Cutting refrigerant emissions

RECYCLING OF REFRIGERANTS FROM MOBILE AIR CONDITIONERS UNTERTITEL: METHODOLOGY AND RESULTS FROM A PILOT IN SOUTH CHINA

Climate and Ozone Protection Alliance (COPA)
Oktober 2024

CONTENTS

INTRODUCTION

As the world's largest producer, consumer, and exporter of refrigerants, China faces significant challenges in refrigerant recovery and reuse. The automotive repair industry is a key area for the use and recycling of refrigerants, but the recycling conditions in this sector segment need to be improved in China. If these gases are not properly recovered, recycled or destroyed, their release has a significant negative impact on the global climate. Consequently, the development, implementation, and validation of standardized processes for the recovery and recycling of refrigerants in this sector is crucial to both improve the efficiency of resource utilization and reduce the negative impact on the global climate and the environment.

This report explains the methodology developed for calculating the emission baseline and different emission scenarios for a pilot project in the Guangzhou region in China. Real data on refrigerant emissions from air conditioning systems in the automotive industry was collected as part of the project "Climate and Ozone Protection Alliance (COPA)", implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and funded by the German Federal Ministry for Economic Affairs and Climate Action under the International Climate Initiative (IKI). The pilot report is available in full length on the COPA website.

1 METHODOLOGY FOR THE CALCULATIONS OF THE BASELINE EMISSIONS

The methodology was developed for calculating the baseline emissions of passenger cars serviced at a workshop owned by the company Harson in the city of Guanzhong. In addition, the methodology covers the calculation of baseline emissions for all Harson workshops in Guangzhou and for all passenger cars in the Guangzhou metropolitan area. This methodology follows the principles of the IPCC Guidelines for National Greenhouse Gas Inventories[1] (IPCC, 2006). Two data collection campaigns in the Harson workshop, with a duration of 4-weeks each, took place between the months of May and Augst of 2024 in order to collect necessary data for the calculation of the baselines. The baseline is first calculated for the workshop where the data collection took place, as well as for all Harson workshops and then extrapolated to the Guangzhou metropolitan area. Moreover, different scenarios were developed to estimate the total emission reduction potential in the mobile air conditioning (MAC)[2] sector in the Guangzhou metropolitan area as well as in all Harson workshops. The emissions calculated for each scenario are compared in the results chapter to study the impact of the use of refrigerant recycling machines, proper training and other measures that can be applied in the MAC servicing sector in China. The MAC sector as referred to in this chapter includes only passenger cars for private use.

1.1 SCENARIOS

Four scenarios are considered for comparing results and calculating the baseline. These are Business as Usual (BAU), Workshop Scenario 1 (WS1), Workshop Scenario 2 (WS2) and Mitigation Scenario (MIT). WS 1 and 2 are based on the actual conditions of the workshop where the data collection campaigns (Phase 1 and 2) took place. The BAU scenario is based on the actual conditions of a regular auto repair shop in the country, where currently all refrigerant contained in the cars ACs is vented and replaced with virgin refrigerant. The MIT scenario is based on assumption that workshops follow international best practices for refrigerant management, this means using refrigerant recycling machines and safely storing and disposing of the used refrigerant that cannon be recycled. The possible leakage associated to the handling of refrigerants (not to the venting) is not considered in this study. The scenarios are characterized by the following practices and conditions:

- **BAU scenario:** As it is common in China and many other countries around the world, workshops do not have refrigerant recycling machines. Therefore, all the gas contained in the MAC unit of a vehicle is vented during the servicing. This occurs as the refrigerant cannot be properly cleaned (recycled) and the unit is refilled with virgin refrigerant until a full charge is reached.

- **WS1:** Workshop Scenario 1 reflects the conditions of the workshop in the time of the **first data collection campaig**n. The workshop had refrigerant recycling machines; however, no training had been conducted for the technicians to learn how to operate them. This could have led to irregular use of the machines depending on the technician. In addition, when the recycling machines were not in use, the refrigerant was vented.

- **WS2**: Workshop Scenario 2 reflects the workshop conditions at the time of the **second data collection campaign**. At this time, all technicians were trained in the proper use of the refrigerant recycling machines. Therefore, it is assumed that in all cases the refrigerant was recycled whenever possible. Only in cases where the refrigerant was too contaminated to be recycled it was assumed to be vented..

- **MIT scenario**: The mitigation scenario assumes that no refrigerant is vented in the workshops. Instead, all refrigerant is recycled or collected for reclamation (if recycling is not an option). This is an ideal scenario where direct refrigerant emissions from the workshop are zero and when all the refrigerant can be treated and reused.

