Report summary ski treatment

Contents

1. Uses / Applications

PFAS have commonly been used in the production of gliders and other ski wax products used for preparation of skis (including both cross country and downhill skis), snowboards, as well as in mixtures for cleaning and impregnation. The key property that PFAS provide in this application is a high water repellence (hydrophobicity) thus allowing a suitably low surface tension for the skis on snow. Waxes are an important means of lubrication in skiing, to reduce friction between the base of the skis and snow, allowing the skis to glide more freely. It has been shown that the use of high fluorinated waxes can result, on average, in a 4% increase in performance of the skis[1]. There are three main types of friction that require specific lubrication in skiing:

- Dry friction – when dry snow granules come in contact with the ski base.
- Wet friction – when a high moisture content snow creates suction between the ski base and snow.
- Electrostatic friction – when a ski base runs on snow creating an electrostatic attraction between the ski and snow.

Ski wax can come in a variety of different types, each designed for specific conditions, compositions, or a certain performance level. The most common forms of wax are listed in table 1.
Fluorinated waxes tend to be used primarily during competitions; however, professionals are known to use fluorine-free waxes during training. Similarly, amateur skiers mostly use fluorine-free alternatives. However, in some countries it is still common to use fluorinated waxes, also among amateur skiers.

Table 1. Overview of different ski wax types (both grip and glide wax)[2]

Type	Market insights	Method of application	Use
Block wax	Most common wax form	Block wax needs to be melted on the ski base once it is heated up with an iron, then ironed in to the pores of the bases evenly to allow faster gliding.	Waxes in block form last the longest on skis.
Liquid wax	Found at high and low end of the cost spectrum	Supposed to be applied onto a cloth or it comes with an applicator then rubbed on the bases of the skis Often used in conjunction with other forms of wax including fluorocarbon waxes	Short-term solution to allow for faster gliding properties for up to 24hrs.
Paste wax	Very economical and easy to apply.	Small fabric applicator to apply and buff in. The longer you buff it into the base the longer it lasts on your skis. Can be used as an overlay	Typically available in a universal temperature range

[1] Breitschädel F., Haaland N., Espallargas N. 2014. A Tribological Study of UHMWPE Ski Base Treated with Nano Ski Wax and its Effects and Benefits on Performance. Procedia Engineering. 72:267-272

[2] https://www.skis.com/Buying-Guide-for-Ski-Wax/buying-guide-5-3-2013,default,pg.html

Type	Market insights	Method of application	Use
Powder wax	Typically have high costs due to the high amount of fluorocarbons they contain	Designed to be used after a few layers of block wax are applied. Used to increase gliding properties	Often used sparingly for important races only
Spray wax	Typically used on top of several layers of high-end block wax to offer the best gliding properties.	Once it is sprayed on, allow it to absorb and dry for 5 minutes, then use a cork to further buff it in.	Most commonly found in high-end finishing racing wax as an overlay

Information obtained from stakeholders suggests that the total ski wax market is split approximately 50/50 between consumer and professional sales, and the racing market accounts for ~10% of the market sales[3]. No information was available on the sales of specific alternative products nor the tonnages associated with the various wax types (block, liquid, powder etc).

Historical trends in use of ski wax indicate that:

- The highest use year for non-PFAS based ski wax was 1978, where 300 tonnes of glide waxes were used.
- Some companies no longer manufacture ski waxes containing PFAS and are currently selling off their remaining stock. Companies have been working on the development of non-fluorinated alternatives since 2013.
- Since 2017 the PFAS-based ski wax market has shrunk for various reasons: because of the higher prices of some PFAS-based waxes; due to global policy developments related to the use of PFOS/PFOA, and also due to decreasing number of professional athletes.

Production of PFAS based waxes is expected to decrease in the following years. Due to increasing concern and publicity regarding the potential human health and environmental effects caused by the use of PFAS in ski wax treatments, there is a concerted move within this sector towards phasing out the use of PFAS and moving towards safer alternatives. In particular, in 2019 the International Ski Federation (FIS) set to introduce a ban on PFAS in waxes in all competitive ski disciplines from their 2020-2021 season, a move that follows national-level bans imposed, for example by the Norwegian Ski Association in 2017. However, in October 2020 the FIS Council decided to postpone the implementation of the ban of fluorinated waxes until the start of the 2021-22 season, beginning on July 1, 2021. This delay was due to the fact that they are still developing a Fluorine Tracker, an instrument that would detect the presence of PFAS on the ski, that would make the competitions fair.

It is assumed by 2030 there will be an 80% decline in use (against the baseline 2020 usage rates). The remaining 20% in use reflects non-race events and activities outside of Norway. It is further expected that this usage rate will continue to decline over the subsequent 10 years as other alternatives reach market saturation. Post-2040 a small quantity (assumed to be 10% by the current baseline) may continue.

[3] Guidance on information requirements and chemical safety assessment – Chapter R.16: Environmental exposure assessment. V3.0, published in February 2016. ECHA guidance document.

2. Skin skis

Skin skis differ from traditional skis in that they are designed to allow skis to slide forward but not backward. Initially, mohair, a natural material from the hair of goats, was used for skin skis. It was then substituted by nylon skin material treated with Teflon or by a mix of the two.
Real mohair treated with Teflon is used on high-performance models[4]. Nowadays, mainly synthetic skins are used for both cross country and alpine skiing when going uphill. The skins grip the snow, thus providing a forward kick. The skins are then easily removed for skiing downhill[3], while they may be permanent attached under the ski on cross country skis. Given that the skin mimics the functions provided by the grip wax, it is not necessary to use grip wax on the skis. However, it can be necessary to apply anti-icing products to the skins to eliminate icing, as it is done for grip wax-treated skis. In addition, the skin should be cleaned periodically[5]. The glide zone of the skis (i.e. in front of and behind the kick) needs to be re-waxed every 100km travelled, similar to classic skis[6] and in most cases, it is possible to use the same wax for both skin and traditional skis.
This document excludes skis with a sole made out of PTFE that do not require wax.

3. Main PFAS substances

PFAS substances present or potentially present in ski wax are shown in Figure 1. The main PFAS substances used in ski waxes are perfluoroalkanes and semi-fluorinated alkanes. The semi-fluorinated alkanes used are di-block and tri-block semi-fluorinated n-alkanes (SFAs) and are typically mixed with normal paraffins in the formulations of ski waxes. Fluoropolymers are also used in some waxes. Perfluoroalkyl carboxylic acids (PFCAs) of varying carbon chain lengths (6–22 carbons) are often found as residual impurities from the manufacture in commercially available fluorinated ski waxes, see the Nilsson et al. study[7]. PFCAs are not thought to have a technical function in the ski waxes given their relative low levels compared to the perfluoroalkanes and SFAs. Perfluoroalkane sulfonic acids (PFSAs) have also been measured in ski wax, but often at even lower levels than the PFCAs.

