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Reducing emissions from mobile air conditioning: Policy opportunities for China

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Background

Mobile air conditioning (MAC) systems are a significant source of greenhouse gas (GHG) emissions. An estimated 3%–7% of all fuel used by the global light-duty fleet goes to running MAC systems.[1] GHG emissions from MAC include direct and indirect emissions. As shown in Figure 1, direct emissions are related to the production, use, maintenance, and scrappage of MAC refrigerants, including hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs).

For vehicles with internal combustion engines, indirect emissions are released when fuel is consumed to run the air conditioning; these include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and black carbon.[2] Electric vehicles also consume more energy during MAC operations, creating indirect emissions from the generation of electricity to charge EV batteries.

Regulators have taken a variety of actions to address indirect emissions from MAC systems. The United States has implemented incentives to improve the energy efficiency of MACs. The European Union will give credit toward emission-reduction targets to manufacturers who use "eco-innovation" technologies to make MAC systems more efficient, beginning in 2025.[3] China has provided fuel-consumption incentives for high-efficiency MACs in its fuel-consumption regulations for passenger vehicles. Recently, China announced the goal of a peak in carbon emissions by 2030 and carbon neutrality by 2060.

1 Kate Blumberg, Aaron Isenstadt, Kristen N. Taddonio, Stephen O. Andersen, and Nancy J. Sherman, "Mobile Air Conditioning: The Life-Cycle Costs and Greenhouse-Gas Benefits of Switching to Alternative Refrigerants and Improving System Efficiencies," (ICCT: Washington, D.C., 2019), https://theicct.org/publication/mobile-air-conditioning-the-life-cycle-costs-and-greenhouse-gas-benefits-of-switching-to-alternative-refrigerants-and-improving-system-efficiencies/.

2 Blumberg, Isenstadt, Taddonio, Andersen, and Sherman, "Mobile Air Conditioning."

3 European Union, "Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 Setting CO_2 Emission Performance Standards for New Passenger Cars and for New Light Commercial Vehicles, and Repealing Regulations (EC) No 443/2009 and (EU) No 510/2011," *Official Journal of the European Union*, L 111/13 (25.4.2019), https://eur-lex.europa.eu/eli/reg/2019/631/oj/eng.

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For direct emissions, both the United States and the European Union have implemented bans on high global warming potential refrigerants for MACs.[4] China's ratification of the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer took effect in September 2021. Under the agreement, China will phase down the production and use of HFCs.[5] Policies that more directly promote MAC innovation can help China meet both its carbon-neutrality goals and its commitments under the Kigali amendment. A review of international best practices shows there are policy opportunities for reducing GHG emissions—in both conventional and electric light-duty vehicles (LDVs)—through the development of more efficient MAC systems and alternatives to HFCs.

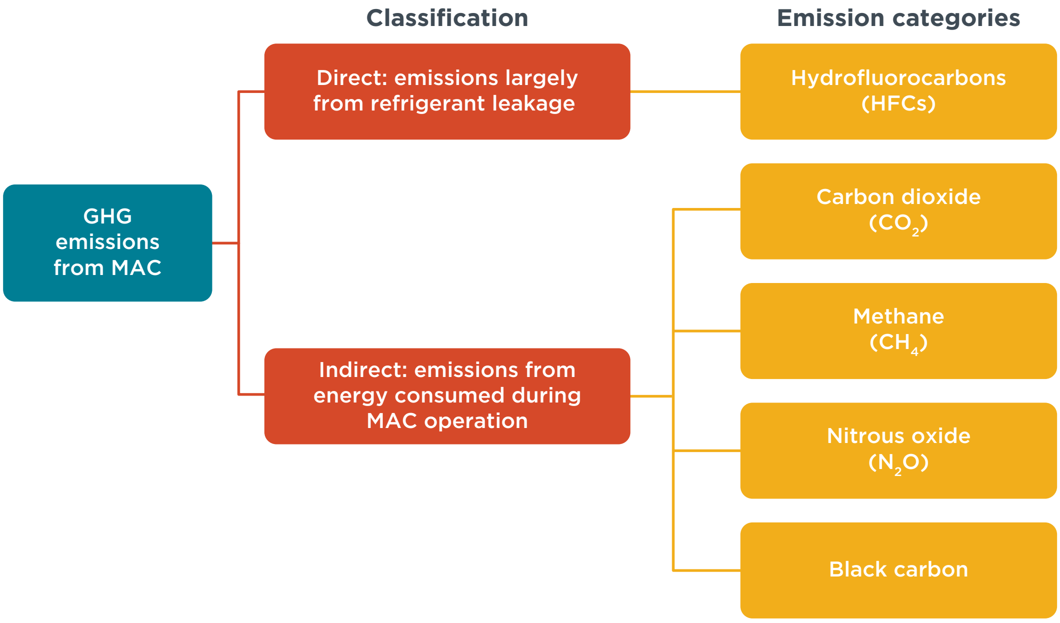

Figure 1. Composition of greenhouse gas emissions from mobile air conditioning systems. Figure adapted from Yang et al., "Measures for Reducing Greenhouse Gas Emissions From Motor Air Conditioning in China."

