SOCIO-ECONOMIC ANALYSIS OF THE VALUE OF F-GASES

Final Report

Report for: EFCTC

Ref. CN02670

Ricardo ref. ED16040 Issue: 3 07/09/2022

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Customer:
European FluoroCarbons Technical Committee (EFCTC)

Customer reference:
CN02670

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1. SUMMARY OF THE SEA

This study has been commissioned by the European FluoroCarbons Technical Committee (EFCTC) to provide an independent Socio-Economic Analysis (SEA) of the contribution of the fluorinated greenhouse gas (F-gas) industry to the European Economic Area's[1] (EEA) economy and society.

1.1 THE PROPOSED REACH RESTRICTION

In July 2021, four Member States + Norway submitted a joint intention for a universal REACH restriction of PFAS due to concerns about their persistence in the environment. The proposed restriction would cover the manufacture, placing on the market and use of PFAS in the EEA.

PFAS Definition from restriction intention

Substances that contain at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any H/Cl/Br/I atom attached to it).

Source: RoI[2].

Substances classified as PFAS in the restriction intention are also PFAS under the July 2021 OECD's recent definition: "*PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS*"[3].

In the present context, a proposal to amend the current F-gas Regulation (Regulation (EU) No 517/2014 of the European Parliament and the of Council of 16 April 2014 on fluorinated greenhouse gases) has been published by the European Commission[4], aiming to achieve additional F-gas emission reductions in line with the Montreal Protocol and the Paris Agreement on Climate Change. Pathways to limit global warming at 1.5°C include requiring emission decreases for F-gases of up to 90% by 2050 globally compared to the year 2015. As a result, the quota system for hydrofluorocarbons (HFC phase-down) is expected to be tightened in comparison with the 2014 F-gas Regulation (HFCs would be severely restricted, up to 2.4% of 2015 levels in 2050). The proposal also updates other obligations for companies, such as best practices, leak checks, record keeping, training of workers and appropriate waste treatment. Licensing and labelling obligations are also reinforced as a measure to enforce trade restrictions, as well as existing monitoring and verification systems to ensure compliance and setting penalties for illegal trade of F-gases. The new proposal also focusses on preventing ODS emissions from formerly legal applications in products and equipment, making it mandatory to recover or destroy ODS from some insulation foams during renovation and demolition of buildings. Training and emissions prevention measures also extend to H(C)FOs. A restriction of all PFAS would render this Regulation obsolete, and the GWP emissions reduction pathways considered therein would become non-viable.

1.2 SCOPE OF THE ASSESSMENT

The scope of this assessment is limited to a set of 10 F-gases (and the mixtures in which these form a component part), which have been identified as meeting the proposed definition of PFAS at risk of a REACH restriction and are of interest to the European F-gas manufacturers. These are listed in the following table.

Table 1-1 Detailed list of substances in scope of this study. H(C)FOs are highlighted with an asterisk. Source: PubChem, ECHA and CLI.

Trade Name	Chemical/Common Name	CAS Number
HFC-125	Pentafluoroethane	354-33-6
HFC-134a	Norflurane	811-97-2

[1] The EEA comprises the current EU-27 and Iceland, Liechtenstein and Norway.

[2] See Registry of Intention for the proposed restriction: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

[3] OECD. Series on Risk Management No. 61, 2021.

[4] European Commission 2022. Proposal of a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Accessible under: https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF

Trade Name	Chemical/Common Name	CAS Number
HFC-143a	1,1,1-trifluoroethane	420-46-2
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	431-89-0
HFC-245fa	Propane,1,1,1,3,3-pentafluoro-	460-73-1
HFC-365mfc	1,1,1,3,3-pentafluorobutane	406-58-6
HFO-1234yf	2,3,3,3-Tetrafluoroprop-1-ene	754-12-1
HFO-1234ze	1-Propene, 1,3,3,3-tetrafluoro-	1645-83-6
HFO-1336mzz(Z)	2-Butene,1,1,1,4,4,4-hexafluoro-, (2Z)-	692-49-9
HCFO-1233zd	(1E)-1-chloro-3,3,3-trifluoroprop-1-ene (E)-1-chloro-3,3,3-trifluoroprop-1-ene	102687-65-0 2730-43-0

This study explores the potential economic and social effects of the proposed restriction on activities associated with the manufacture, placing on the market and use of the F-gases in scope. In addition, it also aims to capture the social and environmental effects: i.e. describing the potential human health and environmental impacts of these substances, alongside their contribution to the wider society.

The geographical scope of the analysis is the European Economic Area[5] (EEA), in line with the scope of the proposed restriction. The analysis consists of a comparison between:

- A baseline scenario projection of the F-gas supply, which takes into account the phase-down of F-gases imposed by the current F-gas Regulation until 2030, with no further policy developments.
- A restriction scenario representing the intended blanket restriction on all PFAS including the F-gases in scope.

Baseline and restriction scenario projections are extended to 2040 in order for the restriction and its effects to fully take place.

The analysis utilises data from the baseline developed in Section 2.2.2, the most recent data on F-gases placed on the market in the EEA, evidence from a survey of 9 F-gas producers and/or importers (representing the whole F-gas industry with a margin of error estimated in +/- 6-7%) and 29 downstream users from different industries, and secondary research.

The economic analysis is presented for F-gas producers/importers, and downstream users separately, and considers:

- The scope and potential scale of impacts as indicated by the business portfolio that would be affected by the restriction;
- A consideration is made of business responses to these impacts – this includes a summary of qualitative responses to the survey on key F-gas alternatives that may be available today or in the future and their comparison with F-gases vis a vis their costs, properties, safety profile, and energy consumption;
- Costs and benefits for the F-gas industry and downstream user industries, including their turnover, Gross Value Added (GVA), intermediate consumption and operating costs, capital investment and R&D expenditure, and the regulatory burden faced by these sectors;
- Other qualitative business considerations.

[5] The EEA comprises the current EU-27 and Iceland, Liechtenstein and Norway.

1.3 RESULTS

To assess the net impacts of the proposed restriction on the EEA F-gas producing/importing sector, a baseline and two policy scenarios were developed (and analogous two sectors for F-gas downstream users):

- The sectoral **baseline** (2019-2040) was developed by employing statistical techniques and trend analysis on publicly available evidence of the turnover from Eurostat's Structural Business Statistics[6], combined with reported data by industry stakeholders. This baseline scenario assumes that the proposed restriction is not implemented, and the current F-gas Regulation is in force, as well as the HFC phase-down established therein.
- A first policy scenario (**Scenario 1**) considers the proposed restriction entering into force in 2025. The affected products would be withdrawn from the market unless they are substituted and/or reformulated, which happens instantaneously.
- A second scenario (**Scenario 2**) considers that businesses may need time to adapt so they can bring substitutes and/or reformulated products to the market. Based on the available evidence[7], it has been assumed that companies may need, on average, around 5 years to adjust their operations and place their substitutes and/or reformulated products on the market. This would lead to larger turnover losses earlier on. Over time, turnover will converge to the levels estimated in Scenario 1.

A targeted consultation with the F-gas producers, importers, and downstream users from various application sectors, and economic analysis reveals that the proposed restriction is likely to have significant impacts on EEA F-gas producers and importers, downstream users and the wider economy, including consumers. In particular, **EEA F-gas producers and importers are estimated to lose between €550 million and €640 million of turnover per year on average between 2025 and 2040, when compared to baseline projections, as a result of the restriction.** In 2040, sectoral turnover in any of the proposed restriction scenarios considered in this study is estimated to be 14% lower than the baseline. **For EEA F-gas downstream users, their loss is estimated to range between €2.2 and €4.1 billion per year jointly for all F-gas applications on annualised terms between 2025 and 2040, compared to baseline projections.** These losses for downstream users would result from products containing F-gases no longer being allowed to be placed on the market, and with no alternative substances, formulas or other manufacturing changes to make them viable without F-gases. In 2040, sectoral turnover in any of the proposed restriction scenarios considered in this study is estimated to be 5.4% lower than the baseline for downstream users.

These estimated losses are significant despite already accounting for the actions that businesses would take to mitigate the effects of the legislative changes, such as substitution and reformulation. For example, F-gas producers and importers have suggested that they would be able to substitute and/or reformulate around 52% of the portfolio of products that could be affected by the proposed policy changes, while for downstream users up to 80% would be expected to be substituted, reformulated or subject to other productive changes. However, baseline product technical characteristics (such as safety, flammability or toxicity) and performance (including energy efficiency) are not guaranteed by these strategies, the outcomes of which might constitute the placing on the market of entirely new products, that may be more costly[8], with uncertainty in how consumers will receive them.

It is also estimated that operating expenditures would decline when compared to the baseline. These net reductions would be driven by the losses that are estimated to the size of operations of the F-gas production and imports market, and of the F-gas downstream users' markets. At the same time, capital expenditure or investment would decrease overall due to business size reduction, but some new investments would be needed in order to sustain the needed levels of substitution and reformulation for the mitigation of further turnover losses. These estimates do not suggest that there will be any cost savings from the adoption of the legislative changes, at least in unit terms. In fact, unit expenditure is expected to increase for both F-gas importers and producers, and their downstream users.

On the side of demand, consumers are assumed to progressively change and/or adapt their currently owned equipment as it reaches its end of life and have to switch to a non-fluorinated alternative. Therefore, sudden increases in demand as a result of the proposed restriction are not expected or modelled. However, end consumers, especially commercial and industrial ones, may need to replace their entire technology systems

[6] Eurostat (2022), *Structural Business Statistics Database*. [online] Eurostat Available from: Database - Structural business statistics - Eurostat (europa.eu) [Accessed 05/2022]

[7] ECHA (2020) *"Impacts of REACH restriction and authorisation on substitution in the EU"*; DOI: 10.2823/39789. and ECHA (2021) *"Costs and benefits of REACH restrictions proposed between 2016-2020"*. DOI: 10.2823/122943

[8] In this sentence, products refer to final end-consumer applications containing F-gases, such as an RACHP system.

in some cases; instead of a simple renewal of an existing system (e.g., RACHP), if technology experiences substantial changes, consumers may need to adapt and make new investments too. The replacement of the equipment may even happen earlier if the existing one needs servicing before the end of its life, since F-gases would not be available. These two instances would incur additional investment for equipment owners that has not been possible to quantify in this study.

The proposed restriction would also affect the sector's and its downstream users' employment. It is estimated that, **by 2040, around 80-90 jobs in the EEA F-gas production and import sector would be lost against the baseline scenario, which is equivalent to around 1% of their baseline workforce in 2040**. **These impacts would have knock-on effects in the EU economy, which could lead to losing around 300 jobs by 2040 when compared against the baseline.**

For downstream users, job losses are estimated to be around 5,100 by 2040, compared to the baseline. This loss is estimated to be equivalent to almost 4% of their baseline workforce in 2040[9]. **Including knock-on effects in the EU economy, those losses could reach between 6,000 and 15,000 fewer jobs**, on average, when compared to the baseline in any given year between 2025 and 2040 **in Scenario 1**, and **between 9,000 and 27,000 fewer jobs, on average, in Scenario 2**.

The direct contribution of F-gas production and import to GVA would be between €75 and €90 million lower per year over the period 2025-2040, on average and when compared to the baseline. When adding indirect and induced effects, **the total contribution of the EEA F-gas production and import to GVA would be between €220 and €250 million lower per year over this period, on average.** Resulting from the restriction, **downstream users would directly contribute from €0.8 billion to €1.6 billion less to the EEA GVA per year on average over this period; including indirect and induced effects, GDP in the EEA would then be €1.1 to €5.9 billion lower on average per year**.

Table 1-2 below summarises some of these impacts on key business and economic indicators of the F-gas producing and importing sector against the baseline and across three scenarios.

Table 1-2 Annualised impacts on selected business and economic indicators of the EEA F-gas producing and importing sector, against the baseline scenario (%).

Themes (business or economic indicators)	Scenario 1 (Substitution and Reformulation)	Scenario 2 (Substitution and Reformulation (with delay))
Turnover (first order effects)	A loss of €550 million per year between 2025 and 2040 on average against the baseline	A loss of €640 million per year between 2025 and 2040 on average against the baseline
Total GVA contribution (*direct, indirect, induced*)	A loss of €220 million per year between 2025 and 2040 on average against the baseline	A loss of €250 million per year between 2025 and 2040 on average against the baseline
Regulatory burden	An additional annualised burden of €12 million each year between 2025 and 2040	An additional annualised burden of €9 million each year between 2025 and 2040
Total employment contribution (*direct, indirect, induced*)	275 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040	310 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040

Note: impacts are evaluated over the period 2025-2040 and expressed in average annualised terms.

Table 1-3 below summarises some of these impacts on key business and economic indicators of the F-gas downstream users against the baseline and across three scenarios.

[9] It should be noted that a total measure of employment for all F-gas downstream users is not available in public statistics, and that this is an extrapolation based on the known production value of F-gas downstream users and the production value reported by the surveyed sample.

Table 1-3 Annualised impacts on selected business and economic indicators of the EEA F-gas downstream users, against the baseline scenario (%)[10].

Themes (business or economic indicators)	Scenario 1 (Substitution and Reformulation)	Scenario 2 (Substitution and Reformulation (with delay))
Turnover (first order effects)	A loss of €2.2 billion per year between 2025 and 2040 on average against the baseline	A loss of €4.1 billion per year between 2025 and 2040 on average against the baseline
Total GVA contribution (*direct, indirect, induced*)	A loss of between €1.1 and €3.2 billion per year between 2025 and 2040 on average against the baseline	A loss of between €2.1 and €5.9 billion per year between 2025 and 2040 on average against the baseline
Regulatory burden	An additional annualised burden of €89 million each year between 2025 and 2040	An additional annualised burden of €3 million each year between 2025 and 2040
Total employment contribution (*direct, indirect, induced*)	Between 6,000 and 15,000 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040	Between 9,000 and 27,000 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040

Note: impacts are evaluated over the period 2025-2040 and expressed in average annualised terms.

There is also the need to consider the impact of these restrictions on consumers. F-gases are key inputs to a wide range of products of everyday use. Benefits to human health and the environment as a result of the proposed restriction through the substitution of F-gases with alternatives are far from clear. Some of the lowest global warming potential (GWP) alternatives to HFCs are H(C)FOs, which would fall under the restriction. Additionally, current risks to human health of the current uses of F-gases are considered minimal, while reports by F-gas downstream users highlight the increased safety requirements of some of the most promising alternatives in the most relevant applications, such as Refrigeration, air-conditioning and heating (RACHP). Increased costs and reduced efficiency, both in the performance of the product applications and in their energy consumption, lead to an increased burden on consumers, possibly limiting consumer choice and reducing incentives for technological change from the current equipment containing F-gases. A potential PFAS restriction would limit access to F-gases to service the millions of pieces of equipment, which are currently in operation throughout the EEA. This could significantly increase the demand for illegal HFCs, as equipment owners may want to maintain their current operational equipment and delay investment in new equipment when the equipment they own is not at the end of its useful life, and the new equipment may require costly investments or not be available due to overdemand in the supply chain as a result of the restriction.

The results of this assessment highlight that the proposed restriction of PFAS, as it was conceived including all F-gases in scope of this study, may lead to the reduction in manufacturing and/or use of downstream user applications and increase in costs thereof.

Trade-offs between aiming to reduce GHG emissions with the current F-gas Regulation, that allows the switch from higher GWP HFCs towards low GWP H(C)FOs, and reducing GHG emissions after a blanket restriction of all PFAS that includes all F-gases in scope of this study can lead to worse GHG emission outcomes in the restriction scenario.

1.4 RECOMMENDATIONS

The analysis presented in this report is based on consultation responses from the surveys of F-gas producers and importers, and downstream users. The data provided may not be considered exhaustive, in particular with regard to derogations or exemptions from the proposed PFAS restriction, as companies may not seek derogation/exemption under the same criteria as another. As such, this report does not seek to replace any assessment by other such companies or associations and presents the evidence gathered in the context of this study only.

[10] Results in this table are a rough extrapolation that matches the value of the whole sum of F-gas downstream application sectors, although caveats include the diversity of these sectors and the fact that the sample is not able to provide separate estimates for each of them. Overall, the sample of downstream users that participated in our survey is estimated to represent around a third of the total production value of these sectors jointly.

The analysis highlights that the use of F-gases is key to certain sectors, and it would be very difficult to meet the climate targets of the European Commission without the use of low GWP H(C)FOs. Recommendations stemming from the outputs of this analysis include:

1. It is acknowledged that companies within this sector are seeking to reduce the GWP of their products and systems. A derogation or exemption for the low GWP F-gases in scope and their blends (i.e., H(C)FOs and their blends) would prevent the continued use of high GWP F-gases and encourage the shift to H(C)FOs, whilst allowing the sector to meet the climate targets of the European Commission and maintain operations. This derogation could work alongside the phase down of the F-gas Regulation so as to ensure compliance through transparency and coherence of objectives. It would also be aligned with the proposal amending the F-gas Regulation with more stringent objectives, which also relies on low GWP F-gases as a pathway to achieve climate neutrality in 2050. A shift to non-PFAS alternatives may also result from this derogation, where companies have sufficient time and resource to develop these systems.
2. Should the proposed restriction of PFAS continue without the case for derogation of certain chemical groups or applications, it would be advised to consider a transitional arrangement that allows for continued use of F-gases in scope within a certain timeframe, in order to encourage R&D into non-PFAS alternatives (chemical or technical) and allow business to respond to the changes required. Any transitional arrangement would need to be in line with the phase-down of the F-gas Regulation to prevent double regulation and non-compliance as a result of a lack of coherence in the regulatory conditions that should be followed.

2. AIMS AND SCOPE OF THE SEA

2.1 THE AIM OF THE SEA

This Socio-Economic Analysis (SEA) has been commissioned by the European FluoroCarbons Technical Committee (EFCTC). It seeks to make an independent assessment of the contribution of the fluorinated greenhouse gas (F-gas) industry to the European Economic Area's[11] (EEA) economy and society. The analysis covers both producers and importers of F-gases and downstream users. This analysis will be used to support a response to the European Chemicals Agency's (ECHA) consultation on a registered intention to restrict all Per- and Polyfluoroalkyl Substances (PFAS). The report's structure and approach closely follow ECHA's guidelines[12] for the content and format of an SEA for the purposes of REACH restriction, such that the outputs and conclusions can be readily incorporated into ECHA's review of evidence provided through the consultation.

2.1.1 The proposed restriction

In July 2021, a group of five countries submitted a joint REACH restriction proposal for a universal restriction of PFAS due to concerns about their persistence in the environment. The proposed restriction would cover the manufacture, placing on the market and use of PFAS in the EEA.

ECHA's restriction process generally involves the following phases[13]:

I. **Preparation and submission of a restriction proposal:** the notification of intention to submit a restriction proposal by a Member State (or group thereof) or ECHA starts the restriction process, and the intention is added to the Registry of Restriction Intentions (RoI).

   A restriction dossier is produced which follows the restriction proposal, and needs to discuss hazards and risks, available information on alternatives and a justification for action (restriction) as the most appropriate risk management measure to address the identified risks. It may also include an analysis of socio-economic impacts.

II. A **Consultations:** there are two consultations for which stakeholders can comment or submit evidence. The first allows interested parties, such as stakeholders directly affected by the proposed restriction and the wider society, to submit comments on the restriction report and/or supporting documents within six months of the date of publication. The second consultation concerns the Committee for Socio-economic Analysis (SEAC) draft opinion, where stakeholders have 60 days from publication to submit comments or evidence.

II. B **Opinion development:** within 9 months of the publication of a conforming restriction report the Committee for Risk Assessment (RAC) prepares and adopts its final opinion on the dossier, following the advice of the Forum for Exchange of Information on Enforcement and comments received during the consultation on the restriction report. The RAC opinion considers whether the proposed restriction is the most appropriate form of regulatory management for reducing risks posed to human health and the environment.

   Within the same timeframe, the SEAC issues a draft opinion which is published by ECHA. Additional comments to SEAC's draft opinion can be submitted within 60 days (as noted above). The Forum for Exchange of Information on Enforcement may provide additional advice about enforceability, with scientific, technical and regulatory support from ECHA. SEAC has 12 months from publication of a conforming restriction report to finalise their opinion, including consideration of comments to their draft opinion.

   Should the RAC's opinion diverge significantly from the original proposal, the Commission may delay the final SEAC opinion by a further 3 months. Final opinions and relevant evidence are submitted to the European Commission (EC).

III. **Draft amendment to the list of restrictions (Annex XVII) decision by the EC** is made within three months of receiving compiled opinions. The decision is also submitted to the World Trade Organisation

[11] Ibid footnote 5.

[12] ECHA (2008). Guidance on Socio-Economic Analysis - Restrictions. Available at: https://echa.europa.eu/documents/10162/2324906/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

[13] https://echa.europa.eu/restriction-process

to ensure it does not create technical barriers to international trade, and finally, the restriction is adopted if applicable.

As part of this restriction process, in July 2021, a call for evidence from companies and stakeholders on the hazards of PFAS and their uses was initiated and concluded in October 2021. The submission of evidence to ECHA to inform the adoption of a final opinion by RAC and SEAC will be opened after the submission of the restriction dossier, expected in January 2023. The provision of information to motivate any exemptions to the scope of the intended restriction is encouraged and considered of special relevance. The evidence and analysis generated in this study will underpin a submission in response to the ECHA public consultation expected in 2023.

The RoI for the restriction proposes to classify a substance as PFAS if it contains at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any H/Cl/Br/I atom attached to it)[14]. Substances classified as PFAS in the RoI are also PFAS under the July 2021 OECD's recent definition: "*PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF_3) or a perfluorinated methylene group (–CF_2–) is a PFAS*"[15]. The term "methyl or methylene carbon atom" describes the fully fluorinated saturated carbon moiety. Carbon atoms would not be considered fully fluorinated if a H/Cl/Br/I atom was attached, as such these substances are not considered PFAS. It should be noted that the RoI definition does not include the exceptions, yet it does state that "*substances meeting the chemical scope definition for this restriction proposal will therefore also meet the OECD PFAS definition*"[16].

2.1.2 Objectives of this Socio-Economic Analysis

Contrary to previously used definitions of PFAS[17], the definition in the RoI to restrict PFAS would capture several F-gases (i.e., over 40, including over 30 refrigerants). This includes widely used HFCs and some of the low GWP, unsaturated H(C)FCs (also known as hydrochlorofluoroolefins from hereinafter, H(C)FOs) replacements which have been developed and are increasingly used as alternatives to high GWP F-gases, whether in their pure form or in blends (as incentivised through the phase-down and other measures established under the EU's F-gas Regulation). Note although the proposed restriction will include several key F-gases, other F-gases will not be captured. In addition, there is a wide range of other non-F-gas substances that will also be captured by the proposed PFAS restriction.

The scope of this assessment does not capture all substances included in the proposed restriction. Instead, this study focuses on the set of 10 F-gases (and the mixtures in which these form a component part), which are brought in scope of the PFAS restriction according to the definition of PFAS included in the RoI, and are thus at risk of a REACH restriction and of interest to the European F-gas manufacturers. These are listed in the following table.

Table 2-1 Detailed list of substances in scope of this study. H(C)FOs are highlighted with an asterisk. Source: PubChem, ECHA and CLI.

Trade Name	Chemical/Common Name	CAS Number
HFC-125	Pentafluoroethane	354-33-6
HFC-134a	Norflurane	811-97-2
HFC-143a	1,1,1-trifluoroethane	420-46-2
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	431-89-0
HFC-245fa	Propane,1,1,1,3,3-pentafluoro-	460-73-1
HFC-365mfc	1,1,1,3,3-pentafluorobutane	406-58-6

[14] See https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

[15] OECD. Series on Risk Management No. 61, 2021.

[16] Ibid Footnote 2.

[17] "PFASs, including perfluorocarbons, that contain a perfluoroalkyl moiety with three or more carbons (i.e. –CnF2n–, n ≥ 3) or a perfluoroalkylether moiety with two or more carbons (i.e. –CnF2nOCmF2m−, n and m ≥ 1)." OECD, (2018). Toward a new comprehensive global database of per- and polyfluoroalkyl substances (PFASs). Available from: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Trade Name	Chemical/Common Name	CAS Number
HFO-1234yf	2,3,3,3-Tetrafluoroprop-1-ene	754-12-1
HFO-1234ze	1-Propene, 1,3,3,3-tetrafluoro-	1645-83-6
HFO-1336mzz(Z)	2-Butene,1,1,1,4,4,4-hexafluoro-, (2Z)-	692-49-9
HCFO-1233zd	(1E)-1-chloro-3,3,3-trifluoroprop-1-ene (E)-1-chloro-3,3,3-trifluoroprop-1-ene	102687-65-0 2730-43-0

A REACH restriction of all PFAS could significantly impact the F-gas sector, by prohibiting the use of a large number of F-gases and mixtures for general applications in the EU and the wider EEA. Such a restriction could pose a number of risks and challenges which are explored in this SEA. Key challenges include:

- F-gases are used in a number of valuable (and sometimes critical) applications, and any restriction would cause an immediate impact to these industries;
- F-gases are used in several technologies which form a critical part of the net-zero transition (e.g. heat pumps), as such a blanket restriction would pose an additional challenge to achieving climate targets;
- if in response to a restriction low-GWP F-gases are substituted by higher GWP (non-PFAS) F-gas alternatives, this would also work against the fulfilment of the decarbonisation goals;
- and some of the existing, non-fluorinated alternatives to F-gases pose risks to human health if equipment is not managed properly or if an accident occurs.

The objective of this study is to produce a SEA of selected F-gases which are captured by the proposed REACH restriction of (PFAS). This study explores the potential economic and social effects of the proposed restriction: for example, the impact on revenue generated, investment, and employment (direct and indirect) associated with the F-gas industry producing or using the substances in scope. In addition, it also aims to capture the environmental effects: i.e. describing the potential human health and environmental impacts of these substances, alongside their wider contribution to society. More specifically the report will aim to:

- Provide an overview of the direct and attributable economic contribution of the F-gas industry to the overall EEA economy and its expected evolution in the context of the current F-gas regulatory context (i.e., Regulation (EC) 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[18], the 'F-gas Regulation' - see 2.2.1 for a detailed policy context).
- Show the economic contribution generated along the downstream value chain from the use of F-gases in various critical applications or sectors.
- Present the potential human health and environmental impacts from the use of F-gases covered by the proposed restriction in their various applications and provide a qualitative comparison with those of alternatives.
- Identify and discuss alternatives to F-gases covered by the proposed restriction in various critical applications and assess their economic, environmental and human health costs and benefits compared to the current use of F-gases covered by the proposed restriction, keeping in mind their expected evolution in the context of the current F-gas regulatory context.

The ECHA RAC and SEAC are required to provide scientific and technical advice on the proposed restriction, for which relevant data is required. As part of the REACH restriction consultations, ECHA accepts any party to submit a SEA as part of its evidence gathering. ECHA have published official guidelines on the preferred content and structure of such SEAs[19]. For the PFAS restriction proposal it will be possible to submit SEAs once the ECHA consultation is opened following the dossier submission expected in January 2023. This report aims to support decision-making throughout the restriction process, presenting data that may be useful for ECHA's Phase II-B: "Opinion Development". As such it is intended to be relevant to the opinion forming

[18] Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517
[19] Ibid footnote 12.

activities of the SEAC. Specifically, this SEA should be regarded as an **assessment of the net costs or benefits of the proposed restriction to human health and the environment and the net costs or benefits to manufacturers, importers, downstream users, distributors, consumers and society as a whole**. Potentially, this report will also contribute to a **discussion on the scope or conditions of the proposed restriction and whether potential derogations should be proposed on the basis of socio-economic considerations**.

2.1.3 Methodology overview

2.1.3.1 Scenarios under consideration

This SEA follows closely ECHA's guidance for SEAs on restriction proposals[20] and the report is organised following the structure there established. In particular, a baseline scenario and a proposed restriction scenario must be defined to guide the analysis:

a) **Baseline scenario:** in order to analyse the contribution of the F-gases (in scope of the restriction) and their associated industries to the economy and wider society a baseline scenario is first defined. This presents a business-as-usual situation (BAU), i.e., how would the industry and market continue to develop in the absence of the proposed restriction or any further policies to restrict the use of F-gases beyond the ones already in place.

   The baseline scenario first seeks to define the current status of the industry (i.e. what the industry and market look like today – or the year for which we have most recent historic data), and then projects forward various indicators to describe how the industry (as well as that of the downstream users) could develop going forward. It also explores the environmental and health risks and wider economic and societal contributions of the F-gas industry should no further policy or regulatory action be taken.

   The baseline scenario also incorporates effects from the existing legislation. This most notably included the various measures imposed under the existing F-gas Regulation[21] currently in force, which will determine the evolution of the F-gas industry and market over the next decade. It is noted that the European Commission have recently made a legislative proposal to update the F-gas Regulation. However, given this proposal is at an early stage in the process of adoption, and there is uncertainty still around what the final Regulation may look like, the baseline scenario for this study maintains the existing F-gas Regulation as part of its regulatory baseline.

   It should also be noted that even though the regulatory baseline imposes a phase down of HFCs, it is assumed that F-gas producers and/or importers react accordingly switching to alternatives to the phased down substances in order to maintain their businesses and their expected growth in economic terms. In that sense, it is possible to differentiate between the regulatory baseline and the economic or business baseline. The 'Baseline scenario' itself includes both regulatory and economic baseline.

b) **Policy (or 'with restriction') scenario:** The baseline scenario is used as a reference for the comparison with the policy scenario, i.e., where the proposed PFAS restriction is put in place, restricting the F-gases in its scope. If the restriction is put in place, the possibility to manufacture and place on the market F-gases in scope in the EEA will no longer be viable. Within the F-gas market, producers and/or importers, and downstream users will need to respond to such a restriction, and could respond in a number of different ways. This strategic response by affected stakeholders is considered in order to assess the net impacts of the proposed restriction on their businesses. A summary of such potential strategic actions for different actors is as follows:

   - F-gas producers and/or importers could: switch to producing alternative and compliant substances in order to maintain their business; fostering other business lines almost unrelated to F-gases in order to mitigate potential losses; where substances are intended for export, shift production outside the EEA; pass through of new costs to consumers (hence having a second-order impacts via prices); pursue derogations, etc.
   - Downstream users could: source alternative substances for use in downstream equipment (whilst taking into account potential differences between F-gases and the alternatives in terms of costs, performance and risk profile); adapt existing technologies to make-use of alternative substances;

[20] ECHA (2008), Guidance on Socio-Economic Analysis – Restrictions. Available from: https://www.echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0150&from=EN

pursue derogations; invest in new alternative technologies making use of alternative substances; abandoning the manufacture of certain products, etc.

Additionally, impacts from the proposed restriction of the F-gases in scope on human health and the environment are assessed in the policy scenario and consider both the impacts of the restricted substances, and those emanating from the adoption of alternative substances and/or technologies.

2.1.3.2 Mapping and screening of impacts

Impacts within the scope of this assignment can be classified in five main categories: economic, human health, environmental, social, and wider economic impacts (i.e., impacts on trade, competition and economic development, following ECHA's guidelines for SEA restriction reports[22]). In order to identify the impacts that will be included in the scope of the SEA, first, a longlist of nine economic impact categories was developed. This long-list was subsequently screened and refined down to a short-list of the most significant impacts for inclusion in the scope of analysis. This short-list was split into 'economic impacts' and impacts that would fall under an assessment for 'wider' economic impacts (as presented in the table below), i.e., knock-on effects, that are shown further below as a separate category. The nature of the business impacts of this proposed restriction may significantly affect both F-gas producers/ importers and their downstream user sectors. Therefore, the economic, social and wider economic impacts are assessed both at the level of F-gas producers/ importers and at the level of application manufacturers.

Table 2-2 Longlist of the impact categories mapped for screening. Developed by Ricardo for the EFCTC.

Impact category	Impact Sub-categories
Economic	• Revenue, operating costs and conduct of business (e.g. substantive compliance costs) • Administrative burdens on businesses (e.g. costs associated with registration obligations or other administrative activities) • Innovation and research (e.g. stimulation or hindrance of investment in alternatives, etc.) • Public authorities (e.g. administrative costs or savings from additional or lessened requirements, etc.) • Size of operations (e.g. production, turnover)
Human health	• Health hazards presented to consumers and professionals associated with exposure to F-gases in the scope of the proposed restriction • Changes in health hazards presented to consumers and professionals (e.g. through substitution with alternative compounds)
Environmental	• Impacts on greenhouse gas emissions and the feasibility of achieving the EU's climate targets • Change in energy efficiency of application systems through use of alternatives • Disruption to greener technology markets (e.g. heat pumps) and their adoption
Social	• Employment (e.g. number of jobs created or lost) • Consumers and households (e.g. ability to benefit from the internal market)
Wider economic	• Knock-on effects (i.e. outside F-gas industry) in terms of value added • Knock-on effects in terms of employment • Trade and investment flows (e.g. imports and/or exports effects) • Competitiveness (sectoral) of businesses (e.g. effects on the market share and comparative advantages in an international context) • Position of SMEs (e.g. burden on small firms and impacts on their financial sustainability, etc.)

[22] Ibid footnote 12.

Impact category	Impact Sub-categories
	• Functioning of the internal market and competition (e.g. impacts on the free movement of goods) • Macroeconomic environment (e.g. consequences on economic growth and employment) • Third countries and international (e.g. effects on EU foreign policy)

This mapping is based on the development of impact pathways from the proposed restriction of the F-gases in scope. The pathways highlighted how pertinent stakeholders may be affected: enterprises (F-gas producers/ importers and downstream user manufacturers), workers, consumers, EEA citizens, public authorities and third countries.

Following this mapping, a screening exercise was conducted to identify the most significant impact categories for a more in-depth assessment. This exercise focussed on the categories of most relevance for F-gas manufacturers or on manufacturers of downstream user applications, and considered the following:

- The likelihood or uncertainty of an impact materialising
- Its relation to the proposed restriction on F-gases (i.e. whether it is a direct and/or an indirect impact from the restriction of the F-gases in scope)
- The magnitude of the potential impact and whether the impact is more or less significant for certain business stakeholders (i.e. SME vs large firms, different downstream using sectors, etc.)
- The relevance of the impact in meeting the EU's ambitions and commitments (i.e. whether the proposed restriction and its impacts are aligned or not with the underlying objectives and the particular context of the F-gas Regulation).

For this screening exercise, evidence was collected through secondary research and rapid literature review of published reports and papers, input from EFCTC members in discussions prior to the launch of the consultation surveys, and the knowledge and expertise of the project team.

As a result, six 'primary' sub-categories of economic impact were shortlisted as likely to be significant for a more in-depth quantitative assessment. Three additional 'secondary' sub-categories were considered for qualitative exploration and, where possible, quantitative assessment, depending on the evidence available and/or collected via consultation. The relevance of the shortlisted key business impacts is mapped against the indicators selected for assessment below.

Table 2-3 Shortlist of the economic impacts for more in-depth assessment, and how these are linked to the indicators selected for the quantitative assessment. Developed by Ricardo for the EFCTC.

Priority	Key Impact sub-categories	Indicators selected as proxies for these key impact sub-categories
Primary impacts	• Operating costs and conduct of business (e.g. substantive compliance costs) • Administrative burdens on businesses (e.g. costs associated with notification obligations or other administrative activities) • Position of SMEs (e.g. burden on small firms and impacts on their financial sustainability, etc.) • Innovation and research (e.g. stimulation or hindrance of investment in chemical and/or non-fluorinated alternatives, etc.) • Employment (e.g. number of jobs created or lost within the sector)	• Sectoral output or production value or turnover (€ millions), where possible by business size (**Turnover**) • Sectoral Gross Value Added (€ millions), approximately capturing the sector's contribution to Gross Domestic Product) (**GVA**) • Gross investment (€ millions) (**CAPEX**) • Operating expenditure (€ millions) (**OPEX**) • Research and Development expenditure (€ millions) (**R&D**) • One-off or recurring regulatory costs (€ millions), where possible by business size (**Regulatory burden**) • Number of jobs supported by the sector (Number of jobs) (**Employment**)

Priority	Key Impact sub-categories	Indicators selected as proxies for these key impact sub-categories
	• Macroeconomic environment (e.g. consequences on economic growth and employment of the whole EEA)	
Secondary impacts	• Trade and investment flows (e.g. imports or exports effects) • Competitiveness (sectoral) of businesses (e.g. effects on the market share and comparative advantages in an international context) • Price and demand effects	• Exports (€ millions) to countries outside of the EEA (**Exports**) • Imports (€ millions) into the EEA (**Imports**) • These sub-categories were considered qualitatively and captured indirectly as part of the analysis of turnover and GVA (since exports contribute to the sectoral turnover and GVA in the EEA). • Reported pass-through capacity and demand elasticity were collected in consultation.

Although these impact categories are likely the most significant in the face of an F-gas restriction, the specific impacts across these categories would differ in nature, direction and scale.

Social and environmental impacts that may result from an F-gas restriction are assessed based on secondary research of academic literature and papers. Any second-order social and environmental impacts from a restriction of F-gases, and therefore, the indirect economic impacts driven by these (e.g. the subsequent impact of immediate health effects on productivity or the public and private health systems) were not in the scope of this assessment.

2.1.3.3 Data gathering

The assessment of impacts triangulates evidence from two complementary information gathering exercises:

- **Stakeholder consultation process**. Data (in particular on the economic profile of the industry) was obtained through both survey responses and focussed stakeholder interviews. This provided an understanding of F-gas production, import and downstream user markets. Qualitative information on environmental and human health impacts of alternatives according to stakeholders' views was used as supportive evidence to desk-based research on these types of impacts.
- **Data collection through online desk-based research**. This focused on reviewing relevant reports, academic literature and industry reports. This assessment was quantitative to the extent that data was available, and qualitative in the cases where relatively limited quantitative information was contained within the publicly available sources. When assessing business indicators this review provided an indication as to the current market of the F-gas industry and downstream user application sectors to the extent that information was available. For environmental and human health impacts, this was the main approach to gather evidence.

The stakeholder consultation process included two separate surveys, which were each live for a period of six weeks:

1) One survey specifically designed for ***producers and/or importers of F-gases***, i.e., those covered by the current F-gas Regulation and directly affected by the proposed restriction as manufacturers or importers of F-gases. Their current business volumes in euros and tonnes were assessed in the survey, as well as other economic metrics, including investment, operating costs, and employment. Assessing their expected strategic response to the proposed restriction of the F-gases in scope was a central part of the consultation. Finally, producers and importers of F-gases were also directly asked about their expectations of the scale of impacts of the proposed F-gas restriction on their business and conduit of business.
2) One survey specifically designed for ***downstream users of F-gases*** in their various applications. Their current business volumes in euros were assessed in the survey, as well other economic metrics, including investment, operating costs, and employment. Similarly, to the survey of producers and importers, their expected strategic response to the proposed restriction of the F-gases in scope was a

central part of the consultation, and they were also directly asked about their expectations of the scale of impacts of the proposed F-gas restriction on their business and conduit of business. The key applications (i.e. end uses for F-gases in scope) were determined based upon discussion with EFCTC and an expert understanding of the market. See Sections 2.2.2.3.2 - 2.2.2.4 for a detailed characterisation of downstream using sectors.

To assess the quantitative effects (where possible) of the proposed restriction, a model was built in order to define and project various parameters depicting the F-gas industry going forward, both under the baseline and 'with restriction' scenarios. The information collected via the surveys constituted a key input to the model. Data from different questions was triangulated to elicit the potential business impacts of the proposed restriction, and directly reported expectations were combined with economic theory (e.g., concepts of supply and demand, demand elasticity, relationships between production and different types of costs, input-output models, etc.) to model direct business impacts, impacts along the value chain, and wider economic impacts on the overall EEA economy. 2019 is taken as the reference year to avoid using 2020, which is not considered a representative year due to the effects of the pandemic, and 2021 being too recent to obtain official figures at the time of this study.

Additional and complementary historical data from public sources was used to independently assess the baseline scenario for the businesses of producers/importers and downstream users, as well as any other business variables to the extent that the quality of the data allowed. Specifically, two key sources of evidence were the European Environment Agency (EEA)[23] F-gas reports, and the Structural Business Statistics[24] from Eurostat.

In order to assess the historical trends in the F-gas market, a number of datasets, reports, and academic literature were reviewed. The initial review of key datasets, such as Eurostat and EEA reports, demonstrated the challenge in obtaining useful information on specific F-gas production. In order to understand the current and historical state of the F-gas market, the literature review has therefore focussed on assessing the economic trends of the applications in which the F-gases are used.

2.2 DEFINITION OF THE "BASELINE" SCENARIO

2.2.1 Background and policy context

2.2.1.1 PFAS

PFAS have been used in industrial, professional and consumer products since the 1940s. Their unique and desirable physical and chemical properties mean they are used in a wide variety of applications. For instance, they are stable under intense heat, many have surfactant properties, and some can be used as refrigerants. Some of the major industry sectors using PFAS include: aerospace and defence, textiles, electronics, firefighting, medical articles, and refrigeration.

Before the RoI was placed to restrict all PFAS, common definitions of PFAS did not include all F-gases. Note the following, as an illustration[25]:

Definition
PFAS are per- and polyfluoroalkyl substances. A 2020 Commission Staff Working Document[26] defines PFAS as man-made organic substances containing alkyl groups in which many/all of the hydrogen atoms have been substituted by fluorine atoms. The group is inclusive of short and long chain substances as well as polymers.

The definition of PFAS has continued to evolve over time. In the first widely accepted definition, Buck et al. defined PFAS as "highly fluorinated aliphatic substances that contain 1 or more C atoms on which all the H substituents (present in the nonfluorinated analogues from which they are notionally derived) have been

[23] EEA, 2020. Fluorinated Greenhouse Gases 2020. Accessible under: https://www.eea.europa.eu/data-and-maps/data/fluorinated-greenhouse-gases-aggregated-data-2, and EEA, 2021. Fluorinated Greenhouse Gases 2021. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021

[24] Eurostat (2022), *Structural Business Statistics Database*. [online] Eurostat Available from: Database - Structural business statistics - Eurostat (europa.eu)

[25] The highlighted definition does include HFC-134a, but not other F-gases in scope of this study.

[26] European Commission, (2020). COMMISSION STAFF WORKING DOCUMENT Poly- and perfluoroalkyl substances (PFAS). Available from: SWD_PFAS.pdf (europa.eu)

replaced by F atoms, in such a manner that they contain the perfluoroalkyl moiety CnF2nþ1–."[27] According to the 2018 definition of PFAS by the OECD/UNEP Global PFC Group (i.e. they contain at least one perfluoroalkyl moiety)[28], around 4,700 substances were identified. The intention with this revision was to obtain a simple definition of PFAS based on their chemical structure. However, considering the most recent definition of PFAS[29], also referred to in the Registry of Intention of the PFAS restriction, several additional substances would meet this definition. Therefore, PFAS is a very large group of substances where F-gases represent a specific sub-group with very different physical and chemical properties compared to other PFAS, as shown by the discrepancies between definitions of PFAS over time. It should be noted that the OECD highlighted that "the decision to broaden the definition compared to Buck et al. is not connected to decisions on how PFAS should be grouped in regulatory and voluntary actions"[30], even though the universal ban on PFAS would mean the adoption of this route (i.e., taking a broad definition as the basis for regulatory action).

Certain PFAS are extremely persistent in the environment and can be harmful to human and environmental health. The continued production and use of a subset of PFAS (not including HFCs and H(C)FOs) has been shown to have resulted in severe contamination of soil, water and food, resulting in potentially harmful levels of exposure for humans, animals, and the environment generally. Epidemiological studies exploring the effects of exposure to human health have revealed associations between exposure to specific PFAS, such as perfluorooctane sulfonate and perfluorooctanoic acid, and a variety of health effects, including altered immune and thyroid function, liver disease, lipid and insulin dysregulation, kidney disease, adverse reproductive and developmental outcomes, and cancer[31]. These health effects predominantly impact the areas local to emission sites, but PFAS are widely used and some have been shown to persist in the environment. This has led to their detection globally, meaning the harmful effects of certain PFAS are a global risk to human health and the environment[32]. Some PFAS are also known to bioaccumulate which increases the risks of the substances to humans, animals and ecosystems as a whole[33].

Many of the detrimental health effects have been linked to a select number of PFAS compounds. The environmental and human health impacts of the F-gases in the scope of the proposed PFAS restriction are explored further in Sections 3.2 and 3.3. The most serious human or environmental risks identified to date are associated with other substances, with which F-gases are grouped under the broad PFAS definition.

Over the past decades, global manufacturers have started to substitute some harmful PFAS with alternative substances, driven by the increasing recognition of PFAS' potential harmful effects on human health and the environment. In this context, the European Commission (EC) has outlined actions intended to address both the use of PFAS and the contamination they cause in the environment[34]. To prevent further contamination, the actions aim to ensure the use of PFAS is phased out in the EU, unless their use is proven essential for society.

2.2.1.2 F-gases and Regulation affecting the F-gas market

F-gases are man-made substances used in numerous industrial, commercial or residential applications. F-gases include a broad range of chemical compounds, including but not limited to, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Many HFCs and PFCs fall under the European Commission's former definition of PFAS[35] as they are anthropogenic substances containing fluorinated alkyl groups. These F-gases are expected to be included in the proposed PFAS restriction under REACH (and hence are the subject of this SEA).

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[27] Buck. R, C., Franklin, T., Berger, U., Conder, J., Cousins, I., de Voogt, P., Astrup Jensen, A., Kannan, K., Mabury, S., van Leeuwen, S. (2011) Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification and origins. Available at: https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/ieam.258

[28] OECD, 2018. Toward a new comprehensive global database of per- and polyfluoroalkyl substances (pfass): summary report on updating the oecd 2007 list of per- and polyfluoroalkyl substances (pfass). ENV/JM/MONO(2018)7. Available at: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env-jm-mono(2018)7&doclanguage=en

[29] "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS." - OECD, 2021. Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. ENV/CBC/MONO(2021)25. Available at: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO(2021)25&docLanguage=En

[30] Ibid footnote 3

[31] Fenton SE, D. A. (2021). Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research. doi:10.1002/etc.4890. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/33017053/

[32] Aditi Podder et al. (2021) Per and poly-fluoroalkyl substances (PFAS) as a contaminant of emerging concern in surface water: A transboundary review of their occurrences and toxicity effects, Journal of Hazardous Materials, Volume 419, https://doi.org/10.1016/j.jhazmat.2021.126361

[33] Aditi Podder et al. (2021) Per and poly-fluoroalkyl substances (PFAS) as a contaminant of emerging concern in surface water: A transboundary review of their occurrences and toxicity effects, Journal of Hazardous Materials, Volume 419, https://doi.org/10.1016/j.jhazmat.2021.126361

[34] European Commission (2022). PFAS, Overview. Retrieved from: https://ec.europa.eu/environment/chemicals/pfas/index_en.htm

[35] Ibid footnote 26.

F-gases in the EEA are regulated under multiple pieces of legislation given their global warming potential (GWP) if emitted. GWPs of each of the F-gases in scope of this study are shown in the Table 2-4 below for reference. It is clear that H(C)FOs have the potential to play a fundamental role in the decarbonisation of the F-gas industry and downstream user applications, as they have similar technical properties to the HFCs but very low GWPs.

Table 2-4 GWP of the F-gases in scope. H(C)FOs are highlighted with an asterisk. Source: F-gas Regulation. Based on 100-year AR4 and AR6 IPCC values.

F-gases in scope	GWP (AR4)	GWP (AR6)
HFC-125	3,500	3740
HFC-134a	1,430	1530
HFC-143a	4,470	5810
HFC-227ea	3,220	3600
HFC-245fa	1,030	962
HFC-365mfc	794	914
HCFO-1233zd*	4.5	0.454
HFO-1234yf*	4	0.501
HFO-1234ze*	7	0.315
HFO-1336mzz(Z)*	9	2.08
*: H(C)FOs[36]		

Given some F-gases are potent greenhouse gases, and their emission has the potential to contribute to climate change, their manufacture, sale and use are governed by international protocols and EU legislation. The table below provides an overview of the current EU and international legislation of relevance.

Table 2-5 An overview of the current EU and international legislation of relevance. Developed by Ricardo for the EFCTC.

Jurisdiction	Legal text	Regulatory Implications
International	United Nations Framework Convention on Climate Change (UNFCCC) - The Kyoto Protocol[37]	Parties to the Protocol must achieve greenhouse gas emission reduction targets. Emission reporting is also required annually from the Parties.
	The Kigali Amendment to The Montreal Protocol on Substances that Deplete the Ozone Layer (The Montreal Protocol) [38]	The Montreal Protocol requires all parties to phase out various ozone depleting substances (ODS) and provide data on emissions and trade of ODS. The Kigali Amendment to the Protocol requires the Parties to phase down their use of hydrofluorocarbons (HFCs), which were widely introduced as an alternative to ODS.
	The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI Prevention of Air Pollution from Ships	IMO has used the Montreal Protocol as the base and developed Regulation 12 with main aim of phasing out the harmful ODS used by ships Other than hydrochloroflurocarbon (HCFC) all other ODS were banned in new ships from 19

[36] Also described as Hydro(Chloro)fluoroolefins or H(C)FOs
[37] The United Nations (1998) Kyoto Protocol To The United Nations Framework Convention On Climate Change. Available from: kpeng.pdf (unfccc.int)
[38] The United Nations, (1987), The Montreal Protocol on Substances that Deplete the Ozone Layer. Available from: Preamble | Ozone Secretariat (unep.org)

Jurisdiction	Legal text	Regulatory Implications
		May 2005 (Reg.12.3.1). HCFC were banned in new ships from 1 January 2020 (Reg.12.3.2) Supplement to IAPP Certificate - Maintain a list of equipment containing ODS (Reg.12.5) Ships are required to complete an ODS Record Book (Reg. 12.6) for rechargeable systems
EEA	Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action ("Monitoring Mechanism Regulation", MMR)[39] and Commission Implementing Regulation (EU) No 2020/1208 sets the requirements for national reporting under Regulation (EU) 2018/1999[40]	MMR sets out the mechanism for monitoring and reporting greenhouse gas emissions in Europe, which is implemented via Regulation No 2020/1208.
	Regulation (EC) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases[41]	The main mechanism through which the EU complies with the Kigali Amendment to the Montreal Protocol. The 'F-gas Regulation' includes several measures, most notably the phase-down and restrictions/prohibitions, which hand-in-hand seek to reduce the use of high-GWP F-gases. The Regulation also has measures concerning: leakage checks and control, technician certification, F-Gas reporting.
	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)[42]	Substances manufactured or imported into the EU in quantities of one tonne or more per year must be registered. The registration dossiers may also undergo evaluation which may require additional information.
	Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures (CLP)[43]	Requirement for substance self-classification and compliance with any associated labelling requirements.
	Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste[44]	Prohibits the export of wastes in Annex V (inc HFC and HCFC) which are destined for recovery in countries to which the OECD Decision (control of transboundary movements of wastes destined for recovery operations) does not apply.

[39] European Commission (2018) Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council ELI: http://data.europa.eu/eli/reg/2018/1999/2021-07-29

[40] European Commission (2020) OMMISSION IMPLEMENTING REGULATION (EU) 2020/1208 of 7 August 2020 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council and repealing Commission Implementing Regulation (EU) No 749/2014. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R1208

[41] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[42] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). ELI: http://data.europa.eu/eli/reg/2006/1907/oj

[43] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures. ELI: http://data.europa.eu/eli/reg/2008/1272/oj

[44] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006R1013

Jurisdiction	Legal text	Regulatory Implications
	Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles (MAC Directive)[45]	Since 2017 fluorinated greenhouse gases with GWP over 150 have been banned from new vehicles placed on the EU market.
	Directive 2001/95/EC of the European Parliament and of the Council on general product safety (The General Product Safety Directive)[46]	Businesses are responsible for ensuring the products placed on the EU market are safe and/or consumers are informed of the risks associated with the product.
	Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles[47]	Sets out the way in which waste from vehicles must be disposed, including air-conditioning system fluids.
	Directive 2012/18/EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances (The Seveso III Directive)[48]	Organisations which use or store substances identified in the Seveso Directive need to report to the relevant Member States on the safety measures implemented.
	Proposal[49] for a Directive of the European Parliament and of the Council on the protection of the environment through criminal law and replacing Directive 2008/99/EC[50]	Proposed criminalisation of the illegal production, placing on the market, import, export, use, emission, or release of fluorinated greenhouse gases (as defined by Article 2 (1) of Regulation 517/2014).

Production and consumption of F-gases, specifically HFCs, has increased considerably over the last 30 years as they have been widely used as substitutes for ozone depleting substances (ODS). The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) entered into force in 1989, which aimed to reduce the emission of ODS globally. The Montreal Protocol initially required the parties to phase out the use of ODS such as chlorofluorocarbons (CFCs). The Montreal Protocol has been effective in protecting the ozone layer and thus further amendments have been made to the Protocol to address additional atmospheric issues.

However, in response to the phase-out of ODS, many applications increased their use of F-gases with high GWP as a replacement. The Kigali Amendment was introduced to the Montreal Protocol in 2016, with the aim to phase down the use of HFCs due to their GWP, and it entered into force in 2019. HFCs often have a high GWP, some of them more than 1,000 times greater than carbon dioxide (CO_2). Increasingly, lower GWP F-gases such as hydrochlorofluoroolefins(H(C)FOs and other lower GWP products are being developed and used to replace higher GWP F-gases (in particular through the incentives and prohibitions put in place by the F-gas Regulation).

F-gas emissions have long been addressed by international conventions such as the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. As a party to the Kyoto Protocol, the EU must report on the status of the reduction commitments made under the UNFCCC and in relation to EU legislation on greenhouse gas (GHG) emission reductions. Regulation (EU) 2018/1999 on the Governance

[45] Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles and amending Council Directive 70/156/EEC. ELI: http://data.europa.eu/eli/dir/2006/40/oj

[46] Directive 2001/95/EC of the European Parliament and of the Council of 3 December 2001 on general product safety. ELI: http://data.europa.eu/eli/dir/2001/95/2010-01-01

[47] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELI: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32000L0053

[48] Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances. ELI: http://data.europa.eu/eli/dir/2012/18/oj

[49] Proposal for a Directive of the European Parliament and of the Council on the protection of the environment through criminal law and replacing Directive 2008/99/EC. Available from: https://ec.europa.eu/info/files/proposal-directive-european-parliament-and-council-protection-environment-through-criminal-law-and-replacing-directive-2008-99-ec_en

[50] Directive 2008/99/EC of the European Parliament and of the Council of 19 November 2008 on the protection of the environment through criminal law. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0099

of the Energy Union and Climate Action ("Monitoring Mechanism Regulation", MMR)[51] stipulates the overarching mechanism for monitoring and reporting greenhouse gas emissions. In more detail, Commission Implementing Regulation (EU) No 2020/1208 sets the requirements for national reporting under Regulation (EU) 2018/1999[52].

The EU was the first region in the world where dedicated legislation on F-gases was established. Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases[53] was the first piece of legislation to regulate F-gases exclusively, supplemented with nine Commission Implementing Regulations. The 2006 F-gas Regulation contained provisions related to: certification of technicians and companies dealing with F-gases, reporting on F-gases, leakage checking and recovery requirements for F-gas containing equipment, bans for placing on the market of certain products and equipment containing or relying on F-gases, as well as prohibitions of the use of certain F-Gases in specific applications.

Following the 2006 Regulation, Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 (ODS Regulation)[54] acknowledged the need to implement an accelerated phase out of hydrochlorofluorocarbons with due consideration to the risks of phasing in alternatives with high GWP, and set out plans to phase out production, trade and use of hydrochlorofluorocarbons.

