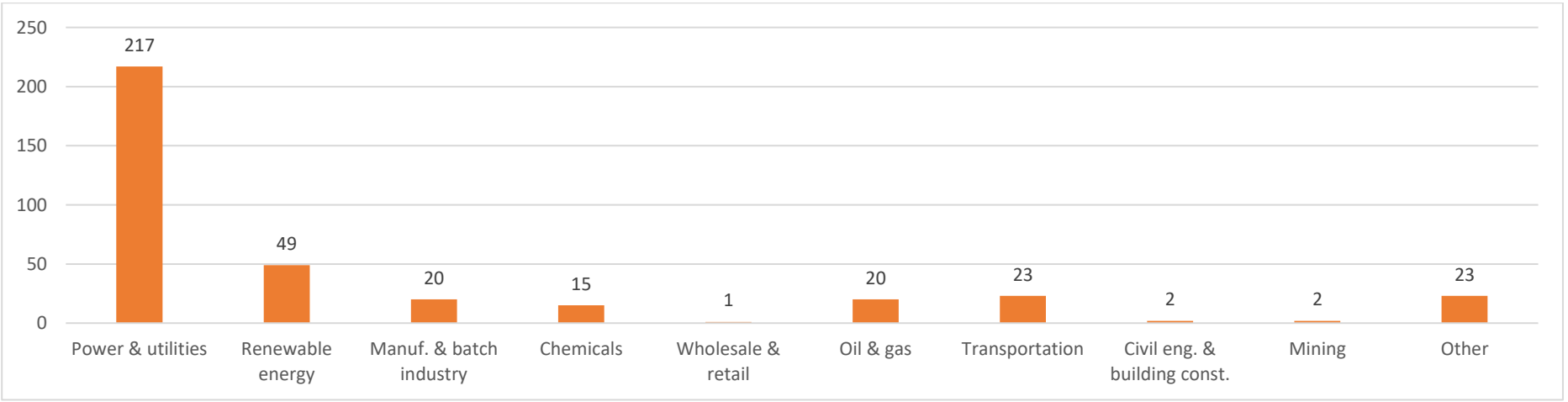


Figure 5: Is your company a ...? (Multiple answers possible)

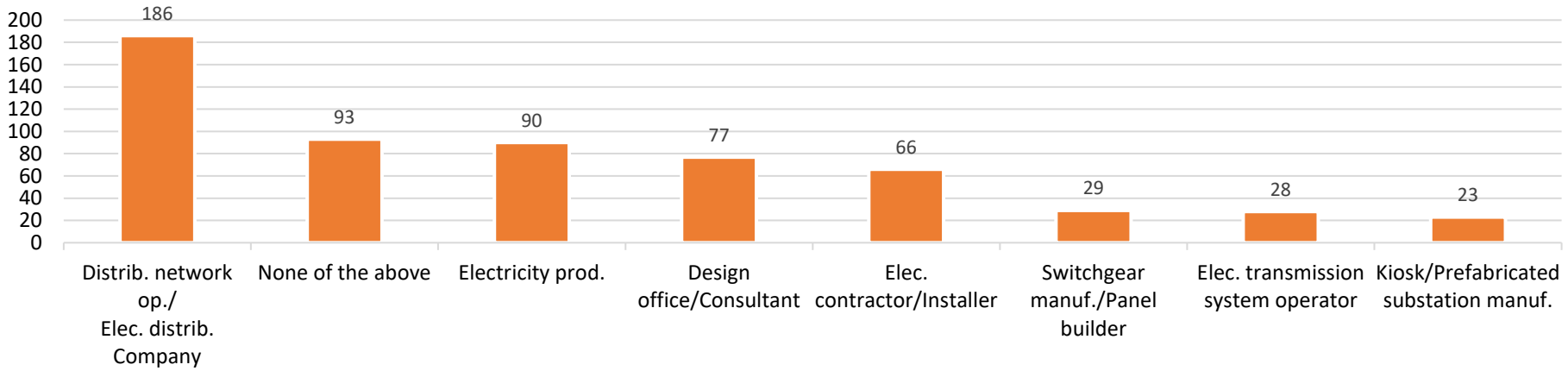


Figure 6: Approximately, what was the number of employees in your company in 2018?

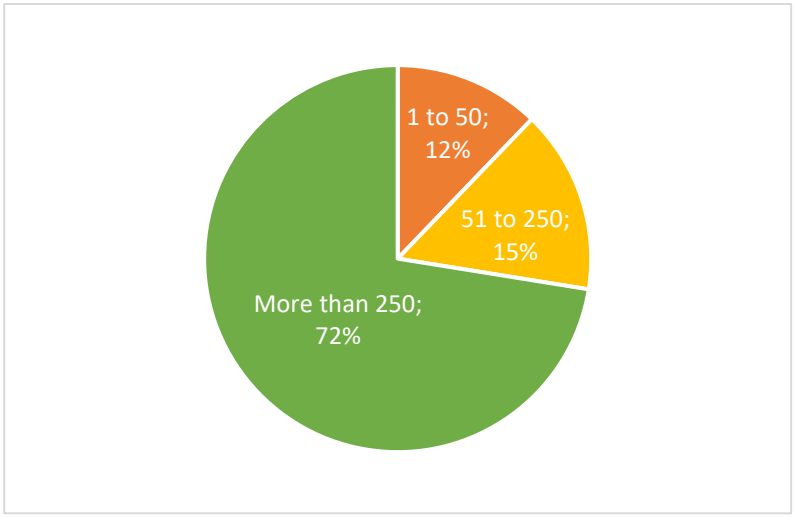
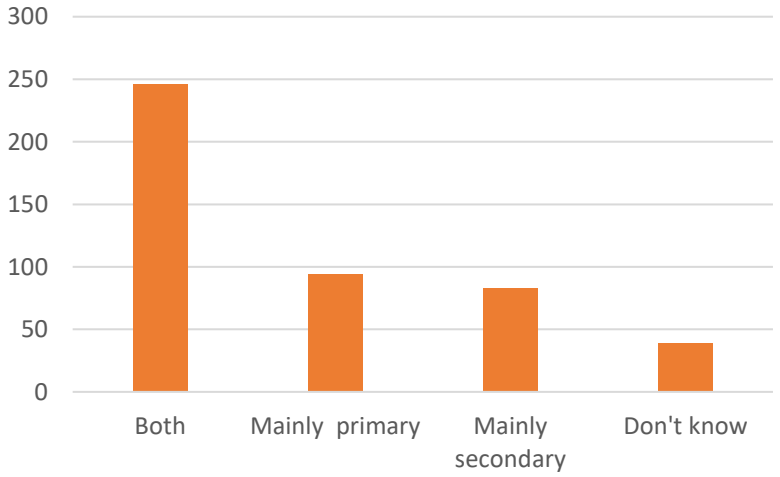


Figure 7: Is your company mainly dealing with primary or secondary MV switchgear (i.e., MV switchgear for primary or secondary distribution networks)?



Results from the declarative survey

When asked about MV switchgear that their company had been dealing with over the past three years, close to **90% of respondents indicated that at least part of the MV switchgear contained SF6** (see Figure 8a). The share was highest in Spain (see Figure 8b) and higher for companies active in the power and utility sector and/or the renewable energy sector compared to other sectors (see Figure 8c). Close to 50% of respondents indicated that their company did not use alternative, SF6-free, technologies (see Figure 8d). **When alternatives where used, air was found to be by far the most frequently used one**, both in primary and secondary switchgear. Other technologies, including C5-PFK, C4-PFN and CO2 (included in "Other") were used only marginally.

Looking at arc-breaking technologies, vacuum technology appears to have penetrated a large part of the market. For both primary and secondary switchgear, more than 40% of respondents indicated that their company used vacuum technology in at least some of their recently purchased switchgear. There seem to be, however, substantial differences across countries and users. In our survey, vacuum technology was found to be less common in France compared to Germany and Spain and more common among larger companies and companies active in the power and utility sector and/or the renewable energy sector (see Figures 9 a b and c).

When asked about switchgear that their company was planning to purchase within the next three years, less than 70% of respondents indicated that at least part of these MV switchgear would likely contain SF6 as an arc-breaking or insulation medium (see Figure 10a). This corresponds to a considerable decrease in the share of SF6-based switchgear compared to purchases during the last three years: -20 percentage points for primary switchgear and -15 percentage points for secondary switchgear. **These findings suggest that MV switchgear users expect a significant decrease in SF6-based switchgear in the imminent future**. In France, a larger share of respondents expects their companies to shift away from SF6 to alternative technologies than in Germany or Spain (see Figure 10b). Moreover, respondents working for companies in the power and utility sector and/or the renewable energy sector less often believe that their company will move away from SF6 technology in the next three years compared to respondents working in other sectors (see Figure 10c).