This paper is a follow-up study of a previous ICCT paper on reducing GHG emissions from MACs in China. The previous paper introduced the types and sources of GHG emissions from MACs, detailed emission-reduction measures, reviewed international regulations for controlling direct and indirect emissions, and described the status and challenges of developing MAC technologies and refrigerants in China.[6] This paper focuses on light-duty passenger vehicles and reviews the technical details of international regulations and testing protocols for indirect emissions from LDVs. After identifying international best practices and policy opportunities in China, the paper provides policy recommendations for the development of testing protocols and regulations for MAC-related GHG emissions from LDVs in China.

4 Luihanzi Yang, Hui He, Yihao Xie, Shiyue Mao, Jiabao Ren, Chaoqian Wang, Dong Ma, Jie Yin, and Qian Wu, "Measures for Reducing Greenhouse Gas Emissions From Motor Air Conditioning in China. (ICCT: Washington, D.C., 2022), https://theicct.org/publication/mac-ghg-china-lvs-feb22/.

5 Ministry of Ecology and Environment of the People's Republic of China. "China has Officially Accepted the Montreal Protocol on Substances that Deplete the Ozone Layer (Kigali Amendment)," 2021, https://www.mee.gov.cn/xxgk/hjyw/202106/t20210621_841062.shtml

6 Yang, He, Xie, Mao, Ren, Wang, Ma, Yin, and Wu, "Measures for Reducing Greenhouse Gas Emissions From Motor Air Conditioning in China."

Impact of mobile air conditioning operations on CO_2 emissions and electric energy consumption

Greenhouse gas emissions associated with MAC systems are dominated by indirect emissions, which account for about 81%–88% of the GHG emissions from MAC systems.[7] For this study, we performed a literature review of the impact of MAC operations on fuel consumption and CO_2 emissions from conventional and battery electric light-duty electric vehicles. For conventional LDVs, MAC only has an effect when it is used for cooling because combustion engines create waste heat that can be used to keep vehicle interiors warm. However, MAC systems in battery electric LDVs must be used for both cooling and heating the vehicle interior while also controlling the temperature of the battery itself. Previous energy-consumption studies focused mostly on MAC operations under laboratory testing conditions. In this study, we summarize the results from some of the few studies that have evaluated the impact of MAC operations under real-world driving conditions.

For conventional, internal-combustion powered LDVs, Zhang et al. collected more than 1 million real-world driving records in China from a consumer-reported fuel-consumption database. The analysis found that using MAC in hot weather (>25°C) accounted for a 1.3% increase in total fuel consumption.[8] In the United States, Khan and Frey tested the fuel consumption of 78 vehicles with the air conditioning off and 55 vehicles with the air conditioning on using a portable emissions measurement system and on-board diagnostics under real-world driving conditions. The testing, carried out over a wide range of driving conditions, found that the fleet-average fuel-efficiency penalty for using MAC varies from 1.3% to 7.5%.[9]

For electric LDVs, Jin, Wang, and He analyzed the real-world energy consumption of 10 best-selling battery electric passenger car models in China from 2017 to the end of 2021.[10] The total sample size was 140,000 vehicles. In the study, the impact of ambient temperature on real-world energy consumption was evaluated. Figure 2 shows the real-world energy consumption percent difference from nominal values under different ambient temperatures by vehicle model. In “very cold” conditions, energy consumption increased by 40% to 90%, and in “cold” conditions energy consumption increased 30% to 65%. The impact of “hot” conditions was less significant, with the increase in energy consumption staying under 20%. Unfortunately, the energy consumption data analyzed in this study did not include whether the MAC was in use. Nevertheless, the results indicate that the impact of MAC on real-world energy consumption of battery electric LDVs is significant and that the impact from heating the vehicle in cold weather is more significant than the impact from cooling the vehicle in hot weather.

The studies discussed above indicated that indirect GHG emissions from MAC systems in light-duty vehicles are significant. Furthermore, MAC operations increase energy consumption more in electric vehicles (in part to help control battery temperature) than in conventional vehicles.

7 Blumberg, Isenstadt, Taddonio, Andersen, and Sherman, “Mobile Air Conditioning.”

8 Da Zhang, Jun Gao, Ding Tang, Xiaomeng Wu, Junye Shi, Jiangping Chen, Yinghong Peng, Shaojun Zhang, Ye Wu, “Switching on Auxiliary Devices in Vehicular Fuel Efficiency Tests Can Help Cut CO_2 Emissions by Millions of Tons,” *One Earth*, 4, No. 1 (January 22, 2021): 135-145, https://doi.org/10.1016/j.oneear.2020.12.010.

9 Tanzila Khan and H. Christopher Frey, “Effect of Air-Conditioning on Light Duty Gasoline Vehicles Fuel Economy,” *Transportation Research Record*, 2673, No. 5 (May 2019): 131-141, DOI: 10.1177/0361198119838507.

10 Lingzhi Jin, Shuo Wang, and Hui He, “Real-World Performance of Battery Electric Passenger Cars in China,” (ICCT: Washington, D.C., 2023), https://theicct.org/publication/pv-china-real-world-performance-apr23/.

