Submission in support of time-unlimited derogation request for refrigerant R-474A for electric vehicles (2nd submission)

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Contents

1. Executive summary

Following our first submission in June 2023 to the public consultation on the REACH restriction on all PFAS, Daikin Chemical Europe takes now the opportunity to submit further comments with respect to the automobile air conditioning refrigerant R-474A. R-474A falls within the scope of the anticipated restriction as it contains R-1234yf, which qualifies as a PFAS according to the restriction proposal's definition. Considering both submissions as complementary to each other, in the following study we focus on the assessment of the alternative refrigerant CO_2, also known as R-744, in comparison with R-474A.

While Daikin supports the REACH restriction process for managing substances of concern, we are concerned about the inclusion of a number of fluorinated gases (F-gases), such as R-1234yf, due to their degradation to trifluoroacetic acid (TFA)[1]. The 2022 UNEP Environmental Effects Assessment Panel (EEAP) report states that TFA has very different biological properties from the longer chain PFAS and no adverse effects for humans or ecosystems were found nor are anticipated even based on a projected future increase. Therefore, the EEAP comes to the conclusion that the inclusion of TFA in the larger group of PFAS chemicals for regulation is scientifically not defensible and would be inconsistent with the risk assessment of TFA. This shows that there is no consensus of the environmental impact by TFA even among the specialists using different studies and risk assessments.

F-gases used in mobile air conditioning (MAC) are not intended for release into the atmosphere, but are used in closed systems. The only emission sources would be leakages or improper recovery at end-of-life. However, provisions for containment and recovery with a focus on hydrofluorocarbons (HFCs) are already contained in the F-gas Regulation, which will be extended to hydrofluoroolefins (HFOs) in its revision expected to enter into force on 1st January 2024. Therefore, their degradation potential to TFA can be heavily reduced by various measures, such as the recovery and recycling or reclamation of refrigerant at the end of life. This type of mitigation option shall be explored as a first step.

[1] This was confirmed by the five Dossier Submitters during a PFAS-related webinar organized by the association EFCTC on 23rd May 2023.

Recent results of vehicle and system tests show that the new automotive refrigerant blend R-474A enables the thermal system to deliver high thermal capacity at great efficiency across all conditions. It allows the expansion of the operation conditions in the heat pump (HP) mode at very low ambient temperatures up to high temperatures in air conditioning (AC) mode, helping to reduce the vehicle's carbon footprint and global warming impact.

On the other hand, the refrigerant alternative CO_2 (R-744) mentioned in the ECHA dossier proposal from March 2023 presents important limitations in its applicability to the MAC system for BEVs. In particular, R-744 presents severe performance limitations at hot ambient temperatures and a low efficiency overall. This could translate into a) limited market adoption of BEVs in warmer regions inside and outside the EU and b) an increased energy usage by the European BEV vehicle fleet, which needs to be provided out of a power generation network already under strain to meet CO_2 emissions targets. In this paper, we present some comparison data between R-744 and R-474A to support this claim.

Herewith we emphasize that the ban of R-474A as a consequence of the ban of R-1234yf is not appropriate. Therefore, we would like to reiterate our request for a time unlimited derogation for the use of R-1234yf in R-474A as automobile refrigerant for electric vehicles

2. Environmental impact of automotive refrigerant

2.1 Risk analysis of R-1234yf refrigerant

Among several thousand PFAS chemicals, the proposed restriction also affects the automotive refrigerant R-1234yf. According to the PFAS restriction dossier proposal, the basic reason behind the full ban of R-1234yf is the fact that it leaks into the atmosphere where it degrades into Trifluoroacetic acid (TFA). TFA is however commonly produced through the oxidation of trichlorofluoroethane (CFC-113) or the hydrolysis of hexafluoropropylene oxide (HFPO). It is widely found in nature coming from different natural sources. Related to this, the European Fluorocarbons Technical

Committee (EFCTC[2]) and also the UNEP EEAP report refer to several scientific papers confirming that one of the main sources identified is oceanic hydrothermal activity[3] with concentrations in oceans and freshwater expected to rise. According to the authors of the PFAS restriction dossier, this could result in a future risk to human health and other organisms.

The risk evaluation of TFA in the environment can be done using different approaches and criteria as there is no globally agreed procedure available. We perceive that the ECHA is following a very different risk analysis and results than other international agencies such as the UNEP Environmental Effects Assessment Panel (EEAP). We will try to describe the differences as we understand them in the next paragraph.

According to our understanding of the differences in the risk assessment of R-1234yf, the point of divergence between ECHA and the UNEP seems to be when it comes to the environmental and health risks associated with the said increase in TFA concentrations. Whereas the UNEP clearly states that there is no concern even at concentrations orders of magnitude higher than the worst-case scenario of future emissions ("[...] based on projected future use of these precursors of TFA, no harm is anticipated. There is a large uncertainty associated with the magnitude of other sources of TFA (e.g., potential natural sources, fluorinated pesticides, and pharmaceuticals), which do not fall under the purview of the Montreal Protocol. Trifluoroacetic acid has biological properties that differ significantly from the longer chain polyfluoroalkyl substances (PFAS) and inclusion of TFA in this larger group of chemicals for regulation would be inconsistent with the risk assessment of TFA."[4] ECHA seems to take a precautionary approach, proposing a ban nevertheless.

If the goal is to minimize TFA formation and accumulation to prevent a purported future risk, we believe a proportionate approach needs to be found that still allows

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[2] EFCTC Webinar, The Universal PFAS restriction proposal and possible impact on F-gases, 5/23/23

[3] Scott, B., Macdonald, R., Kannan, K., Fisk, A., Witter, A., Yamashita, N., Durham, L., Spencer, C., & Muir, D. (2005).
Trifluoroacetate profiles in the Arctic, Atlantic, and Pacific oceans. Environmental Science & Technology, 39, 6555-6560. https://doi.org/10.1021/es047975u

[4] UNEP 2022 Assessment Report of the Environmental Effects Assessment Panel, page 25

industry to use efficient solutions. That is why we believe that mitigation is the better approach. There are several mitigation strategies that can be implemented to minimize the amount of R-1234yf degrading into TFA. They are described in the next section.
Instead, the approach of the PFAS restriction proposal is to ban R-1234yf. We think that a cost-benefit analysis of this approach is mandatory in order to justify such a radical approach. This foundation is missing in the ongoing PFAS discussions.