While respondents seem to generally anticipate a decrease in the use of SF6 technology, **they remain uncertain which technology will most likely replace SF6**. A small share of respondents expects that their company will start using dry air (+ 4 percentage points). Besides, we observe only marginal increases in other insulation technologies including C5-PFK, C4-PFN and CO2. 8% of respondents indicate that they do not know what technologies they will use in the future. Lastly, regarding vacuum technology for arc-breaking, we observe an increase in France only (+15 percentage points for primary and +17 percentage point for secondary switchgear).

Figure 8a: Technologies used in MV switchgear over the past three years (multiple answers possible) [6]

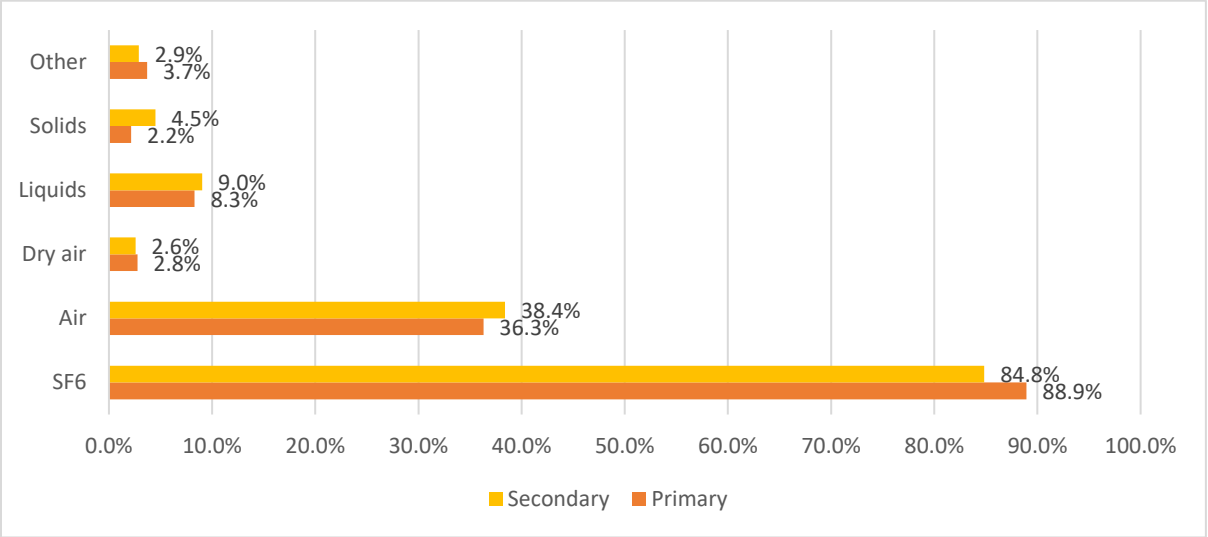
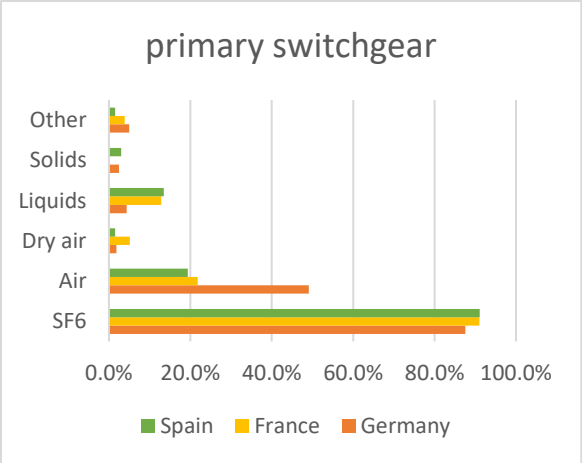
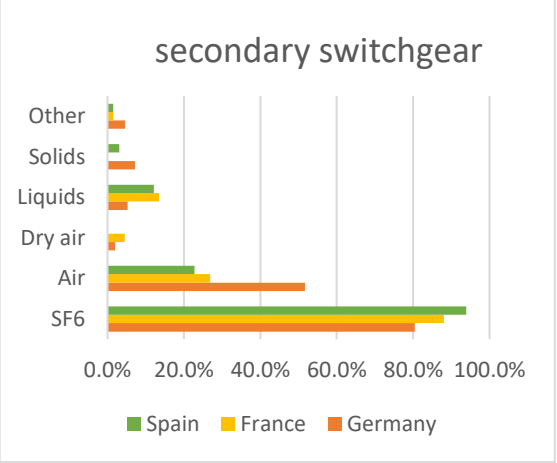


Figure 8b: Technologies used in MV switchgear over the past here years (multiple answers possible)





[6] The relatively high share of liquids (i.e., oil) that we observe could be driven by respondents mistakenly including older switchgear and not only switchgear dealt with over the past three years, or by respondents considering transformer substations rather than switchgear when answering this question.

Figure 8c : Technologies used in MV switchgear over the past three years (multiple answers possible)

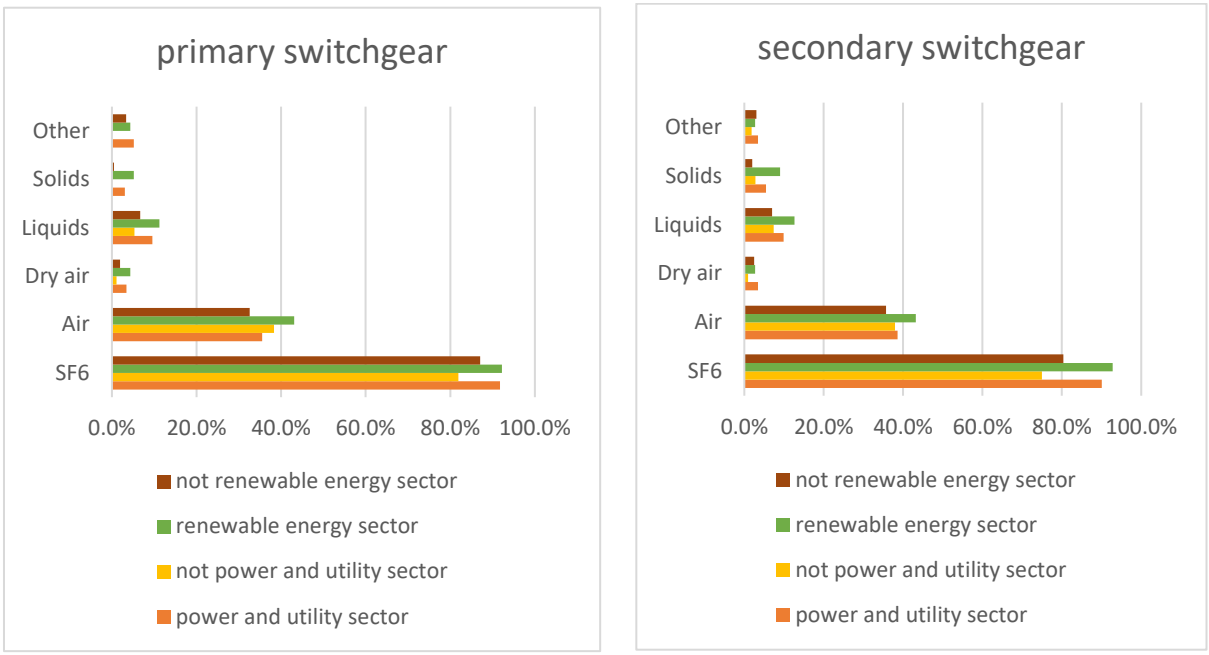


Figure 8d: Technologies used in MV switchgear over the past three years (multiple answers possible)

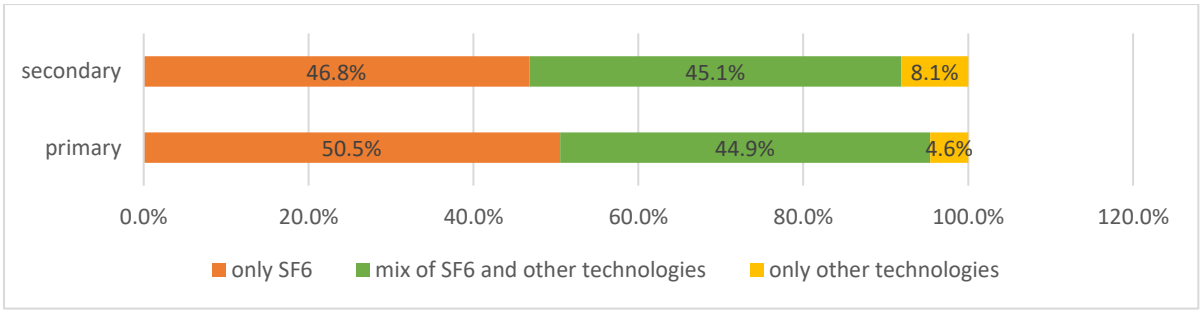


Figure 9a: Companies having used vacuum technology for arc-breaking in at least part of their switchgear over the past three years

