REFRIGERANT EMISSION TECHNICAL WORKING GROUP

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May 13th, 2026

Version 2

SEAC draft opinion: summary (page 55)

- ***Fluorinated gases used in HVACR systems in transport vehicles:***
  - Dossier Submitter's proposal:
    - A **5 year + 18 months** derogation for the use of PFAS as refrigerants in mobile air conditioning (MAC) and heat pump systems in **light duty electrical vehicles**.
    - A **12 year + 18 months** derogation for the use of PFAS as refrigerants in mobile air conditioning (MAC) and heat pump systems in **all vehicles, excluding light duty electrical vehicles**.
  - SEAC's view:
    - SEAC concluded that there is sufficiently strong evidence for low substitution potential at entry into force for the use of PFAS as refrigerants in mobile air conditioning (MAC) and heat pump systems for all transport vehicles.
    - SEAC notes that costs related to a ban of this use are likely not insignificant.
    - SEAC notes that according to RAC, the derogations as proposed by the Dossier Submitter would lead to additional emissions of 198 089 t over 30 years.

Due to the above considerations SEAC cannot conclude on a derogation for use of PFAS as refrigerants in mobile air conditioning (MAC) and heat pump systems.

SEAC acknowledges the low substitution potential but wishes to emphasize again the high additional emissions resulting from the above-named derogations and notes that RAC proposes to require additional risk management measures to ensure PFAS emissions are minimised along all life cycle stages in case the derogations are supported by the decision maker. The costs associated with such additional risk management measures are, however, unknown to SEAC. Although RAC would recommend pursuing RO3 rather than RO2, SEAC cannot conclude whether a ban of PFAS in the transport sector is more proportionate with or without the above-named use specific derogations and how additional risk management measures under RO3 affect this conclusion.

https://echa.europa.eu/documents/10162/3e58abe2-ed98-9667-29ee-6ec5005a3506

Lifecycle emissions

Lifecycle emissions – high level overview (all working groups)

			Baseline - status quo			Proposed regulatory measures		
Annual refrigerant emissions [MT]	**2021**	**2026**	**2030**	**2050**	**2030-2050**	**2030**	**2050**	**2030-2050**
Production (not in EU)	-	-	-	-	-	-	-	-
Logistics incl. downpack (~0.01%)	2	2	3	3	63	3	2	45
First fill	8	9	9	9	192	9	9	192
Design architecture	11’652	11’570	11’505	8’851	218’892	11’307	4’726	132’612
Accidents	221	246	301	257	6’184	301	257	6’184
Repair	1’959	2’186	2’966	4’310	83’774	1’928	708	26’544
Service (recovery rate, # services)	1’110	1’626	2’595	1’804	58’416	1’770	341	19’515
End of life	27	34	48	119	1’800	48	40	816
Refrigerant recycling (~0.01%)	0	0	0	0	1	0	0	1
Total	14’979	15’674	17’427	15’353		15’366	6’083	
% change annually (vs 2050 baseline)						-12%	**-60%**	
% change annually vs 2026							**-61%**	
Total 2030-2050 emissions					369’322			185’909
Total reduction versus baseline (2030-2050)								**-50%**

Regulatory measures to reduce refrigerant emissions as condition of use – summary (all working groups)

<table>
<tr><th rowspan="2">Workstream</th><th rowspan="2">Category</th><th rowspan="2">Measure (Entry Into Force, Jan 1st, 2030)</th><th colspan="3">New vehicle production</th><th colspan="2">Existing vehicles</th><th rowspan="2">Additional cost in € / vehicle lifetime</th><th rowspan="2">Total cost [Euro MM]</th><th rowspan="2">Emissions saved</th><th rowspan="2">Cost/kg emission saved</th></tr>
<tr><th>ICE</th><th>Hybrid</th><th>BEV</th><th>ICE/Hybrid</th><th>BEV</th></tr>
<tr><td rowspan="2">Design architecture</td><td rowspan="2">Design leak rates</td><td>Maximum design leak rates for new vehicle registrations, linear reduction (g/vehicle):
ICE: 7.6g (2030) to 7.4g (2034)
BEV: 7.5g (2030) to 6.5g (2050)</td><td>Yes</td><td>Yes</td><td>Yes</td><td>-</td><td>-</td><td>-</td><td rowspan="7">€0 as increased maintenance improves AC component life with 30-50% **</td><td rowspan="7">141k MT</td><td rowspan="7">€ 0/kg due to the increased AC component life expectation, **</td></tr>
<tr><td>First fill and retrofit of AC service port caps (during service) replacement with a tethered caps</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td><td><1</td></tr>
<tr><td rowspan="5">Repair, accidents</td><td>Design robustness</td><td>Compliance to new condenser robustness design specification, similar to SAE J2842 (to be developed)</td><td>Yes</td><td>Yes</td><td>Yes</td><td>-</td><td>-</td><td><20</td></tr>
<tr><td rowspan="3">Inspection</td><td>Obligation for UV Dye inclusion, SAE J2297</td><td>First fill</td><td>First fill</td><td>First fill</td><td>At service</td><td>At service</td><td><1</td></tr>
<tr><td>Compulsory for a major service (e.g. oil/break fluid change) every ~2 years: AC check & visual inspection*** (UV dye) & requirement to repair, AC condenser water cleaning & debris clearing***. Inspection certificate issue for road worthiness test inspection.</td><td>-</td><td>-</td><td>-</td><td>Yes</td><td>Yes</td><td rowspan="2"><200</td></tr>
<tr><td>Verify the AC check & visual inspection and condenser cleaning have been carried out in the last two years during road worthiness testing (verify inspection certificate).</td><td>Test at factory</td><td>Test at factory</td><td>Test at factory</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Ongoing monitoring</td><td>AC system health monitoring, according to industry design specification (to be developed)</td><td>Yes</td><td>Yes</td><td>Yes</td><td>-</td><td>-</td><td><5</td></tr>
<tr><td>Service / End of Life</td><td>Service/recovery machines</td><td>Recovery, Recycling and Re-charge machine, compliance to SAE J2788 & J2843, 40g to ensure repair</td><td colspan="5">Yes, all recovery and RRR machines in EU</td><td>-</td><td>€89MM</td><td>38k MT</td><td>€3/kg</td></tr>
<tr><td rowspan="2">End of life</td><td>Traceability</td><td>Requirement for full refrigerant traceability, from first fill, service, end of life, recovery & recycle/reclaim. Requirement for recovery and recycling/reclaim at end of life (EPR)</td><td colspan="5">Yes, management via refrigerant digital log-book</td><td rowspan="2">-</td><td rowspan="2">€8.6MM</td><td rowspan="2">983 MT</td><td rowspan="2">€9/kg</td></tr>
<tr><td>Compliance with good working practices</td><td>Registration and audit of authorized treatment facilities, each country requires a registration and audit system to ensure compliance with good working practices</td><td colspan="5">ICE/Hybrid/BEV</td></tr>
</table>

** < €200 / existing vehicle: 259*200 = €51'800 MM; and < €27 / new build vehicle: 10.4*21*27 = €5'897 MM. Total: €57'697 MM. Cost per kg emission saved (direct equivalent cost impact): €57'697 MM / 141k MT = €409/kg

*** Inspection / condenser cleaning where components are easily accessible. Where components are not accessible without extensive part removal, relying on AC Health monitoring is compulsory. Condenser cleaning involves a simple low pressure water spray, carefully applied not to damage the condenser fins.

Refrigerant emissions from design architecture

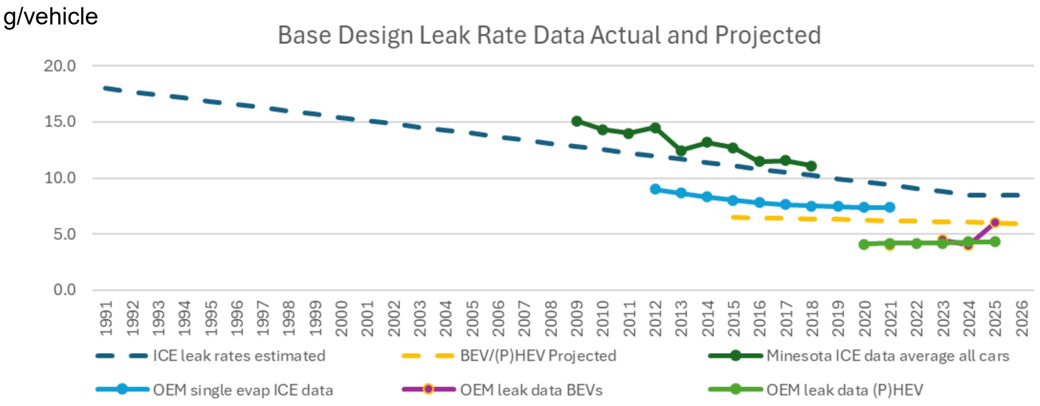
Data set 1: Refrigerant emissions from the inherent design architecture

Data set 1: describes two main areas impacting the AC system architecture

- **Initial design leak rate** of the refrigerant due to the inherent design architecture (first 3 years)
- **Degeneration factor** (aging of the system) as seals wear out, fittings become loose due to vibrations, etc.

Data set 1: shows industry has reduced initial design leak rates significantly

- Data set 1 comprises of industry general refrigerant emission data (Minnesota state*) and single OEM data (assumed to be best in class for ICE, PHEV and BEV)
- The 1991 design leak rate of 18g/yr is likely given single O-rings and non-barrier hose material
- Improved sealing technology over time and the increased use of electric compressors (no lip seal) account for reduced leak rates out to 2050 (see BEV/PHEV projection)
- The design leak rate (SAE J2727) is linearly projected and used to calculate aged leak rate which increase over time.



*https://www.pca.state.mn.us/business-with-us/high-global-warming-potential-greenhouse-gases#:~:text=Leakage%20from%20vehicle%20air%20conditioners,t%20included%20in%20the%20requirement.