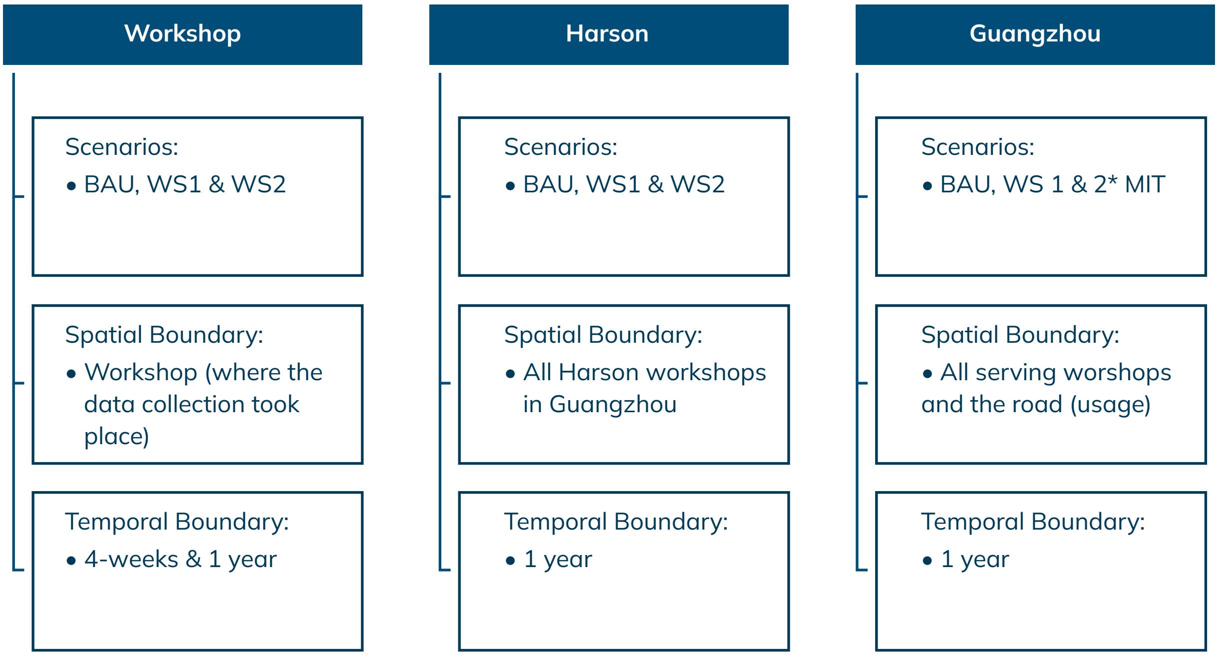
1 https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
2 In this case the sector consists of only passenger cars

1.2 BASELINE EMISSIONS CALCULATIONS AND STANDARDIZATION

The baseline (BL) is calculated under the assumption of the BAU scenario in order to estimate all the emissions that can be potentially reduced by introducing refrigerant recycling machines to servicing workshops and conducting proper training. In the BAU scenario, it is assumed that all the refrigerant contained in the vehicles is vented in the workshops and replaced with new refrigerant. Even though, it is not possible to collect data on the amounts of refrigerant vented in the workshops, as the gas is simply released from the vehicle and therefore cannot be weighted, data is available for these quantities because the recycling equipment has been in use since the start of the first data collection campaign and is able to measure the weight of the refrigerant being recycled. In addition, for the cases where the refrigerant was vented, an average value for the remaining charge of the vehicle was used. It is therefore assumed that the refrigerant contained in the vehicles serviced in the workshops is equal to the BL. For the calculation of the BL all the data collected was used, while the emissions on the WS1 and WS2 were calculated using data from only one of the data collection campaigns (respectively). The results were standardized by using the total number of cars that were used for the calculations of each scenario and the average number of cars serviced by the workshop on a 4-week period. This enabled a comparison of the results of the different scenarios.

An overview of the scenarios and the spatial and temporal boundaries is presented in *Figure 1*. This figure shows the three different scopes: the workshop, the Harson workshops and the Guangzhou metropolitan area. It is important to note that the spatial boundaries of the methodologies differ; for the workshop and Harson, only emissions that occur on-site are considered, while for the Guangzhou metropolitan area, both refrigerant leakage on the road and emissions in the workshop are included.