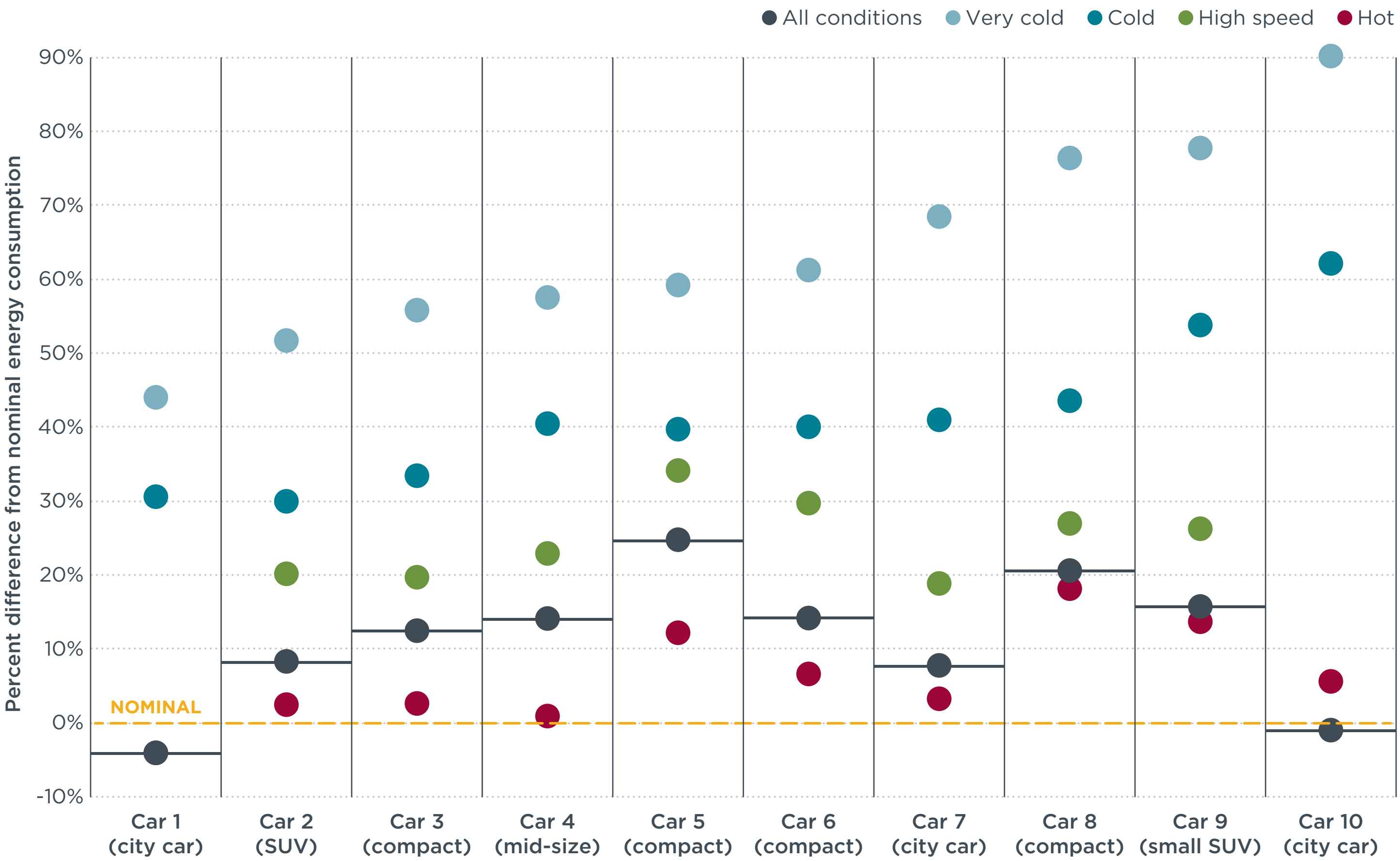

Figure 2. Variation in real-world energy consumption by 10 types of battery-electric vehicles under different weather and driving conditions. Circles mark the percent difference from nominal or average consumption, shown as the yellow line. "All conditions" represents all the data collected in all driving conditions.

Policy developments in the United States, European Union, and China

MAC greenhouse gas regulations and test procedures in the United States

There are four types of regulations that contain test procedures for MAC systems of light-duty vehicles in the United States: pollutant emissions standards, GHG emissions standards, fuel economy standards, and fuel economy labeling programs. As this paper focuses on controlling greenhouse gas emissions from MACs, this section introduces the technical details of the U.S. GHG emission standards for LDVs.

In 2009, the Corporate Average Fuel Economy standards, which set miles-per-gallon targets, were expanded to include GHG emissions for LDVs. The joint rulemaking by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation set a limit on grams of CO_2 emissions per mile. The first phase was implemented for the 2012 model year. In 2021, the LDV GHG emission standards was amended and has been implemented for 2023–2026 model years.[11] In April 2023, the

11 U.S. Environmental Protection Agency, "Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards," 86 Fed. Reg. 74434 (December 30, 2021), https://www.govinfo.gov/content/pkg/FR-2021-12-30/pdf/2021-27854.pdf.

EPA proposed new multipollutant emission standards for model year (MY) 2027 and later light-duty vehicles.[12]

In the United States, CH_4 and N_2O are managed through individual vehicle limits, CO_2 is managed through corporate average limits, and HFCs are managed through regulations and incentive credits. The U.S. GHG emission standards include an averaging, banking, and trading (ABT) provision. The ABT program is designed to give manufacturers time to plan and implement the phase-in of emissions control technology in their production over multiple years. It allows additional flexibility to comply with the standards and encourages manufacturers to accelerate the introduction of emission-reduction technologies.

Credits for low MAC leakage rate, alternative refrigerants, and high-efficiency MAC technologies

Through MY 2026, manufacturers have the option of obtaining credits against the CO_2 grams-per-mile limit by reducing leakage of refrigerants, switching to lower-GWP refrigerants, improving the efficiency of MAC systems, and reducing cooling demand. A new multipollutant emission standards proposal would, starting from 2027, end the credits for reducing leakage and using alternative refrigerants. Table 1 presents the maximum leakage and refrigerant credits in the U.S. LDV GHG emission standards for MY 2023–2026.[13] Details of how to generate these credits are explained in detail below.