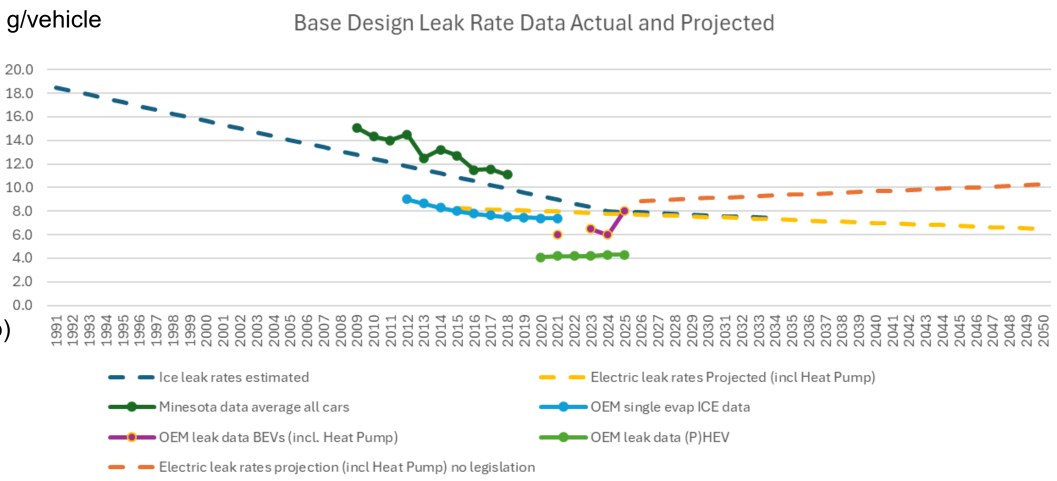
Measure 1: set maximum design leak rates to allow whole industry to invest in lower design refrigerant leak rates

OEMs make different design choices that impact refrigerant emissions

- Different design architectures show a difference in refrigerant emission rates e.g. (P)HEV versus BEV versus ICE
- Different OEMs make different investment choices (reducing refrigerant emissions has a cost impact) e.g. OEM ICE data shows lower refrigerant g/vehicle emissions compared to industry ICE Minesota data

Measure 1:

- Set maximum design leak rates for new vehicle type certification to allow the whole industry to invest in lower initial design refrigerant leak rates
- Cost pressure and lack of legislation could reverse the trend of lower refrigerant design leak rates (e.g. beyond Minnesota state* levels, e.g. 10.25g/r for BEV incl Heat Pump)
- Set targets such that the industry can catch up to best in class today by 2050



*https://www.pca.state.mn.us/business-with-us/high-global-warming-potential-greenhouse-gases#:~:text=Leakage%20from%20vehicle%20air%20conditioners,t%20included%20in%20the%20requirement.

Data set 2: AC system degeneration over time
Measure 2 & 3: Ensure AC system is running in optimal conditions

Data set 2: Most ICE vehicles without regular AC maintenance, no condenser cleaning, no AC health monitoring, etc. require an annual top-up at age 21-22

- Without preventative maintenance, no compulsory leak-checks, uncertain AC "health" condition
- ~25% charge size loss / year, ~125g/vehicle per year
- **Equates to degeneration factor of 14% / year for ICE (9% for BEV),** starting after warranty period (year 4)

Measure 2: mandatory repair of the AC system in case a leak is detected during service (service machine vacuum test)
This means that underlying leaks are systematically eliminated during service (assumed not common practice today). The mandatory repair assumption **reduces the total accumulative leak rate once after repair by 25%** (in case the leak rate/year is >40g/year) and continuing to increase afterwards.

Measure 3: Ensure the AC system is running in optimal conditions (basic check, no visual leaks, troubleshooting in case of low refrigerant level); **increase component life due to optimal AC running conditions (30-50%)**

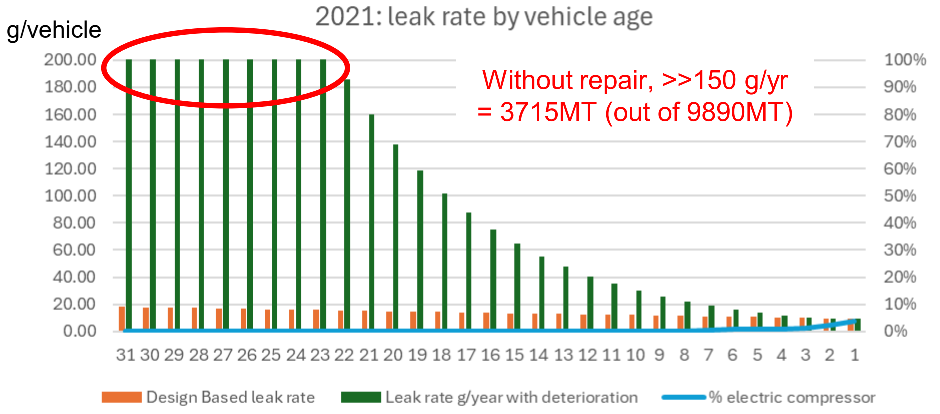
- Compulsory check / inspection / condenser washing / check for debris during major service and inspection road worthiness testing (please refer to Measure 1 in the repair section)
- Increased condenser design robustness, Compulsory AC health monitoring, tethered service port caps
- Reduction of the **degeneration factor for ICE to 11% and BEV to 7% post 2030**

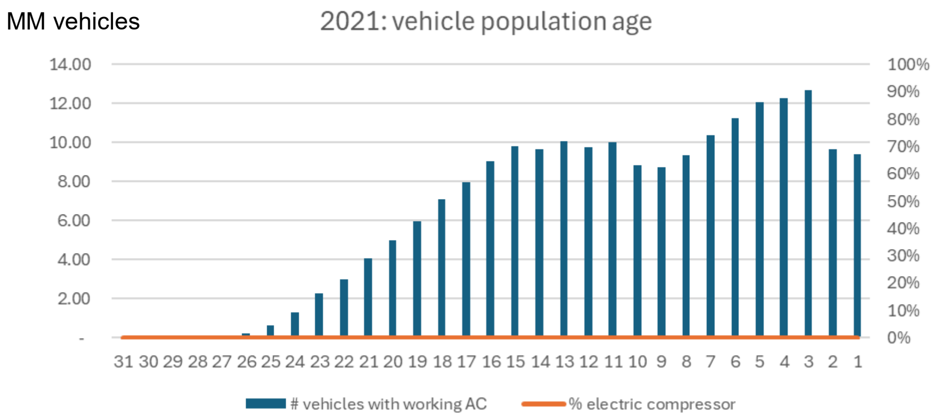
Modeled design refrigerant leak rates and degeneration factor

	Refrigerant leak rate assumptions*						
	BEV-PHEV design leak rate g/vehicle		Degeneration factor ICE / EV-PHEV				
Modeled scenario	**2015**	**2050**	**2030**	**2035**	**2040**	**2045**	**2050**
Status quo, lowest cost as no regulatory requirements	8.25	10.25	14% / 9%	14% / 9%	14% / 9%	14% / 9%	14% / 9%
Max leak rate legislation implementation, 14% degeneration	8.25	6.5	14% / 9%	14% / 9%	14% / 9%	14% / 9%	14% / 9%
Regulatory requirements, leak checks, repair, max design leak rates, etc.	8.25	6.5	11% / 7%	11% / 7%	11% / 7%	11% / 7%	11% / 7%

* Using the design architecture emission model, calculations for 2021, 2035 and 2050 where 2030, 2040 and 2045 are determined via linear interpolation.

Modeling assumption for 2021: baseline scenario (conservative assumption)

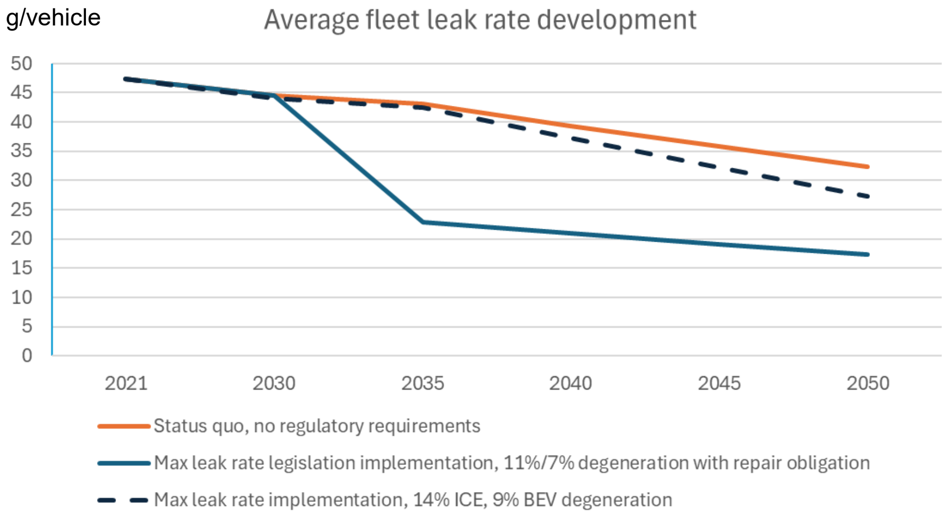




Assumptions:

- Leak rates deteriorate (increase) over time; data set 2 shows that most vehicles over 21-22 years old with functional AC systems will require an annual top-up (= 14% annual degradation after year 3)
- For the very high leak rate vehicles (>150g/yr) with age >22 a conservative assumption has been made as:
  - Unlikely all these vehicles will receive a top-up each year (economic feasibility?)
  - Some of these vehicles will have been repaired showing lower leak rates
- Very low % of electric compressors
- Each year, EU exports ~5M vehicles between the age of 10-15 years

Modeling assumption post 2030: degeneration rate reduction from 14% to 11% for ICE and from 9% to 7% for BEV-PHEV



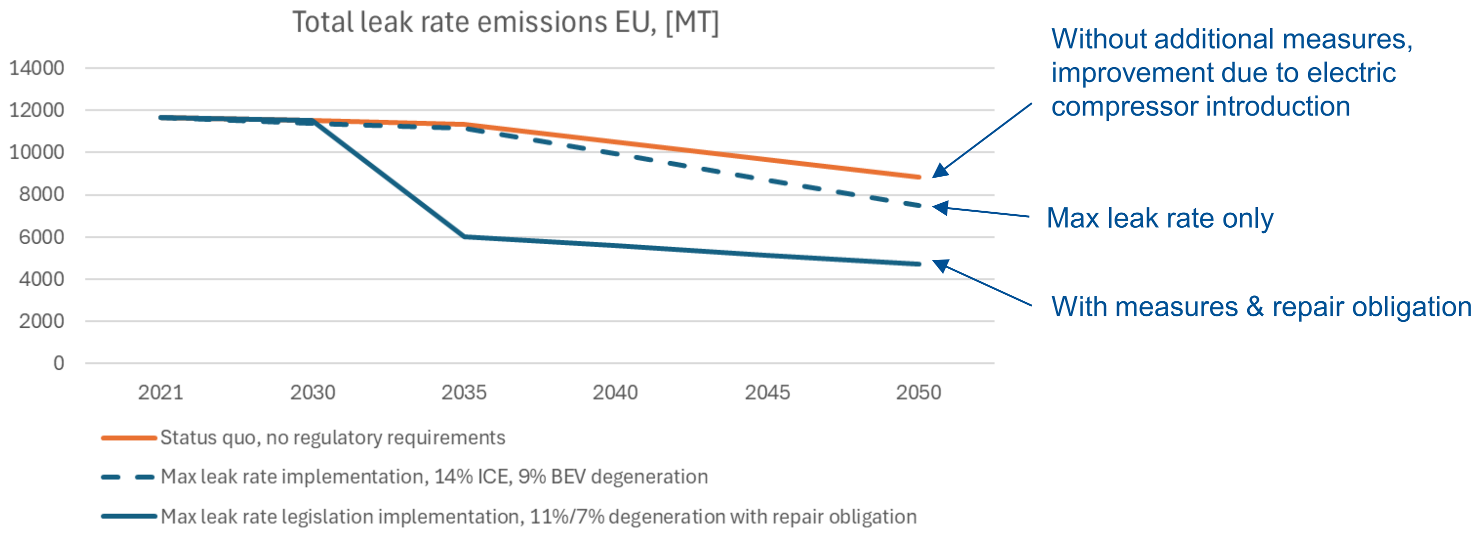
Assumptions*:

- Assuming all vehicles are well maintained (obligation)
- Introduction (21 years) of additional measures:
    - Compulsory inspection / condenser washing / check for debris during major service & inspection road worthiness
    - Increased condenser design robustness, Compulsory AC health monitoring, tethered service port caps
- >15 years of ~100% electric compressor usage during new build

Overall degeneration leak rate reduction from ~45g/vehicle in 2021 to ~<20g/vehicle by 2050

* Using the design architecture emission model, calculations for 2021, 2035 and 2050 where 2030, 2040 and 2045 are determined via linear interpolation.