Figure 1: *Overview of the calculation's boundaries and scenarios*



* For the region of Guangzhou an average of the results of the WS1 and WS2 was used for the calculations

All variables calculated are presented in *Table 1*. In the following sections the methodologies for the calculation of emissions in the workshop and in the Guangzhou metropolitan area are presented separately. Note that the methodology for the workshop and for Harson is the same, therefore only the methodology for the workshop is presented. The text follows a logical calculation process where the emissions of the workshop are then upscaled to the metropolitan area using parameters and information from the Guangzhou metropolitan area. To calculate the emissions in carbon dioxide equivalent units (CO_2eq), the kilograms of refrigerant are multiplied by the Global Warming Potential[3] (GWP) of each refrigerant. The average charge of the cars surveyed in this study is 0.8 kg. In this case only the refrigerant HFC-134a is considered. This HFC has a GWP value of 1530 kgHFC-134a/kgCO_2eq (IPCC, 2022).

Table 1: *Variables calculated in the pilot project*

N°	Variables	Name	Units	Sepcial Boundaries	Temporal Boundaries	Data Sources
1	R_{cryl}	Refrigerant vented	kg	Workshop	4 weeks	Measured with refrigerant recycling machines. Data collection campaigns
2	R_{vent}	Refrigerant vented	kg	Workshop	4 weeks	Calculated using the measurements from the refrigerant recycling machines. Data collection campaigns
3	VR	Virgin refrigerant needed for servicing	kg	Workshop	4 weeks, 1 year	Data collection campaigns
4	Em	Refrigerant emissions	CO_2eq	Workshop	4 weeks, 1 year	Calculated using the measurements from the refrigerant recycling machines. Data collection campaigns
5	BL_{BAU}	Baseline emissions	CO_2eq	Workshop	4 weeks, 1 year	Estimation based on data
6	AvEm	Total avoided emissions	CO_2eq	Workshop	4 weeks, 1 year	Estimation based on data
7	PR_{rcov}	Potential refrigerant for recovery	Kg	Workshop	4 weeks, 1 year	Theoretical variable for MIT scenario
8	BL_{mac}	Baseline emissions	kg, CO_2eq	Guangzhou*	1 year	Extrapolation using data from Harson
9	Em_{mac}	Refrigerant emissions	kg, CO_2eq	Guangzhou*	1 year	Extrapolation using data from Harson
10	Em_{w}	Workshops refrigerant emissions	kg	Guangzhou*	1 year	Extrapolation using data from Harson
11	Em_{road}	Refrigerant emission on the road	kg	Guangzhou*	1 year	Extrapolation using data from Harson
12	PRR_{mac}	Potential refrigerant for recycling	kg	Guangzhou*	1 year	Extrapolation using data from Harson
13	VR_{mac}	Virgin gas needed for servicing	kg	Guangzhou*	1 year	Extrapolation using data from Harson
14	$AvEm_{mac}$	Total avoided emissions	kg	Guangzhou*	1 year	Extrapolation using data from Harson

* This refers to all the emissions of passenger cars in the city. This includes the emission due to leakage during operation (emission on the road) and emissions in the workshop during servicing.

3 The GWP values used for the calculation are taken from the IPCC Sixth Assessment Report

1.3 METHODOLOGY OF BASELINE EMISSIONS CALCULATIONS IN THE WORKSHOP

The recycled refrigerant is calculated for a 4-week period by summing all relevant data collected during each of the campaigns. This is calculated using **Equation 1**, which is the sum of all the refrigerant recycled that was reported by the technicians. In this equation "n" is the total number of cars serviced in the workshop during the data collection period and "i" is each entry.

Equation 1 $$R_{rcy} = \sum_{i=1}^{n} R_{recycled,i}$$

Similarly, **Equation 2** and **Equation 3** are used to calculate the refrigerant vented and the virgin refrigerant used in the workshops. All three variables are calculated in kilograms for each data collection campaign, corresponding to the WS1 and WS2, described above. To calculate these variables for a 1-year period, the total number of vehicles serviced in the workshop during this period could be used. This data was provided directly by Harson.

Equation 2 $$R_{vent} = \sum_{i=1}^{n} R_{vented,i}$$

Equation 3 $$VR = \sum_{i=1}^{n} R_{virgin,i}$$

The refrigerant emissions are calculated using **Equation 4**. This variable is calculated for a period of 4 weeks (corresponding to the duration of a data collection campaign) and then multiplied by the GWP value of R134a to obtain the emissions in CO_2eq. The emissions in the workshop equal the refrigerant vented, as it can be seen in the equation.

Equation 4 $$Em = R_{vent} \times GWP$$

As explained above, the calculated emissions for the BAU scenario are considered as the baseline (BL). In this scenario, it is assumed that all the refrigerant contained in the vehicles is vented in the workshops and replaced with new refrigerant. The baseline is calculated using **Equation 5**, where Q_{ref}, the amount of refrigerant vented, is multiplied by the GWP value of the refrigerant. in this case by 1530 kgHFC-134a/kgCO_2eq. It is important to note that the emissions that occur on the road (leakage) are not considered, nor are emissions from leakage during the handling of refrigerant in the workshop.

