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Activating Circular Economy for Sustainable Cooling

How can India Effectively Manage the Lifecycle of Refrigerants?

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About the report: This report on *How can India Effectively Manage the Lifecycle of Refrigerants?* is part of a series of publications on "Activating Circular Economy for Sustainable Cooling" through lifecycle refrigerant management in India under the INDEE+ project. The series offers a comprehensive analysis of refrigerant management practices in India and globally, including a case study of Norway's legislation and practices, proposals for effective implementation in India, and innovative business models.

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Organisations: The **Council on Energy, Environment and Water (CEEW)** is one of Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. In 2021, CEEW once again featured extensively across ten categories in the *2020 Global Go To Think Tank Index Report*, including being ranked as South Asia's top think tank (15th globally) in our category for the eighth year in a row. The Council has also been consistently ranked among the world's top climate change think tanks. Follow us on Twitter @CEEWIndia for the latest updates.

Future Refrigeration India (INDEE+) is an umbrella project, focused at enhancing the use of natural refrigerants, and lifecycle management of refrigerant gases having ozone depletion and high global warming potential. Overall, this project aims to achieve the goals of the ratified Kigali Amendment of the Montreal Protocol. Under this project, CEEW and NEA have collaborated to support the lifecycle management of highly potent refrigerants in an environmentally sound manner in India.

The **Norwegian Environment Agency (NEA)** is a government agency under the Ministry of Climate and Environment, Government of Norway. The NEA employs over 700 personnel across two offices stationed in Trondheim and Oslo and at the Norwegian Nature Inspectorate's (SNO) sixty local offices. NEA's primary tasks are to reduce greenhouse gas emissions, manage Norwegian nature, and prevent pollution.

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About CEEW

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and one of the world's leading climate think tanks. **The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources.** The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

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In 2021, CEEW once again featured extensively across ten categories in the *2020 Global Go To Think Tank Index Report*, including being ranked as **South Asia's top think tank (15th globally) in our category for the eighth year in a row**. CEEW has also been ranked as South Asia's top energy and resource policy think tank for the third year running. It has consistently featured among the world's best managed and independent think tanks, and twice among the world's 20 best climate think tanks.

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The Council's major contributions include: The 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; *the first independent evaluation of the National Solar Mission*; India's first report on global governance, submitted to the National Security Adviser; irrigation reform for Bihar; the birth of the Clean Energy Access Network; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); critical minerals for *Make in India*; modelling uncertainties across 200+ scenarios for India's low-carbon pathways; India's largest multidimensional energy access survey (ACCESS); climate geoengineering governance; circular economy of water and waste; and the flagship event, Energy Horizons. It recently published *Jobs, Growth and Sustainability: A New Social Contract for India's Recovery*.

The Council's current initiatives include: A go-to-market programme for decentralised renewable energy-powered livelihood appliances; examining country-wide residential energy consumption patterns; raising consumer engagement on power issues; piloting business models for solar rooftop adoption; developing a renewable energy project performance dashboard; green hydrogen for industry decarbonisation; state-level modelling for energy and climate policy; reallocating water for faster economic growth; creating a democratic demand for clean air; raising consumer awareness on sustainable cooling; and supporting India's electric vehicle and battery ambitions. It also analyses the energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka and Vietnam.

The Council has a footprint in 22 Indian states, working extensively with state governments and grassroots NGOs. It is supporting power sector reforms in Uttar Pradesh and Rajasthan, scaling up solar-powered irrigation in Chhattisgarh, supporting climate action plans in Gujarat and Madhya Pradesh, evaluating community-based natural farming in Andhra Pradesh, examining crop residue burning in Punjab, promoting and deploying solar rooftops in Delhi, Bihar and Jharkhand.

Contents

Proper recovery of refrigerants from decommissioned cooling devices at e-waste management facilities is imperative, as it curtails significant emissions and ensures responsible management of refrigerants at its end-of-life.

Image: iStock

Executive summary

India's commitment to phasing out hydrochlorofluorocarbons (HCFC) and initiating the phase-down of high global warming potential (GWP) hydrofluorocarbons (HFC) aligns well with the targets set under the Montreal Protocol and its Kigali Amendment. However, according to the *India Cooling Action Plan (ICAP)*, the demand for cooling in India is set to rise eight-fold in the next two decades. This will result in the significant accumulation of ozone-depleting and high GWP gases in refrigerant banks at the end-of-life (EOL) of cooling devices (MoEFCC 2019). Furthermore, gas leakages during the operational lives of these devices, which account for approximately 40 per cent of annual refrigerant consumption, pose significant environmental challenges (MoEFCC 2019).

To prevent the emission of these potent refrigerant gases and accelerate progress toward phase-down targets, a comprehensive lifecycle refrigerant management (LRM) plan is essential. Such a plan should focus on minimising leakages; promoting recovery, recycling, and reclamation for reuse; as well as ensuring the proper destruction of gases at EOL. By implementing LRM practices, India can mitigate the adverse environmental impacts that can be caused by refrigerant gas emissions.

This report aims to provide recommendations for operationalising LRM in India and answers the following research questions:

- What are the major barriers to the lifecycle management of refrigerants in India?
- What policies and regulations can enable the effective lifecycle management of refrigerants in India?
- What are the financial, standards, capacity-building, and supportive ecosystem requirements for facilitating the lifecycle management of refrigerants in India?

To address these research questions, we conducted extensive desk research, collecting information on the current status, policies, regulations, challenges, and issues related to refrigerant management in India. Furthermore, we undertook a literature review of global best practices and a study trip to Norway to gain insights and learn from successful policy initiatives, implementation mechanisms, and practices in refrigerant management.

In addition to desk research, we held focused interviews and discussions with experts and stakeholders from the refrigeration and air-conditioning industry. These engagements were aimed at gathering valuable insights and perspectives on existing challenges as well as potential policy initiatives, implementation mechanisms, infrastructure requirements, and other support needed for the effective implementation of lifecycle refrigerant management in India.

A. Defining the contours of LRM

The leakage of refrigerants into the atmosphere happens at every lifecycle stage of a cooling product. Leakages could occur due to improper installation or due to leaks in the cooling circuit that have developed over time due to exposure to corrosive environmental conditions. Sometimes, the refrigerant gases are also vented off during servicing or EOL. LRM aims to avoid any release of refrigerant gases into the atmosphere either through leakages or intentional venting. Thus, LRM must focus on the following:

- Preventive measures to minimise leakages during installation and operation of the devices.
- Recovery of gases during servicing or EOL, and recycling/reclaiming them for reuse or destroying the non-reusable gases.

B. Global best practices towards LRM

Globally, several countries have undertaken refrigerant management initiatives. These initiatives include regulations, policy mandates, incentive schemes, or a combination of these, and they differ in their approach and scope. While some countries have established strong regulations with robust procedures for monitoring and enforcement (e.g., Japan), others have initiatives based on incentivising the stakeholders in the EOL management value chain (e.g., Norway, Denmark, US, Japan). The refrigerant management programmes also vary in scope – while some countries focus on reclamation and reuse, others focus on the destruction of gases after recovery.

> **Refrigerant gas leakages in India, account for up to 40% of total annual refrigerant consumption, during the operational lives of cooling devices.**

ES Table 1 Sector-wise cumulative greenhouse gas emissions avoidable by 2050 through LRM

Sectors	RAC	RR	MAC
Potential GHG emissions avoidable by 2050 in million metric tonnes (MMT)	1302.8	29.2	581.5

Source: Authors' analysis

Drawing from global best practices and factors that have contributed to the effective management of refrigerants in other countries, we have identified the following mechanisms, which are relevant for India:

- **Establish a policy initiative for refrigerant management** (whether mandatory or voluntary) that goes beyond the scope of the Montreal Protocol and its Kigali Amendment.
- **Establish systems and infrastructure for reverse logistics** and refrigerant management.
- **Create mechanisms for financing** and incentivising processes and stakeholders.
- **Develop processes and standards for refrigerant management,** such as providing training and certifications for the workforce (capacity building); establishing standards for tools, equipment, and processes to ensure quality and safety; and creating a market for the use of reclaimed gases.

C. An opportunity to mitigate 2 billion tons of CO_2 eq emissions by 2050 through LRM in India

Successful implementation of LRM practices in the residential air-conditioning (RAC), residential refrigeration (RR), and mobile air-conditioning (MAC) sectors could help mitigate approximately 1.91 billion tons of cumulative $CO_{2\,eq.}$ emissions by 2050. The sector-wise mitigation potential is presented in ES Table 1 above.

D. Barriers and challenges to LRM in India

Operationalising LRM in India has the following barriers and challenges:

- **Absence of a policy directive for refrigerant management and coherence in policies**
One of the key barriers in LRM is the absence of a clear policy directive. The current policies and regulations related to India's commitments under the Montreal Protocol and its Kigali Amendment focus on the phase-down or phase-out of targeted refrigerant gases. These do not provide any direction regarding LRM practices. Without any policy directive, it is difficult to channel support for essential measures needed for refrigerant management, such as skill development, establishing infrastructure and mobilising investments, and the development of standards.

In addition, there is a need for coherence and synergies between related policies. For example, according to the *E-Waste (Management) Rules 2016*, EOL air-conditioners and refrigerators must be recycled. Still, it does not provide any mandate for the recovery and safe processing of refrigerants in these devices. Coherence between policies and rules relating to refrigerant management, e-waste management, and vehicle scrappage will help integrate refrigerant management practices with existing waste management practices and infrastructure in the automobile and home appliances sectors.