Moreover, we would like to quote the experts' voice in the UNEP EEAP report mentioning that "all PFAS should not be grouped together, persistence alone is not sufficient for grouping PFAS for the purpose of assessing human health risk, and that the definition of appropriate subgroups can only be defined on a case-by-case manner"[5]. Especially regarding the toxicology "it is inappropriate to assume equal toxicity/potency across the diverse class of PFAS".

Therefore, we think that the restriction of R-1234yf is not an adequate measure and that its use in automotive refrigerant R-474A for electric vehicles should be granted a time-unlimited derogation.

2.2 Proposal for mitigation countermeasures

Considering the environmental impact of the refrigerant R-1234yf following the described risk analysis, the key concern is the refrigerant leakage to the atmosphere. Therefore, it is obvious to pay attention to refrigerants' leakage reduction during the complete lifetime. For refrigerants used in automotive applications, this includes the time from the first filling in the car manufacturers' assembly plants until the vehicles' recycling at end of life (EOL).

Today's state-of-the-art systems using electric compressors can be considered as hermetically sealed, and leakage data from the market for such types of compressors show leakage rates below 1% per year. The large part of leakage occurs either due to breakage or malfunction of the thermal system, related maintenance, or during the vehicle disposal process at EOL.

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[5] Xue, J. S., Zhang, B., Zhan, H., Lv, Y. L., Jia, X. L., Wang, T., Yang, N. Y., Lou, Y. X., Zhang, Z. B., Hu, W. J., Gui, J., Cao, J., Xu, P., Zhou, Y., Hu, J. F., Li, L., & Yang, Z. N. (2020). Phenylpropanoid derivatives are essential components of sporopollenin in vascular plants. Molecular Plant, 13(11), 1644-1653, https://doi.org/10.1016/j.molp.2020.08.005.

The main target remains to avoid any exposure of R-1234yf to the environment that can degrade to TFA. Therefore, it is essential to consider regulatory incentives to minimize the leakage rate during the lifetime of the vehicle. In addition to the pure regulatory framework, there is also the very effective method of refrigerant recovery, recycling, reclamation, and finally destruction. The next chapter will explain this measure more in detail.

2.3 Potential of refrigerant recovery, recycling and reclamation

The use of fluorinated gases in mobile air conditioning (MAC) systems is regulated throughout the entire life cycle by regulations and directives. The aim of these regulations and directives is to reduce the emissions of refrigerants in this application to a minimum.

The EU Directive 2006/40/EU limits the maximum greenhouse gas potential of the refrigerant in automotive air conditioning systems to a GWP of 150. At the same time, the EU regulation EU307/2006 refers to 2006/40/EU and prescribes minimum requirements for the qualification of service personnel for automotive air conditioning systems. The minimum requirements include theoretical knowledge of the properties of fluorinated gases in air conditioning systems and recovery processes, as well as practical knowledge of handling refrigerant containers and recovery equipment, which is mandatory for service workshops. The End-of-life Vehicle Directive 2000/53/EU ensures that when the vehicle is scrapped, the refrigerant from vehicle air conditioning systems is properly handled and disposed of.

BEVs use electrically driven, hermetically sealed compressors. The average emission rates during operation are several times lower than those of conventional, belt-driven compressors. Accordingly, an increased recovery rate can be expected at the end of the vehicle cycle. With compliant behavior of service personnel and disposal operations, refrigerant emissions from BEVs are reduced to a minimum.

Fluorinated refrigerants have a high material value. For example, the current price for R-1234yf on gas distributor level is approximately 80€/kg[6]. Automotive workshops are able to recover the complete amount of the contained refrigerant.

[6] Price quotation German Gas distributors, 31.08.2023

Modern refrigerant recovery equipment at automotive workshops guarantees almost a 100% recovery rate from the MAC system for further use[7].

Figures demonstrating the higher recovery rate through the use of electrically driven, hermetically sealed compressors in BEVs are not yet available. The reason for this is that BEVs have only recently been introduced to the market and have not yet reached their end of life.

3. Assessment of refrigerant alternative R-744

For BEVs the vehicle’s energy efficiency is directly linked to the driving range. The efficiency of the thermal system providing heating or cooling to the passengers, battery, and other vehicle systems has a large impact on the total energy efficiency of the vehicle. The refrigerant impacts the system efficiency based on its thermodynamic properties that both increase the capacity and efficiency independent of the demand for either cooling or heating while driving or during fast-charging stops.

Most BEVs in the market today are equipped with sophisticated thermal systems based on R-1234yf as a refrigerant. Single examples of systems based on R7-44 are also available. Due to their thermodynamic properties, both refrigerants fail to fulfill the mission of the thermal system entirely. In particular, R-1234yf shows limitations in heat pump mode at low temperatures and R-744 on the contrary struggles when outside temperatures are high. This issue is generally understood by the industry, as it is reflected in the fact that the SAE is currently running a Cooperative Research Program to look for alternatives. R-474A is showing promising results as to its ability to fulfill said requirements.

Upon our previous evaluation results of R-474A in comparison with the refrigerants R-1234yf and R-744 actual results are now available from recent benchmark investigations. The aim of those measurements is to present a comprehensive analysis and comparison of different refrigerants in a thermal system. The benchmark has been performed as a comparison of R-474A with the base system equipped with R-1234yf and towards the proposed alternative R-744. As environmental

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[7] see product description WAECO ASC 6300G LE
https://www.waeco.com/en/de/products/ac-service/ac-service-units/waeco-asc-6300-g-le-_-322297

concerns and energy efficiency continue to gain prominence, the selection of a suitable refrigerant plays an important role in optimizing the performance and sustainability of the thermal management as part of the overall vehicle. In the various studies we explored the different characteristics, thermodynamic properties, overall performance and the related efficiency of the thermal system using different refrigerants.

For this benchmark analysis a series VW ID.3 vehicle under driving conditions and a system bench of the same vehicle have been used. We selected this vehicle due to being the only vehicle in the market fitting both a R-1234yf-based system and in a small series a R-744 version. Overall, the testing focused on the air condition (AC) and will be explained in detail in the following chapter.