In a similar spirit to the phase-out established by the ODS Regulation, the EU introduced Regulation (EC) No 517/2014 on the 16 April 2014 on fluorinated greenhouse gases (F-gas Regulation)[55]. A new measure under the updated F-gas Regulation obliged a phase down of hydrofluorocarbons for all applications. The phase-down established in the F-gas Regulation defines maximum potential CO_2-equivalent (CO_2-e) quantity of a subset of F-gases that can be placed on the market every year until 2030 (maximum quantities measured in CO_2-e are presented in Figure 2-1). This places a strong incentive to switch to F-gases with lower GWP and to non-HFC alternatives, like H(C)FOs. All the HFCs in scope of this study are subject to this phase-down, while the four H(C)FOs in scope of this study are not, and they remain as viable low GWP alternatives in this regulatory baseline. The introduction of a universal restriction on PFAS that includes all the F-gases in scope of this assessment would therefore also restrict many low GWP alternatives to HFCs. The F-gas Regulation is the main mechanism through which the EU's compliance with the Kigali Amendment to the Montreal Protocol, ratified by the EU, is delivered.

HFCs are addressed not only by the F-gas Regulation, but also by Directive 2006/40/EC relating to emissions from air conditioning systems in motor vehicles ("MAC Directive")[56], which banned the use of HFCs with a GWP > 150 in new passenger cars since 2017.

[51] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council (Text with EEA relevance.). Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R1999

[52] Commission Implementing Regulation (EU) 2020/1208 of 7 August 2020 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council and repealing Commission Implementing Regulation (EU) No 749/2014 (Text with EEA relevance). Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R1208

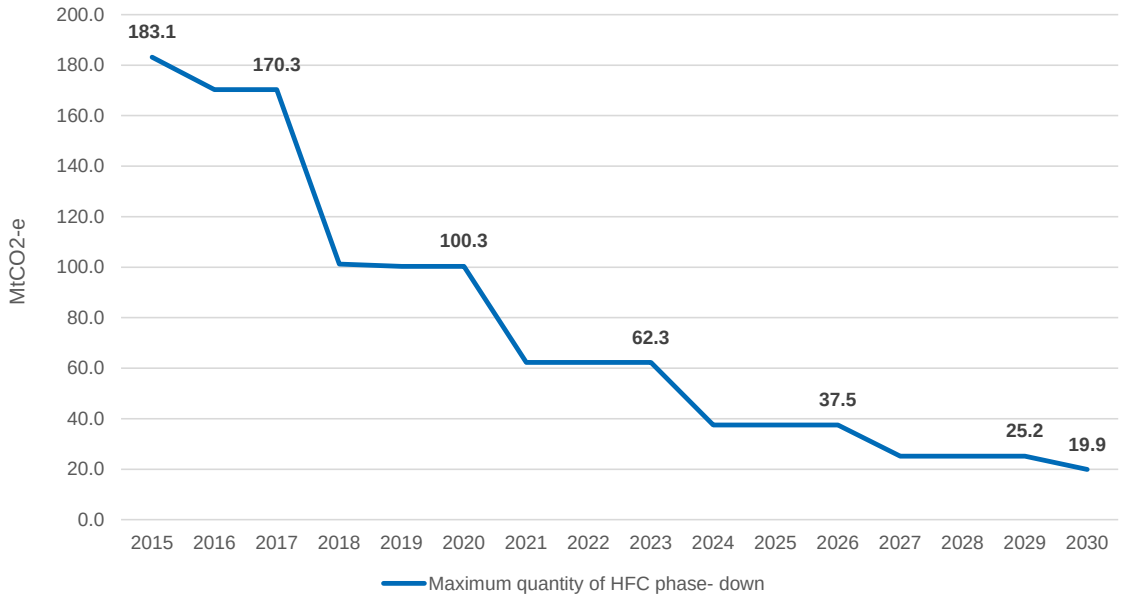
[53] Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases (Text with EEA relevance). Accessible under: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32006R0842

[54] Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 on substances that deplete the ozone layer (Text with EEA relevance). Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009R1005

[55] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[56] Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles and amending Council Directive 70/156/EEC (Text with EEA relevance). Accessible under: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006L0040

Figure 2-1 Maximum quantity of HFCs placed on the market (POM) established by the F-gas Regulation, EU-27. Source: (EEA, 2021)[57]. Changes from year to year are produced in full, from the 31st December of the year ending to the 1st January of the new year.



Notes: The geographical scope of presented POM data is the EU-28 for the period 2015-2019 and EU-27 and UK for 2020. The EEA provides recalculated EU-27 maximum quantities for 2021 onwards to reflect the effects of Brexit.

The F-gas Regulation contains several other measures governing the F-gas market. The EU also regulates, to an extent, how F-gas containing products should be treated at end-of-life. The F-gas Regulation, for example, requires recyclers of refrigeration equipment to ensure the F-gases contained in equipment do not escape into the atmosphere, and this is further underpinned by the requirements of Directive 2012/19/EU on waste electrical and electronic equipment (WEEE Directive)[58].

The EU has recently conducted an evaluation of the existing F-gas Regulation (EU No 517/2014)[59]. This evaluation found it has been mostly effective and has achieved low-cost emissions abatement, with a reported reduction in emissions as shown in Figure 2-6. That said, since the 2014 F-gas Regulation was adopted, there have been developments at the international level which mean the existing Regulation is no longer fully fit for purpose. In addition, the F-gas Regulation has not successfully addressed some high emitting sectors, such as crucial medical applications linked with high emissions, and the illegal trade of F-gases has been a prevalent issue over the implementation period. In that context, the European Commission has recently published a proposal[60] to amend legislation on F-Gases (Directive (EU) 2019/1937 of the European Parliament and of the Council of 23 October 2019[61] and the F-gas Regulation[62]). The proposed changes aim to achieve additional F-gas emission reductions in line with the Montreal Protocol and the Paris Agreement on Climate Change[63], enhance implementation and enforcement, improve monitoring and reporting, and improve clarity and internal coherence regarding understanding of requirements. Additional proposals to prevent end-of-life emissions from other applications are also suggested under the ongoing revisions of the F-gas and ODS Regulations, most notably for CFCs and F-gases in foam insulation panels.

Pathways to limit global warming at 1.5 °C include requiring emission decreases for F-gases of up to 90% by 2050 globally compared to the year 2015. As a result, the quota system for hydrofluorocarbons (HFC phase-down) is expected to be tightened in comparison with the 2014 F-gas Regulation (HFCs would be severely

[57] EEA, 2021. Fluorinated Greenhouse Gases 2021. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021.

[58] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019

[59] Öko-Recherche, 2022. Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases, CLIMA.A2/ETU/2019/0016, Evaluation Final Report. European Commission: DG Clima. Available from: https://ec.europa.eu/clima/system/files/2022-04/f-gas_evaluation_report_en.pdf.

[60] European Commission 2022. Proposal of a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Accessible under: https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF

[61] Directive (EU) 2019/1937 of the European Parliament and of the Council of 23 October 2019 on the protection of persons who report breaches of Union law. Accessible under: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32019L1937

[62] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[63] United Nations, (2015) Paris Agreement. Available from : https://unfccc.int/sites/default/files/english_paris_agreement.pdf

restricted, up to 2.4% of 2015 levels in 2050[64]). In our baseline scenario, however, and due to uncertainty over the final change to the Regulation and whether the current 2030 targets would change, only the current F-gas Regulation is considered for comparisons.

The proposal also updates other obligations for companies, such as best practices, leak checks, record keeping, training of workers and appropriate waste treatment. Licensing and labelling obligations are also reinforced as a measure to enforce trade restrictions, as well as existing monitoring and verification systems to ensure compliance and setting penalties for illegal trade of F-gases. The new proposal also focusses on preventing ODS emissions from formerly legal applications in products and equipment, making it mandatory to recover or destroy ODS from some insulation foams during renovation and demolition of buildings[65]. Both training and emissions prevention measures also extend to H(C)FOs.

2.2.1.3 Broader chemicals legislation acquis

Depending on the use, the respective manufacturing/import tonnage, or the associated hazards of the substance, certain F-gases may be required to comply with various pieces of EU Chemicals Legislation. As listed in Table 2-5 the manufacturers, importers, and distributors of F-gases will be required to comply with REACH Regulation, the CLP Regulation, the MAC Directive, the General Product Safety Directive and the Seveso III Directive. The requirements under each are covered below.

Regulation (EC) No 1907/2006 - The Registration, Evaluation, Authorisation and Restriction of Chemicals

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH Regulation) is comprised of 4 main components, Registration, Evaluation, Authorisation and Restriction.

a) Registration

F-gases, either manufactured or imported into the EU, in quantities of one tonne of more per year must be registered under REACH. This entails compiling and submitting a registration dossier to ECHA. It is stated in the legislation that the registration dossier should include the following details:

- Information on the manufacturer or importer;
- Information on the intrinsic properties of the substance; Substance identity;
- Classification and labelling of the substance; Details on the intended uses of the substance;
- The manufactured or imported tonnage range for the substance per year[66].

A fee according to Commission Regulation (EC) 340/2008 of 16 April 2008 on the fees and charges payable to the European Chemicals Agency[67] should accompany the dossier submission. The fees payable to ECHA depend on the tonnage band of the registration and can vary if the registrant is a small or medium-sized enterprise (SME).

b) Evaluation

REACH evaluation is two-fold:

- Dossier evaluation
  - Compliance check evaluations (CCH) – Conducted by ECHA.

    Compliance with the standard information requirements under REACH are reviewed and further information may be required from the registrant. These checks can be expected across all registered substances, ECHA is currently aiming to have all registration dossiers for substances in the tonnage bands over 100 tonnes per year (submitted before the 2018 deadline) checked for compliance by 2023 with the remaining registrations (submitted before the 2018 deadline) checked by 2027.

[64] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_2190

[65] Ibid.

[66] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). ELI: http://data.europa.eu/eli/reg/2006/1907/oj

[67] Commission Regulation (EC) No 340/2008 of 16 April 2008 on the fees and charges payable to the European Chemicals Agency pursuant to Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) ELI: http://data.europa.eu/eli/reg/2008/340/2021-06-21

- The examination of testing proposals- Conducted by ECHA.

  ECHA is required to review the testing proposal for studies on vertebrate animals if listed in Annexes IX and X of REACH to ensure the tests are necessary for the information requirements.

- Substance Evaluation – Conducted by Member States.

  This is required when a specific substance has been listed in the Community rolling action plan (CoRAP)[68], the risks posed by the substance to human health or the environment are assessed and further information may be required.

Table 2-6 The registration and evaluation status of the F-gases in scope of this assessment, as of April 2022. Source: ECHA[69].

Trade Name	CAS Number	REACH Registration	Evaluation Status
HFC- 125	354-33-6	Joint Submission ≥ 10,000 to < 100,000 tonnes	Concluded Compliance Check Evaluation (CCH) - Comprehensive
HFC-134a	811-97-2	Joint Submission ≥ 10,000 to < 100,000 tonnes	Concluded Compliance Check Evaluation (CCH) – Targeted
HFC-143a	420-46-2	Joint Submission ≥ 1,000 to < 10,000 tonnes	Concluded Compliance Check Evaluation (CCH) – Targeted and Comprehensive
HFC-227ea	431-89-0	Joint Submission ≥ 1,000 to < 10,000 tonnes	Concluded Compliance Check Evaluation (CCH) - Comprehensive
HFC-245fa	460-73-1	Joint Submission ≥ 100 tonnes	No evaluation
HFC-365mfc	406-58-6	Individual Submission Tonnage data confidential	No evaluation
HFO-1234yf	754-12-1	Joint Submission ≥ 1,000 to < 10,000 tonnes	Concluded Compliance Check Evaluation (CCH) – Targeted
HFO-1234ze	1645-83-6	Joint Submission ≥ 1,000 to < 10,000 tonnes	Concluded Compliance Check Evaluation (CCH) – Targeted
HFO-1336mzz(Z)	692-49-9	Joint Submission ≥ 100 to < 1,000 tonnes	No evaluation
HCFO-1233zd	102687-65-0 2730-43-0	Joint Submission ≥ 1,000 to < 10,000 tonnes	No evaluation

c) Authorisation and Restriction

[68] Community rolling action plan (CoRAP) lists substances for priority evaluation, these substances will be evaluated over three years. The substances are prioritised due to hazard concerns. For more information: https://www.echa.europa.eu/regulations/reach/evaluation/substance-evaluation/community-rolling-action-plan

[69] Data sourced from PACT - Public Activities Coordination Tool - ECHA (europa.eu) in April 2022.

REACH also includes the authorisation and restriction of substances; currently F-gases are not listed in REACH Annex XIV (Authorisation) nor Annex XVII (Restriction).

Regulation (EC) No 1272/2008 - on Classification, Labelling and Packaging of Substances and Mixtures

All manufacturers, importers, and downstream users in the EU must comply with Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging of Substances and Mixtures (CLP Regulation)[70] unless exempt under Article 1(2).

a) Classification

Manufacturers, importers, and downstream users are required to 'self-classify' their substances under the CLP Regulation. Self-classification is required when a substance, which has hazardous properties, is not listed under Annex VI of the CLP Regulation with a harmonised classification or if an additional hazardous property is identified, not covered by the harmonised classification. The classifications may include exposure considerations however an exposure assessment is not required for classification, the hazardous properties of the substance are the deciding factor in classification. The self-classifications resulting from the application of Titles I and II of the CLP Regulation should be included in REACH registration dossiers. Manufacturers, importers, and downstream users are responsible for keeping their notifications up-to-date according to scientific advances in testing and new information on their substances. Below is a table listing the hazard classifications for the F-gases in scope of this assessment.

Table 2-7 The harmonised and self-classified hazard codes of the F-Gases in scope of this assessment. The codes are explained in Table 2-8. Source: REACH and CLI[71].

Trade Name	CAS Number	Harmonised C&L	REACH registered classifications
HFC- 125	354-33-6		H280
HFC-134a	811-97-2		H280
HFC-143a	420-46-2		H221, H280
HFC-227ea	431-89-0		H280
HFC-245fa	460-73-1		H280
HFC-365mfc	406-58-6	H225	H225
HFO-1234yf	754-12-1		H221, H280
HFO-1234ze	1645-83-6		H280
HFO-1336mzz(Z)	692-49-9		Not classified
HCFO-1233zd	102687-65-0 2730-43-0		H280, H412

Table 2-8 The classification hazard statement codes and their associated hazard statements[72].

Hazard statement code	Hazard statement
H221	Flammable gas
H225	Highly Flammable liquid and vapor
H280	Contains gas under pressure; may explode if heated

[70] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures. ELI: http://data.europa.eu/eli/reg/2008/1272/oj

[71] Data sourced from the C&L Inventory - ECHA (europa.eu) in April 2022.

[72] Annex III, Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures. ELI: http://data.europa.eu/eli/reg/2008/1272/oj

Hazard statement code	Hazard statement
H412	Harmful to aquatic life with long lasting effects

The majority (eight out of ten) of the F-gases of focus in this report have REACH registered classifications for H280-Contains gas under pressure; may explode if heated. Three of the F-gases are flammable to varying levels of severity (H221, H225) and one is classified as harmful to aquatic life with long lasting effects (H412).

b) Labelling

The identified hazardous properties of a substance must be communicated according to the labelling and packaging requirements under the CLP Regulation. The following information must be included on the product label if the product includes substances with identified hazards:

- The identity and contact information of the supplier;
- the nominal quantity of the substance or mixture in packages made available to the general public;
- the identity of the hazardous substance;
- the relevant hazard pictograms and statements, signal words, precautionary statements and any additional information as dictated by complementary legislation[73].

There are also strict packaging requirements to ensure safe containment and transport of substances. The packaging of hazardous substances must be strong, resistant to damage and possible to open and reseal without the substance escaping. Additional requirements under CLP restrict the packaging design to prevent attracting children to the hazardous product. All of the F-gases here have identified hazard classifications listed in the C&L Inventory, this mean all of these substances are subject to the Labelling and packaging requirements mentioned.

Directive 2001/95/EC - on general product safety

Producers are responsible for ensuring the products they place on the EU market are safe, or that consumers are informed of the risks associated with the product, this applies to any F-gas products placed on the EU market.

Directive 2012/18/EU -on the control of major-accident hazards involving dangerous substances

In addition to REACH and CLP requirements, certain F-gases meet the conditions of Annex I of the Seveso Directive III, e.g. HFC-365mfc (CAS 406-58-6) falls into the categories P5a/P5b/P5c of Part 1 of Annex I due to the hazard classification flammable liquid category 2 (H225)[74]. This requires the organisations responsible for industrial processes involving HFC-365mfc (CAS 406-58-6) or the storage of large quantities of the substance to submit information to the relevant Member State Competent Authorities (MSCA). Information must be provided on the locations where the substance is stored and used, the internal emergency plans, safety reports, accident prevention policies and additional information on actions in case of accidents.[75] All these requirements aim to reduce the risk and severity of large-scale chemical accidents and minimise human health and environmental impacts if they do occur.

Proposal for a Directive of the European Parliament and of the Council on the protection of the environment through criminal law and replacing Directive 2008/99/EC

Part of the wider package of initiatives under the European Green Deal. The proposal aims to improve how Member States address the most serious environmental offences by amended Directive 2008/99/EC. Directive 2008/99/EC provides minimum rules to criminalise environmental crime. However, offences related to the illegal production, placing on the market, import, export, use, emission or release of fluorinated greenhouse gases are not yet covered by this Directive and are thus proposed to be included.

[73] Labelling and packaging - ECHA (europa.eu)

[74] ECHA (no date) Summary of Classification and Labelling. Available: https://www.echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database/-/discli/details/1362

[75] Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances. ELI: http://data.europa.eu/eli/dir/2012/18/oj

2.2.2 Current status and projected future of the F-gas market in the EEA

The main economic statistics for the EEA F-gas sector and downstream user sectors, presenting the picture of their current business context and trends, are presented in this Section. Baseline projections are presented for selected business indicators, and constitutes the baseline scenario for the analysis of economic impacts of the F-gas industry and its downstream users in Section 3.1. Differences between large businesses and SMEs are considered where possible and applicable, and any divergence from the defined scope is clarified accordingly.

2.2.2.1 F-gas sector and market context

Editorial note

Public data on F-gases within the geographical scope of this assessment is only available at the level of the EU-28 (EU-27 + UK in 2020, we will use EU-28 for short). Data is presented for the EU-28, and additional data at the level of the EEA will be shown for comparison. Overall, differences between an EU-28 scope and an EEA scope (i.e., the scope of the proposed restriction) are minimal.

The total supply of ***all*** F-gases[76] (i.e. not just those in the scope of the restriction proposal) in the EU-28 was 78.8 thousand tonnes in 2020[77]. Over the last five years, this supply has decreased at an average rate of 4% per annum, or by 19% in cumulative terms. According to the EEA's '2021 Fluorinated Greenhouse Gases'[78] report, the volume of F-gases placed on the market in the EU has decreased by a cumulative 22% between 2015 and 2020, following the F-gas Regulation entry into force on 1 January 2015, and in spite of a slight increase in 2020 after continuously decreasing until 2019. According to the report, the 2020 increase has been mostly due to a higher supply of HFCs, but HFCs placed on the market still remained 4% below the market limit set by the F-gas Regulation.

The supply of F-gases is mostly imported from outside of the EU, with only 21.8% of supply (in tonnes) in 2020 produced within the EU. EU production of F-gases has been steadily decreasing during the last decade. 74.5% of the 2020 supply is net imports of F-gases (i.e., imports minus exports), while the remaining 3.6% corresponds to reclamation and destruction of F-gases. Figure 2-2 below shows the historic evolution of these series[79].

This distribution is consistent with findings from the survey of F-gas producers and importers that was conducted for this study. Figure 2-3 shows the distribution between own production, imports, and activities of recovery, reclamation and destruction of F-gases of those who participated in the survey. Differences with the distribution shown in Figure 2-2 come from the fact that the latter shows net imports, that is, discounting exports, and from a margin of error arising from the fact that information in the survey was provided in ranges.

[76] See A2 LIST OF F-GASES of the Appendix for full list.

[77] EEA, 2020. Fluorinated Greenhouse Gases 2020. Accessible under: https://www.eea.europa.eu/data-and-maps/data/fluorinated-greenhouse-gases-aggregated-data-2, and EEA, 2021. Fluorinated Greenhouse Gases 2021. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021.

[78] Ibid footnote 77.

[79] Ibid footnote 77.

Figure 2-2 Total supply of all F-gases in the EU-28 and composition by origin between 2007 and 2020, '000 tonnes. Source: (EEA, 2021)[80].

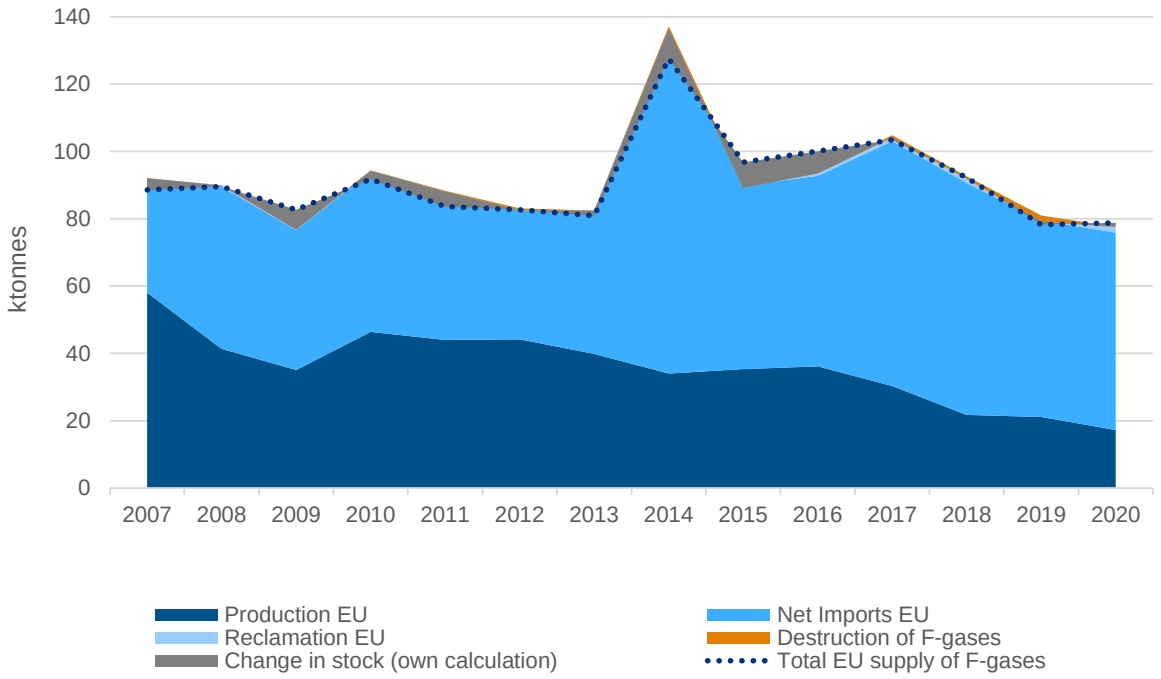
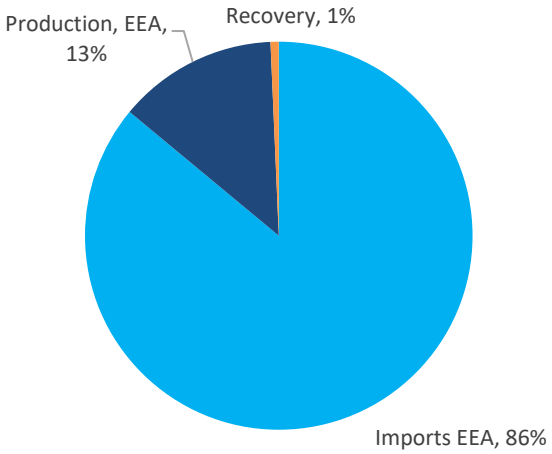


Figure 2-3 Total supply of F-gases in the EEA and composition by origin in 2019[81], split of quantities in tonnes. Source: bespoke survey to F-gas producers and importers.



When measured in terms of tCO_2-e, the supply of F-gases in the EU-28 has reduced by 41% from base year 2015 to 2020, as shown in Figure 2-4. The variance to the trend in quantities placed on the market is explained by the different GWP of the supplied F-gases.

[80] Ibid footnote 77.

[81] It is acknowledged that recovery includes the activities of reclamation, recycling and destruction, of which the latter would not be a part of the supply of F-gases in a given year. However, it was not possible to separate between those recovery actions in our survey. Hence, the 1% F-gas recovery represents a possibly overestimated contribution to the total supply in 2019.

Figure 2-4 Total EU-28 supply of F-gases by intended application of use (as defined in terms of tCO_2-e). Source: EEA.

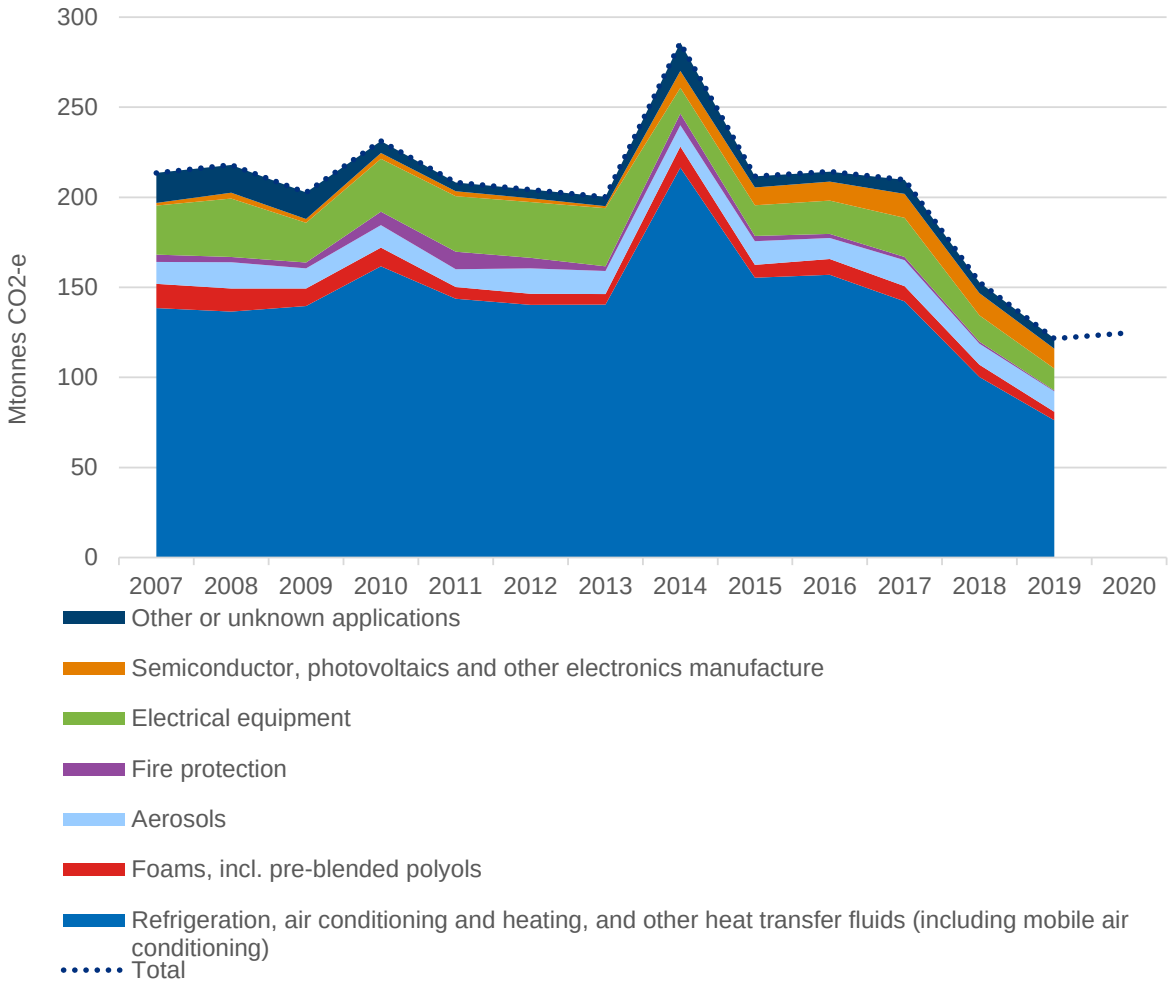
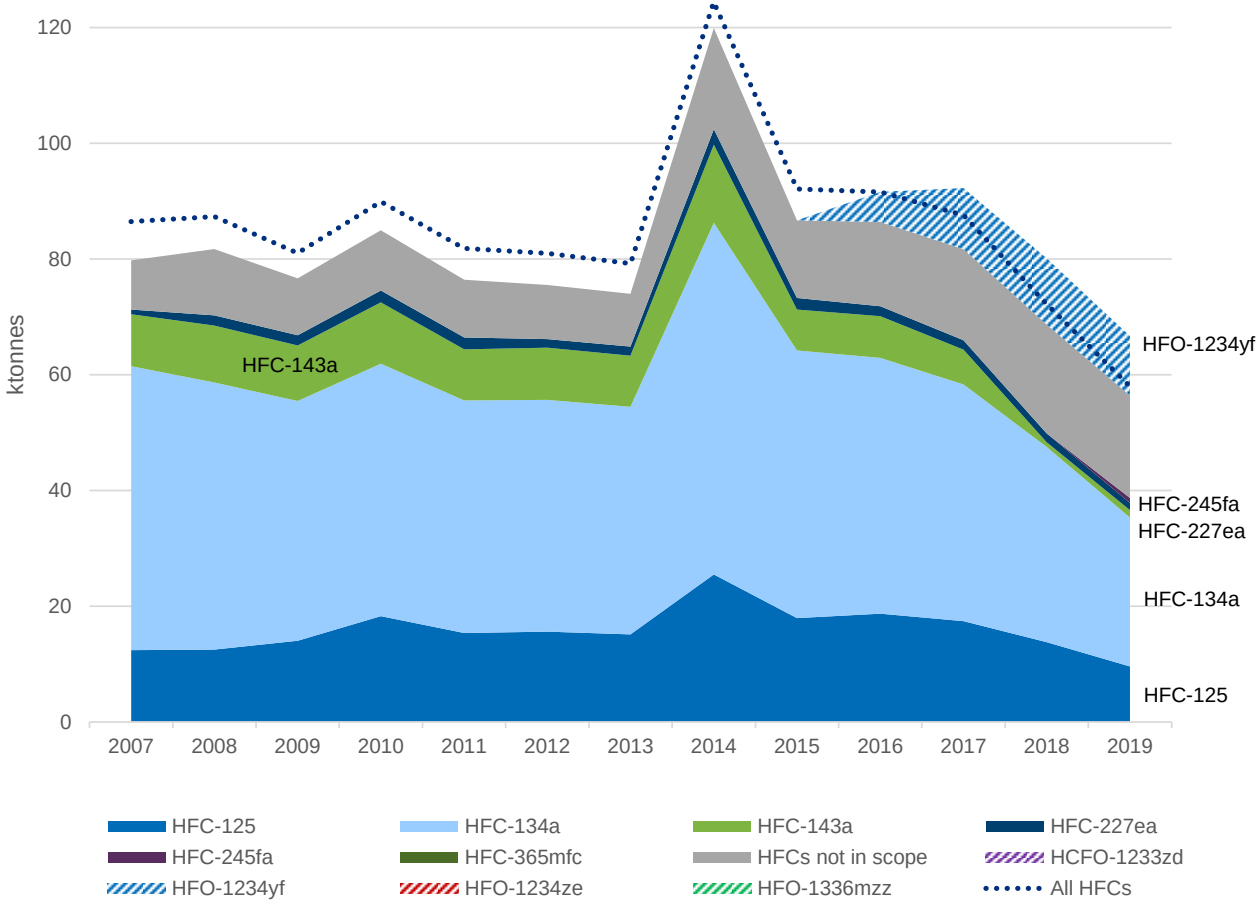


Figure 2-5 below shows the historic evolution of the supply of HFCs specifically in the EU-28. Hence this chart excludes trends for some F-gases in the scope of the proposed restriction, namely HFC-365mfc, HCFO-1233zd, HFO-1234ze and HFO-1336mzz(Z). Furthermore, the dotted line representing 'All HFCs' does not include H(C)FOs which would fall in the scope of the proposed restriction and this study. Following the definitions set in the F-gas Regulation, H(C)FOs are not HFCs, and are therefore not subject to the phase-down on F-gases. This group is differentiated from HFCs in the graph by a distinct striped pattern.

Information on some of the F-gases in scope is censored in the published statistics due to confidentiality reasons (i.e., the whole series for HFC-365mfc and 2007-2018 of HFC-245fa), as a very limited number of producers or importers work with those, and confidential data could be identified. This is also the case for all H(C)FOs except for HFO-1234yf, which are therefore not possible to be shown in the graph below. The blank area between the dotted line for 'All HFCs' and the top of the grey area for 'HFCs not in scope' will therefore be the sum of all HFCs, whether in scope or not scope of the proposed restriction, for which individual data was censored from publication. Those are therefore only possible to observe jointly as the difference between the total and the HFCs for which there is public data. In 2019, there were two F-gases not in scope of this study with censored information, and in other years of the historic series, no more than two F-gases beyond the scope of this study are censored from publication for any given year.

The reduction in HFCs since 2015 has been steeper than overall reductions in F-gas supply, with a cumulative reduction of 35% between 2015 and 2020 in terms of tonnes, indicating the possibility that in some applications, a high-GWP HFC has been substituted by lower GWP HFCs and H(C)FOs (i.e., F-gases not subject to the phase down imposed by the F-gas Regulation). However, HFCs still make up the majority of all F-gases placed on the market. Of those (i.e., all F-gases placed on the market), three substances, all within the scope of this study, make up 58% of that supply: HFC-125, HFC-134a and HFO-1234yf.

Figure 2-5 EU-28 supply of HFCs and H(C)FOs, ktonnes. Breakdown by F-gases in scope of the study. Source: own elaboration with EEA data[82].



The most relevant HFCs that led to an overall decrease in emissions were HFC-143a and, to a lesser extent, HFC-134a (Figure 2-7). HFC-143a showed a reduction in emissions from 28 $MtCO_2$-e in 2014 to 18 $MtCO_2$-e in 2019, and HFC-134a from 40 $MtCO_2$-e to 34 Mt O_2-e. One of the main reasons for the reduction in HFC-134a is its replacement in new vehicles due to Directive 2006/40/EC[83]. In addition, the blend R404A[84] was replaced in refrigeration applications. The fact that HFC-125 did not show a comparable reduction in emissions (the decrease was 3 Mt CO_2-e from 2014 to 2019) is because many replacement blends for R404A, such as R448A, R449A and R452A contain significant quantities of HFC-125.

By targeting the quantities of HFCs placed on the market (and not H(C)FOs), the F-gas Regulation regulates towards increased use of low-GWP F-gases and as a result, to reduce overall GHG emissions. Emissions of all F-gases have also shown a declining trend since 2014 (expressed in $MtCO_2$-e), as presented in Figure 2-6, based on reported data under UNFCCC (National Inventory Report for EU27+UK). This reduction in emissions has mainly been driven by the placing on the market (POM) phase-down of HFCs in the EU.

[82] Ibid footnote 77.

[83] Directive 2006/40 of The European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC. Retrieved from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:161:0012:0018:EN:PDF

[84] 52 % HFC-143a, 44 % HFC-125 and 4 % HFC-134a

Figure 2-6 F-gas emissions in the EU27+UK by substance group. Source: (European Union, 2021)[85].

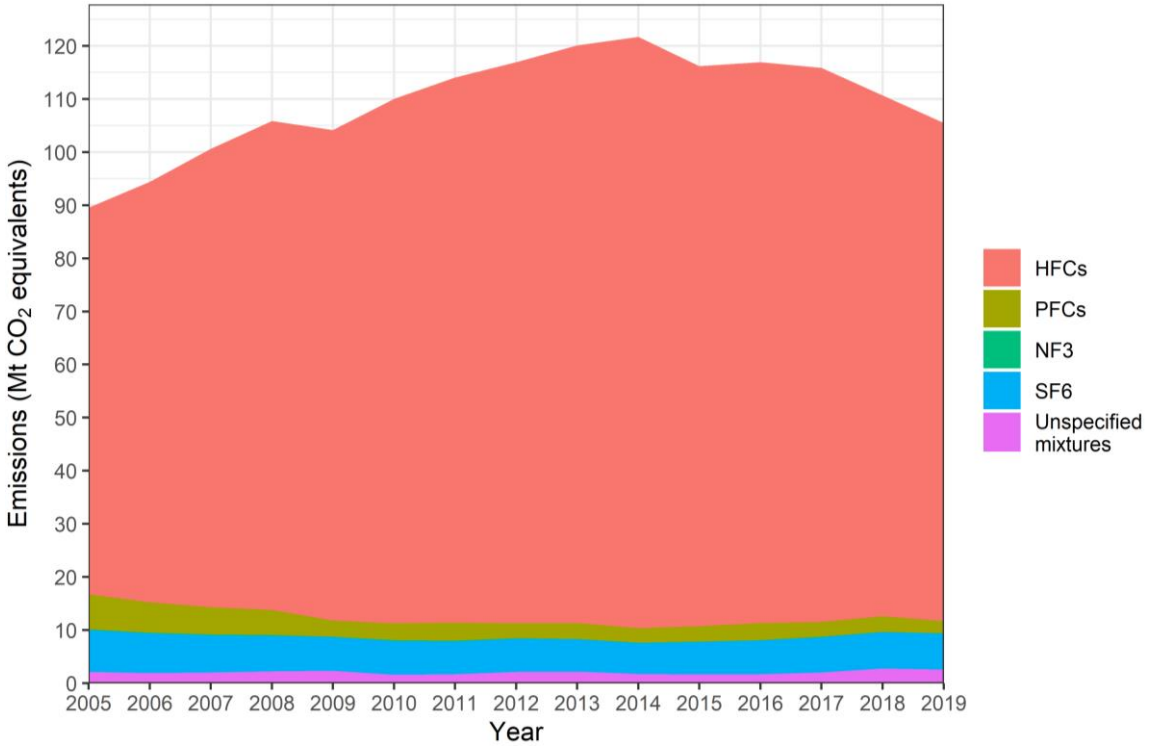
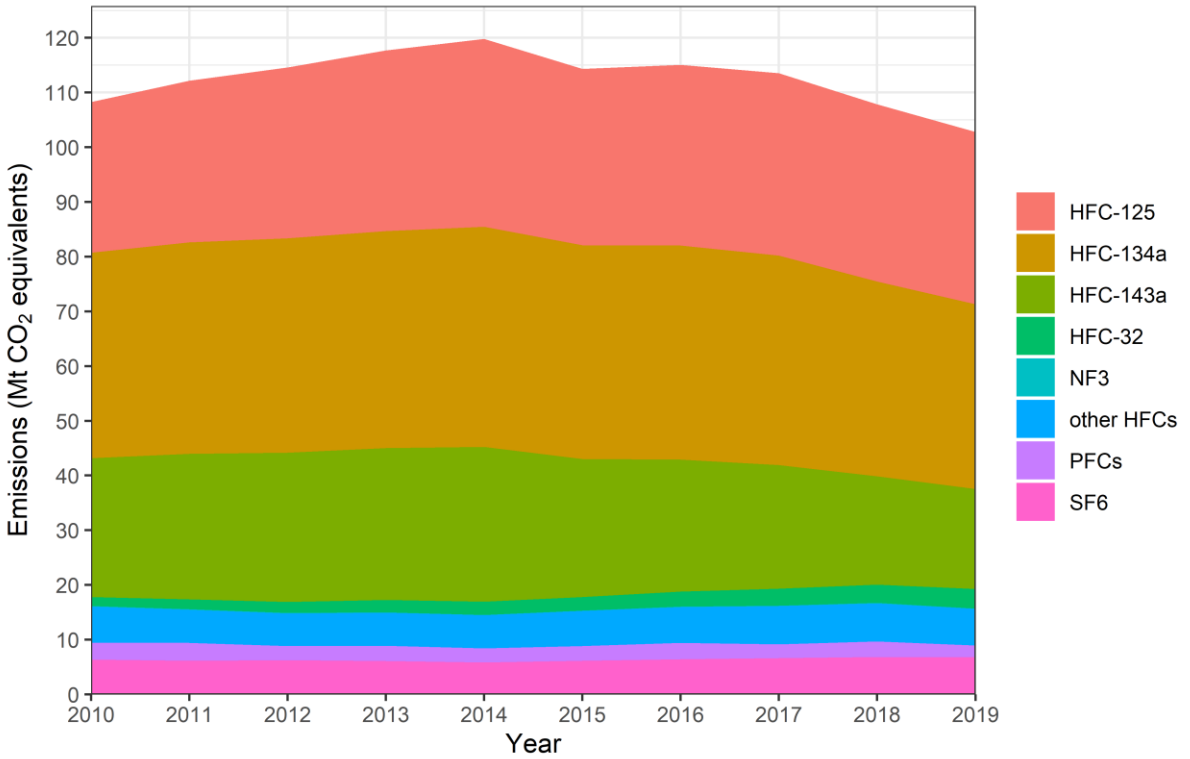


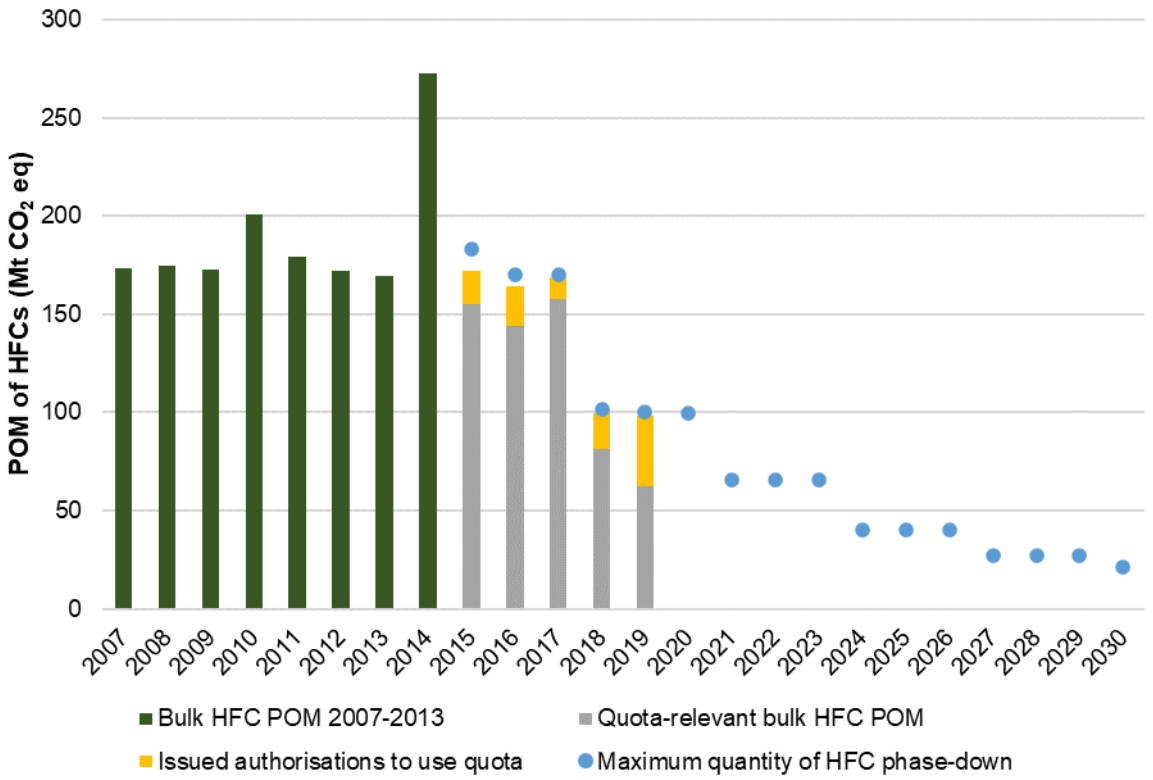
Figure 2-7 F-gas emissions EU27+UK by important HFCs and other F-gas groups. Source: (European Union, 2021)[86]



[85] Analysis of data contained in National Inventory Report - https://unfccc.int/documents/275968.
[86] Ibid footnote 59.

The F-gas Regulation[87] sets out reduction targets (or a 'phase-down') for the placing on the market of a subset of the most common F-gases, namely HFCs. The phase-down steps are defined in terms of their tCO_2-e reduction from a historic benchmark and cover the period 2015-2030. Additionally, it introduces restrictions for other of the F-gases with the highest GWPs in common applications. The following sections present the baseline economic figures of the F-gas sector and of producers and importers of their downstream user applications, as well as their expected evolution.

Figure 2-8 Placing on the market (POM) of HFCs in the EU-27 volumes projected under the existing phase-down. Source: EEA, 2020.



2.2.2.2 Trade of F-gases

Net imports (i.e. imports minus exports) of F-gases into the EU represent almost three quarters of the total EU supply of F-gases. Although total imports have declined since 2018 both in tonnes and in tCO_2-e, net imports in 2020 remained broadly comparable to 2015 levels in tonnes, when the phase-down established by the F-gas Regulation came into effect (0.4% increase in tonnes). In terms of tCO_2-e, however, F-gas imports decreased by 31% in 2020, compared to 2015. This reflects a switch to lower GWP gases.

Total imports of F-gases are dominated by HFCs, which accounted for 77% in tonnes and 84% in tCO_2-e of their respective totals in 2020, according to EEA reports[88]. H(C)FOs made up 21% of imports in tonnes and only about 0.1% in tCO_2-e. While the share of HFCs in total F-gas imports shows a decreasing trend both in tonnes and tCO_2-e, reflecting the impact of the phase-down under the F-gas Regulation, the share of H(C)FOs has significantly increased since 2015, by 4.2 times. Due to their much lower GWP compared to HFCs, the increase has been lower when measured in tCO_2-e.

Equipment imports made up 12% of the total imported volume of F-gases in tonnes, or 8% of their potential in terms of tCO_2-e in 2020. Imported equipment was predominantly charged with HFCs, versus other F-gases, which accounted for 94% in tonnes (or 98% in potential CO_2-e emissions), the remainder being almost

[87] Ibid footnote 41.
[88] Ibid footnote 77.

completely HFO-1234yf[89]. In the bulk imports of F-gases, HFCs represented 75% in tonnes and 83% in tCO_2-e in 2020.

Bulk exports[90] of F-gases from the EU show a decreasing trend in recent years, having declined by about 14% cumulatively in 2020 from 2015. Measured in terms of tCO_2-e, the decline is steeper, with a 24% cumulative reduction in 2020 compared with 2015. In 2020, HFC exports are about 17% lower than in 2015. It should be noted that bulk exports cannot be attributed to European F-gas producers alone, as these exports represent a larger amount than that of the production of F-gases. It is therefore likely that a large share of bulk exports is imported for export.

In a baseline scenario, without further policy action, the trend of F-gas imports towards increasing the share of all F-gases placed on the European market would be expected to continue (see Section 2.2.1.2 defining the regulatory baseline and Figure 2-2 showing the mentioned trends). This baseline trend was contrasted and confirmed with industry stakeholders' expectations collected via survey, both manufacturers and importers of F-gases. As reported, the group of F-gases that is currently being imported corresponds precisely to those F-gases subject to the phase-down established in the F-gas Regulation. H(C)FOs not subject to the phase-down are hence expected to increase their import share in the F-gas supply in the following decade, in the baseline.

2.2.2.3 F-gas baseline business figures and baseline projections

Economic statistics specifically for the F-gas sector alone are not publicly available, in part as this industry does not have its own defined NACE code, but has activities spread across several NACE codes which are in turn combined with non-F-gas activities. Therefore, the baseline economic and business figures for the F-gas industry in this section has been gathered from the stakeholder consultation. A check on the volume of F-gases placed on the market by survey respondents against the volume reported by the EEA of the F-gases in scope suggests that the survey results can be used directly with a high level of accuracy, requiring only minor adjustments: Tonnes of F-gases in scope placed on the market by survey participants are found to differ from the total volume of F-gases in scope placed on the market as reported by EEA by only 6-7%. Figures from the survey that appear in this study are adjusted by 6-7% to account for this margin of reporting error. Additionally, data from Eurostat's Survey of Business Statistics at the level of the Industrial Gases sector (NACE Rev. 2 Class C20.11[91]) has been used to complement the context around the impact of the pandemic and expected rhythm of recovery, as well as to contrast respondents' expectations with the wider sector's trends.

The F-gas industry comprises a limited number of companies in the EEA. A stakeholder consultation of 9 producers and importers of F-gases covered the placing on the market of the F-gases in scope with a margin of error of 6-7% in 2019. Only two of the surveyed companies were SMEs; the figures for this subgroup cannot be reported without breaching anonymity, so they will be reported on aggregate for the whole sector.

Most of the F-gases in the EEA are supplied through imports, with the companies from the sector importing around 85% of the F-gases in basic form, and then formulating other mixtures and/or articles. In 2019[92], the turnover accrued by these F-gas producing and importing companies from their F-gas related sales was around €1.2 billion. Of this, F-gas exports to extra-EEA countries represented 2% of the sector's total turnover (i.e., including income from other economic activities performed by these companies), or 9% of the sector's sales of F-gases, in turnover value (€). Further, the F-gas sector's contribution to the Gross Value Added (GVA) of the EEA's economy (i.e., the direct contribution of F-gas production and imports to Gross Domestic Product (GDP), measured as the value of production minus the value of purchases of intermediate consumptions used in production) is estimated to be around €170 million in 2019. It is worth mentioning that most of these companies have wider activity scopes, and the aggregate reported turnover across all producers and/or importers and their F-gas and other activities is in the neighbourhood of €4.3 billion in 2019. As reported

[89] Ibid footnote 59.

[90] Exports of F-Gases contained in products and equipment are not subject to obligatory reporting

[91] This class includes: manufacture of liquefied or compressed inorganic industrial or medical gases: elemental gases, liquid or compressed air, refrigerant gases, mixed industrial gases, inert gases such as carbon dioxide, isolating gases. This class excludes: extraction of methane, ethane, butane or propane, see 06.20 – manufacture of fuel gases such as ethane, butane or propane in a petroleum refinery, see 19.20 – manufacture of gaseous fuels from coal, waste etc., see 35.21 – manufacture of gas. Source: Eurostat, (2008). Statistical classification of economic activities in the European Community. NACE Rev. 2. Eurostat Methodologies and Working papers. Available from: https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.pdf/dd5443f5-b886-40e4-920d-9df03590ff91 (europa.eu)

[92] 2019 is taken as the reference year to avoid using 2020, which is not considered a representative year due to the effects of the pandemic, and 2021 being too recent to obtain official figures at the time of this study.

in the consultation, the F-gas industry (i.e., production and import of F-gases and their mixtures and/or articles) employs close to 850 workers, and more than 13,000 employees when considering their full scope of activities.

Regulatory costs that the F-gas sector is subject to will also be a part of the analysis. A 2016 study of the cumulative costs of the most relevant EU legislation with a bearing on the EU chemical industry[93] suggests that the regulatory burden affecting the wider chemicals sector represents 2.3% of their turnover[94]. This also represents 30% of the industry's Gross Operating Surplus, which suggests that this burden plays a role in shaping the sector's profitability. The existing chemicals-specific legislation in the EU is estimated to generate around a third of this total burden. For the F-gas industry, this regulatory burden is expected to represent 3.7% of their turnover according to the 2016 study, as an industry that produces specialty chemicals, i.e. those used for specific purposes due to their special properties.

2.2.2.3.1 Trends and baseline projections for F-gas producers and importers

The expected growth for the sector over the next decade, as reported by surveyed F-gas producers and importers (i.e., 'the sector', or 'the F-gas industry'), is consistent with the growth projected by the study team for the wider industrial gas sector, based on past trends and future macroeconomic projections from the OECD. On average, the sector expects their turnover to grow at a Compound Annual Growth Rate (CAGR) of 3.3%, including inflation, while projections by the study team deliver a 3.1% growth rate including inflation. Based on this, and on the feasibility of this approach for all variables under analysis in a consistent way, the external and independent projections by the study team will be used to form the future baseline scenario for the F-gas sector and the figures presented here. From this point forward, all monetary measures will be presented in constant euros based on 2021 prices (i.e., presented in real prices), thus removing the effects of inflation.

Over the last decade, the turnover (i.e., revenue) from the EEA's F-gas industry is estimated to have grown between 0.9% and 1.5% per year, on average, to 2019[95]. The Covid-19 pandemic, however, has likely had an impact on the operations of the sector, which has been estimated to be around a 21% drop in production and turnover in 2020[96]. That said, the sector has somewhat recovered since: following the European Commission's estimations of GDP recovery[97], the sector revenue is estimated to have grown by 10% in 2021 and 6% in 2022. Thereafter, the sector is expected to continue on its longer-term growth trend.

As noted, most of the sector's sales volume coming from F-gases (reported in the survey as 85%) is represented by imports of F-gases in basic form. That is also consistent and in line with the EEA's reports (see Figure 2-2).

Over the coming decades, these key trends are assumed to continue if no further regulatory action is taken (i.e. This is the baseline or 'Do nothing' scenario, i.e., a counterfactual case in which the proposed restriction of PFAS including F-gases is not implemented). That is, it is understood that survey respondents have taken into account the F-gas phase-down in their own expectation of business volume, and further, projections solely based on the sector's history and the macroeconomic environment for the coming decades are aligned with those expectations by the industry. These baseline scenario projections and trends are considered for seven different business indicators:

- Turnover and volume (tonnes)
- Gross Value Added
- Intermediate consumption and operating expenditure
- Capital expenditure
- Research and development
- Regulatory burden
- Employment.

[93] Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), Technopolis Group, VVA. (2016). Cumulative Cost Assessment for the EU Chemical Industry. European Commission. Available from: https://op.europa.eu/en/publication-detail/-/publication/8eb1b47a-ee94-11e6-ad7c-01aa75ed71a1/language-en

[94] The study assessed costs across the EU-28 between 2004 and 2014, so it should be understood as an indicative reference or approximation, given that this considers the burden within the EU-27 for the period 2008-2018 and projects this forward as part of the baseline.

[95] This and other historical trends are estimated by the study team based on current (2019) data provided in consultation by F-gas producers and importers and on past trends observed for the wider 'Industrial gases' sector. The underlying assumption is that overall trends will have been similar.

[96] Ricardo own estimations from econometric regressions relating the output of the EEA Industrial Gases sector to EEA's GDP and population.