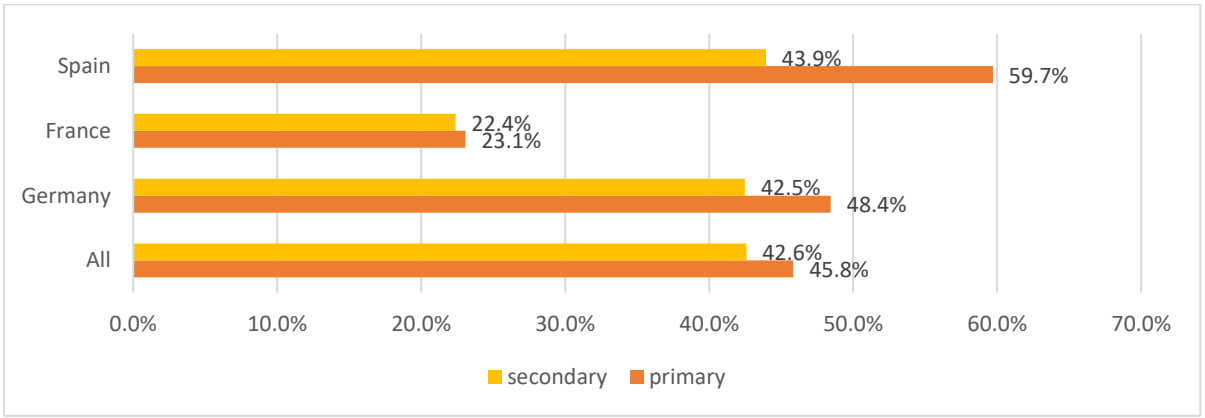


Figure 9b: Companies having used vacuum technology for arc-breaking in at least part of their switchgear over the past three years

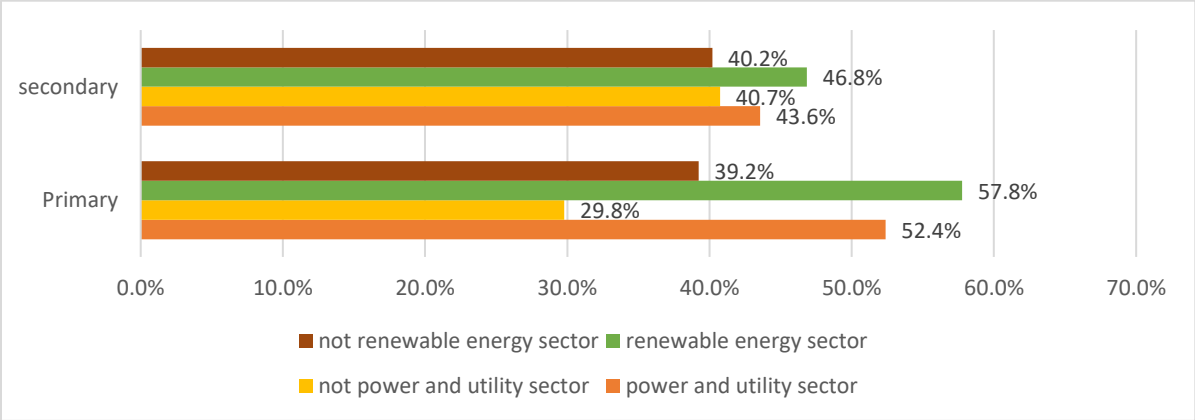


Figure 9c: Companies having used vacuum technology for arc-breaking in at least part of their switchgear over the past three years

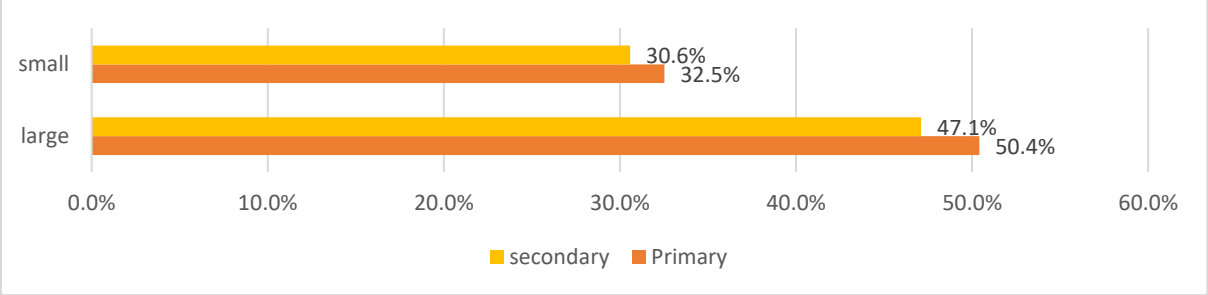


Figure 10a: Technologies that will likely be used in the next 3 years (multiple answers possible)[7]

[7] In France, Germany and Spain, liquids (i.e., oil) are not used in new MV switchgear anymore. We observe a very small share of respondents nevertheless answering that their company would use liquids in at least part of their switchgear in the next three years. These respondents might have considered transformer substations rather than switchgear when answering this question.

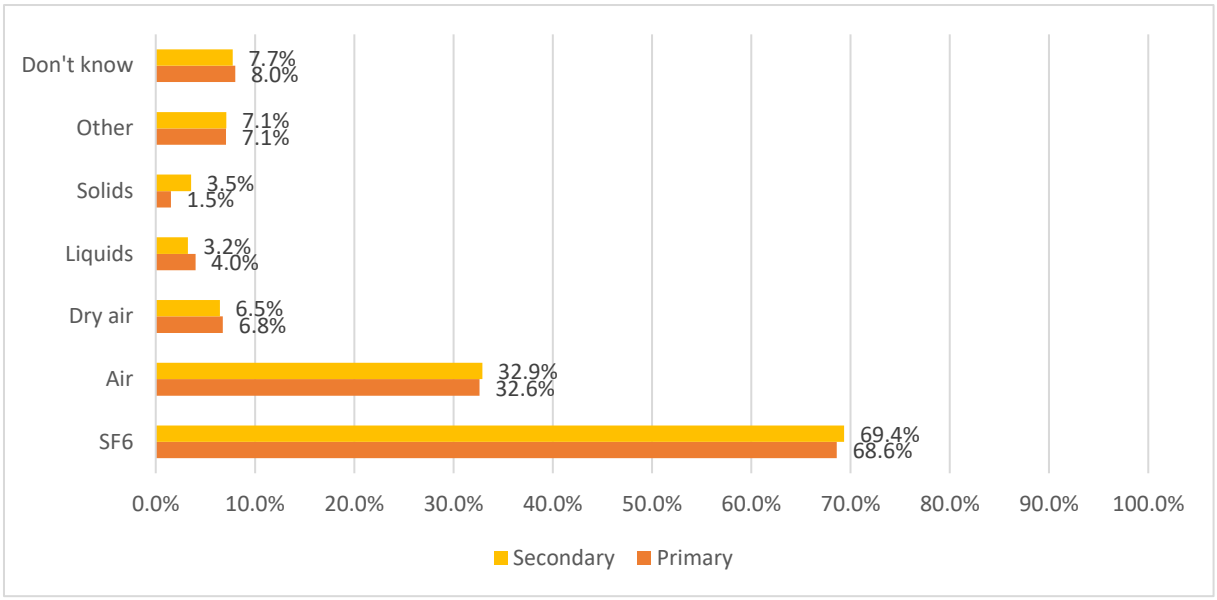


Figure 10b: Technologies that will likely be used in the next 3 years (multiple answers possible)