- **Lack of standards and guidelines**
For effective refrigerant management and to ensure the quality of the processes involved, various standards and guidelines are required for tools, equipment, and processes, such as standards for recovery machines, reclamation tools and processes, storage, and branding and handling of reclaimed gas cylinders. Standards from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and the International Organization for Standardization (ISO) are available globally for many of these tools and processes, but these need to be modified for Indian conditions and must be adopted. In addition, as some refrigerant gases are flammable and toxic, there is a need for guidelines and standard operating procedures (SOP) to ensure safety at the workplace.

- **Limited skilled workforce available for all the jobs needed in refrigerant management**
As per the estimates in the *ICAP*, the demand for servicing technicians is expected to grow from 200,000 in 2017 to 20,000,000 by 2037 (MoEFCC 2019). A massive shortage of skilled and certified technicians for the proper installation, servicing, and maintenance of cooling devices is forecasted. In addition, refrigerant management practices will involve skill sets not covered in existing skill development programmes, such as the skills involved in performing recovery, recycling, and reclamation processes.

- **Absence of a reverse supply chain and infrastructure**
  Without any policy directive or refrigerant management practices, the reverse supply chain and infrastructure required for refrigerant management (such as reclamation and destruction facilities, refrigerant collection, and testing centres) and the scale at which this is needed do not exist in India.
- **Lack of awareness and negligence among end users about the impacts of refrigerant emissions and irresponsible waste disposal**
  There is a need to increase awareness among end users about the adverse impacts of refrigerant leakages on the environment and the efficiencies of cooling products. Increased awareness of the benefits of good installation and servicing practices, and the options available for refrigerant management and proper waste product recycling and disposal, is essential in ensuring pro-active participation by end users in refrigerant management.
- **Limitations related to refrigerant destruction facilities**
  The Technology and Economic Assessment Panel (TEAP) provides a list of destruction technologies and their destruction efficiency, which can guide the establishment of effective infrastructure. This information can be used to set up and enhance facilities with high destruction efficiency, ensuring the optimal disposal of refrigerants and contributing to sustainable waste management practices. Destruction of refrigerant gases in cement kilns is one of the measures recommended by TEAP. Given the availability of several cement kilns in India, establishing proper linkages between these facilities and ensuring their efficiency can help address limitations in refrigerant management. Through effective collaboration between relevant stakeholders, and by leveraging the insights from TEAP, the industry can overcome barriers and improve the overall refrigerant management system. Research and development are also needed to make improvements in the design and manufacturing of cooling products, for example, to reduce corrosion or enable the early detection of leakages using the Internet of Things (IoT).

E. Recommendations for effective LRM in India

A multi-pronged approach is recommended for the effective operationalisation of LRM in India (ES Figure 1). The following recommendations result from the inputs received from stakeholder consultations, the literature review, and the learnings from global best practices.

ES Figure 1 A multi-pronged approach is needed for operationalising LRM in India

Source: Authors' analysis

Regulatory measures

There should be a clear and firm policy directive for LRM. In addition, amendments to the *Ozone Depleting Substances (Regulation and Control) Rules 2000, E-Waste (Management) Rules 2022, and Vehicle Scrappage Policy 2021* will be required to include provisions that are needed to operationalise LRM in India.

Developing standards and guidelines

Establishing rigorous standards for the tools, equipment, and processes involved in LRM would be essential for maintaining the quality of these tools and their performance. In particular, there is a need for:

- Standards for tools and equipment needed for recovery, recycling, reclamation, gas storage, and transportation.
- Standards for processes such as recovery, reclamation, and destruction.
- Safety standards and guidelines for handling flammable and toxic refrigerants.

Training and certification of the workforce

Existing training or skill development programmes for technicians in the air-conditioning and refrigeration sectors mostly focus on installing, servicing, and repairing equipment. Under the *HCFC Phase-out Management Plan (HPMP)*, efforts have been made to train a few thousand technicians across the country on good servicing practices (GSP) (MoEFCC 2017). The curriculums of these training programmes include some elements of LRM. However, to have a larger impact on controlling refrigerant emissions, these curriculums need to be modified to cover all the processes of LRM. In addition, these LRM elements must also be included in courses under the *National Skill Development Mission* (NSDM). The objectives of this proposed training initiative and certification are to:

- Expand the reach of already existing training and certification programmes to help create a larger workforce to cater to the growing demand.
- Develop and deliver training and certification programmes for skill sets not already included in existing programmes but which are required for refrigerant management.

Creating a supportive ecosystem for LRM

In addition to policy and regulatory measures, substantial efforts would be required to establish infrastructures and reverse supply chains for refrigerant management. Initiatives should aim to:

- Establish a network of reclamation centres for pilots and demonstrations.
- Support indigenous manufacturing of the tools and equipment required for refrigerant management.
- Facilitate research and development in key areas (identified during interactions with the stakeholders):
  - Reuse of recovered refrigerant blends after recycling and reclamation is generally avoided and not recommended by original equipment manufacturers (OEMs) due to overall efficiency concerns in India. However, this is a prevalent practice in developed countries such as the US. The US Environmental Protection Agency (EPA) standards or any other recognised standards on reclaiming and reusing refrigerant blends could be adopted as an initial step.
  - Leakages due to corrosion are a typical issue in areas near open sewerages or corrosive environments.
  - Reclamation and separation of a mix of different refrigerant gases stored together.
- Enhance synergies and cooperation among relevant government agencies and their policies.

Awareness generation and nudging end user behaviour

Consumers should be educated on the harmful impacts of refrigerant emissions and encouraged to participate in refrigerant management. This could be by adopting good installation and servicing practices or proactively handing the discarded cooling products or vehicles to an authorised waste recycler.

Finance for LRM

Finance and investment will be one of the key pillars in operationalising LRM in India. Finance will be required on many fronts; however, in particular, access to finance must be ensured for:

- Financing refrigerant management processes, including the recovery of gases, storage, aggregation and transportation of the recovered gases, recycling or reclamation, or destruction of the recovered gases.
- Cost of setting up infrastructure (a network of gas collection and aggregation centres, reclamation centres, etc.).
- Creating awareness and nudging end-user behaviours through campaigns

> **Finance and investment will be one of the key pillars in operationalising LRM in India.**

1. Introduction

Climate change is one of the most pressing issues facing our planet today. In its *Sixth Assessment Report*, the United Nations Intergovernmental Panel on Climate Change (IPCC) warns that urgent action is needed to prevent the worsening of climate change–related threats such as heatwaves, sea level rise, droughts, flooding, and rising temperatures (IPCC 2023). The report further highlights that merely adapting to the impacts of climate change will not work, and greenhouse gas emissions must be drastically reduced to limit global warming to 1.5°C (IPCC 2023).

Short-lived climate pollutants (SLCP), having a shorter atmospheric life than CO_2, are a significant contributor to global warming and climate change. Avoiding SLCP emissions is an immediate action that can potentially prevent 45 per cent of current global warming (IGSD 2013). For instance, SLCPs like fluorinated refrigerant gases (F-gases) have a shorter atmospheric life than CO_2, but they have up to 11,700 (HFC-23) times greater ability to warm the atmosphere than CO_2 (IPCC 1995). As a result, even small amounts of F-gases in the atmosphere can significantly raise global temperatures and contribute to climate change. Preventing the emission of F-gases can avoid up to 57.15 gigatonnes of cumulative $CO_{2\,eq}$ emissions by 2050 (Purohit and Höglund-Isaksson 2017).

The Montreal Protocol is one of the world's most successful international environmental treaties that phased out the production and consumption of chlorofluorocarbons (CFCs) globally (UNEP 2022). In addition, HCFCs, which emerged as a transitional substitute to replace CFCs because of their substantially lower ozone depletion potential (ODP), are also being phased out. The HFCs replaced the CFC and HCFC gases containing ozone-depleting substances (ODSs) as an ozone-friendly alternative. Though HFCs do not harm the ozone layer and are widely used the world over, many of these gases have very high GWP. The Kigali Amendment to the Montreal Protocol was adopted in 2016 to address the global warming impacts of HFCs (Ozone Secretariat 2016). The Amendment aims to phase down the production and consumption of HFCs, potent greenhouse gases (GHG) used as refrigerants. As a result, countries party to the Kigali Amendment have been taking initiatives to transition towards low GWP refrigerants.

However, simply phasing out or phasing down the production and consumption of refrigerant gases with ODP and high GWP with low GWP alternatives is not enough. According to the International Energy Agency's (IEA) estimates, the total number of room air conditioners worldwide will increase from 1.6 billion units in 2018 to 4.5 billion units by 2050; in India, the increase could be from approximately 27 million units in 2016 to as many as 1.1 billion by 2050 (IEA 2018). Additionally, *ICAP* estimates that the stock of room air-conditioners in India will increase from around 30–40 million units in 2017 to approximately 300–350 million units in 2037 (MoEFCC 2019). India is currently phasing out HCFCs and will initiate the phasing down of HFCs post-2028. This means that the cooling devices that are already operational or which will enter the market in the next few years will be based on HCFCs or high GWP HFCs. This will lead to the accumulation of a huge stock of HCFCs and high GWP HFCs in these cooling devices. Stockpiles of refrigerants in cooling devices, such as air conditioners and refrigerators, are generally referred to as 'refrigerant banks'. Leakage and venting from refrigeration and air conditioning systems during their operational lifespan and at EOL are major sources of F-gas emissions. Thus, it is imperative to address these emissions, and it calls for LRM practices that prevent leakages through proper installation and servicing; refrigerant recovery, recycling, and reuse; and safe destruction of the refrigerant at its EOL.

The Montreal Protocol and its Kigali Amendment focus on limiting the production and consumption of gases and do not directly regulate emissions from refrigerant banks (Garg, Kumar, and Bhasin 2023). However, many countries have regulations or voluntary measures to reduce refrigerant emissions while these products are in use and when they are discarded at their EOL, through recovery and recycling or reuse, and safe destruction of the gases.