3.1 R-474A / R-744 vehicle benchmark testing results

The vehicle evaluation was performed with a series VW ID.3 vehicle using the series thermal system and the refrigerant R-1234yf offering the opportunity to evaluate R-474A as a drop-in. For the evaluation of the performance of each refrigerant, the system was equipped with various sensors to understand the system behavior. Those sensors included temperature and pressure sensors before and after each system component as well as related expansion valves. The passengers' cabin was also equipped with several temperature sensors at all vents, the front and rear footwell areas and the headroom to evaluate the cabin comfort based on the thermal system's performance.

Aiming a reliable comparison of both refrigerants under dynamic conditions, the following test procedures have been considered as common test method within the automotive industry:

- Cool-down measurement based on DIN 1946-3-2006 with the air conditioning controller set to Auto 22°C
- Cool-down measurement based on DIN 1946-3-2006 with the air conditioning controller set to MAX Cool

The different test conditions for the cool-down measurements are shown in Table 1. Both refrigerants were tested with the same series thermostatic expansion valve (TXV) as a pure drop-in solution. For this study, the results of the cool-down test at an ambient temperature of 35°C using the vehicle's automatic control of the cabin temperature will be described in detail.

Table 1. Test condition vehicle cool-down for benchmarking R-1234yf and R-474A

Cool-down Auto 22°C	Condition 1	Condition 2	Condition 3
Ambient temperature	40°C	50°C	30°C
Relative air humidity	40%	30%	50%
Cool-down MAX Cool	Condition 1	Condition 2	Condition 3
Ambient temperature	40°C	50°C	30°C
Relative air humidity	40%	30%	50%

The comprehensive range of test conditions allows to verify the differences of performance between the original refrigerant R-1234yf and the new refrigerant R-474A. Figure 1 shows the test result for the cool-down measurement Auto 22°C at the condition 1 as reference for the complete testing. The graph shows the compressor speed and the air temperature after the evaporator as key parameters for the performance of the air conditioning system (R-1234yf = red lines, R-474A = blue lines). The test duration is one hour and starts after the complete vehicle has been soaking in the climate chamber at the ambient temperature of 40°C.

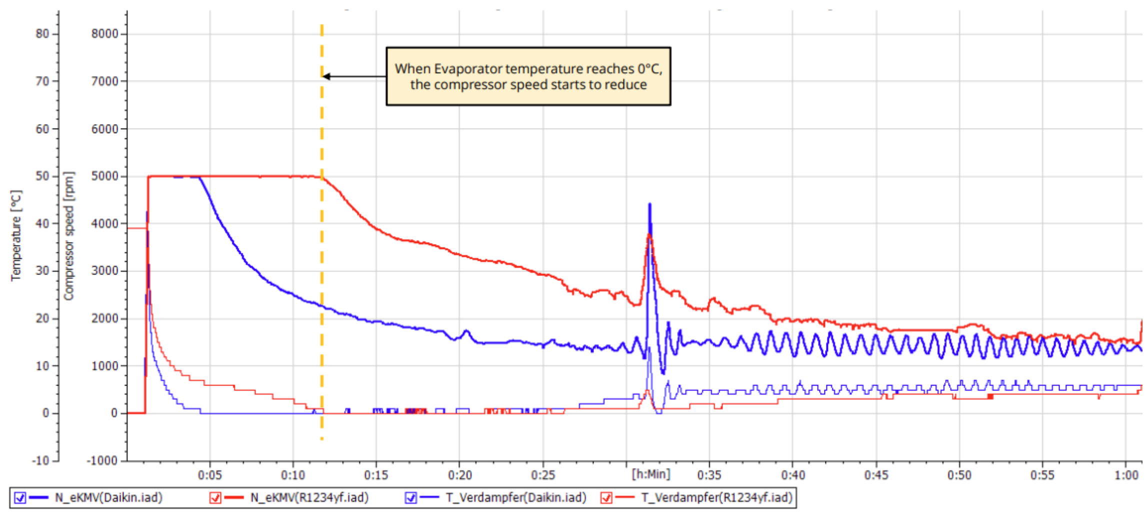

Figure 1. Vehicle cool-down result (VW ID.3) R-1234yf vs. R-474A at 40°C/40% (air temperature after evaporator)

The vehicle's climate control is targeting the set temperature of 0°C for the air after the evaporator. The compressor speed for that test conditions is set at 5,000rpm and this speed is kept until the required air temperature of 0°C is achieved by the system. The chart clearly shows that the refrigerant R-474A enables the thermal system to reach the target temperature after three minutes whereas the series system with R-1234yf requires 11 minutes. During this longer period the compressor needs to turn at the maximum speed for a much longer time compared to the compressor using R-474A.

As per the fact that the test was performed under drop-in conditions replacing the refrigerant but keeping the hardware and software exactly the same, the results after the fresh air flush after 30 minutes can be neglected.

The earlier reduction of the compressor speed results in a reduced noise impact of the cabin and the vehicle surroundings. Furthermore, the reduced speed also allows a reduced power consumption of the compressor (see Figure 2).

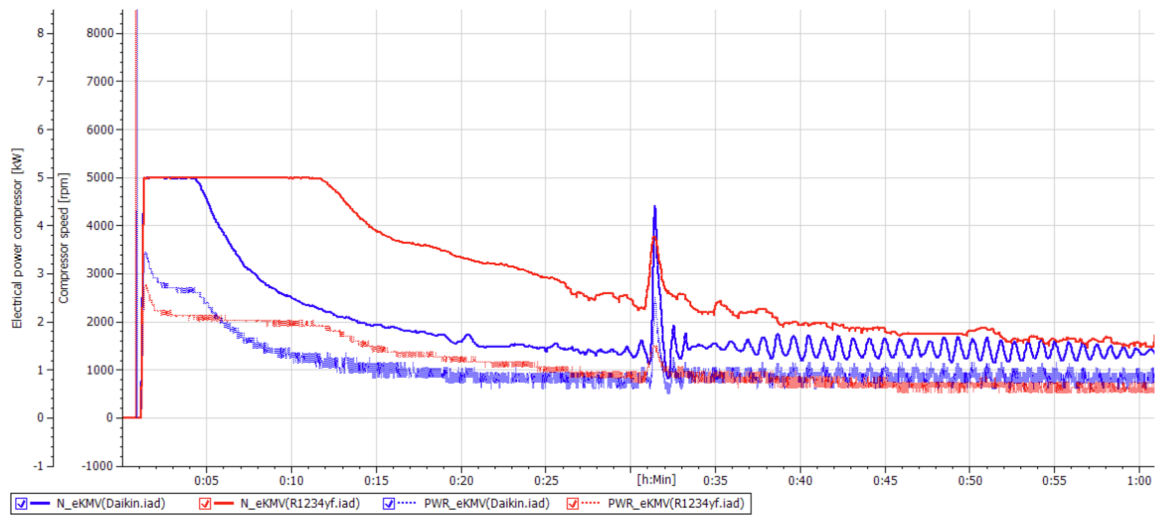

Figure 2. Vehicle cool-down result (VW ID.3) R-1234yf vs. R-474A at 40°C/40% (compressor power consumption)

The higher compressor power of R-474A at the same compressor speed of 5,000rpm compared to R-1234yf refers to the higher pressure level of R-474A at this test condition providing the higher cooling performance to the thermal system (see Figure 3). As the compressor speed is reduced also the power consumption goes below R-1234yf while the total energy is expected to be lower for R-474A.