Emission profile modelling*
Refrigerant emissions from design architecture



* Using the design architecture emission model, calculations for 2021, 2035 and 2050 where 2030, 2040 and 2045 are determined via linear interpolation.

2030-2050 overall refrigerant emission reduction versus “without measures”~40%

Accidents

Data set 1: Driving aids – legislation in EU & implementation timelines

- **Autonomous Emergency Braking (AEB):** Detects potential forward collisions with vehicles, pedestrians, and cyclists, issuing warnings and automatically braking if the driver doesn't respond.
- Intelligent Speed Assistance (**ISA**): Helps drivers adhere to speed limits by controlling vehicle speed, with driver override available.
- Driver Drowsiness and Attention Warning (DDAW): Monitors driver attention and warns of fatigue or distraction.
- **Emergency Lane Keeping Systems (ELKS):** Assists in preventing unintentional lane departures.
- Reversing Detection Systems (**REV**): Warns of obstacles behind the vehicle, crucial for safety.

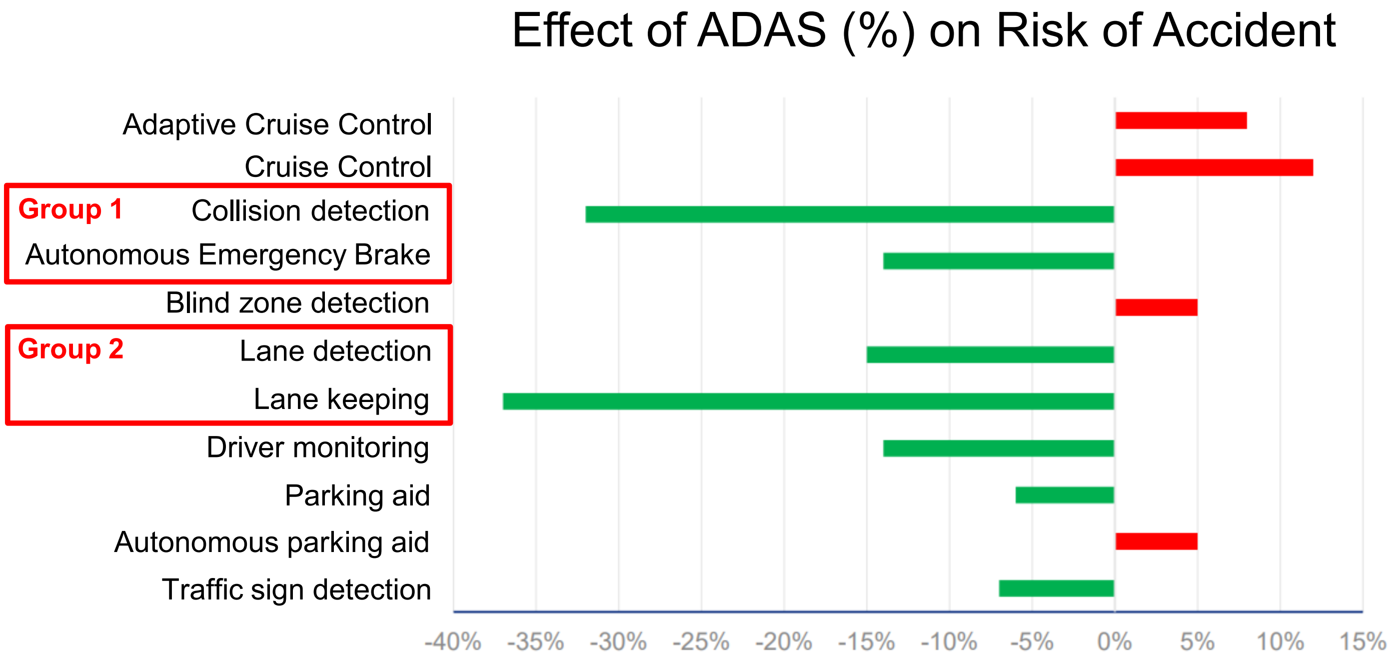
- Implementation Timeline (**GSR 2019/2144**):
  - **July 2022: New type approvals (M1/N1 vehicles) must have AEB (car-to-car) and DDAW.**
  - July 2024: AEB for pedestrians/cyclists mandatory for new types; **ELKS** & DDAW for buses/trucks.
  - July 2026: AEB (pedestrian/cyclist) mandatory for all new commercial vehicles; ISA for all new vehicles.

- Modelling assumptions: implementation following legislation requirements

Legislation is already in place that will help to drive down refrigerant emissions due to accidents

Data set 2: Effectiveness of driving aids

(Association of Insurance Companies, Netherlands)



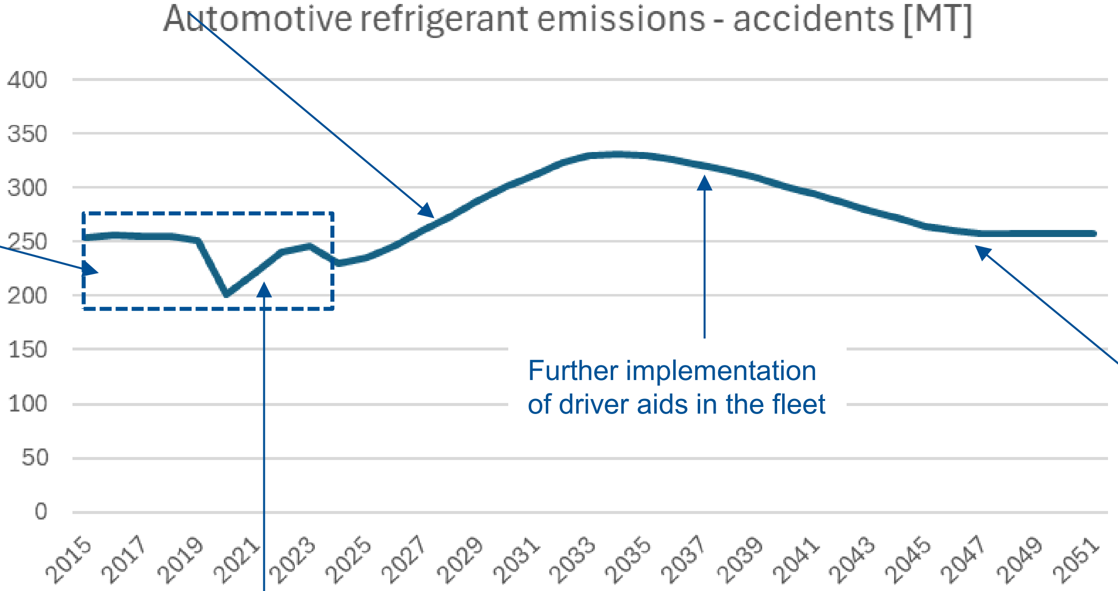
A total of **692,951** private passenger cars were included in the dataset, of which **14.9%** were involved in at least one accident between 2015 and 2022. Within this group of accidents, **1.5%** occurred in poor weather conditions on 81 days with code red and code orange warnings in the Netherlands.

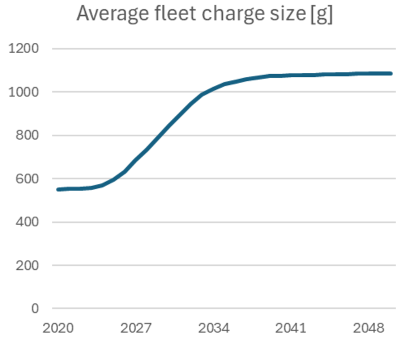
https://swov.nl/sites/default/files/bestanden/downloads/R-2024-16.pdf
https://www.verzekeraars.nl/media/xepdraxc/samenvatting-onderzoek_geavanceerde-rijhulpsystemen-adas-verkeersveiligheid-en-co2-uitstoot_02-2024_nederlands.pdf

Emission profile modelling
Accidents

Increase due to charge size increase from 550g to 1100g due to BEV increase

2015-2023 accident data





Charge size stabilizes at 1100g/vehicle

2022 first introduction of Automatic Breaking AEB, Group 1

2030-2050 overall refrigerant emission reduction already “baked-in” due to existing legislation

Repair

Data set 1: Garage: non-accident-related service data (average vehicle age 11.3)

- Data set: 250k services (across France) carried out in 2024, charge size ~550g
  - 70%, AC does not work
    - 50% Leak detected that needs repair
    - 20% AC break down, component failure, requires work, compressor change, other component change
  - 30% preventative maintenance, just requires top up, leak check is passed
- In case of leak or break down
  - 70% condenser issue
  - 13% compressor issue
  - 17% hoses, other issues
- For 40% leak or break down cases, no refrigerant left
  - ~80% related to condenser issue
  - ~20% related to other issues

Total services 250k***	Work required	Refrigerant loss, EU [MT], 2024
30%	Topup, no leak	366**
70%	Condenser failure (70%)	**1469**
	Compressor issue (13%)	256
	Hoses, other issues (17%)	290
	Sub total	**2016**
	Grand total	**2382**
Refrigerant consumption	R-134a + R-1234yf actuals	**2380**

- Average service without full charge loss*: **125g (on 550g charge size, 22.75% of total)**

Condenser failure equates to ~63% of total service emissions

* Calculated based on # services with full charge loss as part of total and actual refrigerant consumption, ** For reference only, topup volumes considered as part of design architecture.
*** Table shows the refrigerant consumption for the EU based on the 250k services (scaled by the vehicle population in France).