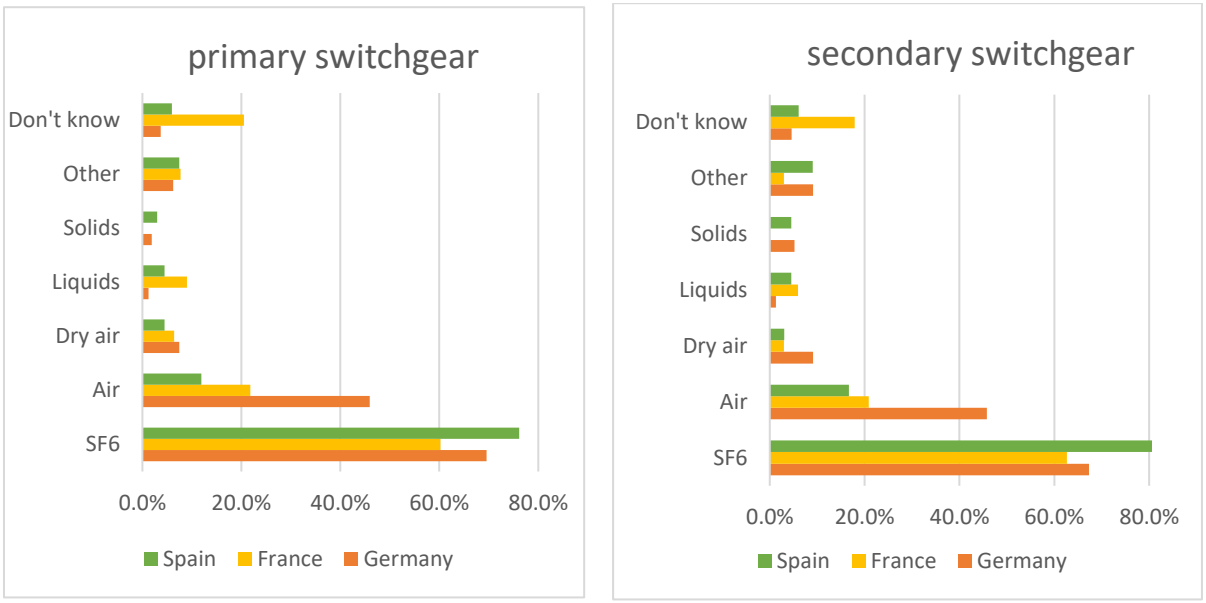
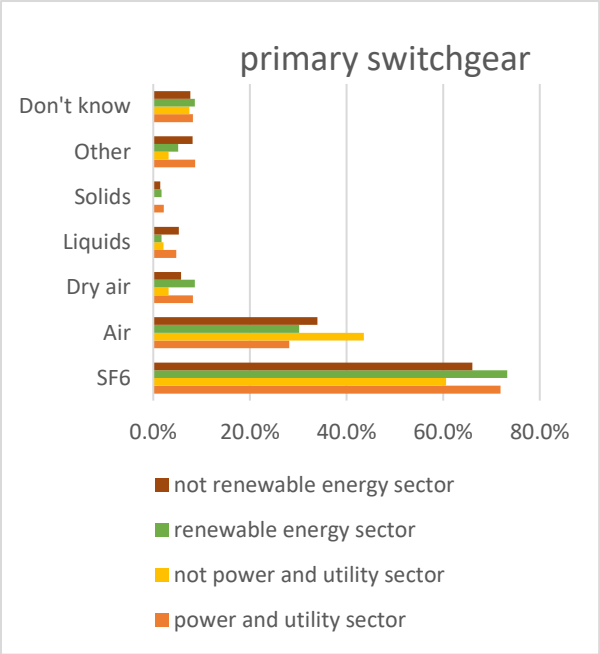


Figure 10c : Technologies that will likely be used in the next 3 years (multiple answers possible)


primary switchgear
Don't know
Other
Solids
Liquids
Dry air
Air
SF6
0.0%
20.0%
40.0%
60.0%
80.0%
not renewable energy sector
renewable energy sector
not power and utility sector
power and utility sector

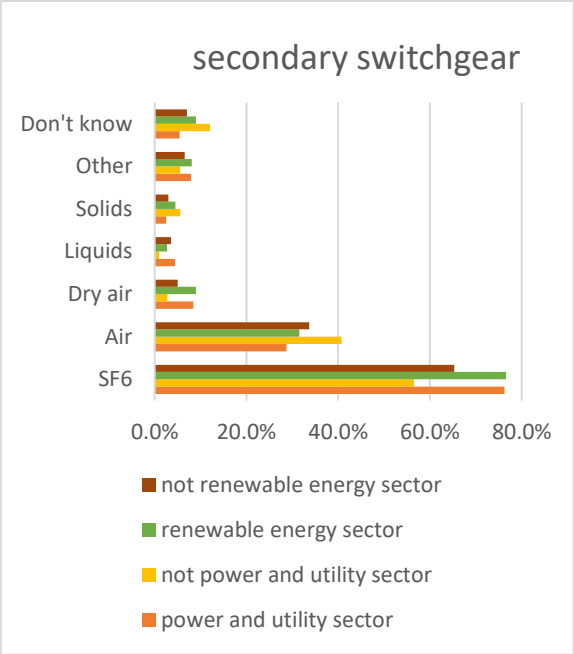
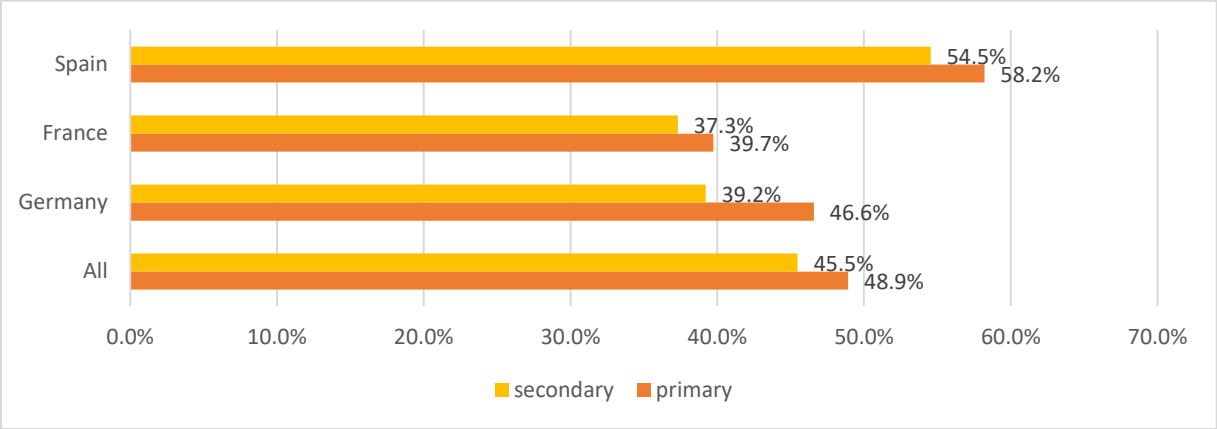

secondary switchgear
Don't know
Other
Solids
Liquids
Dry air
Air
SF6
0.0%
20.0%
40.0%
60.0%
80.0%
not renewable energy sector
renewable energy sector
not power and utility sector
power and utility sector

Figure 11: Companies expecting to use vacuum technology for arc-breaking in at least part of their switchgear over the next three years



The expected decline in SF6 is mainly driven by policies and regulation (see Figure 12). Out of 190 respondents who indicated that their company would likely use alternative technologies to SF6 in the next three years, 102 (54%) stated that policies and regulations were among the most important drivers for SF6-free alternatives. **Low global warming impact of SF6-free alternatives and other environmental considerations were, however, also identified** as important drivers by 42% and 28% of respondents, respectively. On the other hand, only 20% of respondents indicated better performance as a reason to purchase SF6-free alternatives. At the same time, according to respondents, **the principal barriers to replacing SF6 by other technologies are need for more space, higher purchasing price, and lack of reliable suppliers for SF6-free alternatives** (see Figure 13). The principle barriers and drivers identified by respondents are similar across countries and sectors.

Looking at the importance of different purchase criteria in general, we observe that different aspects seem to play a role. **Among the most important purchase criteria are technical aspects, (conformity with technical specifications**, compactness), but also environmental aspects (eco-friendliness), **and economic aspects** (long term reliability, no or low need for maintenance) (see Figure 14). The fact that purchase price does not figure among the five most frequently selected aspects could be an indicator that respondents are per se willing to consider products that are more expensive but, e.g., also more eco-friendly. On the other hand, the fact that high purchase price has also been identified as one of the main barriers to SF6-free alternatives highlights that financial constraints remain nevertheless relevant.