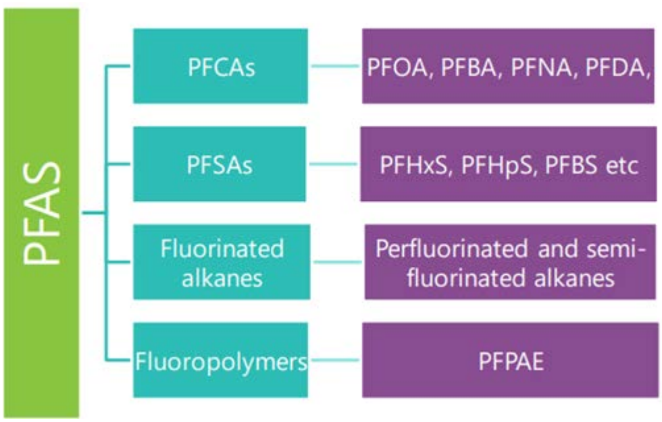


Figure 1. Typical PFAS substances present in ski waxes (including impurities or unintentionally added)

[4] https://www.webcyclery.com/about/skin-skis-101-pg259.htm
[5] https://www.webcyclery.com/about/skin-skis-101-pg259.htm
[6] https://www.crosscountrysports.com/care-for-your-skin-skis/
[7] Nilsson, H. et al. (2010). A time trend study of significantly elevated perfluorocarboxylate levels in humans after using fluorinated ski wax. Environ Sci Technol, 44, 2150–2155

Based on the complex interplay of PFAS substances with regard to some PFAS being a precursor and/or impurity to each other, it is in some cases difficult to state if individual substances are used intentionally or are the product of degradation or an impurity. The main ingredients in fluorocarbon-based ski waxes are di-block and tri-block semi-fluorinated n-alkanes (SFAs); powder waxes typically contain perfluorinated alkanes[8]. However, PFCAs and PFSAs have been found in ski waxes but they are thought to be degradation products or residual impurities.

In each case, the specific composition of the wax varies depending on the different snow conditions, humidity levels and weather conditions for which they are designed. Commonly the composition of waxes is divided into the following categories (*Table* 2).

Table 2. Overview of different ski wax composition

Wax composition	Price	Properties	Labelling
Pure Fluorocarbon	Expensive products as they have a high fluorocarbon content	Comes in liquid, powder or block form. Liquid form is the most popular. High resistance to dirt and oils to provide a long lasting, fast gliding ski	Typically have FC or Cera in the title of the wax.
High Fluorocarbon	Typically more expensive ski waxes. The higher the fluorocarbon content the more expensive	Provide the highest amount of gliding properties in areas with high humidity, man-made snow, dirty snow or places with very cold temperatures Made for every temperature range	Typically has HF in the title of the wax
Low Fluorocarbon	Best value wax when you compare price and performance	Available in every temperature range. Can be used by themselves or to prepare the base	Typically has LF in the title of the wax
Hydrocarbon	Contain no fluorocarbons and are very economical	Very durable and repel dirty snow conditions very well Can be used by themselves (best in colder conditions), or they can be used to help prepare bases for use with higher-end waxes	Typically has CH in the title of the wax
Eco-friendly/plant based wax	More expensive than typical hydrocarbon wax	Often made from a mix of naturally occurring waxes. Tend to be biodegradable	Often labelled 'eco'

<u>Tonnage band:</u>

It is estimated that the total global production of ski wax is 120 tonnes (in 2020). Of these, the EU produces 60%, which equals 72 tonnes. Ca. 30% of the 72 tonnes of ski wax produced in the EU annually is PFAS-based, i.e. 21 tonnes. An average PFAS concentration of 7.6% w.w. is assumed influorine-based wax, which amounts to 1.6 tonnes (or 1,640 kg) of PFAS used annually in the EEA for ski-wax formulations.

[8] https://pubs.rsc.org/en/content/articlehtml/2020/em/d0em00357c

Import & Export:

Since the European Union is a major manufacturer of ski-waxes (60% of global production), it is assumed that no imported ski-wax will be needed and that all ski-wax manufactured will service the EU's needs, hence that net export/import is zero. It is possible that the EU is a net-exporter of ski-wax but data on exports was not identified.

4. Manufacturing & Market price + market development

Regarding manufacturing in the text above already information has been given. In figure 2 a high level market overview in EEA is given. In table 3 a historic overview of production tonnages are plotted.

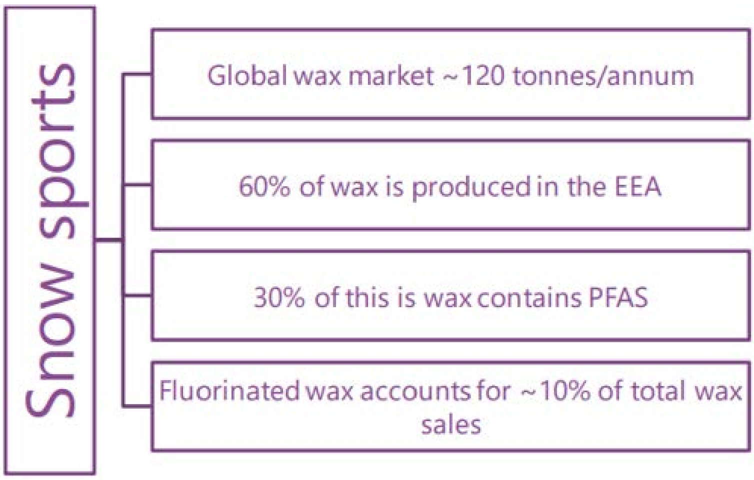


Figure 2. High level market overview of ski waxes in the EEA (information obtained from stakeholder consultation)

Table 3. Assumed production rates for PFAS-based wax used to calculate the backward looking time-series.

Year	Global production (tonnes)	EEA fraction of production (percentage)	Total EEA ski-wax production (all formulations) (tonnes)	Proportion of EEA production covering fluorinated waxes (percentage)	PFAS-based ski-waxes produced in the EEA (tonnes)
1978	300	60%	180	0%	0
1990	250	60%	150	10%	15
1995	225	60%	135	30%	40.5
2000	200	60%	120	50%	60
2005	175	60%	105	50%	52.5
2010	150	60%	90	50%	45
2015	135	60%	81	40%	32.4
2020	120	60%	72	30%	21

<u>Market price & autonomous market development:</u>

Average market price is 2,35 €/g, with a min. price of 0.23 €/g and a max. price of 6.33 €/g.