Data set 1:
Garage: non-accident-related service data (average vehicle age~11.3)

Further insights:

- **AC Issues:** In 70% of cases involving AC problems, the cause is a leak in the condenser or its circuit (pipes, connections, etc.). These vehicles are typically found to be mostly empty of charge.
- **Condenser Issues: Micro-leaks***** caused by gravel or road debris are the most common issue.
- **Breakdown Mapping: Vehicle design and type are more significant factors than age.** Some newer R1234yf vehicles are more exposed due to lower circuit capacities (approximately 100g less).
- **Service caps missing: Estimated to happen for <20% of the vehicles entering service.** During servicing, technicians often place them on the windshield cowl or near the engine compartment, and they can occasionally be forgotten or fall into hard-to-reach areas.

Following data regarding average vehicle age for servicing:

- R-134a vehicles: 14.4 years, 56% of services**
- R-1234yf vehicles: 7.3 years, 44% of services**
- **IPTV: 18.4 (at average of 11.3 years)***

*250k services (out of 6.66M vehicles) in total of which 70% have AC problems of which 70% have condenser issues
= (250,000 x 0.7 x 0.7) / 6660
** Aligns to the estimated R-1234yf / R-134a market ratio based on EU average
*** Cause of micro-leak may be difficult to assess (e.g. corrosion vs debris)

Data set 2:
Tier 1 Warranty: non-accident-related service data

Based on Tier 1 warranty data:

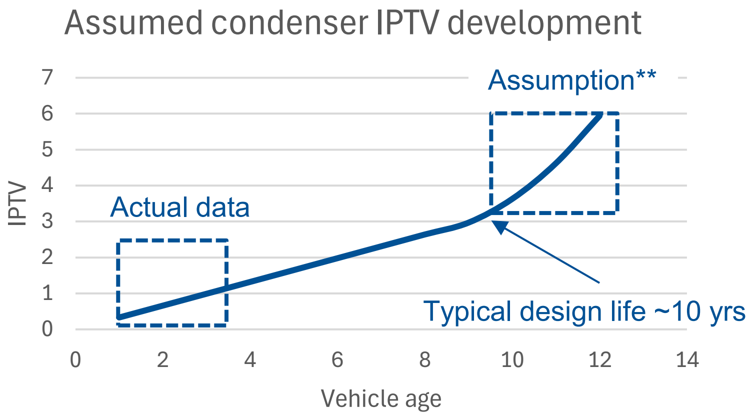
- IPTV condenser:
  - Year 1: 0.3 Total
  - Year 3: 1.0 Total
  - Year 3: ~0.1 Identified as "damage" to condenser which can include stone damage (NA)

- IPTV other components are lower

- IPTV warranty condenser includes (~typical):
  - Overall corrosion protection
  - Increased leading edge thickness*

- Different condenser design specifications per OEM (can vary significantly)

- **IPTV at year 11.3 ~5.0** (assuming non-linear increase beyond 10 years of age**)



* For certain Tier 1 designs, folded tube and center condensers, went to double thickness nose starting around 2012 which served as higher protection against stone damage.

**no data/information regarding failure leak rate or damage at 10-15 years

Data set 2:
Tier 1 Warranty: non-accident-related service data

Other observations

- **Corrosion will certainly play a significant role** particularly in certain environments, for instance high road salt use areas, by the oceans, etc. (typically the case for Western Europe with **frequent freeze-thaw cycles** during the winter)

- Study concluded that stone damage to condensers was generally to **specific vehicles and a redesign of cooling module**. Added stone guards, is advised more so than condenser change.

- Use of a radiator in front of the condenser such as a Low Temperature Radiator in EVs will result in some stone damage to this component and less to the Condenser

Potential measures to reduce refrigerant emissions (1/3)

<u>Measure 1:</u> Increased AC system check & leak inspection**

- **Include UV dye (SAE J2297 standard),** very low cost, <1 Eur/vehicle:
  - First fill, OEM level (many already do like e.g. all NA OEMs, etc.)
  - Existing vehicles (without UV dye), if AC parts are replaced e.g. desiccant (that includes UV dye)
  - During RRR machine vehicle service, introduce UV dye during the final charging phase of the service
- **Requirement to perform basic AC check and clean condenser** (simple low pressure water spray, carefully applied to prevent fin damage) and **check for debris blockage and UV dye evidence of leaks** (requirement to repair) at major car service like oil / break fluid change would help significantly and doesn't cost much (only takes a few minutes).
- **Road worthiness testing, visual check for UV dye evidence for leaks** (garage certificate of AC visual inspection)

<u>Measure 2:</u> Condenser design robustness specification

- Corrosion resistance and stone damage are major drivers for the condenser issues/repairs (IPTV 18.4). OEM warranty data shows (IPTV = 0.3, 1 year, IPTV = 1.0, 3 years, IPTV stone impingement = 0.1, 1 year). Industry condenser design specification does not exist, hence corrosion resistance and robustness against stone damage varies significantly.
  - **This requires a condenser "SAE industry style" standard** (e.g. similar to SAE J2842) to push overall design >10 years that defines:
    - Define aspects covering corrosion resistance:
      - Brazing quality assurance requirements
      - Zinc arc spray surface treatment
      - Careful design of the seal around the condenser that prevents the air from going around the condenser. Material selection here around the condenser is key to minimize the corrosion risk of the condenser*.
    - Define aspects covering robustness against damage:
      - **Double nose design (maximum practical thickness)** at the leading edge (stone guards may be considered in addition)

*The seal material and design along the bottom and sides of the condenser should be designed as best possible not to trap debris causing extended wetness and accelerating corrosion

** Inspection / condenser cleaning where components are easily accessible. Where components are not accessible without extensive part removal, relying on AC Health monitoring is compulsory

Potential measures to reduce refrigerant emissions (2/3)

<u>Measure 3:</u> AC Health monitoring, requires development of a "SAE standard" to functionally define:

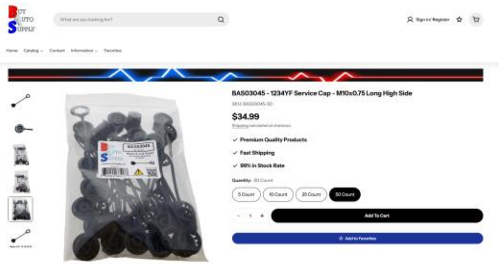
- The HVAC system should continuously measure:
  - Ambient temperature;
  - Evaporator inlet temperature;
  - Cabin outlet temperature (interior cabin temperature);
  - Battery coolant temperature (if applicable);
  - Refrigerant pressure transducer;
  - The status of the A/C and/or heater ON/OFF switch on the cabin control panel;
  - The temperature selected by the rotary dial on the driver's control panel.
- And monitor for unusual behavior (that would trigger a service notification):
  - Indication of condenser blockage, filter blockage
  - Refrigerant pressure (versus table with expected pressure at certain ambient temperature at start)
  - Compressor power draw to achieve requested cabin temperature
  - Ability to achieve the requested cabin temperature

- **Goal:**
  - **Set a criteria for servicing** to increase AC equipment life expectation and reduce risk of major event leading to a full refrigerant charge release (requires software / tables & calibration to be developed per OEM)

Potential measures to reduce refrigerant emissions (3/3)

<u>Measure 4:</u> Obligation to use tethered closure caps

- Field experience has shown that AC closure caps are not always fitted after a service is completed (the cap may get lost, forgotten, could fall into the engine bay), up to 20% of the vehicles entering for a service
- SAE-J3267, January 2022, Automotive AC Service Ports Task Force Field Survey Results. Main conclusion: Missing service port caps are common allowing debris and corrosion. The older the vehicle, the more likely it is to be missing caps.
- The cap is an integral part of the port*:
  - Security of this cap is essential to the leak integrity of the port
  - These caps include a rubber seal around the port mouth (primary seal, otherwise a small amount of refrigerant will leak over time)
  - SAE J639 requires caps be used for charge ports and suggest that these caps be tethered to prevent loss
  - Mandate use of <u>tethered</u> closure caps (experience shows significant lower risk of missing cap if tethered)
  - Used during first fill
  - Retrofit any vehicle coming in for visual AC inspection or AC service
- Visually check if AC port cap is fitted during roadworthiness testing
- Total emissions: 20% of 250M vehicles, 5g/year leak due to missing caps = 250MT/yr
- A tethered cap is very low in cost (< 1Eur/vehicle) and takes little time to fit



https://www.buyautosupply.com/products/bas03045-1234yf-service-cap-m10x0-75-long-high-side?variant=43328017170525

* https://schrader-pacific.com/wp-content/uploads/AC-Valve-Manual.pdf

** On a trial with 8 vehicles, 13 out of 16 caps showed detectable refrigerant leaking when caps were removed and the engine was running. These leaks all disappeared once caps were appropriately fitted.
https://www.autoacforum.com/viewtopic.php?t=15043

Typical refrigerant sensitivity detection level of a sniffer is ~5g/year equivalent leak (hand- held device, medium sensitivity)
https://climalife.com/leak-detection-for-refrigeration-systems-a-major-challenge-for-the-21st-century/

Modelling assumptions (1/2)

Measure 1**: AC check & visual inspection, AC cleaning with water / debris clearing during each regular major service incl. UV dye (requirement to repair)

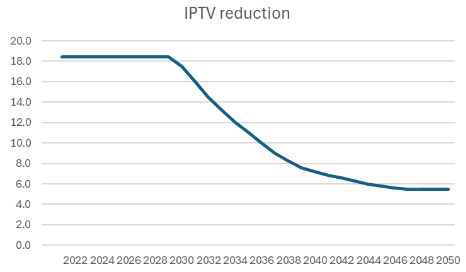
- Average **charge loss can be limited to 125g max or ~25% of charge** (of cases identified in 2024 as full charge loss)
- Full charge losses will still happen, but are more aligned with warranty data (e.g. 0.1 IPTV relating to stone damage results in 26k incidents in EU/year resulting in <15MT emissions)
- Cost impact: <200 Euro/vehicle during lifetime

Measure 2: Inspections, including road worthiness, requirement to repair to pass the test

- Overall early detection of tiny leaks, "pinhole leaks" before loosing significant refrigerant and will prevent structural failures, reduce wear and tear. **Assuming an overall 35% leak reduction.**
  - Regular, proactive inspection of your AC unit can reduce refrigerant leaks and associated loss by 30% to 50% annually, according to industry experts and data referenced by the USA Department of Energy*
  - Verify via inspection certificate obtained during last AC visual inspection

Measure 3: With "SAE style" condenser design standard

- Over time (post 2030), **reduce IPTV from 18.4 to ~5** (at average 11.3-year age when full fleet conversion has been completed).
- Combined impact of measure 1 & 2 driving IPTV to ~5
- Cost impact: <20 Euro/vehicle during lifetime



* https://facilio.com/blog/hvac-refrigerant-leak-rate-calculation/#:~:text=Preventive%20maintenance%20is%20your%20first,and%20repair%20standards%20are%20met.