[97] European Commission. (2022). Winter 2022 Economic Forecast. Available from: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_926

All baseline growth projections are estimated based on publicly available data at the level of the wider EU Industrial Gases sector, and then applied to the figures reported by the F-gas industry members in consultation, in the following way (see Annex A3.1 for a detailed overview):

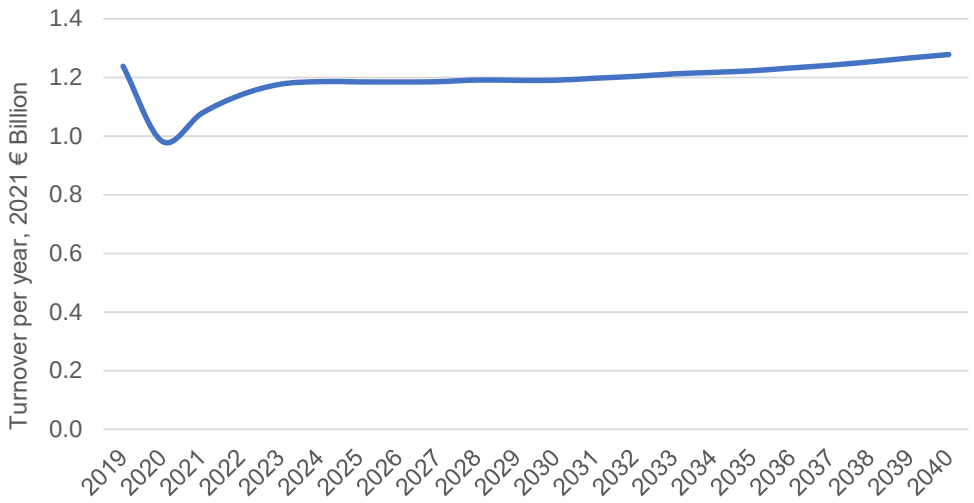
- The historical data from Eurostat's Survey of Business Statistics on the turnover of the Industrial Gases sector was included in a model that related it to overall economic trends in the EEA, namely GDP and population, from Eurostat.
- Long-term macroeconomic projections by the OECD[98] for real GDP and population were then used to project forward the turnover of said sector from 2021 to 2040.
- The resulting growth rates estimated for the period 2022-2040 were applied to the F-gas level figures reported in consultation by F-gas producers and importers.

I. Turnover and tonnes of the EEA F-gas sector

The EEA F-gas sector's turnover is projected to grow at a CAGR of 0.5% over the next two decades in real terms (i.e. excluding inflation), as depicted in Figure 2-9 below. This estimate is based on the current and expected growth for the European economy, the overall business context and the policy baseline, and is in line with stakeholders' expectations as provided in consultation. These projections are in line with the growth that may be expected from a mature and well-established industry, stable but moderate, and amounts to a cumulative growth close to 9% from 2023 to 2040.

Regarding the phase-down established by the F-gas Regulation, this growth accounts for the switch from higher GWP F-gases towards low GWP H(C)FOs. Volumes reported for each of the F-gases in scope for a baseline scenario in 2030 are shown below.

Figure 2-9 Turnover associated with EEA supply of F-gases in scope, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat[99].

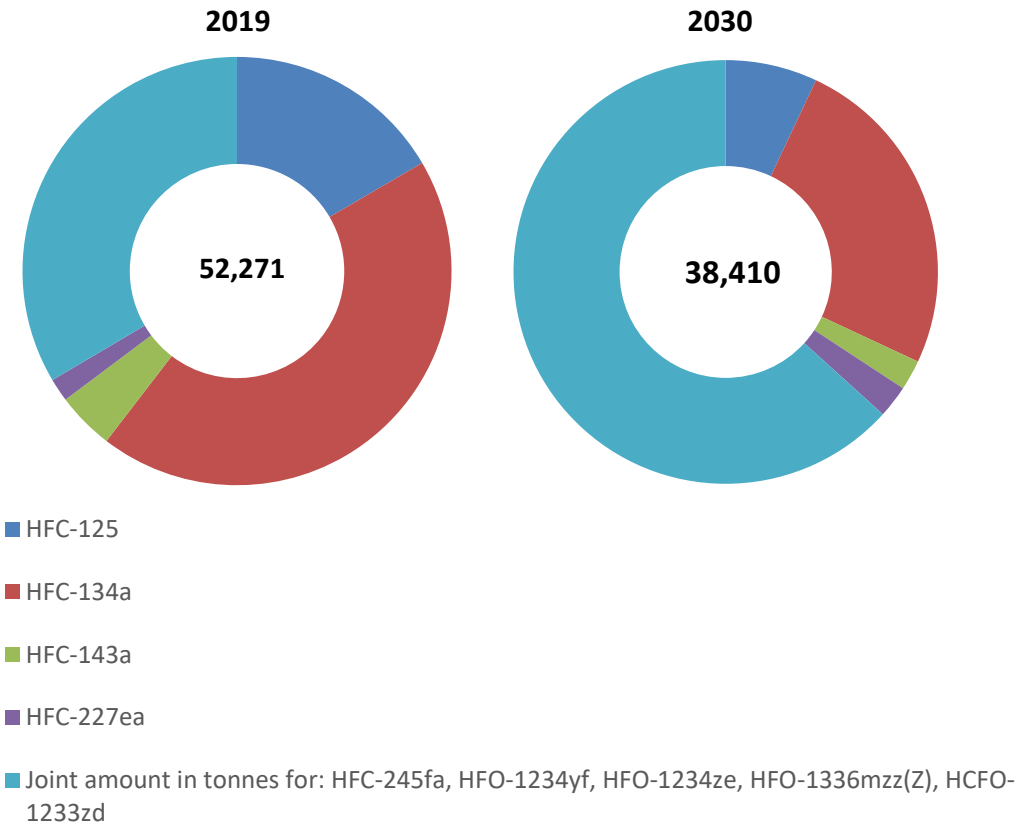


While the projected turnover presents a growing trend, the same cannot be said of the tonnes of F-gases expected to be placed on the market. These volumes are shown in Figure 2-10 for 2019 and 2030, as reported by industry stakeholders. Overall, tonnes are expected to decrease at a CAGR of 2.8% over the next decade, or a cumulative 27%. This trend, along with the change in distribution of tonnes POM from HFCs to H(C)FOs highlights the continued expected effect of the F-gas Regulation driving a reduction in GWP of the F-gases placed on the market. This expected reduction of HFCs POM towards H(C)FOs, that have much lower GWP, can be observed in Figure 2-10 below.

[98] OECD. Long-term baseline projections, No. 95 (Edition 2014). Accessible from: https://www.oecd-ilibrary.org/economics/data/oecd-economic-outlook-statistics-and-projections/long-term-baseline-projections-no-95_data-00690-en

[99] Ibid footnote 95.

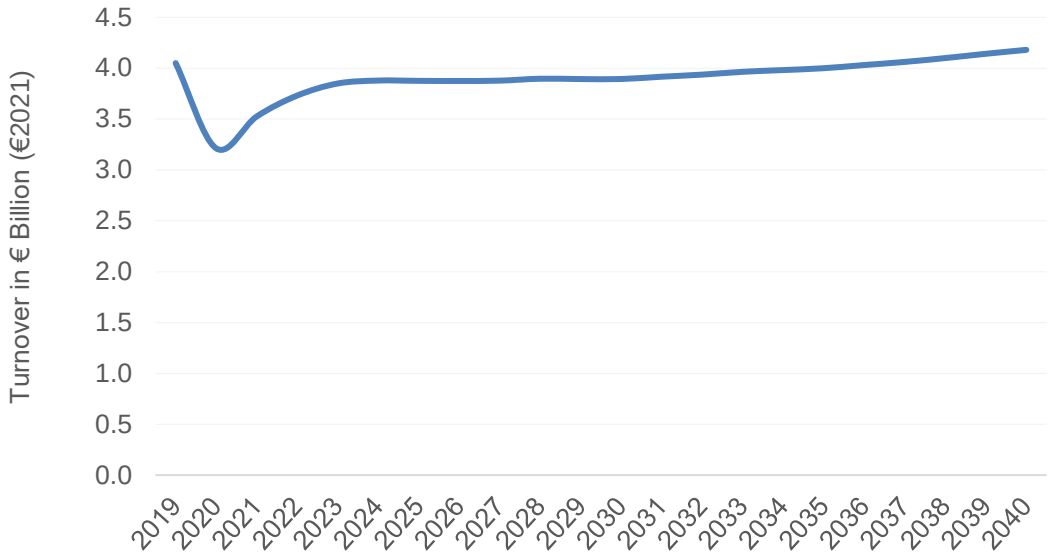
Figure 2-10 Tonnes of each of the F-gases in scope[100] to be placed on the market in 2019 and in 2030 according to industry stakeholders.



Additionally, companies in the F-gas industry report a larger turnover when economic activities other than production and/or import of the F-gases in scope are included. This could be other F-gases and/or additional business beyond F-gases, such as other chemicals. This will be an important aspect when evaluating business impacts of the proposed restriction, as being involved in other activities may help mitigate the potential losses from the proposed restriction. However, the majority of the surveyed companies' business scope is 100% F-gas production and/or import. The total turnover of F-gas producers and/or importers is presented in the graph below in aggregate terms.

[100] HFC-245fa, HFO-1234yf, HFO-1234ze, HFO-1336mzz(Z), and HCFO-1233zd have been grouped to maintain confidentiality.

Figure 2-11 Total turnover of F-gas producers and/or importers in the EEA, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.



II. Gross Value Added of the EEA F-gas sector

The GVA of producers and importers of F-gases in the scope of the proposed restriction, more technically defined as the value of output or production minus intermediate consumption of goods and services (gross, i.e., before taxes), refers to its contribution to Gross Domestic Product (GDP). The stakeholder consultation returned data on historic GVA which was used to produce baseline projections.

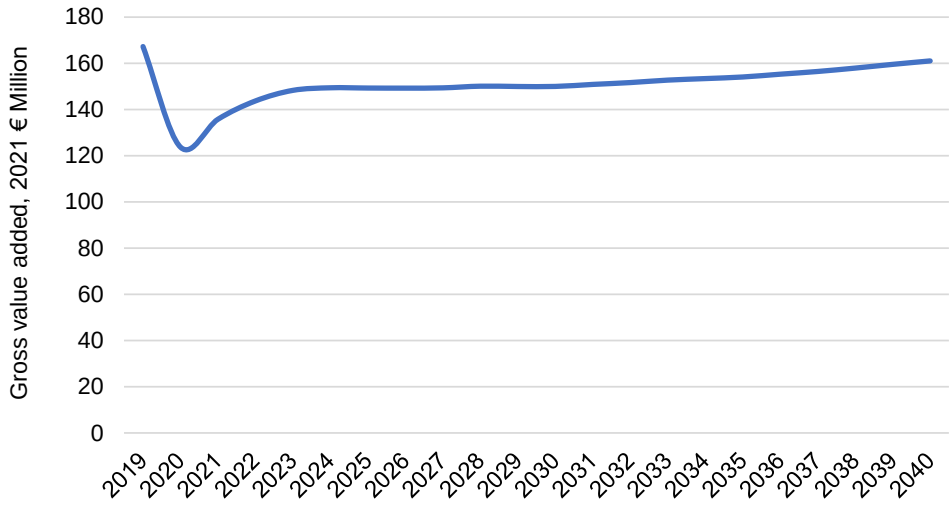
The GVA of the sector amounted to around €170 million in 2019, equivalent to 14% of its economic output. GVA increased in the 10 years between 2009 and 2019 at a CAGR of 2.2%[101], which is slightly higher than the sector's output growth. Based on the responses received to the survey, although not directly linked by respondents, the study team considers that two trends have potentially contributed to this:

- Intermediate costs (OPEX) have grown at a slightly slower pace than output (1.3% vs 1.5% per year) over the last decade.
- The sector's expenditure on R&D has grown more rapidly than output (2.7% vs 1.5%). The sector's innovation has likely translated into higher value added in the sector.

In the baseline scenario, these trends are not assumed to deepen; OPEX will remain proportional to production volume, thus producing growth for GVA at a CAGR of 0.5%, as shown below in Figure 2-12.

[101] Ibid footnote 95.

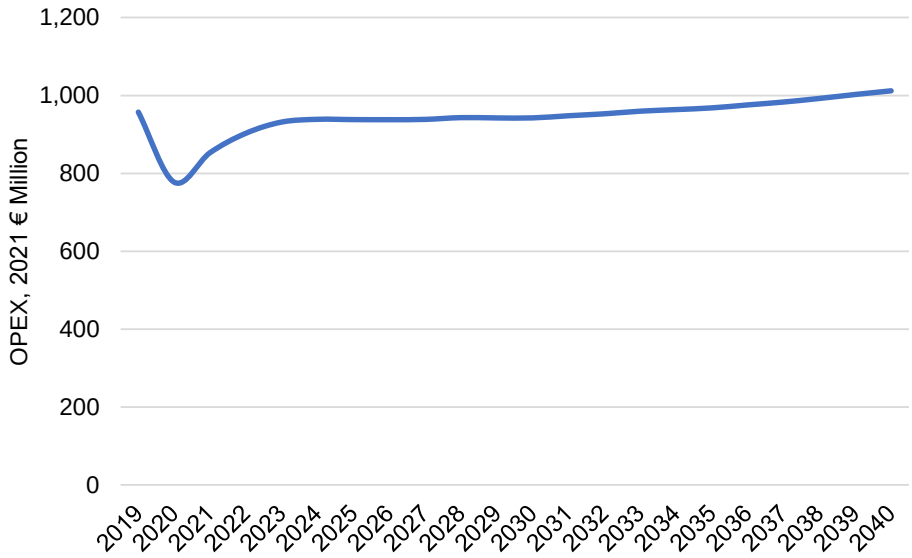
Figure 2-12. Gross value added of the EEA F-gas producers and/or importers, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.



III. Operating expenditure

The operating expenditure of producers and importers of F-gases within the scope of this study refers to the value of costs incurred by the industry to maintain operations. The stakeholder consultation provided data on operating expenditure for 2019. Between 2009 and 2019, OPEX grew at a CAGR of 1.3% in the last decade. This growth in OPEX, together with a past growth rate for turnover of 1.5% per year during that period, means that intermediate consumption per unit of revenue has declined. Growth in OPEX is expected to continue in line with turnover growth, as this type of costs are generally proportional to production, with a CAGR of 0.5%, as showcased in Figure 2-13 below.

Figure 2-13. Operating expenditure (OPEX) of the EEA F-gas producers and/or importers, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.



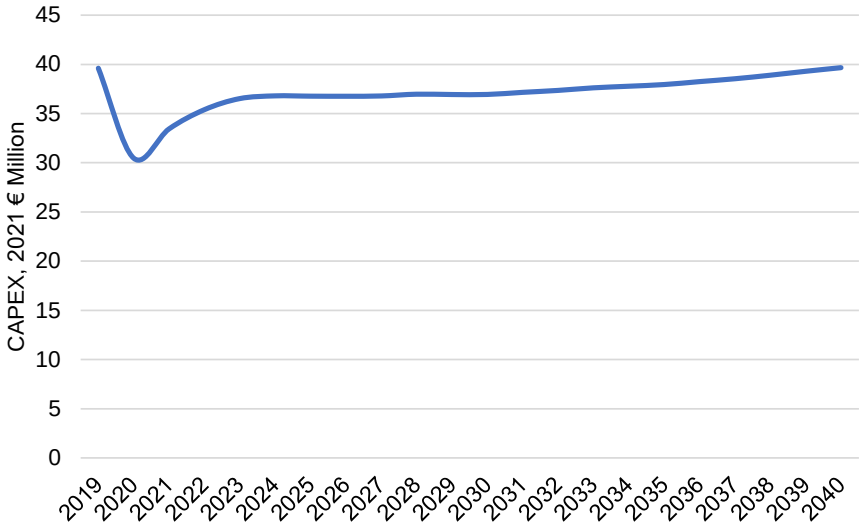
IV. Capital expenditure

In this study, capital expenditure (CAPEX) refers to the money spent on acquiring assets. Between 2009 and 2019, CAPEX grew at a CAGR of 1.8%[102]. In line with the wider chemicals sector, the energy transition that has been achieved so far has likely implied a large growth in investment to renew energy sources and systems within the industry, as well as to improve the energy efficiency of many processes. According to Cefic's Facts

[102] Ibid footnote 95.

and Figures 2021[103], the energy intensity of the chemicals industry has halved from 1990 to 2018. More recent developments, such as the increasing focus in moving faster towards climate neutrality and other demands on the sector, may require faster growth in the capital expenditure of F-gas producers and importers as they seek to increase their production capacity to meet the anticipated increase in demand. Future projections of capital expenditure for the EEA F-gas sector are shown in Figure 2-14. For the next two decades, the observed growth trend in capital expenditure is assumed to continue at a lower rate than in the previous decade in the absence of further requirements, at 0.5%, in line with turnover growth based on macroeconomic projections.

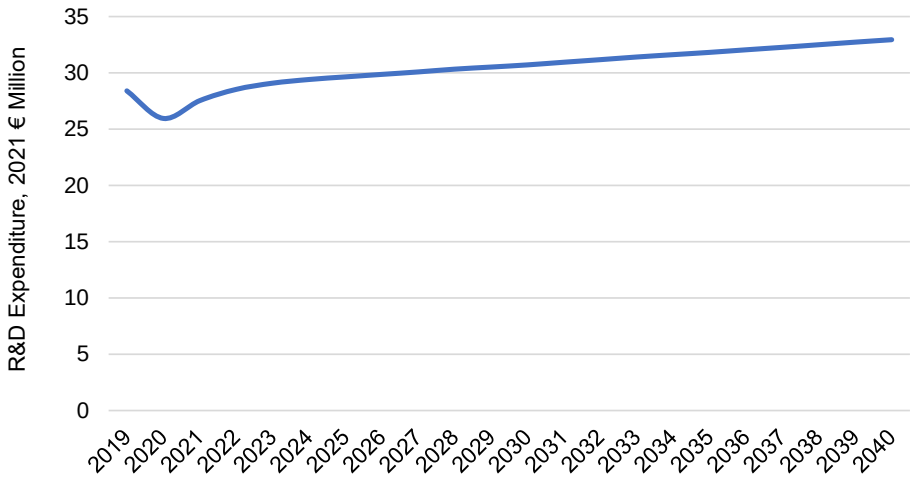
Figure 2-14. Capital expenditure (CAPEX) of the EEA F-gas producers and/or importers, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.



V. Research and development

Expenditure in R&D by producers and importers of F-gases grew at a CAGR of 2.7% between 2009 and 2019 which was slightly high compared to its turnover growth. This is thought to be likely in part due to its lower magnitude in €, in comparison to turnover (i.e., there is room for intense growth, and quantities still remain low). Future R&D trends will depend upon the recovery from the global pandemic crisis and general economic growth. Based on the evidence available, it is estimated that R&D expenditure will grow at a CAGR of 0.7% between 2023 and 2040, at a rate which is slightly above turnover CAGR (0.9%), but feasible overall, due to its relatively lower amount in € million. The projected baseline evolution is shown in Figure 2-15 below.

Figure 2-15. Research and development (R&D) expenditure of the EEA F-gas producers and/or importers, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.

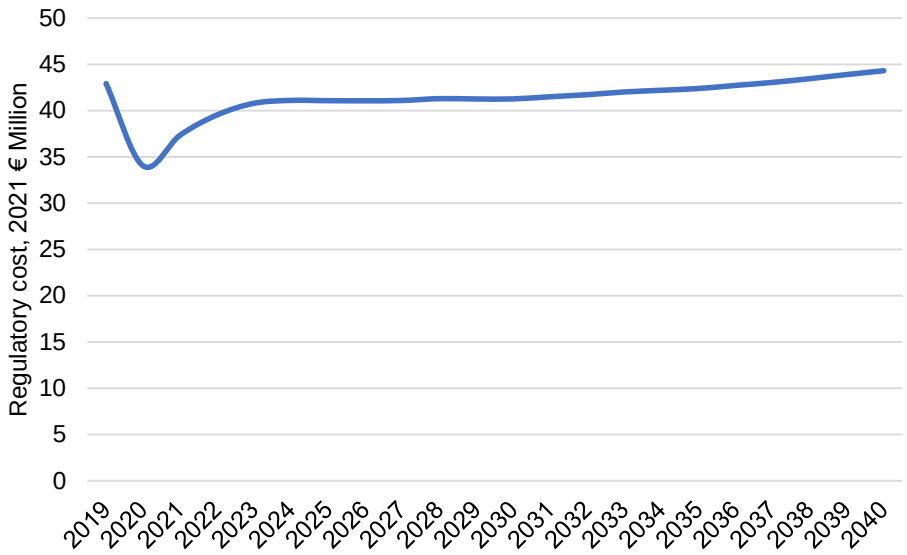


[103] Cefic (2021). *Facts and Figures*.

VI. Regulatory cost

Regulatory burden estimates capture the administrative costs generated by EU chemicals legislation, which includes the cost of the preparation and submission of information for registrations, the issue of permits, and information for product users (e.g., labels). In the baseline scenario between 2009 to 2019, on average regulatory burden is considered to be 3.7% of turnover[104] with a CAGR of 1.5%. This level of burden is assumed to grow between 2023 and 2040 with a CAGR of 0.5%, in line with turnover growth. The projections are shown in Figure 2-16 below.

Figure 2-16. Regulatory costs of the EEA F-gas producers and/or importers, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members and data from Eurostat.



VII. Employment

Overall, the chemicals industry is characterised by the employment of highly qualified and highly paid professionals. Employment compensation in the chemicals industry is among the highest out of EU industries, and the same is found for the F-gas industry. As the EEA F-gas sector continues to expand in the future, this is likely to be complemented by an increase in labour demand. However, this relationship between the sector's output and employment has some particularities:

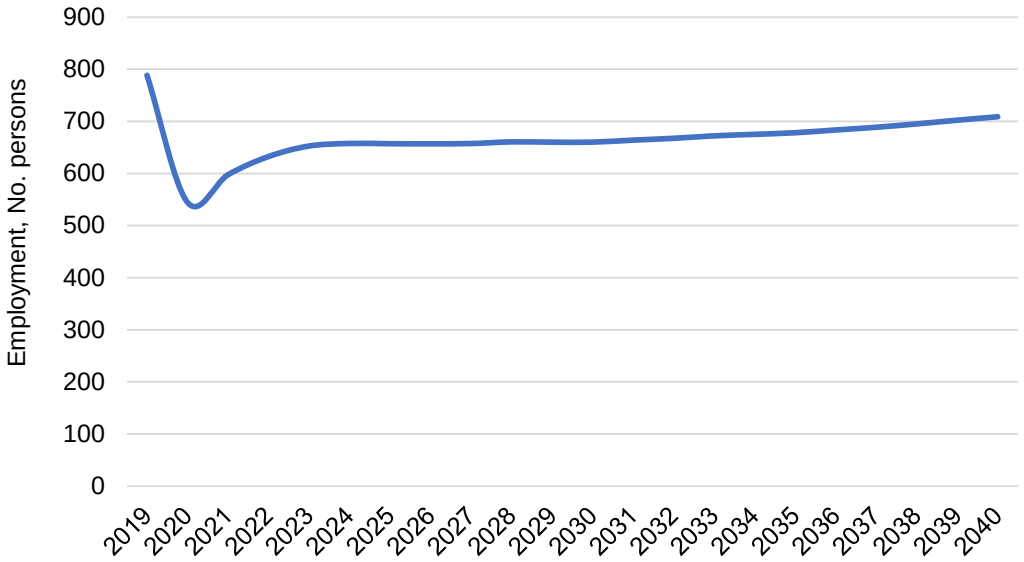
- In the short run, employment has historically been less volatile than sectoral output or production. For example, when output drops, employment declines with lower intensity and, usually, with a time lag. The adjustment in employment is also likely to spread over a longer period than for output. This is driven by the relative rigidity of the labour market in the EU-27 when compared to the market of goods and services, meaning that production is more easily and immediately adjusted than employment.
- In the long run, however, employment and production are assumed to follow similar trends, unless any significant technological and/or production process changes substantially affect this relationship between production and employment. As these changes are uncertain, they have not been considered in the baseline projections below.

Based on these considerations, the contraction in 2020 and following recovery has been modelled *ad-hoc*, after which employment is assumed to grow in line with turnover at a CAGR of 0.5% per year between 2023 and 2040. This is shown below in Figure 2-17.

It must also be noted that employment in 2019 was found to be anomalously high in this sector (45% higher than in 2018), and therefore, the estimated growth does not allow it to recover the levels from 2019, but rather the level from the previous years (not depicted).

[104] Ibid footnote 103.

Figure 2-17. Employment figures of the EEA F-gas industry, 2019 to 2040. Source: Ricardo estimation based on consultation to industry members.



2.2.2.3.2 Trends and baseline projections for F-gas downstream users

F-gases are used for a wide range of downstream applications which are important for the continued functioning of society, including applications such as, refrigeration, air conditioning, heating, insulation, metered dose inhalers. Together, these represent multi-billion EUR industries (with a joint turnover of around €32 billion in 2020, see Figure 2-18 below), although a monetary valuation does not reflect their full social value. Implementing this restriction would have an immediate impact on these essential products and services, including:

- The cold food supply chain,
- Residential, industrial and commercial space heating and cooling, along with their accompanied effects on productivity, wellbeing and preservation of the health of vulnerable people, especially significant in hot climates,
- Energy consumption if highly efficient insulation foams become unavailable for buildings,
- Thermal management of batteries in battery electric vehicles requiring it,
- Medical treatment of people with respiratory problems,
- Broad access to vaccines and medical treatment requiring low temperature transport and storage.

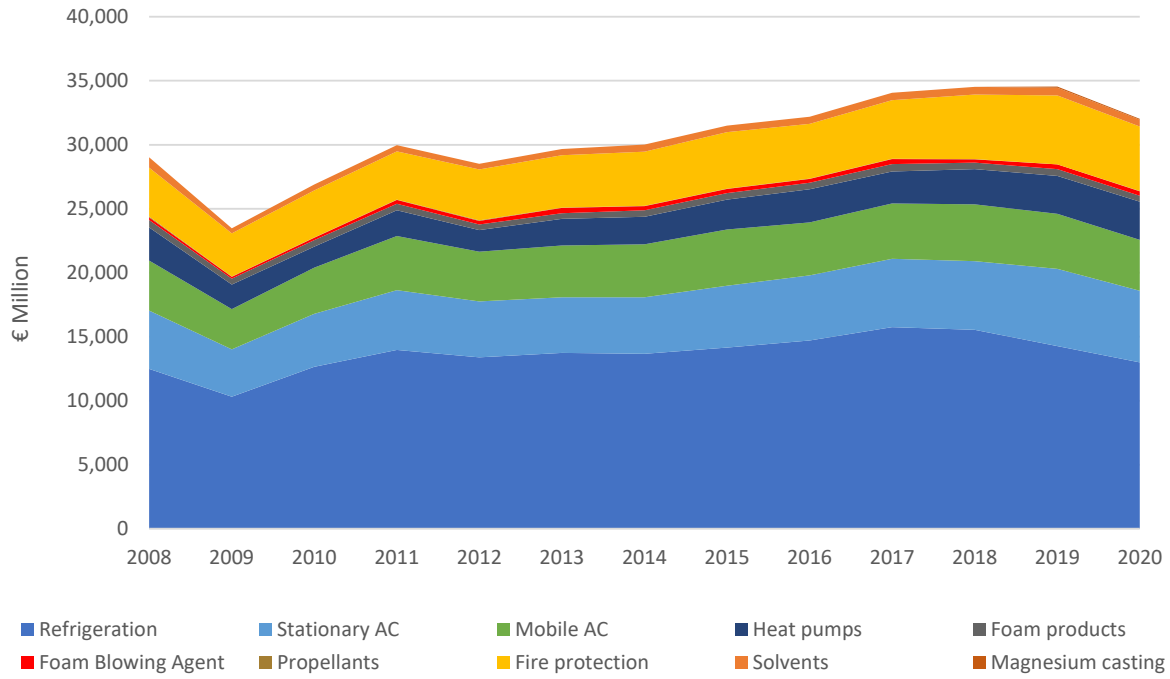
This would have negative social and economic impacts for most people in EEA societies who rely on the properties of these products.

The graph below displays the aggregate production value of all the downstream user applications for each category over the period 2008-2020. Overall, the production of downstream user application sectors has grown at a CAGR of 2.3% between 2015 and 2019[105], afterwards dropping from almost €35 billion to €32 billion in 2020 when the Covid-19 recession hit.

Figure 2-18 shows that the greatest production value for F-gas applications is linked to refrigeration, which is also the largest end use of F-gases. Its share of the overall value of downstream user applications has decreased over the last decade from a maximum of 47% in 2010 to its current 41%. Other application sectors, namely the ones related to fire protection, stationary air conditioning, and heat pumps, have grown more rapidly.

[105] The same reference years as in previous sections on the F-gas market are used for consistency and comparability. 2020 is considered an anomalous year due to the effects of the pandemic and lockdowns during that year.

Figure 2-18 Production value by relevant product application (€ Billion, constant 2021 prices), historical data and baseline projections. Source: Prodcom database (2008-2020).



The historical data from Prodcom on the production value of each downstream user application was included in a model that related it to overall economic trends in the EEA, namely GDP and population, from Eurostat. Long-term macroeconomic projections by the OECD[106] for real GDP and population were then used to project forward production values of each of the F-gas downstream user applications from 2021 to 2040. The resulting growth rates estimated for the period 2022-2040 (2022 is considered the first year after the effect of the COVID-19 pandemic and restrictions are overcome) are varied, but overall moderate. The results of the F-gas Evaluation[107] show that manufacturers have been able to continue their business as usual and will continue to grow even in the face of the F-gas phase-down, assuming they will have enough preparation time and/or resources to acquire alternative substances/technologies. The results of the Impact Assessment to the F-gas Regulation also found the impact on the macroeconomy of the F-gas Regulation was small as the changes included concern only limited areas of the economic system[108]. Respondents to the survey conducted for this study also indicated they will not be significantly impacted by the F-gas phase down coordinated by the F-gas Regulation. Economic impacts from the proposed restriction of PFAS on downstream users of F-gases will be compared against this baseline.

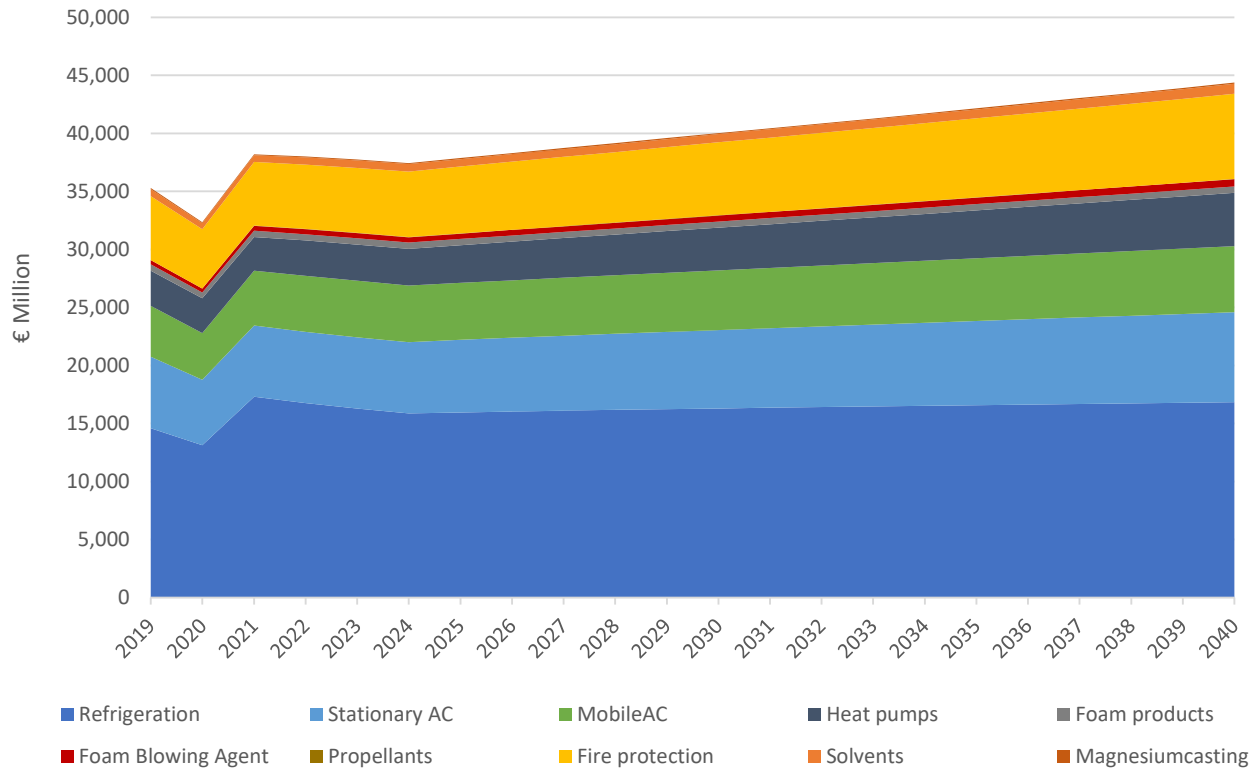
The downstream user application sectors that are projected to grow the most (i.e. between 1.6% and 2.3% per year on average as a result of the abovementioned projections) are heat pumps, foam products, solvents, and fire protection equipment, based on their historic growth and relationship with overall GDP and population. For the other applications, the growth that results from baseline projections is below 1.0% per year on average. Figure 2-19 below shows the resulting baseline projections for each downstream user sector's production value.

[106] OECD. Long-term baseline projections, No. 95 (Edition 2014). Accessible from: https://www.oecd-ilibrary.org/economics/data/oecd-economic-outlook-statistics-and-projections/long-term-baseline-projections-no-95_data-00690-en

[107] Ibid footnote 59.

[108] Ibid footnote 59.

Figure 2-19 Baseline projections of the selected downstream using sector applications' production value (€ Million, constant 2021 prices). Own elaboration based on Prodcom data.



The characterisation of the remaining economic variables of the downstream user application sectors in the rest of this section rely on the figures provided by industry members in consultation. 29 F-gas downstream users manufacturing products belonging to 11 different application categories responded to the consultation. Downstream applications are fine product categories for which this information, beyond the production value figures shown above, is not publicly available in aggregate. Moreover, responses cover around a third of the joint value of all applications as shown in Figure 2-18 for 2019. Hence, this baseline for downstream users will be shown at the sample level only (i.e., not extrapolated to the whole sector in general[109]).

Regarding the product scope of each of the companies participating in the consultation, it usually spans multiple compatible F-gas applications (e.g., refrigeration, air conditioning and heat pumps). This makes it impossible to provide a disaggregation of figures by fine application; therefore, these economic figures will be provided jointly for all applications, and differences between them will be assessed where possible. This issue was also present in the survey to F-gas producers and/or importers; it was commented that the end-use of F-gases placed on the market is not always clear. Some report that they typically send their products to distributors. As a result, it is challenging to determine the final destination of F-gases through this alternative route as well.

Baseline scenario projections and trends are considered for the following seven business indicators (shown below in Table 2-9 along with their current, 2019, aggregate levels as reported by survey participants).

Table 2-9 Current (2019) values for each of the variables of analysis, on aggregate for the whole sample of surveyed F-gas downstream users.

Business indicators	2019 value (2021 €)
Turnover	€11,700 million
Gross Value Added	€4,700 million

[109] Impacts from the restriction on downstream users' economic figures will also be calculated using the sample as reference, and extrapolations will be commented where possible, with the caveat that those extrapolations will be heavily impacted by the sample composition. Capturing what could happen to that many sectors on aggregate requires either oversimplifying assumptions or a much larger sample that was not possible to obtain.

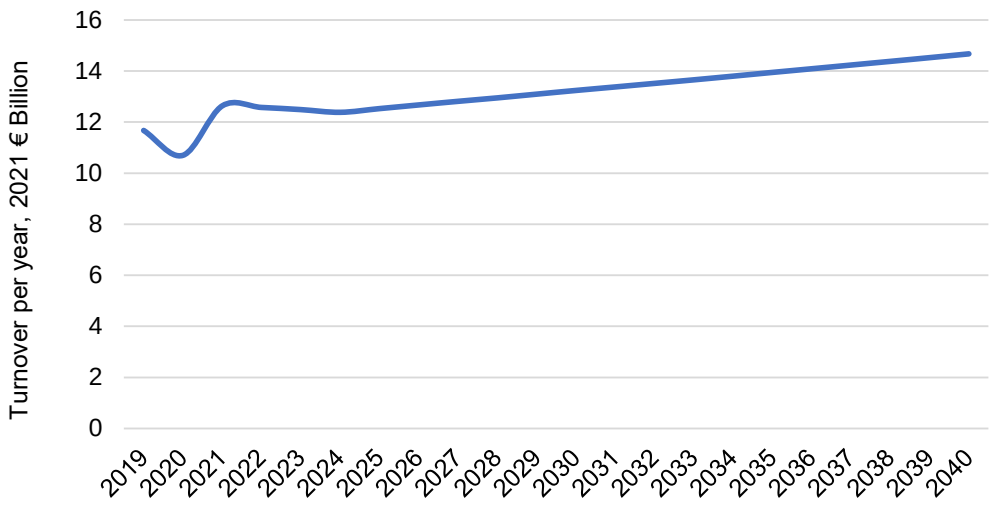
Business indicators	2019 value (2021 €)
Intermediate consumption and operating expenditure	€5,500 million
Capital expenditure	€600 million
Research and development	€300 million
Regulatory burden	€500 million
Employment	40,700 FTE jobs

All baseline growth rates are estimated based on publicly available data of the production volume at the level of the each of the application sectors in the EU (see Figure 2-18), and then applied to the figures reported by industry respondents in consultation.

I. Turnover of (sample of) EEA F-gas Downstream Users

Based on the projections presented in Figure 2-19, the total turnover of the sample of EEA F-gas downstream users is expected to grow at a CAGR of 1.0% over the next two decades, as depicted in Figure 2-20 below. This estimate is based on the responses provided by downstream users of F-gases within the EEA. These projections amount to a cumulative growth of approximately 18% over this period. As shown in the figure below, a consistent upward trend is expected from 2024. Prior to this, there was a steep decrease from 2019 – 2020 before a subsequent rise in 2021 when the recovery from the Covid-19 recession begins.

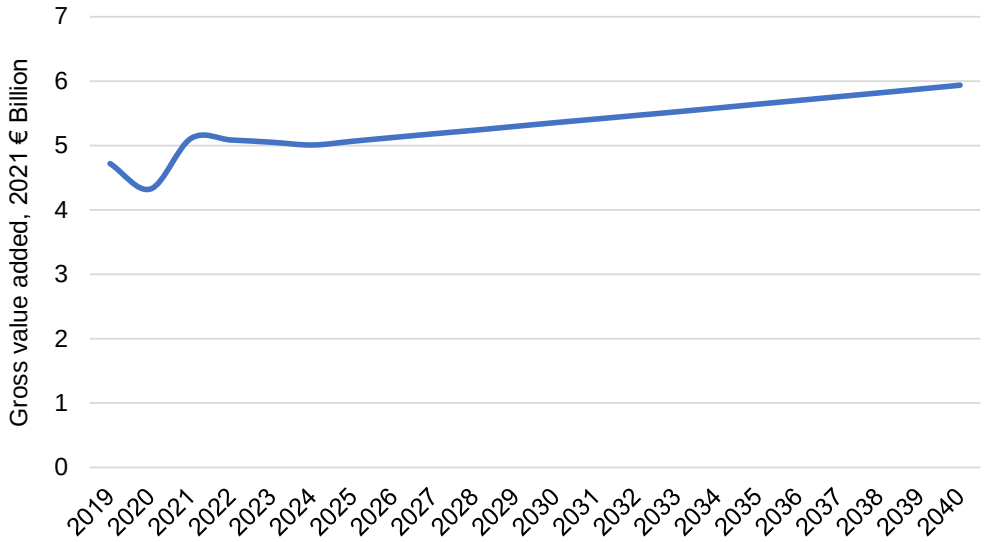
Figure 2-20 Total turnover of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



II. Gross Value Added of the (sample of) EEA F-gas Downstream Users

The GVA of the sample of downstream users of F-gases in the scope of the proposed restriction amounted to approximately €4.7 bn in 2019, equivalent to approximately 40% of turnover for the year. The total GVA of the downstream users is expected to grow at a CAGR of approximately 1.0% over the next two decades, as depicted in Figure 2-21.

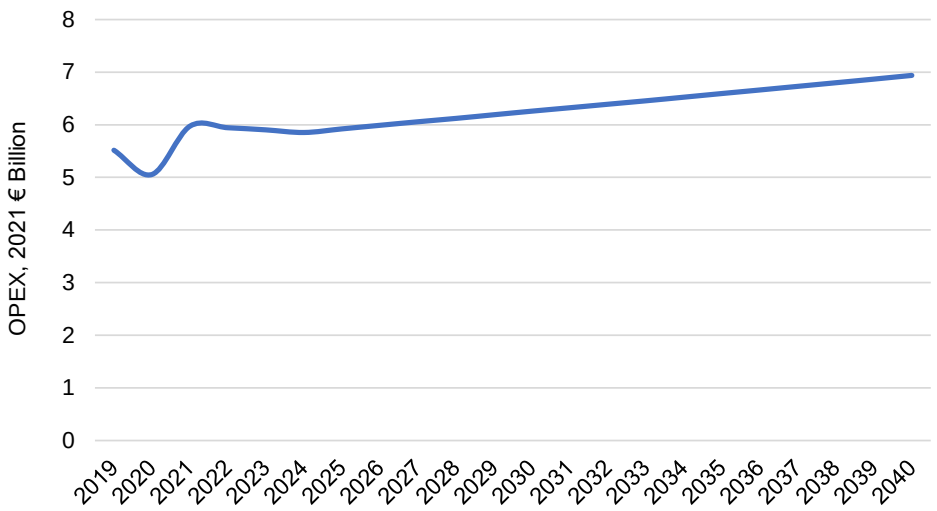
Figure 2-21 Total GVA of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



III. Intermediate consumption and operating expenditure of the (sample of) EEA F-gas Downstream Users

The operating expenditure of downstream users of F-gases within the scope of this study refers to the value of costs incurred by the industry to maintain operations. The total operating expenditure of the downstream users is expected to grow at a CAGR of approximately 1.0% over the next two decades, as depicted in Figure 2-22, just in line with turnover growth. This estimate is based on the responses provided by downstream users of F-gases within the EEA covering operating costs in 2019 and expectations in baseline.

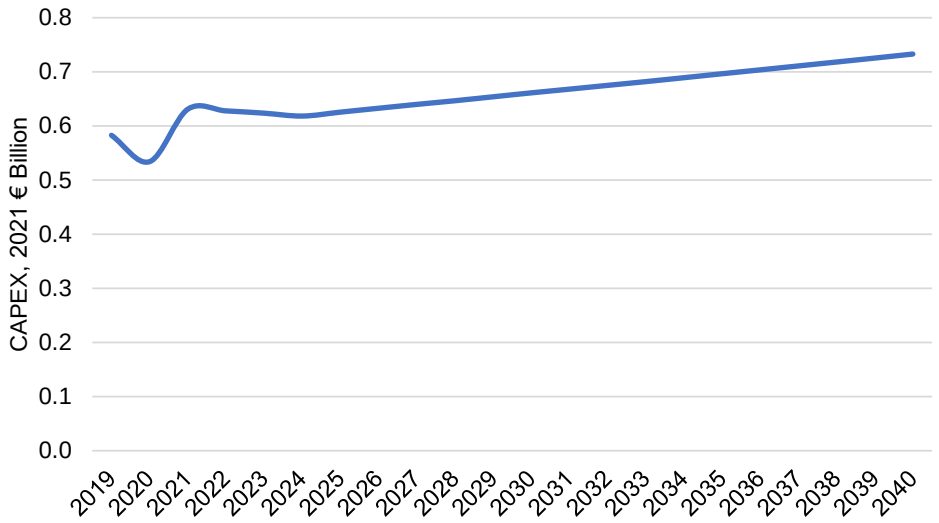
Figure 2-22 Total OPEX of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



IV. Capital expenditure of the (sample of) EEA F-gas Downstream Users

Between 2022 and 2040, the expected growth in capital expenditure is estimated to be just in line with turnover growth. This estimate is based on the responses provided by downstream users of F-gases within the EEA. The projections to 2040 are shown in Figure 2-23.

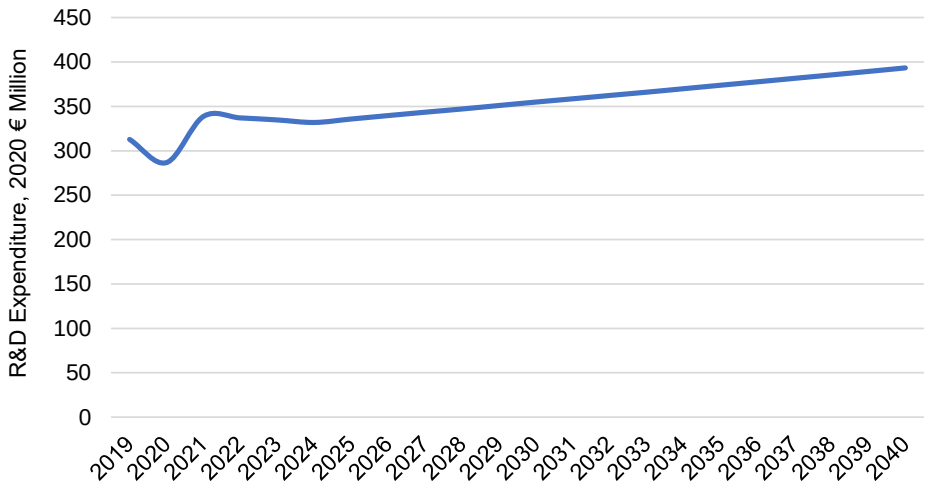
Figure 2-23 Total CAPEX of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



V. Research and development of the (sample of) EEA F-gas Downstream Users

Figure 2-24 displays the expected future trend for expenditure in R&D over the next two decades. Although future R&D trends will depend upon the recovery from the global pandemic crisis and general economic growth, as shown in the figure, R&D expenditure of the downstream users is expected to grow at a CAGR of close to 1.0%. This estimate is based on the responses provided by downstream users of F-gases within the EEA.

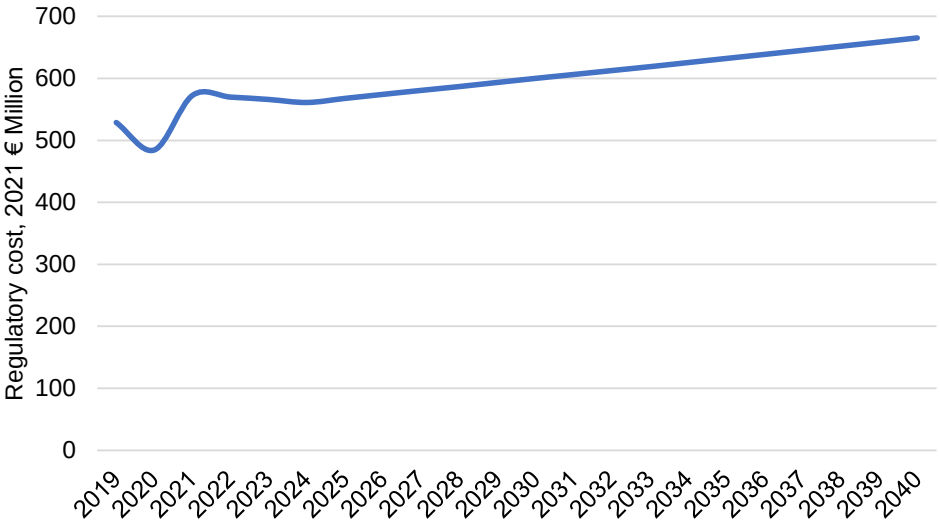
Figure 2-24 Total R&D of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



VI. Regulatory burden of the (sample of) EEA F-gas Downstream Users

Regulatory burden estimates capture the administrative costs generated by EU legislation, which includes the cost of the submission of information for registration dossiers, the issue of permits, certification, and information for product users (e.g., labels), and possibly other sector-specific costs. Based on survey responses by F-gas downstream users, regulatory costs represent on average 4.5% of the sampled companies' turnover. As displayed in Figure 2-25, the regulatory cost for downstream users is expected to grow at a CAGR of 1.0%, in line with turnover growth.

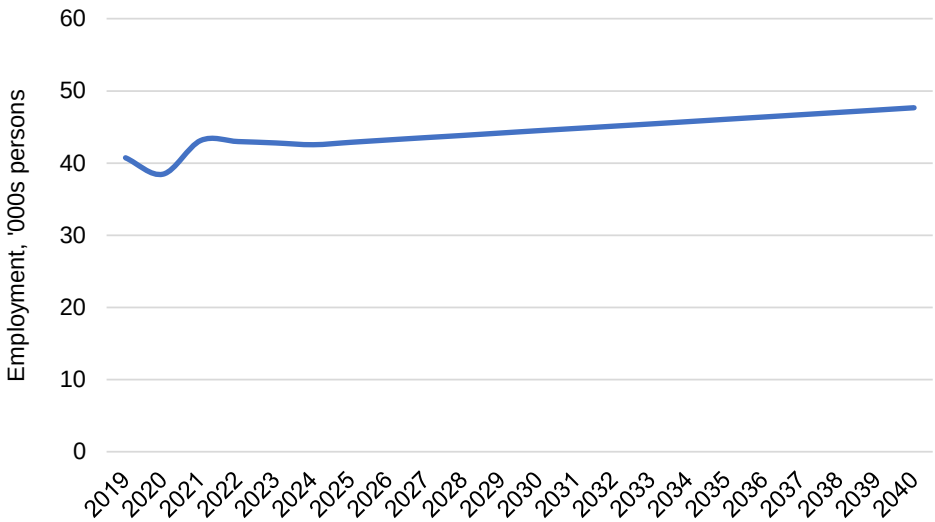
Figure 2-25 Total Regulatory Cost of the sample of EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



VII. Employment of the (sample of) EEA F-gas Downstream Users

As the production volume of F-gas downstream users continues to expand in the future (see Figure 2-19), this is likely to be complemented by an increase in labour demand. There is typically a high correlation between economic output and employment, and this can be expected over the upcoming two decades with both economic indicators projected to increase. As shown in Figure 2-26, employment in F-gas downstream user industries is expected to grow at a CAGR of approximately 0.6% and with a cumulative growth of approximately 11% over this period. This estimate is based on the responses provided by downstream users of F-gases within the EEA.

Figure 2-26 Total Employment levels of the EEA F-gas downstream users. Source: Ricardo estimation based on consultation with downstream users.



2.2.2.4 Use of F-gases and trends towards uptake of low-GWP F-gases and non-fluorinated alternatives

According to the most recent data[110], in 2019, 71% of the supply of all F-gases placed on the market was intended to be used in refrigeration, air conditioning (including mobile air conditioning) and heating, and other heat transfer fluids (RACHP) applications. A breakdown of the intended use of F-gases is shown in Figure

[110] Ibid footnote 77.

2-27 below. F-gases are predominantly used in RACHP, foams, and aerosols. By comparison, use in semi-conductors, fire protection, electronics and other or unknown applications is marginal and below 5% overall.

Figure 2-27 Intended applications of the supply of F-gases in the EU in 2019 (split of quantities in tonnes). Source: EEA.

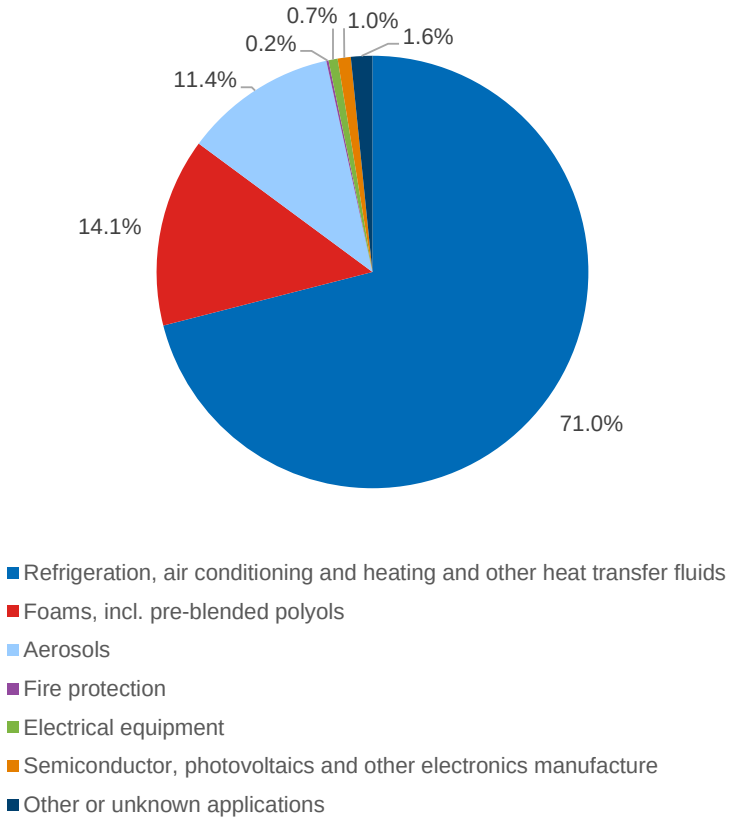
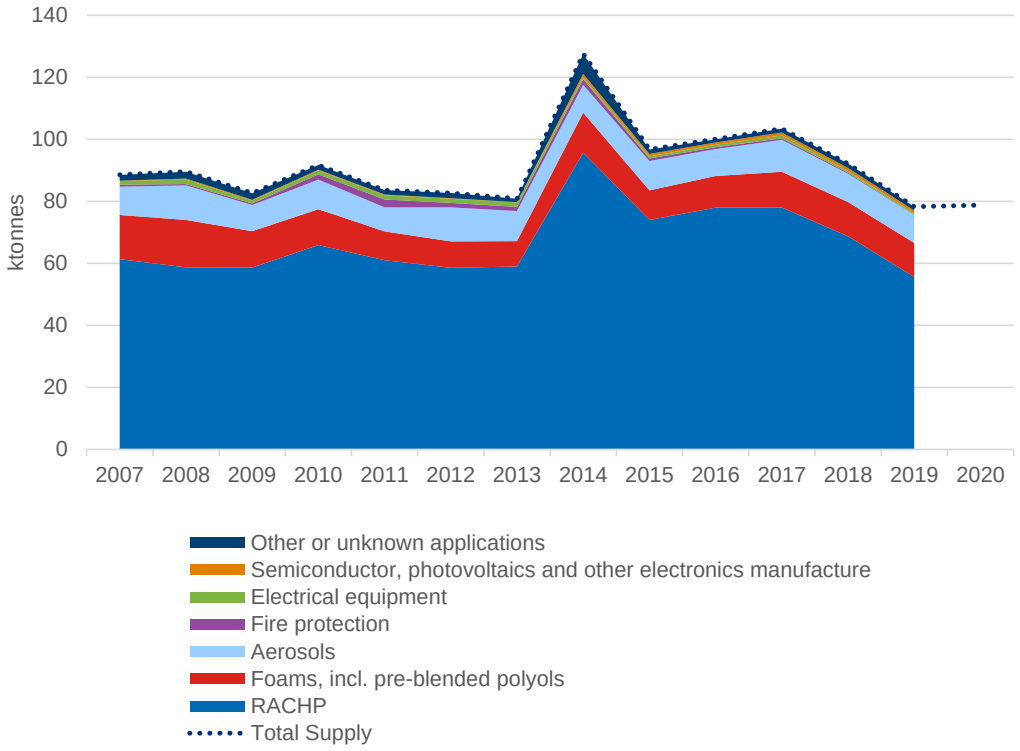


Figure 2-28 below shows the observed history of supply by application of intended use until 2019, as reported by the EEA. All applications reduced their F-gas use by 2019, in comparison to 2015, when the F-gas Regulation was introduced. The largest reduction in tonnes in the last year with data available is observed in RACHP, which is also the largest intended destination of the supply of F-gases (19.0% reduction, or 18 thousand tonnes). That said, the largest relative reduction was observed in fire protection, with total tonnes of F-gases intended for this purpose reducing by 59.9%.

Figure 2-28 Intended use of the total EU supply of F-gases, tonnes. Source: EEA.