<u>No. of production sites:</u>

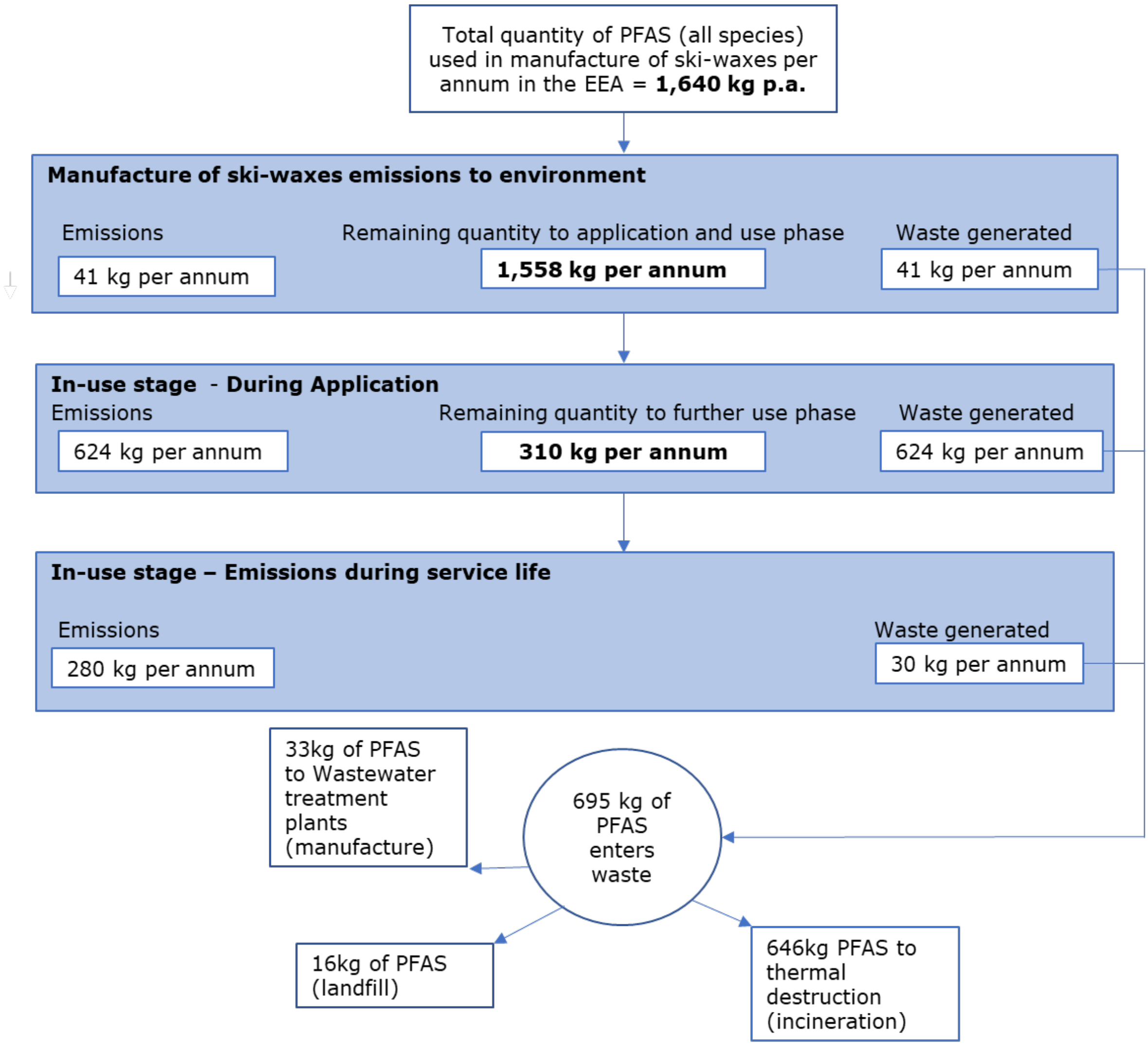
Unknown

5. Emissions

For this assessment, a basic source-flow model has been developed. The development of this source-flow approach began with a consideration of the key life-cycle stages and what kinds of emissions may occur at each life-cycle stage. Four basic life-cycle stages are considered where it is possible for emissions to occur, or for material to flow through into the next life cycle stage (Figure 3):

- **Formulation of the ski wax.** This includes consideration of the PFAS substances used within the ski wax. Note, that it was assumed that the life-cycle begins at this stage rather than the manufacture of the PFAS themselves.
- **Storage.** For other sectors beyond ski-waxes, storage can potentially be an important life-cycle stage for potential emissions. Therefore, for completeness 'Storage' has been included within the current source-flow approach. However, during storage of ski waxes it is unlikely that leaks or spillages occur, which would directly contribute to environmental emissions. Therefore, emissions from this stage are assumed to be zero.
- **In-use.** Active use of ski waxes is likely the most important life-cycle stage. To provide a higher level of disaggregation this phase is split into two sub-components:
    - Emissions to the environment during the application of ski-wax to skis/snowboards etc.
    - Further emissions to the environment associated with the continued service life (i.e., during skiing).
- **Waste.** The waste cycle includes three key pathways: landfill of wastes and/or end of life product (i.e., any unused final quantities of wax discarded), thermal destruction (incineration) and wastewater treatment plants.

Figure 3. Material flow diagram for PFAS (all species, including fluoropolymer) in ski-waxes for the European Union



Active use of ski waxes is likely the most important life-cycle stage. To provide a higher level of disaggregation this phase is split into two sub-components based on a basic source-flow model that has been developed to make use of the data from the market analysis and substance identification:

- Emissions may occur during the application of ski-wax to skis/snowboards. This is potentially the single biggest point of release in the life-cycle. Based on consultation with industry, the efficiency of applying ski-wax to skis/snowboards etc is relatively poor. The average of the values provided suggests that 80% of ski-wax applied is lost during the application process. This can occur both indoors and outdoors over snow. Further feedback suggests a significant proportion of lost material may be recaptured and consigned to waste (e.g., via vacuuming). Therefore, it is assumed that 80% is initially lost, with 40% (half) recaptured and consigned to waste and 40% (half) truly lost to the environment, with an equal split between water and land. The remaining 20% is retained on the skis/snowboard. The application life-cycle stage is estimated to emit 624kg of PFAS to the environment annually (equivalent to 38% of the total quantity of PFAS used in ski-waxes per annum).
- Secondly, after application there may be further losses during service life (i.e., skiing). It is assumed that 100% of the wax applied is lost during this phase through erosion of the wax with further emissions to air, water, and soil during active skiing. This amounts to 280kg lost

directly to the environment per annum. In lieu of better data it is assumed 10% (approximatley 30kg) of the wax purchased is not used and enters the waste cycle (this is where the ski-wax bars are worn particularly thin, or liquid products are residue amounts in containers).