** Inspection / condenser cleaning where components are easily accessible. Where components are not accessible without extensive part removal, relying on AC Health monitoring is compulsory. Condenser cleaning involves a simple low pressure water spray, carefully applied not to damage the condenser fins.

Modelling assumptions (2/2)

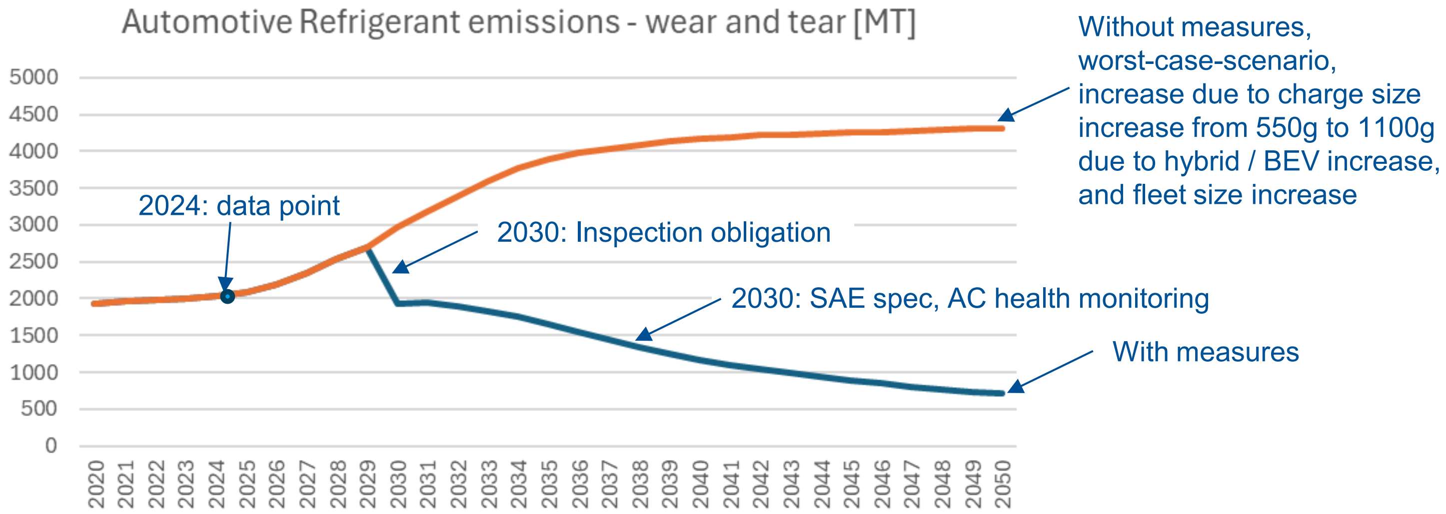
Measure 4: AC health monitoring, “SAE style” standard

- Notice AC performance deterioration earlier
- Prevent more significant losses of refrigerant (via service notification)
- Doesn’t completely prevent loss of charge, but reduces the risk of full charge losses significantly (vs 2024 data):
  - On average, **charge loss can be limited to 125g max or ~25% of charge** (of cases identified in 2024 as full charge loss)
  - Full charge losses still happen, but are more aligned with warranty data (e.g. 0.1 IPTV relating to stone damage results in 26k incidents in EU/year resulting in <15MT emissions)
- Cost impact: ~<5 Euro/vehicle during lifetime

Measure 5: tethered AC system caps

- Madate tethered cap
- Contributes to Assuming an overall 35% leak reduction (measure 1).
- Increases the leak integrity of the vehicle charge port
  - First fill
  - Retrofit during AC service
- Check during roadworthiness testing that caps are fitted (to pass the test)
- Cost impact: <1 Euro/vehicle during lifetime

Emission profile modelling
Measures to reduce component failure



2030-2050 overall refrigerant emission reduction versus "without measures"~65-70%

Services

Data set 1: RRR Machines Leakage Rates

An A/C **RRR machine (Recover, Recycle, Recharge)** is an automotive service unit designed to remove old refrigerant, clean it, and refill vehicle A/C systems to precise manufacturer specifications. These units automate the handling of R134a or R1234yf refrigerants, ensuring SAE compliance in the US, vacuum leaks checks, and accurate oil recharging.

- Recovery: The machine extracts refrigerant, filtering it and separating oil, with recovery efficiencies often exceeding 95% (United States per SAE J2788).
- Recycle/Vacuum: The machine cleans the refrigerant and creates a vacuum in the system to remove moisture and contaminants.
- Recharge: The system is refilled with the precise amount of refrigerant and oil, often within ±0.5 oz of accuracy.

RRR Machine Recovery Rates (current state)

- 95% recovery: US RRR machines, SAE J2788 standard
- 80% recovery: 10% of EU machines
- 95% recovery: 90% of EU machines

During this process, meetings were conducted with 3 well-known, reputable RRR machine suppliers in both the EU & US. During these discussions, it was learned that SAE International, in the USA, has standards where the RRR machines have to recover at least 95% of the refrigerant, per SAE J2788, of the refrigerant in the system. The EU doesn't have regulations for RRR machines, and the ones used in this region recover only approximately 80% of the refrigerant. It is currently estimated that ~90% of the service machines in the EU can meet a recovery efficiency exceeding 95% with the remaining machines achieving ~80% recovery. As machines with lower recovery rate are significantly cheaper, this part of the market is expected to more than double by 2030 (hence to >20%).

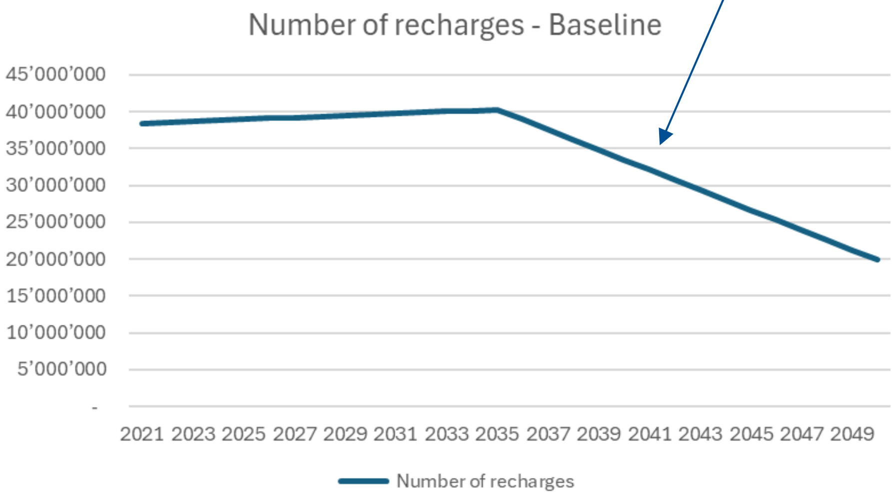
Calculation of baseline number of services and related emissions without the implementation of legislation

Evolution of the number of vehicle services until 2050 with the reduction of the design emissions described in the Refrigerant emissions from design architecture section*

# Services	Baseline (ICE 14%, BEV 9%, leak rate 2050: 10.25g/vehicle)		
	2021	2035	2050
Without repair	38'446'764	40'300'505	19'873'595

# Services	Improved (ICE 11%, BEV 7%, leak rate 2050: 6.5g/vehicle)		
	2021	2035	2050
Without repair	38'446'764	-	-
With repair	-	20'695'719	8'264'750

Reduction # services due to amount of electrical compressors



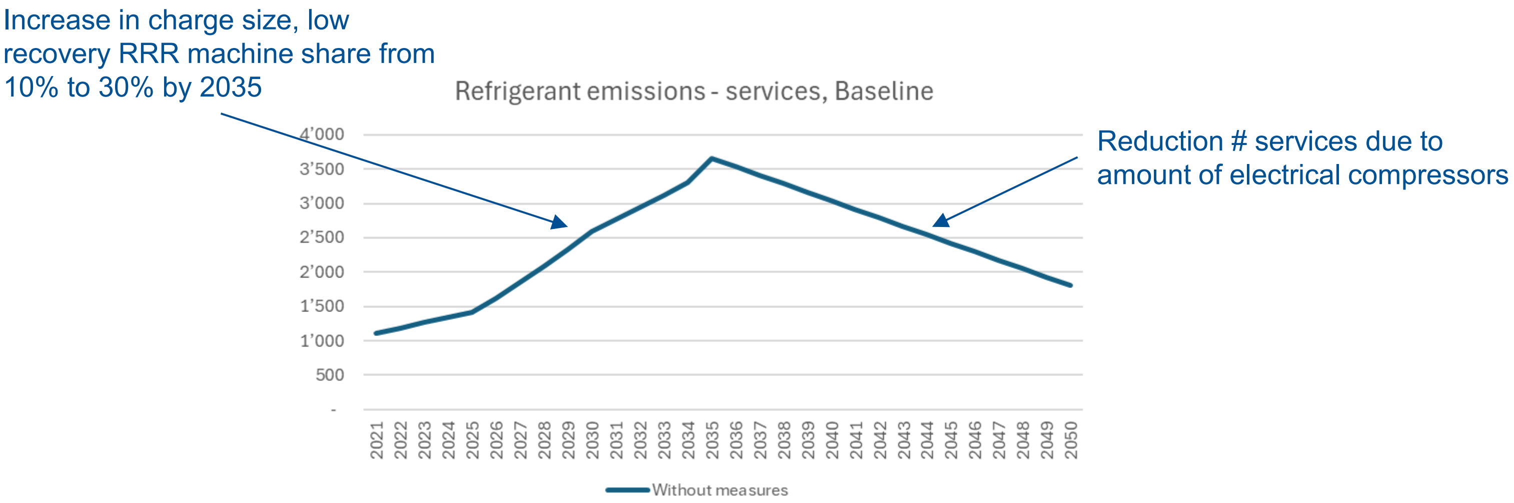
* Using the design architecture emission model, calculations for 2021, 2035 and 2050 where 2030, 2040 and 2045 are determined via linear interpolation.

Calculation of baseline number of services and related emissions without the implementation of legislation

Evolution of the emissions from service until 2050 in the baseline case

Emissions increase as the charge size increases and as the proportion of lower recovery rate RRR machine increases.