The distribution of supply defined in terms of tCO_2-e by application differs somewhat from that of F-gas supply in tonnes, as reported by the EEA. In particular, Figure 2-29 shows how minor applications that jointly represent less than 4% of the total F-gas supply in tonnes in the EU-28, would represent 24% in terms of tCO_2-e, namely electrical equipment, semiconductors, and photovoltaics; also including to a lesser extent other electronics manufacture, fire protection and other or unknown applications. As a consequence, relatively larger GWP improvements could be expected in these minor applications if viable alternatives of lower GWP are available. There is no data available on the breakdown of application in “other or unknown applications”, which includes application in MDIs, which have a very high social and indirect economic value.

Figure 2-29 Intended applications of the supply of F-gases in the EU in 2019 (split of quantities in CO_2-e). Source: EEA

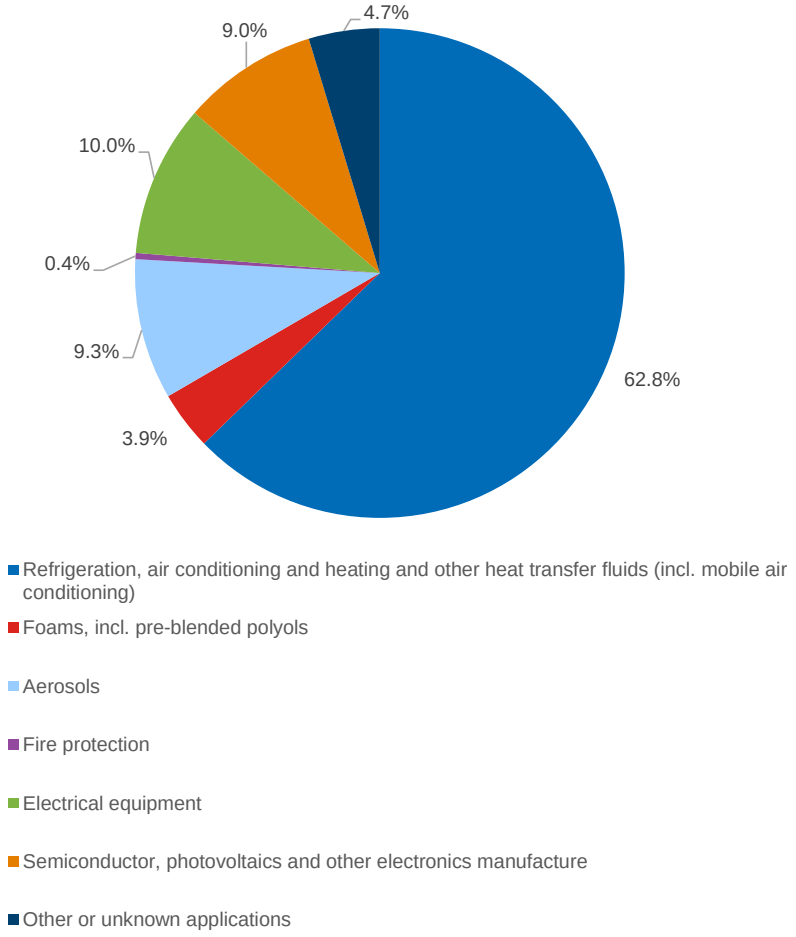


Table 2-10 provides an overview of how F-gases in the scope of the proposed restriction are used across different applications. Within each of these sectors, the F-gases in scope of the proposed restriction have varying importance (i.e., are used in different amounts). The table shows a range of H(C)FOs included in the scope of this study are used in RACHP and in foams. By comparison, a smaller range of F-gases are used for fire protection, aerosols, and metered dose inhalers (MDIs).

Table 2-10 Key F-gas sectors and F-gases in the scope of this study commonly used in these sectors. Source: Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases[111] and EU Inventory.

Sector	Relevant F-gas groups	F-gases in the scope of this study
Refrigeration, air-conditioning and heating (RACHP)	HFCs	HFC-134a, HFC-125, HFC-143a
	H(C)FOs	HFO-1234yf, HFO-1234ze(E) , HCFO-1233zd(E)
Foam	HFCs	HFC-365mfc, HFC-245fa, HFC-227ea, HFC-134a
	H(C)FOs	HFO-1234ze(E), HCFO-1233zd(E), HFO-1336mzz(Z)
Fire protection	HFCs	HFC-227ea
Aerosols	HFCs	HFC-134a – *now banned; HFCs with a GWP greater than 150 cannot be used for almost all non-medical aerosols from 1 January 2018*
	H(C)FOs	HFO-1234ze(E)
Metered dose inhalers (MDIs)	HFCs	HFC-134a, HFC-227ea
Magnesium cover	HFCs	HFC-134a
Solvents	HFCs	HFO-1336mzz(z)

In the largest applications to which F-gases are supplied, there has been a shift to lower GWP HFCs and mixtures containing HFCs and H(C)FOs, as well as to non-fluorinated alternatives, although progress is uneven between the different sectors, as discussed in the subsections below. For example, the refrigeration industry has begun transitioning to lower GWP F-gas alternatives for R-404A and R-507A and there is recognition from some actors that there will need to be increasing use of non-fluorinated alternatives to F-gases[112]. However, the European Commission's Evaluation of the F-gas Regulation identified barriers to the uptake of alternatives, which have dampened their adoption over the period of implementation to date[113].

Initial analysis indicates one such barrier included existing high health and safety standards which relate to the use of non-fluorinated alternatives to F-gases. EU-level standards regulate the use of natural refrigerants based on flammability and toxicity properties to define classifications and practical limits for different systems. According to stakeholder views submitted to the Evaluation, application of natural refrigerants is limited by strict safety requirements. For example, when flammable natural refrigerants are used as substitutes for F-gases, the health and safety regulations require an adjusted system and technology[114]. Based on a review of existing international, EU-level and Member State standards and stakeholder consultation, the Evaluation concluded the existing health and safety standards need to be reviewed because they could be overly restrictive[115]. According to stakeholder views submitted to the Evaluation, safety codes have not been updated in line with technological progress. Although the Commission and industry have taken steps to address this[116], and progress has been made in some Member States (e.g., Italy and Spain), the F-gas evaluation confirmed that this issue still exists but maybe focused on some Member States (e.g., France) and certain refrigerants (safety classification A3).

Second, the Evaluation also identified that there is an insufficient number of technical personnel qualified experienced to plan, install, service, maintain and repair equipment with climate-friendly alternatives in the EU. A 2016 report[117] found that 71% of Member States provided training for ammonia but only 35% for hydrocarbons and 20% for HFOs. Further to this, the proportion of certified fluorinated gas personnel trained

[111] Ibid footnote 59.

[112] Bitzer, 2020. Refrigerant Report 21. Accessible under: https://www.bitzer-refrigerantreport.com/fileadmin/Content/01_Startseite/A-501-21_EN.pdf

[113] Ibid footnote 59.

[114] Ibid footnote 59.

[115] Ibid footnote 59.

[116] E.g., Commission mandate (M/555)

[117] European Commission (2016): REPORT FROM THE COMMISSION on availability of training for service personnel regarding the safe handling of climate-friendly technologies replacing or reducing the use of fluorinated greenhouse gases, COM/2016/0748 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0748

in alternative refrigerants in the EU is considerably lower (0.2-3%), with the lowest estimates recorded for HFOs. The estimates were based on a survey to EU Member State authorities, and it has been noted that due to difficulties in obtaining accurate data on the number of technicians trained, the true number is likely to be higher. Since 2016, training activities around alternatives has continued. The EU funded REAL Alternatives training, a voluntary training programme on F-gas alternatives, covers both flammable refrigerants, including hydrocarbons and low GWP flammable refrigerants now widely in use, and carbon dioxide modules[118]. Up to March 2020, around 600 technicians passed this personnel training on F-gas alternatives across 17 Member States. Also, other training is offered by commercial providers or through associations, although uptake has remained on the whole low.

The initial findings confirm there has been a transition to low GWP F-gases and in some cases to non-fluorinated alternatives. Uptake of low-GWP F-gases has been strong, which can be partly attributed by the strong signal and direction set by the 2014 F-gas Regulation. Uptake of non-fluorinated alternatives has not progressed in some sectors which industry stakeholders attributed to external barriers, including safety requirements and access to trained engineers. Implementation of this proposed restriction would increase reliance on non-fluorinated alternatives as well as non-PFAS F-gases.

Sections 2.2.2.4.1 to 2.2.2.4.6 provide a detailed overview of the application of F-gases within the scope of the study (both incumbent and emerging versions), and possible non-fluorinated alternatives. Table 2-11 summarises the information gathered in these sections to provide an overview of the F-gases and alternatives by application. Further information on the detailed uses of the F-gases and identified in Table 2-11 can be found in sections 2.2.2.4.1 to 2.2.2.4.6.

[118] The REAL Alternatives training does not cover the use of ammonia as a refrigerant as it is argued that currently already training in ammonia is available and the demand is said to be limited due to its specialist applications.

Table 2-11. The table identifies incumbent and emerging F-gases applied, and possible non-F-gas alternatives. Adaptation of own research detailed in below section.

Sector	Application	Incumbent F-gases in scope of the study	Emerging alternatives in scope of the study	Incumbent alternatives outside scope of the study	Emerging alternatives outside scope of the study
RACHP	Hermetically sealed standalone units	R-404A, HFC-134a	R-454C, R-455A, R-448A, R-449A	R-290	
RACHP	Distributed systems	R404A, R-34a	R-454C, R-455A	R-290	
RACHP	Centralised Systems	R-404A, HFC-134a	R-448A, R-449A, R-450A, R-513A, R-454C, R-455A		R-744
RACHP	Ultra-low temperature refrigeration	HFC-23, R-508	R-472A, R-473A		HFC-1132a, R-170, R-1150
RACHP	Industrial refrigeration	R-507A, R404A,	HFC-134a, HFO-1234yf, HFO-1234ze, R-455A, R-454C	R-717	
RACHP	Mobile refrigeration (road)	HFC-134a, R-404A, R-410A	R-452A, R-513A, R-513B, R-456A		
RACHP	Ship Refrigeration	R-404A	HFO-1234ze, R-513A	R-744, R-717	
RACHP	Transport: Passenger cars (ICE)	HFC-134a, R-410A, R-407c, HFO-1234yf	HFO-1234yf		R-744
RACHP	Transport: Passenger cars (EV)	HFO-1234yf		R-744	
RACHP	Trucks and Trailers	HFC-134a	HFO-1234yf, R-513A		R-744
RACHP	Buses	HFC-134a	R-1234yf and R-513A	R-744	
RACHP	Rail	HFC-134a, R-407C	R-513A, HFO-1234yf		R-744, R-290
RACHP	Ships	HFC-134a	R-513A	R-744, R717	

Sector	Application	Incumbent F-gases in scope of the study	Emerging alternatives in scope of the study	Incumbent alternatives outside scope of the study	Emerging alternatives outside scope of the study
RACHP	Moveable room air conditioning	R-410A, R-407C	R-454C	R-290	
RACHP	Stationary air conditioning: Single split systems (one indoor and one outdoor unit connected by a pipe carrying refrigerant)	R410A, R407C	R-454B, R-454C	R-290, R-32	
RACHP	Air conditioning: Multi split systems (VRF)	R-410A		R-32	
RACHP	Chillers	R410A, R407C, HFC-134a	R-513A, R-452B, R-454B		R-32, R-290
RACHP	Heat Pumps	HFC-134a, R-407C, R-410A,	R-455A, R-452A, R-452B, R-454B, R-513A, R-454C	R-290, R-600a, R-744	
RACHP	Industrial heat pumps and power generation	HFC-134a and HFC-245fa	HFO-1336mz(Z), HFO-1336mzz(E) HFO-1234yf, HCFO-1233zd(E)		R-290
Foams	Extruded Polystyrol or XPS	HFC-134a	HFO-1234ze	HFC-152a, R-744	
Foams	Polyurethane (PU) (used in SPF)	HFC-134a, HFC-245fa, HFC-365mfc, HFC-227ea	HFO-1336mzz, HCFO-1233zd(E)	H_2O, fiberglass, mineral wool, cellulose, natural fibres, polystyrene, and cementitious foam	
Foams	One component foam (OCF)	HFC-134a	HFO-1234ze	R-600a, R-600	

Sector	Application	Incumbent F-gases in scope of the study	Emerging alternatives in scope of the study	Incumbent alternatives outside scope of the study	Emerging alternatives outside scope of the study
Foams	Metered Dose Inhalers (MDIs)	HFC-134a, HFC-227ea	HFO-1234ze(E)	Dry Powder Inhalers	HFC-152°, R-600a
Solvents	Solvents	HFE-7200, PFPEs	HCFO-1233zd, HFO-1336mzz(Z)	HFC-43-10mee	
Fire Protection	Fire Protection	HFC-227ea, HFC-125		HFC-236fa	

2.2.2.4.1 RACHP

The RACHP sector includes technologies that are used to control the temperature. RACHP devices use a working fluid, commonly an HFC, to create a temperature difference and cool or heat spaces. RACHP technology is crucial in both commercial and private applications, for example, delivery and storage of chilled goods, industrial processes, and maintaining thermal comfort. At the time of writing, HFCs are the main component of the working fluid which is essential for the technology to function. Alternatives can be used; however, their different physical and thermal properties mean there are some differences compared to the use of HFCs.

In the RACHP sector, measured in tonnes, was the intended use for 71% of all F-gases (i.e. not just including those in scope of the proposed restriction) supplied in 2020[119]. According to the evaluation of the F-gas Regulation, HFCs are the most used F-gas group in this sector[120]. The most commonly used individual HFCs in RACHP include HFC-134a, HFC-125, HFC-143a and HFC-32, although HFO-1234yf is being used increasingly due to its low GWP[121]. The blends which are most used include R-404A[122] , R-407C[123] and R-410A[124] (all of which contain F-gases in the scope of this study).

2.2.2.4.1.1 Refrigeration

In the context of domestic refrigeration, recent legislation has tightened requirements relating to HFCs and general environmental performance. For domestic units, HFCs with GWP >150 were banned under the F-gas Regulation.

In the context of commercial refrigeration, the F-gas Regulation restricts the use of HFCs with GWP of 2500 or more in stationary refrigeration equipment, with the exception of ultra-low refrigeration (below -50°C). Annex III, point 13, requires refrigerants in multipack centralised refrigeration systems not to exceed GWP 150 in systems over 40kW with the exception of cascading systems, where the refrigerant in the primary circuit can have a maximum GWP 1500. In addition, new hermetically sealed equipment with a GWP >150 were banned. This came into effect on January 1, 2022.

Table 2-12 provides a detailed overview of the F-gases used in the refrigeration sector by application. The table confirms, across the different applications there is an ongoing transition away from high-GWP refrigerants such as, HFC-134a, R-404A, to low GWP blends (e.g., R-448A[125] and R-449A[126]) and non-fluorinated alternatives. Crucially for this study, many of the low-GWP alternative blends include F-gases within the scope of the proposed restriction.

[119] EEA, 2020. Fluorinated Greenhouse Gases 2020. Accessible under: https://www.eea.europa.eu/data-and-maps/data/fluorinated-greenhouse-gases-aggregated-data-2, and EEA, 2021. Fluorinated Greenhouse Gases 2021. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021.

[120] Oko-Researche, 2022. Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases, CLIMA.A2/ETU/2019/0016, Evaluation Final Report. European Commission: DG Clima

[121] Ibid. p.40.

[122] 52% HFC-143a, 44% HFC-125, 4% HFC-134a

[123] 52% HFC-134a, 25% HFC-125, 23% HFC-32

[124] 50% HFC-125, 50% HFC-32

[125] HFC-32: 26%, HFC-125: 26%, HFC-134a: 21%, HFO-1234yf: 20%, HFO-1234ze: 7%

[126] HFC-32: 24,3%, HFC-125: 24,7%, HFC-134a: 25,7%, HFO-1234yf: 25,3%

Table 2-12 HFCs used in refrigeration, including specific usage and refrigerants used. Information extracted from the Annex to the F-gas Evaluation[127].

Refrigeration	Application or sector	F-gases used currently, and new F-gases	Alternatives to F-gases
Hermetically sealed standalone units	Heat pumps in tumble driers, dishwashers and washing machines Ice cream makers Water coolers Milk coolers Display units	R-404A and HFC-134a are the main refrigerants used. As an alternative to the incumbent refrigerants, HFC-HFO blends R-448A[128] and R-449A[129] are being used by some manufacturers and R-454C [130]and R-455A[131] have been announced as potential replacements.	There is a transition to non-fluorinated refrigerants such as R-290 (propane) and R-600a (isobutane), in units with small (<0.15 kg) to large (0.5 kg) charge sizes. Hydrocarbons (HC) are flammable; therefore, standards limit charges to avoid safety hazards. In Germany, the market share of R-290 units is growing fast and is assumed to reach 85% by 2025. Increasing uptake is the same in other countries however, at a slower rate due to different levels of concern for the safety of products.
Distributed systems	Range from 1 kW to 20kW Small supermarkets and convenience stores Cold chambers for non-retail refrigeration (restaurants, hotels, catering)	HFO blends are used in this market segment. Many condensing unit manufacturers announced in recent years new equipment operating with A2L HFOs. The blends R-454C and R-455A are used in distributed systems.	Some systems[132] use a small (<5kg) charge of R-290. Distributed systems used in supermarkets (e.g., display units) have a large charge size and are located in public spaces. Therefore, the safety of the refrigerant and system are a priority for the industry.[133] Consequently, the transition away from R-404A and HFC-134a has been slower than the hermetically sealed units described above and there has been more emphasis on HFO-based refrigerants and transcritical CO_2 systems compared to flammable hydrocarbon-based refrigerants.[134] In addition to flammability, R-290 requires high pressure levels and discharge gas can be of a high temperature.

[127] Ibid footnote 59.
[128] HFC-32: 26%, HFC-125: 26%, HFC-134a: 21%, HFO-1234yf: 20%, HFO-1234ze: 7%
[129] HFC-32: 24,3%, HFC-125: 24,7%, HFC-134a: 25,7%, HFO-1234yf: 25,3%
[130] HFC-32: 21,5%, HFO-1234yf: 78,5%
[131] HFC-32: 21,5 %, HFO-1234yf: 75,5 %, R744 (CO_2): 3 %
[132] Such as ESyCool Green by Viessmann
[133] Bitzer, 2020. Refrigerant Report 21. p.30. Accessible under: https://www.bitzer-refrigerantreport.com/fileadmin/Content/01_Startseite/A-501-21_EN.pdf
[134] Ibid.

Refrigeration	Application or sector	F-gases used currently, and new F-gases	Alternatives to F-gases
Centralised systems	For large installations in: Supermarkets Display cases Storage rooms	R-404A and HFC-134a were used most often in centralised systems. There is a transition to H(C)FO-blends, namely R-448A, R-449A, R-450A[135] and R-513A[136]. There is some development in the use of systems with R-454C and R-455A but there is no widespread use today. In the context of centralised systems it is still a relatively new solution. Due to the lower flammability of these refrigerants, the quantities are limited (per system) for safety reasons.	CO_2 (R-744) systems are also growing. Transcritical CO_2 systems can be used in colder climates. In warmer climates subcritical cascade systems enable CO_2 to perform. Parallel compression systems enable CO_2 to perform better in warmer climates[137]. The market share of CO_2 centralised supermarket systems in the EU was estimated by industry experts at approximately 15% in 2020. Some research indicates CO_2 refrigeration systems are less efficient and produce more excess heat than conventional HFC blends. One study of 8kW cooling units indicates the Coefficient of Performance of a CO_2 system is between 33 and 54% lower than a HFC blend (R-404A)[138]. Furthermore, in the same study, the research found the discharge temperature of a unit using CO_2 was significantly higher. Higher discharge temperature limits the environment in which the CO_2 units can operate in. The research indicates it is possible switching from fluorinated refrigerants to CO_2 in the context of medium scale refrigeration would lead to increased energy consumption and additional safety considerations.
Ultra-low temperature refrigeration	Equipment delivering temperatures between -50°C and -100°C. Applications include: • Freeze-drying • Pharmaceuticals • Chemicals • Petrochemicals	HFC-23 and R-508 were commonly used, however, they are heavily restricted on the EU market. Two new blends, R-472A[139] and R-473A[140] have been announced.	HFC-1132a, R-170 (ethane) and R-1150 (ethylene) are considered potentially suitable alternatives to R23 for certain applications; however, they are highly flammable.

[135] HFC-134a: 42%, HFO-1234ze: 58%
[136] HFC-32: 44%, HFO-1234yf: 56%
[137] Danfoss, 2016. Making the case for CO_2 refrigeration in warm climates. Retrieved from: https://www.danfoss.com/en-gb/service-and-support/case-stories/dcs/making-the-case-for-co2-refrigeration-in-warm-climates/
[138] Haddad, E., et al, 2021. Test of condensing units' performance and operating limits using different refrigerants. Retrieved from: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3144&context=iracc
[139] 69% R-744, 12% R-32, 19% HFC-134a
[140] 60% CO_2, 20% R-1132a, 10% R-125, 10% R-23. Retrieved from: https://www.ashrae.org/technical-resources/standards-and-guidelines/ashrae-refrigerant-designations

Refrigeration	Application or sector	F-gases used currently, and new F-gases	Alternatives to F-gases
	• Material research		
Industrial refrigeration	Food processing Cold storage Ice rinks Heavy industry	Recently there has been a shift away from R-404A and R-507A towards low GWP alternatives. F-gas alternatives to HFC-134a and R404A include HFO-1234yf and HFO-1234ze, as well as R-455A, R-513A and R-454C[141].	Currently, ammonia is the main refrigerant used, especially in large installations.
Road transport	Vans, trucks, trailers, and reefer containers	For vans, HFC-134a and R-404A are the main refrigerants. R-452A and R-513A have been introduced in recent years in this application by major manufacturers. For trucks and trailers, R-404A and HFC-134a are the main refrigerants. There is also limited use of R-410A. Reefer containers previously relied on R-452A, HFC-134a and R-404A[142]. R-513A, R-513B, and R-456A are potential candidates to replace HFC-134a and R-404A.	Non-fluorinated alternatives have not been used based on safety concerns.
Ship refrigeration	Onboard refrigeration	Most fishing vessels in the EU are used for coastal fishing and are not equipped with refrigeration systems. Where small, compact chillers are used, they often use HFO-1234ze and R-513A. Larger vessels are more likely to require large scale refrigeration. In the past, R-404A was the main refrigerant. It is not clear what the incumbent refrigerant is currently. According to industry expert elicitation, use of HFO-1234ze and R-513A is increasing.	In Norway, transcritical CO_2 systems are being promoted[143]. Ammonia systems are commercially available[144].

[141] Industry expert elicitation
[142] Industry expert elicitation
[143] R-744, 2015. CO_2 increasingly seen as a solution for the Norwegian shipping and cruise industry. Retrieved from: https://r744.com/co2-increasingly-seen-as-a-solution-for-the-norwegian-shipping-and-cruise-industry/
[144] Refrigeration Industry, 2019. Refrigeration system marine application: ammonia VS CO2. Retrieved from: https://refindustry.com/news/market-news/refrigeration-system-marine-application-ammonia-vs-co2/

2.2.2.4.1.2 Heating and cooling

Table 2-13 provides a detailed overview of the different types of heating and cooling systems including specific application, the F-gases currently used, and their alternatives. The table shows HFC-134a has been used to replace older high GWP blends, such as, R-410A, in several different contexts, including heat pumps and chillers. HFO-1234yf, 1234ze (types both E and Z) have been identified as the alternative F-gases to HFC-134a in several sectors, including mobile air conditioning, industrial heat pumps and chillers. Propane, Carbon Dioxide and Ammonia are also viable alternatives in many sectors, however, research and development to understand how they can be applied varies between the different sectors. In addition, switching to alternatives could require a complete system redesign to accommodate different safety classes and pressure regimes.

The table also makes it possible to compare which applications have advanced or lagged in the transition to low-GWP alternatives. For example, passenger cars are advanced in comparison to buses, medium and heavy-duty trucks and trailers, rail, and ships (where there are no EU-level regulatory drivers to adopt a lower GWP refrigerant, see table of regulations Table 2-5 for role of MARPOL Annex VI). Several factors, including legislation, safety concerns, energy efficiency and efficacy of the refrigerant, affect uptake of low-GWP F-gases or non-fluorinated alternatives.

The table also supports insight into potential sector-by-sector impacts of the proposed restriction on F-gases. The restriction of H(C)FOs, such as, HFO-1234yf, could be disruptive to sectors which rely on these F-gases to transition to low GWP alternatives. Sectors where use of non-fluorinated alternatives is already feasible, or research and development has already begun, will be less affected by the proposed restriction, relative to those where no non-fluorinated alternatives readily exist. However, there is also expected to be a disruptive impact upon some sectors which have begun to switch towards alternatives. For example, although rail has lagged behind in the transition to low GWP alternatives, the application of CO_2 air conditioning in some rail networks suggests this sector may be less seriously affected. In contrast, research into low-GWP for industrial heat pumps has found the F-gases HFO-1234yf, HFO-1234ze, HFO-1336mzz(Z) and HFO-1336mzz(E) are good alternatives to existing high-GWP refrigerants. Current research for this report has not confirmed whether non-fluorinated alternatives are suitable in industrial heat pumps. However, existing information indicates the proposed restriction would incur costs spent on research and capital equipment used to transition to low-GWP F-gases in this particular application.

Table 2-13 F-gases used in heating and cooling, including specific usage, refrigerants used and alternatives. Information extracted from the Annex to the F-gas Regulation Evaluation[145].

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
Air conditioning: mobile	Transport: Passenger cars (ICE)	For light vehicles capacity ranges from 2-7 kW and the refrigerant charge from 0.5-0/6 kg[146]. In the past HFC-134a, R-410A and R-407c were common refrigerants for mobile air conditioning[147]. HFC-134a is being replaced by HFO-1234yf and to small extent by CO_2 in new car models since 2014. However, as HFC-134a is not replaced in the stock of existing vehicles it will remain the incumbent refrigerant on the market until the mid-2020s.	Hydrocarbons are used in the USA and Australia for this application (Maclaine-cross, 2004)[148], although these were not adopted in the EU due to safety concerns related to the flammability for the refrigerant. Research has indicated use of propane blended with CO_2 is also possible[149]. However, there are no commercial applications to date. The United States EPA[150] and the Australian Refrigerants Association[151] advise against the use of flammable hydrocarbons in MAC.
	Transport: Passenger cars (EV)	No single technical solution for battery cooling, heating and cooling EVs is established. As in conventional vehicles, HFO-1234yf plays a prominent role.	CO_2 has been used in heat pump systems in the Audi e-tron[152] and Volkswagen model ID.3 (heat pump costs an additional EUR 1000 for the ID.3. It should also be noted that they experienced challenges meeting efficiency targets, but the report has not investigated how these

[145] Öko-Recherche, 2022. Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases, CLIMA.A2/ETU/2019/0016, Evaluation Final Report Annex 10. European Commission: DG Clima. Pp.148-156. Available from: https://ec.europa.eu/clima/system/files/2022-04/f-gas_evaluation_report_en.pdf.

[146] Industry expert elicitation

[147] Ibid footnote 145.

[148] Maclaine-cross, I.L., 2004. Usage and risk of hydrocarbon refrigerants in motor cars for Australia and the United States. International Journal of Refrigeration, Volume 27, Issue 4, Pages 339-345. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0140700704000052

[149] Yu, B. et al, 2018. Performance improvements evaluation of an automobile air conditioning system using CO_2-propane mixture as a refrigerant. International Journal of Refrigeration. No.88, pp172-181. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S014070071830001X

[150] US EPA, 2022. Questions and Answers About the Safety Risks of Using Hydrocarbons (HCs) in Motor Vehicle Air Conditioners (MVACs). Retrieved from: https://www.epa.gov/mvac/questions-and-answers-about-safety-risks-using-hydrocarbons-hcs-motor-vehicle-air-conditioners

[151] Refrigerants Australia, 2022. Retrieved from: https://www.refrigerantsaustralia.org/use-of-hydrocarbon-refrigerants.html#:~:text=Refrigerants%20Australia%20advises%20the%20service%20industry%20not%20to,use%20is%20not%20approved%20by%20the%20equipment%20manufacturer

[152] Audi, 2021. Battery, thermal management and charging. Retrieved from: https://www.audi-mediacenter.com/en/electric-suvs-in-the-premium-compact-segment-the-audi-q4-e-tron-and-the-q4-sportback-e-tron-13887/battery-thermal-management-and-charging-13902

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
			compare to conventional systems)[153] . There are no commercial applications with propane due to higher flammability. Such systems would require complete redevelopment and would have to meet high safety standards. However, early research indicates that in cold climates propane is a higher performing refrigerant than CO_2[154].
	Trucks and truck trailers	HFC-134a is the main refrigerant at present. There is a gap in the regulation driving technological change (e.g., the MAC Directive for passenger cars). Consequently, the shift from HFC-134a to low GWP alternatives. HFO-1234yf and R-513A is commercially viable for some vehicles. Some medium/heavy duty truck OEMs have transferred to HFO-1234yf. HFO-1234yf is technically feasible to replace HFC-134a with small equipment changes (similar transition to passenger vehicles), for example Volvo Trucks.[155]	CO_2 has not been introduced on the market by any manufacturer beyond prototypes, but their use is feasible.[156]
	Buses	Not all buses have air conditioning. The MAC Directive has not been applied to buses. Due to the lack of regulatory drivers the transition away from HFC-134a to low GWP F-gases has been slower in buses than in passenger cars.	There are around 500 buses operating in the EU market equipped with CO_2[157]. Two examples of CO_2 being used by bus manufacturers, include one in Germany (Konvekta) since 2003 and one in Poland (Solaris) since 2012[158]. This number is not expected to be significantly greater due to limited regulatory pressure to use alternative to HFC-134a. Konvekta offer a heat pump for

[153] Ecomento, 2022. VW-Gutschrift für ID.3- und ID.4-Kunden wegen geringerer Wärmepumpen-Leistung. Retrieved from: https://ecomento.de/2021/06/02/vw-gutschrift-id3-id4-kunden-wegen-geringerer-waermepumpen-leistung/

[154] Liu, C. et al, 2018. Performance evaluation of propane heat pump system for electric vehicle in cold climate. International Journal of Refrigeration. No.95, pp.51-60. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0140700718303165

[155] Krafthand Truck, 2021. Cool change: The changeover to the refrigerant R1234yf is picking up speed. Retrieved from: https://www.krafthand.de/truck/artikel/umstellung-auf-das-kaeltemittel-r1234yf-27646/

[156] Ibid footnote 145.

[157] Ibid.

[158] Ibid

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
		HFO-1234yf and R-513A are registered for use in public transport vehicles so can also be used.	electric buses, the Ultralight 500-700 CO_2 Heatpump[159]. Solaris also offer a CO_2 heat pump in their electric model Urbino 15 LE[160].
		Standard refrigerants are HFC-134a and R-407C (mainly in Southern Europe; in trams and underground railcars). The long lifespan of rail vehicles is a key consideration. R-513A has been introduced as a retrofit option for HFC-134a systems but is seen as an interim solution only. HFO-1234yf is a possible alternative to HFC-134a and is technically feasible to replace HFCs.	CO_2 and Propane are possible alternatives, research is ongoing[161].
	Ships	HFC-134a is the incumbent choice for marine air conditioning. HFOs are technically feasible alternatives to conventional HFCs.. Cruise liners operating with centrifugal chillers on HFC-134a have been successfully retrofitted to R513A with a 1% reduction in energy efficiency.	Systems using flammable alternatives will require radical re-design of equipment. However, R-744 and R717 have been used in fishing vessels.
Moveable room air conditioning	Domestic and commercial applications	In the past R-410A and R-407C were common refrigerants for moveable air conditioning units. Movables are relatively small air conditioners with capacity ranging between 2a and 7 kW with a refrigerant charge between 0.2 and 2 kg. They have a significant market share in Europe[162]. According to industry expert elicitation R-454C is an emerging alternative to incumbent F-gases.	Recently, R-290 has gained a large market share[163]. The estimated number of units running on hydrocarbons is around 200,000 units as of 2020[164].

[159] Konvekta, 2022. Ultralight 500-700 CO_2 heatpump. Retrieved from: https://www.konvekta.de/en/busklima/electric-hybrid-bus/ultralight-700-co2-heat-pump
[160] MUTA srl, 2020. The new bus Solaris Urbino 15 LE equipped with a Konvekta CO_2 heat pump. Retrieved from: https://www.mutasrl.com/en/news/new-bus-Solaris-Urbino-Konvekta-CO2-heat-pump
[161] Ibid footnote 145.
[162] Ibid footnote 145.
[163] Ibid, p.154
[164] Ibid, p.154

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
Stationary air conditioning: Single split systems (one indoor and one outdoor unit connected by a pipe carrying refrigerant)	Various uses, computer server rooms, hotel rooms, etc.	R-32 replaced R-410A in split air conditioners. Most Member States reached a share of R32 for single split systems of more than 80% in 2019 and this share is expected to grow[165, 166]. However, ISO 817:2016 classifies R-32 as A2L flammability. There is some divergence on safety standards between Member States: while Italy and Spain have relaxed their legislation in the past two to three years, allowing for an increase of R32 in single split systems, France still prohibits A2L and A3 refrigerants in high rise buildings[167]. The blend R-454C is a possible alternative to high GWP fluorinated refrigerants. For example, Mitsubish Heavy Industries recently produced a residential air conditioning system which uses R-454C.[168] There is also evidence showing the use of HFOs blends (R454C) being used in dehumidifiers, which are a component of air conditioning units[169]. An example of a R-454C usage is in Biemmedue air conditioning units[170].	R290 is already used in smaller air conditioning systems with low refrigerant charges[171] based on the literature reviewed which has shown that the R290 systems are already in place. Although R290 is highly flammable, categorised in safety group A3, it can be used safely in small charges following the relevant safety requirements standards (IEC 60335-2-40:2022 although the most recent standard is not harmonised as an EU standard). A European technical report concludes it is technically possible to replace F-gases with R-290 in single split air conditioning with a cooling capacity below 7 kW[172]. Some small split system air conditioning units using propane can be classified as market ready. Although in 2018 one Chinese system was awarded the German ecolabel “Blue Angel”[173], there remain questions about the energy efficiency and capacity of R-290 units. In a position paper submitted by EPEE, an industry body for RACHP industry in Europe, the stated capacity of R-290 models is compared with conventional models using fluorinated refrigerants.[174] They state the model which won the ecolabel has a heating to cooling design point ratio of 69%, which limits its capacity to heat a space to not greater than 24 m^2. By comparison, conventional

[165] Ibid, p.155

[166] European Commission, 2020. The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact. Brussels, 30.09.2020. P.9. Retrieved from: https://ec.europa.eu/clima/system/files/2020-09/c_2020_6637_en.pdf

[167] Ibid footnote 145.

[168] Retrieved from: https://www.coolingpost.com/world-news/mhi-plans-euro-launch-of-small-split-using-refrigerant-r454c/

[169] Cooling Post, 2019. MHI plans Euro launch of small split using refrigerant R454C. Retrieved from: https://www.coolingpost.com/world-news/mhi-plans-euro-launch-of-small-split-using-refrigerant-r454c/

[170] Biemmedue, 2022. PROFESSIONAL DEHUMIDIFIERS. Retrieved from: https://biemmedue.com/it/deumidificatori-professionali-arcodry

[171] Bitzer, 2020. Refrigerant Report 21. p.30. Accessible under: https://www.bitzer-refrigerantreport.com/fileadmin/Content/01_Startseite/A-501-21_EN.pdf

[172] European Commission, 2020. The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact. Brussels, 30.09.2020. P.8. Retrieved from: https://ec.europa.eu/clima/system/files/2020-09/c_2020_6637_en.pdf

[173] Green Cooling initiative, 2018. Midea Air Conditioner receives German Ecolabel Blue Angel. Retrieved from: https://www.green-cooling-initiative.org/news-media/news/news-detail/2018/04/01/midea-air-conditioner-receives-german-ecolabel-blue-angel#:~:text=On%20February%2014%2C%202018%2C%20Midea,trade%20fair%20in%20Milan%2C%20Italy.

[174] EPEE, 2022. Additional comments on European Commission report Split AC. Retrieved from: https://epeeglobal.org/wp-content/uploads/2022/03/2022.03.08-EPEE-F-Gas-WG-Position-on-split-AC.pdf

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
			models have a minimum ratio of 100%, with many which exceed this. The industry body compared the energy efficiency of the Blue Angel model to a selection of conventional models (the industry described these models as the "best available") and found that in heating model conventional models could be 28% more energy efficient than the R-290 model. With respect to safety of R-290 models, the European Union Technical report also notes that national legislation has prevented widescale rollout of R-290 equipment[175]. With respect to price, they are available at a modest price increase which could fall if mass produced and marketed at scale[176].
Air conditioning: Multi split systems (VRF)	Commercial and domestic settings (e.g., residential, hotels, restaurants)	VRF systems have significantly higher refrigerant charges than single split and moveable units and their capacity is typically >12 kW (can range up to 300 kW). The typical refrigerant remains R-410A. The range of charge size is between 5 and 50 kg (specific HFC refrigerant charges tend from around 0.3 kg/kW cooling capacity upwards). Since 2019, some R-32 based VRF systems have been on the market, however, these are only available for small capacities (e.g. <35kW)[177]. Hybrid VRF systems[178] were introduced from around 2015 onwards. The refrigerant charge is smaller than non-hybrid systems. They use R-410A and R-32.	No information was found on alternatives to F-gases.

[175] Ibid, p.8
[176] Ibid, p.8
[177] E.g., Mitsubishi Electric R32 City Multi YNW range: https://les.mitsubishielectric.co.uk/latest-news/new-r32-vrf-air-conditioning-provides-complete-solution
[178] They represent indirect systems where the refrigerant is circulating between the outdoor unit and a "hydro unit" while water is circulating inside the building.

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
Chillers	Large and micro chillers	Smaller chillers (<100 kW) have relied on R410A or R407C. Large chillers (>100 – 1500 kW) often run on HFC-134a, R-410A or R-407C and have typical refrigerant charges between 50kg and 500kg. In the last 2-3 years, also R32 and several HFC-HFO blends were introduced such as R-513A, R-452B, R-454B. Turbochillers (>1500 kW) are estimated to have a long lifetime of 25 years. HFC-134a was the most common refrigerant in this application in the past. However, due to the long lifetime of this type of chillers, HFOs have been and are estimated to be the main refrigerant solution from approximately 2025 onwards, at the latest. Chillers are increasingly used for district heating[179].	Alternatives are being researched and propane is expected to play a role. Although charge sizes are currently restricted by safety standards due to the higher flammability (e.g., EN378:2016 Annex C, Table C1 - For human comfort application A3 flammable refrigerants are limited to 5 kg per system when the system is located in open air or machinery room, limits R-290 charge to 5 kg for publicly accessible buildings); chillers are often inaccessible to the public, although not necessarily. Therefore, it is likely that propane will be a suitable alternative in chillers where safety requirements are met. Low-charge ammonia chillers (20 kW at AC conditions; total system charge < 800 g) are also being researched and provide particularly high energy efficiency[180]. Examples of experimental small capacity ammonia chillers: • Cooling capacity of 2.54 kW to 1.91 kW at ambient temperature of 29.7 to 44.2 °C[181] • Cooling capacity ammonia–water absorption chiller 3.5 kW[182] • Modelling for a single-effect ammonia–water absorption chiller 10.5 kW[183]

[179] Industry expert elicitation

[180] Ibid footnote 145.

[181] Goyal, A., et al, 2017. Experimental evaluation of a small-capacity, waste-heat driven ammonia-water absorption chiller. International Journal of Refrigeration. 79, pp.89-100. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0140700717301421

[182] Viswantha, V.K., et al, 2013. Dynamic model for a small-capacity ammonia–water absorption chiller. HVAC&R Research. 19.7, pp.865-881. Retrieved from: https://www.tandfonline.com/doi/full/10.1080/10789669.2013.833974?needAccess=true

[183] Kim, B. & Park, J., 2007. Dynamic simulation of a single-effect ammonia–water absorption chiller. International Journal of Refrigeration. 30.3, pp.535-545. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0140700706001411

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
			Absorption chiller for residential scale applications, 7 kW[184]. However, for safety reasons, ammonia cannot be used in all settings, especially those accessible to the public.
Heat pumps	Space heating in small to medium sized spaces and hot water	HFC-134a, R-407C and R-410A have been widely used in water and space heating heat pump systems. HFC-HFO blends are entering the market as well, several manufacturers presented new models running R-454C (Stiebel-Eltron, MHI) and R-513A (Ochsner). Other options suggested by heat pump manufacturers include R-455A (especially for heat recovery systems) as well as R-452A R-452B and R-454B.	The hydrocarbons propane, isobutane and propene are another alternative for small to medium sized heat pumps. Propane heat pumps in the EU have been commercialised at larger scale in recent years. Charge size limitations in safety standards represent a barrier. Other non-fluorinated alternatives are growing although the existing market share is low. CO_2 has been introduced in Europe for medium sized water heating heat pumps. Air and ground source water heat pumps are available up to 50kW. Significant modifications are required for these options. One industry expert argued that although the market for small hydronic heat pumps is growing, their potential application could be limited. In addition, the industry expert also argued the lifecycle safety of the product is not resolved, especially risks at the end of life and decommissioning stage.
Industrial heat pumps and power generation	District heating and cooling Waste heat recovery	R717, HFC-134a and HFC-245fa were used in the past. Research identified, HFO-1336mz(Z), HFO-1336mzz(E), HFO-1234ze(E) and HFO-1234yf as ideal candidates to replace HFC-134a. HFO-1336mzz(E), HFO-1336mzz(Z)	Research identified propane as a promising low-GWP refrigerant to replace HFC-245fa.

[184] Staedter, M.A. & Garimella, S., 2018. Development of a micro-scale heat exchanger based, residential capacity ammonia–water absorption chiller. International Journal of Refrigeration,. 89, pp.93-103. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S014070071830063X

Heating and cooling	Application or sector	F-gases used currently and new F-gases	Alternatives to F-gases
	Industrial processes Mechanical or electrical power from low temperature natural (e.g., geothermal) or industrial (e.g., process) heat	HCFO-1233zd(E) and HCFO-1224yd(Z) were the most promising low-GWP refrigerants to replace HFC-245fa. In Europe, industrial activity can provide a large resource of low temperature heat. Commercial heat pumps could use waste heat in order to reduce reliance on fossil fuels for heating. Identified HFOs could support this transition.	

2.2.2.4.2 Foams

Foams are used in the construction of items which require insulation or a seal. This includes a variety of products, such as, technology which needs to be sealed against liquids and homes which need insulating to maintain the desired temperature. Foams used to insulate the built environment provide significant social, economic, and environmental value by providing thermal comfort, and reducing energy demand which reduces both energy bills and fossil fuels burnt.

Foams used for insulation require a blowing agent to reduce the density of the foam and serve as an insulating component. The blowing agent should have a boiling point near room temperature, have moderate solubility in the polyol yet have a low solubility for the polymer to ensure desired mechanical properties are achieved. The molecular weight should be low enough so that when it converts from a liquid to a gas, it can have enough "blowing power" to reduce the density of the foam. Some products require the use of gaseous blowing agents, such as adhesives, sealants, and low-pressure foam insulation. In this case, the blowing agent also serves as a propellant to dispense the product from a pressurised container, without the need to constantly apply external pressure.

Polyurethane (PU) foam, often marketed as spray polyurethane foam (SPF) is one of the most commonly used foams for insulation and packaging. In the downstream users' survey, businesses using SPF state the blowing agent for SPF products should have several physical, thermal, environmental and health-related attributes[185]. In addition, for the downstream users they must also be affordable and have good market availability. To achieve a thermal insulating foam, the blowing agent should have low thermal conductivity and low permeability to achieve long-term thermal insulation performance. As discussed in Table 2-13, non-F-gas alternatives do not currently meet all of the desired properties which the current F-gas blends do. To meet equivalent performance characteristics of F-gases a blend of alternatives would be necessary. This could incur additional capital costs of the construction and training for downstream users.

Table 2-14 provides an overview of three foams which use F-gases which are in the scope of the proposed restriction. The initial desk-based research indicates that production heavily relies on F-gases within the scope of the proposed restriction and also as low-GWP alternatives. Currently HFC-245fa, HFC-227ea, HFC-365mfc/227ea and HFC-134a are used as foam-blowing agents[186]. By 2023, HFCs with GWP greater than 150 will cease being used in foam manufacturing in the EU[187], as stated in the F-gas Regulation, which will cover all the HFCs currently used in foam blowing except HFC-152a. Non-fluorinated alternatives currently used include methyl formate, cyclopentane, iso-pentane, n-pentane and carbon dioxide water (otherwise known as dry ice).

[185] Non-flammable, non-toxic, zero ODP (ozone depletion potential), zero volatile organic compounds, low to no chemical reactivity with other components, low thermal conductivity, low permeability, appropriate vapor pressure, and must result in resilient mechanical properties & product performance criteria (including moisture resistance, dimensional stability, compressive strength of product)

[186] Holland, M. & Hollins, S., 2021. Application of fluorinated gases (F-Gases) on the European Economic Area. Exponent International Ltd. For the Norwegian Environment Agency. P.10. Retrieved from: https://www.miljodirektoratet.no/sharepoint/downloaditem?id=01FM3LD2VZ2PFZD5VJ2JB2ZZ2GDG7TWV6B

[187] Ibid.

Table 2-14 F-gases used in foams, including specific usage, refrigerants used and alternatives. Information extracted from the Annex to the F-gas Evaluation[188].

Foam	Application	F-Gases used currently and new F-gases	Alternatives to F-gases
Extruded Polystyrol or XPS	Insulation	HFC-134a and HFC-152a are the main F-Gases used in foam blowing, they replaced HCFC-142b and HCFC-22 (both are ozone depleting). Requirements for board thickness varies between Member States and applications. HFO-1234ze is a potential replacement to HFC-134a and HFC-152a[189] where the thickness of the foam boards is relevant. HFO-1234ze has been shown to have low thermal conductivity in insulating panels (20 to 25% lower compared to CO_2 blow foam[190]. In 2015, Honeywell began full-scale production of HFO-1234ze[191].	As discussed, requirements for board thickness varies between Member States and applications. Where thickness is not relevant, CO_2 has already been used for many years and is a natural replacement to HFC-152a.
Polyurethane (PU) (used in SPF)	PU rigid foam is used in several contexts: • Continuous and discontinuous panels or blocks • Laminate	There are three HFCs in use: HFC-134a, HFC-245fa and HFC-365mfc replaced HCFC-141b in the early 2000s. HCFC-141b replaced CFC-11 in the 1990s. The most widespread ODS blowing was HCFC-141bb. HCFO-1233zd(E) has been found to have superior mechanical and thermal properties to conventional blowing agents one company which develops foams and blowing agents has developed a blowing agent using HCFO-1233zd, Forane, FBA 1233zd which is intended as a replacement to HFC-365mfc[192].	The use of water as the primary chemical blowing agent to make carbon dioxide is useful in open cell spray foams. Closed cell spray foams remain reliant on physical, non-flammable blowing agents with low boiling points. Carbon dioxide, nitrogen / air, and methyl formate do not have the appropriate vapor pressures and foaming abilities to work alone as propellants and foaming agents Fiberglass, mineral wool, cellulose, natural fibres, polystyrene, and cementitious foam have reduced

[188] Ibid footnote 145.

[189] Green Building Adviser, 2015. A new blowing agent with a lower environmental impact. Retrieved from: https://www.greenbuildingadvisor.com/article/a-new-blowing-agent-with-a-lower-environmental-impact

[190] EFCFC, 2015. HFO-1234ZE BLOWING AGENT FOR HIGH PERFORMANCE XPS (EXTRUDED POLYSTYRENE) AND PUR (POLYURETHANE) INSULATING FOAMS. Retrieved from: https://www.fluorocarbons.org/news/hfo-1234ze-blowing-agent-for-high-performance-xps-extruded-polystyrene-and-pur-polyurethane-insulating-foams/

[191] Green Building Adviser, 2015. A new blowing agent with a lower environmental impact. Retrieved from: https://www.greenbuildingadvisor.com/article/a-new-blowing-agent-with-a-lower-environmental-impact

[192] elicited from industry expert

Foam	Application	F-Gases used currently and new F-gases	Alternatives to F-gases
	• Appliances • Pipe-in-pipe foam • Spray foam	HFO-1336mzz(Z), is a replacement and near drop in for HFC-245fa, HFC-365mfc and HFC-227ea and is stable with catalysts that were used with HFC-245fa and HFC-365mfc.	performance compared to polyurethane spray foam. In isolation, they do not provide all the performance requirements of polyurethane spray foam[193,194]. Secondary products are required to meet SPF's performance.
One component foam (OCF)	10% contain HFCs	HFC-134a was the main type until it's use was prohibited in the EU for most cases in 2008. i-butane and n-butane are also common in OCF. when flammability is not a concern. HFO-1234ze is an emerging foam, which can also be used in OCF if flammable butane cannot be used.	No alternatives to F-gases were identified.

[193] Air barrier, moisture barrier, vapor retarder, thermal and acoustic barrier, and added structural strength

[194] Gradient, 2020. Abridged Alternatives Analysis Report for Two-component Low- and High-pressure Spray Polyurethane Foam Systems Containing Unreacted Methylene Diphenyl Diisocyanate, Gradient prepared for American Chemistry Council, Center for the Polyurethanes Industry, Spray Foam Coalition. Retrieved from: https://calsafer.dtsc.ca.gov/documentitem/index/?guid=8d4ac098-1b78-4954-89e5-846e1b88cfa9

2.2.2.4.3 Aerosols

In the past, the use of HFC-134a as an aerosol propellant was common for certain specialised applications. Examples include: sprays for testing and some industry applications, but also household and leisure products to a limited extent (e.g. signal horns, confetti sprays). However, in recent years its use has decreased as its GWP is significant and there are more environmentally friendly alternatives available[195].

2.2.2.4.4 Medical applications

F-gases within the scope of this study are used in medical applications. The main use of F-gases in medical applications is in respiratory drugs. There are two common types of inhalation devices for the delivery of respiratory drugs: metered dose inhalers (MDIs) and dry powder inhalers (DPIs) which come in single or multiple doses. MDIs use a propellant to deliver the medication. DPIs deliver powdered medication without the need for a propellant. Other methods of delivering drugs to the lung include soft mist inhalers and nebulisers. The choice of the most suitable treatment method is a complex decision taken between the health care provider and the patient.

The current EU F-gas Regulation exempts MDIs from the EU HFC phase-down, hence there are no direct regulatory pressures on this application of HFCs. A 2019 study for the United Kingdom's Committee on Climate Change found, in the context of the UK, that without any change to the current prescribing practices usage and emissions will continue to rise slowly[196]. The report suggested a conservative estimate is a further 10% rise of MDI use by 2030. However, there is variation between different countries' usage of MDIs relative to DPIs and other medications. These proportions vary for many reasons including prescribing practices, cost, availability, patient preference, and national government guidance. In Europe, an assessment of inhaler uptake has not been undertaken since 2011[197]. MDI usage in European Member States at this time was lower than in the UK. Therefore, this projection may not be true for the European market. The 2011 study used retail sales of inhalers to understand what the market share of the different types are. The study found MDIs are widely prescribed in Europe although there is some variability between Member States which can be attributed to varying health policies and approaches to health care. The study suggests MDIs are likely to be the drug of choice due to their low cost and the range of medications which can be delivered in this way.

Medical devices are subject to extensive regulation by national health authorities to ensure product safety, product efficacy and product quality. The process for developing HFC propellants for MDIs includes the equivalent checks to develop a new drug, involving full safety testing, stability testing and clinical trials[198]. Therefore, developing a propellant suitable for use in MDIs is a lengthy, challenging, costly and resource-intensive process. For example, a HFC for an asthma MDI requires at least 12 months clinical trial, as well as lifetime studies in laboratory animals which means it can take 6 years to reach the physician and 10 years to become established on the market[199,200]. This example serves to highlight that the proposed restriction is not the most effective form of regulation as MDIs are already subject to stringent and bespoke requirements which ensure safety and quality in a manner supportive of the industry.

Data on the F-gases used in European MDIs was not found, however, global data was identified. Globally, HFC-134a is the major propellant in MDIs (around 10,600 tonnes in 2018), followed by HFC-227ea (~900 tonnes in 2018)[201]. In the context of the proposed restriction, alternatives to the existing incumbent HFCs are in varying stages of development. Three F-gases have been under development to replace high-GWP MDI HFCs (HFC-152a, and HFO-1234ze(E))[202]. HFO-1234ze(E) is within the scope of the proposed restriction. HFC-152a is at the most advanced stage of development, which is led by pharmaceutical company Koura

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[195] https://www.spraywayinc.com/content/hfc-134a-technical-brief

[196] CCC, 2019. Assessment of the potential to reduce UK F-Gas emissions beyond the ambition of the F-gas Regulation and Kigali Amendment. Ricardo for the CCC. Retrieved from: https://www.theccc.org.uk/wp-content/uploads/2019/05/Assessment-of-potential-to-reduce-UK-F-gas-emissions-Ricardo-and-Gluckman-Consulting.pdf

[197] Lavorini, F., 2011. Retail sales of inhalation devices in European countries: So much for a global policy. Respiratory Medicine. Vol.105, Issue 7, pp.1099-1103. https://doi.org/10.1016/j.rmed.2011.03.012

[198] UNEP, 2018. Medical and Chemicals Technical Options Committee, 2018 Assessment Report. Retrieved from: https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf

[199] Ibid.

[200] CCC, 2019. Assessment of the potential to reduce UK F-Gas emissions beyond the ambition of the F-gas Regulation and Kigali Amendment. Ricardo for the CCC. Retrieved from: https://www.theccc.org.uk/wp-content/uploads/2019/05/Assessment-of-potential-to-reduce-UK-F-gas-emissions-Ricardo-and-Gluckman-Consulting.pdf

[201] UNEP, 2018. Medical and Chemicals Technical Options Committee, 2018 Assessment Report. Retrieved from: https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf

[202] Ibid.

(formerly Mexichem)[203]. Isobutane and HFO-1234ze(E) are at an earlier stage of development than HFC-152a. At the time of writing, no MDI products containing isobutane are on the market. Previous studies had reported toxicological concerns for isobutane used in combination with medication required to relax muscles in the airways[204]. Furthermore, isobutane's flammability would need to be addressed by engineering the device appropriately.

Alternative treatment options also exist which do not require fluorinated gases. It is possible to replace a significant proportion of the MDIs used in treatment with DPIs, which eliminates the need for a propellant[205,206]. In addition to these two main options, nebulisers and other aqueous spray inhalation devices could also be used as an alternative to MDIs, however, they currently represent a small part of the market.

Furthermore, studies have shown MDIs are more difficult to use than DPIs[207]. MDIs require coordination of aerosol release with an intake of breath. If this is not done correctly much of the drug is wasted. By contrast, DPIs are actuated by the intake of breath, so coordination is not required, and effective use is easier to achieve. This makes DPIs useful for daily use inhalers, but challenging as an alternative to rescue inhalers or for patients with insufficient breathing capacity. Changes to prescribing practices will be required to achieve a shift from MDIs192, according to a study. However, changes to prescribing practices will be required to achieve a wholesale shift from MDIs[208], according to a study. To achieve the required levels of changes in prescribing practices the study finds investment in patient education and affordable DPIs will be required. The study puts the cost of salbutamol at $0.06 USD per dose (used in MDIs), but $1.07 USD per dose for LABA/ICS (the drug commonly used in DPIs). However, overall, the article argues patients can use DPIs more effectively with some exceptions. Young and old patients and those undergoing an acute exacerbation will still require a pMDI. Therefore, MDIs ,must still be available, although on the whole DPIs can be prescribed more widely.