Considerable amounts of refrigerant emissions could be prevented by 2050 through LRM; doing so will require a coordinated effort from governments, private industry, and individuals to switch to more environment-friendly cooling technologies and prevent refrigerant emissions from the already installed systems (CCAC 2022).

If not properly managed, large quantities of potent greenhouse gases from these refrigerant banks will ultimately get released into the atmosphere (IGSD 2013). This makes it crucial for India to implement effective LRM practices. By doing so, India can play its part in reducing GHG emissions while also contributing to *Mission LiFE (Lifestyle for Environment)*, which promotes sustainable development and protects the environment by encouraging the adoption of circular economy principles and practices to achieve India's net-zero goals by 2070 (PIB 2022).

This study was conducted to develop recommendations for operationalising LRM in India and contribute to achieving its net zero goals. In light of the foregoing discussion, the following research questions were investigated in this report:

- **What are the major barriers to the lifecycle management of refrigerants in India?**
- **What policies and regulations can enable the effective lifecycle management of refrigerants in India?**
- **What are the financial, standards, capacity building, and supportive ecosystem requirements for facilitating the lifecycle management of refrigerants in India?**

This study is focused on the usage of refrigerants as cooling fluids for refrigeration and cooling devices. It does not include refrigerant gases used for other purposes such as in foam, blowing agents, or any other applications. The sectors considered for this study include:

- Residential air conditioning (RAC)
- Residential refrigeration (RR)
- Commercial refrigeration (CR)
- Commercial air-conditioning (CAC)
- Mobile air-conditioning (MAC)

The recommendations proposed in this report for developing an LRM ecosystem in India are based on extensive consultations with a wide range of stakeholders. The approach and methodology adopted for this study to develop the recommendations are described in Chapter 2. The key findings related to the current status of industry and consumer practices for LRM; issues, challenges, barriers, and global best practices; and the emerging policy landscape are discussed in Chapter 3. Chapter 4 provides the proposed recommendations for LRM in India.

With an increasing demand for cooling in India comes increasing responsibility to manage the environmental impact of this demand. Effective LRM practices can help India meet its net zero goals while continuing to meet its cooling needs.

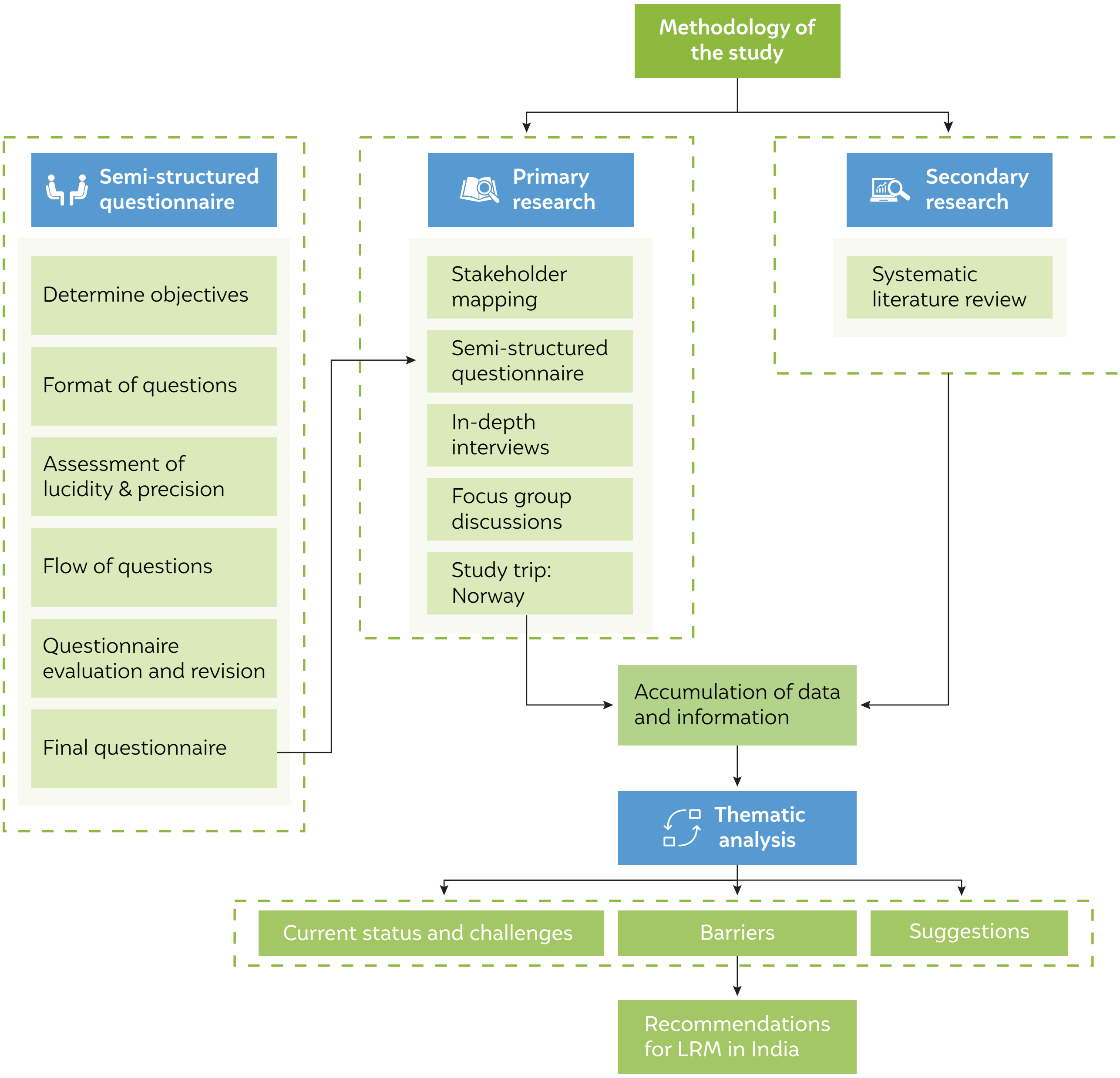
2. Research methodology

This study highlights impedances to LRM practices in India across sectors in a holistic manner. Further, it focuses on understanding the role of regulations, standards, capacity building, the supportive ecosystem, and finance in enabling India's sustainable LRM ecosystem from the stakeholder's perspective. This study used an explorative approach because it allows for more accurate screening by identifying the attitudes and desires of various industry stakeholders, both of which are crucial for decision-making. This chapter discusses the methodologies adopted to address the research questions highlighted in the previous chapter and develops the recommendations for LRM.

Image: iStock

Recovered refrigerants must be stored separately in cylinders by refrigerant type to ensure refrigerant reprocessing and for further reuse.

Figure 1 Key methodological steps undertaken for this study



Source: Authors' analysis

2.1 Refrigerant management landscape in India and developed nations

In the absence of appropriate measures, refrigerant emissions are happening at a fast rate in the refrigeration and air conditioning sector across the globe. It begins at the cooling device installation phase, continues during the equipment's operational life, and persists until its EOL. It is challenging to limit emissions from different lifecycle stages and types of equipment when refrigerants are odourless and invisible. It requires industry awareness and willingness, trained servicing personnel, motivation, incentives, and proper infrastructure, accompanied by robust regulations and enforcement mechanisms. To understand these in-depth, a literature review, a study trip to Norway, and an industry stakeholder mapping exercise were undertaken to map guidelines, standards, enforcement mechanisms, monitoring and reporting mechanisms, funding sources, performance of LRM programmes, training, and the reverse supply chains of refrigerants.

Literature review

The literature review provided a deeper understanding of the current situation in India with regards the management of refrigerants throughout their lifecycle. Additionally, global best practices for refrigerant management were examined to draw insights and learnings. We also undertook a case study on refrigerant management initiatives in the European Union and Norway. These methodologies gave us a deeper understanding of the present scenario of refrigerant management practices in India and other countries, which helped us develop recommendations for implementing LRM effectively in India. Chapter 3 highlights the key findings from the literature review on the current status and barriers to refrigerant management in India, along with an analysis of global policies. The detailed findings of the literature review have been published separately in the form of issue briefs and the Norway case study.

Study trip to Norway

We undertook a study trip to Norway to understand better its regulatory framework, implementation mechanisms, incentives, and the infrastructure and reverse supply chain established for refrigerant management. During the trip, we visited facilities that manage e-waste and refrigerants from discarded refrigerators and air conditioners and facilities that collect and destroy refrigerants. The purpose of the field visit was to understand best practices and learnings from Norway's successful refrigerant management system that could be applied in the context of India. The field visit provided valuable insights into challenges and opportunities in implementing an effective refrigerant management system and helped us to shape the methodology for this study.

Stakeholder mapping

The key sectors where different classes of refrigerants are used are RAC, RR, CAC, CR, and MAC, and they are also the focus of this study. The challenges to restricting refrigerant emissions differ according to the sectors, the stakeholders involved, and the lifecycle stage of the refrigeration and air conditioning device. To establish a comprehensive LRM ecosystem in India, it is imperative to understand the challenges from the perspective of multiple stakeholders' familiar with the various applications and the actions they foresee as crucial to refrigerant management. Thus, the research requires focused discussions with key persons in the refrigeration and air conditioning sector, preferably from upstream to downstream, who are involved with different cooling devices.