- Service garages will need to invest in new R-1234YF RRR machines as the amount of vehicles using R-1234YF will continue to increase. If there is no control over the type of RRR machine that can be used, there is a risk that cheaper machines with lower recovery rates are purchased. This will lower the amount of refrigerant recovered and increase the amount of refrigerant emitted.
- We have estimated that the proportion of RRR machine with low recovery rates in the EU will increase from 10% in 2021 to 30% by 2035. The recovery rate in 2021 is estimated to be approximately 93%, and this rate could go as low as 89% from 2035



Potential measures to reduce refrigerant emissions

Measure 1: **Recover rate of RRR machines >95%**

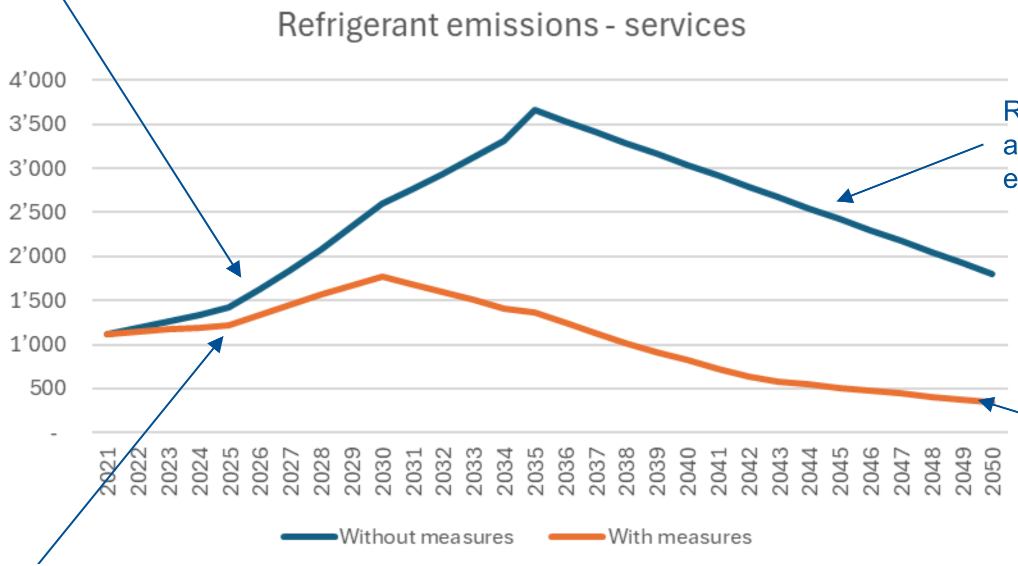
- **All RRR machines sold in the EU from 01/01/2030 need to be certified SAE J2788 or SAE J2843 compliant or transpose these standards into European standards**
  - **Feasibility:** Machines are available on the market to purchase.
  - **Affordability:** The average cost difference between a high quality and a low-quality machine is estimated to be EUR 1,350. 66,000 additional high-quality machines would need to be purchased between 2030 and 2050, representing an additional investment of EUR 89M for the entire value chain over 20 years.

Measure 2: **Refrigerant recovery monitoring**

- To ensure the full reporting and traceability of all refrigerant recovered, a reporting system needs to be in place that also allows and encourages the possibility to report the refrigerant that is reused or sold
- **This could be handled through the implementation of a refrigerant digital logbook.**
- This reporting is already compulsory under the F-gas regulation for all equipment with a charge above 1kg . This measure would simply extend the reporting obligation to all motor vehicles.
  - **Feasibility:** Good feasibility since the data on recovered refrigerant is stored in the RRR machines
  - **Affordability:** The only cost is the development of an electronic logbook and the centralization of the data, which cost can be spread over all the users of such a logbook.

Emission profile modelling
Refrigerant emissions from services

Increase in charge size, low recovery RRR machine share from 10% to 30%



Reduction # services due to amount of electrical compressors

With measures

Introduction RRR machine standard (25% share low recovery machines in 2030 to 0% in 2043) and overall reduction in # required services

2030-2050 overall refrigerant emission reduction versus “without measures”~67%

End of Life

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Data set 1: end of life recovered refrigerant extrapolated to the EU level and baseline EOL emissions

Data set 1.1: describes how to extrapolate the recovered refrigerant of The Belgium and Dutch producer responsibility organizations (PRO) to the European level:

- Febelauto, the Belgium PRO treated 103,659 vehicles in 2021 and recovered 6,489kg refrigerant
- ARN, Auto Recycling Netherlands treated 178,180 of the 197,046 vehicles treated in the Netherlands in 2021 and recovered 4,034kg refrigerant

2021	Belgium	Netherlands
Recovered refrigerant (kg)	6,489	4,461*
Number of vehicles treated	103,659	197,046
Proportion of EU vehicles	1.82%	3.47%
EU extrapolation recovered refrigerant (kg)	**355,753**	**128,663**
Weight of vehicles treated (MT)	129,979	210,248
Proportion in the EU	1.99%	3.22%
EU extrapolation recovered refrigerant (kg)	**326,250**	**138,662**

* As a total of 197,046 vehicles were treated in the Netherlands in 2021, we can extrapolate the amount of refrigerant recovered by ARN to a total amount for the Netherlands in 2021: 4,461kg

Data set 1: 2021 end of life recovered refrigerant extrapolated to the EU level and baseline EOL emissions

Data set 1.2: describes the baseline emissions at end of life assuming a 93% average refrigerant recovery rate:

- The emissions represent the amount of refrigerant left in the vehicle after the depollution process.
- This amount is dependent on the amount of refrigerant in the vehicle at end of life and the performance of the RRR machines used to depollute the vehicle.

2021	Belgium	Netherlands
Based on number of vehicles treated:		
EU extrapolation recovered refrigerant (kg)	**355,753**	**128,663**
Estimated EU Emissions (kg)*	**26,777**	**9,684**
Based on weight of vehicles treated:		
EU extrapolation recovered refrigerant (kg)	**326,250**	**138,662**
Estimated EU Emissions (kg)*	**24,556**	**10,437**

* Emissions considering an average recovery rate of 93%

Based on the data available, we can estimate a bracket of recovered refrigerant in the EU in 2021: Between 128,663kg and 355,753kg and the amount of refrigerant emitted in the EU in 2021: between 9,684kg and 26,777kg

Data set 2: 2050 extrapolation of EU recovered refrigerant and emissions

Data set 2.1: describes the factors used to extrapolate the refrigerant recovered until 2050

- Factors used: 2021 vehicle age distribution at end of life, AC penetration, increased BEV penetration, reduction in accident rates impacting the vehicles suffering catastrophic damage, degradation in the recovery rates due to the increased use of RRR machines with lower recovery rate:

	Low case	High case
2021 extrapolated recovered refrigerant (kg)	128,663	355,753
2021 AC penetration vehicles at end of life (%)	71.3	72.5
2021 BEV penetration at end of life (%)	0%	0%
2021 RRR machine average recovery rate (%)	93%	93%
2050 AC penetration vehicles at end of life (%)	100%	100%
2050 BEV penetration at end of life (%)	73%	76%
2050 Accident rate reduction on totalled vehicles (%)	36.9%	36.9%
2050 RRR machine average recovery rate (%)	85%	85%
2050 extrapolated recovered refrigerant (kg)	**200,644**	**672,042**

- Authorized Treatment Facilities (ATFs) will need to invest in new R-1234YF RRR machines. if there is no control over the type of RRR machine that can be used, there is a risk that cheaper machines with lower recovery rates are purchased, which will lower the amount of refrigerant recovered and increase the amount of refrigerant emitted.
- We have estimated that the proportion of RRR machine with low recovery rates in the EU will increase from 10% in 2021 to 50% by 2039. The recovery rate in 2021 is estimated to be approximately 93%, and this rate could go as low as 85% from 2039

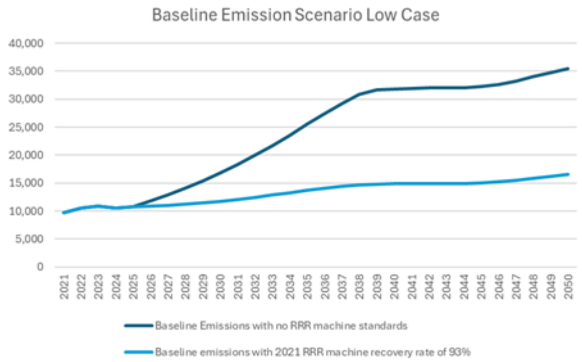
Data set 2: 2050 extrapolation of EU recovered refrigerant and emissions

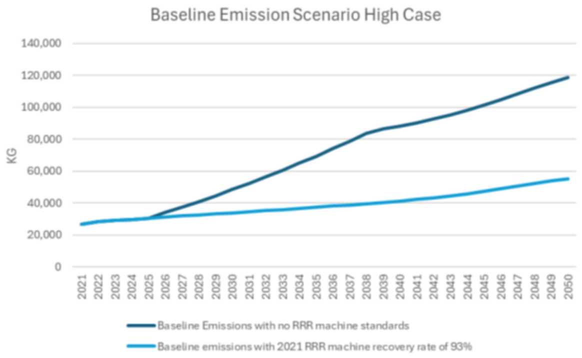
Data set 2.2: describes the 2050 extrapolated emissions if no legislative measures are taken

- To estimate the amount of refrigerant emitted we need to consider the assumption around the change of the RRR machines average recovery rate:

	Low case	High case
2050 extrapolated recovered refrigerant (kg) at 2021 RRR machine average recovery rate (93%)	219,528	735,293
2050 emissions at 2021 RRR machine average recovery rate	17,808	55,345
2050 extrapolated recovered refrigerant (kg) at 2050 RRR machine average recovery rate (85%)	**200,644**	672,042
2050 emissions at future RRR machine average recovery rate (85%)	**35,408**	**118,596**

The impact of the evolution of the RRR machines average recovery rate increases the 2050 EU refrigerant emissions between 18,884kg and 63,252kg.





Potential measures to reduce refrigerant emissions (1/2)

<u>Measure 1:</u> Recover rate of RRR machines >95%

- **All RRR machines sold in the EU from 01/01/2030 need to be certified SAE J2788 or SAE J2843 compliant or transpose these standards into European standards**
  - **Feasibility:** Machines are available on the market to purchase.
  - **Affordability:** The average cost difference between a high quality and a low quality machine is estimated to be EUR 1,350. 6,834 additional high-quality machines would need to be purchased between 2030 and 2050, representing an additional investment of EUR 8,600,000 for the entire value chain.

<u>Measure 2:</u> Refrigerant recovery monitoring

- To ensure the full reporting and traceability of all refrigerant recovered, a reporting system needs to be in place that also allows and encourages the possibility to report the refrigerant that is reused or sold by the authorised treatment facility
- **This could be handled through the implementation of a refrigerant digital logbook.**
- This reporting is already compulsory under the F-gas regulation for all equipment with a charge above 1kg . This measure would simply extend the reporting obligation to all motor vehicles.
  - **Feasibility:** Good feasibility since the data on recovered refrigerant is stored in the RRR machines
  - **Affordability:** The only cost is the development of an electronic logbook and the centralization of the data, which cost can be spread over all the users of such a logbook, not only the ATFs.