Figure 12: Drivers for SF6-free alternatives (multiple answers possible)

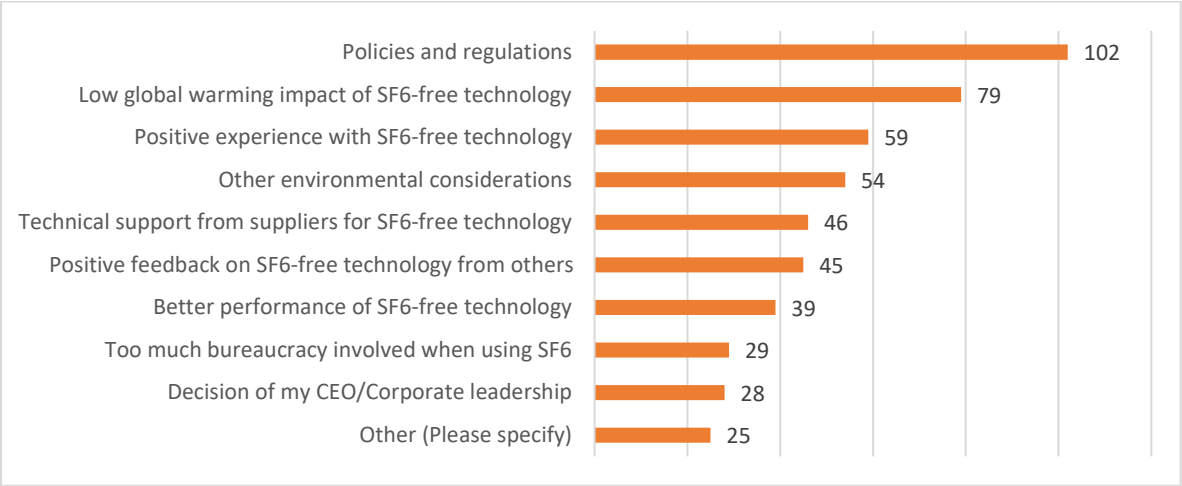


Figure 13: Barriers to SF6-free alternatives (multiple answers possible)

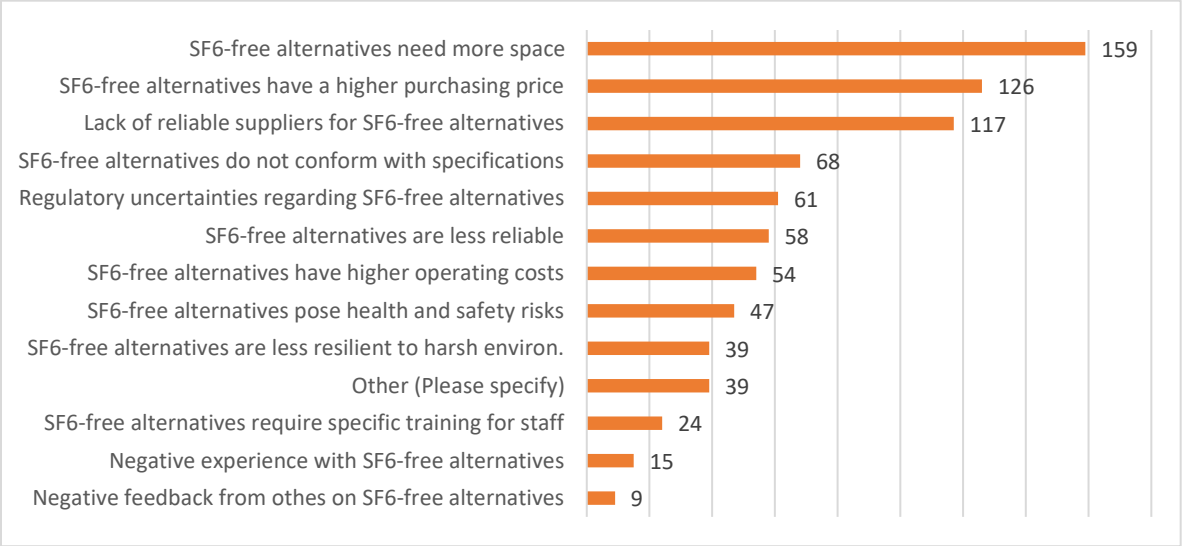
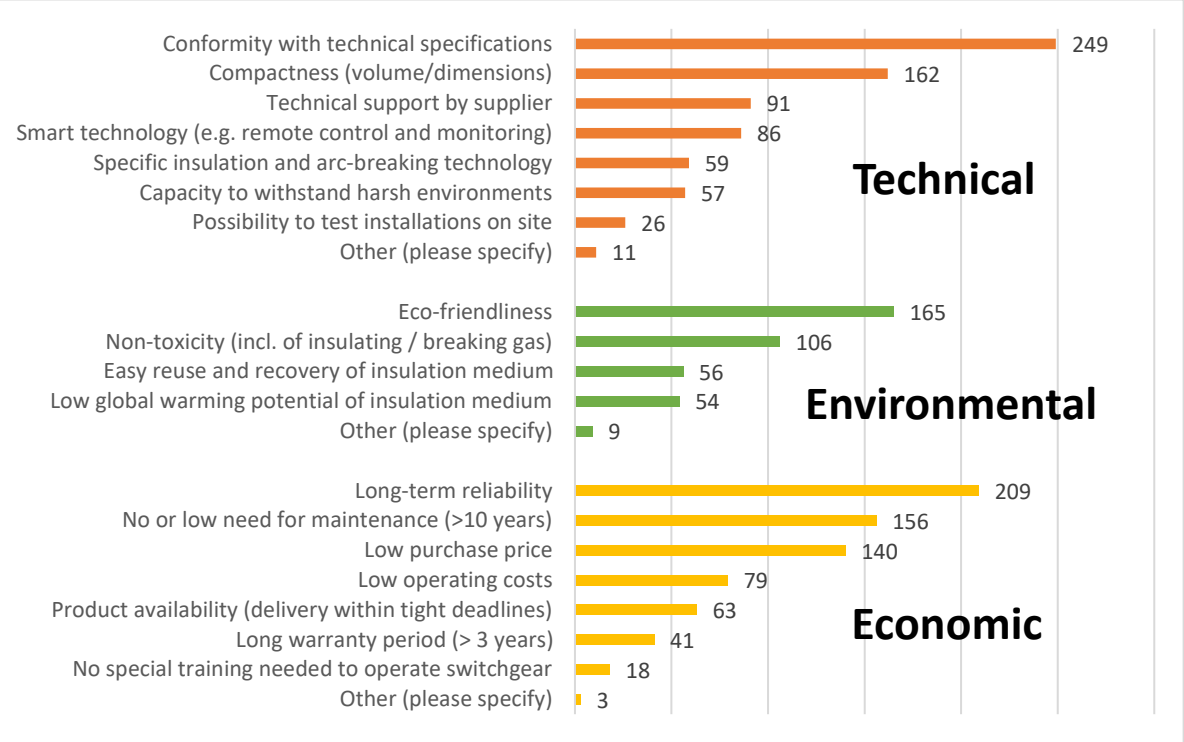
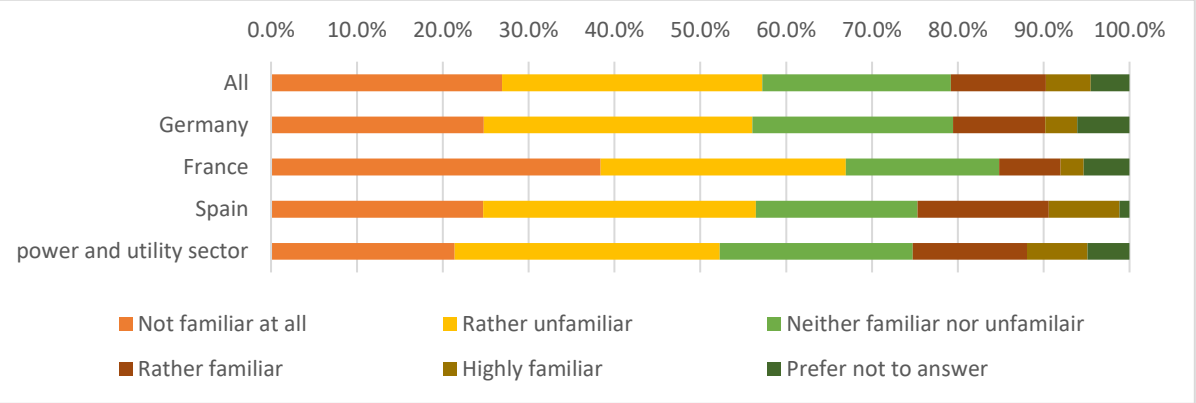


Figure 14: Most important purchase criteria (multiple answers possible)



While participants identified policies and regulations as the most important driver for SF6 alternatives, a majority of respondents describe themselves as not familiar at all (27%) or rather unfamiliar (30%) with EU policies on F-gas emissions. This holds true across countries and industries (see Figure 15).