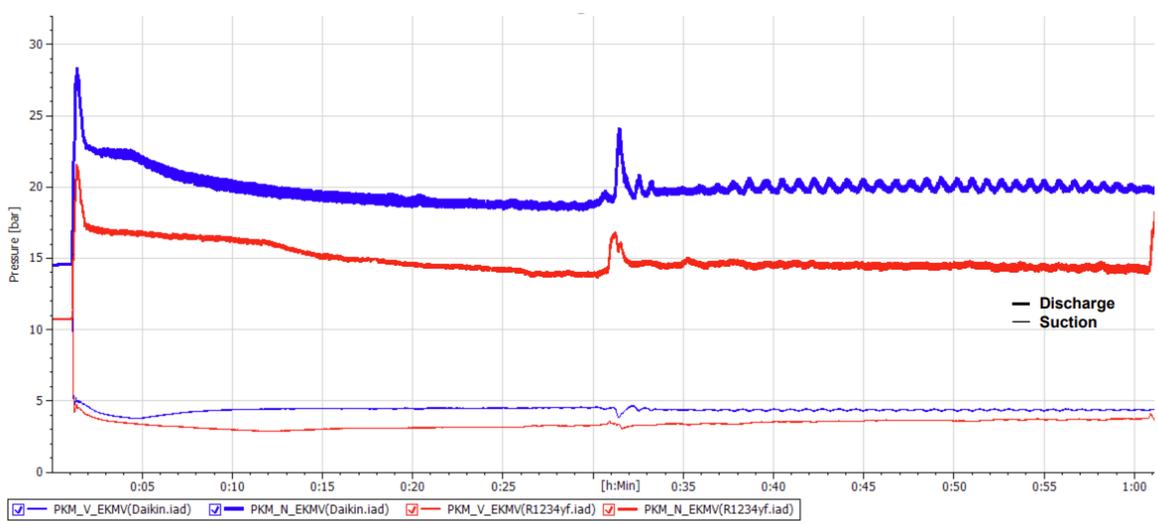

Figure 3. Vehicle cool-down result (VW ID.3) R-1234yf vs. R-474A at 40°C/40% (refrigerant pressure)

Taking into account the above test results, we compared the performance of R-474A with R-744 using a ID.3 vehicle fitted with a R-744 system. The test condition of a vehicle cool-down has been performed with R-744 under the same condition 40°C and 40% relative humidity as also previously described. While the direct comparison of R-744 with R-474A as drop-in is not possible due to the different system architecture required for the refrigerant R-744, the same conditions allow the comparison of the different behaviors of the thermal systems.

Figure 4 and Figure 5 show the behavior of the R-744 system split into the compressor data (see Figure 4) and the cabin temperature (see Figure 5).

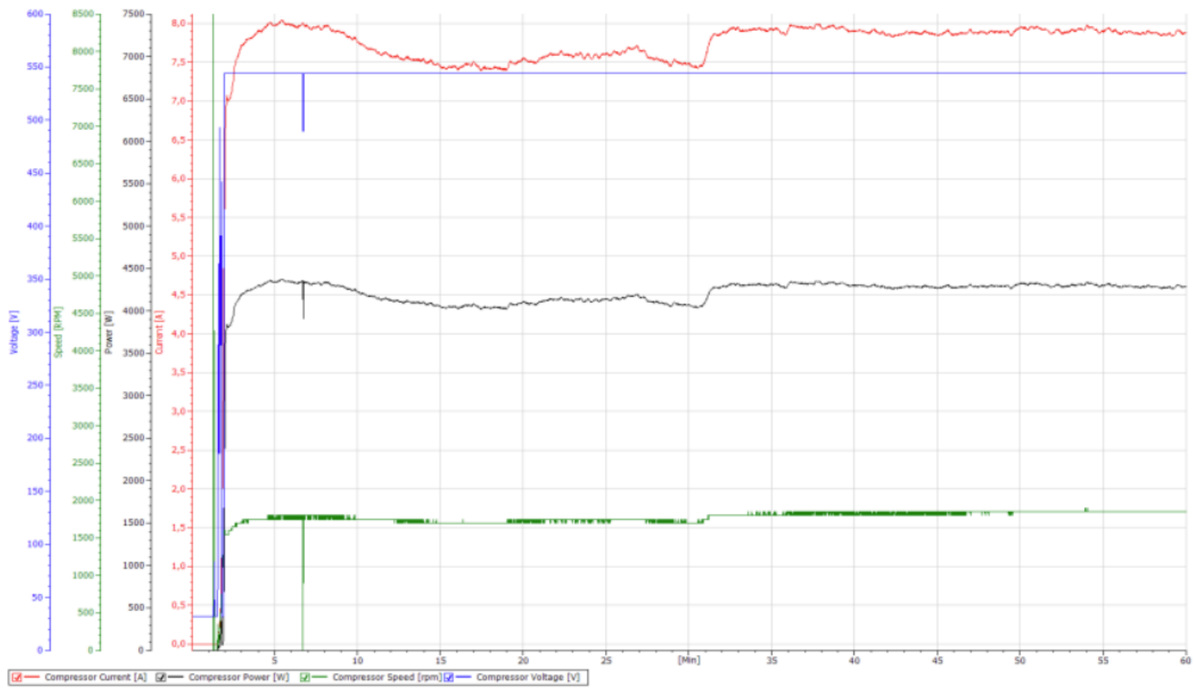

Figure 4. Vehicle cool-down result (VW ID.3) R-744 at 40°C/40% (compressor data)