Potential measures to reduce refrigerant emissions (2/2)

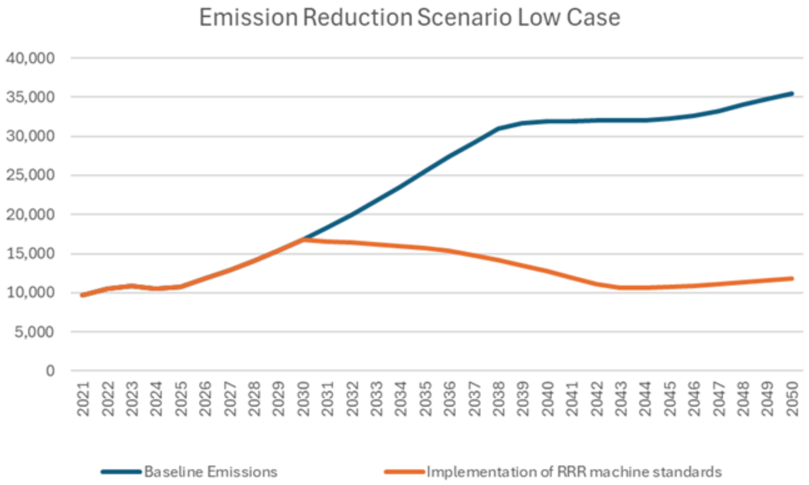
Measure 3: **Registration and audit of authorized treatment facilities:**

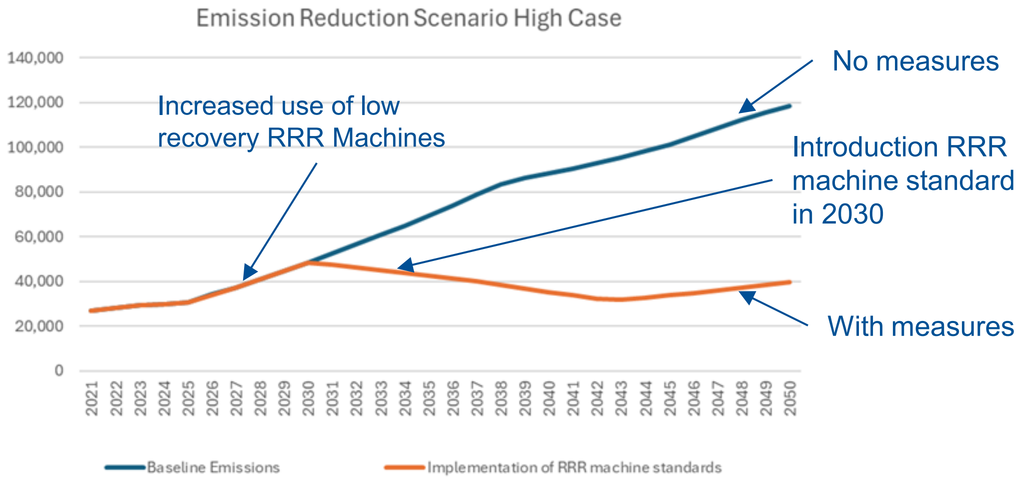
- **ATFs also need to be certified to perform the depollution practices and regular audits need to take place to ensure that good practices are followed. We propose that these requirements be written into the European regulation.**

Measure 4: **Subsidy for refrigerant destruction:**

- **Use a recovery tax to pay for the destruction of refrigerant that cannot be brought back to a recognized quality specification (AHRI 700)** to incentivize the ATFs to recover all refrigerant and send it for destruction if the refrigerant cannot be used.
- Promote the correct behavior by ensuring that the treatment of the recovered refrigerant for destruction is not a financial burden to the ATFs

Emission profile modelling
Refrigerant emissions from End of Life





2030-2050 overall refrigerant emission reduction versus “without measures”~55%

Amount of emissions saved (2030-2050) and cost effectiveness Refrigerant emissions from End of Life

We can estimate the base case emissions between 2030 and 2050 to be between 607,058kg and 1,799,924kg

- Implementing the suggested legislative measures to reduce emissions and increase transparency:
  - RRR machine standards
  - Better refrigerant reporting and traceability
  - ATF audits
- We can estimate the total emissions between 2030 and 2050 to reduce to between 279,937kg and 816,301kg, representing emissions savings of between 327,121kg and 983,614kg or a reduction in emissions in the period between 54% and 55%

2030-2050	Low case	High case
Total emissions Base Case (kg)	607,058	1,799,924
Total emissions RRR machine standards and accident reduction measures (kg)	279,937	816,301
Saved emissions (kg)	327,121	983,614
Total emission reduction 2030 to 2050	**54%**	**55%**
Cost of reduction (EUR/kg)	**26.27 EUR/kg**	**8.74 EUR/kg**

2030-2050 overall refrigerant emission reduction versus “without measures”~55%

References

AC health monitoring

- **Inputs**
  - Power draw compressor
  - Ambient external temperature + humidity?
  - Evaporator inlet temperature
  - Cabin outlet temperature
  - Requested internal cabin temperature (driver input)
  - ICE/Electric motor average power requirement
  - Battery / Powertrain temperature?
  - Condenser blockage? How to measure?
  - Air filter blockage?
  - Refrigerant pressure transducer, measures refrigerant pressure at the compressor's outlet and converts it into an electrical signal sent to the Engine Control Unit (ECU) or HVAC module

- **Indicators**
  - Ability to deliver requested internal cabin temperature (driver input) ≤ ± internal cabin temperature
  - Power draw compressor required to achieve requested internal cabin temperature (without clear reason e.g. ambient external temperature increase, etc.)

SAE J2842 R-1234yf and R744 Design Criteria and Certification for OEM Mobile Air Conditioning Evaporator and Service Replacements

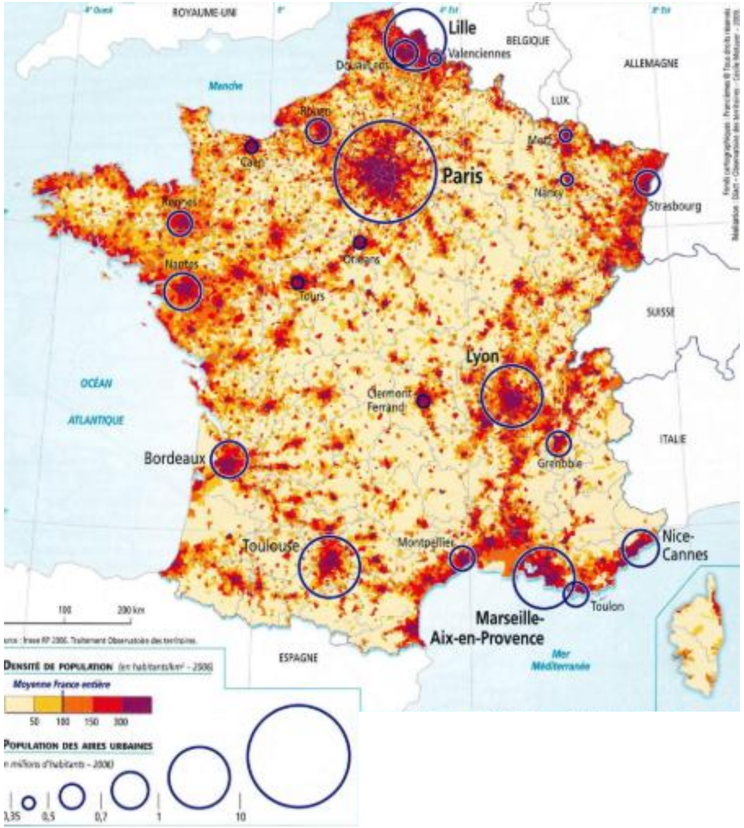
SAE J2842 is a technical standard developed by SAE International that provides design criteria and certification requirements for evaporators used in mobile air conditioning systems using the refrigerants R-1234yf (hydrofluoroolefin) and R-744 (carbon dioxide). This standard is intended to address appropriate testing and labeling requirements to minimize risks associated with the use and service of these evaporators.

The SAE J2842 standard is necessary because it addresses the safety, performance, and compatibility concerns associated with the use of newer refrigerants—specifically, R-1234yf (hydrofluoroolefin) and R-744 (carbon dioxide)—in mobile air conditioning systems. The reasons for this importance of this standard include:

- Ensures safety with flammable or high-pressure refrigerants: R-1234yf is mildly flammable. R-744 (carbon dioxide) operates at very high pressures. Evaporators must be designed and tested to minimize the risk of leaks, withstand the pressure, and prevent fire hazards in the event of a malfunction or accident.
- Protects end users and technicians: This standard provides testing and certification and helps prevent:
  - Dangerous leaks
  - Inconsistent part quality
  - Incorrect identification of spare parts

https://www.sae.org/standards/j2842_201102-r-1234yf-r744-design-criteria-certification-oem-mobile-air-conditioning-evaporator-service-replacements

Dataset – 250k services throughout France



- Good representation of services carried out to vehicles in coastal areas
- Much of Europe (incl France*) that commonly salts (northwestern Europe, Germany, Scandinavia) has frequent freeze–thaw cycles and coastal moderation where NaCl remains effective and economical.
- Western Europe (e.g., Germany/Netherlands): dense networks, shorter distances to depots, and milder winters in many areas make widespread NaCl anti-icing spraying more common and visible.

https://www.eurosalt.nl/en/salt-in-france/

Why regular inspections?

How Regular Inspection Reduces Leaks

- **Early Detection of Tiny Leaks:** Inspections can identify small, "pinhole" leaks in coils or connections before they lose significant refrigerant. Technicians use specialized tools like electronic detectors or UV dye tests to pinpoint these leaks, which might be invisible to the naked eye.
- **Preventing Structural Failures:** Routine check-ups include assessing the entire refrigerant circuit, including coils, joints, and lines, for corrosion or damage.
- **Reducing Wear and Tear:** By lubricating moving parts and tightening connections, regular service reduces vibrations that cause fittings to loosen and leak over time.
- **Maintaining Proper System Function:** Low refrigerant levels, often caused by small leaks, can cause coils to freeze. Regular maintenance ensures that if a leak does start, it is repaired before it puts strain on the compressor.