Equation 5 $$BL_{BAU} = Q_{ref} \times GWP$$

In addition, the avoided emissions are calculated using **Equation 6**, which compares the baseline emissions (BL_{BAU}) with the emissions calculated for each scenario (Em). This calculation makes it possible to determine the effectiveness in terms of emission reduction of each measure that was taken during the project[4]. The equation also serves to estimate the impact of best practice (MIT scenario), where all refrigerant is recycled or recovered.

Equation 6 $$BvEm = BL_{BAU} - Em_{scenario}$$

4 Measures applied during the pilot project include introducing refrigerant recycling machines and conducting training for their proper use..

Lastly, **Equation 7** is used to calculate all the refrigerant that could be recovered from the workshops. Currently, the workshops do not have the capacity to recover and store refrigerant for safe disposal or reclamation, they can only recycle in-situ. This always some refrigerant left that could not be recycled due to poor quality. However, if sector best practices are followed, all the used refrigerant in the workshops will be recycled, reclaimed or properly disposed of (destroyed).

Equation 7 $$PR_{rcov} = R_{vent}$$

1.4 METHODOLOGY OF BASELINE EMISSIONS CALCULATIONS IN THE GUANGZHOU METROPOLITAN AREA

As it was previously mentioned, some of the variables that are calculated for the Harson workshop are also calculated for the Guangzhou metropolitan area. This is carried out by using the parameters shown in *Table 2*. The initial charge and the leakage rate were calculated using the data collected during the campaigns and compared with the data provided by Harson. These two parameters are an average of passenger cars in the metropolitan area, which are the type of vehicles serviced in the Harson workshops. The number of cars and the frequency of servicing were provided by Harson.

Table 2: *Parameters for upscaling variables to the Guangzhou metropolitan area*

N°	Parameters	Name	Value	Units	Source
1	IC	Initial refrigerant charge	0.8	kg	Estimated using the data collected and data provided by Harson
2	LR	Annual leakage rate	4.1	%/year	Estimated using the data collected and data provided by Harson
3	n_c	Number of passenger cars in Guangzhou	2,800,000	N° of unites	Harson
4	S_y	Servicing frequency	6.5	Years	Harson
5	E_r	Emissions on the road relative to the initial charge during the servicing frequency period (6.5 years)*	27	%	Estimated using the data collected and data provided by Harson

* This parameter represents the emissions during the servicing frequency period (S_y) and is used to calculate the annual leakage rate (LR) by dividing it by S_y.

Equation 8 is used to estimate the baseline emissions in the BAU scenario for the Guangzhou metropolitan area. Here it is assumed that the total number of cars (n_c) emit their entire initial refrigerant charge (IC) during the servicing frequency-period (S_y), which in this case is 6.5 years. This assumes that any refrigerant that has not been leaked on the road during that period is then vented in the workshop.

Equation 8 $$BL_{mac} = n_c \times \frac{IC_{avg}}{S_y}$$

In the WS1 and WS2, some of the emissions are avoided through the recycling of refrigerant at the workshops during the servicing of the cars. **Equation 9** is used to calculate the emissions of the passenger cars in the Guangzhou metropolitan area for these scenarios. This equation is the sum of the emission that occur on the road due to refrigerant leakage (Em_{road}) and in the workshops when the refrigerant is vented (Em_W). **Equation 10** uses the initial charge, the leakage rate and the total number of vehicles to estimate the annual emissions that occur on the road. This differs from previous emissions calculated in the last subchapter, where the special boundary was restricted to the workshops.

Equation 9 $$Em_{mac} = Em_{road} + Em_{w}$$

Equation 10 $$Em_{road} = n_c \times IC_{avg} \times LR$$

Em_W are the emissions that occur in the workshops during the servicing of the vehicles. These emissions are zero on the MIT scenario and are calculated for the WS1 and WS2 scenarios using **Equation 11**, where all the potential refrigerant available for recycling (PRR_{mac}) is multiplied by a factor expressed as a percentage. This factor is calculated by dividing the total refrigerant recycled during the 4-week data collection period by the total amount of used refrigerant handled in the workshops. This total is the refrigerant recycled plus the vented one[5]. Moreover, the potential refrigerant for recycling is calculated using **Equation 12**. This is all the refrigerant left in the vehicles when they arrive in the workshop, and it is calculated by estimating the number of vehicles that are serviced every year $\frac{n_c}{S_y}$ times all the refrigerant that they contained.