- All material not lost directly to the environment during formulation or use will enter the waste phase through three main pathways (i.e., wastes generated during formulation; excess wax discarded during application; and unused ski wax which has expired).

Figure 3 and Table 4 provide the results of the emission estimates, which highlights the main receiving environments to be equally shared between surface water and soil. This is based on the use of the ERC emission factors. In practice it could be expected that the main receiving environment is snow itself, which in due course (i.e., spring melts) will lead to contamination of surface waters and soil. Figure 3 also highlights that of the 1,640kg of PFAS (within ski-wax) used per annum a total of 945kg is lost to the environment (58% of the total used), primarily during application, and 695kg per annum enter the waste stage (equivalent to 42% of total PFAS used).

Table 4. Overview of emissions by different environmental compartment for all life-cycle stages combined in kg for 2020.

Substance group	Air	Fresh surface water	Soil (true release)	Total
PFAS (all species)	41	452	452	**945**

It should be noted that ski waxes account for only a small share of total PFAS use. As a consequence, ski waxes are most likely not very significant in terms of total environmental PFAS exposure. However, environmental exposure might occur when waxes are released during skiing onto the track where people are skiing. Stakeholder consultation highlighted contrasting opinion with respect to the amount of ski wax released to the environment during skiing, ranging from 1-5% – depending on the contact area between the ski and the snow and on the snow conditions – to all of the wax. One interviewee claimed, without providing evidence, that given the very small amounts of PFAS in the waxes it should be considered that the amounts of PFAS found in snow could come from other sources like air, the ski clothes, lubricants used in lifts and vehicles, or fire-fighting foams[9]. However, a scientific study examining the presence of PFAS in soil, earthworms (Eisenia fetida), and Bank voles (Myodes glareolus) from a skiing area in Trondheim, Norway found long chain PFCAs at high concentrations, compared to the reference area with no skiing activities which was dominated instead by short-chained PFCAs[10]. Similarly, a more recent study found evidence of extremely high levels of both long and short chain PFAS in the snow at the starting line of a ski race. Importantly, the 14 PFAS detected in the snow matched what has been found in ski wax. PFAS levels diminished at around 4 km from the starting line. The soil was contaminated by the same four dominant PFAS that were present in the

[9] Interview with FIS.

[10] Grønnestad R, Vázquez BP, Arukwe A, Jaspers VLB, Jenssen BM, Karimi M, Lyche JL, and Krøkje Å (2019). Levels, Patterns, and Biomagnification Potential of Perfluoroalkyl Substances in a Terrestrial Food Chain in a Nordic Skiing Area. https://pubmed.ncbi.nlm.nih.gov/31691564/

snow samples, although at a lower concentration. Groundwater contained only short chain PFAS at low concentrations[11].

The environmental impact of ski wax use on an outdoor recreation area with significant cross-country ski activity was recently examined by measuring PFAS levels in melted snow, soil and water following a collegiate ski race[12]. Findings indicated that high levels of long- and short-chain PFAS (C4-C14) were found in snow at the race start line, with the longer-chain analytes (C10-C14) predominating. Importantly, the 14 PFAS detected in snow matched what has been found in ski wax. Snow contamination was found to be greatly reduced at 3.9 km into the race but soil and groundwater were also found to be contaminated with PFAS. The authors conclude that ski wax use, from which fluorocarbons abrade onto snow during a ski race, was the main source of PFAS contamination at that specific sampling site. Grønnestad et al. (2019) also investigated levels, patterns, and biomagnification of PFAS in soil, earthworms (*Eisenia fetida*), and Bank voles (*Myodes glareolus*) from a skiing area in Trondheim, Norway. In general, there was higher PFAS levels in the skiing area compared to the reference area with no skiing activities. The soil PFAS pattern in the skiing area was comparable to analyzed ski waxes, indicating that ski products are important sources of PFAS in the skiing area. [13]

Emission projections:

The current study has also included emission projections from the baseline year (2020) to 2050, covering two scenarios: a baseline business as usual scenario and a REACH restriction scenario. To support this work a review of the backward-looking trends was also created. This backward-looking trend reflected that use of ski-wax generally has fallen since peak use in the 1970s (300 tonnes per annum globally) to the current baseline (120 tonnes per annum globally), while the first patents for PFAS based ski-wax date from ~1990. The Call for Evidence (CfE) highlights that steps to reduce the use of PFAS within ski-wax have already been taken voluntarily since 2014, with work to develop and implement alternatives. Furthermore, the International Ski Federation (FIS) has highlighted that a movement is underway to ban the use of PFAS-based waxes at sporting events run by FIS.

Under the business-as-usual (BAU) scenario, voluntary steps by industry mean that by 2030 there is expected to be an 80% decline in PFAS-based ski wax usage rates (Table 5 and Figure 4). The BAU scenario estimates that this decline in use and associated emissions would continue to dwindle, meaning that by 2040 only 10% of the existing use rate would remain, with the associated emission at 95kg per annum (compared to 945kg per annum for 2020). The BAU scenario assumes total emissions of PFAS to the environment (all species) between 2021 and 2050 of 7,000 kg.

[11] Carlson, L and Tupper, S (2020). Ski wax use contributes to environmental contamination by per- and polyfluoroalkyl substances https://www.researchgate.net/publication/343914356_Ski_wax_use_contributes_to_environmental_contamination_by_per-and_polyfluoroalkyl_substances

[12] Gail L. Carlson and Skylar Tupper 2020. Ski wax use contributes to environmental contamination by per- and polyfluoroalkyl substances. https://doi.org/10.1016/j.chemosphere.2020.128078

[13] Grønnestad R, Vázquez BP, Arukwe A, Jaspers VLB, Jenssen BM, Karimi M, Lyche JL, and Krøkje Å (2019). Levels, Patterns, and Biomagnification Potential of Perfluoroalkyl Substances in a Terrestrial Food Chain in a Nordic Skiing Area. https://pubmed.ncbi.nlm.nih.gov/31691564/

Table 5. Usage rates and emission projections for the Business-as-usual scenario.