Table 1. Maximum leakage and refrigerant credits in the U.S. LDV GHG emission standards for MY 2023–2026 (grams/mile)

		Passenger car (g/mile)	Light truck (g/mile)
Maximum direct credits for low leakage rate and alternative refrigerants	For HFC-134a	6.3	7.8
	For low-GWP refrigerants	13.8	17.2
Maximum indirect credits for high efficiency technology		5	7.2
Maximum total credits		**18.8**	**24.4**

To reduce MAC direct emissions, the United States has implemented two sets of regulations for HFCs management, including an HFC-134a ban and an incentive program in the GHG emission standards. The use of HFC-134a in LDV as a refrigerant has been completely banned in the country since 2021. The EPA encourages the use of low-GWP refrigerants and technologies that reduce refrigerant leakage in MAC systems through a credit-incentive program in the GHG standards.

A manufacturer choosing to generate leakage credits is required to calculate a leakage score for the specific MAC system. This score is based on the number, performance, and technology of the components, fittings, seals, and hoses of the MAC system and is calculated as refrigerant emissions in grams per year, using the procedures specified by the SAE Standard J2727.[14] The score is then converted to a CO_2 grams-per-mile credit value based on the GWP of the refrigerant.

12 U.S. Environmental Protection Agency, "Redline Version of EPA's Proposed Regulations to Adopt New Standards for Light-Duty and Medium-Duty Vehicle Standards," 2023, https://www.epa.gov/system/files/documents/2023-04/lmdv-multi-pollutant-emissions-nprm-redline-memo-2023-04.pdf.

13 U.S. Environmental Protection Agency and U.S. Department of Transportation, "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards," 77 Fed. Reg. 62624 (October 15, 2012), https://www.govinfo.gov/content/pkg/FR-2012-10-15/pdf/2012-21972.pdf

14 SAE International, "Mobile Air Conditioning System Refrigerant Emission Charts for R-134a, R-1234yf, and R-152a," SAE Standard J2727_202011, 2020, https://www.sae.org/standards/content/j2727_202011/.

To reduce indirect emissions, manufacturers can improve the energy efficiency of MAC systems by applying more efficient compressors, fans, motors, and advanced system controls. For vehicles equipped with automatic temperature-control systems, cooling or heating efficiency can be improved by real-time adjustment of several aspects of the overall system. A table of air conditioning system technologies and their corresponding credits in the U.S. GHG standards for LDVs is presented in Table 2. The maximum credit available for improved MAC efficiency is 5 g/mile for cars and 7.2 g/mile for trucks.

The EPA introduced the AC17 test procedure to verify the credit applicability for MAC systems. AC17 (Figure 3) is performed at 25°C and 50% relative humidity, beginning with Federal Test Procedure 75 (the preconditioning section), followed by 30 minutes of solar loading (850 W/m^2), the SC03 supplemental test procedure,[15] and the Highway Fuel Economy Test. The AC17 test procedure measures CO_2 emissions in grams per mile and needs to be performed once on a vehicle with the improved technology and once on the same vehicle model without the improved technology. If the AC17 CO_2 test result equals or surpasses the amount of menu credit compared to a baseline AC17 test of a vehicle without the improved technology, the manufacturer will receive the full menu credit amount. If the AC17 CO_2 test result is less than the menu value, the manufacturer will receive the amount of credit corresponding to the AC17 test result.

Table 2. CO_2 emission-reduction effects of MAC efficiency technologies and their credits in the U.S. LDV GHG emission standards for MY 2023–2026

Technology	MAC CO_2 emission reduction	Car AC credit (g/mi)	Light-duty truck AC credit (g/mi)
Reduced reheat, with externally controlled variable displacement compressor	30%	1.5	2.2
Reduced reheat, with externally controlled fixed displacement or pneumatic variable displacement compressor	20%	1.0	1.4
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 24°C or higher	30%	1.5	2.2
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 24°C or higher	20%	1.0	1.4
Blower motor control that limits wasted electrical energy (e.g., pulse with modulated power controller)	15%	0.8	1.1
Internal heat exchanger (or suction line heat exchanger)	20%	1.0	1.4
Improved evaporators and condensers [coefficient of performance (COP) improvement >10%]	20%	1.0	1.4
Oil separator (internal or external to compressor)	10%	0.5	0.7
Advanced and efficient air-conditioning compressor technology by using an additional variable crankcase suction valve		1.1	1.1
Maximum credit		**5**	**7.2**

It should be noted that the credits for high-efficiency MAC systems are also applicable to electric vehicles. Manufacturers may omit AC17 testing for electric vehicles but must submit an application for certification that includes a detailed description of the vehicle's MAC system and identifies any technology items eligible for MAC efficiency credits. The EPA will determine whether credits will be given.

15 SC03 supplemental Federal Test Procedure has been introduced to represent the engine load and emissions associated with the use of MAC. It is a chassis dynamometer test performed with MAC on at a lab temperature of 35°C. The test results have been used for determination of the on-road economy ratings since MY 2008.

CH_4 and N_2O limits

New and in-use vehicles are required to meet individual CH_4 and N_2O limits. Under the Federal Test Procedure and Highway Fuel Economy Test protocols, N_2O shall not exceed 0.01g/mile, and CH_4 shall not exceed 0.03g/mile.