Equation 11 $$Em_{w} = PRR_{mac} \times \left(\frac{R_{vent}}{R_{rcyl} + R_{vent}} \right)$$

Equation 12 $$PRR_{mac} = \frac{n_c}{S_y} \times \left(IC_{avg} - IC_{avg} \times E_r \right)$$

As explained before **Equation 8** and **Equation 9** calculate the total refrigerant lost by the vehicles on the road and in the workshops (emissions). Any refrigerant emitted would have to be replaced with virgin refrigerant () in the workshops. Therefore, **Equation 13 (a)** is valid for the BAU scenario and **Equation 13 (b)** for the other three WS1, WS2 and MIT.

Equation 13 (a) $$VR_{BAU} = BL_{mac}$$ (b) $$VR = Em_{mac}$$

Finally, **Equation 14**, similar to **Equation 6**, is used to calculate the emissions avoided in each of the scenarios by comparing them to the passenger cars baseline emissions (BL_{mac}) in the Guangzhou metropolitan area.

Equation 14 $$AvEm_{mac} = BL_{BAU} - Em_{mac}$$

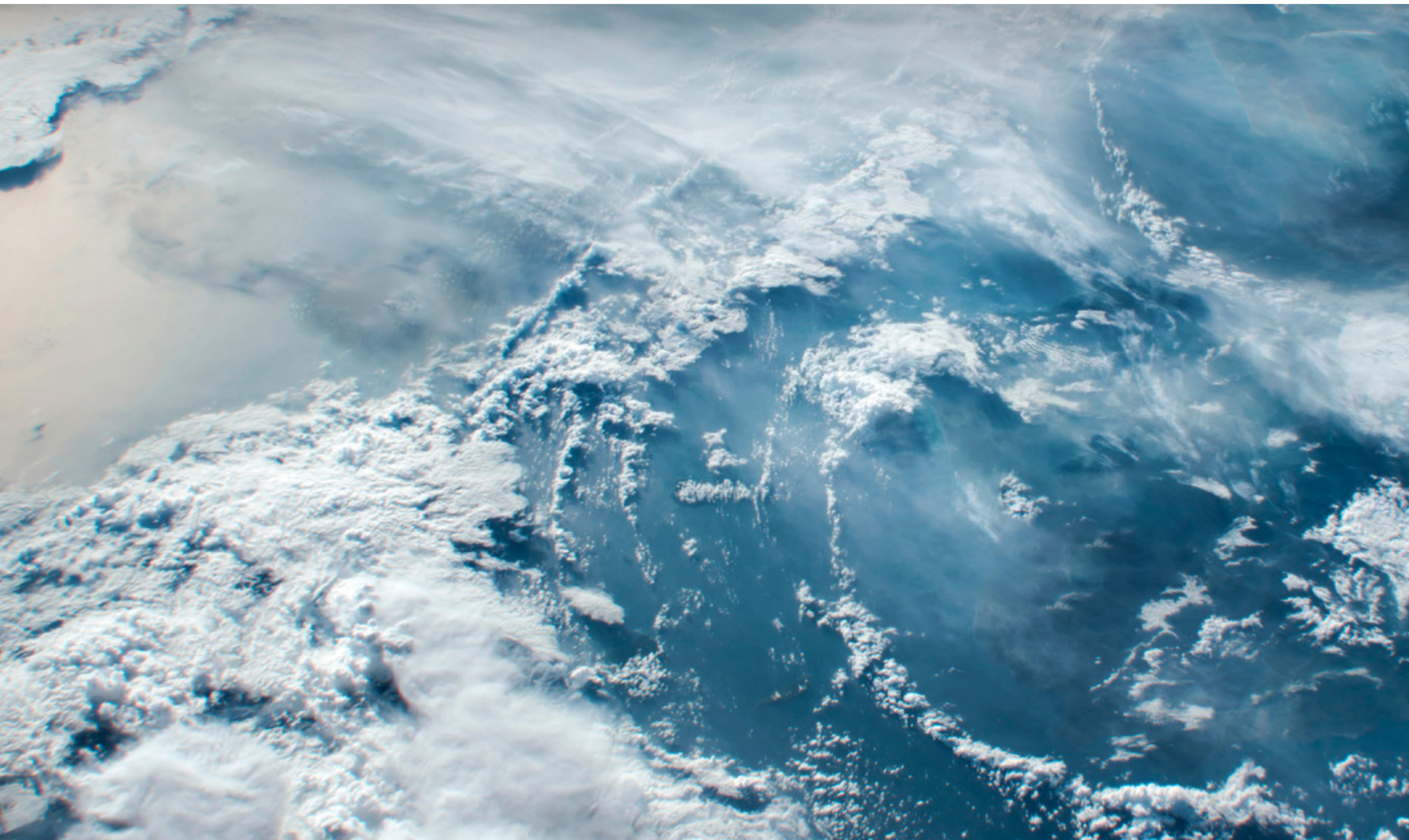
5 This factor is calculated using the average of the two data collection campaigns.