Assumptions: Crashes by Technology Group

Table 1-3
Summary of Target Crashes by Technology Group

	Safety Systems	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
1	FCW/DBS/CIB	1,703,541 29.4%	1,275 3.8%	883,386 31.5%	2,641,884 36.3%	$132.45 B 17.4%
2	LDW /LKA/LCA	1,126,397 19.4%	14,844 44.3%	479,939 17.1%	863,213 11.9%	$232.17 B 30.4%
3	BSW/BSI/LCM	503,070 8.7%	542 1.6%	188,304 6.7%	860,726 11.8%	$31.72 B 4.2%
4	PAEB	111,641 1.9%	4,106 12.3%	104,066 3.7%	6,985 0.1%	$61.29 B 8.0%
5	RAB/RvAB/RCTA	148,533 2.6%	74 0.2%	35,268 1.3%	231,317 3.2%	$5.63 B 0.7%
	Combined	3,593,182 62.0%	20,841 62.2%	1,690,963 60.3%	4,604,125 63.3%	$463.26 B 60.7%

PDOVs: property-damage-only vehicles; B: Billion
Source: 2011 to 2015 FARS and GES

Assumption: **Group 1 & 2 would in most cases lead to severe traffic accident leading to a full charge release**

Group 1, Forward Collision - FCW/CIB/DBS. Annually, each safety system in this group would affect an average of 1.70 million policed-reported front-to-rear (or rear-end) crashes. These crashes represented 29.4 percent of all policed-reported crashes that occurred in the United States. Consequently, these safety systems would affect 1,275 fatalities (3.8% of all fatalities), 883,386 MAIS 1-5 injuries (31.5% of all MAIS 1-5 injuries) and 2.6 million PDOVs (36.3% of all PDOVs). In terms of economic values, these safety systems would eliminate a portion of the estimated $132.4 billion (17.4% of all societal costs) societal costs associated with front-to-rear crashes.

Group 2, Lane Keeping - LDW/LKA/LCA. Each system in this technology group would affect 1.13 million (19.4% of all crashes) lane departure (type) crashes annually. These crashes resulted in 14,844 fatalities (44.3%), 0.48 million MAIS 1-5 injuries (17.1%), and 0.86 million PDOVs (11.9%) annually. Further, these crashes were estimated to cost society $232.2 billion (30.4%) annually.

Group 3, Blind Zone Detection - BSW/BSI/LCM. Each system would affect 0.50 million (8.7%) blind zone/lane change merger related crashes annually. These crashes resulted in 542 fatalities (1.6%) and 0.19 million MAIS 1-5 injuries (6.7%). In addition, there were 0.86 million PDOVs (11.8%) associated with the crashes. In total, these cashes would cost society $31.7 billion (4.2%) annually.

Group 4, Pedestrian Forward Impact - PAEB. Pedestrian automatic emergency braking can affect 0.11 million (1.9%) pedestrian/cyclist crashes annually. These crashes resulted in 4,106 pedestrian/cyclist fatalities (12.3%) and 0.10 million MAIS 1-5 injuries (3.7%). The crashes resulted in an annual average of $61.3 billion (8.0%) to society.

Group 5, Backing - RAB/RvAB/RCTA. Each of the safety systems in this group can affect 0.15 million backing crashes (2.6% of all crashes) annually. These crashes resulted in 74 fatalities (0.2%) and 0.04 million MAIS 1-5 injuries (1.3%). The cashes were estimated to cost society $5.6 billion (0.7%) annually.

Target Crash Population For Crash Avoidance Technologies in Passenger Vehicles, Wang, 2019, NHTSA

https://www.google.com/url?sa=i&source=web&rct=j&url=https://www-nrd.nhtsa.dot.gov/departments/esv/24th/files/24ESV-000430.PDF&ved=2ahUKEwipoaHEm4uSAxVj-QIHHU3dFMoQ1fkOegQIBRAF&opi=89978449&cd&psig=AOvVaw3xhHz60Fw9UJ4qhOveBsoC&ust=1768486445494000

Assumptions: total amount of accidents

A. Road traffic accidents. 2009-2019

Country	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2009-2019 (% change)
												Unit : number
Albania	1 465	1 564	2 472	1 870	2 075	1 914	1 992	2 032	1 978	1 718	1 498	2.3
Armenia	2 002	1 974	2 319	2 602	2 824	3 156	3 399	3 203	3 535	4 111	4 799	139.7
Austria	37 925	35 348	35 129	40 831	38 502	37 957	37 960	38 466	37 402	36 846	35 736	-5.8
Azerbaijan	2 792	2 721	2 890	2 892	2 846	2 635	2 220	2 006	1 833	1 817	1 870	-33.0
Belarus	6 739	6 363	5 897	5 187	4 730	4 550	4 151	3 654	3 418	3 399	3 567	-47.1
Belgium	41 944	45 745	47 761	44 259	41 347	41 474	40 300	40 123	38 025	38 455	37 699	-10.1
Bosnia and Herzegovina	7 799	7 127	7 088	6 600	6 908	7 106	7 627	7 716	7 255	7 494	7 256	-7.0
Bulgaria	7 068	6 610	6 638	6 716	7 016	7 019	7 226	7 404	6 888	6 684	6 730	-4.8
Canada	125 456	125 636	124 199	124 683	122 143	116 292	119 550	118 321	114 412	111 334	105 791	-15.7
Croatia	15 731	13 274	13 229	11 774	11 228	10 607	11 038	10 779	10 939	10 450	9 694	-38.4
Cyprus[1]	1 197	1 198	1 058	919	774	758	660	650	608	499	456 *	-61.9
Czechia	21 706	19 675	20 487	20 503	20 342	21 054	21 561	21 387	21 263	21 890	20 806	-4.1
Denmark	4 174	3 498	3 525	3 124	2 984	2 881	2 853	2 882	2 789	2 964	2 808	-32.7
Estonia	1 506	1 348	1 508	1 383	1 382	1 436	1 391	1 467	1 405	1 474	1 413	-6.2
Finland	6 414	6 072	6 408	5 725	5 334	5 299	5 185	4 752	4 432	4 312	4 002	-37.6
France	72 315	67 288	65 024	60 437	56 812	58 191	56 600	57 515	58 609	55 762	56 006	-22.6
Georgia	5 482	5 099	4 486	5 359	5 510	5 992	6 432	6 939	6 079	6 452	5 839	6.5
Germany	310 806	288 297	306 266	299 637	291 105	302 435	305 659	308 145	302 656	308 721	300 143	-3.4
Greece	14 789	15 032	13 849	12 398	12 109	11 690	11 440	11 318	10 848	10 737	10 712	-27.6
Hungary	17 863	16 308	15 827	15 174	15 691	15 847	16 331	16 627	16 489	16 951	16 627	-6.9

A. Road traffic accidents, 2013–2023

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2013-2023 (% change)
												Unit: number
Albania	2 075	1 914	1 992	2 032	1 978	1 718	1 498	1 234	1 376	1 165	1 285	-38.1
Andorra	…	…	312	285	276	260	283	215	252	283	241	
Armenia	2 824	3 156	3 399	3 203	3 535	4 111	4 799	4 016	4 604	4 308	4 613	63.3
Austria	38 502	37 957	37 960	38 466	37 402	36 846	35 736	30 670	32 774	34 869	35 809	-7.0
Azerbaijan	2 846	2 635	2 220	2 006	1 833	1 817	1 870	1 587	1 649	1 668	1 636	-42.5
Belarus	4 730	4 550	4 151	3 654	3 418	3 399	3 567	3 599	3 371	3 186	3 173	-32.9
Belgium	41 347	41 474	40 300	40 123	38 025	38 455	37 699	30 232	34 640	37 643	36 855	-10.9
Bosnia and Herzegovina	6 908	7 106	7 627	7 716	7 255	7 494	7 256	6 317	6 874	…	…	
Bulgaria	7 016	7 019	7 226	7 404	6 888	6 684	6 730	5 710	6 080	6 605	6 993	-0.3
Canada	123 149	117 211	119 978	119 490	116 241	111 695	104 762	76 536	82 858	90 957	94 337	-23.4
Croatia	11 228	10 607	11 038	10 779	10 939	10 450	9 694	7 709	9 146	10 005	10 633	-5.3
Cyprus	774	758	660	650	608	499	490	341	326	372	-	
Czechia	20 342	21 054	21 561	21 387	21 263	21 890	20 806	18 419	18 156	19 733	20 769	2.1
Denmark	2 984	2 881	2 853	2 882	2 789	2 964	2 808	2 527	2 402	2 563	2 438	-18.3
Estonia	1 382	1 436	1 391	1 467	1 405	1 474	1 413	1 409	1 538	1 671	1 676	21.3
Finland	5 334	5 299	5 185	4 752	4 432	4 312	4 002	3 608	3 243	3 110	2 944	-44.8
France	56 812	58 191	56 600	57 515	58 609	55 762	56 008	45 122	53 521	52 371	51 627	-9.1
Georgia	5 510	5 992	6 432	6 939	6 079	6 452	5 839	4 999	5 863	5 469	5 594	1.5
Germany	291 105	302 435	305 659	308 145	302 656	308 721	300 143	264 499	258 987	289 672	291 890	0.3
Greece	12 109	11 690	11 440	11 318	10 848	10 737	10 712	9 083	10 454	10 487	10 553	-12.8
Hungary	15 691	15 847	16 331	16 627	16 489	16 951	16 627	13 778	14 233	14 748	14 452	-7.9

Statistics of Road Traffic Accidents, UNECE, in Europe and North America, United Nations, 2021

https://unece.org/sites/default/files/2022-01/2113621_E_pdf_web.pdf

Statistics of Road Traffic Accidents, UNECE, in Europe and North America, United Nations, 2026

https://unece.org/sites/default/files/2026-02/2518859_E_PDF_WEB.pdf

Example: AC health monitoring

Paper: Predictive Repair of Vehicle R1234yf Refrigerant Systems Based on Monitoring of Micro-Leakages

“It is possible to infer the **presence of minor leaks through online or frequent pressure monitoring after the system has been “resting” (last ignition off for at least 5 h to allow system stabilization:** air conditioner vs. outer or engine coolant temperature). Using this method, it can be determined whether the given pressure losses fall within the normal operating range. The essence of the technique is to detect a possible small amount of leakage by monitoring the pressure change (Δp) of the air conditioning system, supported by dashboard(s). The results on the test fleet with 500 cars show that the procedure can be suitable for detecting defects that cause micro-leaks immediately after production. The false-negative detection rate was 0.2, and the false-positive rate was 1.2 at a threshold of ±0.5 bar.”

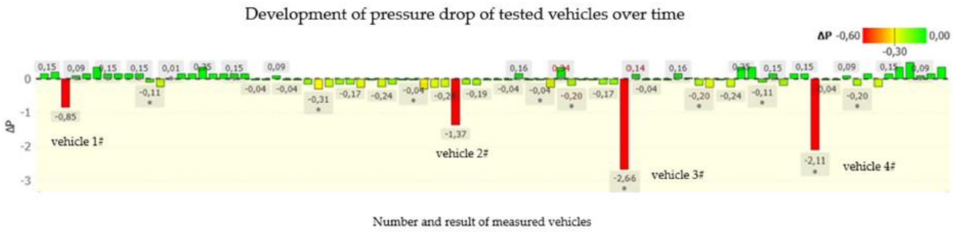


Figure 13. Possible anomaly monitoring (interpolated values) by the dashboard. Vehicle 1# and 2# were conspicuous after a few days during the first test (early failure with a higher level of leakage); vehicles 3# and 4# were also measured directly from customer delivery after 30–60 days, and they showed the anomaly (micro-leakage). The dot under the pressure value means that at least two tests have been performed.