Year	Production and usage rates for PFAS-based ski-waxes (kg)	Emissions of PFAS to all vectors (kg)	Annual decline compared to previous year (percentage)
2020	21,600	945	-
2021	19,870	870	8%
2022	18,100	795	8%
2023	16,400	720	8%
2024	14,700	640	8%
2025	12,900	570	8%
2026	11,200	500	8%
2027	9,500	410	8%
2028	7,700	340	8%
2029	6,000	265	8%
2030	4,300	190	8%
2035	3,200	140	-
2040	2,100	95	-
2045	2,100	95	-
2050	2,100	95	-

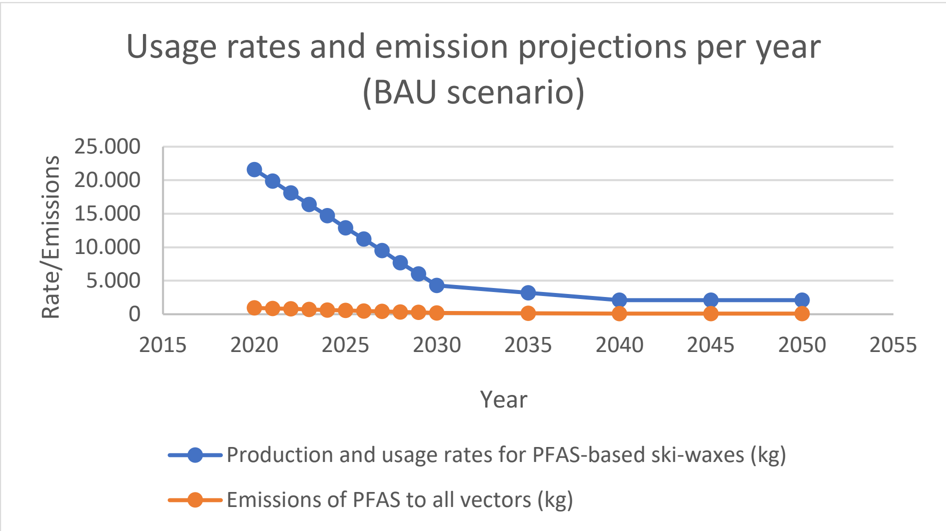


Figure 4. Usage rates and emission projections per year (based on a BAU scenario)

The REACH restriction scenario assumes a full restriction without exemptions would be implemented with total phase-out at an earlier juncture. Within this scenario a conservative estimate is made that the REACH restriction would be implemented by the end of 2023, with a phase-in ‘grace’ period to allow transition and use of products already manufactured and held in storage of three years. On that basis under this scenario, it is assumed that total phase-out and end of use is achieved by 2026. No further use or emissions would occur after 2026 in this scenario (save for waste which is out of scope).

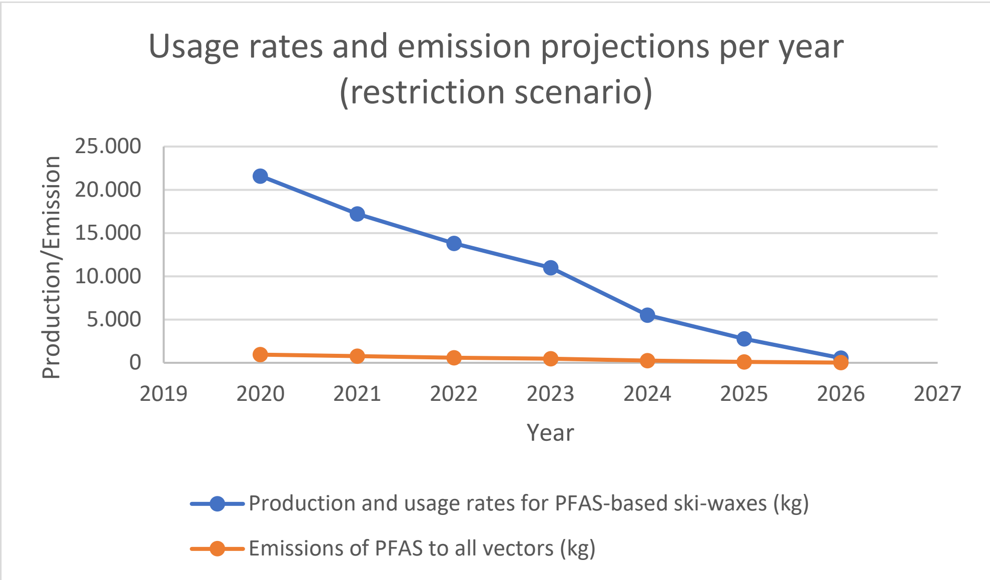
The service-life of ski-wax is short (estimated as two years) so long-lasting legacy issues from in-use stocks are not expected. The REACH restriction scenario estimates total emissions of PFAS (again all species) over the same period would be 2,200 kg. Note that this assumes no further releases to environment after 2027. This means that between 2021 and 2050, the REACH restriction scenario would prevent ~7,000kg of PFAS being lost to environment.

Using these two scenarios (accepting the uncertainty in the estimates and assumptions made in adopting these estimates) would mean a saving of 4,800 kg of PFAS to the environment. Note that the true emission saving would depend further on how the real-world BAU situation might transpire in actuality. The projections for this scenario are provided in Table 6 and Figure 5 (below).

Table 6. Usage rates and emission projections for the REACH restriction scenario.

Year	Production and usage rates for PFAS-based ski-waxes (kg)	Emissions of PFAS to all vectors (kg)	Annual decline compared to previous year (percentage)
2020	21,600	945	-
2021	17,200	757	20%
2022	13,800	605	20%
2023	11,000	484	20%
2024	5,500	242	50%
2025	2,765	121	50%
2026	550	24	80%

Figure 5. Usage rates and emission projections per year (based on a restriction scenario)



In the table below a summary of assumptions is given.

Table 7. Summary of assumptions and factors applied to data

Component	Value	Assumption and justification
Import/export	Imports = 0 tonnes Per annum. Exports = 0 tonnes per annum. All manufacture remains for use in the EU.	Assumption: There is reasonable market data to suggest that 60% of global manufacture of ski-wax occurs within the European Union. However, data on imports/exports has not been identified.
		Justification: The justification is that the EU is a primary location for manufacture of ski-wax and can be largely assumed to meet all EU demand. Therefore, we do not expect any imports. It is possible that the EU is a net exporter but data on exports has not been identified. It is therefore assumed all manufacture and use remains inside the European Union.
Working concentrations of PFAS in ski-wax	Average concentration of 7.6% w.w	Assumption: Industry responses indicate working concentrations for PFAS between 0.2 – 15% w.w in ski-wax, however, specific concentrations may vary widely. Assume a middle value for the model estimates.
		Justification: The range provided by industry is relatively broad. In lieu of better data it is possible to justify the use of a middle value recognising the potential high uncertainty in the final outputs.
Emission factors during formulation of ski-wax	Use SpERC emission scenario for 'formulation into a mixture' 2.5% w.w to air; 2% w.w to wastewater; and 0.01% to soil. Furthermore assume 0.5% w.w as solid waste residue for waste management.	Assumption: Data on monitoring of emissions for formulation of ski-wax has not been identified. The production of ski-wax is expected to be completed at elevated temperature using both liquid and solid processes. Therefore, emissions to air (from thermal processes), wastewater (from liquid processes) and generation of solid waste residues (liquid and solid processes) are expected. Trace amounts of PFAS are expected in these wastes. In lieu of better data values from the SpERC for formulation of mixtures have been used (see SpERC No2).
		Justification: Potential emission pathways can be readily identified, however assigning emission factors is more challenging. For consistency against other PFAS-based Annex XV dossiers the current values have been assigned from the SpERC.
Losses during storage.	Assume 0% from spillages/accidents. Assume 0% from volatisation to air.	Assumptions: Storage is a potentially important life-cycle stage for other sectors and so has been included within the emission model. Industry feedback suggests that storage may cover a period of up to 2 years (including both warehousing and stocking within retail outlets). The product is sold as both a solid (wax) and liquid formulation. Therefore, accidental release is possible but perhaps less likely. In lieu of better data releases are assumed to be zero in this life-cycle phase.
		Justification: For completeness, this life-cycle has been included within the model.