1.5 DATA AND CALCULATIONS UNCERTAINTIES

In accordance with the IPCC Guidelines for National Greenhouse Gas Inventories[6] for the calculation of emissions in the refrigeration and air conditioning (RAC) sector, uncertainties related to the data and the calculations are presented here.

The data collection, errors can occur when entering information into the spreadsheets, as well as due to misunderstandings on the use of the templates. However, to avoid errors and reduce uncertainties as much as possible, the data collection process was refined through a 4-week trial in which the template and the data collected were reviewed and modifications to the process were made. On the other hand, there is an uncertainty associated with the data collection because of the short period surveyed (4-weeks). This data collection process could miss changes in seasonality and temperature. For example, the number of cars serviced in workshops is expected to fluctuate with the need for air conditioning and therefore with ambient temperature. It is also important to note that the leakage (not the venting) during the handling of refrigerant in the workshops is not considered. Therefore, workshop emissions might be slightly underestimated, as this source is not included. Finally, the parameters (e.g. initial charge, leakage rate) used for calculating the variables for the Guangzhou metropolitan area are based on data from Harson and the surveys, which mainly services larger, higher-end European cars, which are more expensive in China than other brands. This is a potential source of data-errors as Harson does not service the full range of passenger cars in the metropolitan area. Other parameters such as the total number of cars in the metropolitan area are estimates.

6 *https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html*



2 RESULTS OF THE CALCULATIONS: BASELINE AND EMISSIONS

This chapter presents the results of the calculations, differentiated for the workshops and the Guangzhou metropolitan area. A comparison is made between the baseline emissions (BAU scenario) and those of the WS1 and WS2 and the mitigation scenario (MIT). However, to avoid redundancy the MIT scenario is not shown for the workshop emissions. For the metropolitan area of Guangzhou an average of the WS1 and WS2 is presented.

2.1. WORKSHOP BASELINE AND EMISSIONS

As explained in the methodology, the results were standardized using the average number of cars serviced in the workshop per day and in a 4-week period. These are shown in Table 3. Results were divided by the total number of cars that were used in the calculations of the emissions for each scenario and then multiplied by 19 (the average number of cars on a 4-week period).

Table 3: *Standardizing Parameters*

N°	Name	Value	Units	Source
1	Number of cars serviced per day at the workshop	0.67	N° of unites	Estimated using the data collected
2	Number of cars serviced in a 4-week period at the workshop	19	N° of unites	Estimated using the data collected
13	Number of cars serviced in a year in the workshop	180**	N° of unites	Data provided by Harson

* This value is calculated based on the data collected and therefore does not represent an annual average.
** In 2023 the average number of vehicles that were serviced at this workshop per month was 15.

During the data collection period (May to August) the average number of vehicles serviced was higher than the monthly average (15 vehicles). This because the air conditioning systems are used most frequently in the warmer months. The number of vehicles serviced per month in 2023 are shown in *Figure 2*. In 2023 the period from April to September had a higher number of vehicles serviced in the workshop than during the period from October to March. If the period from April to September is used to calculate the average number of cars serviced per month, the result is 19. This is the same number found for a 4-week period (shown in *Table 3*) using the data collected.

The number of cars used for the calculations for each scenario are presented in *Table 4* together with the results. In *Table 4* the baseline emissions calculated for the BAU scenario are 9.5 kg of R134a representing 14,481 kgCO_2eq. This scenario assumes that the refrigerant recycled is zero, as it is common in most workshops in China that service the MAC sector. In total, 13.1 kg of virgin refrigerant are needed in this scenario to service all the cars in a 4-week period. On the contrary, in the WS1 9.3 kg of refrigerant are recycled leading to only half a kilogram of emissions (776,3 kgCO_2eq). In the WS2 8.5 kg of R134a are recycled with a total emission of 0.7 kg (1051,2 kgCO_2eq). On the other hand, the annual emissions of the workshop are 90.8 kg in the BAU scenario. These emissions amount in the WS1 and WS2 scenarios 4.9 kg and 6.6 kg respectively. This reduction results into 131,410 kgCO_2eq and 128,774 kgCO_2eq of saved emissions in the WS1 and WS2 scenarios in one year.