Alternatively, vehicle manufacturers may elect not to meet the individual vehicle limit but instead include CH_4 and N_2O emissions in the determination of their fleet average GHG emissions. Manufacturers must include CH_4 and N_2O full useful-life values as CO_2-equivalent emissions in the fleet-average GHG calculations. Typically, the inclusion of CH_4 and N_2O increases the fleet's average CO_2 emissions by 3–4 g/mile. For manufacturers using this approach, the CO_2 emissions must meet the same limit after the inclusion of CH_4 and N_2O.

Most manufacturers choose to meet individual vehicle limits. For some manufacturers that cannot meet the N_2O and CH_4 limits in a short period of time, the regulation also gives them the flexibility to meet the overall fleet GHG limits if the vehicle's CO_2 emissions are low enough or if they apply energy-efficient air conditioning technologies.

Effects of United States regulations

From 2013 to 2021, the use of HFO-1234yf in LDVs has increased significantly in the United States. In 2021, 95% of the new LDVs used HFO-1234yf as refrigerants. Of the remaining 5%, all except a very small number achieved MAC leakage credits through improved performance of the MAC systems.[16] In 2021, the fleetwide industry-reported average MAC credit was 20.8 g/mile, while the fleetwide GHG performance value was 239 g/mile. As a comparison, in 2012 the fleetwide industry-reported average MAC credit was 6.1 g/mile, while the fleetwide GHG performance value was 287 g/mile. From 2012 to 2021, the increased MAC credit was 14.7 g/mile, and the reduction of GHG performance value was 48 g/mile, which indicates that the increased use of MAC credits amounted to 30% of the reduction.

Since 2012, when the MAC credits were first introduced, low-GWP refrigerants and high-efficiency technologies have been readily deployed, and the share of the MAC credits has increased significantly. However, the maximum credit for MAC systems has not changed. Because efficiency technologies affect vehicle fuel use and CO_2 emissions on a percentage basis, using a set number for credits increasingly overcounts improvements. The U.S. MAC credit values were established in 2011 and 2012 using data from 2009–2012 and older vehicles. The average CO_2 emission level in these years was around 300 g/mile, meaning that a 20 g/mile in credits amounted to 6% of emissions. Over time, the credits amounted to a larger portion of vehicle-emissions reductions. With a 2025 fleet-average CO_2 level of 173 g/mile, 20 g/mi would amount to 12% of the fleet emissions. This effectively doubles the impact of the credit program compared to the original data basis of the established preapproved credits. This indicates that the same technologies are getting increasing relative credits and the MAC credits are generally easier to implement and appear to be a more cost-effective option than other engine fuel-efficiency technologies.

Another concern is the high uncertainty of the real-world impact of MAC technologies. The MAC credits are determined largely based on laboratory tests, without validated real-world benefits. Recent data indicate that some of the credit values are out of line with their real-world effects.[17]

16 U.S. Environmental Protection Agency, "The 2022 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975," 2022, https://www.epa.gov/system/files/documents/2022-12/420r22029.pdf.

17 Nic Lutsey and Aaron Isenstadt, "How Will Off-Cycle Credits Impact U.S. 2025 Efficiency Standards?" (ICCT: Washington, D.C., 2018), https://theicct.org/publication/how-will-off-cycle-credits-impact-u-s-2025-efficiency-standards/.

Policy developments in the European Union

Hydrofluorocarbons bans

In 2006, the European Union adopted the first policy for the use of refrigerants in MAC systems, Directive 2006/40/EC.[18] According to this Directive, the use of refrigerant with a GWP higher than 150 is banned in all new vehicles for sale in the EU, beginning in 2017. New vehicles with MAC systems using these gases cannot be registered, sold, or entered into service in the European Union.

Eco-innovations

Starting from January 1, 2025, the EU LDV CO_2 standards will allow improvements to air conditioning systems to be counted as "eco-innovations" for the first time. Eco-innovations are defined as any technology that is novel and contributes to significant real-world CO_2 savings. Manufacturers can apply for MAC credits as eco-innovation credits starting from January 1, 2025.[19]

To gain access to these credits, manufacturers must submit to the European Commission verification reports provided by certified third-party agencies. The testing methodology must demonstrate that the technology significantly reduces CO_2 emissions during real-world driving conditions. Figure 3 provides a graphic illustration of the basic process.[20]