The stakeholder mapping exercise was driven by our understanding of the actors involved in the circular economy, the literature review, existing networks, consultations with experts, and a snowballing method. It enabled us to map the stakeholders directly handling the refrigerants, from upstream to downstream, the refrigerant manufacturers, equipment manufacturers, servicing personnel and agencies, and e-waste handlers. In addition, experts from the refrigeration and air conditioning sector, government agencies such as Ozone Cell, and relevant industry associations such as the Refrigeration and Air-conditioning Manufacturers Association (RAMA), Refrigeration and Air-conditioning Trade Association (RATA), Refrigeration and Air-conditioning Servicing Sector Society (RASSS), and the Society of Indian Automobile Manufacturers (SIAM), which are crucial to establishing a comprehensive refrigerant management ecosystem in India, were mapped for consultation.

2.2 Estimation of GHG emissions mitigation potential from LRM in India

The refrigerant emissions can happen either during the installation and operation of the cooling devices or at their EOL. We used an equipment-based approach to estimate the refrigerant emissions that could be avoided by 2050 through LRM practices (GIZ 2017). The study only focuses on operational and EOL refrigerant leakages from three sectors, namely RAC, RR, and passenger cars in MAC, as they account for the majority of refrigerant consumption, and because of the availability of published relevant data. The emissions produced during the production, transportation, and distribution of refrigerants are not included in this study. In addition, our estimate only focuses on high GWP refrigerants, HFCs and HCFCs, specifically HFC 32, HFC 410A, HCFC 22, and HFC 134a used in the RAC, RR, and MAC sectors in India.

Refrigerant emissions during equipment operation and servicing are currently not subject to any regulation or measures to limit them. Further, there are no initiatives toward recovering these gases at their EOL (Garg, Kumar, and Bhasin 2023). Thus, in this estimation, it is assumed that once a device leaks, it leaks out completely, and the entire quantity of refrigerant contained in it is released into the environment. In addition, at the EOL of the device, the entire quantity of refrigerant contained in it is released into the atmosphere.

The steps followed for estimating refrigerant emissions till 2050 during operation and the EOL of cooling devices in the three selected sectors are discussed below. These estimations highlight the GHG emission mitigation potential that can be achieved by preventing these emissions through effective LRM practices.

Step 1: Estimation of annual sales of devices/units in the RAC, MAC, and RR sectors till 2050

- This step involves gathering historical sales data for the cooling sector until 2022, including refrigerators, air conditioners, and passenger cars.
- Data on the annual sales of refrigerators, room air conditioners, and passenger cars are taken from the records of the Bureau of Energy Efficiency (BEE) and the Society of Indian Automobile Manufacturers (SIAM) (BEE 2019; SIAM n.d.).
- Based on the historical sales data and the associated growth rate, this step forecasts annual sales until 2050, assuming the growth in sales will continue at the same rate. The compound annual growth rate (CAGR) calculated and assumed for RAC, RR, and MAC are 10 per cent, 5 per cent, and 10 per cent, respectively (Table 1).

Step 2: Estimation of annual refrigerant consumption

- A variety of refrigerants are usually used in a particular sector. Based on consultations with industry experts and the HCFC phase-down targets, the historical and forecasted market share (till 2050) of different refrigerants for each sector were determined.
- In addition, the average quantity of refrigerant charge per unit is taken from ICAP and in consultation with industry experts (Table 2).

Table 1 Historical and projected annual sales of devices in the RAC, RR, and MAC sectors

Year	Annual sales (in million units)		
	RAC	RR	MAC
2010	2.8	NA	2.5
2011	2.8	NA	2.6
2012	3.3	NA	2.7
2013	3.5	10.6	2.5
2014	4.6	10.1	2.6
2015	6.4	11.4	2.8
2016	7.7	11.3	3.1
2017	7.7	12.4	3.3
2018	7.2	12.9	3.4
2019	8.9	11.7	2.8
2020	6.6	12.2	2.7
2021	8.5	12.9	3.1
2022	9.0	13.5	3.9
2022 onwards till 2050	Annual sales with CAGR of 10%	Annual sales with CAGR of 5%	Annual sales with CAGR of 10%

Source: Authors' analysis

Table 2 Average initial refrigerant charge per unit for different sectors

Sectors	Refrigerant quantity (kg/unit)					
	R-22	R-410A	R-32	R-290	R-134a	R-600a
RAC	0.9	0.9	0.9	0.35	NA	NA
MAC	NA	NA	NA	NA	0.5	NA
RR	NA	NA	NA	NA	0.15	0.15

Source: Authors' analysis

- The annual consumption of a particular refrigerant (say Ri) is calculated as per the formula below.

$$C_{R_i} in\ year\ n = \left[(S \times R_{i-MS} \times R_{i-Q})_{RAC} + (S \times R_{i-MS} \times R_{i-Q})_{RR} + (S \times R_{i-MS} \times R_{i-Q})_{MAC}\right] \div 1000$$

Where,

- C_{Ri} Consumption of refrigerant *i* in year *n* in million metric tons per year (MMT/year)
- S Annual sales of units in a particular sector in year *n* (million units)
- $R_{i\text{-}MS}$ Market share of refrigerant *i* in a particular sector in year *n* (per cent)
- $R_{i\text{-}Q}$ Quantity of refrigerant *i* in one unit in a particular sector (kg/unit)
- *RAC* Residential air conditioning sector
- *RR* Residential refrigeration sector
- *MAC* Mobile air conditioning sector

Step 3: Estimation of cumulative refrigerant emissions till 2050

- The refrigerant emission happens (a) during the operation of devices through leakages due to various reasons and (b) at the EOL of the devices.
- The refrigerant emission from EOL devices in a year *n* will happen from the devices that were installed in the year (*n* – *L*), where *L* is the lifespan of the respective device in years. In order to estimate the EOL refrigerant emissions, the lifespans are assumed to be 10 years for devices in the RAC and RR sectors and 15 years for the devices in the MAC sector. The EOL refrigerant emissions are estimated as per the following formula.

$$E_{EOL-R_i} in\ year\ n = \left[\left\{(S \times R_{i-MS} \times R_{i-Q})_{RAC} + (S \times R_{i-MS} \times R_{i-Q})_{RR} + (S \times R_{i-MS} \times R_{i-Q})_{MAC}\right\} \div 1000\right]_{(n-L)}$$

Where,

- $E_{EOL\text{-}Ri}$ EOL emissions of the refrigerant *i* in the year *n* in million metric tons (MMT/year)
- S Annual sales of units in a particular sector in year *n* (million units/year)
- $R_{i\text{-}MS}$ Market share of refrigerant *i* in a particular sector in year *n* (per cent)
- $R_{i\text{-}Q}$ Quantity of refrigerant *i* in one unit in a particular sector (kg/unit)
- *L* Lifespan of devices in years
- *RAC* Residential air conditioning sector
- *RR* Residential refrigeration sector
- *MAC* Mobile air conditioning sector

- To calculate the refrigerant emission during the operation of devices, i.e., the lifespan emissions of devices, an annual leakage rate of 20 per cent, 10 per cent, and 20 per cent were considered for the RAC, RR, and MAC sectors, respectively. The lifespan refrigerant emission in the year *n* would happen from the devices that are operational in the year *n*, i.e., the devices that are installed during the past (*n* – *L* + 1) years.

$$E_{LS-R_i} in\ year\ n = \sum_{j=n-L+1}^{n-1} \left[\{((S \times R_{i-MS} \times R_{i-Q})_{RAC} \times LR_{RAC}) + ((S \times R_{i-MS} \times R_{i-Q})_{RR} \times LR_{RR}) + ((S \times R_{i-MS} \times R_{i-Q})_{MAC} \times LR_{MAC})\} \div 1000\right]_j$$

Where,

- $E_{LS\text{-}Ri}$ Lifespan emissions of refrigerant *i* in the year *n* (MMT)

- S Annual sales of units in a particular sector in year n (million units/year)
- $R_{i\text{-}MS}$ Market share of refrigerant i in a particular sector in year n (per cent)
- $R_{i\text{-}Q}$ Quantity of refrigerant i in one unit in a particular sector (kg/unit)
- LR Leakage rate (per cent)
- L Lifespan of devices in years
- J Year
- RAC Residential air conditioning sector
- RR Residential refrigeration sector
- MAC Mobile air conditioning sector

- The cumulative refrigerant emissions from 2023 to 2050 are then calculated by adding the annual refrigerant emissions, which include EOL and lifespan emissions.

$$E_{Total-R_i} = \sum_{k=2023}^{2050} (E_{EOL-R_i} + E_{LS-R_i})_k$$

Where,

- $E_{Total\text{-}Ri}$ Cumulative emission of the refrigerant i from 2023 till 2050 (MMT)
- $E_{LS\text{-}Ri}$ Lifespan emissions of refrigerant i in a particular year k (MMT/year)
- $E_{EOL\text{-}Ri}$ EOL emissions of refrigerant i in a particular year k (MMT/year)
- K Year

Step 4: Estimation of cumulative GHG emissions mitigation potential by 2050

- In order to calculate the CO_2 equivalent of refrigerant emissions, the GWP of respective refrigerants is multiplied by the quantity of refrigerant emissions.
- The GWP values of the refrigerants considered in this study are taken from the IPCC AR 4 report since the same values were considered for the HCFC and HFC phase-out targets set under the Montreal Protocol (IPCC 2007).

$$\text{Cumulative } CO_2 \text{ eq emissions} = \sum_{i=1}^{m} E_{Total-R_i} \times GWP_{R_i}$$

Where,

- $E_{Total\text{-}Ri}$ Cumulative refrigerant emissions from 2023 till 2050 (MMT)
- GWP_{Ri} GWP of refrigerant i (ton CO_2 eq.)
- m Refrigerant type

2.3 Focused stakeholder consultation

Given the lack of information, data, and relevant research on refrigerant management in the Indian context, it becomes essential to gather the relevant data. We conducted focused interviews with key stakeholders to collect information on the issues and challenges they face or foresee in various refrigerant management practices, such as installing and servicing devices and recovery, recycling, reclamation, reuse, and destruction of refrigerants. Stakeholders' views and ideas on policy initiatives, implementation mechanisms, infrastructure, and other support needed for the effective implementation of LRM in India were also gathered during the interviews. The stakeholders consulted were refrigerant manufacturers, original equipment manufacturers (OEMs), industry associations, e-waste and EOL vehicle handlers, producer responsibility organisations (PRO), servicing technicians and franchises, contractors, experts, and government officials.