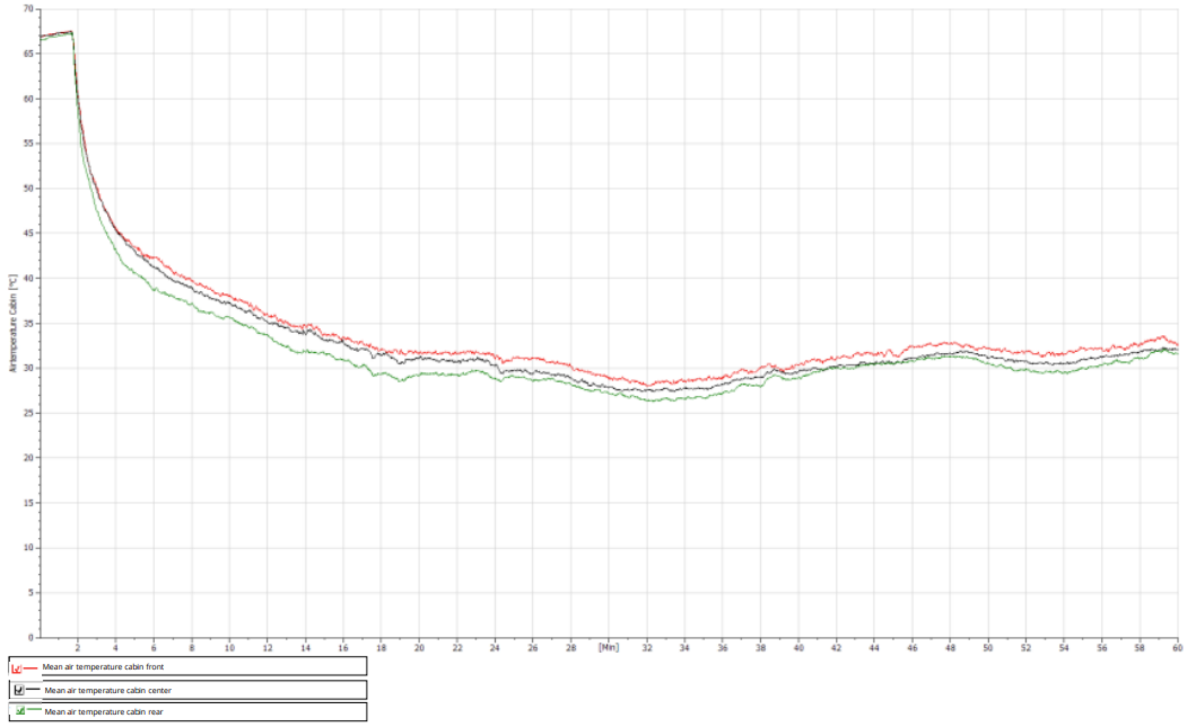

Figure 5. Vehicle cool-down result (VW ID.3) R-744 at 40°C/40% (cabin temperature)

The above results show that the compressor speed was set at the value of about 1,800rpm. At this compressor speed the power is approximately 4,300W. Comparing this value with the compressor power measured with the refrigerant R-474A, the refrigerant R-474A allows compressor power lowered by approximately 35% compared to R-744. While the power consumption is much higher for R-744 at this point, the performance is lower than for R-474A. Figure 6 shows that the cabin temperature in the front, which is comparable to the measured headroom temperature for R-474A, reaches a level of about 30degC after 18 minutes while the R-474A system (as shown in Figure 6) reached that value already after nine minutes.

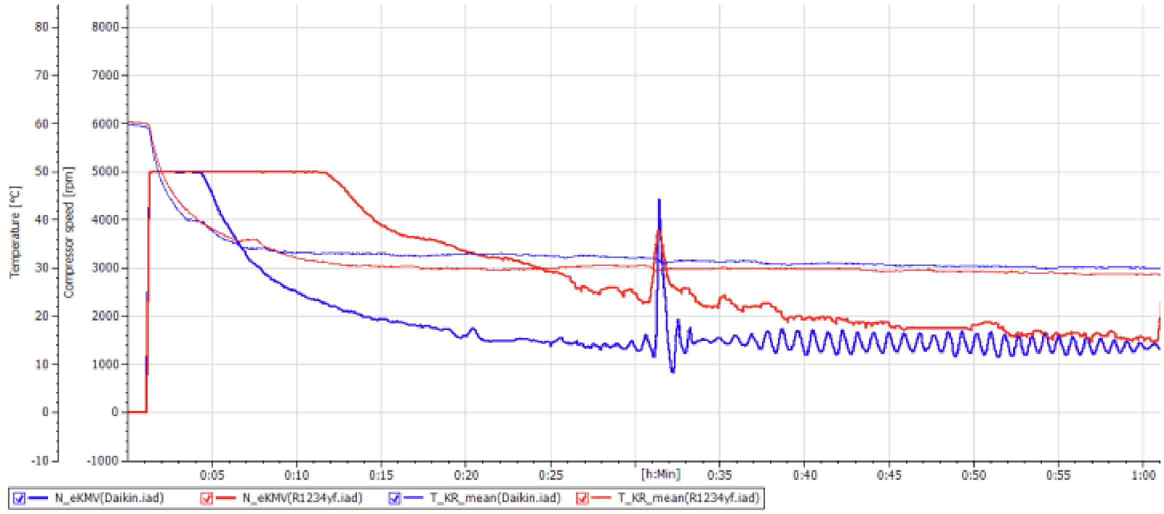

Figure 6. Vehicle cool-down result (VW ID.3) R-1234yf vs. R-474A at 40°C/40% (cabin temperature)

Taking into consideration the above results, we strongly recommend to perform further analysis of the viability of R-744 as a refrigerant alternative for Europe. The PFAS restriction proposal offers R-744 as an alternative that started in a few vehicles as an option for the heat pump system. In past measurements, the cooling performance of R-744 under ambient temperature conditions above 30°C was severely reduced due to the fact that this refrigerant is operating transcritical. Beside the performance-loss, the efficiency is tremendously reduced in comparison to R-474A. By restricting high-performance and high-efficient technologies like R-474A, the PFAS restriction proposal for R-1234yf will limit the success of current efforts of automotive carmakers to develop highly efficient electric vehicles.