Figure 15: Respondents' stated familiarity with EU policies on F-gas emissions[8]

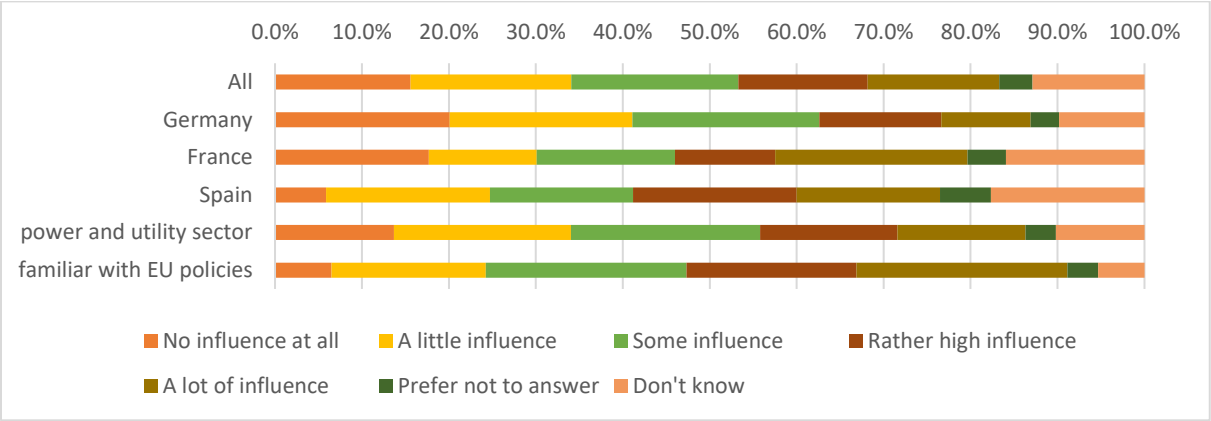


At the same time, **respondents have different views on whether the European Union's goal to reduce F-gas emissions influences their company's choice of technology**. 15% of respondents believe that there is no influence at all, while another 15% believe that there is a lot of influence. Respondents in Spain as well as respondents who also stated that they are

[8] "power and utility sector" refers to those respondents who indicated that their company was active in the power and utility sector

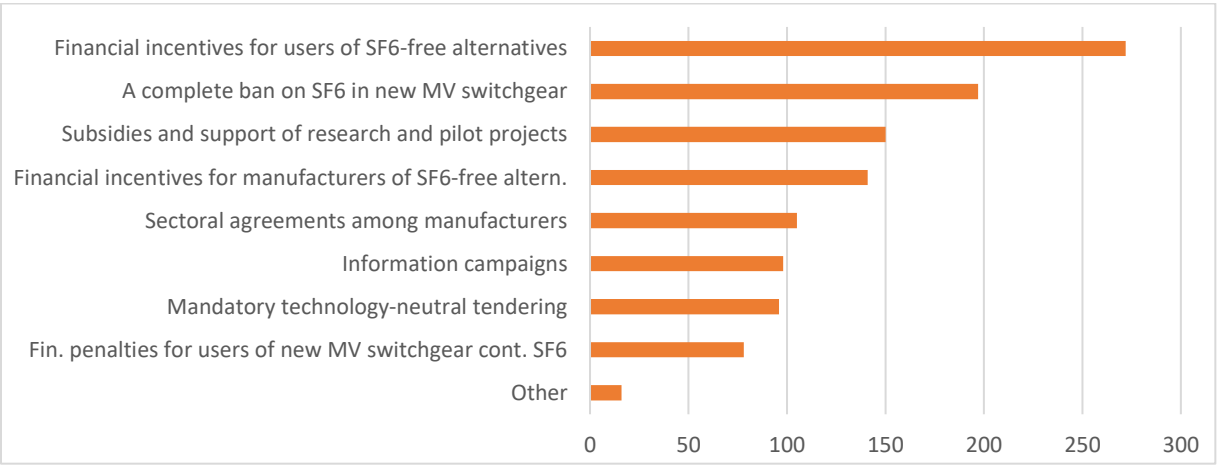
familiar with EU policies on F-gas emissions rate the influence higher compared to other respondents.

Figure 16: Influence of the EU's goal to reduce F-gas emissions on company's choice of technology[9]



Looking at respondents' perception of different policy instruments, we observe that **financial incentives (e.g., subsidies) and a complete ban on SF6 are considered the two most useful policies to promote SF6-free MV switchgear** (see Figure 17). These results could be driven by a combination of both desirability of policies and their expected effectiveness.

Figure 17: Most useful policy tools in promoting SF6-free MV switchgear (multiple answers possible)



Regarding the impact of different policy measures, **44% of respondents indicate that a complete ban on SF6 in new MV switchgear would have a strongly negative or negative impact on their company's business** (see Figure 18a). Given the coercive nature of a ban, and the absence of obvious SF6-free alternatives, this is to be expected. However, another 20% of respondents indicate that a complete ban on SF6 in new MV switchgear would have a positive or even strongly positive impact on their company's business.

[9] "familiar with EU policies" refers to those respondents who stated that they were rather familiar or highly familiar with EU policies on F-gas emissions in the previous question (see Figure 15).

A majority of 51% of the respondents **believes that financial penalties for users of newly installed MV switchgear have a strongly negative or a negative impact on company's business.** In comparison, **two thirds** of respondents **expect financial incentives to have a positive or a strongly positive effect** on their company's business. Overall, respondents' view on policies appears to be similar across countries and sectors.

Figure 18a: Expected impact of changes in regulation on company's business

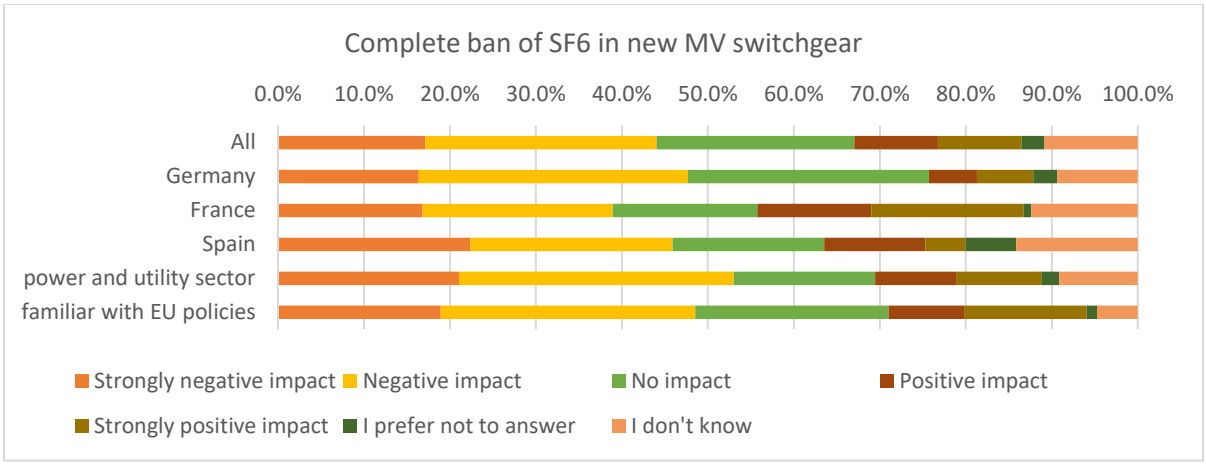


Figure 18b: Expected impact of changes in regulation on company's business

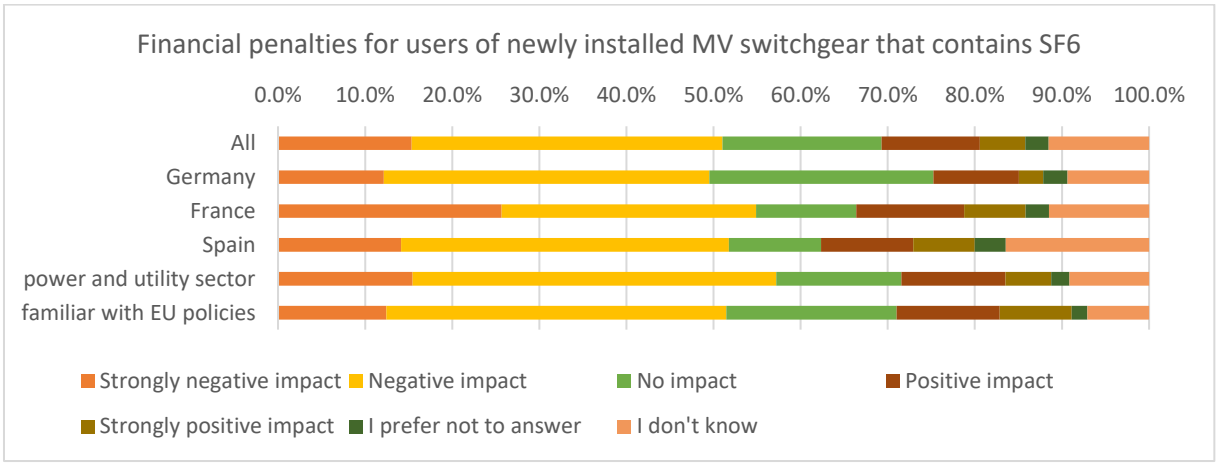
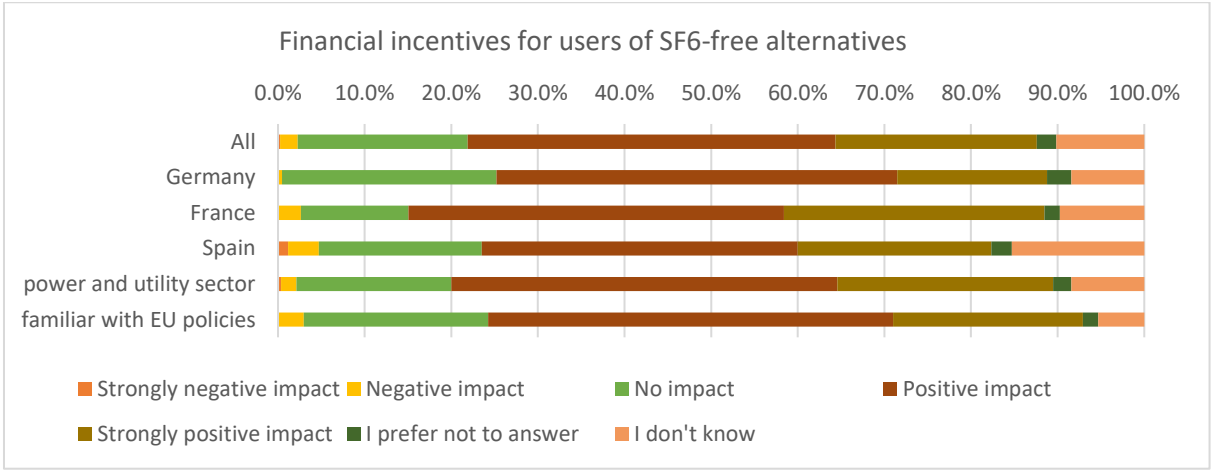