As the next step to collecting qualitative data from in-depth interviews, we used the thematic analysis approach as an analytical methodology. It helped to empirically analyse stakeholders' challenges and opportunities in refrigerant recovery, recycling, reclamation, reuse, and destruction and to generate a framework for action from the interactions with policymakers and industry. The following section details the stakeholders interviewed, the questionnaire that facilitated the interviews, and the thematic analysis approach used for analysing the data.

Interviews

We developed a target interview list of industry actors in the RAC, RR, MAC, CAC, and CR sectors based on the stakeholder mapping conducted for this study. Approximately 60 industry stakeholders were identified and contacted for interviews based on their role in the supply chain and sector and their importance. In the first instance, the interviews were conducted to gather factual information to form an initial understanding of the topic. It was then focused on understanding the industry's challenges and the actions they foresaw as required to foster the refrigerant management ecosystem in India. Ultimately, given the project's tight timeline and such we were reaching the saturation limit on responses, a total of 35 interviews and one focus group discussion (FGD) with servicing technicians and agencies were conducted. Interviews and discussions were conducted with stakeholders from the RAC, RR, MAC, CAC, and CR supply chains across

India. While most interviews were in person, some were conducted over virtual platforms. Hindi was used in certain instances, but English was the primary language of communication. All the interviews were transcribed based on notes taken during interviews and using AI tools.

Questionnaire

The authors developed a semi-structured questionnaire that was reviewed and approved by eminent and experienced professionals in the heating, ventilation, and air-conditioning (HVAC) sector. The interviews were designed to obtain a better understanding of stakeholders' perceived experiences during the CFC phase-out regime. The questionnaire had several open-ended questions on challenges for refrigerant management operations; interviewees' past experiences with phasing out CFCs and HCFCs; the supportive ecosystem required; anticipated jobs, required skills, and gaps therein; sector-level challenges in handling refrigerants, standards, and safety norms; and the need and sources for financing refrigerant management processes and infrastructure. The semi-structured questionnaire was developed to investigate the industry's challenges and the solutions they see as an effective problem-solver. The in-depth interviews were limited to the scope of refrigerant management. They covered the elements associated with it, such as the formalisation of the servicing sector, high demand for trained personnel during the peak season and their unavailability, low remuneration of servicing personnel, industry negligence, and much more. Key findings from these interviews are discussed in Chapter 3. The questions also addressed the mechanism required, from the stakeholders' perspective, to build a reverse supply chain for refrigerants once the equipment reaches EOL and when it is handed over to the formal or informal waste handler. A central element of the questionnaire was to explore the source and responsibility for financing the refrigerant management programme and associated infrastructure in India.

Qualitative data interpretation using thematic analysis

We used thematic analysis to analyse the qualitative data collected through the interviews and focus group discussions. Thematic analysis is a qualitative research method that can be particularly useful in determining recommendations that are regulatory in nature (Braun and Clarke 2008). Thematic analysis is an inductive approach to data analysis, where the themes and patterns emerge from the data. An inductive approach to data analysis involves generating theories or insights from the data rather than starting with preconceived ideas or hypotheses (Nowell, Norris, and Moules 2017). This approach was particularly useful in identifying and analysing patterns and themes within the qualitative data collected using stakeholder interviews on the regulatory measures required for refrigerant management in India.

The thematic analysis allowed us to systematically examine and categorise the various themes that emerged from the feedback provided by stakeholders. By identifying common themes and patterns, we gained a comprehensive understanding of the perspectives and experiences of stakeholders, including areas of consensus, disagreement, and potential gaps in the current regulatory framework for the effective implementation of the refrigerant management ecosystem in India.

Through this process, we could provide evidence-based recommendations grounded in feedback from key stakeholders. The insights gained from the thematic analysis of qualitative data allowed us to develop sector-targeted and context-specific regulatory recommendations that address the needs and priorities of stakeholders while also considering the broader regulatory landscape.

Overall, the use of a thematic analysis enabled a comprehensive understanding of the regulatory constraints surrounding LRM and helped in arriving at recommendations that were both evidence-based and responsive to the perspectives, experiences, and preferences of key stakeholders.

The following steps were used for analysing the data collected from key stakeholders using thematic analysis:

- **Data collection:** Interviews with stakeholders were transcribed in as much detail as possible in Microsoft Word and in different files.
- **Familiarisation with the data:** Transcripts from the stakeholder interviews were read multiple times to familiarise ourselves, gain an overall sense of the data, and identify initial ideas or themes that emerged.

> **Interviews and discussions were conducted with stakeholders from the RAC, RR, MAC, CAC, and CR supply chains across India for this study.**

- **Coding:** This step involved identifying and labelling meaningful data segments into codes. Significant phrases or passages related to the research question were highlighted and noted.
- **Generating initial themes:** After coding, all the codes were reviewed and grouped under preliminary themes. This involved comparing codes across the stakeholders.
- **Reviewing and refining themes:** This step involved further grouping or categorising the themes.
- **Defining theme:** After reviewing and refining the themes, they were defined and named based on how they related to the research questions.

We used the NVIVO software for analysing the qualitative data. It helped us organise the data in one place and in the subsequent processes of coding, re-coding, generating initial themes, and eventually grouping the themes.

3. Key findings and discussion

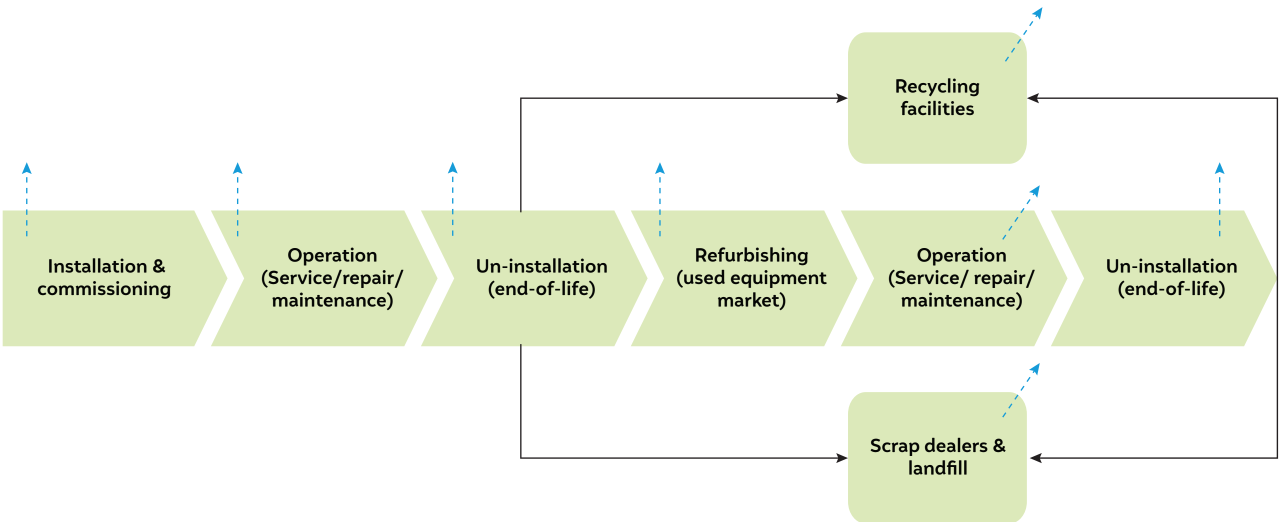
The desk research and focused one-on-one consultations with stakeholders served specific objectives in order to gain valuable insights. The primary goal was to develop a comprehensive understanding of current practices within the selected sectors, spanning different stages of the product lifecycle such as installation and commissioning, operation (including service and maintenance), and EOL waste management. Through this process, we aimed to identify key areas where refrigerant leakages occur, determine the underlying reasons behind these leakages, and explore potential measures and approaches to effectively prevent leakages and implement LRM. Additionally, by engaging with stakeholders, we sought to uncover challenges and identify existing gaps in order to gather valuable inputs for the development of a robust LRM plan tailored specifically for India.

This chapter discusses the key findings and the interventions required for LRM in India.

3.1 Understanding LRM

The leakage or venting of refrigerant into the atmosphere happens at every lifecycle stage of a cooling product. Occasionally, the leakages happen due to improper installation or cracks that have developed over time because of exposure to corrosive environmental conditions. At other times, the gases are vented during servicing or the EOL of the product. *ICAP* estimates that approximately 40 per cent of annual refrigerant consumption in India is by the servicing sector, primarily to recharge the leaked equipment (MoEFCC 2019). Inputs received from stakeholders suggest that improper installation practices are one of the key reasons for refrigerant leakages in room air-conditioners, and adopting proper installation practices can substantially reduce refrigerant leakages. Thus, LRM must focus on both – preventing leakages during installation and operation and recovering the gases during servicing or EOL of the product. Figure 2 represents the lifecycle stages of a cooling device and the possibility of refrigerant emission at any of these stages.