Figure 2: *Vehicles serviced in the workshop for the year 2023*

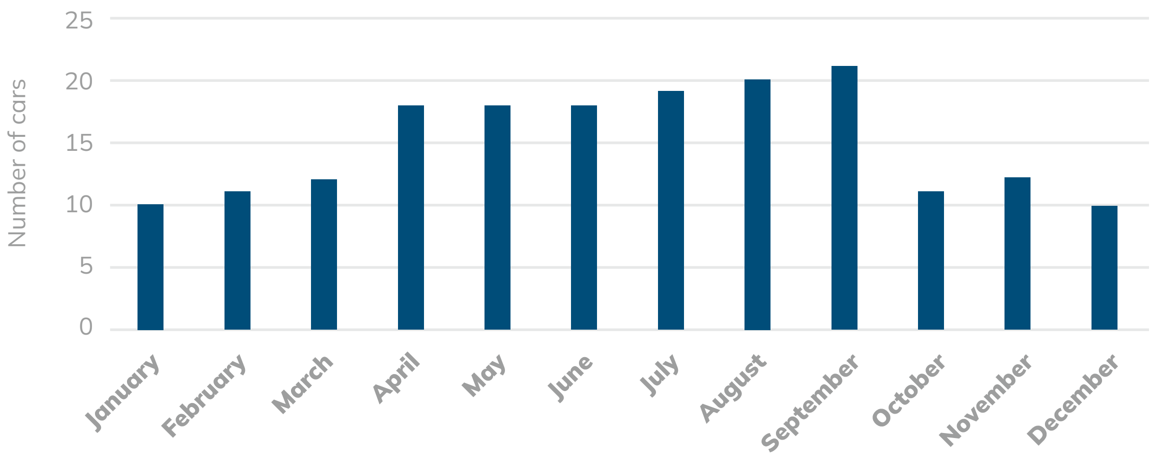


Table 4: *Baseline and emissions results for the workshop*

Variable	BAU Scenario (Baseline)	Workshop Scenario 1	Workshop Scenario 2
Start date	09.05.2024	27.05.2024	08.07.2024
End date	04.08.2024	23.06.2024	04.08.2024
Number of days	88	28	28
Number of weeks	12.57	4.00	4.00
Number cars surveyed	59	13	24
Cars surveyed per day	0.67	0.46	0.86
Standardized results 4-week period			
Refrigerant recycled (R_{rcyl})	0 kg	9.3 kg	8.5 kg
Virgin refrigerant (VR)	13.1 kg	3.8 kg	4.6 kg
Refrigerant emissions (Em) or Potential refrigerant for recovery (PR_{rcov})*	0 kg	9.3 kg	8.5 kg
Refrigerant emissions (Em)	**14,481 $kgCO_2eq$ (BL)**	**776 $kgCO_2eq$**	**1051 $kgCO_2eq$**
Total avoided emissions (AvEm)	**-**	**13,705 $kgCO_2eq$**	**13,430 $kgCO_2eq$**
Standardized results 1 year			
Refrigerant recycled (R_{rcyl})	0 kg	88.9 kg	81.4 kg
Virgin refrigerant (VR)	125.6 kg	36.7 kg	44.1 kg
Refrigerant emissions (Em) or Potential refrigerant for recovery (PR_{rcov})*	90.8 kg	4.9 kg	6.6 kg
Virgin refrigerant (VR)	**138,853 $kgCO_2eq$ (BL)**	**7,443 $kgCO_2eq$**	**10,079 $kgCO_2eq$**
Total avoided emissions (AvEm)	**-**	**131,410 $kgCO_2eq$**	**128,774 $kgCO_2eq$**

* The refrigerant emissions (Em) equal the potential refrigerant for recovery (PRrcov), because, in this case the emissions are counted only as the vented refrigerant in the workshop. This is exactly the refrigerant that can be recovered (*See Equation 7*).

The WS1, as mentioned, above uses the data collected on the first campaign when the workshop had already access to new refrigerant recycling machines. However, the emissions are slightly lower than in the WS2 which occurred after the technicians had received proper training. In total, of the 13 vehicles serviced during the first data collection campaign only the refrigerant of one of them was vented. This can be compared to the 24 vehicles serviced during the second data collection campaign, where the refrigerant of two of them was vented. One possible explanation for the venting of refrigerant is that, in these three cases, the refrigerant was too polluted to be recycled. In addition, it should be considered that the first data collection campaign happened a month after the data collection process started. The first 4 weeks were used to refine the templates and make sure all technicians knew how to collect the data properly. This period, consequently, allowed the technicians to learn how to (informally) use the machines properly which resulted in an outstanding rate of refrigerant recycling from the beginning of this pilot and the data collection process.