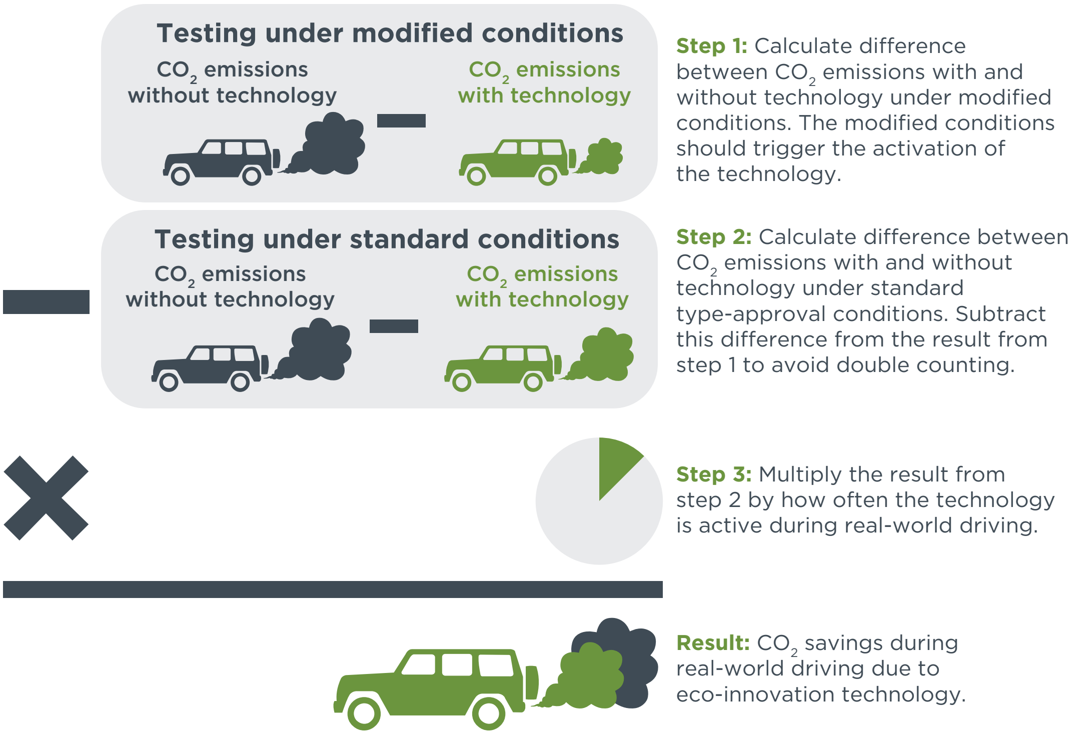

Figure 3. Simplified representation of measuring CO_2 savings from eco-innovations.

18 European Union, "Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 Relating to Emissions From Air Conditioning Systems in Motor Vehicles and Amending Council Directive 70/156/EEC," *Official Journal of the European Union*, OJ L 161 (14.6.2006), https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:161:0012:0018:en:PDF#:~:text=This%20Directive%20lays%20down%20the,and%20refilling%20of%20such%20systems.

19 European Union, "Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019."

20 Uwe Tietge, Peter Mock, and Jan Dornoff, "Overview and Evaluation of Eco-Innovations in European Passenger Car CO_2 Standards," (ICCT: Washington, D.C., 2018), https://theicct.org/publication/overview-and-evaluation-of-eco-innovations-in-european-passenger-car-co2-standards/.

Emission savings are quantified by measuring the difference in CO_2 emissions between identical vehicles with and without the eco-innovation technology installed. The tests are first conducted under modified conditions, which alter select parameters in the procedure so that the eco-innovation technology is triggered. The tests are then repeated under standard conditions. Any CO_2 savings during standard conditions are subtracted from savings under modified conditions to avoid double counting. Lastly, the result is multiplied by the so-called usage factor, which represents how often the technology is active during real-world driving.

Eco-innovation credits are currently capped at 7 g/km. They will be capped at 6g/km from 2025 to 2029, 4g/km from 2030 to 2034, and phased out by 2035. The program does not establish pre-defined technologies or their corresponding credits.

On-board fuel and energy consumption monitoring (OBFCM) provision

There is a growing gap between real-world CO_2 emissions and the emission values demonstrated during the approval process for types of vehicles and components. To counteract this, the EU type-approval procedure regulation requires manufacturers to install on-board fuel and energy consumption monitoring (OBFCM) devices in all new light-duty combustion engine vehicles, including plug-in hybrid vehicles. OBFCM devices collect the fuel and electric energy consumption and distance driven by a vehicle. OBFCM devices have been mandatory for new types of passenger vehicles and most light commercial vehicles since January 2020; all new vehicles in these categories must have the devices starting in January 2021.[21] The European Commission is required to publish anonymized and aggregated OBFCM data annually, including the gap between real-world and type-approval CO_2 emissions by manufacturer, vehicle category, and fuel type. Although whether the MAC is on or off is not part of the required OBFCM data collection, the real-world CO_2 emissions data does provide the opportunity to verify if the eco-innovation technologies—including high-efficiency MAC technologies—can bring real-world CO_2 savings as the manufacturers have claimed.

Implications from the European Union's experience

In the EU's eco-innovations program, high-efficiency MAC technologies and the corresponding CO_2 savings will not be predetermined. Manufacturers will need to demonstrate that the technology can achieve significant CO_2-reduction benefits based on verifiable, repeatable, and comparable measurements. The European Commission has the authority to determine whether credits will be awarded to a certain technology and how many credits can be awarded. Given the rapid pace of technological developments, the EU program ensured that eco-innovation technologies are not awarded credits after they become standard technologies in new vehicles. Therefore, once a certain technology is deployed in a sizeable share of new vehicles, the technology can no longer be considered innovative and be awarded CO_2 eco-innovations credits. In this way, the eco-innovation program can guarantee that only the most advanced and innovative technologies can be incentivized and promoted, and thus encourages manufacturers to develop and apply such technologies.

In the EU, there are concerns about why vehicle manufacturers are rewarded for eco-innovations when most new technologies appear to deliver more CO_2 savings during type approval than during real-world operation.[22] The collection of OBFCM data could be an opportunity to ensure CO_2 reductions are achieved in real-world driving conditions. Once the OBFCM data is available, it is possible that the results

21 Jan Dornoff and Nikiforos Zacharof, "Coming back to reality: A Proposal for Real-World Accuracy Requirements for Vehicle On-Board Fuel And Energy Consumption Monitoring," (ICCT: Washington, D.C., 2022), https://theicct.org/publication/obfcm-accuracy-verification-feb22/.