The stakeholder consultation conducted for this study received responses from two producers and/or importers of MDI HFCs. The respondents argued MDIs should be classed as essential issue, therefore, derogations from the proposed restriction would be appropriate.

Downstream users were also consulted for this study, two respondents worked with MDIs. Similarly, to MDI HFC producers and/or importers, respondents argued MDIs constitute essential use. All respondents argued the medicines are lifesaving, and some medicines are listed as essential by the WHO. MDIs are often the only respiratory therapy available to patients to manage their life-threatening conditions. Furthermore, the EU supplies these medicines globally, including to low- and middle-income regions. Further restriction would disrupt the availability of lifesaving medicines in the EU and globally with consequences for human health and the pharmaceutical industry. Therefore, derogations from the proposed restriction would be appropriate for MDIs.

Table 2-15 F-gases used in medical applications, including specific usage, refrigerants used and alternatives. Information extracted from the Annex to the F-gas Evaluation[209].

Foam	Application	F-gases used currently	Alternatives
Metered Dose	Aerosol sprays for drug application	Two F-gases, HFC-134a and HFC-227ea are used for MDIs. Globally, the share of HFC-	Isobutane. There are safety concerns relating to toxicity when combined with medication and also flammability[210].

[203] OINDP news, 2020. Koura announces investment in Zephex HFA 152a propellant production. Retrieved from: https://www.oindpnews.com/2020/06/koura-announces-investment-in-zephex-hfa-152a-propellant-production/

[204] UNEP, 2018. Medical and Chemicals Technical Options Committee, 2018 Assessment Report. Retrieved from: https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf

[205] Starup-Hansen, J., et al, 2020. Climate change in healthcare: Exploring the potential role of inhaler prescribing. Pharmacology Research Perspective. Retrieved from: https://bpspubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/prp2.675

[206] CCC, 2019. Assessment of the potential to reduce UK F-Gas emissions beyond the ambition of the F-gas Regulation and Kigali Amendment. Ricardo for the CCC. Retrieved from: https://www.theccc.org.uk/wp-content/uploads/2019/05/Assessment-of-potential-to-reduce-UK-F-gas-emissions-Ricardo-and-Gluckman-Consulting.pdf

[207] Albertson, T.E., et al, 2017. The Salford Lung Study: a pioneering comparative effectiveness approach to COPD and asthma in clinical trials. Pragmatic Observational Research. 8:175, pp.175-181. Retrieved fro: https://pubmed.ncbi.nlm.nih.gov/29033625/

[208] Pritchard, J. N., 2020. The Climate is Changing for Metered-Dose Inhalers and Action is Needed. Drug Design, Development and Therapy. Vol. 14, pp.3043-3055. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7410333/

[209] Ibid footnote 145.

[210] UNEP, 2018. Medical and Chemicals Technical Options Committee, 2018 Assessment Report. Retrieved from: https://ozone.unep.org/sites/default/files/2019-04/MCTOC-Assessment-Report-2018.pdf

Foam	Application	F-gases used currently	Alternatives
Inhalers (MDIs)		227ea is about 8% compared to 92% of HFC-134a. HFC-152a is currently being researched intensively and two MDI manufacturers announced that they will put products for asthma and COPD treatment employing this propellant. The performance of HFC-152a is considered to be at least as good as HFC-134a and HFC-227ea or better. HFO-1234ze(E) has also been identified as a possible alternative	Other ways of administering the drug have also been considered, for example, dry powder inhalers.

2.2.2.4.5 Solvents

A small residual market remains for HFC-based solvents which are mainly used for degreasing of metal prior to precision coating and in the optics and electronics sector. HFC-43-10mee is the main HFC-based product. HFC-43-10mee has a GWP of 1660[211] which is relatively high. Driven by the F-gas Regulation, low GWP options for alternatives to HFC-43-10mee have been identified. Two such alternatives are HCFO-1233zd and HFO-1336mzz(Z). The presence of chlorine in HCFO-1233zd means its effectiveness is higher than the original HFC-43-10mee. HFE-7200 and Perfluoropolyethers (PFPEs), both fall under the PFAS definition, can also be used as alternatives, however PFPEs have very high GWPs.

2.2.2.4.6 Fire protection

The Commission and ECHA recently commissioned a study on potential regulatory options to address the risks associated with the use of PFAS in fire-fighting foams in the EU. The results of the study found fluorine-free fire-fighting foams are generally available and technically feasible. The study identified the most relevant technologies for the remediation of PFAS contamination from use of fire-fighting foams[212]. However, it should be highlighted that F-gases are not used in the manufacture of fire-fighting foams.

Typical applications could include chemical storage areas, clean rooms, communications facilities, laboratories, museums, robotics, military vehicles, military and commercial aviation. Fixed fire protection systems use HFC-227ea and HFC-125, while HFC-236fa is used in portable fire extinguishers. HFC-227ea is the most used gas in the EU, followed by HFC-125 (introduced as halon replacement). The market for portable devices containing HFC-236fa is said to represent a niche in military or naval applications, along with some commercial aviation applications. Sectors such as the military, aviation and oil and gas sectors still require the use of HCFCs, HFCs and halons in portable/wheeled unit applications, because they require substances with superior extinguishing capacities, which cannot be satisfied by the alternatives currently on the market. This emphasises the importance of the substance being excluded from the proposed restriction as evidence shows its essential application to support key public sectors and the absence of an alternative approach.

Strong reliance on HFC-227ea in fire suppression systems suggests the proposed restriction could have a significant detrimental impact on this sector. There are numerous alternatives to F-gases for fire suppression systems, with further limitations on performance and/or safety. Between 2014 and 2019, the HFCs supplied for the fire-protection sector has fallen by over 90%. It is likely that the small remaining supply is for topping-up existing HFC-based systems and specialist systems for which substitutes are less available[213]. This

[211] Arnold, T., et al, 2014. HFC-43-10mee atmospheric abundances and global emission estimates. Geophysical Research Letters. Vol.41, Iss. 6. Retrieved from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013GL059143

[212] ECHA, 2022. Proposal to ban 'forever chemicals' in firefighting foams throughout the EU. Retrieved from: https://echa.europa.eu/-/proposal-to-ban-forever-chemicals-in-firefighting-foams-throughout-the-eu#:~:text=The%20European%20Chemicals%20Agency%20brings.for%20people%20and%20the%20environment.

[213] EEA, 2020. Fluorinated Greenhouse Gases 2020. Accessible under: https://www.eea.europa.eu/data-and-maps/data/fluorinated-greenhouse-gases-aggregated-data-2, and EEA, 2021. Fluorinated Greenhouse Gases 2021. Table A5.22. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021.

indicates that compared with other sectors the restriction may not be as potentially disruptive. Although not F-gases, many of the alternative substances would also be included within the proposed PFAS definition, e.g., FK-5-1-12.

2.3 DEFINITION OF THE "PROPOSED RESTRICTION" SCENARIO

The proposed restriction translates into an immediate restriction of the manufacture, placing on the market (including import) and use of these F-gases. Therefore, companies within the F-gas industry (both manufacturers/importers and their downstream users) would lose their full portfolios related to the F-gases in scope unless they were able to manufacture alternatives.

Businesses are therefore expected to be able to mitigate a share of the potential product withdrawals that would result from the restriction of the F-gases in scope. In order to achieve this mitigation, they would need to incur additional capital, operating and R&D expenditure. In particular, as a result of the restriction, businesses would need to increase their Capex and Opex per unit of sales, costs associated with substitution and/or reformulation. On the other hand, costs associated to any share of products that may be lost as a result of the restriction, would be lost as well.

These impacts would therefore affect the size and cost of operation of the companies within the EEA F-gas industry. The net reduction in EEA business operations, or direct impacts, would propagate through the EEA economy and have indirect and induced effects (indirect effects constitute a reduction in demand for inputs through the value chain of suppliers to the F-gas industry, while induced effects refer to the reduction in overall demand of consumer goods in the whole economy due to job losses as a result of the direct and indirect impacts) estimated in terms of potential reductions in the sector's contribution to GDP and employment over time.

The mitigation strategies that businesses may follow to mitigate portfolio losses could include the substitution of F-gases with other substances or with other technologies, the abandonment of certain production lines in the EEA, etc.

There is a large amount of evidence required for the assessment of economic impacts of the restriction of F-gases that fall within the scope of the proposed PFAS restriction. There are a few F-gas producers in the EEA, but an indeterminate number of importers, which also generate economic activity within the EEA and would be affected by the restriction. There is also a range of F-gas downstream user sectors that can be classified with various degrees of detail, conditional on data availability.

The evidence available in published reports and studies, as well as economic statistics, is insufficient to quantify the potential business impacts of the restriction of the F-gases in scope without the introduction of a wide range of assumptions. Therefore, engaging business stakeholders from across the whole F-gas industry and downstream user sectors to gather primary evidence on their operations and their value has been central to the assessment of economic impacts of the restriction proposal.

The consultation activities involved two targeted consultations with business stakeholders, one with F-gas producers and importers, and the other one with downstream users for all the F-gas applications.

2.3.1 Economic impact surveys to producers and importers, and to downstream users

The aim of both surveys was to collect evidence that would form the basis for an assessment of the extent to which a restriction on the F-gases in scope would impact the operations of EEA producers, importers and downstream users. The assessment also took into account how all these businesses would expect to respond to the restriction (e.g. by resourcing to alternatives – either non-fluorinated or other chemicals not subject to the restriction-, both as producers, importers and as consumers of the F-gases in scope, considering potential derogations, etc.). The intention was for this to allow the quantification of knock-on effects through the value chain, based on the evidence collected directly from businesses.

Generally, both surveys consisted of the following four parts:

- Part 1, gathering data about the respondents in terms of their size, activities, area of operation, etc.
- Part 2, seeking to form a baseline for the sector's turnover, costs, expenditures, employment, regulatory burden, based on current information provided by companies and their expectations of growth over the next decade.

- Part 3, assessing businesses' expected responses or reactions to the restriction proposal (e.g. substitution of F-gases with other substances, with other technologies, abandonment of certain production lines, application for derogations, etc.) and their costs and benefits over the next decade.
- Part 4, collecting a direct assessment by participants of the overall expected impacts of the proposed restriction, to be used as complementary to the previously provided information on reactions to the restriction and as a sense check (e.g. turnover, employment, overall investment and costs).

The survey covered all of the key business and economic impacts that were screened as potentially most significant (Section 2.1.3.2). The types of questions covered across these key business impacts and/or proxies are outlined in Table 2-16 below:

Table 2-16 Types of questions covered by both economic impact surveys.

Policy, key business impacts or proxies	Information sought by the survey for evidence on operations in the EEA (not an exhaustive list)
Policy	Establishing the relevance of the restriction proposal for each respondent
Turnover / business size	• 2019 turnover and tonnes of F-gases in scope sold (or of downstream applications), number of products; annual growth expected in the absence of the restriction over 10 years; annual growth expected upon adoption of a potential restriction over 10 years. • Percentage (or sales value) of the affected portfolio that would be in scope for substitution and/or reformulation with alternatives; and potential derogations from new legislative requirements; expected pass through of potential regulatory burden; considerations of customer responses from price changes based on historical evidence
OPEX	• 2019 annual operating costs; annual growth expected in the absence of the restriction over 10 years; annual growth expected upon adoption of the proposed restriction over 10 years (for the retained business) • Recurring costs of substitution and/or reformulation, and derogations, across different cost categories. Detailed questions associated with administrative burden from the wider regulatory context were also considered.
CAPEX	• 2015-2019 average annual total capital investment; annual growth expected in the absence of the restriction over 10 years; annual growth expected upon adoption of the proposed restriction over 10 years • Recurring costs of substitution and/or reformulation, and derogations, across different cost categories
R&D	• Level of operating expenditure/ capital investment devoted to R&D expenditure in the EEA and expected evolution in the absence of the proposed restriction; annual growth expected upon adoption of the proposed restriction over 10 years.
Regulatory burden	• Percent of annual operating and capital costs driven by the EEA Regulatory acquis and likely evolution in the absence of the proposed restriction; annual growth expected upon adoption of a restriction over 10 years • Additional operating and capital requirements driven by the changes considered
Employment	• 2019 employment; annual growth expected in the absence of the restriction over 10 years; annual growth expected upon adoption of a potential restriction over 10 years

Policy, key business impacts or proxies	Information sought by the survey for evidence on operations in the EEA (not an exhaustive list)
	• Potential labour requirements for substitution and/or reformulation; additional administrative activities associated with the restriction
Other economic impacts	• Consideration of impacts on imports and exports • Qualitative effects on competitiveness

Evidence from the consultation of stakeholders was elicited and triangulated across responses to multiple questions (e.g. more implicit versus explicit approaches to gather evidence from businesses' informed views), in order to compare and contrast the impacts and test the robustness of the information gathered.

The data obtained in this consultation is deemed sensitive under competition law. In order to ensure compliance, access to responses to the consultation is limited to study team members from Ricardo and the data is stored in a folder with limited access rights. EFCTC and participants do not have access to any data, other than that which they submitted themselves. In the analysis of the data, Ricardo follows the statistical rules of Cefic, of which EFCTC is a member association, ensuring that all data is aggregated[214] and anonymised to prevent reverse engineering.

Finally, it is noted that 2019 is taken as the baseline year for eliciting evidence of potential impacts from businesses through survey, as 2020 is not considered representative of normal operating conditions of the EEA F-gas and downstream user sectors due to the COVID-19 pandemic. Expectations for baseline growth and impacts over the next decade consider the decade starting in 2022. This means that the information gathered referred to potential impacts with regards to 2019 business operations, considering that the contractive effects of the pandemic over the EEA economy have been overcome by 2022. Nevertheless, the information gathered is triangulated with available projections from the European Commission[215] as to the expected recovery from the pandemic to generate a baseline and Impact Assessment that aligns with said expectations.

2.4 TIME AND GEOGRAPHICAL BOUNDARIES OF THE SEA, AND OTHER SCOPE CONSIDERATIONS

The analysis focusses on the direct and indirect contributions to the economy, human and environmental health, and the wider economy and society of the following selected list of F-gases:

- HFC-125
- HFC-134a
- HFC-143a
- HFC-227ea
- HFC-245fa
- HFC-365mfc
- HFO-1234yf
- HFO-1234ze
- HFO-1336mzz(Z)
- HCFO-1233zd

[214] The aggregated data used always must come from more than five independent companies, the latter being understood as the collection of undertakings whose relations with the company participating to the statistical exercise come within the terms of one or more of the sub-paragraphs of Article 5(4) of the EU Merger Regulation. Any input of less than 5% of the total volume reported by companies cannot be taken into consideration. Even when aggregated, the data must not come from one company with more than 70% of the total volume. No price information is included in the report.

[215] European Commission, Winter 2022 Forecast. Available from: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_926.

Geographically, it covers the European Economic Area[216] (EEA), in line with the scope of the proposed restriction. The analysis consists of a comparison between:

- A baseline scenario projection of the F-gas supply, which takes into account the phase-down of F-gases imposed by the current F-gas Regulation until 2030, with no further policy developments.
- A restriction scenario representing the intended blanket restriction on all PFAS including the F-gases in scope.

In order to do this comparison, baseline and restriction scenario projections are extended to 2040 in order for the restriction and its effects to fully take place.

Baseline and restriction scenarios for downstream user applications of F-gases are included in the analysis. This split between applications is taken into account in the analysis to the extent that the data allows, which has been limited mainly due to the fact that all downstream users are producing in at least two of these applications, and in up to seven of them. The list of applications includes:

- Refrigeration: commercial, industrial, domestic and transport refrigeration.
- Stationary AC
- Mobile AC
- Heat pumps
- Solvents
- Propellants
- Fire protection
- Foam products
- Foam Blowing Agent
- Magnesium Casting
- Others (to be collected in consultation).

[216] Ibid footnote 11.

3. ANALYSIS OF THE RESTRICTION IMPACTS

3.1 ECONOMIC IMPACTS

An ex-ante assessment of the economic impacts of a PFAS restriction that includes the F-gases in scope is presented in this section. Economic impacts will consist of business impacts borne by the F-gas industry and by producers and/or importers of downstream user applications of F-gases. Additionally, potential knock-on effects throughout the whole European economy are presented. This analysis constitutes a focussed assessment of business-driven economic impacts, based on quantitative and qualitative insights provided in consultation.

First, the assessment of potential impacts that the F-gas industry (i.e. producers and/or importers) may face from the proposed restriction, accounting solely for the impacts on their F-gas portfolios, is presented. Second, the assessment of impacts of the proposed restriction on F-gas downstream users is presented. These two assessments rely on: the baseline developed in Section 2.2.2, the most recent data on F-gas placing on the market from the European Environment Agency (EEA), evidence on expected outcomes of the restriction gathered via survey of 9 F-gas producers and/or importers (representing the whole F-gas industry with a margin of error estimated in +/- 6-7%) and 29 downstream users from different industries, and secondary research.

These outputs are presented separately for the F-gas industry, and for F-gas downstream users. For each of these groups, results are structured in the following way:

- The scope and potential scale of impacts as indicated by the business portfolio that would be affected by the restriction
- A consideration is made of business responses to these impacts – this includes a summary of qualitative responses to the survey on key F-gas alternatives that may be available today or in the future and their comparison with F-gases vis a vis their costs, properties, safety profile, and energy consumption
- Costs and benefits for the F-gas industry and on downstream user industries, including their turnover, GVA, intermediate consumption and operating costs, capital investment and R&D expenditure, the regulatory burden faced by these sectors, and employment
- Other qualitative business considerations.

3.1.1 Business impacts on F-gas producers and/or importers

The proposed restriction translates into an immediate restriction of the manufacture, placing on the market (including import) and use of these F-gases. Therefore, companies within the F-gas industry would lose their full portfolios related to the F-gases in scope unless they were able to manufacture alternatives.

Businesses expect to be able to mitigate a share of the potential product withdrawals that would result from the restriction of the F-gases in scope. In order to achieve this mitigation, they would need to incur additional capital, operating and R&D expenditure. Therefore, as a result of the restriction, businesses would need to increase their Capex and Opex per unit of sales, costs associated with substitution and/or reformulation.

These impacts would therefore affect the size and cost of operation of the companies within the EEA F-gas industry. The net reduction in EEA business operations, or direct impacts, would propagate through the EEA economy and have indirect and induced effects (indirect effects constitute a reduction in demand for inputs through the value chain of suppliers to the F-gas industry, while induced effects refer to the reduction in overall demand of consumer goods in the whole economy due to job losses as a result of the direct and indirect impacts) estimated in terms of potential reductions in the sector's contribution to GDP and employment over time.

The effects presented above are presented in the following sections:

- The affected portfolio (3.1.1.1)
- Expected business responses (3.1.1.2)
- Costs and benefits driven by the impacts on EEA F-gas businesses (3.1.1.3)

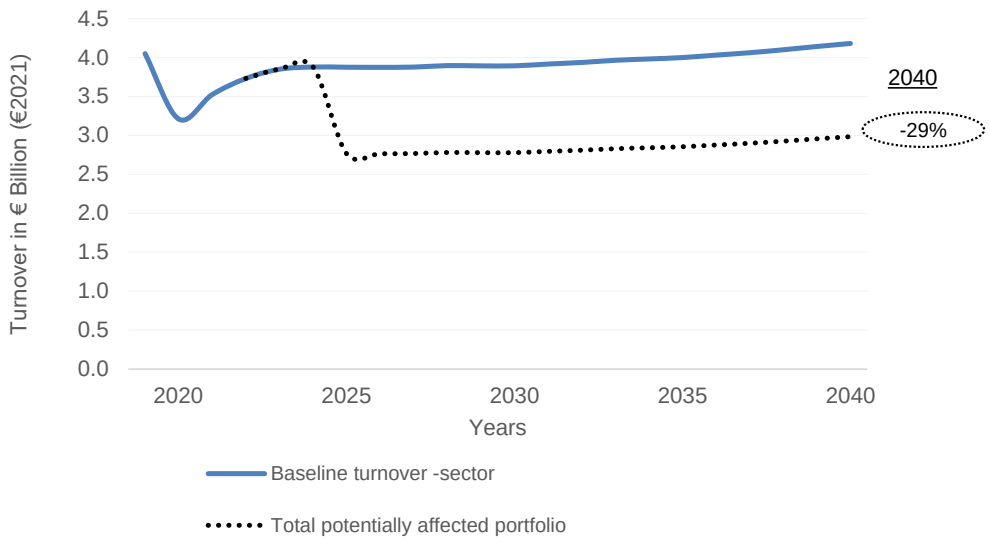
3.1.1.1 The affected portfolio

The business scope of companies participating in the consultation was generally wider than just F-gas production and import. Overall, their portfolios of the F-gases in scope represented on average[217] 29% of the total turnover of the surveyed companies, or €1.2 billion. This is a first measure of the potential loss of business in the restriction scenario, which will be referred to as the **'affected portfolio'**. However, this measure differs by company, and for the majority of respondents, it represented the totality of their business.

According to the expected regulatory timelines, the restriction would not be likely to enter into force before 2025, but after that date, it would be implemented in full. Evidence collated from the survey was overlayed with this expected schedule to produce the total affected portfolio series until 2040 to show the maximum potential losses if no alternatives are found for F-gases by the F-gas industry[218].

Figure 3-1 presents the estimates of the size of the portfolio of products in scope of the restriction for the companies of the F-gas industry against the baseline projections of turnover until 2040.

Figure 3-1 Production portfolio (in terms of total turnover) that is in scope of being affected by the restriction of the F-gases in scope.



Source: Ricardo analysis based on Eurostat data and a bespoke survey to F-gas producers and/or importers.

These estimates can be considered unlikely upper bounds for the potential reduction of the EEA F-gas industry's business volume, as it assumes the industry does not adapt, where possible, to mitigate these impacts. This projection is taken forward as the basis for the quantification of the potential impacts on the EEA F-gas industry and knock-on effects on the broader economy.

As outlined above, on average the F-gas portfolio represents 29% of the whole F-gas producers and/or importers' total turnover[219]. However, for the majority of the companies it represents 100% of their business, implying that they would be forced out of business in the absence of a strategy that allows them to steer their production towards other products.

3.1.1.2 Expected business responses

The evidence collected suggests that, in response to the proposed restriction, businesses will substitute and/or reformulate more than half of their products, in turnover value €, to mitigate market losses, although this will depend on a positive market uptake and on the degree of substitutability of the new products and formulas (e.g. product performance, costs, hazard profiles, and energy consumption). Box 3-1 outlines the evidence

[217] 29% is the weighted average of the F-gas portfolio in turnover value € over each company's total turnover. While for a majority of survey participants this percentage is 100%, there is a number of large companies with a much larger business scope. This entails distributional effects in the event of a restriction (e.g., smaller businesses may be pushed out of the market with higher likelihood than larger ones).

[218] Alternatives might still be found in other sectors. Results from the consultation to downstream users provide additional insights on viable alternatives to the ones provided by the F-gas industry.

[219] 29% is the weighted average of the share of each company's turnover from F-gases in scope over their total turnover. Companies with a share of 100% of F-gases in scope in their turnover are smaller (i.e., have much lower annual turnover figures).

collected related to the EEA F-gas sector's capacity to substitute and/or reformulate that has been considered in this analysis.

Box 3-1 Substitution and/or reformulation of products that may be affected by the proposed restriction.

9 businesses were surveyed to gather evidence as to the extent to which they may implement specific actions resulting from the adoption of policy changes and their likely scale, especially including substitution and/or reformulation. F-gas businesses are in some cases producers of F-gases in basic form, and in most cases importers of said F-gases and formulators of mixtures and articles containing F-gases.

Businesses surveyed suggest that they would be able to substitute and/or reformulate around 52% of the products (in terms of turnover) that may be affected by the proposed restriction, although there is some uncertainty.

Business expectations are affected not only by what might be technically and economically feasible but also how their customers may react to the substitutes and/or reformulated products.

The survey suggests that the ability of businesses to substitute the products that may be affected could range between 45% and 58% of their affected portfolio (52% is the central estimate), on average, although this is uncertain and will depend on a positive market uptake. Further, the degree of expected substitution and reformulation varies widely across respondents. Ability of businesses to substitute and/or reformulate will be very different across business type, size and affected products. However, this reported ability to substitute/reformulate was not found to differ significantly for businesses entirely dedicated to F-gases in comparison to companies with wider business scopes.

Businesses may also need time to adjust their operations and establish a final substitute and/or reformulated product that can be placed on the market. In some cases, businesses may already have a readily marketable alternative to place on the market upon adoption of policy changes. In others, businesses may require years of research and development and product approval before an alternative can be brought to the market.

ECHA (2020)[220] presents results from a survey on the time that may be required for substitution. Their survey responses suggests that "36% of respondents may take more than seven years, (…) 20% indicated four to six years as sufficient time to complete the substitution activities, [and] 44% (…) could switch to an alternative in less than three years…".

In conclusion, some substitution and/or reformulation is likely, and businesses will attempt to maximise this where economically viable; however, this is only likely to mitigate around 45%-58% of total potential market withdrawals resulting from regulatory changes and take time to implement (and to generate a stream of income).

Producers and/or importers have also provided their views presenting where alternatives are applicable for certain applications or settings. Respondents have stated that the emissions reduction targets in the European Green Deal cannot be achieved without F-gases since H(C)FOs are more efficient, use less energy and therefore have lower overall greenhouse gas emissions than existing alternatives. Their views included the following shortcomings of alternatives (for a more in-depth discussion of environmental and health impacts of the proposed restriction, see 3.2 and 3.3):

- Total GWP throughout the life cycle, thus including the direct emissions of an alternative as well as indirect (e.g., from the energy consumed in their manufacturing process as well as during the operation of the equipment) should be considered to evaluate whether a natural alternative will have a lower impact on global warming than PFAS. This should include their energy efficiency.
- Further restrictions on the use of F-gases in refrigeration would have a disproportionately high negative impact upon society when compared with the risk to human health or the environment arising from the use of F-gases, particularly as F-gases are already sufficiently regulated to mitigate those risks.
- The environmental impacts of F-gases are limited, stating, "there is no evidence that current and projected concentrations of TFA from the breakdown of F-gases would cause harm to health and the environment".
- Switching to alternatives will require capital investment in equipment, e.g., gas sensors and ventilation to prevent new hazards in RACHP applications.

[220] ECHA (2020) *"Impacts of REACH restriction and authorisation on substitution in the EU"*; DOI: 10.2823/39789

Source: Ricardo analysis based on a bespoke survey of F-gas producers and/or importers; and ECHA (2020). "Impacts of REACH restriction and authorisation on substitution in the EU"

Business will adjust capital and/or R&D expenditure plans and manufacturing or operating processes more broadly to mitigate portfolio losses. In this case, the evidence collected suggests that businesses have some capacity to pass some of this new regulatory burden through to their clients. Additionally, the survey responses suggest that overall sales of the EU F-gas sector are not very responsive to price changes. Therefore, the increase in regulatory burden is unlikely to affect the market significantly, at least within the EEA. This can be different for the extra-EEA export market if there is a strong or growing competition from players based outside of the EEA and not subject to the proposed restriction. However, and according to information elicited in the survey, the extra-EEA export market for F-gases is a minor part of the total turnover from F-gases, representing less than 10% of the latter. Box 3-2 outlines the evidence collected of the EEA F-gas sector's capacity to pass increased regulatory burden onto clients and the market responsiveness to potential product price changes.

Box 3-2 Pass through of regulatory burden for products that may be affected by the proposed restriction.

Businesses participating in this consultation also considered the extent to which they would be able to pass through any additional regulatory burden down their supply chain, which is estimated to be around 52%.

These businesses also explored the price elasticity of their product portfolio in the EEA. Respondents were not asked to report any information of the prices of their products, but rather their ability to pass through any increases in regulatory costs to their customers and their customers' potential responsiveness to such adjustments in prices. Overall, they considered that their products are, on average, price inelastic, with price elasticity of demand estimated at around -0.5. This means that the tonnes or quantity sold in the EEA are not very responsive to price changes, that is, a 10% increase in prices would only result in a 5% reduction in the quantity sold.

This means that, given current market dynamics, businesses may be able to pass through part of the increased regulatory burden to their clients with limited additional impacts on the size of their operations. This could, however, change (i.e., worsen), for example, if customer preferences vary or product performance of the new alternatives is different, which will be considered qualitatively in this study.

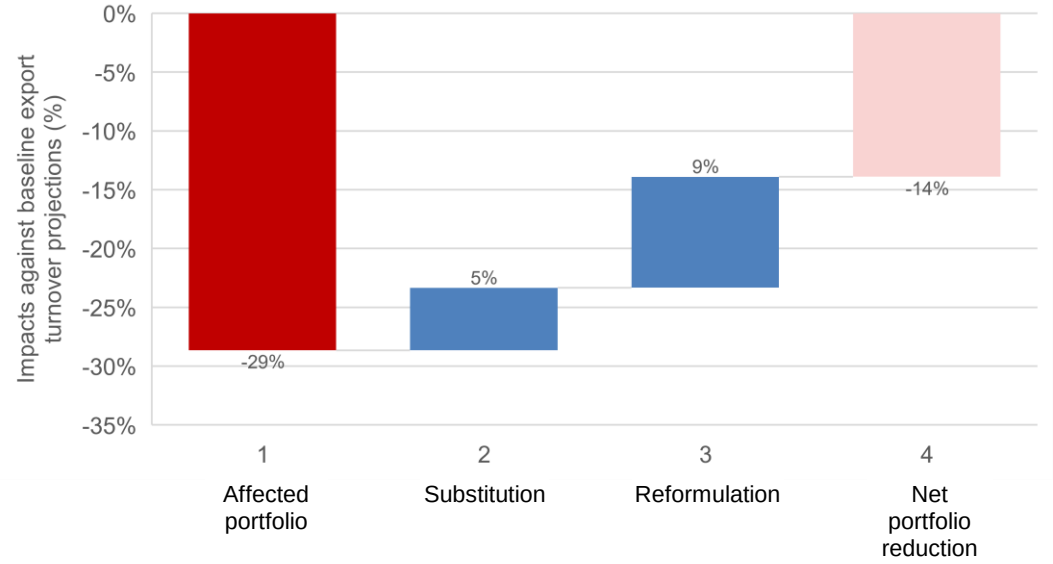
Additionally, if alternatives to be sold to downstream users require substantial alterations to existing articles or products to ensure safety due to differing hazard properties, this would require additional Capex and Opex also from downstream users, thus increasing the cost burden that is transferred to them and reducing their willingness to pay more for alternatives.

Therefore, due to uncertainty in the degree to which this transfer of additional costs would be implemented in practice, these second-order impacts will be excluded from the figures presented below.

Source: Ricardo analysis based on a bespoke survey of F-gas producers and/or importers

Finally, Figure 3-2 below illustrates the different steps of the impact pathway statically, from the estimation of the total potentially affected portfolio to the turnover losses that are estimated to result from the introduction of the restriction considered in this study (central estimates).

Figure 3-2 Static stepwise representation of the portfolio in scope of being affected by the proposed restriction and expected responses from businesses (only first-order impacts[221], in percent of baseline turnover)



Source: Ricardo analysis based on EEA and Eurostat data, and a bespoke survey to F-gas producing and importing companies.

In sum, and following Figure 3-2, the total potentially affected product portfolio from the proposed restriction is equivalent to 29% of the baseline total turnover or market of the F-gas producers and/or importers (i.e., wider business scope) (**Step 1**).

Around 5 percentage points of this market will likely be substituted (**Step 2**), and 9 percentage points are expected to be reformulated (**Step 3**).

This means that the proposed restriction, when accounting for potential business responses, could lead to a reduction in product portfolio and business (in turnover terms) of around 14% or equivalent to €0.6 billion of the 2019 market (**Step 4**).

Producers and/or importers have noted through stakeholder consultation their views on the availability of viable alternatives which are not within the scope of the restriction. These views include:

- Estimates are based on the main system configurations and conditions, as it is not possible to cover all possible applications and conditions. Alternatives are then compared to the best-in-class PFAS in the application and the best-in-class F-gas technology available.
- Performance is highly dependent upon the required temperature; potential hydrocarbon alternatives to F-gases are listed, namely, ethane, propane, butane, isobutane, and pentane.
- Potential substitutes do not provide the required technical specifications/performance of final products/installations, in particular, for critical uses and applications in warm climates. The reasoning behind this is generally that functional alternatives that are acceptable from standpoints of safety, health, environment, and costs would not be available. CO_2 and ammonia (NH_3) have been noted as potential alternatives, however increasing emissions of CO_2 and ammonia is not coherent with the aims of the EU Green Deal and Paris Agreement which seek to reduce pollutant emissions One examples of these goals in practice is the 2016 National Ceilings Directive[222] which has set an aim to reduce NH_3 emissions by 19% by 2030 (compared to 2005 levels).

They also detailed the risks associated with using carbon dioxide as an alternative to F-gases, highlighting the indirect environmental impacts which result from carbon dioxide's comparatively low energy efficiency. Similarly, that ammonia, relative to F-gases, presents a greater hazard to human health (harmonised classifications for skin corrosion cat. 1B and Acute toxicity cat. 3) compared to F-gases. Hydrocarbons have a similar hazard profile to F-gases with regard to human health and a lower GWP in comparison to F-gases. However, hydrocarbon flammability means they have a poor physical hazard profile relative to F-gases. Regarding the use of carbon dioxide, it was noted that it requires a high operating pressure, which can restrict

[221] First-order impacts exclude adjustments via prices (see Box 3-2).

[222] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG

its use, e.g., for mobile air conditioning. The following section delves into the net impacts of the policy options on the EEA F-gas sector across a number of business and economic indicators, explores the sensitivity of some of the key assumptions employed in the analysis, and considers the core limitations.

3.1.1.3 Costs and benefits driven by the impact on EEA F-gas businesses

The consultations with F-gas producers and/or importers enabled the confirmation of the scope of their production portfolio that is likely to be affected by the proposed restriction and the identification of potential business responses.

To assess the net impacts of these policy options on the EEA F-gas sector, a baseline and two policy scenarios were developed:

- The sectoral **baseline** (2019-2040) was developed by employing statistical techniques and trend analysis on publicly available evidence of the turnover from Eurostat's Structural Business Statistics[223], combined with reported data by industry stakeholders. This baseline scenario assumes that the proposed restriction is not implemented.
- A first policy scenario (**Scenario 1**) considers the proposed restriction entering into force in 2025. The affected products would be withdrawn from the market unless they are substituted and/or reformulated, which happens instantaneously.
- A second scenario (**Scenario 2**) considers that businesses may need time to adapt so they can bring substitutes and/or reformulated products to the market. Based on the available evidence[224], it has been assumed that companies may need, on average, around 5 years to adjust their operations and place their substitutes and/or reformulated products on the market. This would lead to larger turnover losses earlier on. Over time, turnover will converge to the levels estimated in Scenario 1.

Based on these policy scenarios and the available evidence from the bespoke business consultations, Eurostat and secondary research, the net impacts on the EEA F-gas sector and the knock-on effects on the European economy were assessed against the baseline scenarios. These are described against the five business measurements:

- Turnover
- Intermediate consumption and operating costs
- Capital expenditure and Research and Development
- Regulatory burden
- Other opinions and insights by the F-gas industry.

Since the restriction is not expected to enter into force until at least 2025, results are presented in annualised terms over the period 2025-2040.

3.1.1.3.1 Turnover

The adoption of the policy options considered is estimated to lead to a reduction in sales or size of the EEA F-gas sector in terms of turnover[225] and tonnes manufactured and sold. The extent of this reduction will depend upon the scope and timetable of the legislative changes as well as the type of business responses expected.

First order effects, that is, the impacts on business operations excluding any pass through of additional regulatory costs to customers through price adjustments, are considered in Table 3-1. This loss of turnover stems from products and product lines which cannot be substituted or reformulated, and hence are restricted and lost altogether as a consequence of the restriction. Those product lines which can be substituted or reformulated continue to provide a source of revenue, and hence this is not lost, although such behavioural response carries other impacts for producers and importers (e.g., Opex and Capex effects, as explained in subsequent sections).

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[223] Eurostat (2022), *Structural Business Statistics Database*. [online] Eurostat Available from: Database - Structural business statistics - Eurostat (europa.eu) [Accessed 05/2022]

[224] ECHA (2020) *"Impacts of REACH restriction and authorisation on substitution in the EU"*; DOI: 10.2823/39789. and ECHA (2021) *"Costs and benefits of REACH restrictions proposed between 2016-2020"*. DOI: 10.2823/122943

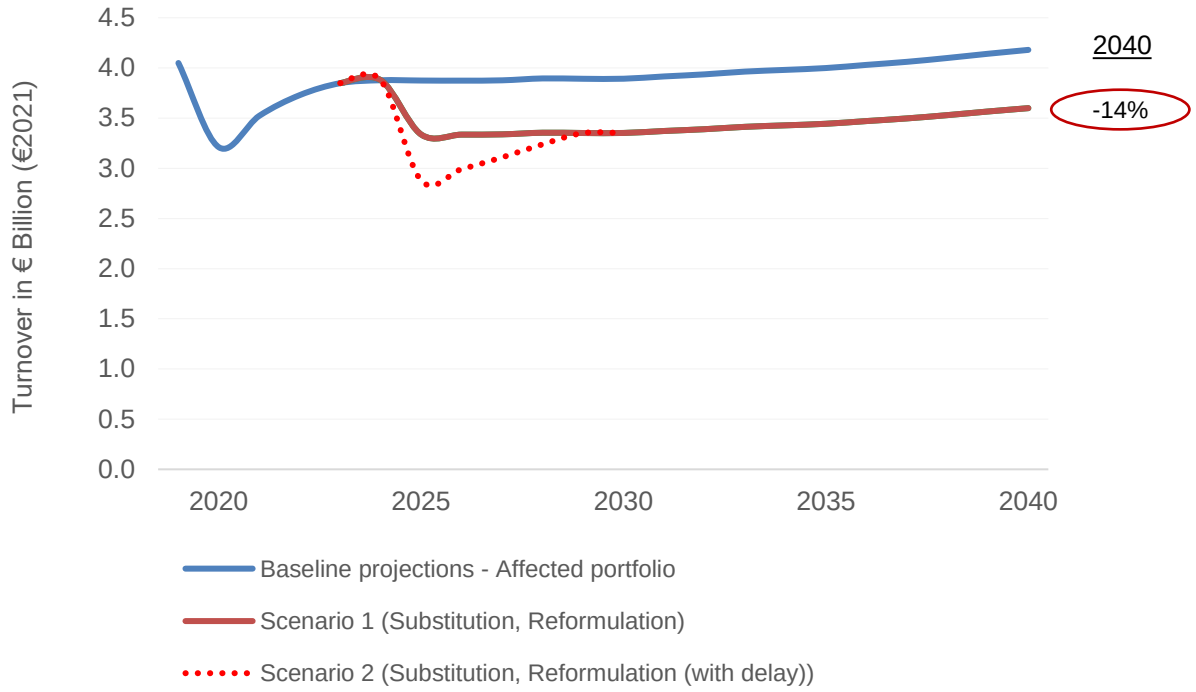
[225] Turnover refers to total sales of the EEA F-gas producers and importers, thus including sales of products in the EU or abroad. There is an implicit assumption that activities targeting export markets will also be affected, on average, in a similar way to the market targeting EU customers. The effects on the exports are uncertain and could be more or less significant than the impacts that may apply to the manufacturing and/or use of substances within or for customers in the EU.

Table 3-1 Annualised impacts on the size of the EEA F-gas producers and importers' business against the baseline scenario in terms of total turnover (€ 2021).

Scenario	First order effects or impacts on businesses overall
Scenario 1 (Substitution and Reformulation)	Producers and importers in the EEA F-gas sector are estimated to **lose €550 million (€ 2021) of turnover each year on average** over the period 2025-2040, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	Producers and importers in the EEA F-gas sector are estimated to **lose €640 million (€ 2021) of turnover each year on average** over the period 2025-2040, when compared to the baseline scenario.

The impacts are also presented over time in the Figure below.

Figure 3-3 Estimated impacts on the total turnover of F-gas producers and importers in the EEA against the baseline scenario (€ 2021)[226].



Source: Ricardo analysis based on Eurostat and EEA data and a bespoke survey to producers and importers in the EEA F-gas sector.

These first-order effects (as shown in Figure 3-3) reflect the direct business response to the proposed legislative changes: by 2040, the EEA F-gas producers' and importers market would be around 14% lower than the estimated baseline, which is equivalent to a turnover loss of around €580 million in both Scenario 1 and Scenario 2 against the baseline, although following different paths. These effects exclude whether companies might pass the additional regulatory burden through to their customers and the associated implications, which we refer to as 'second-order effects'.

These second-order effects have been considered based on the evidence gathered through the survey of F-gas producers and importers. Overall, based on the data available, it is estimated that companies would pass through around 51% of the additional regulatory burden resulting from the proposed restriction and given that, as reported by survey participants, F-gas products appear to be price inelastic, this would mitigate the estimated reduction in turnover albeit marginally (by around 1 or 2 percentage points at most; see Box 3-2 for a discussion on the uncertainties surrounding mitigation via prices).

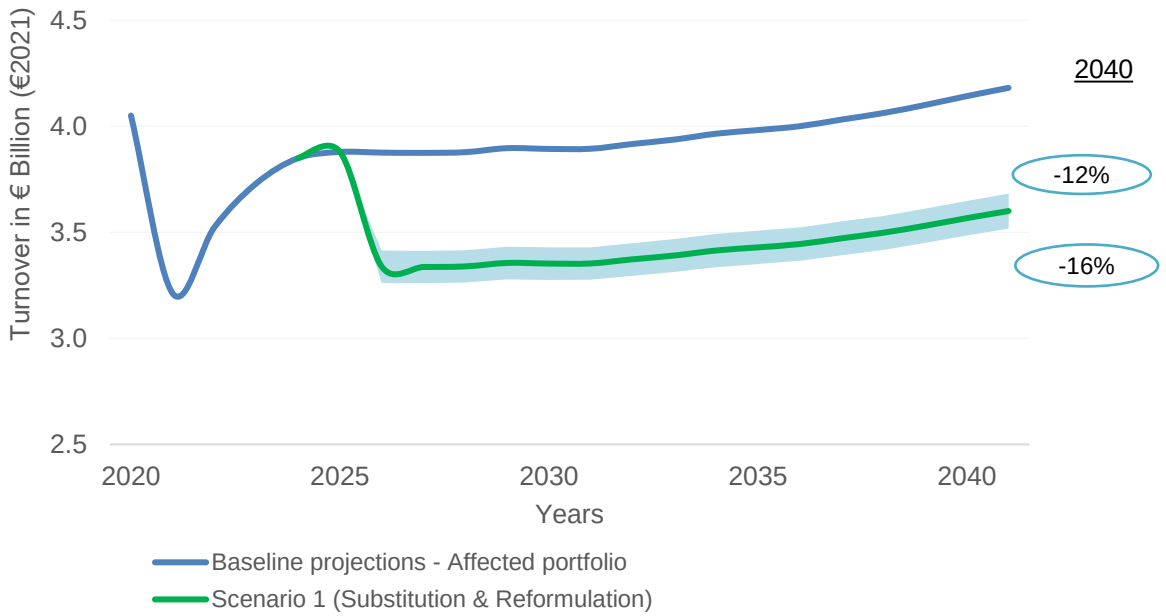
[226] Please note that the diagrammatical illustrations in this study smooth the changes in turnover over time, thus assuming that these changes are continuous (rather than discrete reductions in business). For example, in Scenario 1, it is implicitly assumed that the impact of a policy change is felt immediately and businesses start to adjust their operations slightly in advance as a way of preparing for the year in which the legislation comes into effect. In reality, businesses may take action much earlier or have a 'grace period' during which they can adjust their operations and meet the new legal requirements.

Overall, this suggests that **even if businesses were to introduce mitigation measures whilst incurring additional operating and capital costs (first order effects) and they were able to pass through some of these costs to their customers (second order effects), their operations and associated economic footprint would still be likely to reduce significantly, with annual turnover losses against the baseline are estimated to range from €550 million to €640 million per year, on average[227], between 2025 and 2040.**

The scenarios established for estimating the potential policy impacts on the turnover of the EEA F-gas producers and importers present the implications of key uncertainties relating to the timeframe of the proposed restriction's impacts on turnover**. Scenario 1** considers the proposed restriction happening in 2025 and mitigating actions taking effect immediately upon restriction, versus **Scenario 2** which considers that businesses may need time to adapt so they can bring substitutes and/or reformulated products to the market. Within each of these scenarios there are other assumptions, and hence uncertainties, which could affect these estimations. In particular, the sensitivity of the results to the extent to which businesses may be able to substitute and/or reformulate has been explored.

Therefore, as noted earlier, if businesses do not substitute and/or reformulate at all, the EEA F-gas producers and importers could lose 29% of their total turnover estimated in the baseline (which is around twice as much as the central estimate of 14% loss). The best available evidence suggests that businesses will be able to substitute and/or reformulate 52% of their affected product portfolios (in terms of turnover). However, uncertainty around the degree of substitution in the estimates elicited from the survey to F-gas producers and importers provides a range of possible substitution and reformulation that is between 45% and 58%. In any of these cases, turnover losses are not estimated to vary significantly from the central estimate. This is illustrated in Figure 3-4 below, with losses in these two more extreme cases ranging between 12 and 16% of the total turnover from F-gas producers and importers' businesses.

Figure 3-4 Illustration of the sensitivity of the estimated impacts on the turnover of EU F-gas producers and importers against the baseline scenario (€ 2021) to expected substitution and/or reformulation



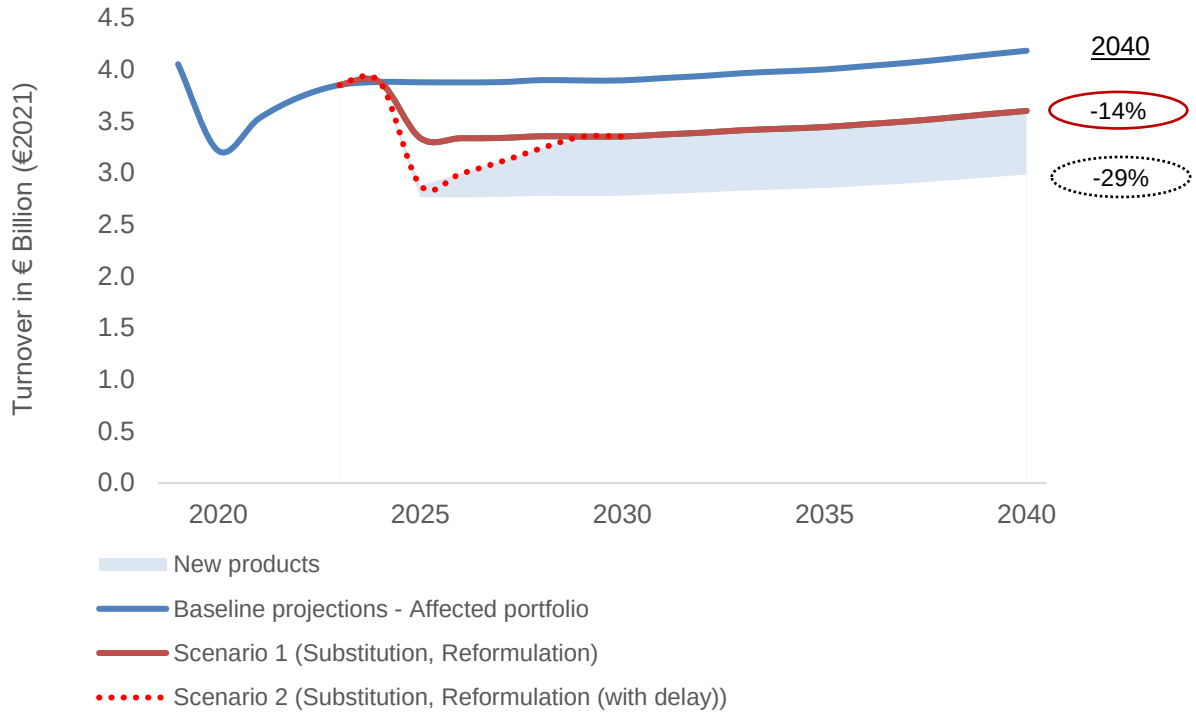
Source: Ricardo analysis based on Eurostat and EEA data and a bespoke survey to producers and/or importers in the EEA F-gas sector.

Moreover, substitution and reformulation could affect the quality and attractiveness of the substances and/or products sold by EEA F-gas producers and/or importers. This could have additional indirect impacts on EEA F-gas producers and/or importers, potentially limiting the ability of businesses to reduce turnover losses especially in the face of international competition. This is highlighted in Figure 3-5 below; the shaded area represents the scope of turnover related to the sale of alternatives to the F-gases in scope that, as reported, is expected to be achieved to mitigate losses resulting from the proposed restriction. If that expectation fails (supply side) or those alternatives are not well received in the market (demand side), losses would be higher

[227] A net present value of turnover losses against the baseline has been calculated, and later annualised over the period to estimate 'equivalent annual losses of turnover' as a result of the legislative changes. A real discount rate of 3.5% has been employed in line with the European Commission's Better Regulation Guidelines.

and up to the full 'potentially affected portfolio' shown in Figure 3-1, 29% of F-gas producers and importers' turnover.

Figure 3-5 Estimated impacts on the total turnover of F-gas producers and importers in the EEA against the baseline scenario (€ 2021). The scope of new products / substitutes / alternatives is shaded in light blue for reference.



Source: Ricardo analysis based on Eurostat and EEA data and a bespoke survey to producers and/or importers in the EEA F-gas sector.

Producers and/or importers have also provided their views as to the grounds on which they would defend an exemption based on REACH restriction procedure. A wide range of examples were provided, including on economic grounds to continue to use existing equipment until it was replaced at end of life, given that replacing them before end of life based purely on its refrigerant does not meet either economic or sustainability goals.

In addition, the estimated turnover losses assume that the sector's capacity to pass through the higher regulatory costs remains relatively unchanged, whereas this need not be the case in the face of growing international competition, especially in the market for F-gas alternatives. If international competition of alternative substances with similar performance to F-gases were high, EEA F-gas producers and/or importers would need to act quickly and might not be so able to share the additional costs via price increase, which would limit the ability to mitigate losses in any given scenario. It has not been possible to quantify this effect in this study.

Finally, sectoral economic output is assumed to be affected by the same proportion as turnover. GVA, however, depends on impacts not only on turnover and output, but also on intermediate consumption (or operating minus employment costs). Intermediate consumption is considered in the next section.

3.1.1.3.2 Intermediate consumption and operating costs

More than 66% of the EEA F-gas producers and/or importers surveyed for this study expected their annual operating expenditure to change during the next 10 years as a result of these policy changes.

First, the withdrawal of products from the market would necessarily imply that F-gas producers and importers would reduce their operating activities and, as a result, operating expenditure will fall. This reduction is likely to be proportional to turnover losses against the baseline. Therefore, a reduction in business operations of around 14% would result in a similar reduction in operating costs over time. For example, in 2019, this would have been equivalent to a reduction in intermediate consumption of around €550 million.

Secondly, companies would also take action to find alternatives and/or substitutes to alleviate the estimated reduction in their business. Thus, some of the current operations would need to be adjusted for the manufacturing and placing on the market of substitutes and/or reformulated products. Further, additional administrative and compliance requirements, such as seeking derogations and/or adjusting the labelling of products, and associated costs would also be incurred. Estimates based on the survey of EEA F-gas producers

and/or importers suggest an additional annual €10 million of recurring costs could be incurred as a result of substitution, reformulation, and testing and changes to the manufacturing process.

Overall, intermediate consumption and operating costs are likely to fall, as business size reductions outweigh increased costs. These net reductions on intermediate consumption and OPEX would be driven by the losses that are estimated to the size of operations of the EEA F-gas market. **It is estimated EEA F-gas producers and importers OPEX would fall in annualised terms by €460 to 540 million compared to the baseline over 2025-2040 in Scenario 1 and Scenario 2, respectively**. These estimates do not suggest, however, that there will be any cost savings from the adoption of the legislative changes. In fact, unit costs are estimated to increase. For example, the 'ratio of intermediate consumption to turnover' is estimated to increase by up to 2.8% on average, over the period 2025-2040 against the baseline.

3.1.1.3.3 Capital and R&D expenditure

Similarly, the withdrawal of products from the market would have some implications on the capital and R&D expenditure by EEA F-gas producers and importers. If the size of their business declines, it is assumed that their overall expenditure will decline as well. A 10% reduction in the size of chemical companies manufacturing or importing F-gases in the EEA may lead to an eventual reduction in overall investment of similar proportion, which would be equivalent to reducing investment by over €40 million each year against the baseline.

Nevertheless, these producers and importers will also need to increase their investment in capital and R&D as they work to, for example, change their manufacturing processes, identify quality substitutes and alternatives and reformulate products. Based on the survey of F-gas producers, it is estimated that an additional €6 million (€ 2019) would be invested over 10-15 years from the adoption of the policy changes to support the changes that chemical companies would need to embark on to mitigate further operational and turnover losses.

Overall, net reductions on intermediate Capex and R&D expenditure are estimated in line with business size reductions. These reductions in expenditure do not mean that there will be any cost savings per unit of output from the adoption of the legislative changes. In fact, per unit expenditure could increase, at least with regards to adjusting manufacturing processes and completing the required investments for effective substitution and reformulation. Based on the survey of F-gas producers and/or importers for this study, the 'ratio of CAPEX to turnover' is estimated to increase against the baseline by up to 4.9% on average, over the period 2025-2040.

3.1.1.3.4 Regulatory Burden

Regulatory burden refers to all of the administrative and compliance costs that result from legislation in the EEA. This includes direct administration costs (e.g., sharing information, engaging with administrative process and associated charges, etc.) as well as compliance costs, including Opex and Capex, associated with the response to any regulatory change (e.g., changes to manufacturing or products that incur both operating as well as capital expenses).

The Cumulative Cost Assessment (2016) estimated a regulatory burden affecting the EU Chemicals sector of 2.3% of turnover. In particular for specialty chemicals (the category in which F-gases fall), regulatory burden is estimated to be 3.7%. This estimate was used as a benchmark to develop a baseline against which to assess potential impacts. The survey of chemical companies carried out for this study also confirmed that regulatory costs are likely to be between 1%-10% of the turnover.

Impacts on regulatory burden convey the increased administrative and compliance activities that stem from the proposed restriction, including as such the additional costs associated with substitution and reformulation strategies. As a result of the proposed restriction of F-gases, **regulatory burden is likely to increase against the baseline during the years of more intense investment in alternatives and new formulas, while it would decrease due to the overall loss of business. These two effects account for an overall increase in regulatory burden of €9-12 million per year on average over the period 2025-2040.**

Further, as noted earlier, introducing the proposed restriction would also lead to potential turnover or operational losses. If these impacts were considered direct opportunity costs of the regulatory changes, it would imply that actual or effective regulatory burden would be significantly higher and likely equivalent to around 15% of turnover by 2040, when compared to the baseline.

Producers and/or importers have also provided their views about the impact of the restrictions on regulatory burden. Uncertainty in the regulatory implementation of the proposed restriction means they cannot accurately predict its business impacts. Their best assessment is that the ban will likely have adverse effects on their operations, financial condition, and cash flows. There is concern about the fact that there already exists a strong international regulatory framework to manage F-gases, and the stated aim of the F-gas Regulation is to reduce emissions by limiting the total amount of HFCs which can be sold from 2015 onwards, while the

proposed restriction will conflict with this aim. Additionally, it has been argued that increasing the regulatory burden conflicts with the principle of the EU REFIT program[228] which seeks to make EU legislation simpler and less costly. The Chemicals Strategy for Sustainability also aims to avoid duplication of efforts.