3.2 Impact of the thermal system on the energy efficiency and the resulting practicality of BEVs

The comprehensive test results we obtained through various testing activities in the past two years with ID.3 vehicles and ID.3 systems always showed the same tendency: the thermal system with R-744 requires more energy than the comparable thermal system with R-474A. Beside the fact that the performance of R-744 at hot temperature conditions is not reaching the performance of R-474A, in this study we discuss the impact of the higher energy consumption in regards to sustainability and usability of electric vehicles.

Relevant use cases and driving patterns chosen for this assessment are as follows:

1) Taxi using the reference of an eight hours shift with a defined share of idle, city driving and highway diving ratio based on the dissertation of A. von Manstein[8]
2) Family trip with a long-range drive with a total length of 800km requiring charging stops to reach the destination using mainly the highway
3) Simulating a Worldwide Harmonized Light Vehicles Test Procedure (WLTP) at summer conditions and with the operation of the air conditioning system

Our study is based on the assumption that the overall energy consumption of the vehicle comes from the powertrain and the thermal management system. Following the general methodology and understanding of a Life Cycle Climate Performance (LCCP) evaluation, we prepared a related tool with the focus on the environmental impact of thermal management showing the differences in energy consumption. For this evaluation the following main parameters were measured using two series thermal system of the VW ID.3 (R-1234yf and R-744 versions) and operated on a test rig under stationary conditions for the AC mode that are required for the evaluation for a thermal system:

- Heating, ventilation, air conditioning (HVAC) performance data
- Heat exchanger performance data (evaporator, condenser or gas cooler, chiller)
- Compressor speed and power
- Refrigerant pressure and temperature
- Refrigerant mass flow

Enabling the tool to use the results of the stationary performance evaluation, the three previously described driving patterns 1-3 consist of relevant driving or idle phases. The calculation method applies steady conditions in order to apply the existing

[8] von Manstein, A., Energieeffiziente Klimatisierung der Fahrzeugkabine mittels elektrisch angetriebenem Kältemittelverdichter in seriennaher Fahrzeugapplikation, 17. September 2019

stationary test results. The consumption of the powertrain has been set as constant according to the marketing information of the VW ID.3[9].

As an excerpt of the overall results provided by the evaluation tool the temperature condition 35°C, the average energy consumption of R-744 is significantly higher than for R-474A (see Table 2).

Table 2. Efficiency tool results for 35°C with different driving cycles for R-1234yf, R-474A and R-744 regarding the average energy consumption

AVG Consumption [kWh/100km]		Taxi ID.3		Family trip (Long-range) ID.3		WLTP ID.3	
		Powertrain	Thermal System	Powertrain	Thermal System	Powertrain	Thermal System
R1234yf	35degC	14.40	2.73	19.04	0.98	14.78	1.74
R474A	35degC	14.40	2.40	19.04	0.96	14.78	1.52
R744	35degC	14.40	3.95	19.04	1.60	14.78	2.37

Table 2 shows the consumption for a driving range of 100km for the related cycles and we want to highlight the portion of the thermal system on the overall consumption for driving cycles with a high ratio of low-speed city driving. The impact of the low-efficient refrigerant R-744 is even more visible taking under consideration the following scenarios based on above use-cases (see Table 3).

[9] https://www.volkswagen.de/de/modelle/der-neue-id3.html

Table 3. Defined scenarios considering the region of Sevilla, Spain providing a climate spectrum comparable to test condition of 35°C

Region of Sevilla, Spain		
Total population	[-]	2,000,000
Total number of vehicles	[-]	950,000
Number of taxis	[-]	2,800
Number of days with hot weather conditions	[-]	150
Use case TAXI		
Difference R-474A vs. R-744 per shift	[kWh]	3.80
Number of shifts per day	[-]	2
Additional energy consumption R-744 per year*), per taxi	[kWh]	1,139.35
Total additional energy consumption R-744 per year*), taxi fleet	[MWh]	3,190
Use case WLTP		
Difference R474A vs. R744	[kWh/100km]	0.83
Average mileage per vehicle per year*)	[km]	10,000
Additional energy consumption R-744 per year*), per vehicle	[kWh]	339
Total additional energy consumption R-744 per year*), vehicle fleet	[GWh]	322
Use case FAMILY TRIP		
Number of charging stops R474a	[-]	2
Number of charging stops R744	[-]	3

*) 150 days with hot weather conditions considered

Elaborating more on the driving scenario of a taxi and the city traffic of Sevilla, Table 4 shows the perspective of the additional power uptake of R-744 versus R-474A on a summer day.

Table 4. Power uptake of a R-744 vehicle compared to a R-474A vehicle on a summer day

Difference R-474A vs. R-744 per vehicle	[kW]	0.485
Total number of taxis	[-]	2,800
Additional power uptake R-744 by taxis on a summer day	[kW]	1,358
Additional power uptake R-744 by all city traffic [*2)]	[kW]	16,491

[*2)] Assumption: 1/10 of vehicles driving on the streets (340,000 vehicles in the city of Sevilla)

Upon the general figures of the region of Sevilla, the three use cases are showing different perspectives on the additional energy consumption of R-744 compared to best-in-class refrigerant R-474A.

The additionally required energy will be discussed in the next chapter. In this chapter we want to mention that the presented use cases and results confirm that a BEV becomes less practical using a low-efficient refrigerant R-744 considering today's level of battery sizes for the various vehicle categories. Considering the case of a family trip with a long-range drive of 800km the change from R-744 to the high-efficient R-474A eliminates one charging stop out of three equal to 30% of reduced charging time. On the other hand, the impact of the efficiency of the thermal system is felt most in city traffic conditions at low speed and long stand-still times, where it can take up to 30% of the total power consumption of the vehicle. In this situation, a thermal system fitted with R-474A can provide up to a 10% energy efficiency increase versus the equivalent vehicle with R-744.

We also evaluated the energy consumption at a mild temperature of 15°C that is similar to the temperature level commonly used for homologation driving cycles. Table 5 shows the average consumption for the driving scenarios TAXI and FAMILY TRIP.

Table 5. Average consumption at 15°C ambient temperature for driving patterns TAXI and FAMILY TRIP as a total of powertrain and thermal system consumption

AVG Consumption [kWh/100km]		Taxi ID.3	Family trip (Long-range) ID.3
R-1234yf	15degC	14,71	19,83
R-474A	15degC	14,53	19,83
R-744	15degC	14,54	19,83

Looking at that data, the difference between the refrigerants is negligible. However, the above conditions describe the situation where the thermal system is running a low performance resulting in a lower direct impact on the overall energy consumption.