22 Tietge, Mock, and Dornoff, "Overview and Evaluation of Eco-Innovations in European Passenger Car CO_2 Standards."

can be used to quantify the gap between real-world and type-approval CO_2 emission and to reevaluate the cap credits for the eco-innovation program. However, the MAC's operating status is not required to be reported in the EU's OBFCM provisions. Countries considering a similar monitoring program could require manufacturers to report data about when the MAC system is in use in the OBFCM provisions. This would allow authorities to look at the impact of using MAC systems, to verify or correct eco-innovation credits, and to understand the real-world differences in emissions between vehicles with and without the eco-innovations to inform future policies.

Policy developments in China

Test procedures for internal combustion engine vehicles

Currently, the Chinese standards for passenger car fuel consumption provide additional energy-saving incentives for using off-cycle technologies and devices. High-efficiency MAC is included as an off-cycle technology. When calculating corporate average fuel consumption, the fuel consumption of a vehicle model can be reduced accordingly based on the energy-saving effect of using high-efficiency MAC. On May 1, 2022, the technical standard "Off-cycle technology/device energy saving effects evaluation methods for passenger cars—Part 3: Automotive air conditioner" was implemented.[23] This standard only applies to combustion engine passenger cars and doesn't apply to plug-in hybrid and electric vehicles.

The test procedure is similar to U.S. procedures with different temperature settings and test cycles. The first step is to test the fuel consumption of the vehicle with the air conditioning on. The ambient temperature is set at 30°C ± 2°C, the relative humidity is set at 50% ± 5%, all the windows are opened, the air conditioning air circulation switch is placed at the external circulation position, the air volume adjustment switch is placed in the middle position, and the compressor is kept off. Then, the vehicle is driven at 90 ± 2 km/h for 20 minutes. After that, the vehicle power system is turned off and all windows are closed, and the solar irradiation simulation is set to 850 ± 45W/m^2 for 30 minutes. For automatic-control MAC systems, the temperature is set to no more than 25°C and to internal circulation. For the manual control MAC, the temperature is switched to the maximum cooling mode position, and the air volume is switched to the middle position. Immediately after setting the vehicle MAC, a fuel consumption test is conducted over the China light-duty vehicle test cycle and the fuel consumption with AC on (FC_{ON}) is calculated.

This procedure is followed by performing vehicle fuel consumption measurements with the MAC off. After turning off the solar irradiation simulation, the vehicle pretreatment process is repeated. Immediately after turning off the vehicle power system and closing all windows, without turning on the MAC, the fuel consumption (FC) test is conducted and the test results (FC_{OFF}) are calculated. The fuel consumption of the MAC system of the vehicle is calculated as $FC_{AC} = FC_{ON} - FC_{OFF.}$

The target (T) fuel consumption of the MAC system is defined as:

$$T_{AC}\ (\text{L/100 km}) = 0.000772 \times \textit{curb mass of the vehicle(kg)} + 0.725\ (\text{L/100 km})$$

If the FC_{AC} is greater than the target value T_{AC}, the MAC system is not qualified as a high-efficiency MAC. If the FC_{AC} is less than the target value T_{AC}, the manufacturer will receive the amount of credit corresponding to the test result. To promote the

23 State Administration for Market Regulation, "Off-Cycle Technology/Device Energy Saving Effects Evaluation Methods for Passenger Cars—Part 3: Automotive air conditioner," 2021, https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=04E008878873631389D108386A1FAD55

simultaneous development of multiple energy-saving technologies, incentives for high-efficiency MAC technology are capped at 0.2 L/100 km.

Test procedures for electric vehicles

For electric vehicles, “Test methods for energy consumption and range of electric vehicles—Part 1: Light-duty vehicles” was amended in 2021 and has been implemented since October 1, 2021.[24] In this standard, methods are specified for testing energy consumption of the MAC heating system at low temperatures and the MAC cooling system at high temperatures, but there are no limits required under these test conditions.

For testing the energy consumption of the MAC heating system at low temperatures, the ambient temperature is set at -7°C ± 3°C. The windows are closed and the MAC system is set to external circulation mode. For automatic-control MAC systems, the temperature is set to 22°C. For manual-control MAC, the temperature switch is placed at the maximum heating mode, and the air volume switch is placed at the maximum. After the inside temperature reaches 20°C, the air volume switch is placed at 50% and the temperature inside the car is kept in the range of 20°C–22°C.

For testing the energy consumption of the MAC cooling system at high temperatures, the ambient temperature is set at 30°C ± 2°C, and solar irradiation is simulated with 850 ± 45W/m^2. During the test, the windows are closed and the MAC is set to internal circulation. For automatic-control MAC, the temperature is set to 25°C. For manual-control MAC, the temperature switch is set to the maximum cooling mode and the air volume switch is set to the maximum. After the inside temperature of the car reaches 25°C, the air volume switch is placed in the middle, and the temperature inside the car is kept in the range of 23°C–25°C.

Summary and policy suggestions for China

Based on the review of international best practices and the current regulatory measures in China, we identify the following policy opportunities for China in Table 3 and discuss them in more detail below.