Component	Value	Assumption and justification
		Potential accidental losses could be assumed to be very low and therefore to avoid increasing the uncertainty in the estimates and simplicity of the model the emissions calculated to be zero.
In use emissions (application)	Assume 80% is lost during application. However, feedback from industry and NEA is that application sites are typically well maintained and lost material may be recaptured (e.g. through vacuuming/sweeping)and consigned to waste (typically thermal destruction/landfill). In lieu of better data assume 50% of the lost material is recaptured, and 50% genuinely lost to environment. The lost fraction is then evenly split between water and land. This gives the following fractions: Recaptured and consigned to waste = 40% Lost to land (true emission) = 20% Lost to water (true emission) = 20% Retained on the skis/snowboard and pass to next life-cycle stage = 20%	Assumption: The in-use phase is split in two, with application the first sub-phase. The interview notes from the consultation (see section E.5.1.3.) comment that application efficiency can be quite poor with a range of values quoted. The average of these values is 80% loss. The interviewees also commented that application can take place directly over snow or indoors. Further feedback suggests a significant proportion of lost material may be recaptured and consigned to waste (e.g. vacuuming). Therefore, it is assumed that 80% is initially lost, with 40% (half) recaptured and consigned to waste and 40% (half) truly lost to the environment, with an equal split between water and land.
		Justification: The consultation interviews with industry provided good data on the application efficiency which allows estimates to be made. Realistically application will occur indoors and outdoors. As a worst case assume 100% occurs outdoors but recognise that this may overestimate direct environmental losses (note even losses indoors will reach environment either through tracking on footfall or washing to wastewater).
In use emissions (service life)	90% over the course of active use. Split: 50% to water 50% to land	Assumption: Emission rates for the active use of ski-wax during skiing have not been identified. Where wax is applied to the underside of skis or snowboards and is eroded during use (requiring further application) it is assumed 100% of the wax used is emitted to environment. In lieu of better data it is assumed 10% of the wax purchased is not used and enters the waste cycle (this is where the ski-wax bars are worn particularly thin, or liquid products are residue amounts in containers). Emission will be directly to snow/ice. Assumptions about melted ice and run-off to rivers would require significant data and is a high complex process. Therefore, for high level estimates an assumption is made that equal amounts reach surface water and soil, respectively.
		Justification: Upon use of ski-wax the emission to environment is absolute. i.e., the function of use causes the wax to be emitted. It is possible that close to 100% of the ski-wax purchased is used, however, where winter sports are seasonal, it is more likely that some remaining product does

Component	Value	Assumption and justification
		enter the waste cycle (i.e., end of season/end of vacation etc). An expert judgement of 10% has been applied for remaining fraction to waste.
Landfill / incineration.	100% of formulation wastes are incinerated. 100% of recaptured PFAS wastes from application are incinerated. 50% of waste from in-use goes to landfill 50% of waste from in-use goes to incineration.	Assumption: Data on wastes for ski-wax has not been identified. Feedback from industry suggests that it should be incinerated, but what happens in practice is less clear. It is assumed that manufacturers will have greater control over the formulation of ski-wax, so all solid wastes from this life-cycle stage will be incinerated. The 'in-use' phase covers a wide set of activities, with the most likely pathway being disposal to public bins or household waste. It is assumed that equal portions are landfilled and incinerated
		Justification: Data on waste has not been identified and is a very challenging element of the model. Feedback from industry does suggest incineration would be preferred. It can be justified that manufacturers have greater control over wastes from formulation. Wastes from in-use phases, are more likely to be typical of other wastes discarded to public bins or household refuse.

6. Exposure (workers, consumers)

Direct human exposure to PFAS can occur when applying ski wax treatments, as the application often includes heating, melting, brushing and sanding of mixtures containing PFAS close to the airways, meaning users can be exposed to high concentrations of PFAS.

To provide context about the potential magnitude of human exposure to PFAS from ski waxes, the **magnitude of the use** should be considered. About 21 tonnes of PFAS-based waxes are produced per year in the EEA[14]. It is expected that a similar quantity of PFAS-based ski waxes is currently used in the EEA, because they are mostly produced and used in the EU (interviewees suggested the EU accounts for some 60% of the global production and 70% of the global market[15]). PFAS-based ski wax may contain up to 100% PFAS, although the concentrations depend on the formulation. However as noted previously, the reported concentration data only looks at a subset of PFAS substances for which analytical methods and standards are available and does not quantify total PFAS content or allow differentiation between those substances present in ski wax (including as impurities) or those actively used/added. The following input was received from stakeholders regarding the **potential for human exposure** to PFAS from ski waxes:

[14] Interview with Rodewax
[15] Interviews with Rodewax and Swix

- No specific information was provided regarding PFAS exposure during **production of ski waxes**, although producers suggested that the main potential for exposure is during application of the wax to the ski.
- The **traditional way to apply ski wax** was to place a powder on the ski and melt it with an iron, after which much of the wax is removed from the ski base by scraping and brushing[16]. This has led to several concerns:
    - The range between melting point and boiling point of the compound is very narrow, so fumes can be released even when the boiling point is not reached. As a result PFAS has been found in the blood of people applying ski wax[17]. It should be noted however that emissions of fumes from the application of fluorine-free alternatives may also have health concerns.
    - A proportion of the wax applied will fall to the floor.[18]
    - Scraping and brushing can lead to formation of dust that could be inhaled[19].
- The **modern method to apply ski wax** reduces the potential for exposure compared to the traditional way. It works as follows[20]:
    - Around 6-15 grams of wax are applied per ski (for liquid wax, instead, only 0.5g are applied per set of skis). The wax is applied once before each competition.
    - Producers recommend to (and professionals are reported to) use protection equipment to shield them from potential exposure, including gas masks, gloves and long sleeves, and to apply wax in an open or well-ventilated area.
    - Liquid and hard wax are applied with a rotor fleece, so there it is expected that all the wax is either contained or applied to the ski (none is released, e.g. by falling to the floor). Most of the applied quantity is contained during the application process (around two thirds), the rest remains on the ski.
    - It is reported that in some cases, the contained wax is disposed of in general waste or even in the snow/outside, but some ski wax producers and EEA countries (e.g. Norway) have recommendations in place for waste wax to be disposed of by waste handling companies (e.g. through incineration).