For a better understanding of the influence of the ambient temperature on the energy consumption of the thermal system, Figure 7 shows the comparison of the average energy consumption for R-474A versus R-744 in regards to the TAXI driving cycle under 35°C and 15°C condition as shown in Table 2 and Table 5. As mentioned, the powertrain consumption in our scenario is not dependent on the refrigerant and is therefore constant for the arithmetic impact of the refrigerant on the energy consumption.

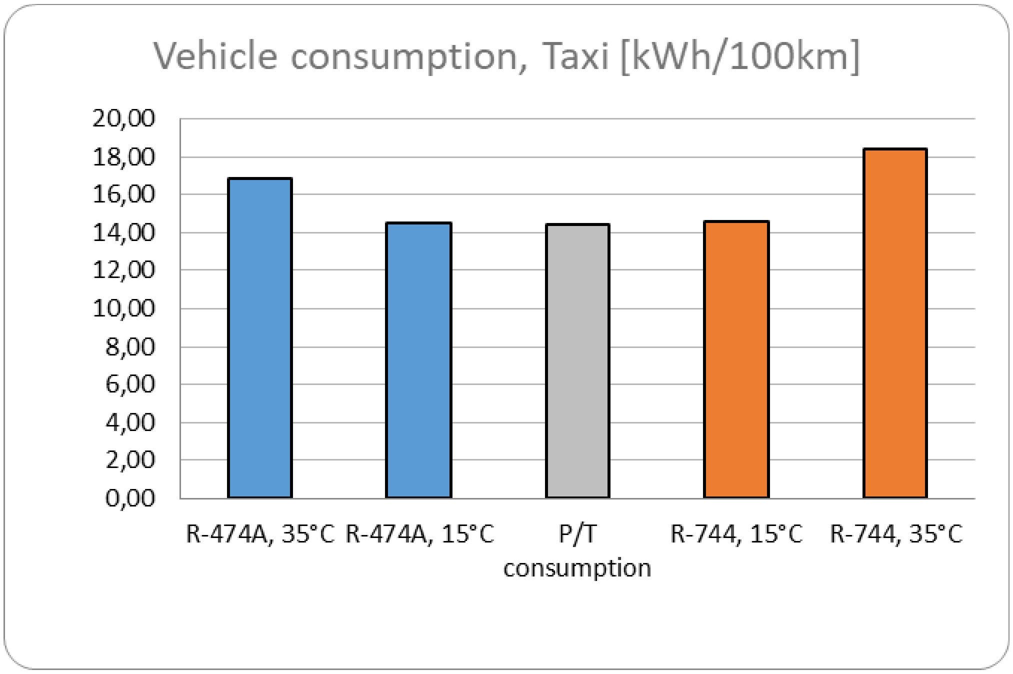

Figure 7. Energy consumption of thermal system with R-474A vs. R-744 at 15°C ambient temperature

For us as a refrigerant manufacturer, availability of detailed vehicle data is limited. For a comprehensive LCCP assessment considering stages like production, utilization, including the Well-to-Wheel (WtW), and recycling can only be done by the car manufacturers themselves. In addition, a complete LCCP requires detailed information about the related energy consumption of the thermal system throughout the complete temperature range considering the relevant temperature distribution in various regions.

Under consideration of the described results we strongly recommend investigating the impact of the thermal system efficiency dependency regarding the different refrigerants. Based on the existing results, we expect a heavy impact of a R-744 system on the vehicle efficiency not only at the described scenario but for a much wider range of use-cases of electric vehicles.

As an outlook regarding a future publication, we aim to extend the past evaluation of R-744 and R-474A under winter conditions in heat pump mode. Based on first test and simulation results, the refrigerant R-474A achieves at least the same performance like R-744 under HP conditions at low ambient temperatures. Upon the availability of a relevant range of results, the build-up of a comprehensive LCCP tool is the next logical step towards a holistic evaluation of the vehicle efficiency.

3.3 Implications on energy consumption and CO_2 equivalent emissions

In the previous section, we estimated the additional energy consumption of a BEV by switching from best-in-class R-474A to R-744. The next step is to calculate the CO_2 equivalent emissions related to the additionally required electrical energy for R-744.

The CO2 equivalent emissions (CO2eq) related to a defined energy consumption depends on the local energy mix. For an estimation of the related CO_2 equivalent emissions in the EU we relied on figures published in 2019[10] through a scientific paper by the European Commission[11]. The study states that in the EU the carbon emissions based on the energy mix at that time is 334gCO2eq/kWh.

With the results in Table 3 the use cases TAXI and WLTP are showing the necessity of additional 3,190MWh for taxis only in the Sevilla region during a 150-day-period at hot weather conditions. Assuming the current vehicle fleet in the Sevilla region to be completely replaced by BEVs in future, the additional required energy of 322GWh equals approximately 10% of the annual net output of the Borssele Nuclear Power Station in the Netherlands[12].

While remaining at the considered scenario of a 150-day-period with hot weather conditions in the region of Sevilla we can translate the higher energy consumption for a taxi fitted with a R-744 system to a CO_2 equivalent of 1,065t that are emitted more with R-744 than by the usage of R-474A. Changing the current Sevilla vehicle fleet to high efficient BEVs with a R-474A thermal system saves 107,548tCO2eq within the same 150 days under high temperature conditions. Scaling this figure over the whole southern european region, the total impact on CO2eq emissions can easily get on the order of magnitude of millions of tonnes.

[10] Eurostat. Electricity generation statistics - first results. Statistics Explained; 2020
[11] Scarlat, N. et al., Applied Energy, Quantification of the carbon intensity of electricity produced and used in Europe,2021, https://doi.org/10.1016/j.apenergy.2021.117901
[12] https://en.wikipedia.org/wiki/Borssele_Nuclear_Power_Station

The discussed results are based on the related assumptions and scenarios but show that the impact of the energy efficiency of a thermal system is important and relevant for the efficiency of the complete vehicle. Especially under consideration of an extrapolation of above data to the complete European vehicle fleet in future. Herewith we want to emphasize the impact of the thermal system in the overall energy efficiency of BEVs, and thus the importance of allowing high-efficient refrigerants as a contribution to the expected sustainability of the automotive industry. In our next submission we plan to provide a more exhaustive calculation of the estimated impact over all weathers and regions of Europe.