3.1.1.3.5 Other opinions and insights by the F-gas industry

Quantitative information on the extent of **recovery activities** in tonnes was provided by F-gas producers and/or importers, although it has been found to be minimal at present, representing around 1% of the total tonnes placed on the market in 2019[229]. Recovery activities are key towards the avoidance of the F-gases that are contained in equipment being released to the atmosphere (and hence realising their GWP), and will continue to be of extreme importance even in the event of the proposed restriction happening. It has also been noted that if the PFAS restriction enters into force, the reclamation business will come to an end. All recovered F-gases will have to be sent to destruction, and one of the economic incentives to recover the gases disappears.

Additional comments provided in the survey regarded involvement in **producer responsibility schemes.** Responses highlighted that even when they are not involved in the scheme (due to the nature of their work), they do encourage and support the producer responsibility efforts at utilised third-party facilities. There exist producers that have reclamation and destruction facilities (e.g., thermal conversion) or that participate in such programmes in Germany and France, where national legislation can play a role towards fostering the participation in such initiatives.

Producers and/or importers have also provided their views regarding **potential exemptions** to the PFAS ban. It was argued that there should not be any restrictions upon PFAS. One reason put forward is that there is no defined method to evaluate the overall environmental damage of PFAS in comparison to alternatives. Additionally, they consider F-gases essential for some uses. It has also been highlighted that in many cases F-gases show a better human health hazard profile than alternatives, arguing that where alternatives are possible, they have already been adopted. Overall, derogation is considered appropriate for critical applications, such as climate chambers and MDI.

Other general suggestions included allowing the chemicals sector to support the EU and industry to achieve the EU Green Deal, and that energy and material efficiency should be central to decision making upon the proposed restriction.

Producers and/or importers have also provided their **broader views** on the introduction of a possible PFAS ban. The ban may lead to a reduction in production of other low GWP technologies in the EU. A restriction of all F-gases will disrupt the transition from higher-GWP products HFCs to global warming neutral H(C)FOs and will likely undermine and impede the EU Green Deal ambitions. A parallel ban of H(C)FOs will have negative social consequences, for example if large quantities of existing systems are made obsolete, such as existing refrigeration A/C and Heat Pump (RACHP) systems including car, van and truck systems. Additionally, the OECD PFAS definition does not inform whether a substance is harmful or not (nor persistent). At present, fluorinated compounds like H(C)FOs and HFCs are not defined as persistent, bio accumulative, nor toxic under REACH. H(C)FOs have been vetted and approved as safe alternatives by regulatory bodies in countries around the world.

By application, F-gas producers and importers particularly consider the proposed restriction likely to have consequences for the automotive industry's ability to comply with the MAC Directive. As reported, HFO-1234yf is essential for them to comply with this Directive, lacking alternatives for this use.

The absence of high-performance non-flammable blowing agents for insulation foams in building/construction sector has also been highlighted, as well as the lack of alternatives for metered dose inhalers (MDIs) used in medical treatments for conditions including asthma and COPD[230].

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[228] The EU REFIT programme is a component of the Commissions' Better Regulation agenda. The objective of the programme is to support EU laws deliver on their aims whilst supporting an effort to ensure that legislation implemented is simple and easy to comply with, including simplifying existing laws through cutting red tape. The greatest beneficiary of the programme are SMEs which benefit from a reduction in burden associated with complying with the Regulations.
https://ec.europa.eu/info/law/law-making-process/evaluating-and-improving-existing-laws/refit-making-eu-law-simpler-less-costly-and-future-proof_en#:~:text=The%20REFIT%20programme%20is%20part,cutting%20red%20tape%2C%20whenever%20possible.

[229] Missing information on recovery of the F-gases in scope in the stakeholder consultation makes this estimate lower than the 2.1% that is reported to have been reclaimed in EEA's 2020 report. Additionally, reclamation in that report refers to all F-gases, so its scope is larger than the scope of this study. The amount of F-gases reclaimed according to the latter represent 1,619 tonnes.

[230] Chronic obstructive pulmonary disease.

Some also expect that the PFAS ban would damage the import and export market, causing spillovers to third countries. A number of country-specific issues have also been reported regarding the impact of the PFAS ban. These include:

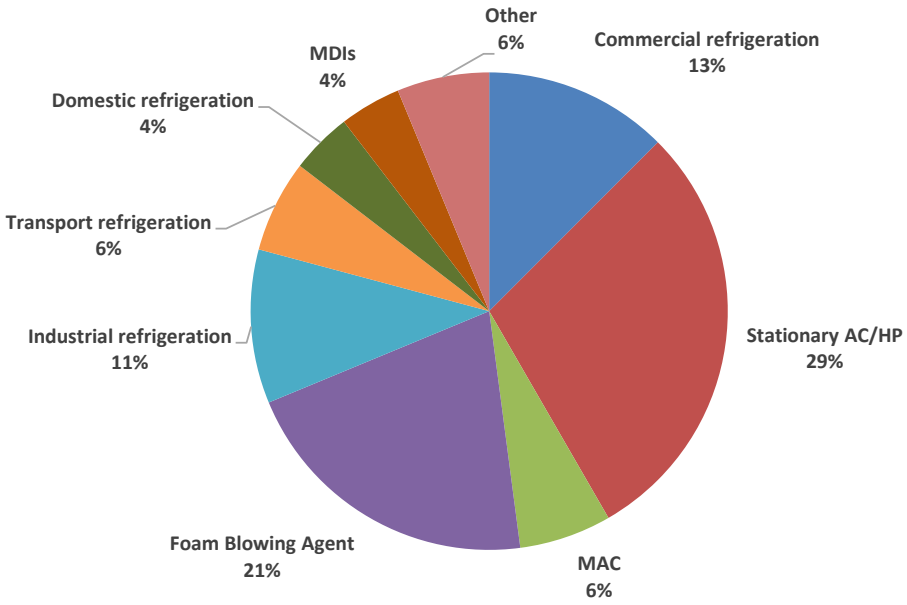
- The impact caused by divergences between building codes between EEA countries. For example, in some countries, national building codes prohibit the use of flammable refrigerants (e.g., France and Italy) in certain (often public) locations, often seen as alternatives to the F-gases in scope. In parallel, national building codes and international and national safety standards may need revision to allow applications using flammable refrigerant alternatives (non-PFAS), which typically require 7-10 years.
- Producers and importers are concerned that the restriction would reduce EU Member States' competitiveness and flexibility on the international stage if other countries continue producing and using F-gases.
- Member States would also be impacted based on their climate. Higher-temperature Member States (e.g., Spain, Portugal, Italy, Greece, Croatia, Cyprus, Bulgaria, Malta) would face less challenge than lower-temperature countries (Estonia, Finland, Latvia, Lithuania, Sweden).
- REACH Regulation should not overlap with existing F-gas Regulation. There already exists a strong international regulatory framework to manage these substances and the stated aim of the F-gas Regulation is to reduce emissions by limiting the total amount of HFCs which can be sold from 2015 onwards. The ban will conflict with this stated aim.

3.1.2 Business impacts on F-gas downstream users

The restriction of the manufacture, placing on the market and use of these F-gases will also affect downstream users, who will need to take adaptive measures to remain in the market. Downstream users would lose the ability to manufacture and recharge their products unless they were able to manufacture them without F-gases or with non-F-gas alternatives that provide similar performance and that consumers would be willing to use.

The business scope of downstream users participating in the consultation was wider than one single application. The degree to which each of the applications is represented in survey responses is shown in Figure 3-6. It is important to note all of the 29 survey respondents are involved in more than one application: on average, they are manufacturers in three different downstream using application niches.

Figure 3-6 Representation of downstream using applications in survey responses.



Source: Ricardo analysis based on Eurostat and EEA data and a bespoke survey of F-gas downstream using companies.

Due to the fact that survey respondents are present in multiple application sectors as manufacturers, economic impacts presented in the section below will be limited to the **sample of respondents and shown on aggregate** (i.e. for the overall group of application sectors). Conclusions on how this could affect the totality of their sectors in the EEA will be drawn where possible, but this caveat must be made explicit. Therefore, estimates are shown for the sample of respondents to the survey, rather than the whole affected downstream sector in the EEA. Their extrapolation to the whole industry size of these downstream using applications will also be commented where possible. **In practice the impacts will be much larger than those presented at the level of the sample.**

The following sections present how the impacts from the proposed restriction are expected to be experienced by F-gas downstream users:

- The affected portfolio (3.1.2.1)
- Expected business responses (3.1.2.2)
- Costs and benefits driven by the impacts on EEA F-gas businesses (3.1.2.3)

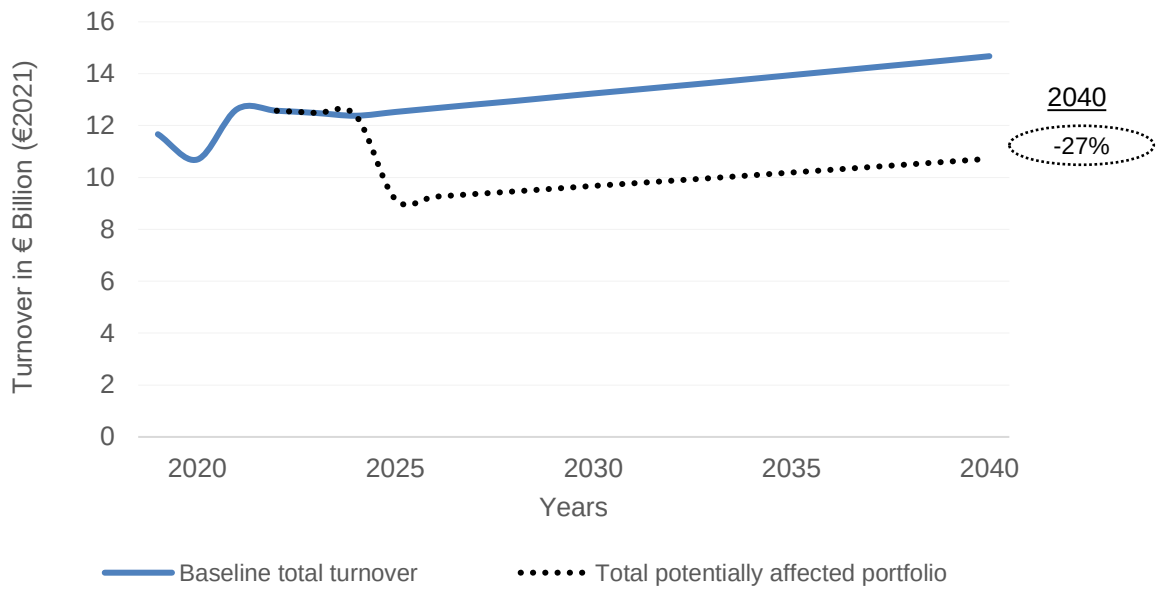
3.1.2.1 The affected portfolio

For downstream users, the portfolio of products affected by the restriction will comprise their products containing the F-gases in scope. Based on survey responses, this was found to be 27% of the total turnover of the surveyed companies, or €3.1 billion out of a total turnover of €12 billion in 2019. This is a first measure of the potential loss of business in the restriction scenario, which will be referred to as the **'affected portfolio'**. However, this differs by company; just like in the case of producers and importers of F-gases, for the majority of respondents (58%), the affected portfolio represents the totality of their business.

According to the expected regulatory timelines, the restriction would not likely enter into force before 2025, but after that date, it would be implemented in full. Evidence collated from the survey was overlayed with this expected schedule to produce the total affected portfolio series until 2040 to show the maximum potential losses if no alternatives are found for F-gases by the F-gas downstream users[231].

Figure 3-7 presents the estimates of the size of the portfolio of products in scope of the restriction for the surveyed sample of F-gas downstream uses against their baseline projections of turnover until 2040.

Figure 3-7 Production portfolio (in terms of total turnover) that is in scope of being affected by the restriction of the F-gases in scope for sample of downstream users.



Source: Ricardo analysis based on Prodcom, Eurostat and OECD data and a bespoke survey to F-gas downstream users.

This percentage estimate can be considered an unlikely upper bound for the potential reduction of the EEA F-gas downstream user sectors' business volume, taking into account that companies have other product scopes in their portfolios, in the event that the proposed restriction is adopted in full, and the affected sectors do not adapt, where possible, to mitigate these impacts.

On average, the portfolio of products that contain F-gases in scope represents 27% of the sample of F-gas downstream users' turnover in 2019. However, for the majority (58%) of the companies it represents 100% of their production, implying that they would be forced out of business in the absence of an innovation strategy that allows them to steer their production towards an F-gas-free portfolio.

3.1.2.2 Expected business responses

Survey responses from F-gas downstream users suggest that, on average, 80% of this affected portfolio that would be affected by the restriction could be substituted and/or reformulated with alternatives not containing F-gases. Therefore, businesses may be able to mitigate the majority of the potential product withdrawals that would result from the restriction of the F-gases in scope although this will depend on a positive market uptake and on the degree of substitutability of the new products and formulas (e.g. product performance, costs, hazard profiles, and energy consumption). Box 3-3 outlines the evidence collected related to the sample of F-gas downstream users' capacity to substitute and/or reformulate that has been considered in this analysis.

Box 3-3 Substitution and/or reformulation of products that may be affected by the proposed restriction.

29 businesses manufacturing products that use F-gases were surveyed to gather evidence as to the extent to which they may implement specific actions resulting from the adoption of policy changes and their likely scale, especially including substitution and/or reformulation.

[231] Alternatives might still be found in other sectors. Results from the consultation to downstream users provide additional insights on viable alternatives to the ones provided by the F-gas industry.

Businesses surveyed suggest that they **would be able to substitute and/or reformulate around 80% of the products (in terms of turnover) that may be affected** by the proposed restriction, although there is some uncertainty. Business expectations are affected not only by what might be technically and economically feasible but also how their customers may react to the substitutes and/or reformulated products.

The survey suggests that the ability of businesses to substitute the products that may be affected could range between 68% and 92% of their affected product portfolio, on average, although this is uncertain and will depend on a positive market uptake. Further, the degree of expected substitution and reformulation varies widely across respondents. Ability of businesses to substitute and/or reformulate will be very different across business type, size and affected products. For example, for the businesses that have a larger share of their total turnover affected by the restriction, the expected degree of substitution, reformulation and other changes is actually found to be larger than for others less affected. This is likely due to the fact that the continuation of the whole business depends on these changes. Additionally, F-gas downstream users are producers of different products that use F-gas in their applications, and for some of them there might be no alternative that displays the properties that F-gases confer to their products. **For an extended discussion on the viability and properties of alternatives for different applications as reported by the industry, see the end of this section and Section 3.4.3.**

Businesses may also **need time to adjust their operations and establish a final substitute and/or reformulated product that can be placed in the market**. In some cases, businesses may already have a readily marketable alternative to place on the market upon adoption of policy changes. In others, businesses may require years of research and development and product approval before an alternative can be brought to the market. For downstream users, this might even involve substantial changes to their production processes. Besides the typical substitution of the F-gases that they use with an alternative substance (i.e., substitution), or the recalibration of their formulas or mixtures to remove F-gases (i.e., reformulation), some of the changes for downstream users upon the proposed restriction may involve complex adaptations of their whole manufacturing processes. For instance, adapting key components to accommodate differences in physical properties of the alternatives, which is expected to be an overarching issue of all known alternatives in comparison with the F-gases that are currently being used. Some compromises in terms of performance, energy efficiency or safety are also expected from alternatives.

Finally, end consumers, especially commercial and industrial ones, may need to adapt their systems when those reach their end of life and have to switch to a non F-gas alternative. This, in some cases, will imply the replacement of the entire equipment; instead of a simple renewal of an existing system (e.g., RACHP), if technology experiences substantial changes, consumers may need to adapt and make new investments too. The replacement of the equipment may even happen earlier if the existing one needs servicing before the end of its life, since F-gases would not be available. These two instances would incur additional investment for equipment owners that has not been possible to quantify in this study.

In conclusion, some substitution and/or reformulation is likely, and businesses will attempt to maximise this where economically viable: this is likely to mitigate around 68%-92% of total potential market withdrawals resulting from regulatory changes and take time to implement.

Source: Ricardo analysis based on a bespoke survey of F-gas downstream users.

In order to achieve this mitigation, they would need to incur additional capital, operating and R&D expenditure. Therefore, as a result of the restriction, businesses would need to increase their Capex and Opex per unit of sales, with new costs associated with substitution and/or reformulation.

The evidence collected suggests that businesses have some capacity to pass some of this regulatory burden through to their clients. Additionally, the survey responses suggest that overall sales of the sample of surveyed downstream users are not very responsive to price changes. Therefore, the increase in regulatory burden is unlikely to affect the market significantly, at least within the EEA. This can be different for the extra-EEA export market if there is a strong or growing competition from players based outside of the EEA and not subject to the proposed restriction. According to information elicited in the survey, 62% of respondents consider that the proposed restriction will impact their extra-EEA exports, possibly losing 22% of their exports on average over the 10 years after the restriction is implemented. Box 3-4 outlines the evidence collected of the sample of F-gas downstream users' capacity to pass increased regulatory burden onto clients and the market responsiveness to potential product price changes.

Box 3-4 Pass through of regulatory burden for products that may be affected by the proposed restriction by downstream users

Businesses participating in this consultation also considered the extent to which they would be able to pass through any additional regulatory burden to their customers, which is estimated to be around 26%.

These businesses also explored the price elasticity of their product portfolio in the EEA. Respondents were not asked to report any information of the prices of their products, but rather their ability to pass through any increases in regulatory costs to their customers and their customers' potential responsiveness to such adjustments in prices.

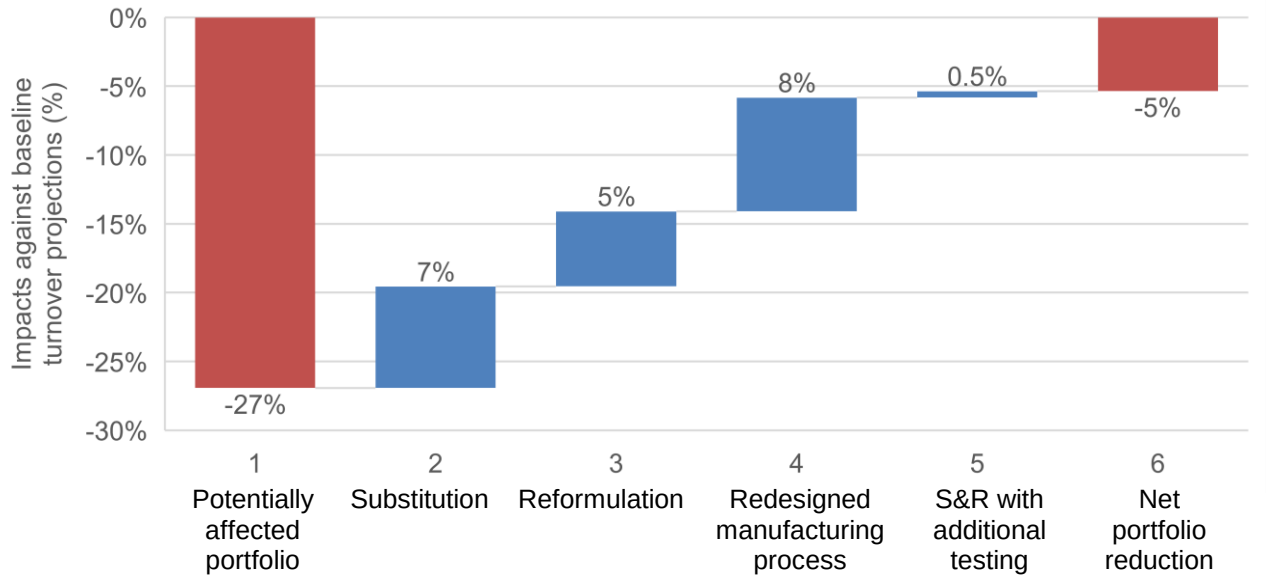
Overall, they considered that their products are, on average, price inelastic, with price elasticity of demand estimated at around -0.75. This means that the volumes of F-gas product applications sold in the EEA are quite responsive to price changes, that is, a 10% increase in product prices would result in a 7.5% reduction in the quantity sold.

This means that, given current market dynamics, businesses may be able to pass on a part (25%) of the increased regulatory burden to their customers with some, but limited, additional impacts on the size of their operations. This could, however, change (i.e., worsen), for example, if customer preferences vary or product performance of the new alternatives is different, which will be considered qualitatively in this study.

Source: Ricardo analysis based on a bespoke survey of F-gas downstream users.

Finally, Figure 3-8 below illustrates the different steps of the impact pathway statically, from the estimation of the total potentially affected portfolio to the turnover losses that are estimated to result from the introduction of the restriction considered in this study (central estimates).

Figure 3-8 Static stepwise representation of the portfolio in scope of being affected by the proposed restriction and expected responses from businesses (in percent of baseline turnover)[232]



Source: Ricardo analysis based on a bespoke survey to F-gas downstream users.

In sum, the total potentially affected product portfolio from the proposed restriction is equivalent to 27% of the baseline turnover or market of the surveyed F-gas downstream users (**Step 1**).

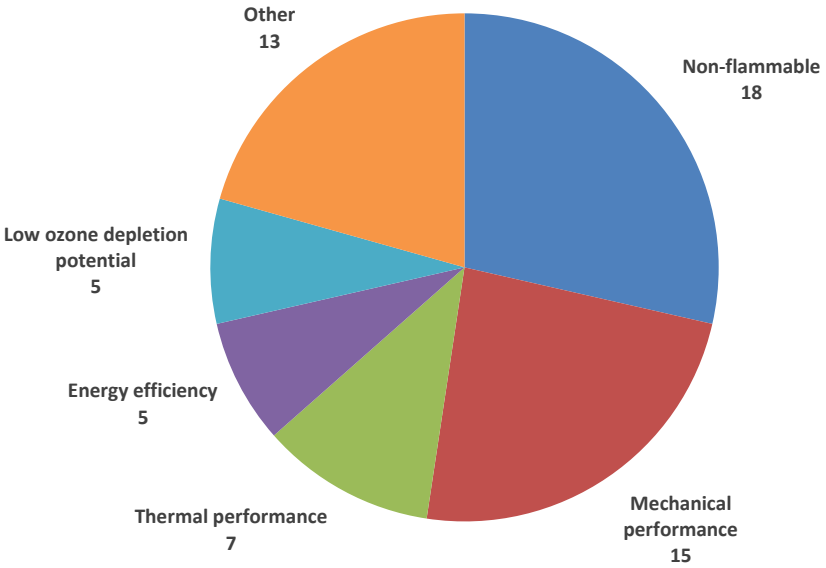
Around 7 percentage points of this market will likely be substituted (**Step 2**), and 5 percentage points are expected to be reformulated (**Step 3**). Additionally, 8 percentage points of this market are expected to undergo redesigns in their manufacturing process (**Step 4**), and less than 1 percentage point (0.5%) are expected to be substituted and/or reformulated with additional testing needed in order to comply (**Step 5**).

[232] In this graph, S&R, for brevity, stands for Substitution and Reformulation.

This means that the proposed restriction, when accounting for potential business responses, could lead to a reduction in product portfolio and business (in turnover terms) of around 5% or equivalent to €0.6 billion of the sample's 2019 market (**Step 6**).

Despite this reported degree of feasible substitution, reformulation and other productive changes, qualitative reports provided by downstream users highlighted the advantages, relative to the alternatives, of the F-gases within the scope of the proposed restriction, detailed in Figure 3-9 below. The responses show F-gases' non-flammability relative to alternatives was the main advantage for downstream users, followed by their mechanical performance (e.g., viscosity and pressure required for operation) and thermal performance (specific to F-gases used as a blowing agent for foams used as insulation). These advantages further introduce uncertainties to the degree to which the reported substitution, reformulation and other changes are feasible; if the new products cannot perform in the same way as they currently do with the use of F-gases and/or they become unsafe, the viability of said alternatives is questioned. See Section 2.2.2.4 for a more in-depth overview of on current uses of F-gases and their alternatives. By application sector, summaries of downstream users' views on alternatives to F-gases can be found in Section 3.4.3.

Figure 3-9 Number of responses highlighting each of the main advantages of F-gases within the scope of the proposed restriction, relative to existing alternatives[233]. Source: Ricardo bespoke survey to F-gas downstream users.



The following section delves into the net impacts of the policy options on the F-gas downstream users across a number of business and economic indicators, explores the sensitivity of some of the key assumptions employed in the analysis, and considers the core limitations. More qualitative information extracted from the downstream users' survey has also been included to show stakeholders views on the impacts of the proposed restriction.

3.1.2.3 Costs and benefits driven by the impact on EEA F-gas downstream using businesses

The consultations with downstream users enabled the confirmation of the scope of their production portfolio that is likely to be affected by the proposed restriction and the identification of potential business responses.

To assess the net impacts of these policy options on the F-gas downstream users, a baseline and the same two restriction scenarios as shown for the evaluation of impacts on F-gas producers and importers (see 3.1.1.3).

[233] 'Other' includes: Low GWP; Non-toxic; Simple or low-cost equipment for operation; Previous experience with using the gas; Approved for use in medical settings; Globally available, and Low persistence in the environment. The number of responses to these categories cannot be provided separately to ensure anonymity.

Based on these policy scenarios and the available evidence from the bespoke business consultations, Eurostat and secondary research, the net impacts on the EEA F-gas sector and the knock-on effects on the European economy were assessed against the baseline scenarios. These are described across four different areas:

- Turnover
- Intermediate consumption and operating costs
- Capital expenditure and Research and Development
- Regulatory burden

3.1.2.3.1 Turnover

The adoption of the policy options considered is estimated to lead to a reduction in sales or size of the sample of downstream users in terms of turnover[234] and tonnes manufactured and sold. The extent of this reduction will depend upon the scope and timetable of the legislative changes as well as the type of business responses expected.

First order effects, that is, the impacts on business operations excluding any pass through of additional regulatory costs to customers through price adjustments, are considered in Table 3-2.

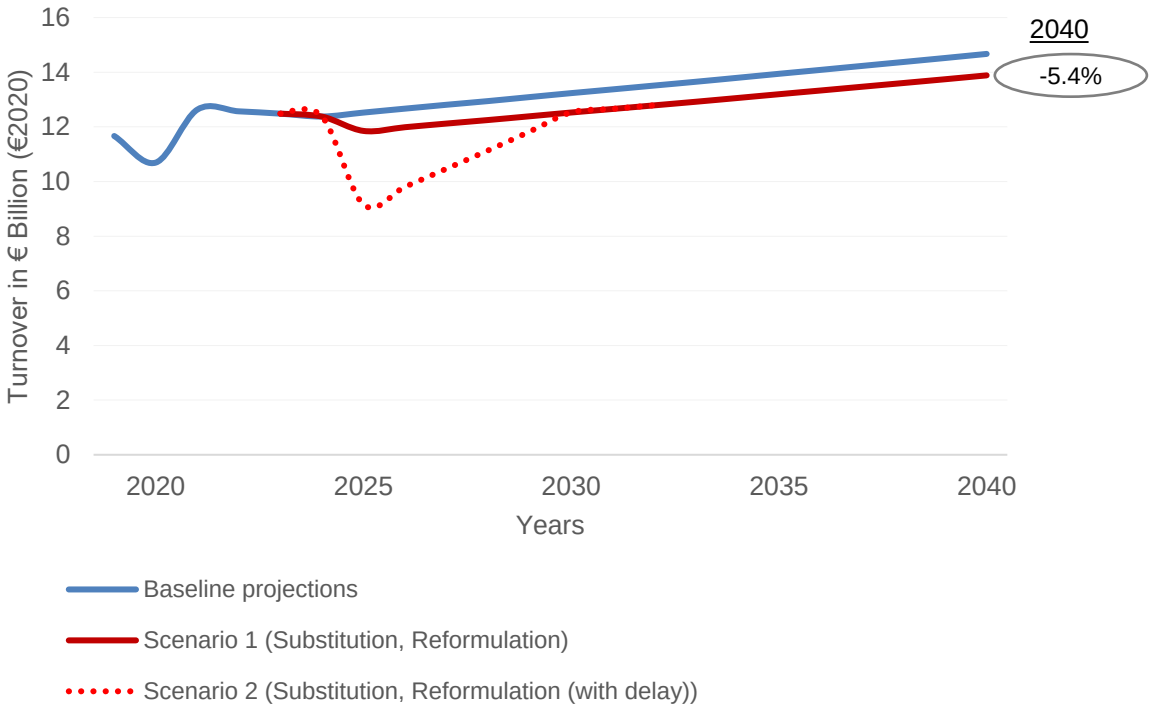
Table 3-2 Annualised impacts on the size of (sample of) downstream users' businesses against the baseline scenario in terms of turnover (€ 2021).

Scenario	First order effects or impacts on businesses overall
Scenario 1 (Substitution and Reformulation)	Surveyed F-gas downstream users are estimated to **lose €0.7 billion (€ 2021) of turnover each year on average** over the period 2025-2040, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	Surveyed F-gas downstream users are estimated to **lose €1.4 billion (€ 2021) of turnover each year on average** over the period 2025-2040, when compared to the baseline scenario.

The impacts are also presented over time in the Figure below.

[234] Turnover refers to total sales, thus including sales of products in the EEA or abroad. There is an implicit assumption that activities targeting export markets will also be affected, on average, in a similar way to the market targeting EEA customers. The effects on the exports are uncertain and could be more or less significant than the impacts that may apply to the manufacturing and/or use of substances within or for customers in the EEA.

Figure 3-10 Estimated impacts on the turnover of F-gas downstream users against the baseline scenario (€ 2021)[235].



Source: Ricardo analysis based on Eurostat data and a bespoke survey to F-gas downstream users.

These first-order effects (as shown in Figure 3-10) reflect the direct business response to the proposed legislative changes: by 2040, the downstream users' market would be around 5.4% lower than the estimated baseline, which is equivalent to a turnover loss at the end of the period of analysis of around €3.1 billion in both Scenarios 1 and 2 against the baseline. These effects exclude whether companies might pass the additional regulatory burden through to their customers and the associated implications, which we refer to as 'second-order effects'.

These second-order effects have been considered based on the evidence gathered through the survey to downstream users. Overall, based on the data available, it is estimated that companies would pass through around 26% of the additional regulatory burden resulting from the legislative changes and given that, as reported by survey participants, products containing F-gases appear to be price inelastic, this would mitigate the estimated reduction in turnover albeit marginally (by less than 1 percentage point).

Overall, this suggests that **even if this sample of downstream users were to introduce mitigation measures whilst incurring additional operating and capital costs (first order effects) and they were able to pass through some of these costs to their customers (second order effects), their operations and associated economic footprint would still be likely to reduce, with annual turnover losses against the baseline estimated to range from €0.7 billion to €1.4 billion per year, on average[236], between 2025 and 2040 (noting that this only captures effects in our small sample of downstream users, not the whole EEA industry).**

The scenarios established for estimating the potential policy impacts on the turnover of the EU F-gas producers/importers present the implications of key uncertainties relating to the timeframe of the proposed restriction's impacts on turnover. Scenario 1 considers the proposed restriction happening in 2025, with mitigation actions taking immediate effect, versus Scenario 2 which considers that businesses may need time to adapt so they can bring substitutes and/or reformulated products to the market. Within each of these scenarios there are other assumptions, and hence uncertainties, which could affect these estimations. In

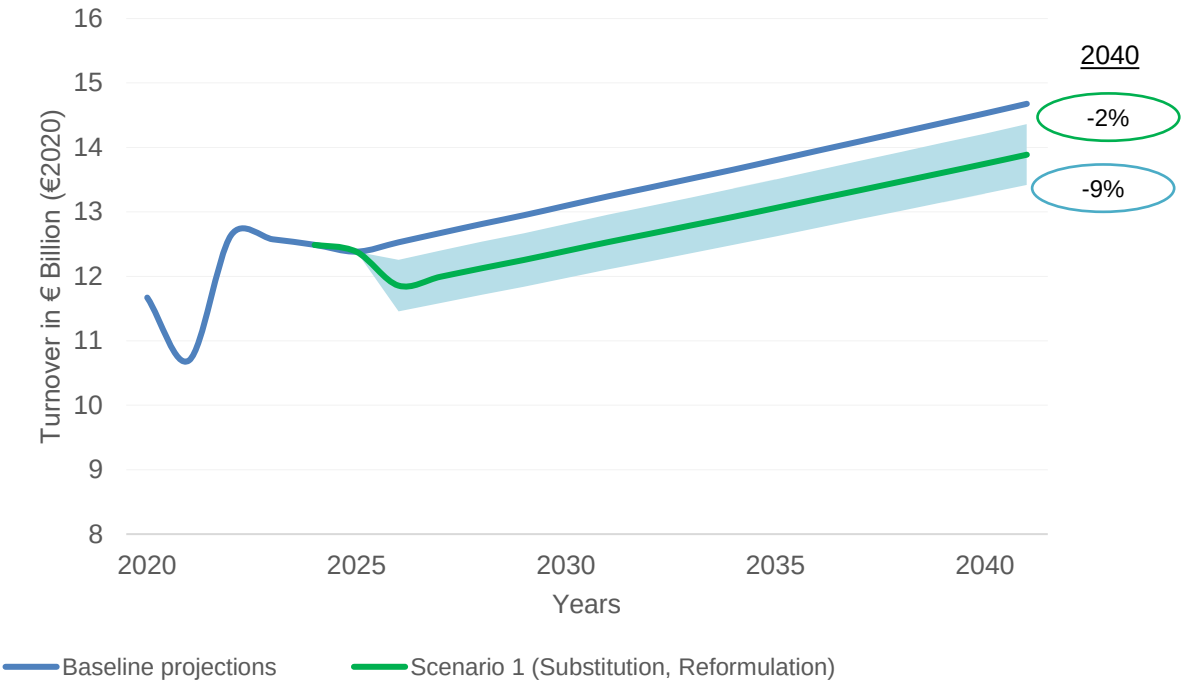
[235] Please note that the diagrammatical illustrations in this study smooth the changes in turnover over time, thus assuming that these changes are continuous (rather than discrete reductions in business). For example, in Scenario 1, it is implicitly assumed that the impact of a policy change is felt immediately, and businesses start to adjust their operations slightly in advance as a way of preparing for the year in which the legislation comes into effect. In reality, businesses may take action much earlier or have a 'grace period' during which they can adjust their operations and meet the new legal requirements.

[236] A net present value of turnover losses against the baseline has been calculated, and later annualised over the period to estimate 'equivalent annual losses of turnover' as a result of the legislative changes. A real discount rate of 4% has been employed in line with the European Commission's Better Regulation Guidelines.

particular, the sensitivity of the results to the extent to which businesses may be able to substitute and/or reformulate has been explored.

As noted earlier in this section, if businesses do not substitute and/or reformulate at all, the EEA F-gas downstream users could lose 27% of the turnover estimated in the baseline (and 5.4% losses in the central estimate with substitution and reformulation). The best available evidence suggests that businesses will be able to substitute and/or reformulate 80% of their product portfolios (in terms of turnover). However, uncertainty around the degree of substitution in the estimates elicited from the survey to F-gas downstream users provides a range of possible substitution, reformulation and other changes that is between 68% and 92%. These two extreme cases would imply that turnover losses would vary within a range between 2% and 9% for F-gas downstream users. This is illustrated in Figure 3-11 below.

Figure 3-11 Illustration of the sensitivity of the estimated impacts on the turnover of F-gas downstream users against the baseline scenario (€ 2021) to expected substitution and/or reformulation



Source: Ricardo analysis based on Eurostat data and a bespoke survey to F-gas downstream users.

Moreover, substitution and reformulation could affect the quality and attractiveness of the products sold by EEA F-gas downstream users. This could have additional indirect impacts on EEA F-gas downstream users, potentially limiting the ability of businesses to mitigate turnover losses especially in the face of international competition.

In addition, the estimated turnover losses assume that the sector's capacity to pass through the higher regulatory costs remains relatively unchanged, whereas this need not be the case in the face of growing international competition, especially in the export market. If international competition increases, it would do so to the detriment of the EEA F-gas downstream users, which would lead to worse potential turnover losses (against the baseline) in any given scenario. It has not been possible to quantify this effect in this study.

Finally, sectoral economic output is assumed to be affected in the same proportion as turnover. Thus, **if the estimates from the sample are applied to the whole production volume of all the different downstream user applications, joint losses in production volume would likely reach €2.4 billion in 2040, or between €2.2 and €4.1 billion per year jointly for all F-gas applications on annualised terms between 2025 and 2040, compared to baseline projections.**

GVA, however, depends on impacts not only on turnover and output, but also on intermediate consumption (or operating minus employment costs). Intermediate consumption is considered in the next section.

3.1.2.3.2 Intermediate consumption and operating costs

Two thirds of the F-gas downstream users surveyed for this study confirmed that they would be required to change their operations and manufacturing processes as a result of these policy changes. For most of those (72%), this will imply negative or very negative effects: dropping some lines of production, or multiple

production lines and even sites. Other respondents report mixed, limited or uncertain impacts on their manufacturing and operations. These changes carry with them cost savings for the lost business, and new costs for the productive changes to be implemented (i.e., substitution, reformulation and other).

First, the proposed restriction would likely force downstream users to reduce their operating activities, unless they can maintain production without the use of F-gases. As a result of this business reduction, operating expenditure will fall. This reduction is likely to be proportional to turnover losses against the baseline: in other words, a reduction in business operations of around 10% would result in reduction in operating costs over time. For example, in 2019, an operational contraction of 5.4% would have been equivalent to a reduction in intermediate consumption of around €0.3 billion.

Secondly, companies would also take action to find alternatives and/or substitutes to alleviate the estimated reduction in their business. Thus, some of the current operations would need to be adjusted for the manufacturing and placing on the market of substitutes and/or reformulated products. Further, additional administrative and compliance requirements, such as training, testing, certification, adjusting the hazard communication and safe use information (labelling, Safety Data Sheets (SDS)) of products, providing information for registration, and associated costs would also be incurred.

Overall, intermediate consumption and operating costs are likely to fall. These net reductions on intermediate consumption and OPEX would be driven by the losses that are estimated to the size or operations of surveyed F-gas downstream users. These estimates do not suggest, however, that there will be any cost savings from the adoption of the legislative changes. In fact, unit costs are estimated to increase, albeit very marginally.

Reliable estimates based on the survey to F-gas downstream users for the figures on additional recurring costs incurred as a result of substitution, reformulation, testing and other compliance activities could not be computed due to a low response rate on this account. But anecdotal evidence from the survey supports the need for additional operating expenditure. In fact, this evidence points towards an average 0.6% increase in unit costs, as measured by the 'ratio of intermediate consumption to turnover'.

3.1.2.3.3 Capital and R&D expenditure

Similarly, the withdrawal of products from the market would have some implications on the capital and R&D expenditure of F-gas downstream users. If the size of their business declines, it is assumed that their overall expenditure will decline as well. A 5.4% reduction in the size of the surveyed businesses in terms of their turnover may lead to an eventual reduction in overall investment of a similar proportion, which would be equivalent to reducing investment by around €30 million each year against the baseline.

Nevertheless, these companies will also need to increase their investment in capital and R&D as they work to, for example, change their manufacturing processes, identify quality substitutes and alternatives and reformulate their products. Based on the survey to F-gas downstream users, it is estimated that an additional €25 million (€ 2021) would be invested annually over 10-15 years from the adoption of the policy changes to support these changes that their companies would need to embark on to mitigate further operational and turnover losses. For these companies, this implies an increase in Capex of around 2.4% for the retained business during that period.

Overall, net reductions on intermediate Capex and R&D expenditure are estimated in a similar degree to turnover losses, but they could be more significant in the absence of the investments in capital and R&D that are required to attain the desired substitution of substances subject to restrictions, reformulation, and redesign of products.

Therefore, these reductions in expenditure do not mean that there will be any cost savings from the adoption of the legislative changes. In fact, unit expenditure could increase, at least with regards to adjusting manufacturing processes and completing the required investments for effective substitution and reformulation. Based on the survey of F-gas downstream user companies conducted for this study, the 'ratio of Capex to turnover' would be expected to increase against the baseline, albeit marginally.

3.1.2.3.4 Regulatory Burden

Regulatory burden refers to all of the administrative and compliance costs that result from EU legislation. This includes direct administration costs (e.g., sharing information, engaging with administrative process and associated charges, etc.) as well as compliance costs, including OPEX and CAPEX, associated with the response to any regulatory change (e.g., changes to manufacturing or products that incur both operating as well as capital expenses).

The survey to downstream users of F-gases estimated a regulatory burden affecting their companies of around 4.5% of their turnover on average. This estimate was used to develop a baseline against which to assess potential impacts.

As a result of the adoption of the proposed restriction, **regulatory burden is likely to increase up to 5% against the baseline, which is equivalent to an additional €1 million to €29 million in regulatory burden per year on average over the period 2025-2040, in Scenario 1 and Scenario 2, respectively.**

Further, as noted earlier, the proposed PFAS restriction would also lead to potential turnover or operational losses. If these impacts were considered direct opportunity costs linked to the restriction, it would imply that actual or effective regulatory burden would be significantly higher and likely equivalent to around 11% of turnover by 2040, when compared to the baseline.

3.2 ENVIRONMENTAL RISKS

Presently there is a wide variety of information available on the environmental impacts of HFCs, HFOs, and H(C)FOs. This includes the climatic impacts of these F-gases in regard to their global warming potential as greenhouse gases. Therefore, the below section has provided a comparative assessment of the GWP of the in-scope F-gases and their suitable low-GWP alternatives, with consideration for the potential long-term and short-term impacts that the restriction proposal would have on global climate change. Furthermore, an assessment of the ecotoxicological effects of F-gases and their breakdown product of TFA has also been assessed based on current literature.

3.2.1 Climate change

When F-gases are released into the atmosphere they cause the earth's average temperature to rise, contributing to anthropogenic climate change. Since the onset of the industrial revolution, HFCs have contributed about 1.1% of radiative forcing (ability of all greenhouse gases to trap heat), according to the US NOAA (National Oceanic and Atmospheric Administration)[237]. The emissions of greenhouse gases (GHGs) including F-gases drive global warming, which has been observed to lead to rising sea levels, more frequent and severe floods, droughts, and wildfires[238]. This has severe impacts on all of earth's ecosystems, subsequently triggering impacts on the health and well-being of populations[239]. The impacts of climate change will cause ecosystem disruption and loss of biodiversity due to multiple factors, including, disruption of food chains, and changes in reproduction cycles[240].

Greenhouse gases trap solar radiation (by absorbing infrared (IR) radiation) and redirect that radiant energy toward the Earth's surface. This so-called positive radiative forcing effect contributes to global warming. Some GHGs are more effective than others at absorbing IR radiation and contributing to global warming, and for each GHG a GWP has been developed to allow comparisons of the global warming impacts of different gases. The impact of an individual GHG released to the atmosphere on global warming is dependent upon three factors: (1) the concentration of the GHG in the atmosphere, (2) the atmospheric lifetime of the GHG, and (3) the GWP of the GHG. GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases).

Anthropogenic greenhouse gas emissions have risen since the industrial revolution in the 18th century[241]. Unlike other GHGs, F-gases are synthetic and therefore have been used and released to the atmosphere over a shorter period. Significant production and emissions of HFCs in the scope of this study began in the past three decades. HFCs were introduced to replace CFCs which have high ozone depletion potential. F-gases exhibit a wide range of GWP values and hence a wide range of impacts on climate change. Certain F-gases are very potent GHGs: SF6 has a GWP of 23,500 times greater than CO_2, whilst other F-gases have low GWPs and hence result in a negligible impact on climate change (e.g., HFO-1234yf GWP <1).

Current global emissions of F-gases are uncertain[242], although atmospheric concentrations of all the main HFCs are measured and reported[243]. However, analysis suggests growing demand for heating and cooling technologies means global emissions of F-gases are projected to rise[244]. One study projects global emissions of F-gases to rise from 700 MT CO_2-e in 2005 to 3700 MT CO_2-e in 2050[245]. At the EU level, emissions of F-gases rose sharply by around 70% between 1990 and 2014. However, the 2018 Scientific Assessment Report stated that global adherence to the HFC phasedown schedule of the 2016 Kigali Amendment to the Montreal

[237] NOAA Global Monitoring Laboratory, 2022. *THE NOAA ANNUAL GREENHOUSE GAS INDEX (AGGI)*. Available at: https://gml.noaa.gov/aggi/aggi.html

[238] IPCC, 2021. Climate Change 2021, The Physical Science Basis, Summary for Policymakers. P.5. Accessible under: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

[239] Ibid, p.8.

[240] Ibid.

[241] Ritchie, H. & Roser, M., 2022. CO_2 emissions. Our World In Data. Accessible Under: https://ourworldindata.org/co2-emissions

[242] UNDP, 2017. Assessments of HFC emissions. United Nations Development Programme. Accessible under: https://www.undp.org/publications/assessments-hfc-emissions

[243] See for example Atmospheric histories, growth rates and solubilities in seawater and other natural waters of the potential transient tracers HFO-22, HFO-141b, HFO-142b, HFC-134a, HFC-125, HFC-23, PFC-14 and PFC-116, Pingyang Li, Jens Mühle, Stephen A. Montzka, David E. Oram, Benjamin R. Miller, Ray F. Weiss, Paul J. Fraser, and Toste Tanhua, Ocean Sci., 15, 33–60, 2019 https://doi.org/10.5194/os-15-33-2019

[244] IPCC, 2021. Technical Summary. Accessible under: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

[245] Purohit, P. and Höglund-Isaksson, L., 2017. Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs. Atmospheric Chemistry Physics. 17, 2795–2816. Accessible under: https://doi.org/10.5194/acp-17-2795-2017

Protocol would substantially reduce future projected global HFC emissions. Emissions are projected to peak before 2040 and decline to around 1300 $MTCO_2$-e in 2050 and less than 1 $GtCO_2$-e yr^{-1} by 2100[246].

Historically EU emissions of F-gases have fallen between 2014 and 2019, although there was a slight rise in emissions in 2020, by 7% compared with 2019[247]. As a proportion of all greenhouse gases released in the EU, in 2019 F-gases represented 2.3% of total CO_2-e emissions.

The GWP of the F-gases in the scope of this study are detailed in Table 3-3. Values for F-gases in the scope of this study were taken from the 2014 F-gas Regulation[248] (derived from the IPCC's AR4 Climate Change Report, 2007). The IPCC AR6 report[249] (Table 7.SM.7) was also consulted to identify additional variations of the F-gases in the scope of the study and to show how the 100-year GWPs of F-gases in scope of the evaluation have changed between AR4 and AR6. Table 3-3 shows that HFCs in the scope of the study have relatively high GWPs, between 693 and 4470 (F-gas Regulation values or IPCC AR4) times the 100-year GWP of CO_2. By comparison, the HFOs and the H(C)FOs have relatively small GWPs. Some H(C)FOs are intended as replacements for higher GWP HFCs, which will be discussed further in Section 3.4.

Table 3-3 100-year GWP of F-Gases within the scope of the study. Values for F-Gases which were included in the 2014 F-Gas Regulation[250] (derived from the IPCC's AR4 Climate Change Report, 2007) were used. The IPCC AR6 report (Table 7.SM.7) was also consulted to identify additional variations of the F-Gases in the scope of the study and to compare 100-year GWPs[251].

Group	Name	100-year GWP (AR4 & F-gas Regulation)	100-year GWP (AR6)
HFC	HFC-125	3500	3740
	HFC-134a	1430	1530
	HFC-143a	4470	5810
	HFC-227ea	3220	3600
	HFC-245fa	1030	962
	HFC-365mfc	794	914
HFO	HFO-1234yf	4[a]	0.501
	HFO-1234ze(Z)	7[a]	0.315
	HFO-1234ze(E)		1.37
	HFO-1336mzz(Z)	9[a]	2.08
H(C)FO	HCFO-1233zd(Z)	4.5[a]	0.454
	HCFO-1233zd(E)		3.88

a. Not evaluated at the time of the IPCC AR4 report. Values taken from the F-gas regulation.

In the refrigerants sector, alternatives to F-gases in the scope of this study have a far lower GWP, outlined in Table 3-4. The significant differences between the AR4 and AR6 GWPs for the hydrocarbons are mainly due to the inclusion of indirect GWP effects for the AR4 values[252]. Note that most of these alternatives have

[246] WMO (World Meteorological Organization), Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. Chapter 2: HYDROFLUOROCARBONS (HFCs) Lead Authors: Stephen A. Montzka and Guus J.M. Velders)

[247] EEA, 2021. Fluorinated greenhouse gases 2021. European Environment Agency. Accessible under: https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2021

[248] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[249] Intergovernmental Panel on Climate Change 2021. Climate Change 2021 The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Accessible under: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

[250] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[251] Intergovernmental Panel on Climate Change 2021. Climate Change 2021 The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Accessible under: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

[252] For more information about indirect GWP effects of hydrocarbons see Lifetimes, direct and indirect radiative forcing, and global warming potentials of ethane (C2H6), propane (C3H8), and butane (C4H10), Atmos. Sci. Lett. 2018;19:e804. wileyonlinelibrary.com/journal/asl2 https://doi.org/10.1002/asl.804 Øivind Hodnebrog, Stig B. Dalsøren, Gunnar Myhre, Center for International Climate and Environmental Research-Oslo (CICERO), Oslo, Norway

limitations, which challenge their uptake as substitutes for F-gases in the scope of this study, such as efficiency in the temperature ranges required, or risk to human health if leaked in significant quantities. This will be further discussed in more detail in Section 3.3.

Table 3-4 100-year GWP of non-fluorinated alternatives to F-Gases within the scope of the study. Values in the left-hand column are retrieved from the F-Gas Regulation[253]. Values in the right-hand column are retrieved from *Climate Change 2021, The Physical Science, IPCC* (Table 7.SM.7)[254].

Group	Name	100-year GWP (2014 F-Gas Regulation)	100-year GWP (AR6)
Non-fluorinated alternatives	Carbon Dioxide	1	1
	Ammonia	0	0
	Propane (R-290)	3	0.02
	Butane (R-600)	4	0.006
	Ethane (R-170)	6	0.437

Reducing emissions of F-gases will contribute to the reduction of overall greenhouse gas emissions globally and in Europe. The F-gas Regulation includes restrictions of F-gases with high GWPs. The F-gas Regulation was based on the EU roadmap's ambition to reduce emissions from non-CO_2 sources, including F-gases, by 72% to 73% by 2030 and by 70% to 78% by 2050, compared to 1990 levels.

The restriction proposal could have significant impacts on the F-gases used in the EEA.

Firstly, the prevention of the use of certain F-gases would provide a benefit, as these gases are removed from use, limiting potential emissions of these specific gases in the future. However, as set out in Section 2.2.1 above, the EU already has in place an extensive policy framework aimed at limiting the emission of GHGs for EU activities. In particular, the F-gas Regulation directly targets this through the phase-down (and in some cases prohibits altogether) in the use of HFCs. The proposed restriction may, therefore, be considered double regulation as a result of the current phase down under the F-gas Regulation.

Furthermore, the true impact on GHG emissions and the use of F-gases would depend on the response of the F-gas industry and consumers to the restriction. In the case where restricted production lines and applications are lost altogether, this would lead to a reduction in the use and future emissions of these F-gases. However, in many cases the industry will seek to switch to using alternatives to the restricted F-gases. In some cases, it may be possible to accelerate the transition towards natural (low or no GWP) alternatives, again delivering a reduction in GHG emissions. However, several of the F-gases in the scope of this restriction are low-GWP alternatives to other F-gases. If producers, importers and users are not able to access these F-gases, the restriction could extend reliance on high-GWP alternatives as the market shifts to higher GWP F-gases not covered by the scope of the restriction, resulting in higher greenhouse gases emissions and a higher risk of climate change as a result. As discussed in section 2.2.2.4, there are barriers towards adoption of non-fluorinated alternatives which may hinder rapid and large-scale adoption of non-fluorinated alternatives, and such alternatives are not readily available for all applications. REPowerEU[255] and its aim of reducing dependency on Russian fossil fuels by 2030 could also have a significant impact on the availability and price of hydrocarbons as alternatives to F-gases, making EU-wide adoption significantly harder for industry.

In practice, the total supply of HFCs is capped by the F-gas Regulation, which could in part limit the use of high GWP substances in place of restricted F-gases. However, where demand increases for such substances and supply is limited, this instead could result in a strong price increase for HFCs. Higher prices could feed through to businesses and eventually to consumers, the wider economy, as well a potentially increasing the risk of illegal trade of HFCs. In addition, unavailability of F-gases, as a result of the restriction, could lead to

[253] 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 Text with EEA relevance. Accessible under: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517

[254] Intergovernmental Panel on Climate Change 2021. Climate Change 2021 The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Accessible under: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

[255] EC (2022). REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

early obsolescence of equipment, increasing waste and obstructing the aims of the circular economy action plan.

Thirdly, the restriction could have a negative impact on energy efficiency of equipment using F-gases. If alternatives to F-gases in scope are applied and as a consequence systems and equipment are less efficient, energy efficiency will be reduced, more energy will be demanded which will also lead to increased GHG emissions (depending on the emissions intensity of the grid). Further research is required to understand how switching to alternative F-gases will affect energy efficiency across the supply chain.

Finally, the F-gases in scope of the proposed restriction are used in technologies which are critical to reducing GHG emissions, particularly heat pumps for residential and commercial heating and cooling. Heat pumps for example can have a Coefficient of Performance (CoP)[256] value of around 2.5[257], meaning that they can produce 2.5kWh of heat output, for every 1kWh of electricity used. Thus, they require less energy to operate and therefore contribute to less indirect emissions.

The restriction is likely to disrupt the heat pump industry, at least in the short term (to be estimated in the social and economic analysis). However, the next decade is also a critical stage for increasing uptake of heat pumps as momentum has built following the EU Green Deal and national level COVID recovery plans to work towards achieving the EU's long-term climate goals. More severe consequences for introduction of the restriction could include removing some critical technologies from the market with negative impacts on supply chains and prices.

3.2.2 Ecotoxicity

HFCs, HFOs and H(C)FO

Most of the HFCs in scope are not toxic to terrestrial plants or aquatic organisms such as algae, invertebrates, and fish[258] (Tsai, 2005). For example, HFC-134a standard acute toxicity tests for algae, daphnia (aquatic invertebrate) and fish resulted in a range of Effect Concentration (EC_{50})[259] between 450 and 980 mg/L[260]. Under the CLP Regulation[261] a substance is deemed Category 1 Acute toxic (and possibly chronic)[262] to aquatic life with a $L(E)C_{50}$ value of <1mg/L. Therefore, studies indicate that HFC-134a doesn't meet the criteria for aquatic toxicity and far exceeds the possibility of being classified as a Category 1 Acute toxic (and chronic) to aquatic life. HFO-1234yf, HFO-1234ze, and HFO-1336mzz(Z) are also not classified under the CLP Regulation as having short-term or long-term chronic toxicity to aquatic life[263]. HCFO-1233zd on the other hand has a REACH registered classification of Aquatic Chronic 3[264] toxicity, based on a 96-h LC_{50} of 38 mg/L in fish (O. mykiss) and a chronic aquatic endpoint 72-h no-observed-effect-concentration-growth-rate NOErC of 115 mg/L for freshwater algae (P. subcapitata). Meaning it is harmful to aquatic life with long lasting effects.

Trifluoroacetic acid (TFA)

TFA is a terminal breakdown product in varying yields for some H(C)FCs (HCFC-123, HCFC-124), some HFCs (HFC-134a, HFC-143a and HFC-227ea), and some HFOs (HFO-1234yf, and potentially HFO-1234ze, HFO 1336mzz and HCFO-1233zd[265]). HFC-125 breaks down completely to hydrogen fluoride (HF) and CO_2 and does not form TFA[266,267], whereas HFO-1234yf breaks down into 100% TFA, at levels around five times more than HFC-134a[268]. The emissions and fate of HFO-1234yf, from its use in mobile air-conditioning have been

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[256] The Coefficient of Performance (CoP) is used to describe the ratio of efficiency of a heat or cooling system.