2.2 HARSON BASELINE AND EMISSIONS

The baseline and emissions are presented in *Table 5* for the Harson workshops over a 1-year period. The refrigerant recycled in the workshop over this period is 677 kg for the WS1 and 620 kg for the WS2. Compared to the BAU scenario, where the annual emissions are 692 kg, the Harson workshops annual emissions on the WS1 and WS2 scenarios amount to 37.1 kg and 50.2 kg respectively. In total the annual emissions that can be avoided by installing refrigerant recycling machines in all the workshops owned by Harson ranges from 981,900 kgCO_2eq to 1 million kgCO_2eq (these are the results for the WS2 and WS1 respectively). In these scenarios, approximately 6% of the refrigerant that is still vented, could be recovered and safely disposed of or reclaimed, avoiding an additional 66,000 kg of CO_2eq emitted per year.

Table 5: *Baseline and emissions results for the Harson workshops (1-year period)*

Variable	BAU Scenario (Baseline)	Workshop Scenario 1	Workshop Scenario 2
Refrigerant recycled (R_{rcyl})	0 kg	677.8 kg	620.7 kg
Virgin refrigerant (VR)	957.7 kg	279.7 kg	336.1 kg
Refrigerant emissions (Em) or Potential refrigerant for recovery (PR_{rcov})*	692.0 kg	37.1 kg	50.2 kg
Refrigerant emissions (Em)	**1,058,757 kgCO_2eq**	**56,755 kgCO_2eq**	**76,856 kgCO_2eq**
Total avoided emissions (AvEm)	**-**	**1,002,001 kgCO_2eq**	**981,901 kgCO_2eq**

2.3 GUANGZHOU METROPOLITAN AREA BASELINE AND EMISSIONS

The baseline and the emissions for the metropolitan area of Guangzhou are presented in *Table 5* for the BAU, WS 1 & 2 and MIT scenarios. The annual emissions from all passenger cars in Guangzhou are estimated to be 527,261 tCO_2eq (344,615 kg). This total figure is the result of 92,360 kg of refrigerant leakage on the road (27%) and 252,255 kg of refrigerant vented in the workshops (73%). This figure clearly shows that the emissions that occur in the workshops, due to the venting of refrigerant, are more than two times higher than the refrigerant leakage happening on the road. Therefore, the most critical point for reducing refrigerant emissions of passenger cars in China is by addressing the refrigerant servicing practices of the workshops. Moreover, the emissions on the WS 1 & 2 are 165,772 tCO_2eq (108,348 kg) which is slightly less than a third of the baseline. This reduction of emissions is achieved thanks to the amount of refrigerant recycled (236,268 kg) on the scenarios WS 1 & 2.

Table 6: *Baseline and emissions results for the metropolitan area of Guangzhou*

Variable	BAU Scenario (Baseline)	Workshop Scenarios 1 & 2 (average)	Mitigation Scenario (MIT)
Refrigerant recycled (R_{rcyl})	0 kg	236.268 kg	252,255 kg*
Refrigerant emission in the workshops Em_w	252,255 kg	15,988 kg	0 kg
Refrigerant emission on the road Em_{road}	92,360 kg	92,360 kg	92,360 kg
Refrigerant emissions (Em_{mac}) or Virgin refrigerant (VR)**	344,615 kg (BL)	108,348 kg	92,360 kg
Refrigerant emissions (Em_{mac})	**527,261 tCO_2eq (BL)**	**165,772 tCO_2eq**	**141,311 tCO_2eq**
Total avoided emissions ($AvEm_{mac}$)	-	**361,489 tCO_2eq**	**385,950 tCO_2eq**

* This also represents the refrigerant that is reclaimed in cases where recycling in-situ is not possible.
** As shown in Equation 13 the refrigerant emissions (Em_{mac}) equal the virgin refrigerant (VR).

The MIT scenario assumes that all refrigerant that arrives in the workshops is recycled or reclaimed. Thus, in this scenario the emissions only occur on the road equivalent (as explained above) to a total of 141,311 tCO_2eq emitted every year. It is important to mentioned that the MIT scenario is theoretical and that some refrigerant might be also too polluted to be reclaimed. However, it shows that if all workshops in the metropolitan area of Guangzhou reach the high rates of refrigerant recycling seen during the data collection campaigns, the reduction will be very significant, as the difference of emissions between WS 1 & 2 and MIT is only 6%.

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COPA
Cutting refrigerant emissions

Implemented by:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

In cooperation with:
UNIDO
UNDP

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
IKI INTERNATIONAL CLIMATE INITIATIVE

Imprint

Published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Design
creative republic || Thomas Maxeiner Communications
Frankfurt a. M. / Germany

On behalf of
The German Federal Ministry for Economic Affairs and Climate Action (BMWK)

Status
October 2024

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