4. Analysis of socio-economic aspects

4.1 Socio-economic impact on European automotive industry

The transport sector in the EU includes the manufacturing of vehicles and their parts, components, and equipment. Furthermore, the automotive industry is of major importance to related upstream industries, amongst others the engineering, plastics and metal processing, and electronics. The automotive sector and its correlated sectors consist of 2.5 million jobs as direct automotive manufacturing employment equal to 8.4% of the total EU employment in manufacturing. Considering all jobs related to the automotive industry, the number increases to 13 million jobs equal to 7.0% of the total EU employment[13].

In addition, the majority of European car manufacturers (OEMs) have assembly plants in Europe exporting vehicles for global sales. In 2022 the EU production was 15.3% of the global vehicle production[14]. According to the European Automobile Manufacturers' Association (ACEA) the EU exports around 5.6 million passenger cars[15] equal to a value of €157.3 billion[16] as of 2022. Being forced to use a specific refrigerant not only for the European market but also for the global market will lead to a weakened

[13] https://www.acea.auto/figure/key-figures-eu-auto-industry/
[14] https://www.acea.auto/figure/key-figures-eu-auto-industry/
[15] https://www.acea.auto/figure/eu-passenger-car-exports-top-10-destinations-in-units/
[16] https://www.acea.auto/figure/eu-passenger-car-exports-main-destinations-by-value/

competitiveness compared to competitors with a broader choice of technologies with higher efficiencies and performances compared to the European OEMs.

Considering the scenario that the European OEMs will all introduce the refrigerant R-744, proposed in the PFAS dossier as being the only alternative that is implemented in a small-series for a few vehicles, the competitive situation in regions outside of Europe, where the ambient temperatures are comparable or higher than in Europe, will worsen compared to OEMs offering vehicles with a more performant and efficient refrigerant. As shown in previous chapters, the refrigerant R-744 is cooling at very low efficiency operating in transcritical conditions. This leads to higher energy consumption and thus to a reduced driving range. Consumers outside of Europe might then prefer vehicles with higher driving ranges and energy efficiency. Beyond the driving range factor, the vehicles with R-744 also have a bigger CO_2 footprint due to the lower efficiency.

Furthermore, a ban of R-1234yf will lead to high transition costs mainly for European OEMs that will also affect suppliers and the complete supply chain. Regarding the supply chain, strong disruptions are expected due to long product development and production process preparation.

Finally, resources for research and development would have to be allocated to R-744 without a positive impact on the environment.

4.2 Impact on consumers

First of all, we have shown that R-744 leads to serious limitations in performance when dealing with high ambient temperature conditions. This is a critical aspect that can have a severe impact in the speed of adoption of BEVs by consumers, if the vehicles are perceived as subpar, and in some cases, as impracticable. Let’s not forget that wide areas of Europe are facing increasingly hot weather, and a non-performing thermal system would result in limitations in situations such as vehicle conditioning at start-up, speed of battery charging in summer weather and the like.

For example, our benchmark test and especially the performed energy consumption assessment has shown that R-744 can reduce the acceptance of European customers due to several aspects.

Vehicles equipped with R-744 will have a higher carbon footprint that is contradictory to the common sense and goal to increase sustainability and reduce the carbon footprint in future. Potential customers that show awareness towards environmental protection will hesitate to purchase electric cars with a R-744 thermal system, taking into account that the sizes of battery packs in electric vehicles are limited due to the vehicle weight, and its cost, the negative impact on the driving range.

Even if a detailed evaluation requires the results of a LCCP assessment, an increased energy consumption can be translated to a reduced driving range. Considering the test results and the established energy evaluation tool outcome (see Table 3), for the VW ID.3 with the 58kWh battery, the driving range reduction at an ambient temperature of 35°C is approximately 18km under WLTP conditions.

The PFAS restriction proposal risks that the choice of technologies for automobile thermal systems is limited to R-744 causing high development and manufacturing costs. This will lead to higher prices of vehicles. This reduced affordability and thus reduced demand for new vehicles will affect particularly mid- and lower-income individuals. As a reference, due to various occurring crises and the resulting high inflation in the EU, the current automotive market slowed down by 4.6% in 2022 compared to 2021[17].

Facing the goal of carbon neutrality by 2050 in the EU, the contribution of each citizen is required. For that contribution, it is necessary to offer affordable products leading to a high market penetration.

5. Conclusion

The ban of R-1234yf and consequently R-474A as proposed in the current PFAS restriction dossier will limit the availability of technologies that increase the efficiency of thermal systems and thus of the complete vehicle. Existing test results and our efficiency evaluation tool are showing considerable demerits of R-744 systems with regard to both performance and efficiency. This leads to a higher use of energy and a reduction of acceptance by the market due to a reduced usability compared to current technologies.

[17] https://www.acea.auto/figure/new-passenger-car-registrations-in-units/

The paper shows that the assumed risk of the current refrigerant R-1234yf and its proposed ban is creating a negative effect opposite to the intention to protect the environment. A sustainable future must be achieved by the reduction of energy consumption increasing the efficiency of the related systems. We want to point out again that the energy consumption of the thermal system has a considerable impact on the environment as described in the previous chapter.

Therefore, we claim that such a ban would have a negative impact on the environment, but also on the rate of adoption of BEVs by end-users and on the competitiveness of the European automotive industry.

Additionally, the risk of R-1234yf described in the PFAS restriction proposal is based on the availability of refrigerant in the atmosphere. Beside the fact that during the lifetime state-of-the-art thermal systems have very low leakage rates, we see the focus on mitigations at the end-of-life of a vehicle. We propose adequate recovery and reclamation procedures to fully avoid any theoretical impact through uncontrolled gas release.

We expect to be able to share test and simulation results including the operation under low temperatures in heat pump mode as well as a comprehensive LCCP assessment in our next submission to this ongoing process to support the decision-making of the risk assessment committee (RAC) and the socio-economic assessment committee (SEAC).

That is why a time unlimited derogation for R-1234 use in automobile refrigerant for electric vehicles R-474A, combined with refrigerant leakage mitigation incentives, is the most reasonable approach in this case to support the rapid transition into low-emission BEVs in Europe.