[257] Haddad, E., Saab, S., Zoughaib, A. (2021). Test of condensing units' performance and operating limits using different Refrigerants. *18th International Refrigeration and Air Conditioning Conference at Purdue*. Available at: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3144&context=iracc

[258] Tsai, W.-T., 2005. An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs). Chemosphere, 61(11), pp. 1539-1547

[259] Effect Concentration 50 - How much concentration of a chemical is required to 'affect' 50% of the test population.

[260] Berends, A. G., de Rooij, C. G., Shin-ya, S., Thompson, R. S., 1999. Biodegradation and Ecotoxicity of HFCs and HCFCs. 146-151, 36.

[261] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures. Available at: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008R1272

[262] Highest and most severe classification category of acute toxicity under the CLP Regulation

[263] ECHA REACH Dossiers.

[264] Aquatic Chronic 3 - 3rd most severe classification category for Chronic toxicity (out of 4) under the CLP Regulation

[265] UBA Final report (2021). Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential | Umweltbundesamt. Table 14. Available at: https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated

[266] Burkholder, J. B., R. A. Cox & A. R. Ravishankara (2015). Atmospheric Degradation of Ozone Depleting Substances, Their Substitutes, and Related Species. Chemical Reviews, 115:3704–3759.

[267] IPCC/TEAP Special Report (2005). Safeguarding the Ozone Layer and the Global Climate System. Chapter 2: Chemical and Radiative Effects of Halocarbons and Their Replacement Compounds, 2005 page 152

[268] Luecken et al., (2010). Ozone and TFA impacts in North America from degradation of 2,3,3,3-Tetrafluoropropene (HFO-1234yf), a potential greenhouse gas replacement. Environmental Science & Technology, 44(1), pp. 343-348.

extensively investigated[269,270,271,272]. In contrast HCFO-1233zd theoretically breaks down to give 2% TFA[273]. There is disagreement about the yields of TFA from HFO-1234ze and HFO 1336mzz. The UBA report[265] states that TFA yields are <10% for HFO-1234ze and <20% for HFO 1336mzz. EFCTC claims that the TFA yields are similar to that for HCFO-1233zd due to the similar atmospheric breakdown pathways, with TFA yields of 0-2% for HFO-1234ze and 0-4% for HFO 1336mzz[274].

TFA can enter ecosystems through generation in the troposphere and subsequent precipitation. Due to TFA being a strong acid, it readily bonds with minerals in soil and surface waters to create trifluoroacetate salts. TFA is stable and persistent in the environment. It is also water soluble and so accumulates in dry-lakes (playas), land-locked lakes, and the ocean, where it combines with cations such as sodium, potassium, calcium, and magnesium[275]. In the environment, salts of TFA behave in exactly the same way as salts of other minerals. Where mineral-salts have accumulated in salt lakes, playas, and oceans, TFA-salts from natural and anthropogenic sources also accumulate[276].

During aquatic toxicity tests, Berends[277] found no effects of TFA at 1,200mg/L on *Daphnia magna* (water flea) and *Danio rerio* (Zebra fish). Moreover, a 7-day study on *Lemma gibba G3* (duckweed) displayed a NOEC of 300mg/L and toxicity tests on various species of algae all showed an EC_{50} value higher than 100mg/L. These tests all suggest a low toxicity to aquatic life as TFA does not meet the criteria for any short-term or long-term aquatic toxicity classifications under the CLP Regulation.

The effects of TFA exposure on seed germination of 10 species of terrestrial plant has been investigated [278]. The 10 species included sunflower, cabbage, lettuce, tomato, mung bean, soybean, wheat, corn, oats, and rice. The seeds were exposed to TFA through aqueous application and the results indicated a no effect concentration of 1000 mg/L (the maximum of the study).

The environmental effects of TFA have been summarised by the Environmental Effects Assessment Panel, Update 2020 [279]. The paper reports that TFA is produced by the environmental degradation of several hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs) and is found in low concentrations within the environment and not at concentrations likely to have adverse toxicological consequences. For example, analysis of 1187 samples of rainwater collected from 8 locations across Germany found a median and a precipitation-weighted mean concentration of TFA of 0.210 µg/L and 0.335 µg/L, respectively (2018-2019). Furthermore, TFA found in the environment as a salt, typically has a no-observed-effect-concentration (NOEC) for aquatic species of >10,000 µg/L.

There is no evidence to date to suggest any adverse health effects in humans from exposure to TFA[279]. TFA salts are of low acute toxicity to mammals under conditions relevant to environmental exposure. Furthermore, historical and current measurements of TFA in soil and surface-water indicate minimal risks when compared to no-observed-effect-concentrations (NOECs) in laboratory and field-based testing[276,279].

3.2.3 Analysis of Impacts

Environmental impacts of a restriction of PFAS that includes F-gases will have to consider a number of forces acting in opposite directions: first, the emission of the F-gases in scope (not including releases from the bank of F-gases at the point the restriction is introduced) would become zero, compared to the baseline; second,

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[269] Papasavva, S., Luecken, D. J., Waterland, R. L., Taddonio, K. N., Andersen, S. O., (2009).“Estimated 2017 refrigerant emissions of 2, 3, 3, 3-tetrafluoropropene (HFC-1234yf) in the United States resulting from automobile air conditioning”, Environmental Science and Technology, 2009, 43, 9252−9259.

[270] Kazil, J., McKeen, S., Kim, S. W., Ahmadov, R., Grell, G. A., Talukdar, R. K., Ravishankara, A. R., (2014). “Deposition and rainwater concentrations of trifluoroacetic acid in the United States from the use of HFO-1234yf”, J. Geophys. Res.-Atmos. 2014, 119, 14-059−14-079.

[271]

[272] Liji M. David, Mary Barth, Lena Höglund-Isaksson, Pallav Purohit, Guus J. M. Velders, Sam Glaser, and A. R. Ravishankara, (2021). “Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East”, Atmospheric Chemistry and Physics, 21, 14833–14849, 2021.

[273] Mads P. Sulbaek Andersen, Johan A. Schmidt, Aleksandra Volkova, Donald J. Wuebbles, Atmospheric Environment 179 (2018). A three-dimensional model of the atmospheric chemistry of E and ZCF3CH=CHCl (HCFO-1233(zd) (E/Z)), 250–259. See the Supplemental Information which summaries the atmospheric chemistry used in the model.

[274] EFCTC Position paper Published evidence supports very low yield of TFA from most HFOs and HCFOs August (2021). Available at 2021_08_EFCTC_Position-Paper_Published-evidence-supports-very-low-yields-of-TFA-from-most-HFOs-and-HCFOs_F.pdf (fluorocarbons.org)

[275] UNEP Ozone Secretariat, 2015. Ecological Issues on the feasibility of managing HFCs: Nairobi, UNEP Ozone Secretariat.

[276] Solomon K, et al., (2016). Sources, fates, toxicity, and risks of trifluoroacetic acid and its salts: Relevance to substances regulated under the Montreal and Kyoto protocols. Journal of Toxicology and Environmental Health B. This report is an Accepted Manuscript of an article published by Taylor & Francis in J Toxicol Environ Hlth B on June 27, 2016. Available: http://www.tandfonline.com/10.1080/10937404.2016.1175981

277 Berends et al., (1999). Toxicity of Trifluoroacetate to Aquatic Organisms Environmental Toxicology and Chemistry. 1053-1059, 18, 5.

278 Thompson, R. S. & Windeatt, A. J., (1994). Sodium trifluoroacetate: Effects on seed germination (ten species, by aqueous exposure), s.l.: Brixham Environmental Laboratory.

[279] Neale, R. E., Barnes, P. W., Robson, T. M., Neale, P. J., Williamson, C. E., Zepp, R. G., et al. (2021), ““Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change: UNEP Environmental Effects Assessment Panel, Update 2020”, Photochemical & Photobiological Sciences https://doi.org/10.1007/s43630-020-00001-x. See sections 7.8 to 7.11 for Trifluoroacetic acid (TFA). Open access paper.

the restriction will trigger the uptake of alternatives which, on occasions could have a higher GWP than that of F-gases; third, illegal trade of F-gases could increase, thus implying some F-gas placing on the market; finally, the timings of CO_2-eq emissions of each of these forces may be different.

Table 3-5 provides the total production (tonnes) of F-gases in 2030, and the GWP of each F-gas volume to be placed on the market, according to the consultation of F-gas producers and importers. The resulting figure represents the total relative CO_2-eq (in tonnes) saving of each F-gas should there be a ban on all F-gas in scope in the EEA.

In the case of HFCs, which generally have a far greater GWP and are produced annually at far greater quantities than other F-gases, the relative GHG saving to the atmosphere is in the tens of millions of tonnes. However, should a ban be enacted the benefits to reducing global warming would not be necessarily immediate and to the extent of a reduction in millions of tonnes of CO_2-eq, as presented in the below table. More likely, the reductions in CO_2-eq emissions will be observed decades from the placing on the market of the F-gases, when the products containing them reach their end of life.

Table 3-5 Total GWP of each F-gas by total placing on the market tonnes in 2019 and 2030 as indicated in the stakeholder consultation to F-gas producers and/or importers. Source: Ricardo bespoke survey to F-gas producers and importers (tonnes), see Table 3-3 for GWP individual values.

	2019			2030		
F-gas	**Total Tonnes**	**Total GWP (AR4 100-year)**	**Total GWP (AR6 100-year)**	**Total Tonnes**	**Total GWP (AR4 100-year)**	**Total GWP (AR6 100-year)**
HFC-125	8,665	30,327,500	32,407,100	4,740	16,590,490	17,728,123
HFC-134a	22,915	32,768,450	35,059,950	14,809	21,177,566	22,658,515
HFC-143a	2,265	10,124,550	13,159,650	1,187	5,307,985	6,899,193
HFC-227ea	916	2,947,910	3,295,800	977	3,147,228	3,518,640
HFC-245fa	*C*	*C*	*C*	*C*	*C*	*C*
HFC-365mfc	0	0	0	0	0	0
HFO-1234yf	*C*	*C*	*C*	*C*	*C*	*C*
HFO-1234ze	*C*	*C*	*C*	*C*	*C*	*C*
HFO-1336mzz(Z)	*C*	*C*	*C*	*C*	*C*	*C*
HCFO-1233zd	*C*	*C*	*C*	*C*	*C*	*C*
Joint amount in tonnes for: HFC-245fa, HFO-1234yf, HFO-1234ze, HFO-1336mzz(Z), HCFO-1233zd	*17,510*	*866,103*	*751,075*	*24,304*	*128,647*	*34,395*
Total	**52,271**	**77,034,513**	**84,673,575**	**46,356**	**46,609,549**	**51,164,081**

Note 1: '*C*' = Censored for confidentiality reasons.

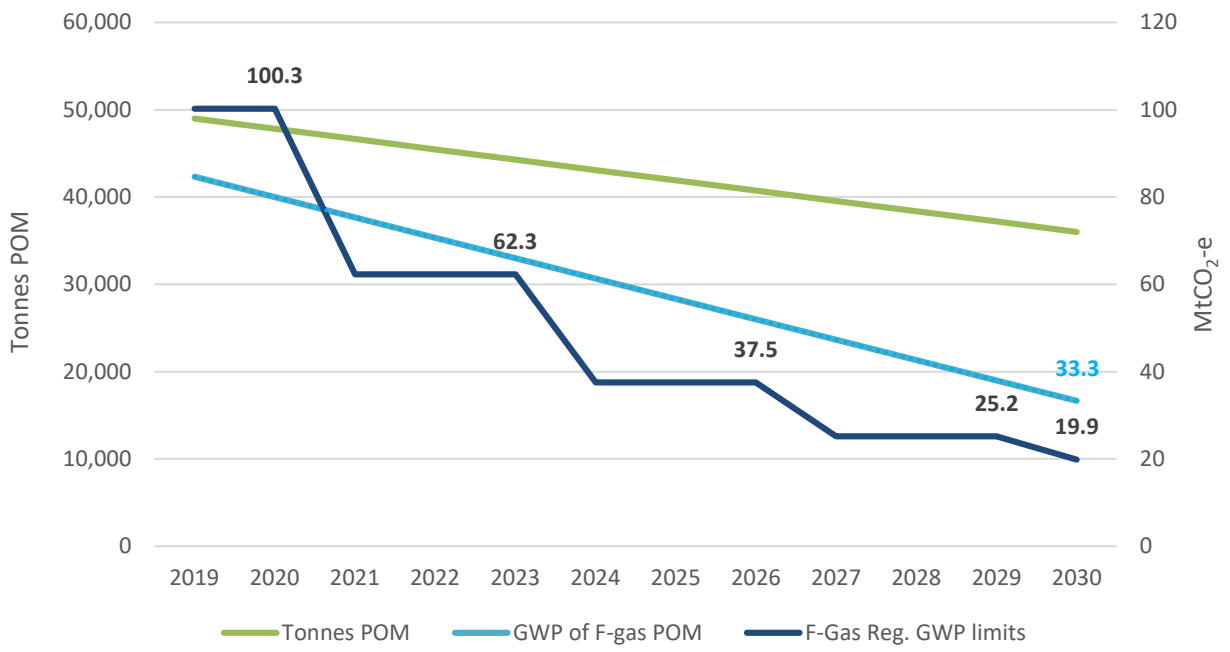
Note 2: Where GWP values for F-gases were not reported in the IPCC AR4 report, values reported in the F-gas regulation have been used for the calculation instead. See Table 3-3 Note 'a' for which F-gases this applies to.

As noted, F-gases will still exist in their current applications (e.g. refrigeration units, vehicles) and could potentially be released into the atmosphere upon their disposal, decades later. Thus, the greatest global warming potential savings will not be realised until at least 2040 and beyond; although there will still be a reduction in GWP between 2019 and 2030 based on a reduction in production. Furthermore, F-gases will continue to persist in the atmosphere for many years (e.g. 14 years in the case of HFC-134a) after their release, and their breakdown to carbon-fluorine bonds would also contribute to global warming, as previously explained.

Figure 3-12 highlights the expected reduction in GHGs as a result of a reduction in tonnes of F-gases placed on the market, as reported by respondents in the stakeholder consultation. A linear reduction in production between 2019 and 2030 has been assumed for simplification, as the exact pathway that a reduction in production will follow is unclear. A 27% reduction in tonnes to be placed on the market is expected, while a 61% reduction in their GWP can be expected based on the reported quantities to be placed on the market, as reported in the stakeholder consultation for 2019 and 2030. These two figures illustrate the switch from higher-GWP F-gases to lower-GWP H(C)FOs in the baseline scenario.

Figure 3-12 also includes the CO_2-eq targets for F-gases under the F-gas Regulation for reference[280]. While the GWP of the reported F-gases to be placed on the market in 2030 does exceed the target limits, it is possible that a reporting error arising from information being provided in ranges could account for this difference. Overall, the F-gas industry appears to be taking into account the regulatory baseline and their expectations seem to be broadly in line with the limits imposed by the F-gas Regulation.

Figure 3-12 Tonnes placed on the EEA market between 2019 and 2030 and their associated GWP (right-hand axis), and GWP limits for HFCs established in the F-gas Regulation. Source: bespoke survey to F-gas producers and importers, and EEA.



In the absence of further regulatory developments, the baseline established by the F-gas Regulation is the one considered to evaluate potential reductions in environmental impacts from a restriction of F-gases. As stated above, reductions in GWP arising from a restriction of F-gases happening in 2025 would be expected at least two decades later, when the last products and applications containing F-gases are disposed.

Should the non-fluorinated alternatives to F-gases highlighted in this report replace the estimated F-gas production in 2030 one-for-one then their production will still somewhat contribute to global warming with the exception of ammonia, as they all have GWP values exceeding 0 (Table 3-4). However, given that some F-

[280] GWP of the expected POM by the industry include all F-gases in scope, while GWP limits set by the F-gas Regulation are just limited to HFCs. However, and due to the low GWP of the HCFOs (not limited by the F-gas Regulation), the difference between including them and not including them in this picture is below 0.1 $MtCO_2$-eq. Hence, for simplification, all F-gases in scope are included under tonnes POM and GWP of F-gas POM reported in consultation.

gases have GWP values 3 orders of magnitudes greater than their potential alternatives, the reduction in GWP will be relatively significant compared to use of conventional F-gases.

Downstream users in the **RACHP** sector argue that the current F-gas Regulation is sufficient, and further regulation would cause unnecessary bureaucracy. The impact of a ban on F-gases would reduce enthusiasm for heat pumps. The following measures are suggested to effectively reduce emissions of F-gases:

- tight refrigerant circuits, installed and maintained by F-gas accredited specialists
- the transfer of refrigerants only in closed systems
- the recovery of refrigerants at the end-of-life by F-gas accredited specialists in order to recycle or reclaim them
- regular checks for leakages in the maintenance of appliances using higher GWP refrigerants
- planned reduction of the quantity of hydrofluorocarbons placed on the market.

3.3 HUMAN HEALTH RISKS

The effects of HFCs, HFOs, H(C)FOs and their breakdown products on human health has been studied and reported in scientific literature. Furthermore, the effects of non-fluorinated alternatives on human health have also been reported in literature. Therefore, the comparative assessment of human health risks between F-gases and their potential substitutes is reported below. This section draws upon peer-reviewed and established studies within the toxicology discipline and provides application specific context as to the potential perceived risks to humans, including professionals and consumers. Due to the inherent physical properties of certain potential alternatives to F-gases, physical health effects such as flammability have also been reviewed based on available literature.

3.3.1 HFCs

HFC applications include refrigeration, metered dose inhalers, heating, air conditioning, foam blowing, aerosols and fire protection, all of which have a potential for inhalation exposure. However, due to their physico-chemical properties, HFCs typically display a low potential for human toxicity[281]. Extensive human testing has shown that HFCs have a very low inhalation toxicity and display no observable evidence to suggest a genetic, reproductive, developmental, and carcinogenic toxicity in humans[281]. For example, HFCs such as HFC-134a[282], HFC-143a[283] , and HFC-245fa[284] were found to all have low to no effect of exposure on human tests after a 2-hour exposure at 300-500ppm 2-hour (with exercise) exposure. Ernstgård[285] did report a statistically significant change in inflammatory markers, however it was not consistent with an inflammatory response. In studies with rats, Dekant[286] showed that even at high concentrations (up to 20,000ppm), HFCs such as HFC-134a and HFC-125 have a low potential for acute and sub-chronic toxicity.

HFC-125[287], HFC-134a[288], HFC-143a[289], and HFC-227ea[290] are all of low acute toxicity via inhalation, as shown by exposure to levels exceeding 500,000ppm (4-h acute toxicity studies in rats), as reported in their respective REACH registration dossiers. The REACH registration dossier of HFC-245fa[291] reports an acute toxicity lethal concentration (LC_{50}) for inhalation of >116,000ppm (4-h rat), again suggesting a low level of acute toxicity via the inhalation route. General and toxicological information supplied in the REACH registration dossier of HFC-365mfc[292] is heavily restricted. However, HFC 365mfc has a C&L harmonised classification of Flammable Liquid 2 (H225) and no notified health classifications.

The National Research Council (US) suggests that HFC 134a's low acute inhalation toxicity is partly due to its rapid elimination and low uptake, with most of the compound being exhaled unchanged[293].

Tsai[281] summarises exposure levels/limits for workplace exposure (Table 3-6). The summary includes No-observed-adverse-effect level (NOAEL) values, Lowest-observed-adverse-effect level (LOAEL) values, and Lethal Concentration 50(LC_{50}) values or Approximate Lethal Concentration (ALC) values compiled from HFC manufacturer's material safety data sheets and available references (primarily the United States). According to the American Industrial Hygiene Association, DuPont Co. (USA), and Deutsche Forschungsgemeinschaft (Germany) the majority of the in-scope HFCs have relatively high occupational exposure limits, with limits of 1000ppm. CO_2 exists in air at around 400ppm.

[281] Tsai, W.-T., 2005. An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs). Chemosphere, 61(11), pp. 1539-1547.

[282] Gunnare et al., 2006. Toxicokinetics of 1,1,1,2-tetrafluoroethane (HFC-134a) in male volunteers after experimental exposure. Toxicology Letters, 167(1), pp. 65-65.

[283] Gunnare et al., 2007. Experimental exposure to 1,1,1-trifluoroethane (HFC-143a): uptake, disposition and acute effects in male volunteers. Toxicology Letters, 172(3), pp. 120-130.

[284] Ernstgård et al., 2009. Experimental Exposure to 1,1,1,3,3-Pentafluoropropane (HFC-245fa): Uptake and Disposition in Humans. Toxicological Sciences, 113(2), pp. 326-336.

[285] Ernstgård et al., 2010. Experimental Exposure to 1,1,1,3,3-Pentafluoropropane (HFC-245fa): Uptake and Disposition in Humans. Toxicological Sciences, 113(2), pp. 326-336.

[286] Dekant, W., 1996. Toxicology of Chlorofiluorocarbon Replacements. Environmental Health Perspectives, 104(1), pp. 75-83.

[287] HFC-125. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/15415

[288] HFC-134a. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/15155

[289] HFC-143a. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/15086

[290] HFC-227ea. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/1989

[291] HFC-245fa. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/18560/1/1

[292] HFC-365mfc. ECHA REACH dossier. Available at: https://echa.europa.eu/de/brief-profile/-/briefprofile/100.102.859

[293] National Research Council (US), 2002. Acute Exposure Guideline Levels for Selected. 2 ed. Washington (DC): National Academies Press (US).

Table 3-6 Summary of exposure limits, NOAEL, LOAEL, LC50 and ALC values of HFCs[281]

HFCs	Exposure level/limit (ppm)	NOAEL (v/v%)[a]	LOAEL (v/v%)[b]	LC50 or ALC (v/v%)[c]
HFC-23	NA[d]	50	50	66.3
HFC-32	1000[e]	NA[d]	NA[d]	52
HFC-125*	1000[e]	7.5	10.0	80
HFC-134a	1000[e,f]	NA[d]	NA[d]	50
HFC-143a	1000[e]	NA[d]	NA[d]	54
HFC-152a	1000[e]	NA[d]	NA[d]	38.3
HFC-227ea	1000[g]	9.0	10.5	78.9
HFC-236ea	NA[d]	NA[d]	NA[d]	8.5
HFC-236fa	1000[e]	NA[d]	15.0	45.7
HFC-245fa	300[e]	NA[d]	NA[d]	20.0
HFC-365mfc	1000[d]	NA[d]	NA[d]	10
HFC-43-10mee	200[g**]	NA[d]	NA[d]	1.1

* The compound rows in blue are within the scope of this report

** 2021 Time weighted average workplace environmental exposure limit TWA WEEL value of 225 ppm[294]

a. No observed adverse effect level.
b. Lowest observed adverse effect level.
c. The concentration lethal to 50 percent of a population (rat) by 4 h inhalation; ALC: approximate lethal concentration.
d. No available data.
e. American Industrial Hygiene Association (AIHA) Workplace Environmental Exposure Limits (WEEL) based on 8h time-weighted average (TWA).
f. Maximum workplace concentration (MAK) (DFG, Germany).
g. Acceptable exposure limit (AEL) (DuPont Co., USA).

The majority of HFCs are classed as non-flammable with the exception of HFC-143a which is has a REACH registered classification as a flammable gas[295]. However, while most HFCs are not flammable on their own, increased room temperature and pressure can lead to greater flammability potential with the air[296]. Increasing air temperature widens both the lower and upper flammability limit values of HFCs, as well as reducing the ignition energy requirement. Furthermore, an increase in pressure can potentially double the upper flammability limit if it increases above 60psi. For example, Ural[296] estimates that HFC-227ea may form an explosive mixture with the air at room temperature if the pressure is above 60psi. This is of particular relevance as HFC-227ea includes applications for fire protection, and therefore carries a greater risk to human health. However, Ural[296] points out that while this behaviour does not affect the intended use and performance of these agents, recognising this property, and determining the critical pressure are vital to establishing safety procedures that can avoid accidental explosions. A summary of the lower and upper flammability limits of HFCs relevant to this report is provided in Table 3-7.

3.3.2 HFOs

Applications of HFOs include refrigeration, heat pumps, air conditioning, inter alia. HFOs typically have only been introduced into commerce relatively recently and so human studies are scarce compared to HFCs. However, multiple mammalian toxicology studies have been carried out to assess acute toxicity as well as other health endpoints. In a 4-h acute inhalation screening study, mice were exposed to HFO-1234yf up to a concentration of 101,850ppm and rats up to 405,800ppm, which produced no lethality. A similar result is

[294] Toxicology and Industrial Health, 2021, Vol. 37(8) 441–450. Available at: https://journals.sagepub.com/doi/pdf/10.1177/07482337211019860

[295] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006R1907

[296] Ural, E. A., 2003. Flammability potential of halogenated fire suppression agents and refrigerants. Process Saftey Progress, 22(1), pp. 65-73.

reported in the ECHA REACH registration dossier of HFO-1234yf[297] with a no mortality finding following 4 hours acute inhalation exposures as high as 405000ppm in rats. Furthermore, rats exposed to HFO-1234yf at levels in the range of 5000-50,000ppm over 6 hours, 5 days a week for 2-4 weeks, and for 90 days (repeat dose studies) showed no treatment-related adverse effects, or biologically significant reproductive toxicity effects[298][299]. No lethality or clinical signs of toxicity resulted following exposures of up to 100,000 ppm HFO-1234yf for 1 hour to pregnant rabbits[299].

It is important to note that HFO-1234yf (2,3,3,3-tetrafluoroprop-1-ene) was added to the Community Rolling Action Plan (CoRAP) for evaluation of possible carcinogenic and mutagenic properties and for possible identification as a Substance of Very High Concern (SVHC). However, CoRAP concluded in December 2021[300] that HFO-1234yf does not qualify as a SVHC and does not require classification/labelling for mutagenicity or carcinogenicity.

HFO-1234ze is consistent with having very low toxicity as demonstrated in acute and repeated dose toxicity studies in rats. In an acute exposure study at exposure concentrations of 100,000-207,000 ppm over 4 hours, no signs of lethality in rats were observed[301]. The ECHA REACH registration dossier also suggests low toxicity, which reports a LC_{50} exceeding 207,000ppm in 4-h acute inhalation studies of rats[302]. In a 13-week inhalation toxicity study, no treatment related changes were observed relating to body weight gain, food consumption and food conversion efficiency in rats exposed to exposure concentrations up to 15,000 ppm 6 h/day, 5 days/week of HFO-1234ze[303]. However, multifocal mononuclear cell infiltrates in the heart of both sexes at 15,000 ppm were observed during microscopic examination in the same study. Thus, the study considered a LOAEL of 15,000ppm and a 5000ppm NOEL for HFO-1234ze[299].

No genotoxic, prenatal developmental toxicity, or reproductive toxicity effects are associated with exposure to HFO-1234ze as demonstrated by animal studies[303][308].

HFO-1336mzz(Z) is consistent with having very low toxicity as demonstrated in acute and repeated dose toxicity studies in rats[304]. It is neither an acute dermal or eye irritant and has very low acute toxicity via inhalation exposure[305]. An acute toxicity study showed a 4-h LC_{50} of >102,000 ppm and a NOAEL and LOAEL of 12,500ppm and 25,000 ppm (respectively) for cardiac sensitisation in dogs[305]. 13-week repeat-dose inhalation studies in male and female rats at concentrations of 0, 500, 1500, and 10,000 ppm, showed no treatment related effects other than reductions in body weight, food consumption and efficiency at 10,000 ppm in both males and females. HFO-1336mzz(Z) is not shown to be genotoxic/mutagenic in *in vitro* and *in vivo* studies[305].

As with HFCs, the majority of HFOs are non-flammable. However, 80% (40) of notifiers to the C&L inventory report that HFO-1234yf meets the criteria for Flammable Gas 1 (H220), and has a lower flammability limit of 9% and an upper flammability limit of >11% as shown in Table 3-7. A combustion study[306] of HFO-1234yf was carried out[306] which found that the risk of fire from HFO-1234yf is low due to the high temperatures required for ignition. However, HFO-1234yf poses a greater risk to humans through its thermal decomposition products of carbonyl difluoride and hydrogen fluoride which are both highly corrosive to the skin, eyes and respiratory tract[306].

3.3.3 H(C)FOs

HCFO-1233zd has applications as a foam blowing agent, refrigerant and solvent. The available toxicity data demonstrates a low potential for toxicity. In a 4h acute toxicological study, HCFO-1233zd was shown to have a 4h LC_{50} of 120,000ppm in rats, and a NOEL of 25,000ppm (cardiac sensitisation study) in beagle dogs[307]. Repeated dose inhalation studies in rats over 14 days (20,000ppm), 28 days (10,000ppm), and 90 days

[297] HFO-1234yf. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/16012/1/1

[298] Tveit et al., 2013a. The acute, developmental, genetic and inhalation toxicology of 2,3,3,3-tetrafluoropropene (HFO-1234yf). Drug and Chemical Toxicology, 36(4), pp. 412-420.

[299] Rusch, G. M., 2018. The development of environmentally acceptable fluorocarbons. Critical Reviews in Toxicology, 48(8), pp. 615-665.

[300] COPRAP, 2021. SUBSTANCE EVALUATION CONCLUSION as required by REACH Article 48 for Polyhaloalkene EC No 468-710-7 CAS RN 754-12-1. Available at: https://echa.europa.eu/documents/10162/a794e3ad-c358-b7f8-bc74-268bfea135e7

[301] Rusch et al., 2013. The acute, genetic, developmental and inhalation toxicology of trans-1,3,3,3-tetrafluoropropene (HFO-1234ze). Drug and Chemical Toxicology, 36(2), pp. 170-180.

[302] HFO-1234ze. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/31292/7/3/1

[303] Rusch, G. M., 2018. The development of environmentally acceptable fluorocarbons. Critical Reviews in Toxicology, 48(8), pp. 615-665.

[304] HFO-1336mzz-Z. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/10030/7/3/1

[305] Toxicology and Industrial Health, 2019. Cis-1,1,1,4,4,4-hexafluoro-2-butene (HFO-1336mzz-Z) (2018). Toxicology and Industrial Health, 35(3), pp. 180-188.

[306] Magnusson et al., 2016. Identification and brief toxicological assessment of combustion products of the refrigerant HFO-1234yf, Stockholm: FOI.

[307] Tveit et al., 2013b. The acute, genetic, developmental and inhalation toxicology of trans-1-chloro,3,3,3-trifluoropropene (HCFO-1233zd(E)). Drug and Chemical Toxicology, 37(1), pp. 83-92.

(4000ppm) showed no adverse treatment related effects. Tviet also found that in a 4-week study in which rats were exposed to 0, 2000, 4500, 7500 and 10000ppm[307], the only observed effect was an increase in potassium of mid-to-high exposure males. Furthermore, tests showed no genetic toxicity (rats) and no developmental toxicity in rabbits[307].

Table 3-7 Flammability explosion limit (%) values of HFCs and H(C)FOs[308]

Compound	Flammability explosion limit (%)	
	LEL	UEL
HFC-125	0	0
HFC-134a	0	0
HFC-143a	7.4	18.8
HFC-227ea	0	0
HFC-245fa	0	0
HFC-365mfc	0	0
HFO-1234yf	6.2	12.3
HFO-1234ze	0	0
HFO-1336mzz(Z)	0	0
HCFO-1233zd	0	0

LEL - Lower explosion limit in air; UEL - Upper explosion limit in air

3.3.4 Trifluoroacetic acid (TFA)

Trifluoroacetic acid (TFA) can be produced from the breakdown of certain HFCs, HFOs and HFOs in the atmosphere and can be considered to be a ubiquitous contaminant of the hydrosphere, due to its widespread recorded presence in air and water samples around the world[309]. There has been limited studies on the effects of TFA on humans and its long-term exposure risk.

Amongst the studies which have been undertaken, TFA is not considered highly toxic to mammals via the inhalation or the oral route. TFA has also been reported to be non-mutagenic and is it is unlikely that it is a reproductive or developmental toxicant[310] (REACH registration dossier[311]). Mammalian toxicity studies have shown that TFA is not metabolised in mammalian systems, and it has a half-life of only 16h in humans. A 4-hour OECD 403 guideline study in rats reports that TFA induced no mortality at the tested concentrations of up to 300 mg/m3[311].

3.3.5 Application specific risks

The majority of toxicological studies of HFCs, HFOs and H(C)FOs have mainly focused on inhalation as the primary route of exposure as it is most relevant to their physico-chemical properties (e.g. gaseous). Furthermore, the primary applications of these F-gases include refrigerant gases, aerosols and foam blowing agents, which by nature can result in a greater risk of inhalation exposure through unintentional discharge.

Foam insulation work in which a blowing agent such as HFC-365mfc, HFC-245fa, HFC-227ea, or HFC-134a is used to form a thick layer of insulating foam in building work, is likely to have a reduced level of risk of inhalation. This is due to its application being mostly carried out by professionals with the appropriate Personal Protective Equipment (PPE) (e.g. mask/respirator). However commercial refrigerants such as HFC-134a, HFC-125, HFC-32, HFC-143a, and HFC-1234yf have a (albeit negligible) potential to expose unprotected humans, (e.g. a supermarket or warehouse) and therefore pose a relatively higher risk to human health. For example, the NGO “EIA”, conducted a refrigerant leak study of 45 stores in the Washington, D.C. metropolitan

[308] ECHA, REACH Registration dossiers

[309] Solomon et al., 2003. Changes in tropospheric composition and air quality due to stratospheric ozone depletion. Photochemical and Photobiological Sciences, 2(1), pp. 62-67.

[310] Tang et al., 1998. Changes in tropospheric composition and air quality. Journal of Photochemistry and Photobiology B: Biology, 46(1), pp. 83-95.

[311] TFA. ECHA REACH dossier. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/5203/7/1

area and found that 55% of stores had measurable leaks of refrigerants such as HFCs within the shop floor[312]. While this is a US case study, the EU F-gas Regulation has pushed for the reduction of the leaks of F-gases. Some studies in Poland showed that in 2020 the average leaks in commercial and industrial refrigeration has dropped to 3.7% (from 16.2% in 2015)[313].

It is important also to remember the appropriate risks associated with decomposition products of F-gases such as hydrogen fluoride (HF) which potentially poses a greater level of risk to human health than its parent compounds. However, these decomposition products and their elevated health risk may only present themselves during certain applications and circumstances such as welding repair work, fire protection, and automotive accidents.

3.3.6 Risks of non-fluorinated alternatives

Ammonia

Ammonia (NH_3) has been used as a refrigerant for decades for its thermal heat transfer properties, in spite of being toxic. It is also favoured because of its GWP value of essentially zero and is recognised as a climate friendly alternative to refrigeration system F-gases such as HFC-134a[314].

Human exposure to ammonia can result in the formation of an ammonia hydroxide compound, through contact with the moisture on the skin, eyes and in the throat of those exposed, resulting in burning or irritation of the affected area. More serious hazards of ammonia at high concentrations include severe burns to skin and eyes, blindness, respiratory damage and death[315]. The EU Commission Directive 2000/39/EC[316] provides an indicative occupational exposure limit (OEL) value for ammonia of 20ppm (8-hours TWA).

Pratiwi[317] provides three case studies in which male workers were exposed to ammonia gas through pipe leakages. All three workers reported burning sensation in the eyes, respiratory tract and skin, and difficulty breathing. All three cases were the result of an exposure to high concentrations of ammonia gas over a short amount of time, which in one case was a short as 1-2 minutes. Ammonia does have one beneficial risk characteristic in its strong characteristic smell, which may alert people to its presence, potentially reducing the exposure time if the person or persons are able to vacate the area.

Ammonia is considered to be a major contributor to air pollution and as such one of the five main air pollutants listed under Directive (2016/2284/EU)[318] which sets out reduction commitments for Member States to reduce the health impacts of air pollution. Ammonia's contributing factor to human health is through secondary particulate matter as a result of reacting with other gases in the atmosphere, such as nitrogen oxides and sulphur dioxide. While the potential effects of ammonia related particulate matter is less understood, short-term exposures, as much as a few hours to a few weeks, to airborne particulate matter air pollution has been associated with small but significant increases in cardiovascular disease-related mortality[319].

While ammonia isn't innately flammable, when exposed to high temperatures it can decompose into hydrogen gas, which is highly flammable and as such is classified as a flammable gas.

Carbon Dioxide

Carbon Dioxide (CO_2) is favoured for its non-flammable and relatively non-toxic properties as a refrigerant. While CO_2 occurs naturally in the air at around 400ppm, at higher concentrations it can cause increased rate of breathing, depression of the central nervous system and asphyxiation. The below table[320] summarises the various health effects as a result of exposure to different concentrations levels of CO_2.

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[312] EIA (2021). Leaking Havoc: Exposing Your Supermarket's Invisible Climate Pollution. Available at: https://www.climatefriendlysupermarkets.org/leaking-havoc

[313] EFCTC (2022). Focus on refrigerant containment. Available at: https://www.fluorocarbons.org/news/focus-on-refrigerant-containment/

[314] European Commission. Climate-friendly alternatives to HFCs. Available at: https://ec.europa.eu/clima/eu-action/fluorinated-greenhouse-gases/climate-friendly-alternatives-hfcs_en

[315] ECHA. Ammonia, anhydrous REACH Dossier. Available at: https://echa.europa.eu/brief-profile/-/briefprofile/100.028.760

[316] Commission Directive 2000/39/EC of 8 June 2000. establishing a first list of indicative occupational exposure limit values in implementation of Council Directive 98/24/EC on the protection of the health and safety of workers from the risks related to chemical agents at work. Available at: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32000L0039

[317] Pratiwi et al., 2018. Why it is often underestimated: Historical Study of Ammonia Gas Exposure Impacts towards Human Health. E3S Web of Conferences, Volume 73.

[318] Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG

[319] Bittman, S., Bleeker, A., Bruulsema, T., (2014). Air Quality, Health Effects and Management of Ammonia Emissions from Fertilizers. Air Quality Management pp 261–277. Available at: https://link.springer.com/chapter/10.1007/978-94-007-7557-2_12

[320] Sawalha, S., 2008. Safety of CO2 in Large Refrigeration Systems, Sweden: Royal Institute of Technology.

Table 3-8 Possible health effects of differing concentration levels of CO_2 in air[320].

PPM	Effects on health	Reference
350	Normal value in the atmosphere	*(Bearg 1993)*
1,000	Recommended not to be exceeded for human comfort	*(ASHRAE 1989)*
5,000	Threshold Limit Value (TLV): concentration to which one may be repeatedly exposed for 8 hours per day 40 hours per week without adverse effect	*(Rieberer 1998)*
20,000	Can affect the respiration function and cause excitations followed by depression of the central nervous system. 50% increase in breathing rate.	*(Berghmans and Duprez 1999)*
30,000	100% increase in breathing rate after short time exposure	*(Amin, Dienhart et al. 1999)*
50,000	Immediately Dangerous to Life and Health Limits (IDLH)	*(Rieberer 1998)*
100,000	Lowest lethal concentration	*(Berghmans and Duprez 1999)*
		(Hunter 1975)
200,000	Death accidents have been reported	*(Berghmans and Duprez 1999)*
300,000	Quickly results in unconsciousness and convulsions	*(Berghmans and Duprez 1999)*

CO_2 is an odourless gas and so does not have the benefit of being self-alarming like ammonia. This presents a considerable risk to human health in areas that are not equipped with CO_2 sensors for any potential releases of concentrations exceeding 5,000 ppm[320]. Additionally, the operating pressure of CO_2 is much higher than many other refrigerants, between 30 and 120 bar[321] and so pressurised CO_2 presents a potential health hazard from blast effects such as explosions. For example, several loud explosions were reported as a result of a CO_2 refrigerant failure in a shop in Germany[322]. CO_2 may also have a greater risk of leakage due to being a smaller compound, held at higher pressures than F-gases. However, the advantage of highly pressurised system is that the size of piping and system components can be much smaller, reducing the overall relative risk from an explosion. Neskå[321] estimates that compared to a HFC-134a system, a CO_2 system can be 80-90% smaller, presenting an explosive energy store not that much different from conventional systems.

Hydrocarbons

The hydrocarbons most commonly used in refrigeration systems are propane (C_3H_8), propylene (C_3H_6), and propane butane/isobutane blends. Hydrocarbons are highly flammable, with lower flammability limits of 1.5-2.1% and upper flammability limits of 8.5-11.4%. Ignition temperatures range from 365 to 491 °C[323]. Hydrocarbons have small scale applications in commercial and residential refrigeration systems, and can provide a suitable substitute for HFC-134a[324]. Hydrocarbons have also been used as large-scale refrigerants in the petrochemical industry for many years[323], which is largely due to the already stringent fire protection systems from the industries primary processes[325].

Propane, butane, isobutane and propylene are all considered to be of low toxicity to humans.

[321] Neskå et al., 2010. CO2 - A Refrigerant From The Past With Prospects Of Being One Of The Main Refrigerants In The Future, Trondheim: SINTEF Energy Research.

[322] Cooling Post (2014). Five injured in CO2 refrigerant leak. Available at: https://www.coolingpost.com/world-news/five-injured-in-co2-refrigerant-leak/

[323] Oliveira, A. C., 1997. Natural refrigerants for refrigeration and air-conditioning systems. Applied Thermal Engineering, 17(1), pp. 33-42.

[324] Emani, M. S. & Mandal, B. . K., 2018. The Use of Natural Refrigerants in Refrigeration and Air Conditioning Systems: A Review. Materials Science and Engineering, Volume 377.

[325] Calm, J. M., 2008. The next generation of refrigerants - Historical review considerations, and outlook. International Journal of Refrigeration, Volume 31, pp. 1123-1133.

A toxicological study of petroleum gases found that liquefied propane gas, n-butane, and isobutane gas are of low toxicity[326]. Through mammalian micronucleus testing (OECD TG 474) there were no toxicologically significant effects relating to systemic toxicity or neurotoxicity for any of these gases at concentrations ranging from 9000 to 16,000 ppm. Moreover, there was no evidence of effects on developmental or reproductive toxicity in the studies of propane or n-butane at the highest concentrations tested. There was however a reduction in mating for isobutane at 9,000 ppm but this was deemed not significant[326].

All standard and non-standard testing for propylene has demonstrated no evidence of *in vivo* toxic effects other than mild rhinitis (nasal inflammation) and associated epithelial (internal tissue) alterations[327]. Through rat inhalation studies over 1, 3, or 20 days (4 weeks, 5 days/week, 6 h/day), Pottenger[327] found that there were no biologically significant genotoxic effects demonstrated at any exposure level (<10,000ppm). Propylene is also not considered carcinogenic to rats or mice through inhalation at concentrations of 5,000 or 10,000 ppm (over 103 weeks)[328].

3.3.7 Analysis of Impacts of the restriction

While F-gases and their alternatives present potential health risks to humans, the risk of exposure is to an extent mitigated by existing EU and national legislation. Therefore, an assessment of impacts that the proposed PFAS restriction would have on human health risks from F-gases must also consider the existing legislative baseline as part of that assessment.

Baseline: Manufacturing workers, technicians and waste managers of F-gases may experience some level of exposure while at their workplace[329]. For example, Tsai[281] states that exposure of HFCs may occur via inhalation through accidental leaks and/or spills from refrigeration systems, recycling of electronic appliances systems, and cleaning of gas delivery pipelines. However, EU legislative measures exist to reduce the overall risk of exposure to professional workers who may come in contact with F-gases either at production or during recovery or disposal.

Articles 3 and 4 of the F-gas Regulation[41] state that natural persons operating and carrying out tasks such as recovery, disposal, servicing, and installation of specific equipment types containing F-gases must take precautionary measures to prevent leakage of F-gases. Article 5 states that operators of specific equipment listed in Article 4 and in quantities exceeding 500 tonnes CO_2 equivalent must employ leakage detection systems and have them checked every 12 months or every 6 years depending on the equipment type.

Furthermore, Article 10 of the F-gas Regulation requires Member States to ensure that training and certification is available for natural persons carrying out the below tasks (listed in Article 10) relating to specific equipment types listed in Article 4:

- installation, servicing, maintenance, repair, or decommissioning
- leak checks of the equipment
- recovery of fluorinated greenhouse gases.

In addition to the prevention of leaks and the requirement of safe handling training, operators of F-gases may employ closed systems, ventilation systems and PPE to further reduce the risk of exposure. From a consultation with a major HFO manufacture by RPA, Anthesis and Caleb[329], production is described as a closed system with monitoring of workplace exposure conducted by independent hygiene specialists and sensors. Moreover, a closed system may also be used in conjunction with other engineering measures (e.g. exhaust ventilation) as well as respiratory and clothing protection.

'Restriction' scenario: Where the restriction is applied, manufacturers, downstream users and consumers must switch to using alternatives, or else stop these activities altogether. Where activities are stopped, any (marginal) health effects associated with exposure to the F-gases in scope would of course be avoided. That said, a more important driver of human health risks under this scenario will be the type alternatives taken up, and in what quantities.

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[326] McKee, R. H. et al., 2014. The toxicological properties of petroleum gases. International Journal of Toxicology, 33(1), pp. 28-51.

[327] Pottenger et al., 2007. Evaluation of Effects from Repeated Inhalation Exposure of F344 Rats to High Concentrations of Propylene. Toxicological Sciences, 97(2), pp. 336-347.

[328] National Toxicology Program, 1985. NTP Toxicology and Carcinogenesis Studies of Propylene (CAS No. 115-07-1) in F344/N Rats and B6C3F1 Mice (Inhalation Studies). Natl Toxicol Program Tech Rep Ser., Volume 272, pp. 1-146.

[329] RPA, Anthesis, and Caleb for the Norwegian Environment Agency. Study on environmental and health effects of HFO refrigerants (Publication number: M-917|2017). Available at: https://www.miljodirektoratet.no/globalassets/publikasjoner/M917/M917.pdf

Some F-gases in scope may be replaced with other F-gases which do not fall in the scope of the restriction.

Regarding the regulatory feasibility of new alternatives, downstream users in the **RACHP sector** illustrate that safety standards diverge between Member States, and some are underdeveloped in each Member State. Regarding the standards used in Italy, only A1 and A2L refrigerants can be used in chiller for centralised systems >400m^2. On variation in the building codes which Member States use, e.g., France and Italy ban the use of flammable refrigerants, respondents highlight that national building codes and international and national safety standards may need revision to allow applications using flammable refrigerant alternatives (non-PFAS), which typically require 7-10 years. For example, the world's first HFC-32 (GWP=675) split AC was introduced in 2012, when the advanced research was already done, while the introduction of GWP limit of 750 for small split AC in Europe is planned in 2025.

Additionally, similar to the argument used by RACHP producers and importers, downstream users producing **MDIs** stated the current F-gas Regulation is sufficient for the use of medical F-gases. Further restriction would disrupt the availability of lifesaving medicines in the EEA and globally with consequences for people and the EEA pharmaceutical industry. Additionally, it is important to consider impacts for patients outside of the EEA, as manufacturers produce a substantial quantity of MDIs within the EEA for export to patients globally. Ensuring a stable supply for all patients worldwide is critical. As reported, the industry is already working to develop next generation propellants for MDIs that will have a significantly lower carbon footprint than today's solution. As highlighted by members of this application sector, the ban would disrupt the supply chain which would have severe consequences for vulnerable patient groups both in the EU and globally.

Some F-gases in scope will be replaced by natural, non-fluorinated alternatives such as CO_2 and propane (C_3H_8), propylene (C3H6), and propane butane/isobutane blends. These alternatives are of low toxicity in much the same way as F-gases are. However, as ammonia is classified as a toxic substance within the EU, its storage, handling, and use, is subject to far greater safety measures.

Ultimately, the replacement of F-gases with CO_2 and or hydrocarbons such as those mentioned, could result in a slight increase to impacts to human health over the baseline, regardless of CO_2 and hydrocarbons being of low toxicity and their exposure risk being controlled by EU legislation and onsite safety equipment. CO_2 in part and hydrocarbons specifically present new physical hazards that F-gases do not, e.g. blast and flammability. Furthermore, regardless of ammonia being subjected to far greater exposure risk measures, the potential health risks (3.3.6) are significantly higher than conventional F-gases through its increased toxicity and as a key air pollutant, as such the proposed restriction of PFAS could result in a slightly higher impact to human health should F-gases be replaced in part or fully with ammonia.

3.4 SOCIAL IMPACTS

The assessment of the social impacts is based upon evidence collected via survey, both quantitative and qualitative. It will focus on the social impacts to the wider community of the proposed restriction, with a focus on employment over the 2025-2040 period. This section will include:

- Impact on employment of F-gas producers and importers and its knock-on effects to the overall EEA employment
- Impact on employment on downstream user application sectors and its knock-on effects to the overall EEA employment
- The performance of relevant applications identified and how this will affect consumers and the wider society (e.g., risks associated, availability of alternatives, performance, costs associated, and fitness in the wider EEA climate policy agenda)

3.4.1 Employment impacts on F-gas producers and importers and the EEA

The adoption of the policy options considered in this study is estimated to lead to a direct net reduction in the jobs supported by F-gas producers and importers in the EEA. This reduction is primarily driven by the potential reduction in size of the F-gas production sector that is estimated to result from the proposed restriction.

The scale of impact on employment is estimated to be lower than the impact on turnover. This has been established by reviewing historical trends and confirmed by businesses participating in a survey for this study. This is partly driven by the need to retain employees to meet any additional regulatory requirements and the rigidity of the labour market, among others.

For example, evidence on the impacts of REACH, e.g. CSES et al (2015)[330], suggests that additional compliance cost led to increased labour requirements in the chemicals sector, not only due to needing additional staff but also the due to additional remuneration, skills, training and/or retraining costs.

In this context, it is estimated that, by the end of 2040, close to 100 jobs would be lost against the baseline scenario in the F-gas sector, which is equivalent to 1% of the overall employment in EEA F-gas producing and importing businesses, and 13% of the workforce directly employed by F-gas producers and importers in the F-gas business lines in the EEA. These direct job losses would be even larger if the chemicals sector were unable to substitute and/or reformulate as noted in their survey responses, which will inevitably depend on a positive market response to the substituted and/or reformulated products. Table 3-9 below describes the estimated average impacts on the sector's employment in the two scenarios.

Table 3-9 Estimated average impacts on the employment of EEA F-gas producers and importers against the baseline scenario (jobs).

Scenario	Estimated average impacts on employment in the sector
Scenario 1 (Substitution and Reformulation)	In any given year over the period 2025-2040, EEA F-gas producers and importers are estimated to employ around 90 fewer workers on average, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	In any given year over the period 2025-2040, EEA F-gas producers and importers are estimated to employ around 100 fewer workers on average, when compared to the baseline scenario.

As noted, the analysis suggests the EEA F-gas producers' and importers' overall[331] employment would likely be 1% lower against the baseline by 2040, equivalent to losing around 100 jobs. These effects are considered direct, in that they reflect the impact on the EU F-gas industry only. Such effects would also have knock-on impacts on the supply chain (indirect effects) and the wider EU economy (induced effects), leading to even larger reductions in the sector's contribution to employment.

Box 3-5 Knock-on effects on employment of the EEA.

Total impacts on employment: The direct, indirect and induced effects

The decrease in employment in the EEA F-gas producers and importers is likely to have knock-on effects across the supply chain (indirect or Type I effects). These direct and indirect effects are also expected to translate into changes on overall compensation and, thus, disposable income, which would in turn further reduce consumption and have broader implications in the economy (induced or Type II effects).

The indirect and induced effects, and thus, the total impacts on the economy driven by the effects of the policy options on the EEA F-gas producers and importers have been estimated using an Input-Output methodology. The cumulative Type I and Type II multipliers have been assumed at around 2.8 and 3.4 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment.

Based on this, **the adoption of changes to F-gas production and their knock-on effects through the EEA economy could lead to a reduction of up to 300 jobs by 2040 when compared against the baseline**.

Source: Ricardo analysis based on Eurostat data and a bespoke survey of EEA F-gas producers.

3.4.2 Employment impacts on EEA F-gas downstream users and the wider EEA

The adoption of the proposed restriction considered in this study is estimated to lead to a direct net reduction in the jobs supported by the surveyed F-gas downstream users. This reduction is primarily driven by the potential reduction in size of their businesses that is estimated to result from the adoption the restriction.

[330] CSES et al (2015). *Monitoring the Impacts of REACH on Innovation, Competitiveness and SMEs*. Available from: monitoring-the-impacts-of-reach.pdf

[331] That is, including employment in all of their business lines and not only F-gas production and/or import.

The scale of impacts on employment is estimated to be lower than the impact on turnover, just like in the case of F-gas producers and importers.

In this context, it is estimated that, by the end of 2040, over 1,700 jobs would be lost against the baseline scenario, which is equivalent to 3.6% of the surveyed companies' workforce. These direct job losses would be even larger if the downstream users were unable to substitute and/or reformulate as noted in their survey responses, which will inevitably depend on a positive market response to the substituted and/or reformulated products. Table 3-10 below describes the estimated average impacts on the sector's employment in two scenarios.

Table 3-10 Estimated average impacts on the employment of the surveyed F-gas downstream users against the baseline scenario (jobs)

Scenario	Estimated average impacts on employment in the sector
Scenario 1 (Substitution and Reformulation)	In any given year over the period 2025-2040, surveyed downstream users are estimated to employ 1,600 fewer workers on average, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	In any given year over the period 2025-2040, surveyed downstream users are estimated to employ 2,800 fewer workers on average, when compared to the baseline scenario.

As noted, the analysis suggests that F-gas downstream users' employment would likely be 3.6% lower by 2040, equivalent to losing over 1,700 jobs against a baseline (or up to 5,100 jointly for all downstream using sectors, as a rough extrapolation from the sample). These effects are considered direct, in that they reflect the impact on their businesses only. Such effects would also have knock-on impacts on the supply chain (indirect effects) and the wider EU economy (induced effects), leading to even larger reductions in the sector's contribution to employment.

Box 3-6 Knock-on effects from the sample of downstream users on employment of the European economy: The direct, indirect and induced effects

The decrease in employment of F-gas downstream users is likely to have knock-on effects across the supply chain (indirect or Type I effects). These direct and indirect effects are also expected to translate into changes on overall compensation and, thus, disposable income, which would in turn further reduce consumption and have broader implications in the economy (induced or Type II effects).

The indirect and induced effects, and thus, the total impacts on the economy driven by the effects of the restriction of F-gases on the surveyed downstream users have been estimated using an Input-Output methodology. The cumulative Type I and Type II multipliers have been assumed at around 0.9-2.4 and 1.2-3.5 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment. These ranges take into account the multiplicity of sectors in which the different F-gas applications lie within the full economy matrix.

Based on this, **the adoption of the proposed restriction could lead to a reduction of between 2,000 and 5,000 jobs by 2040 when compared against the baseline in Scenario 1, and between 3,000 and 9,000 jobs by 2040 when compared against the baseline in Scenario 2, with a very marginal impact on the total employment in the EU-27**. Note this only includes the effects for the sample of downstream users, not the whole industry.

If these impacts are scaled to the whole industry, assuming employment in our sample of downstream users is representative of the average companies in these sectors jointly, these impacts would then be threefold: job losses between 6,000 and 15,000 employments by 2040 when compared against the baseline in Scenario 1, and between 9,000 and 27,000 jobs by 2040 when compared against the baseline in Scenario 2, with a very marginal impact on the total employment in the EU-27. In this latter case, these job losses could surpass 0.01% of the EU's total employment in 2040.