No information was available to quantify the extent to which the traditional method is still applied and to what extent it has been replaced by the modern method. Interviews with ski wax manufacturers seemed to suggest that at least professionals applying ski waxes are expected to use the modern method, but there may be others (notably athletes at lower or amateur level competitions) that may apply ski waxes. However, there have been studies which document a direct correlation between years exposed as a ski waxer and concentration of several different perfluoroalkyl carboxylate (PFCA) compounds in blood, with one study showing that Swedish wax technicians' median blood level of PFOA is 112 ng/mL compared to 2.5 ng/mL in the general population[21].

[16] https://www.glisshop.co.uk/tutorial/cross-country-ski-how-to-glide-wax/
[17] Interview with NILU
[18] Interview with Swix
[19] See e.g. https://fasterskier.com/2012/12/waxing-safety/
[20] Interviews with Rodewax, Swix and NILU.
[21] Freberg, B. et al. (2010). Occupational exposure to airborne perfluorinated compounds during professional ski waxing. Environ Sci Technol, 44, 7723–7728 and Nilsson, H. et al. (2010). A time trend study of significantly elevated perfluorocarboxylate levels in humans after using fluorinated ski wax. Environ Sci Technol, 44, 2150–2155

Starting from the ski wax producers, the potential number of workers through the supply chain and users of PFAS-based ski waxes is estimated in the following.

- **Producers of ski waxes:** According to interviews with some of the main ski wax producers, around 100-200 people are employed by at least 20-25 ski wax producers (many of which are small companies) in the EEA[22]. This includes the production of both PFAS-based and fluorine-free ski waxes. Considering that most producers offer both, it is not possible to distinguish workers relating to only PFAS-based ski waxes.
- **Wholesale, distribution and retail:** No information on the number of workers in wholesale, distribution and retail of ski waxes was available. However, these workers are very unlikely to be directly exposed to PFAS-based ski waxes, because the waxes are packed during these supply chain stages. Hence their numbers of employees are less important in the context of this proposed restriction.
- **Application of waxes to skis:**
    - The total number of people involved in the waxing of skis with PFAS-based ski waxes is highly uncertain, because at lower or amateur level skiing competitions skiers will likely manage their equipment themselves (or their parents will, in the case of junior competitors).
    - For higher level competitions, the number of professionals involved in applying PFASbased ski waxes can be estimated based on interviews with ski wax manufacturers to be around a few hundreds.
- **End-users (skiers):** PFAS-based ski waxes are mostly used during competitions. Competition skiers are then estimated to be in the order of 7 million in the EEA32 . However, such estimate is based on uncertain assumptions so it should be considered as a rough indication of the potential order of magnitude only.

7. Alternatives

Due to increasing concern and publicity regarding the potential human health and environmental effects caused by the use of PFAS in ski wax treatments, there is a concerted move within this sector towards phasing out the use of PFAS and moving towards safer alternatives. As a result, a number of companies have developed alternative fluorine-free ski wax products. In almost all cases a mixture of substances is used in various percentage combinations for each of the fluorine-free alternatives to attain the necessary functions of the wax. The available alternatives are mainly based on hydrocarbons and paraffins, where paraffin waxes make up the majority. Siloxanes are another option, but they are subject to environmental concerns. New nanoparticles are also being developed as alternatives (Table 8). Alterations to the ski itself can also be used to improve the performance of the ski and therefore “replace” some of the functionality of the wax. To assess the possible viability of the alternatives identified, table 8 provides a consideration of both the technical feasibility (i.e., ability to provide the required functionality) and economic feasibility (e.g., unit and operational costs associated with its use) of the possible alternatives compared with the PFAS-based waxes.

[22] Interviews with Rodewax and Swix

The following alternatives have been identified:

- **Fluorine-free ski waxes** have always been in use and widely commercially available[23]. It is estimated that fluorine-free ski waxes account for some 70% of the market, the remaining 30% is divided between products that are completely and partially fluorinated[24]. Different ski wax types are based on primary materials in different proportions to give the wax different properties.
- **Alterations to the ski itself** can also be used to improve the performance of the ski and therefore "replace" some of the functionality of the wax. These include:
    - Modifying the microstructure of the ski base[25]. The thin layer of water that forms between the ski base and the snow must be monomolecular, as too much water would cause too much friction. Researchers are currently looking for an optimal microstructure of the ski that helps limit the amount of water under the ski. Testing is currently under way on 6-10 pairs of skis to find the best structure considering different snow conditions.
    - Fluorinated ski base[26]. There are already ski bases which include side chain fluorinated polymers. It is important to note that the effect of having a thin layer of PFAS-based wax on the ski is bigger than having it in the plastic base of the ski[27].
    - Improve the performance of the polyethylene of the ski[28]. Research is ongoing through a collaboration between polyethylene producers.
    - Heating the base to obtain a better glide which requires energy[29].
    - Methods to minimise friction by controlling the vibrations of the ski are also being researched. It is estimated that 5-10 years or longer will be required for such products to be developed and available[30].

Most **users of ski waxes** already use fluorine-free ski waxes, in particular amateur skiers and athletes during training. FIS and ski wax manufacturers indicated that PFAS-based waxes are primarily used during competitions[31]. Hence, primarily skiers participating in competitions would need to switch from PFAS-based to fluorine-free alternative waxes, potentially also using some of the alterations to the ski itself to improve gliding performance, in addition to using wax. It does not appear likely that competitions would be significantly affected, given that all participants would have to cease using PFAS-based waxes, keeping a level playing field between athletes.

It is therefore expected that the **rest of the supply chain** between ski wax producers and users (i.e. distributors and service providers offering waxing of skis) would also simply switch to fluorine-free alternatives.