Figure 18c: Expected impact of changes in regulation on company's business



Results from the discrete choice experiment

Out of the 443 respondents, 324 indicated that they approximately knew the price of switchgear used by their company and were therefore eligible to participate in the SPCE.[10]

The data from the SPCE is analysed using a mixed logit model. We find the following coherent results[11]:

- An **increase in purchase price decreases the propensity to purchase** a particular MV switchgear option.
- An **increase in the volume/dimensions decreases the propensity to purchase** a particular MV switchgear option.
- A **lower global warming impact increases the propensity to purchase** a particular MV switchgear option.[12]
- The **propensity to purchase** a particular MV switchgear option **is higher if no leakage of F-gases is possible** in the event of an accident.
- **An increase in the warranty period increases the propensity to purchase** a particular MV switchgear option.

Put differently, we observe that respondents on average prefer cheaper, smaller options with lower global warming impact, no possible leakage of F-gases in the event of an accident, and longer warranty periods. At the same time, we observe that preferences are heterogeneous across respondents. I.e., not all respondents value the attributes in the choice experiment equally high. E.g., for some respondents, a lower global warming impact increases the propensity to purchase a particular option more than for other respondents. The same holds true for all attributes.

Given the observed heterogeneity in respondents' preferences for the different attributes in the choice experiment, we ran several additional models to test whether preferences for attributes are systematically different:

- Across countries;
- Across users of primary and secondary MV switchgear;
- Across sectors (comparing the power and utility sector and the renewable energy sector to other sectors);
- Across companies of different size (comparing companies with more than 250 employees to smaller companies).

Overall, **we find only few observable differences**. Across countries, the only difference we observe is that respondents in Spain seem to value an additional year of warranty slightly less compared to other countries. We do not find any evidence that respondents value attributes on average differently depending on whether they were making choices for primary or for

[10] The split of the sample by country is as follows: 72 in France, 171 in Germany, 4 in Poland, 60 in Spain, and 17 in the UK.

[11] All results are statistically significant at a 1% confidence level. Statistics are available upon request.

[12] Global warming impacts in the SPCE was defined as the impact on global warming over the product's entire life cycle rather than the global warming potential of specific components.

secondary switchgear. Respondents working for companies with more than 250 employees react on average more negatively to increases in size. Lastly, while the propensity to purchase a particular MV switchgear option increases if no leakage of F-gases is possible, this effect is weaker for respondents active in the renewable energy sector.

By comparing the estimated parameter for the price attribute and the estimated parameters for other switchgear attributes, we can infer respondents' willingness to pay for these attributes. We find that, **respondents are on average willing to pay**

- **20% more for options with a low global warming impact** compared to option with a high global warming impact
- **16% more for option with no possible leak of F-gases** compared to option where a leak is possible;
- **10% less if an option is 20% larger**;
- **8% more for 5 additional years of warranty**.

Results are summarized in Figure 19. Willingness to pay for one attribute is assumed to be independent of willingness to pay for other attributes. For example, for an option that is 20% larger (compared to commonly used switchgear) but has a low global warming impact and no possible leakage of F-gases, the average respondent would be willing to pay a 26% higher purchase price (-10% for larger option, +20% for low GWI, +16% for no leak of F-gases). [13]

It is possible that WTP figures derived from the SPCE exceed the amounts that companies would be willing to pay in a real purchase situation, especially since no opt-out option was provided in the choice scenarios. (I.e., in each scenario, respondents had to pick one of the switchgear options presented to them and could not indicate that they would choose neither of the options). However, after each choice scenario, respondents were also asked to indicate on a scale from 1 ("very unlikely") to 4 ("very likely") how likely they thought their company would be to actually purchase the preferred option if it was available on the market. **In almost 90% of cases, respondents answered that their company would be "somewhat likely" or "very likely" to actually purchase the selected option**. This finding suggests that prices for the switchgear options in the SPCE were overall reasonable. Moreover, WTP for all attributes was also estimated after excluding choice scenarios in which respondents indicated that their company would be "very unlikely" or "somewhat unlikely" to purchase the selected option if it were available on the market. (This is the case for approximately 10% of choice scenarios.) Excluding these choice scenarios decreases willingness to pay for switchgear attributes only marginally. [14]

[13] While in the SPCE attributes are independent of each other, this is not the case in reality. For example, F-gas free technologies would typically be expected to have a lower global warming impact and to be larger. Consequently, in a real purchase situation, willingness to pay for a combination of attributes might be different from the sum of willingness to pay for individual attributes.

[14] The WTP values presented above are calculated based on all choice scenarios, included those in which respondents made a choice but stated that their company would be unlikely or very unlikely to purchase their preferred option if it was available on the market. Excluding these scenarios can in improve the accuracy of results, but has only a very minor effects in our case.

Figure 19: Average willingness to pay for attributes in the SPCE

Attribute	Medium GWI (compared to high GWI)	Low GWI (compared to high GWI)	No leak of F-gases possible in the event of an accident	Size (+20%)	Warranty (+5 Years)
Average willingness to pay (WTP) (price increase in % compared to typical purchase price)	 + 12.2%[15]	 +20.2%	 +15.8%	 -10.5%	 +8.4%
Differences across countries	No statistically significant difference	No statistically significant difference	No statistically significant difference	No statistically significant difference	**Slightly lower WTP in Spain**
Differences between primary and secondary switchgear	No statistically significant difference	No statistically significant difference	No statistically significant difference	No statistically significant difference	No statistically significant difference
Differences between larger and smaller companies	No statistically significant difference	No statistically significant difference	No statistically significant difference	**Stronger negative WTP for larger companies**	No statistically significant difference
Differences between industry sectors	No statistically significant difference	No statistically significant difference	**Lower WTP for respondents in the renewable energy sector**	No statistically significant difference	No statistically significant difference

[15] Interpretation: Participants are on average willing to pay 12.2% more for an option that has a medium level global warming impact compared to an option that has a high global warming impact.

Discussion and conclusions

The findings from the SPCE suggest that customers of MV switchgear are per se willing to pay more for SF6-free (or more generally F-gas free) alternatives. In the SPCE, this is expressed through a high average willingness to pay for switchgear options with low global warming impact and for switchgear options with no leak of F-gases. This result is also corroborated by our findings from the declarative questionnaire in which eco-friendliness was identified as one of the most important purchase criteria for MV switchgear.

The fact that customers seem to care about environmental aspects when purchasing MV switchgear suggests that an environmental label for MV switchgear would be valorised if introduced on the market. For instance, such a label could feature an evaluation of the products global warming impact or be used to certify F-gas free switchgear – two aspects for which respondents in the SPCE were willing to pay up to 20% more compared to their usual purchase price. Label programs are among the range of policies that can stimulate and influence standard setters, industry associations, and industrial users towards long-term market transformation. In a related study, we reviewed the literature on existing labelling schemes and derived eight recommendations for an environmental label targeting MV switchgear (see Appendix B for details). The full literature review is available upon request.)