3.4.3 Other social impacts of the F-gas restriction

Downstream users compared alternatives to F-gases in the targeted consultation survey. Safety was a major concern for downstream users, therefore, the box below summarises the views of respondents from the RACHP and Foams sectors.

Box 3-7. Downstream users' views on the safety of alternatives to F-gases.

The safety of alternatives relative to F-gases: Flammability and toxicity
Producers and importers of **RACHP** F-gas applications expect a decrease in the safety of appliances which use flammable and toxic alternatives (e.g., propane and ammonia). There were reports on safety concerns, stating propane and ammonia could not be used in public spaces (e.g., schools and hospitals) where a system failure would have serious consequences. However, respondents recognise that carbon dioxide has a much lower hazard profile than propane and ammonia. The differentiation between outdoor and indoor safety requirements, which vary in their stringency, was also pointed out. Indoor, safety requirements require higher design costs, and installation can be prohibited due to regional or national safety requirements (e.g., fire protection). Outdoor safety requirements require minimum distance openings of buildings, and drains.

In **foams applications**, companies highlight the increased safety requirements and reduced performance of alternatives compared to HFO and H(C)FO blowing agents. There was also indication of the increased capital investment costs for alternatives, including that consumers and users will need to purchase safety equipment for potentially explosive devices (enforced by the EU ATEX Regulation[332]) and to increase investment in insulation to achieve the same performance as F-gases. There also exists the opinion that flammable gases are not acceptable due to safety conditions.

Additionally, social impacts of alternatives also have to do with maintaining the current value that the F-gas application products provide to consumers and the whole society today.

Downstream users in **RACHP manufacturing applications** emphasised safety as the main concern of known alternatives of F-gases for these products. As a second concern, the RACHP sector highlighted the comparative efficiency and energy efficiency of alternatives to F-gases. However, some downstream users in RACHP applications stated that using propane as an alternative is possible, and that increased used of propane will have no noticeable impact on the performance of heat pumps. In contrast, however, it has also been noted that the implementation of industrial heat pumps would be significantly less effective and more expensive, and as a result is expected to have a negative impact upon climate change. Increased energy use could increase emissions from the electricity grid (depending on its emissions intensity), and increased costs can dissuade consumers from transitioning from conventional fossil fuel heating systems which will also contribute to climate change. In terms of specific alternatives one large provider of heating, cooling, and refrigeration technology has noted that although HFC-32 is a feasible alternative in some cases, HFC-125 and HFC-134A are used for service and maintenance of already installed equipment on the mark and there is not currently an alternative replacement. Therefore, the conclusion seems to be that RACHP equipment with alternatives to F-gases can be in some cases feasible, although with increased costs and safety requirements, which may undercut the climate objectives of the EU.

Regarding **foam blowing applications**, which are usually used for thermal insulation, downstream users of F-gases for foam blowing emphasised the poor mechanical performance of alternatives and the safety implications of using alternatives, which are also flammable; in particular, in comparison with CO_2 and methyl formate. Poorer insulation could have negative second order impacts on the quality of the built environment which can contribute to illness and reduced economic productivity. Furthermore, inefficient homes contribute more greenhouse gas emissions through increased use of energy to heat and cool them thus contributing to climate change.

Respondents stated that F-gas based solutions provide high quality insulation, which they connected with the need to improve fabric efficiency of the built environment in order to achieve the EU's decarbonisation targets. They also highlighted a report which finds F-gas based insulation is 20% more effective than hydrocarbons and 40% more effective than water-blown alternatives, and that there are significant energy efficiency gains in broad terms[333]. High performance insulation translates into high energy efficiency of buildings and equipment,

[332] Directive 2014/34/EU on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0034

[333] SPFA, 2020. Counting Carbon: Demand a Better Insulation in Your Next Home. Spray Polyurethane Foam Alliance. Retrieved from: https://www.sprayfoam.org/files/Demand%20a%20Better%20Insulation.pdf

comfort, and durability. It was also argued that, instead of a ban, technicians should receive better training and the sector regulated more effectively to reduce uncontrolled emissions of F-gases into the environment.

Overall, downstream users of F-gases for foam blowing were mostly pessimistic about the suitability of alternatives to F-gases. In a best-case scenario, these applications would exist with alternatives to F-gases but supporting increased costs to compensate for safety requirements and reduced performance (i.e., lost efficiency). Research indicates that the sector could be detrimentally impacted by the proposed restriction. There are also potential negative impacts on social and environmental factors. For example, if the proposed restriction made extruded polystyrol more expensive, this would make it more difficult to sufficiently insulate homes, which would reduce the fabric efficiency of homes. This reduces comfort and increases bills, as well as producing higher greenhouse gas emissions to heat less efficient homes. The report *Applications of Fluorinated Gases (F-Gases) in the EEA*[334] indicates that there are no alternatives for a number of our thermal insulation applications, supporting the overall pessimistic view on the availability of alternatives. In terms of heating equipment another respondent has also noted that the use of alternatives would require changes in installations due to space limitation, changes in piping, additional safety measures such as ventilation, which in turn will result in higher consumer costs.

Respondents to the stakeholder consultation in the production and application **of insulation, foams, sealants and adhesives** included reports that they did not believe there are viable alternatives. For example, it was indicated that carbon dioxide and methyl formate do not have the appropriate vapor pressures and foaming abilities to work alone in their products, nor do nitrogen or air, as propellants and foaming agents in products, indicating that the equipment would need to be reformulated for this to take place. The use of water as the primary chemical blowing agent to make carbon dioxide was reportedly only useful in open cell spray foams. Closed cell spray foams were considered to remain reliant on physical, non-flammable blowing agents with low boiling points. Furthermore, flammable gases are considered not acceptable alternatives due to safety requirements during use conditions for spray foams. To safely use flammable blowing agents, there would be significant capital investment costs, stating consumers will need to purchase necessary safety equipment for potentially explosive devices (enforced by the EU ATEX Regulation[335]).

Producers and/or importers of **medical applications** (predominantly MDIs), state that substitution will be especially difficult in this sector due to the long safety trials which replacement products require. In addition, trials of non-F-gas alternatives are incomplete, and their toxicity and flammability are likely to make them unsuitable for use in MDIs. Respondents argue the medicines are lifesaving, some of which are listed as essential the World Health Organisation, and the EU exports MDIs to developing countries which have limited recourse to produce or source medicines elsewhere. The second order impacts of the proposed restriction would be severe for people who rely on these medicines which will have accompanying economic impacts. On this account, alternatives to F-gases do not seem to exist at present for these applications.

[334] Ibid footnote 186.

[335] Ibid footnote 332.

3.5 WIDER ECONOMIC IMPACTS

The assessment of the wider economic impacts builds on the previous results on economic and social impacts. It focusses on the wider economic impacts as a result of the restrictions with a focus on producers, downstream users, and exporters of F-gases over the 2023-2040 period.

This section includes:

- Assessment of the input/output impacts across the value chain from impacts on F-gas producers and importers
- Assessment of the input/output impacts across the value chain from impacts on F-gas downstream users
- Understanding how the restrictions will impact trade, competition and development within the market and external of the EEA with respect to the rest of the world, including the expected impact upon illegal trade
- A review of arguments for derogation as reported by F-gas industry and members and downstream users

3.5.1 Impacts on Gross Value Added (GVA) through impacts on F-gas producers and importers

The adoption of the proposed restriction will also lead to reductions in sectoral GVA[336]. These reductions will, however, be lower in magnitude to that of turnover or output, as costs increase per unit of output. However, this would depend on the ability of the EEA F-gas industry to pass on to their customers some of the increases in regulatory burden. These second order effects would partially alleviate the reductions in turnover and, as a result, mitigate first order impact or reduction in GVA to some extent. Results presented here abstract from price changes due to uncertainties in their feasibility (see Box 3-2).

Table 3-11 below outlines the estimated impacts on GVA of the EEA F-gas production and import[337], excluding the ability of businesses to pass through additional regulatory burden to their customers for the two scenarios.

Table 3-11 Estimated impacts on the GVA of the EEA F-gas producers and importers against the baseline scenario (€ 2021).

Scenario	Direct impacts on sectoral GVA
Scenario 1 (Substitution and Reformulation)	The EEA F-gas producers and importers are estimated to **lose €75 million (€ 2021) of Gross Value Added each year on average** over the period 2025-2040, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	Overall, in this scenario, the EEA F-gas producers and importers is estimated to **lose €90 million (€ 2021) of Gross Value Added each year on average** over the period 2025-2040, when compared to the baseline scenario.

The analysis suggests that the sector's GVA would lose between €75 million and €90 million each year on average over the period 2025 and 2040, when compared to the baseline scenario. These effects are considered direct, in that they reflect the impact on the EEA F-gas producers and importers only. Such effects would also have knock-on impacts on the supply chain (indirect effects) and the wider EEA economy (induced effects), leading to even larger reductions in the sector's contribution to GDP.

Box 3-8 Knock-on effects of the F-gas restriction on the European economy[338].

Total impacts on the economy: The direct, indirect and induced effects

[336] GVA is defined as production value minus the value of raw materials that are used as inputs to the sector's own production. It is therefore a sector's contribution to Gross Domestic Product (GDP).

[337] As opposed to other variables presented above, GVA figures refer only to the value attributed to the production and import of F-gases. This is to show the direct contribution of F-gases to the EEA GDP and indirect and induced contribution thereof in isolation of wider business scopes that businesses in the F-gas industry may have.

[338] The analysis of indirect and induced impacts relies on Input-Output tables, which are at the level of the EU-27 at most. Thus, this analysis is limited to indirect and induced impacts in the EU-27.

The decrease in the GVA of EEA F-gas producers and importers is likely to have knock-on effects on the sector's supply chain (indirect or Type I effects). The direct and indirect effects are also expected to translate into a reduction in employment and thus overall compensation, which would in turn further reduce consumption and have broader implications across the economy (induced or Type II effects).

The indirect and induced effects, and thus, the total impacts on the economy driven by the effects of the policy options on EEA F-gas producers and importers have been estimated using an Input-Output methodology. The cumulative Type I and Type II multipliers have been assumed at around 2.8 and 3.4 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment.

Based on this, total reductions in GVA driven by the effects of the policies considered on the EEA overall economy could range between €220 million and €250 million every year on average between 2023 and 2040, which would be equivalent to shaving between 0.001 to 0.002 percentage points off the EU-27 GDP.

Source: Ricardo analysis based on EEA data and a bespoke survey of F-gas producers and importers.

3.5.2 Impacts on Gross Value Added (GVA) through impacts on F-gas downstream users

These impacts would affect the size and cost of operation of the F-gas downstream users in the EEA. The net reduction in EEA business operations, or direct impacts, would propagate through the EEA economy and have indirect and induced effects, estimated in terms of potential reductions in the sector's contribution to GDP and employment over time.

The restriction on PFAS including F-gases considered will also lead to reductions in GVA for downstream users. These reductions will, however, be lower in magnitude to that of turnover or output, although this would depend on the ability of these businesses to pass on to their customers some of the increases in regulatory burden.

GVA is affected by changes in output, or turnover, and intermediate consumption. The policy options are likely to result in decreases in turnover and increases in intermediate consumption, both drivers leading to reductions in GVA. This impact in GVA would represent first order effects. However, as noted earlier, businesses have the ability to pass through some of these additional regulatory costs or burden to their customers. These second order effects would partially alleviate the reductions in turnover and, as a result, mitigate first order impact or reduction in GVA.

Table 3-12 below outlines the estimated impacts on GVA of the sample of downstream users, accounting for the ability of businesses to pass through additional regulatory burden onto their consumers for the two scenarios.

Table 3-12 Estimated impacts on the GVA of the surveyed downstream users against the baseline scenario (€ 2021).

Scenario	Direct impacts on sectoral GVA
Scenario 1 (Substitution and Reformulation)	Surveyed F-gas downstream users are estimated to **lose €0.3 billion (€ 2021) of Gross Value Added each year on average** over the period 2025-2040, when compared to the baseline scenario.
Scenario 2 (Substitution and Reformulation (with delay))	Surveyed F-gas downstream users are estimated to **lose €0.5 billion (€ 2021) of Gross Value Added each year on average** over the period 2025-2040, when compared to the baseline scenario.

That is, the analysis suggests that downstream users' GVA would lose between €0.3 billion and €0.5 billion each year on average over the period 2025 and 2040, when compared to the baseline scenario. These effects are considered direct, in that they reflect the impact on their businesses only. Such effects would also have knock-on impacts on the supply chain (indirect effects) and the wider EU economy (induced effects), leading to even larger reductions in the sector's contribution to GDP.

Due to the multiplicity of sectors involving downstream user applications of F-gases and the inability to disentangle how each of them is impacted in isolation by the proposed restriction, the analysis of knock-on effects to the overall economy has not been possible to develop with precision. However, based on the sectors involved, the Type I multiplier has been estimated to range between 1.1 and 3.3, while the Type II multiplier is estimated to range between 1.4 and 3.9. The implications of these multipliers are presented in the Box below.

Box 3-9 Knock-on effects of the F-gas restriction from direct impacts on a sample of F-gas downstream users to the European economy[339]: The direct, indirect and induced effects

The decrease in the GVA of F-gas downstream users is likely to have knock-on effects on each of their sector's supply chain (indirect or Type I effects). The direct and indirect effects are also expected to translate into a reduction in employment and thus overall compensation, which would in turn further reduce consumption and have broader implications across the economy (induced or Type II effects).

The indirect and induced effects, and thus, the total impacts on the economy driven by the effects of the policy options on the EEA downstream users have been estimated using an Input-Output methodology. The cumulative Type I and Type II multipliers have been assumed at around 1.1-3.3 and 1.4-3.9 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment.

Based on this, **total reductions in GVA driven by the effects of the policies considered on the EU chemicals sector could range between €0.4-€1.1 billion (Scenario 1) and €0.7-€1.9 billion (Scenario 2) every year on average between 2023 and 2040, which would have a very marginal impact on the EU-27 GDP in all cases.**

If the downstream user sectors indeed are represented by the surveyed sample, the impacts on the European GVA driven by the restriction could reach 0.01-0.02 percentage points of the EU-27 GDP.

3.5.3 Impacts on trade and competition

As a result of the restriction, all trade of F-gases would be restricted; the ban on the manufacture and placing on the market of F-gases *de facto* restricts import and export of F-gases and of mixtures or articles containing them. For F-gas producers, the extra-EEA export market for F-gases is a minor part of the total turnover from F-gases, representing less than 10% of the latter.

Downstream users will not be able to import appliances or equipment containing F-gases either. If there is a strong or growing competition from players based outside of the EEA and not subject to the proposed restriction in the extra-EEA export market, they may encounter difficulties in exporting their products manufactured with alternatives to F-gases. Measures on the importance of extra-EEA exports for downstream users were not collected in consultation, although this is estimated to be potentially impactful for their external competitiveness, especially if the proposed restriction is not implemented by third countries outside of the EEA and with the same scope, i.e., including F-gases.

However, illegal trade of F-gases may still continue and even increase after a ban and so F-gases will still contribute towards global warming, but these are challenging to evaluate due to avoidance of conventional data collection and reporting mechanisms. There is also precedent for the continued use of reclaimed F-gases after a ban has been enacted through exceptions[340]. ConocoPhillips who operates a major UK gas processing facility were allowed to temporarily continue using up to 31.5 tonnes of reclaimed HCFC-22 even after it was banned for use in the EU in January 2015, under Regulation (EC) No 1005/2009[341]. Furthermore, after the exemption period ended in July 2015, the company were required to ensure high levels of recovery of the refrigerant, and that the recovered refrigerant was either exported or destroyed[340].

[339] The analysis of indirect and induced impacts relies on Input-Output tables, which are at the level of the EU-27 at most. Thus, this analysis is limited to indirect and induced impacts in the EU-27.

[340] Cooling Post, 2014. Gas plant given R22 ban exemption. Available at: https://www.coolingpost.com/uk-news/gas-plant-given-r22-ban-exemption/

[341] Regulation (EC) No 1005/2009. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009R1005

3.5.4 Arguments for derogation by F-gas producers, importers downstream users

F-gas manufacturers, importers and downstream users were asked to comment on the potential need for a derogation for F-gases from the proposed restriction. Their arguments can be considered a qualitative summary of the industry's views of the potential impacts of the restriction on society as a whole.

Most of the F-gas downstream users in **RACHP applications** in the EEA consider their products to be of essential nature. Some respondents consider the use of the F-gas to be essential for the required functioning of the product or process, particularly for HFO-1234yf for new mobile air conditioning as per the MAC Directive[342].

Others stated that F-gas refrigerants are necessary for the decarbonisation of heating and AC (mobile and domestic), and to meet the EU's decarbonisation goals. Safety of F-gases in comparison to their alternatives was also argued to contribute to the case of a need for a derogation of F-gases in RACHP applications, due to flammability (see Section 3.4.3). Similar points regarding safety and GWP of alternatives are made for large chillers (used in industrial processes, district cooling and heating), to argue F-gases in their products are essential and cannot be replaced by alternatives.

It has also been argued a multi-faceted approach is required to reduce the burden placed on the environment, which F-gases can deliver while alternatives cannot. The low GWP of H(C)FOs as currently viable alternatives to high GWP HFCs would become unfeasible and higher GWP alternatives would have to be used under the proposed restriction, as argued by F-gas applications.

As reported by RACHP producers and importers, alternatives cannot meet the same technical specifications as F-gas based refrigerants (both for refrigeration and RACHP applications), and therefore, F-gas based refrigerants are required due to their affordability and performance. For example, there are unavoidable and high design costs of products using carbon dioxide as a refrigerant in order to withstand the high-pressure refrigerant circuit. Secondly, the energy efficiency of air conditioners using carbon dioxide is low in warmer climates. The direct expansion of air conditioning applications is also mentioned, of which some, like e.g., Variable Refrigerant Flow (VRF), are argued to be important due to their being more energy efficient than chillers. The rapid response of VRF can contribute to demand response in view of smart electricity grids, necessary for the energy transition. The reasons for their importance that RACHP producers mention are that their advanced features are integrated in one system, assuring higher overall performance as a system, and that the compact outdoor units and small piping diameter meet the need for renovation of buildings which is important for retrofitting old buildings with heat pumps (i.e., an important vector of decarbonisation of buildings).

However, some downstream users in RACHP stated their products containing F-gases may not be considered essential where sufficient timing allows the industry to adapt and react. In contraposition, some survey responses highlighted that alternatives have drawbacks which lead to significant price increases for the customer, which needs to be taken into account, as it could lead to a shift to less environmentally friendly technologies.

Overall, based on the fact that there are no alternatives which do not require compromise in performance, e.g., working temperature range, ambient temperature range, cooling water temperature range, system safety, component availability, and costs, downstream users in the RACHP sector would consider derogations for their use of F-gases to be adequate. For example, a derogation for HFO-1233zd is suggested on the following grounds:

- HFOs like HFO-1233zd are the only applicable coolants for a certain type of power to steam heat pump design (20MW output) requesting a precise enthalpy.
- Existing alternatives, e.g., carbon dioxide and ammonia, will not work at the required temperatures (>160°C).
- Since such systems run in closed loops, derogations are expected for the use of HFO-1233zd as refrigerant.

It has also been argued that without derogation, additional costs of alternatives will be passed onto the consumer and production thereof will move to non-European countries. This idea is reinforced by some companies stating that their business would not be able to continue if the proposed restriction was enacted, and derogations would not lessen the proposed restriction's impact (more detail on this point was not provided). Likewise, it has been suggested that a few applications in the RACHP sector would become unfeasible without

[342] Ibid Footnote 45.

a derogation. However, the expectation is that there would still be some technological change that would enable continued operation, although there will be a financial cost.

While the fact that whether a derogation is needed depends heavily on the use cases and available alternatives appears to be understood, arguments for derogation are widespread across companies in the RACHP sector. For instance, a derogation for F-gases used to refrigerate reefer containers is also considered necessary because of their vital role in the supply chain of essential items (food and medicines) and alternatives not being technically viable or safe. Some others argue derogation would be needed to ensure equipment is not retired before the end of its lifespan to avoid waste.

On heat pumps in particular, the suggestion that a blanket derogation should be issued due to the energy efficiency gains and indirect greenhouse gas emission reductions in comparison to alternatives emerged, or alternatively, case-by-case derogations; for example, indoor installations should be prioritised for a derogation. Finally, in the absence of derogations, a transition period to allow adaptation of the supply chain is considered a third-best option.

The opinion of downstream users producing **foams for insulation** seems to be generally that F-gases are required for their products. F-gas based solutions are argued to provide high quality insulation, which is thought to be linked to the achievement of the EU's decarbonisation targets. In particular, and as reported by companies in this sector, F-gas based insulation is 20% more effective than hydrocarbons and 40% more effective than water-blown alternatives, with significant energy efficiency gains in broad terms. High performance insulation translates into high energy efficiency of buildings and equipment, comfort and durability.

Regarding the possibility of derogations for foams used in insulation, they are thought to potentially enable a high-quality renovation of existing building stock that improves their quality and reduces greenhouse gas emissions for heating. Demand for insulation is expected to grow from a minimum of 3% a year to a maximum of 10%, as reported by companies in this sector. It has been indicated that no alternatives exist to HFOs, and therefore, fundamental development of alternative insulation technologies would be needed to replace HFOs.

Downstream users producing **MDIs** argue their products are essential, as the medicines that use the F-gases in scope are lifesaving, and some are already listed as essential by the World Health Organisation (WHO). MDIs are often the only respiratory therapy available for patients to manage their life-threatening conditions. Furthermore, the EU supplies these medicines globally, including to low- and middle-income regions.

F-gas downstream users producing MDIs consider a derogation for their use would be appropriate. Severe health and socio-economic impacts are anticipated if these medicines are removed for the treatment of respiratory diseases. HFO-1234ze has lower global warming potential than HFA-152a so is more environmentally friendly for use in respiratory medicines. Therefore, respondents suggest that medical-grade HFO-1234ze should receive a derogation.

Overall, the dominating argument across all F-gas downstream using sectors is that a multi-faceted approach to the restriction of PFA is required to reduce the burden placed on the environment by their products, which F-gases can deliver while alternatives cannot. That would mean taking into account different human health and environmental risk profiles, including energy efficiency, of different groups of substances that fall under the PFAS definition in the RoI of the proposed restriction. That perspective should also include the human health and environmental risk profiles of alternatives to be adopted upon the restriction. For F-gases as a distinct group of PFAS, this would likely result in a different regulatory conclusion from the universal restriction of PFAS.

4. CONCLUSIONS AND RECOMMENDATIONS

A targeted consultation with the F-gas producers, importers, and downstream users from various sectors of application, and economic analysis reveals that the proposed restriction is likely to have significant impacts on the EEA F-gas producer and importers, downstream users and the wider economy. In particular, **EEA F-gas producers and importers are estimated to lose between €550 million and €640 million per year on average between 2025 and 2040, when compared to baseline projections, as a result of the proposed restriction.** In 2040, sectoral turnover in any of the scenarios considered in this study where the proposed restriction is adopted is estimated to be 14% lower than the baseline. **For EEA F-gas downstream users, their loss is estimated to range between €2.2 and €4.1 billion per year jointly for all F-gas applications on annualised terms between 2023 and 2040, compared to baseline projections.** In 2040, sectoral turnover in any of the scenarios considered in this study where the proposed restriction is adopted is estimated to be 5.4% lower than the baseline for downstream users.

These estimated losses are significant despite already accounting for the actions that businesses would take to mitigate the effects of the legislative changes, such as substitution and reformulation. For example, F-gas producers and importers have suggested that they would be able to substitute and/or reformulate around 52% of the portfolio of products that could be affected by the proposed policy changes, while up to 80% would be expected to be substituted, reformulated or subject to other productive changes by downstream users. However, baseline product characteristics and performance are not guaranteed by these strategies, the outcomes of which might constitute the placing on the market of entirely new products that may be more costly, with uncertainty in how consumers will receive them.

It is also estimated that operating expenditures would decline when compared to the baseline. These net reductions would be driven by the losses that are estimated to the size of operations of the F-gas production and imports market, and of the F-gas downstream users' markets. At the same time, capital expenditure or investment would decrease overall due to business size reduction, but some new investments would be needed in order to sustain the required levels of substitution and reformulation for the mitigation of further turnover losses. These estimates do not suggest that there will be any cost savings from the adoption of the legislative changes, at least in unit terms. In fact, unit expenditure is expected to increase for both F-gas importers and producers, and their downstream users. On the side of demand, consumers are assumed to progressively change their currently owned equipment as it reaches its end of life. Therefore, sudden increases in demand as a result of the proposed restriction are not expected or modelled.

The proposed restriction would also affect the sector's and its downstream users' employment. It is estimated that, **by 2040, around 80-90 jobs in the EEA F-gas production and import sector would be lost against the baseline scenario, which is equivalent to around 1% of their baseline workforce in 2040**. **These impacts would have knock-on effects in the EU economy, which could lead to losing around 300 jobs by 2040 when compared against the baseline.**

For downstream users, job losses are estimated to be around 5,100 by 2040, compared to the baseline. This loss is estimated to be equivalent to almost 4% of their baseline workforce in 2040[343]. **Including knock-on effects in the EU economy, those losses could reach between 6,000 and 15,000 fewer jobs**, on average, when compared to the baseline in any given year between 2025 and 2040 **in Scenario 1**, and **between 9,000 and 27,000 fewer jobs, on average, in Scenario 2**.

The direct contribution of F-gas production and import to GVA would be between €65 and €75 million lower per year over the period 2023-2040, on average and when compared to the baseline. When adding indirect and induced effects, **the total contribution of the EEA F-gas production and import to GVA would be between €220 and €250 million lower per year over this period, on average.** Resulting from the restriction, **downstream users would directly contribute from €0.8 billion to €1.6 billion less to the EEA GVA per year on average over this period; including indirect and induced effects, GDP in the EEA would then be €1.1 to €5.9 billion lower on average per year**.

Table 4-1 below summarises some of these impacts on key business and economic indicators of the F-gas producing and importing sector against the baseline and across two scenarios.

[343] It should be noted that a total measure of employment for all F-gas downstream users is not available in public statistics, and that this is an extrapolation based on the known production value of F-gas downstream users and the production value reported by the surveyed sample.

Table 4-1 Annualised impacts on selected business and economic indicators of the EEA F-gas producing and importing sector, against the baseline scenario (%)

Themes (business or economic indicators)	Scenario 1 (Substitution and Reformulation)	Scenario 2 (Substitution and Reformulation (with delay))
Turnover (first order effects)	A loss of €550 million per year between 2025 and 2040 on average against the baseline	A loss of €640 million per year between 2025 and 2040 on average against the baseline
Total GVA contribution (*direct, indirect, induced*)	A loss of €220 million per year between 2025 and 2040 on average against the baseline	A loss of €250 million per year between 2025 and 2040 on average against the baseline
Regulatory burden	An additional annualised burden of €12 million each year between 2025 and 2040	An additional annualised burden of €9 million each year between 2025 and 2040
Total employment contribution (*direct, indirect, induced*)	275 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040	310 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040

Table 4-2 below summarises some of these impacts on key business and economic indicators of the F-gas downstream users against the baseline and across two scenarios.

Table 4-2 Annualised impacts on selected business and economic indicators of the EEA F-gas downstream users, against the baseline scenario (%)[344]

Themes (business or economic indicators)	Scenario 1 (Substitution and Reformulation)	Scenario 2 (Substitution and Reformulation (with delay))
Turnover (first order effects)	A loss of €2.2 billion per year between 2025 and 2040 on average against the baseline	A loss of €4.1 billion per year between 2025 and 2040 on average against the baseline
Total GVA contribution (*direct, indirect, induced*)	A loss of between €1.1 and €3.2 billion per year between 2025 and 2040 on average against the baseline	A loss of between €2.1 and €5.9 billion per year between 2025 and 2040 on average against the baseline
Regulatory burden	An additional annualised burden of €89 million each year between 2025 and 2040	An additional annualised burden of €3 million each year between 2025 and 2040
Total employment contribution (*direct, indirect, induced*)	Between 6,000 and 15,000 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040	Between 9,000 and 27,000 fewer jobs, on average, when compared to the baseline in any given year between 2025 and 2040

There is also the need to consider the impact of these restrictions on consumers. F-gases are key inputs to a wide range of products of everyday use. Benefits to human health and the environment as a result of the proposed restriction through the substitution of F-gases with alternatives are far from clear. Some of the lowest GWP alternatives to HFCs are H(C)FOs, which would fall under the proposed restriction. Additionally, current risks to human health of the current uses of F-gases are considered minimal, while reports by F-gas downstream users highlight the increased safety requirements of some of the most promising alternatives in the most relevant applications, such as RACHP. Increased costs and reduced efficiency, both in the performance of the product applications and in their energy consumption, lead to an increased burden on

[344] Results in this table are a rough extrapolation that matches the value of the whole sum of F-gas downstream application sectors, although caveats include the diversity of these sectors and the fact that the sample is not able to provide separate estimates for each of them. Overall, the sample of downstream users that participated in our survey is estimated to represent around a third of the total production value of these sectors jointly.

consumers, possibly limiting consumer choice and reducing incentives of technological change from the current equipment containing F-gases. This in turn could increase the illicit trade in non-compliant products.

The results of this assessment highlight that the proposed restriction of PFAS, as it was conceived including all F-gases in scope of this study, may lead to the reduction in manufacturing and/or use of downstream user applications and increase in costs thereof.

Trade-offs between aiming to reduce GHG emissions with the current F-gas Regulation, that allows the switch from higher GWP HFCs towards low GWP H(C)FOs, and reducing GHG emissions after a blanket restriction of all PFAS that includes all F-gases in scope of this study can lead to worse GHG emission outcomes in the restriction scenario.

4.1 RECOMMENDATIONS

The analysis presented in this report is based on consultation responses from the surveys of F-gas producers and importers, and downstream users. The data provided may not be considered exhaustive, in particular with regard to derogations or exemptions from the proposed PFAS restriction, as companies may not seek derogation/exemption under the same criteria as another. As such, this report does not seek to replace any assessment by other such companies or associations and presents the evidence gathered in the context of this study only.

As can be seen from the analysis, the use of F-gases is key to certain sectors and it would be very difficult to meet the climate targets of the European Commission without the use of low GWP H(C)FOs. Recommendations stemming from the outputs of this analysis include:

1. It is acknowledged that companies within this sector are seeking to reduce the GWP of their products and systems. A derogation or exemption for the low GWP F-gases in scope and their blends (i.e., H(C)FOs and their blends) would prevent the continued use of high GWP F-gases and encourage the shift to H(C)FOs, whilst allowing the sector to meet the climate targets of the European Commission and maintain operations. This derogation could work alongside the phase down of the F-gas Regulation so as to ensure compliance through transparency and coherence of objectives. It would also be aligned with the proposal amending the F-gas Regulation with more stringent objectives, which also relies on low GWP F-gases as a pathway to achieve climate neutrality in 2050. A shift to non-PFAS alternatives may also result from this derogation, where companies have sufficient time and resource to develop these systems.
2. Should the proposed restriction of PFAS continue without the case for derogation of certain chemical groups or applications, it would be advised to consider a transitional arrangement that allows for continued use of F-gases in scope within a certain timeframe, in order to encourage R&D into non-PFAS alternatives (chemical or technical) and allow business to respond to the changes required. Any transitional arrangement would need to be in line with the phase-down of the F-gas Regulation to prevent double regulation and non-compliance as a result of a lack of coherence in the regulatory conditions that should be followed.

Appendices

A1 DATA COLLECTION APPROACH

A1.1 Stakeholder consultation

In order to obtain detailed information on the potential business impacts of the proposed restriction, two surveys were launched: one with F-gas producers and importers, and the other one with F-gas downstream users. The surveys were hosted on Alchemer.

The data received in both surveys formed the basis for an assessment of the extent to which the portfolio of F-gases in scope subject to the proposed restriction would affect F-gas producing and importing companies and their downstream users, once businesses respond e.g., through substitution, reformulation and/or other manufacturing changes; and quantify key knock-on effects based on evidence collected from businesses directly, as much as possible.

A four-part, 62-question survey was designed to elicit evidence and informed views from F-gas producers and importers (57 questions in the case of the survey to downstream users):

- Part 1, gathering data about the respondents, in terms of their size, activities, main country of operation, etc.
- Part 2, seeking to form a baseline, including of their turnover, investment, expenditures, employment, regulatory burden and other key proxies of their economic activity.
- Part 3, considering direct business responses and associated costs and benefits (e.g., substitution, reformulation and/or derogations; investments; expenditures; and employment) over at least 10 years from adoption of the proposed restriction.
- Part 4, collecting information on other economic impacts, primarily qualitative (e.g., imports/exports, competitiveness and other views).

The types of questions covered across these key business impacts and/or proxies for these impacts are outlined in Table 2-16. As outlined previously, the full list of questions has not been presented as numerous questions fed into the analysis of each impact sub-category.

A1.2 Characterisation of the downstream using application sectors

The collection of data on each of the application categories has relied upon Eurostat datasets. This has been based on two main sources:

- The Structural Business Statistics (SBS)[345], which contains data by industrial sector, following classification NACE Rev. 2 of economic activities.
- Prodcom[346] database, for data on the production of manufactured goods, following a fine classification of products that allows the construction of production values for each of the F-gas downstream using applications.

The Prodcom product classification provides a more granular insight into the production value of the applications. The values shown below in Table 4-3 represent the proportion of the production value of relevant Prodcom F-gas applications within the wider sector, as classified by NACE Rev. 2 codes in 2019 in the SBS[347]. As displayed in the table, it is evident that the proportion of relevant Prodcom applications' production value to the wider sector's value according to NACE categories is typically low (below 10% in most instances), and therefore it has been concluded that basing economic assessments on the wider NACE categories would be inaccurate. The use of the Prodcom product classification has enabled the focus to be on the specific manufactured goods that the literature review, complemented by expert judgement, has identified as being F-gas applications.

[345] Eurostat, Structural Business Statistics database (accessed April 2022): https://ec.europa.eu/eurostat/web/structural-business-statistics/data/database

[346] Eurostat, Prodcom database (accessed April 2022): https://ec.europa.eu/eurostat/web/prodcom/data/database

[347] The year 2019 has been selected to present the relative production levels of the F-gas applications to the wider categories as a review of the literature has indicated that the years 2020 and 2021 were significantly impacted as a result of the Covid-19 pandemic and subsequent lockdown, and are therefore not representative of their productive normality.

Table 4-3 Proportion of the production value of applications within their wider sectors available in the SBS, 2019. Source: Prodcom database and SBS.

Application Categories	Prodcom Proportion of NACE Code (%)
Refrigeration	19%
Solvents	2%
Propellants	0%
Fire protection	2%
Stationary AC	17%
Heat pumps	9%
Foams	3%
Foam Blowing Agent	2%
Magnesium Casting	3%

Table 4-4 outlines the relevant Prodcom codes and the applications which have been considered relevant to the F-gases within the scope of the assessment.

Table 4-4 Relevant F-gas Applications by NACE classification and Prodcom classification codes

Application	NACE Sector Codes	Prodcom Product Categories
Refrigeration	• 2751: Manufacture of electric domestic appliances	• 27511110: Combined refrigerators-freezers, with separate external doors • 27511135: Compression-type built-in refrigerators • 27511150: Chest freezers of a capacity <= 800 litres • 27511170: Upright freezers of a capacity <= 900 litres
	• 2825: Manufacture of non-domestic cooling and ventilation equipment	• 28251333: Refrigerated show-cases and counters incorporating a refrigerating unit or evaporator for frozen food storage • 28251335: Refrigerated show-cases and counters incorporating a refrigerating unit or evaporator (excluding for frozen food storage) • 28251360: Refrigerating furniture with a refrigerating unit or evaporator (excluding combined refrigerator-freezers, with separate external doors, household refrigerators, refrigerated show-cases and counters) • 28253050: Parts for non-domestic refrigerating equipment (including evaporators and condensers) • 28253070: Parts of refrigerating or freezing equipment and heat pumps, n.e.s. • 28251390: Other refrigerating or freezing equipment
	• 2813: Manufacture of other pumps and compressors	• 28132300: Compressors for refrigeration equipment

Application	NACE Sector Codes	Prodcom Product Categories
Solvents	• 2561: Treatment and coating of metals	• 25611150: Metallic coating by thermal spraying
Propellants	• 3299: Other manufacturing n.e.c.	• 32991250: Propelling or sliding pencils
Fire protection	• 2059: Manufacture of other chemical products n.e.c.	• 20595250: Preparations and charges for fire-extinguishers; charged fire-extinguishing grenades • 20595967: Fire-proofing, water-proofing and similar protective preparations used in the building industry
	• 2630: Manufacture of communication equipment	• 26305020: Electrical burglar or fire alarms and similar apparatus (excluding of a kind used for motor vehicles or buildings) • 26305080: Electric burglar or fire alarms and similar apparatus for buildings
	• 2829: Manufacture of other general-purpose machinery n.e.c.	• 28292210: Fire extinguishers • 28298340: Parts for mechanical appliances for projecting, dispersing or spraying liquids/powders; fire-extinguishers, spray guns and similar appliances and steam/sand-blasting machines
	• 2910: Manufacture of motor vehicles	• 29105930: Fire-fighting vehicles
Stationary AC	• 2825: Manufacture of non-domestic cooling and ventilation equipment	• 28251220: Window or wall air conditioning systems, self-contained or split-systems • 28251270: Air conditioning machines not containing a refrigeration unit; central station air handling units; vav boxes and terminals, constant volume units and fan coil units • 28253010: Parts for air conditioning machines (including condensers, absorbers, evaporators and generators)
Mobile AC	• 2825: Manufacture of non-domestic cooling and ventilation equipment	• 28251240: Air conditioning machines of a kind used in motor vehicles • 28251250: Air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)
Heat pumps	• 2825: Manufacture of non-domestic cooling and ventilation equipment	• 28251380: Heat pumps other than air conditioning machines of HS 8415 • 28253070: Parts of refrigerating or freezing equipment and heat pumps, n.e.s.
Foam products	• 2319: Manufacture and processing of other glass, including technical glassware	• 23191200: Paving blocks, bricks, tiles and other articles of pressed or moulded glass; leaded lights and the like; multicellular or foam glass in blocks, plates or similar forms
	• 2399: Manufacture of other non-metallic mineral products n.e.c.	• 23991920: Exfoliated vermiculite, expanded clays, foamed slag and similar expanded mineral materials and mixtures thereof
Foam Blowing Agent	• 2896: Manufacture of plastics and rubber machinery	• 28961084: Machines for the manufacture of foam products (excluding machines for processing reactive resins)
Magnesium Casting	• 2445: Other non-ferrous metal production	• 24453028: Other articles of magnesium (excluding waste and scrap), n.e.s.

Table 4-5 shows the aggregate production value for the relevant product categories for the most recent year (non-affected by Covid), 2019. As shown, the greatest value is attributed to the refrigeration sector (€14.3 bn), followed by stationary air conditioning (€6 bn) and heat pumps (€5.4 bn).

Table 4-5 Production value of downstream using product categories (€ bn), 2019. Source: Prodcom database and SBS.

Application Categories	Total Production Value (€ bn)	% Share of Total Value of downstream using applications
Refrigeration	14.3	48%
Solvents	0.6	2%
Propellants	0.002	0%
Fire protection	5.4	18%
Stationary AC	6.0	20%
Heat pumps	3.0	10%
Foams	0.5	2%
Foam Blowing Agent	0.2	1%
Magnesium Casting	0.08	0%
Total	30.1	100%

A2 LIST OF F-GASES

The table below details the long list of F-gases as referred to in Point 1 of Article 2 of the 2014 F-Gas Regulation[41], including all the hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and other greenhouse gases that contain fluorine. The HFCs included within the list are all subject to the HFC phase down except for HFC-161.

Table 4-6 List of Fluorinated Greenhouse Gases as provided in the F-Gas Regulation.

Industrial designation	Name	Chemical formula
Hydrofluorocarbons (HFCs)		
HFC-23	trifluoromethane (fluoroform)	CHF_3
HFC-32	difluoromethane	CH_2F_2
HFC-41	fluoromethane (methyl fluoride)	CH_3F
HFC-125	pentafluoroethane	CHF_2CF_3
HFC-134	1,1,2,2-tetrafluoroethane	CHF_2CHF_2
HFC-134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3
HFC-143	1,1,2-trifluoroethane	CH_2FCHF_2
HFC-143a	1,1,1-trifluoroethane	CH_3CF_3
HFC-152	1,2-difluoroethane	CH_2FCH_2F
HFC-152a	1,1-difluoroethane	CH_3CHF_2
HFC-161*	fluoroethane (ethyl fluoride)	CH_3CH_2F
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	CF_3CHFCF_3
HFC-236cb	1,1,1,2,2,3-hexafluoropropane	$CH_2FCF_2CF_3$
HFC-236ea	1,1,1,2,3,3-hexafluoropropane	CHF_2CHFCF_3
HFC-236fa	1,1,1,3,3,3-hexafluoropropane	$CF_3CH_2CF_3$
HFC-245ca	1,1,2,2,3-pentafluoropropane	$CH_2FCF_2CHF_2$
HFC-245fa	1,1,1,3,3-pentafluoropropane	$CHF_2CH_2CF_3$
HFC-365 mfc	1,1,1,3,3-pentafluorobutane	$CF_3CH_2CF_2CH_3$
HFC-43-10 mee	1,1,1,2,2,3,4,5,5,5-decafluoropentane	$CF_3CHFCHFCF_2CF_3$
Perfluorocarbons (PFCs)		

Industrial designation	Name	Chemical formula
PFC-14	tetrafluoromethane (perfluoromethane, carbon tetrafluoride)	CF_4
PFC-116	hexafluoroethane (perfluoroethane)	C_2F_6
PFC-218	octafluoropropane (perfluoropropane)	C_3F_8
PFC-3-1-10 (R-31-10)	decafluorobutane (perfluorobutane)	C_4F_{10}
PFC-4-1-12 (R-41-12)	dodecafluoropentane (perfluoropentane)	C_5F_{12}
PFC-5-1-14 (R-51-14)	tetradecafluorohexane (perfluorohexane)	C_6F_{14}
PFC-c-318	octafluorocyclobutane (perfluorocyclobutane)	c-C_4F_8
Other perfluorinated compounds		
	sulphur hexafluoride	SF_6

*Not included in the HFC phase down

Table 4-7 is a list of other fluorinated gases which are subject to the reporting requirements set out in Article 19 of the F-gas Regulation[41].

Table 4-7 Other Fluorinated Greenhouse Gases Subject To Reporting In Accordance With Article 19 of the F-Gas Regulation.

Common name/industrial designation	Chemical formula
Hydro(chloro)fluorocarbons	
HFO-1234yf	$CF_3CF = CH_2$
HFO-1234ze	trans — $CHF = CHCF_3$
HFO-1336mzz(Z)	$CF_3CH = CHCF_3$
HCFO-1233zd	$C_3H_2C_lF_3$
HCFO-1233xf	$C_3H_2C_lF_3$
Fluorinated ethers and alcohols	
HFE-125	CHF_2OCF_3
HFE-134 (HG-00)	CHF_2OCHF_2
HFE-143a	CH_3OCF_3
HCFE-235da2 (isofluorane)	$CHF_2OCHC_lCF_3$
HFE-245cb2	$CH_3OCF_2CF_3$

Common name/industrial designation	Chemical formula
HFE-245fa2	$CHF_2OCH_2CF_3$
HFE-254cb2	$CH_3OCF_2CHF_2$
HFE-347 mcc3 (HFE-7000)	$CH_3OCF_2CF_2CF_3$
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$
HFE-43-10pccc124 (H-Galden 1040x) HG-11	$CHF_2OCF_2OC_2F_4OCHF_2$
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$
HFE-347mmy1	$(CF_3)_2CFOCH_3$
2,2,3,3,3-pentafluoropropanol	$CF_3CF_2CH_2OH$
bis(trifluoromethyl)-methanol	$(CF_3)_2CHOH$
HFE-227ea	$CF_3CHFOCF_3$
HFE-236ea2 (desfluoran)	$CHF_2OCHFCF_3$
HFE-236fa	$CF_3CH_2OCF_3$
HFE-245fa1	$CHF_2CH_2OCF_3$
HFE 263fb2	$CF_3CH_2OCH_3$
HFE-329 mcc2	$CHF_2CF_2OCF_2CF_3$
HFE-338 mcf2	$CF_3CH_2OCF_2CF_3$
HFE-338mmz1	$(CF_3)_2CHOCHF_2$
HFE-347 mcf2	$CHF_2CH_2OCF_2CF_3$
HFE-356 mec3	$CH_3OCF_2CHFCF_3$
HFE-356mm1	$(CF_3)_2CHOCH_3$
HFE-356pcf2	$CHF_2CH_2OCF_2CHF_2$
HFE-356pcf3	$CHF_2OCH_2CF_2CHF_2$
HFE 365 mcf3	$CF_3CF_2CH_2OCH_3$
HFE-374pc2	$CHF_2CF_2OCH_2CH_3$
	- $(CF_2)_4CH$ (OH)-
Other perfluorinated compounds	
perfluoropolymethylisopropyl-ether (PFPMIE)	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$

Common name/industrial designation	Chemical formula
nitrogen trifluoride	NF_3
trifluoromethyl sulphur pentafluoride	SF_5CF_3
perfluorocyclopropane	$c\text{-}C_3F_6$

A3 METHODOLOGY

This annex provides additional details of the methodology employed for the assessment of business impacts and knock-on economic effects that could potentially result from the implementation of the proposed restriction. Three aspects are explored:

- Baseline estimation
- Knock-on effects to the wider economy
- Annualization of impacts

A3.1 Baseline estimation

This study defined and characterised how different business figures of the EEA F-gas producers and importers, and EEA F-gas downstream users, would likely evolve in the absence of the proposed restriction, drawing from Tool #57, Tool #58, Tool #59, and Tool #60 of the EC's Better Regulation Toolbox[348]. This includes:

- Defining the **'Do nothing' or baseline scenario**, that is, what the EEA F-gas producers and importers, and EEA F-gas downstream users would look like in the absence of the proposed restriction;
- Identifying key economic and sectoral indicators that can be used to characterise the potential evolution of the EEA F-gas producers and importers, and EEA F-gas downstream users; and
- Quantifying how these indicators would likely evolve over a period of 20 years (2020-2040).

First, policy experts from the study team defined what the 'Do nothing' scenario would look like in terms of EEA legislation. In particular, the study team experts confirmed the existing legislation and the legislative changes that are already expected for implementation over the period without the need for the EEA to take any further legal action. The main legislative change that is expected in the 'Do nothing' scenario would be the revised F-gas Regulation.

From a business perspective, it was assumed that the existing framework with the phase-down established by the F-gas Regulation, would continue broadly as-is over the period, and F-gas producers and importers progressively switching from higher GWP (and subject to the phase-down) F-gases to lower GWP H(C)FOs and blends of HFC/H(C)FOs (not subject to the phase-down).

Secondly, the team established a set of indicators of focus to characterise the baseline of the EEA F-gas producers and importers, the EEA F-gas downstream users, and the EEA economy, which would become the quantitative baseline against which the policy options would be assessed. Table 4-8 below outlines the selected indicators, based on their relevance and the evidence available from Eurostat, the EEA and OECD Statistics.

Table 4-8 Sectoral indicators selected for baseline characterisation.

Theme	Indicators
Business volume and growth	• Sectoral output or production value or turnover (€ billions) • Sectoral Gross Value Added (€ billions), approximately capturing the sector's contribution to Gross Domestic Product • Gross investment (€ billions) • Operating expenditure (€ billions) • Research and Development expenditure (€ billions)
Regulatory burden	• One-off and recurring regulatory costs (€ billions)
Employment	• Number of jobs supported by the sector (Number of jobs)

[348] European Commission, (2021) Tool #57 Methods to assess costs and benefits, Tool #58 EU Standard Cost Model, Tool #59 Cost estimates and the 'one in, one out' approach, and Tool #60 Baselines. Available from: https://ec.europa.eu/info/sites/default/files/br_toolbox_-_nov_2021_-_chapter_8.pdf

Historical evidence and data were collected from multiple, publicly available sources. Table 4-9 provides an overview of these sources for each indicator.

Table 4-9 List of economic indicators and statistics used in the definition of a baseline and analysis of impacts.

Indicator	Scope	Sources
Turnover	• Geo: EU-27 • Time: 2008-2019 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Eurostat Structural Business Statistics
Production value	• Geo: EU-27 • Time: 2008-2019 • Other: F-gas downstream using application product categories	• Eurostat Prodcom Database
Gross Value added (GVA)	• Geo: EU-27 • Time: 2008-2018 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Eurostat Structural Business Statistics
Intermediate consumption/ Opex	• Geo: EU-27 • Time: 2008-2018 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Eurostat Structural Business Statistics
Capital expenditure	• Geo: EU-27 • Time: 2008-2018 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Eurostat Structural Business Statistics
R&D	• Geo: EU-27 • Time: 2008-2019 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Cefic Facts and Figures 2021 and Country Reports
Regulatory burden	• Geo: EU-27 • Time: 2008-2019 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Cefic Facts and Figures 2021 and Country reports
Employment	• Geo: EU-27 • Time: 2008-2018 • Other: industrial gases sector, NACE Rev. 2 Code C20.11	• Eurostat Structural Business Statistics • Eurostat LFSI_EMP_A
GDP	• GDP historic series and baseline projections for EU countries (2020-2040) • GDP deflator historic series and baseline projections for EU countries (2020-2040) • Population historic series and baseline projections for EU countries (2020-2040)	• OECD long-term macroeconomic projections[349] • Eurostat NAMA_10 • Eurostat NAIDA_10 • European Commission (2022). Winter 2022 Economic Forecast.

Some data gaps were identified, which rendered the data series incomplete for some of the economic indicators at the EU-27 industrial gases sector level. These gaps were addressed by employing data available at the sector and country levels for EU-27 and employing trend analysis or other reasonable assumptions to address said gaps.

For those figures for the EEA F-gas producers and importers that are at the level of the EU-27 and/or the industrial gas sector, their percentage annual growth was calculated, and then applied to the figures declared

[349] OECD (2018), GDP long-term forecast (indicator). doi: 10.1787/d927bc18-en (Accessed on April 2022)

in consultation by F-gas producers and importers, which are estimated to represent their whole sector (i.e., F-gas production and import).

For downstream using application sectors, their production value at the level of the EU-27 was the only evidence available that would represent (close to) the whole sector for each of them. Based on the value of production provided via consultation by F-gas downstream users, an extrapolation could be done to obtain sector-level values of turnover and employment, assuming the share of their industries that did not participate in consultation was well represented by the participant sample.

Once a historical dataset was completed based on the best evidence available and expert input, regression analysis techniques were employed to estimate sectoral turnover over the next two decades (2020-2040). A pooled Ordinary Least Squares model was specified to quantify the historical relationships between sectoral turnover (the dependent variable) and real GDP per capita, population growth and a time trend (the independent variables). This was done for the turnover of F-gas producers and importers, and for the production value of each downstream using application with independent estimations and individual sector-specific parameters.

These estimated relationships were coupled with projections of real GDP capita and population by public institutions such as Eurostat and the OECD to produce turnover projections.

All other selected variables were estimated based on their relationship with turnover, as summarised in the Table below.

Table 4-10 Baseline projection of the other selected indicators.

Indicator	Method of projection
Output/ production value	Economic output or production value projections are computed as a proportion of turnover, based on the average historic ratio of turnover to economic output/production value from 2008-2018.
Gross Value added (GVA)	GVA projections are developed from the difference between production value and intermediate consumption.
Intermediate consumption/ Opex	Intermediate consumption is estimated based on the average historic ratio of intermediate consumption per unit of production over the period 2008-2018. Opex is assumed to follow similar annual growth as intermediate consumption.
Capital expenditure	Capital expenditure is estimated based on the historical average capex per unit of turnover from 2008-2018.
R&D	R&D expenditure is estimated to follow a similar growth pattern as turnover.
Regulatory burden	Baseline regulatory burden is expected to remain constant as a 3.7% of turnover, based on Technopolis Group, VVA. (2016) and Cefic Facts & Figures reports, for specialty chemicals.
Employment	Number of employees is computed by assuming a relatively constant relationship in employment per unit of production, whilst taking into account employment stickiness observed in the past (i.e., slower downward adjustments, based on historical evidence and the evidence collected through a bespoke survey).

A3.2 Knock-on effects to the wider economy and Input-Output methodology

The indirect and induced effects, and thus, the total impacts on the economy driven by the effects of the proposed restriction on the F-gas producing and importing sector have been estimated using an Input-Output methodology.

First, GVA measures the contribution that the EEA F-gas producing and importing industry makes to the economy. The two methods of measuring GVA used in this analysis are:

- The production approach that estimates the value of the goods and services produced minus the value of inputs into their production (such as raw materials)
- The income approach that determines the incomes earned by businesses and workers in producing these goods and services

Secondly, the total impact of a policy change in the sectoral GVA equals the sum of:

- Direct impact, that is, the immediate effect of a policy change on the sectoral production and, thus, on its value added; and
- Indirect impacts, that is, any impacts on the sector's value chain, which would be reflected in changes to the intermediate demand for inputs to other sectors; and
- Induced impacts, that is, knock-on effects on the broader economy attributed to how the direct and indirect effects may result in changes to the compensation of employees, which would cause further changes in final demand and spending throughout the whole economy.

The direct effects have been estimated by drawing on the survey to F-gas producers and importers and publicly available data.

The Leontief or Input-Output model, and the associated matrices of economic activity and interconnectedness, provides a methodology for estimating the indirect and induced effects, or the knock-on effects on the economy associated with the direct impacts on the F-gas sector, as pertaining to the wider chemicals sector.

This model allows us to estimate the multipliers or factors that represent the how one euro spent in one sector results in economic activity throughout the supply chain and/or other sectors and so on and so forth).

- Type I multipliers capture the direct and indirect effects only (that is, Type I multiplier – 1 would capture the indirect effects or the economic impacts throughout the supply chain).
- Type II multipliers also capture the induced effects, under the implicit assumption that final consumers do not change their final consumption patterns in response to changes in income (that is, Type II – 1 would capture the indirect and induced effects or the impact throughout the supply chain as well as the effects on the wider economy resulting from changes in compensation to employees).

For the production approach, the cumulative Type I and Type II multipliers have been assumed at around 2.8 and 3.4 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment.

For the income approach, the cumulative Type I and Type II multipliers have been assumed at around 2.1 and 3.1 respectively, based on evidence from Eurostat, national statistical databases from across Europe and expert judgment.

A3.3 Annualization of total impacts and costs

Where required, Equivalent Annual Costs or Impacts were calculated for the selected indicators.

First, the Net Present Value (NPV) of any impact or cost over the period 2023-2040 was estimated by summing the projected cost over the period and discounted at a real discount rate of 4% in line with the Commission's Better Regulation Toolbox #64[350]. The following equation was employed.

Equation 4-1 $NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$, where n refers to the time period from 2023-2040, Ct refers to the costs or impacts in time period t, and r refers to the real discount rate.

Secondly, the NPV of the cost or impact was multiplied by an annualization factor, pertaining to the period of policy impact, which is 2025-2040. This factor is given by the following equation.

Equation 4-2 $AF = \mathrm{r}/[1-(1+r)^{-t}]$, where *r* refers to the real discount rate and *n* refers to the number of periods. Note that this formula and approach were adapted to account for the timetable of policy implementation. No impacts are expected before 2025.

[350] European Commission, (2021) *TOOL #64. DISCOUNT FACTORS* Available from: https://ec.europa.eu/info/sites/default/files/br_toolbox_-_nov_2021_-_chapter_8.pdf

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