23 Interview with Swix
24 Interviews with Rodewax and Swix
25 Interview with NILU
26 Interview with NILU
27 Interview with FIS
28 Interview with Rodewax
29 Interview with Swix
30 Interview with Swix
31 Interviews with Rodewax, Swix and FIS

Table 8. Broad assessment of technical and economic feasibility of non-fluorinated ski wax alternatives

Product type		Hydrocarbon and paraffin waxes
Manufacturer		Multiple – Swix, Toko, Brav
Chemical composition		Substances listed in safety data sheets: Hydrocarbon and paraffin waxes
Technical feasibility	Application areas (as specified in technical specification)	Multiple ski waxes are available for all the different applications types and temperature/weather conditions
	Compliance with international performance standards	N/A
	Examples of use experience and performance compared to PFAS-containing waxes	Performance (speed) is slightly reduced especially in weather conditions with high temperatures and humidity.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	None
	Need for changes in equipment	No change necessary. Same equipment can be used in manufacture of waxes and application to the skis
Economic feasibility:	Unit price	Often less expensive to buy than PFAS waxes
	Unit price as compared with PFAS-containing wax for same application	Often less expensive to buy than PFAS waxes
	Relative volume required to achieve comparable/best possible performance	Depends on product type and application method but similar to PFAS waxes. For hot wax – 10-15g per set. For liquid wax – 0.5g per set
	Storage, shelf-life	~3 years
	Frequency of wax replacement	No different to PFAS waxes. Depends on the amount of skiing performed by the user.
Availability:	Volume manufactured, sold and used in the EU	Data on volume considered confidential by manufacturers. No issues with supply identified
	Production capacity in the EU	No data but no issues with supply identified
Risks:	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	No data
	PBT of vPvB properties	Substances in the product do not meet the PBT/vPvB criteria
	Other environmental risk concern	No data
	Conclusion on risks	As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks with hydrocarbon and paraffin waxes are considered lower than the risks of PFAS-based products.

8. Economic impacts in case of a full PFAS ban

The available evidence suggests that the impacts of the proposed restriction are likely small.
According to interviews with some of the main ski wax suppliers, PFAS-based ski waxes are mainly used for competitions, while recreational skiers and athletes during training already use fluorine-free alternatives. FIS, the main international skiing federation has already declared a ban on fluorinated ski waxes in all of its competitions from the 2021/2022 season. This suggests that the vast majority of use of PFAS-based ski waxes will likely be eliminated regardless of the proposed restriction, and so the potential impacts of a proposed restriction are very limited. However, a restriction on the manufacture and placing on the market of PFAS-based ski wax, in addition to use, would increase the chances that such ski wax is phased out completely and not used illegally in competitions. This is important as exposure to PFAS during application of PFAS-based ski wax may be very high and associated with health effects.
The assessment has also shown that substitution costs and transition (organisational or technical) costs for transitioning from PFAS-based waxes to fluorine-free alternatives are expected to be small (Table 9). Most suppliers, professional users (service providers offering ski waxing) and end users (skiers) already offer/use fluorine-free alternatives. Therefore, no additional testing[32], new equipment, training occupational safety measures would be required to enable the use of alternatives and costs to regulators to enforce the restriction on this niche use would likely be small.

Table 9. Price ranges and averages of reviewed ski waxes

	Average	Minimum	Maximum
PFAS-based ski waxes	2.35 €/g	0.23 €/g	6.33 €/g
Fluorine-free alternatives	0.23 €/g	0.07 €/g	1.13 €/g

Note: the average values are simply an average across all of the listed products; the values are not weighted according to market share (due to lack of data).

There is ongoing research and development to further improve the performance of skis without PFAS-based waxes. However, it is not clear that the associated cost could be considered a necessary cost of the proposed restriction, given that most skiers already use fluorine-free alternatives and athletes in competitions would all be subject to the same potential ban on PFAS-based waxes.
The main potential economic impact that has been identified is related to small ski wax manufacturers. Despite the niche nature of this use, stakeholder interviews suggested that small ski wax manufacturers exist that only offer PFAS-based ski waxes and are likely not yet ready to transition to fluorine-free alternatives.

It has been noted that alternatives can provide the required functionality, but in certain situations the use of alternatives can result in lower performance. The importance of such functionality loss depends among other things on the type of ski sport and on the snow condition. As a result of restricting the use of PFAS-based waxes, the overall speed of ski competitions may be reduced but athletes would

[32] Interview with Swix

compete on a level playing field following a PFAS ban. Given the potential advantage athletes would have in illegally using PFAS-based waxes, it is necessary to develop a testing methodology to verify the presence of PFAS before the competition, which would come as a development cost. While waiting for the testing technology, FIS, the main international ski federation, has already decided to ban fluorinated waxes from competitions. Hence, development costs would not be a direct cost of a REACH restriction with regards to FIS competitions. A potential application cost as a result of the restriction would however be incurred for non-FIS lower-level competitions, that however have a lower likelihood of cheating.

9. Methods used & uncertainties

The collection of data that underpins the analysis and results of this study has comprised three specific aspects:

1) Call for evidence

A call for evidence as part of the ongoing restriction proposal has been carried out by the dossier submitter in the period May to July 2020, and relevant information received is included in this report. The survey questions provided in this consultation yielded useful information, specifically on the uses of PFAS, as well as the alternatives in ski wax products that feeds directly into this project.

2) Literature review

The identification, assessment and dissemination of key information from the existing literature was conducted. Information was primarily collected from the public domain: e.g. scientific papers, reports, ECHA's databases and web pages. The identification of sources of information was carried out through a systematic web search combined with a literature search with the use of search tools like google, google scholar, web of science or others.
The content of the selected literature sources was reviewed in detail, in order to extract relevant evidence.

3) Stakeholder consultation

While the primary source of information underlying this analysis was expected to be from the call for evidence, there remained considerable data gaps. Additional stakeholder consultation was intended to fill key data gaps and this consultation was undertaken primarily in October and November 2020.

Assumptions, uncertainties and sensitivities

There are a few assumptions and uncertainties that have been applied in this study that may affect the impact assessment. In particular, the economic and environmental impact assessment may be affected by the uncertainty on the tonnage of fluorinated ski wax used and produced within the EEA, on which stakeholders and the published literature are in some disagreement.
In addition, the economic and human impact assessment could be affected by the estimated number of skiers using fluorinated wax, which remains an extrapolation. This number may be overestimated as it exceeds the number of athletes licensed with FIS. However, there are many skiers participating in competitions that are not FIS licensed. Similarly, the total number of people involved in the waxing of skis with PFAS-based ski waxes is highly uncertain.

Finally, there are various assumptions used in both the estimated historical and projected future use of PFAS-based ski-waxes. These are described in the section in which emissions are estimated. The estimated emissions should therefore be taken as illustrative rather than exact.

The above conclusions are subject to a range of assumptions and uncertainties. Assumptions have been made based on the results of other sections and are discussed in more detail within those sections.