Results from our declarative survey further reveal that customers clearly expect a decrease in the use of SF6 technology in the near future. This decrease, however, is expected to be primarily driven by policies and regulations, rather than technological change or prices. Customers remain in fact uncertain which technology will most likely replace SF6. Currently available alternative technologies are not attractive to many, mainly because they require too much space or are too expensive. While companies generally appear to be willing to pay more for climate or environmentally friendly products, there remain financial constraints. In line with this finding, a majority of respondents identified financial incentives for users of SF6-free alternatives as one of the most useful policies in promoting SF6-free MV switchgear. Two thirds of respondents believe that financial incentives for users of SF6-free alternatives would have a positive effect on their company's business. In contrast, a complete ban on SF6 in new MV switchgear would have a negative effect on their company's business for 44% of respondents and a positive effect for less than 20%. Nevertheless, almost half the respondents believe that a complete ban on SF6 would still be a useful policy instrument to promote SF6-free alternatives.

Overall, customers appear to be anticipating change and are willing to consider moving towards SF6-free alternatives. These alternatives, however, must meet not only environmental but also technical and economic requirements. Given these constraints, it seems unlikely that market forces will suffice to have the majority of switchgear users switch to alternative technologies in the near future.

References

BBC, 2019, Climate change: Electrical industry's 'dirty secret' boosts warming. 13 September 2019, https://www.bbc.com/news/science-environment-49567197

Klinke, S. (2018). The determinants for adoption of energy supply contracting: Empirical evidence from the Swiss market. Energy Policy, 118, 221-231.

Klinke, S., Reiter, U., Jakob, M., Farsi, M., 2017. Contracting the gap: Energy efficiency investments and transaction costs. Technical report, Swiss Federal Office of Energy.

Olsthoorn M., Schleich J., Wohlfarth K., Klobasa M., 2019. How much load flexibility can a euro buy? Energy Economics 84, S1, 104-603.

Polzin, F., von Flotow, P., Nolden, C., 2016. What encourages local authorities to engage with energy performance contracting for retrofitting? Evidence from German municipalities. Energy Policy, 94, 317-330.

Revelt, D., Train, K. (1998). Mixed logit with repeated choices: Households' choices of appliance efficiency level. Review of Economics and Statistics 80(4), 647–657.

Regulation (EU) No 517/2014 of the European Parliament and of the council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. Official Journal of the European Union.

Roucan-Kane et al., 2013., U.S. Agribusiness Companies and Product Innovation: Insights from a Choice Experiment Conducted with Agribusiness Executives. International Food and Agribusiness Management Review, 16 (4), 123-140.

Schulz et al., 2013. Assessing Farmers' Willingness to Accept "Greening": Insights from a Discrete Choice Experiment in Germany. Journal of Agricultural Economics, Vol. 65, No. 1, 2014, 26–48.

T&D Europe, 2020, T&D Europe position paper on SF6 and SF6 alternative technologies. https://www.tdeurope.eu/publicationss/position-papers.html

Appendix A

Figure A1: Framing of the SPCE

On the following pages, we will describe **eight scenarios, each with two different options for primary MV switchgear**. In each scenario, we would like to know **which option you would choose if you were making a purchase on behalf of your company and these were your only options.**

Please assume that all options shown to you

- only differ in the features shown below,
- conform with any required technical specifications (e.g., rated voltage),
- conform with the relevant laws, prescriptions and standards currently in place.

Please make every decision, as if you would decide in a real purchase process.

Definitions:

1. Purchase price: The purchase price of the switchgear shown to you is **the same or 5%, 10%, 15%, 25% or 35% higher compared to the price** of **primary MV switchgear most frequently purchased by your company.**

2. Global warming impact: The life cycle global warming impact of each switchgear shown to you can be classified as **low, medium or high.**

3. Health and safety: For some switchgear shown to you, **leakage of F-gases** is possible in the event of an accident.

4. Volume/dimensions: The switchgear shown to you are **10% smaller, the same size, 10% larger, or 20% larger compared to the volume/dimensions of primary MV switchgear most frequently purchased by your company.**

5. Warranty: The warranty period for each switchgear shown to you is **2 years, 5 years, or 10 years.**

Figure A2: Example of two choice scenarios

Choice scenario 1:

	Option A	Option B
Purchase price	35% more expensive	5% more expensive
Global warming impact	low impact	high impact
Leakage of F-gases in the event of an accident	leakage not possible	leakage possible
Volume/dimensions	10% larger	same size
Warranty	5 years	5 years

	Option A	Option B
I would choose:	○	○

In your opinion, how likely would your company be to buy the selected option if it was available?

Very unlikely ○ | Somewhat unlikely ○ | Somewhat likely ○ | Very likely ○ | I don't know ○

Choice scenario 2:

	Option A	Option B
Purchase price	10% more expensive	15% more expensive
Global warming impact	high impact	medium impact
Leakage of F-gases in the event of an accident	leakage possible	leakage not possible
Volume/dimensions	same size	10% larger
Warranty	10 years	2 years

	Option A	Option B
I would choose:	○	○

In your opinion, how likely would your company be to buy the selected option if it was available?

Very unlikely ○ | Somewhat unlikely ○ | Somewhat likely ○ | Very likely ○ | I don't know ○

Appendix B

Recommendations for a label for MV switchgear

If an environmental label targeting MV switchgear were to be implemented, the following aspects should be considered to optimally design such a label. (Recommendations are based on a review of the literature on various existing labelling schemes.)

R1 – It is preferable to **implement a label program with a standard**. This allows for robust comparison of information (e.g. IEC for electric motors). All manufacturers must report information according to the same protocol, and thus to the same standard.

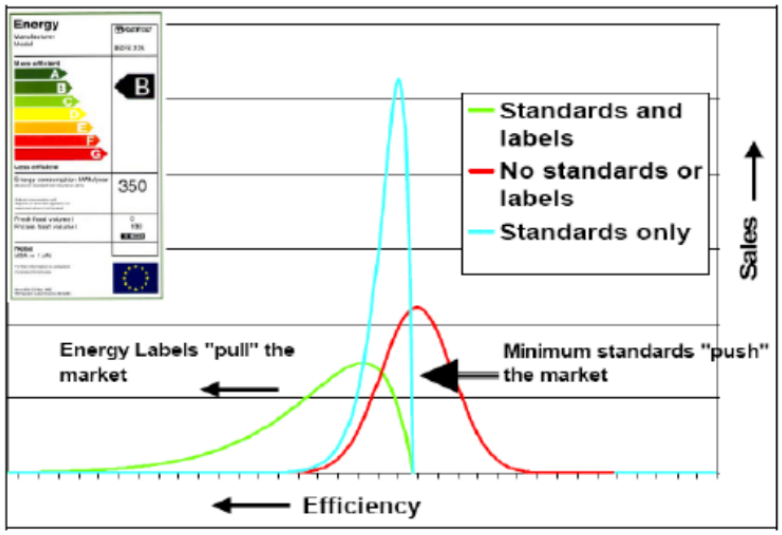


Figure 2: The combined effect of ecodesign ('minimum standards') and energy labels

Source: Proposal for a Regulation of the European Parliament and of the Council setting a framework for energy efficiency labelling and repealing Directive 2010/30/EU

R2 - For the **credibility and the value** of labels it is preferable that the label is **certified/audited by a state or and independent third-party organisation**. Private labels defined by manufacturers that resemble regulated ones can be perceived as a scam (or lenient schemes).

R3- Voluntary labels are not as effective as mandatory labels. Voluntary labels often fail to reach a critical mass and are thus less attractive. Moreover, communication and control by public authorities may be lacking for voluntary labels.

The literature reveals two type of labels: 1) **endorsement labels** for products fulfilling pre-set criteria and 2) **comparative labels** rating and providing transparent information on all models according to pre-set criteria. While endorsement labels provide quick and simple information (i.e. label versus no label), comparative labels may create more competition between models subject to the same rating. In the following, we derive additional recommendations according to these two types of label.

R4 for endorsement labels: Avoid transversal labels, i.e. labels covering a wide range of products. They are more expensive to implement, and some categories may remain without

products. For instance, the Eco Label works well for hygiene products but much less well for household appliances.

R5 for comparative labels: Future EU labels should **follow existing European label layouts** (e.g. energy labels put on washing machines, refrigerators, heating systems, etc.). Note that from 2021 on, all energy labels will have to comply with the new European regulation that stipulates label category from **A to G** (category "+++" will be removed).

R6 for comparative labels: The **scale of the label needs to be sufficiently broad** to allow adequate differentiation between products and to avoid 'bunching' of products within one category at the top of the scale.

R7 for comparative labels: The **first version of a given label is the most important one**. Any update can be long and difficult. The first version hence needs to be well calibrated and ambitious enough to last as long as possible. For instance, it must be challenging but technically feasible for manufacturers to have their products meet the criteria for the best categories.

R8 for comparative labels: For **transparency and acceptability**, the criteria leading to different label categories or any **additional information should be published separately.** (For example, the French label on indoor air emission does not allow the consumers to be properly informed: A French Association found different performances among paints belonging to the same category "A+" but consumers are not informed how these performances are linked to the label category.)