Table 3. International best practices for MAC emission control and policy opportunities for China

International best practices	China’s policy opportunities
MAC is regulated by government authorities as part of automotive GHG emission standards.	China does not have automotive GHG emission standards and does not regulate GHG emissions from MAC. China has not formulated regulations banning certain MAC refrigerants or requiring the use of alternative refrigerants.
Manufacturers must submit MAC-related information to authorities during type approval, including information on refrigerants and MAC system technical specifications.	Technical information on new vehicle MAC refrigerants and MAC systems, as well as data on production, use, and maintenance, is absent.
Incentive credits are granted to vehicle models for using low-GWP refrigerants, switching to low refrigerant leakage rates, improving the MAC system efficiency, and reducing cooling demand.	Fuel-consumption incentive credits for high-efficiency MAC on passenger cars with internal combustion engines have been implemented, but there are no credits for using low-GWP refrigerants and switching to low refrigerant-leakage rates.
MAC credits are applicable to electric vehicles.	Testing procedures for MAC systems on electric vehicles are defined in a technical standard, but there are no energy-consumption limits or credits for high-efficiency MAC systems.
Fuel economy labels include information on the results of fuel-efficiency tests conducted while MAC is in use.	Fuel consumption or energy efficiency labeling for LDVs do not include the results of testing while MAC is in use.
The latest LDV CO_2 regulation in EU requires manufacturers to install OBFCM devices in all new LDVs to collect real-world data on fuel efficiency and CO_2 emissions.	There are no requirements for real-world CO_2 emissions or fuel-consumption data collection in China.

24 State Administration for Market Regulation, “Test Methods for Energy Consumption and Range of Electric Vehicles—Part 1: Light-Duty Vehicles,” 2021, https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=018D351EFF1AACD87C5919D0F21BEEBE

For all vehicles:

- **Incorporate MAC information into the motor vehicle environmental protection information disclosure management system, with the aim of collecting refrigerant consumption data and MAC technology information by 2025**. China has established an environmental compliance regulatory system for the full life cycles of motor vehicles, but it has not officially collected technical information on new vehicle MAC refrigerants and MAC systems. We suggest incorporating information about MAC systems and refrigerants—such as refrigerant type, MAC technology, leakage rate, increased fuel consumption, GHG emissions while MAC is in use—into the information disclosure platform and the configuration list. This may strengthen public participation and oversight of vehicle emissions by authorities.

For internal combustion engine vehicles:

- **Develop GHG emission standards for motor vehicles and incorporate MAC testing into emission test procedures by 2025.** Such testing would help quantify the impact of MAC in on GHGs and pollutants. Detailed requirements for MAC-innovation credits and testing procedures should be further studied.
- **As part of China's GHG emission standards, we suggest establishing a credit management system.** This would provide incentive credits to vehicle models with low-GWP refrigerants, low leakage rates, and high-efficiency AC technologies. Incentive credits encourage manufacturers to develop and apply alternative refrigerants, alternative refrigerant AC systems, and high-efficiency AC technologies. Based on international experience, the list of technologies and their corresponding credits should be temporary and reevaluated every year. For example, if a refrigerant or a technology is widely deployed by the industry, the credits for these technologies should be gradually phased out. Percentage-based credits should also be considered, as they are more accurate than absolute-value credits in reflecting emission reduction benefits. In addition, a robust credit program could be linked with a fleetwide assessment to determine whether the gap is shrinking between real-world GHG emissions and what GHG emissions testing shows. The real-world impact of efficiency technologies should be evaluated to validate manufacturer claims of CO_2-emission reduction benefits. MAC credits by vehicle make and model should be published every year to ensure full transparency.
- **Consider requiring manufacturers to install on-board fuel and energy consumption monitoring (OBFCM) devices in all new LDVs by 2025.** The operation state of AC should be reported in the data collected as total time and/or distance with AC on/off, and the fuel consumption and distance should also be accumulated separately for the times with active/inactive AC. OBFCM data can be used to evaluate the real-world CO_2 emissions from LDVs and the gap to type-approval CO_2 emissions. If AC operation state data and the corresponding fuel consumption data are available, these data can provide policymakers with useful information about the impact of AC systems on real-world CO_2 emissions. Such analysis can be used to support the creation of GHG control policies for MVAC systems. Average real-world CO_2 emissions and the gap to type-approval CO_2 emissions should be published annually to inform policies, for example, to re-evaluate the caps of the credits and to verify the real-world benefits of high-efficiency AC technologies.
- **Fuel consumption under cold and hot ambient test conditions should be published and included in the current fuel-consumption labeling program.**

For battery electric vehicles:

» **Develop energy-consumption limits for EVs by 2025 and include the results of heating and cooling tests in EV efficiency labels.** This will help promote the development and application of energy-efficient MAC systems. The current testing methods for light-duty vehicles specifies test procedures for the heating system at low temperatures and the cooling system at high temperatures but does not set limits on energy consumption.

» **Develop a credit management program and define energy consumption thresholds for MAC.** High-efficiency MAC technologies could receive credits proportional to how much they exceed MAC efficiency thresholds. Providing incentive credits can encourage manufacturers to develop and apply high-efficiency MAC technologies for EVs.

» **Require manufacturers to report data about AC operations and to further study the real-world impact of vehicle cooling and heating on energy efficiency.** This information can be used to inform future policies. Although real-world driving range and efficiency data are collected now from electric vehicles and reported to a national platform, the information does not include whether MAC is in use. As a result, data on the real-world impact of AC use by electric vehicles and relevant research are limited.