Figure 2 Lifecycle stages of a cooling product and possibilities of refrigerant leaks (represented by blue dashed arrows)



Source: Authors' analysis

Defining the contours of LRM

Refrigerant management is commonly referred to as the recovery of gases from the product at their EOL and either reusing it after recycling or reclamation or safely destroying it. However, the purpose of LRM is to avoid the release of refrigerant gases into the atmosphere due to leakages or intentional venting. Thus, for LRM, in addition to the recovery and processing of gases, a range of other interventions, such as those pertaining to the design and manufacturing of products, training and certification of technicians, and nudging user behaviour, would be required.

LRM includes the following elements:

- **Prevention of leakages:** Preventing refrigerant gases from leaking during the installation or operation of a product should be an essential part of refrigerant management. It involves making improvements in the design and manufacturing of products (use of anti-corrosive coatings, use of sensors for early detection of leakages, etc.), adoption of proper installation and servicing practices by technicians (as prescribed by equipment manufacturers), and sensitisation of end users on the impacts of refrigerant emissions and the importance of refrigerant management.
- **Recovery of refrigerants:** Recovery refers to the removal and short-term storage of refrigerants from a system that is being repaired or disposed of.
- **Recycling of refrigerants:** Recycling is the process of filtering and purifying the recovered refrigerant so that it is ready to be used in the same equipment from which it was extracted. Unlike reclamation, recycling does not purify the refrigerant to the quality level of new refrigerant as per industry purity standards. Thus, repackaging and sale of recycled refrigerant is not recommended.
- **Reclamation of refrigerants:** Reclamation is the process of restoring the quality of recovered refrigerant to new specifications in conformity with industry purity specifications (such as AHRI Standard 700) by extracting impurities such as moisture, acid, and non-condensable gases (MoEFCC 2019). Reclaimed refrigerants are suitable for resale, specifically for servicing and maintenance.
- **Destruction of refrigerants:** The non-recyclable and non-reusable fully contaminated refrigerant is neutralised by destruction in an environmentally sound manner using TEAP-approved refrigerant destruction technologies such as cement kilns or plasma arc incinerators (UNEP TEAP 2018).

LRM and ‘circularity’ in the cooling sector

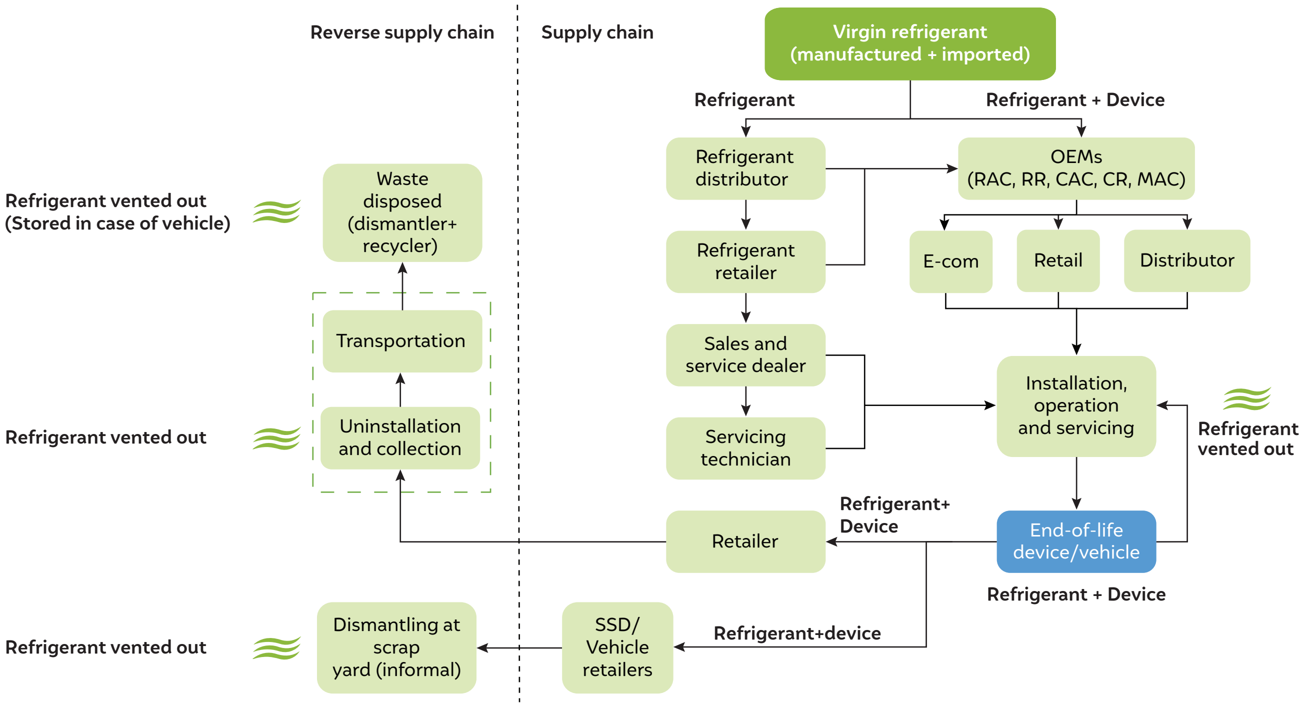
LRM not only helps mitigate the climate impacts of refrigerant emissions, but it also enhances circularity in the cooling sector. Given the unprecedented and expected growth of cooling demand in India, the demand for cooling devices and refrigerants is expected to increase manifold. Thus, it is imperative to recycle and reuse the components of cooling devices and refrigerant gases to minimise the burden on the environment and resources. *The E-Waste (Management) Ruless 2016* and the *Vehicle Scrappage Policy* 2021 are important policy initiatives undertaken by the government in this direction. However, a gap exists concerning the management of refrigerant gases. The recovery of refrigerants and reuse of recycled and reclaimed refrigerants can be an important contributor towards enabling a ‘circular economy’ in the cooling sector.

3.2 The existing supply chain of refrigerants in India and the reverse logistics needed for LRM

As per its international commitments under the Montreal Protocol and the Kigali Amendment, India has undertaken initiatives to restrict the production and consumption of targeted refrigerant gases in accordance with the committed timelines. However, very little has been done concerning LRM (Garg, Kumar, and Bhasin 2023). Currently, all the refrigerant gases used in cooling devices in India get released into the atmosphere at the EOL of a product. The refrigerant gases (either manufactured in India or imported) enter the market either pre-charged in cooling devices or in cylinders for servicing purposes through retail sales channels. Due to poor installation practices or other factors such as corrosion, the refrigerant gets leaked multiple times during the installation and operational stage of the cooling device. Further, due to a lack of regulations and economic incentives, refrigerants are vented at the EOL of the device during their uninstallation, transportation, or dismantling by formal or informal waste handlers. Figure 3 illustrates the existing supply chain of refrigerants in India.

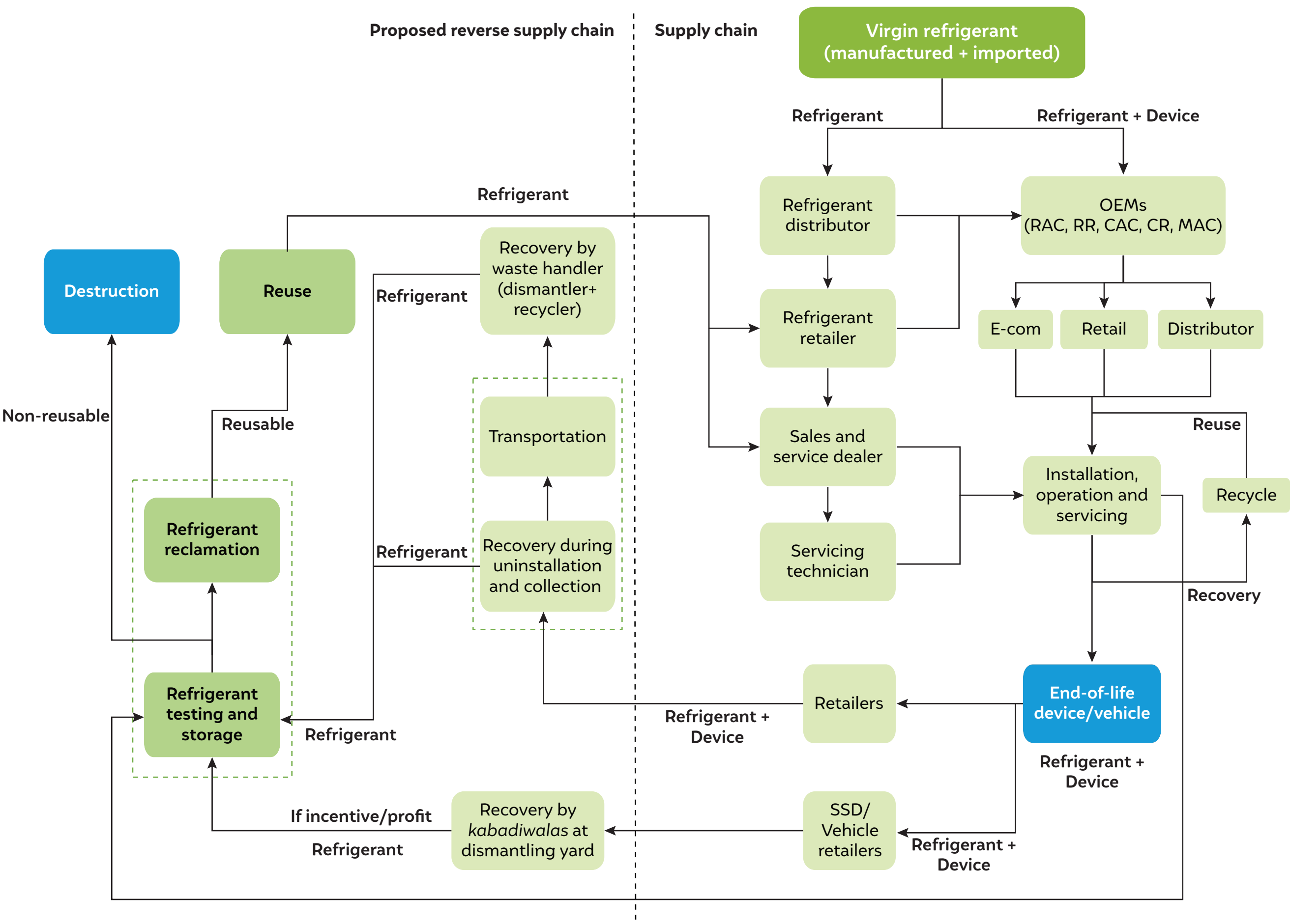
LRM requires establishing a robust reverse supply chain and infrastructure for the recovery, recycling, reclamation, destruction, and transport of refrigerant gases. A proposed reverse supply chain is presented in Figure 4.

Figure 3 Existing supply chain of refrigerant gases in India



Source: Authors' analysis

Figure 4 Proposed reverse logistics needed for refrigerant management in India



Source: Authors' analysis

The proposed approach considers that preventive mechanisms such as good equipment design and proper installation and servicing practices will help minimise the leakage of refrigerant during the operational lifespan of a cooling device. E-waste and EOL vehicle management is at a nascent stage in India. Once it is matured and completely functional, as per the proposed reverse supply chain, the refrigerant will be recovered from EOL devices and transported to a testing cum collection and storage centre.

The recovered gases will be tested and, if found reusable, will be transported to a reclamation facility. If found non-reusable, the gases will be transported to a destruction facility. The reclaimed gases will be introduced to the market through servicing agencies and refrigerant retailers for reuse.

3.3 Emissions mitigation potential and the need for LRM practices in India

Preventing refrigerant emissions can play a critical role in limiting global warming to 1.5°C (WRI 2018). To demonstrate this possibility, we conducted an equipment-based assessment to estimate the potential reduction in operational and EOL emissions through LRM practices in India's HVAC sector by 2050.

The results revealed that LRM practices alone in the RAC, RR, and MAC sectors have the potential to avoid cumulative GHG emissions of 1,913.5 MMT CO_2 eq. by 2050. Table 3 outlines opportunities for individual sectors considered in the estimation of GHG emission mitigation potential. These findings emphasise the critical role of LRM practices in reducing emissions by the HVAC sector and in contributing to global efforts to combat climate change.

3.4 Mapping global best practices

Globally, several countries have begun implementing refrigerant management initiatives. These initiatives include regulations, policy mandates, incentive schemes, or a combination of these. A detailed case study on global best practices has been published separately (Garg, Kumar, Bhasin, and Asphjell 2023). There are differences in the approach to and scope of refrigerant management across different countries. While some countries have established strong regulations with robust procedures for monitoring and enforcement (e.g., Japan), others have incentivised stakeholders in the EOL management value chain (e.g., Norway, Denmark, the US, and Japan). Systems and infrastructure have been created for the collection, transport, aggregation, and reclamation/destruction of gases. While governments have provided initial funds to set up these systems and build capacities in some cases, many of these are operating on funds created through taxes, advance destruction fees, carbon credits, or industry contributions, and in some cases, partly end-user contributions at the time of recovering the gases.

LRM practices have the potential to avoid cumulative GHG emissions of 1,913.5 MMT CO_2 eq. by 2050.

The scope of these refrigerant management programmes is also varied. While some countries have focused on reclamation and reuse, others have focused on destroying the gases after recovery. A summary of these global initiatives is provided in Table 4.

Drawing from learnings based on global best practices, the factors that have contributed to the effective management of refrigerants in these countries and of relevance for India are:

- Establish a policy initiative for refrigerant management (whether mandatory or voluntary) going beyond the scope of the Montreal Protocol and its Kigali Amendment.
- Establish systems and infrastructure for reverse logistics and refrigerant management.
- Create mechanisms for financing and incentivising the processes and stakeholders.
- Develop processes and standards for refrigerant management, such as training and certification of the workforce (capacity building); standards for tools, equipment, and processes to ensure quality and safety; and a market for the use of reclaimed gases.

Table 3 Sector-wise cumulative GHG emissions avoidable by 2050 through LRM

Sectors	RAC	RR	MAC
Potential GHG emissions avoidable by 2050 (MMT)	1302.8	29.2	581.5

Source: Authors' analysis

Table 4 Summary of initiatives taken by different countries for LRM

Country	Sectors covered	Refrigerant covered	Policy measures	Rate of recovery (%)	EOL treatment (Reclamation /destruction)	Impact	Challenges
Norway	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	EU F-gas Regulations Tax and Refund Scheme	NA	Destruction	Destroyed refrigerant in FY 2009–21: 1200 metric tonnes (MT) In general, most gases that can realistically be recovered, are recovered	Uncertainty related to extent of recovery from EOL vehicles and foams
New Zealand	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	Voluntary Industry Arrangement Regulatory Product Stewardship Scheme (RECOVERY)	5% till 2013	Destruction	Collected and destroyed 430 tons of refrigerant from FY1993–2020 Impact of saving up to 423,655 MT of ozone and reducing the build-up of GHGs by up to 938,030 MT of CO_2 eq Approximately 30 MT per year destroyed	Transportation of refrigerants to the recovery centre acts as a disincentive Low recovery from domestic equipment and vehicles
Australia	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	Industry-supported Refrigerant Take-back Programme – Refrigerant Reclaim Australia (RRA) Extended producer responsibility	50–70%	Reclamation & destruction	92% of recovered refrigerant destroyed by RRA Total refrigerant recovered since FY 2013: 4,600 MT Reduction of more than 10 million tons of CO_2 eq. emissions	Leveraging a single organisation/system invites suspicion and anti-competitiveness charges Very low recovery from domestic equipment and vehicles
Japan	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	Strong regulatory framework Extended producer responsibility Industry-specific refrigerant management programmes	41%	Reclamation & destruction	In FY2020 – Refrigerant recovered – 8500 MT Refrigerant recycled – 1300 MT Refrigerant destroyed – 4100 MT	Some non-compliance is caused by the cost of proper disposal of commercial and household appliances at the EOL Despite being a leader in appliance recycling, home appliances only recover 30% of the available refrigerant

Country	Sectors covered	Refrigerant covered	Policy measures	Rate of recovery (%)	EOL treatment (Reclamation /destruction)	Impact	Challenges
South Korea	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	Regulations on phase-down Regulatory framework regulations require record-keeping Extended producer responsibility	NA	Destruction	NA	Absence of comprehensive regulation on refrigerant management
USA	RAC, RR, CAC, CR, MAC	CFC, HCFC, HFC	Robust regulatory framework focused on venting prohibitions Voluntary refrigerant management programmes	Not tracked	Reclamation & destruction	Rate of recovery in commercial systems: ~80% Responsible Appliance Disposal (RAD) recovered refrigerant in FY 2013: 170 MT HCFC destroyed in FY 2016: 800 MT	Low recovery from domestic equipment and vehicles Inconsistent framework (ODS vs HFCs) creates confusion and non-compliance

Source: Authors' compilation from Asphjell et al. (2023), AHRI (2018), ICF (2008), US EIA (2019) and CCAC (2021)

3.5 Policy initiatives in India relevant to LRM

The government of India has undertaken certain policy initiatives that are relevant to LRM.

India's international commitments toward the refrigerant transition and related domestic policies

India is a party to the Montreal Protocol and has ratified the Kigali Amendment. These instruments are aimed at transitioning away from the production and consumption of refrigerant gases having ODSs and high GWP. India has introduced the following policy initiatives to achieve the objectives of these international commitments:

- **Ozone Depleting Substances (Regulation and Control) Rules 2000 and its subsequent amendments** (MoEFCC 2000): These rules regulate the production, import, and consumption of refrigerant gases containing ODS. India has successfully adhered to its committed timelines for phasing out ODS-containing gases as per the Montreal Protocol schedule. This regulation does not mandatorily restrict the venting of gases containing ODS; however, it encourages refrigerant recovery, recycling, and destruction.
- **HCFC Phase-out Management Plans** (HPMP): India has implemented these plans in phases. While *HPMP* Phase-2 just concluded, Phase-3 is expected to start in 2023. In addition to policy initiatives, technical, financial, and capacity-building support are being provided to stakeholders to prepare them for the transition. There has been some focus on refrigerant recovery and reclamation during Phase-2, and with support from the Multilateral Fund (MLF), recovery machines were distributed to technicians at subsidised rates, and a few reclamation centres were established. However, without a comprehensive refrigerant management plan and reverse supply chain, these initiatives have not yielded the intended outcomes. Refrigerant management is also considered one of the key focus areas in *HPMP* Phase-3.
- **HFC phasedown strategy:** India has to initiate the phasing down of high GWP HFC gases post-2028. Therefore, the government has initiated consultations and has begun formulating its strategy for the HFC phasedown. To achieve optimum environmental benefits, LRM must be a key pillar of this strategy.

E-waste (Management) Rules 2016 and its subsequent amendments

The *E-waste (Management) Rules 2016* are based on the premise of extended producer responsibility (EPR) and place the responsibility on producers to collect, store, transport, and recycle e-waste in an environmentally responsible manner (MoEFCC 2016). Domestic air conditioners and refrigerators are also categorised as e-waste and, at their EOL, are required to be handed over to e-waste recycling facilities.

The guidelines for implementing these rules specify that the authorised e-waste collection centres and storage facilities must handle refrigerators and air-conditioners with additional care to prevent any leakage of refrigerants during loading, transportation, and unloading. It also mandates that e-waste dismantlers and recyclers must have adequate facilities and systems to manage the leakage of refrigerants and to deploy skilled manpower having the required tools and personal protective equipment to manually separate the compressors from cooling systems. The dismantlers are further advised to recover and separately store all the hazardous waste and compressor oils from the cooling systems. However, the guidelines do not explicitly mention the recovery of refrigerant gases.

Vehicle Scrappage Policy 2021

The *Vehicle Scrappage Policy 2021* proposes the scrapping of vehicles after a defined lifetime for recycling and recovering various components. This policy proposes establishing registered vehicle scrapping facilities (VSFs) and automated testing stations for scrapping vehicles across the nation (MoRTH 2021). Further, the *Ozone Depleting Substances (Regulation and Control) Rules 2000* applies to the *Vehicle Scrappage Policy 2021*, and VSFs under this policy are directed to recover hazardous wastes, including refrigerants, using suitable tools to ensure zero leakage before dismantling the vehicles.

However, in the absence of reclamation and destruction facilities, as is the case currently, the recovered gases cannot be reclaimed for reuse or safely destroyed. The success of the *Vehicle Scrappage Policy 2021* will, therefore, depend on the setting up of the necessary infrastructure and supply chain for reclamation and destruction of refrigerants.

> **Vehicle scrappage facilities to recover hazardous wastes, including refrigerants, using suitable tools to ensure zero leakage before dismantling the vehicles.**

3.6 Barriers and challenges to LRM in India

During the focused one-on-one consultations, the stakeholders highlighted various barriers and challenges to effective LRM in India. They also shared several ideas and suggestions for effectively operationalising refrigerant management in India. These inputs were collated and categorised using thematic analysis and have been presented under the following six themes:

- Need for policy initiatives and mandates for refrigerant management and coherence among relevant policies
- Need to develop or adopt international standards, benchmarks, and SOPs, such as ISO, AHRI, or International Electrotechnical Commission (IEC)
- Skill development and certification required for technicians
- Support system required for LRM
  - Establishment of reverse supply chains
  - Establishment of infrastructure for the collection, storage, reclamation, and destruction of gases
  - Support for research and development (R&D)
- Awareness generation and consumer behaviour nudges required
- Need for finance and investments

The summary of the barriers and challenges that emerged from the stakeholder consultations and desk research are discussed below.

- **Absence of a policy directive for refrigerant management and policy coherence**
  One of the key barriers to LRM is the absence of any policy directive for it. Policies and regulations related to India's commitments under the Montreal Protocol and the Kigali Amendment focus on the phase-down or phase-out of targeted refrigerant gases. These do not provide any direction with regards LRM practices. In the absence of any policy directive at the top level, it is difficult to channelise support for other essential measures needed for refrigerant management, such as skill development, the establishment of infrastructure, mobilisation of investments, and the development of standards.

  In addition, there is a need for coherence and synergy between related policies. For example, as per the *E-Waste (Management) Rules 2016*, the EOL air-conditioners and refrigerators are required to be recycled, but it does not provide any mandate for the recovery and safe processing of the refrigerants contained in these devices. Coherence between the proposed refrigerant management policy, *E-Waste (Management) Rules 2016*, and *Vehicle Scrappage Policy* 2021 will help integrate refrigerant management practices with existing waste management practices and infrastructure in the automobile and home appliances industries.

- **Lack of industry-specific standards and guidelines**
  For effective refrigerant management and to ensure the quality of the processes involved, various standards and guidelines are required for tools, equipment, and processes. For example, standards are required for recovery machines, reclamation tools and processes, storage, branding and handling of reclaimed gas cylinders, etc. At the global level, AHRI and ISO standards are available for these tools and processes, but they need to be modified (if needed for the Indian requirements) and adopted. In addition, as some of the refrigerant gases are flammable and toxic, guidelines and SOPs to ensure safety at the workplace are needed.

- **Limited skilled workforce needed for all jobs in refrigerant management**
  As per the estimates in the ICAP, the demand for servicing technicians is expected to grow from 200,000 in 2017 to 200,00,000 by 2037 (MoEFCC 2019). A massive shortage of skilled and certified technicians for the proper installation, servicing, and maintenance of cooling devices is expected. In addition, refrigerant management practices will involve additional skill sets that are not covered in existing skill development programmes, such as the skill set required for recovery, recycling, and reclamation processes under refrigerant management.

- **Absence of reverse supply chains and infrastructure**
  Without a policy directive and non-existent refrigerant management practices, the reverse supply chain and infrastructure required for refrigerant management (such as reclamation and destruction facilities, refrigerant collection, and testing centres) and the scale at which this is required do not exist in India.

> **Refrigerant management practices will involve additional skill sets that are not covered in existing skill development programmes.**

- **Lack of awareness and negligence among end users regarding the impacts of refrigerant emissions and irresponsible waste disposal**
  There is a need to raise awareness among end users regarding the adverse impacts of refrigerant leakages on the environment and the efficiencies of cooling products. Raising awareness among end users regarding the benefits of good installation and servicing practices, the options available for refrigerant management, and proper waste product recycling and disposal are essential to ensure their proactive participation in refrigerant management.

- **Limitations related to refrigerant destruction facilities**
  Despite the presence of destruction facilities, such as cement kilns, addressing this limitation in refrigerant management requires establishing proper linkages between these facilities and ensuring their efficiency. The Technology and Economic Assessment Panel's (TEAP) list of destruction facilities, along with their destruction efficiency, can serve as a valuable guide for the establishment of effective infrastructure. Using this information, necessary facilities should be set up or enhanced to improve their destruction efficiency, ensuring optimal disposal of refrigerants and contributing to sustainable waste management practices. Such collaboration between relevant stakeholders, and by leveraging the insights from TEAP, India can overcome barriers and improve the overall refrigerant management system. Research and development are also needed to make improvements in the design and manufacturing of cooling products, for example, to reduce corrosion or enable early detection of leakages using the Internet of Things.

3.7 Proposed approaches to LRM in different sectors

The sectors targeted for refrigerant management require different approaches for LRM. The differences in the characteristics of these sectors are based on the following parameters:

- Nature of service technicians (formal, skilled, and equipped)
- Nature of servicing requirement (onsite or at service centres)

- Prevalent mode of transport for technicians (two-wheelers or four-wheelers)
- Quantities and types of gas being used in a single unit
- Potential for refrigerant recovery at various lifecycle stages
- Characteristics and practices of end users

The residential air-conditioning and refrigeration sectors

The approach or the type of intervention required for refrigerant management varies across lifecycle stages and sectors. We discuss this using an example of room air conditioners. Table 5 summarises the key reasons for the leakage or venting of gases at various lifecycle stages and the suitable interventions required for refrigerant management.

Table 5 Possible reasons for the leakage and venting of refrigerant in RAC and potential interventions

Lifecycle stage	Possible reasons for leakages/venting	Potential measures/interventions
Installation and commissioning	Instant leakage due to improper installation practices by unskilled or unequipped technicians	Focus on preventing the leakage through • Training and certification of technicians • End-user sensitisation (installation by certified technicians, adequate remuneration for certified technicians)
Product operation (operation, service, and repair)	Gradual leakage over a period of time due to improper installation by unskilled or unequipped technicians (by the time a significant drop in performance is observed by the user and a technician is called, approximately 60–80% of the gas has already leaked out)	Focus on preventing the leakage through • Training and certification of technicians • Sensitising end users (installation by certified technicians, adequate remuneration for certified technicians) • Avoiding top-ups without finding and arresting the cause of leakage • Improving the design and manufacture of the product (sensors for early detection of leaks and alarms)
	Gradual leakage over a period of time due to exposure to a corrosive environment (by the time a significant drop in performance is observed by the user and a technician is called, approximately 60–80% of the gas has already leaked out)	Focus on preventing the leakage by • Improving the design and manufacture of the product (anti-corrosive coatings, sensors for early detection of leaks and alarms) • Avoiding top-ups without finding and arresting the cause of leakage
	Compressor failure	Has already been addressed to a great extent through improved technology (very few incidents of compressor failure are reported in recent times)
	Venting during service/repair	Focus on recovery of gases instead of venting (challenges related to carrying bulky recovery machines and additional cylinders by technicians)
	Venting during relocation (uninstallation and reinstallation by unskilled or unequipped technicians)	Focus on preventing the leakage through • Training and certification of technicians • End user sensitisation (installation/ uninstallation by certified technicians, adequate remuneration for certified technicians)
EOL of product	Venting during uninstallation Venting at e-waste recycling facilities Venting by informal scrap dealers/handlers	Focus on preventing venting and recovering gases through • Uninstallation by certified technicians • Mandating recovery at e-waste recycling facilities to the extent possible • Incentives for informal scrap handlers for the recovery of gases • Initiatives for the formalisation of e-waste collection and recycling

Source: Authors' analysis

Table 6 Proposed approaches for LRM at various lifecycle stages in the targeted sectors

Sectors	Proposed approaches for LRM	
	Installation and operating life	End-of-life (EOL)
RAC	• No mandatory recovery and LRM practices (recommend LRM to the extent possible) • Focus on reducing leakages through – Improving product design and manufacturing – Promoting the adoption of good installation and servicing practices	• Mandatory gas recovery at formal waste recycling facilities • Promote formalisation of waste management • Promote and incentivise recovery in waste management in the informal sector
RR	• No mandatory recovery and LRM practices • Focus on reducing leakages through – Improving product design and manufacturing – Promoting the adoption of good installation and servicing practices	• Mandatory gas recovery at formal waste recycling facilities • Promote formalisation of waste management • Promote and incentivise recovery in informal sector waste management
CAC	• Mandatory LRM practices for service contractors/ end users	• Mandatory LRM practices
CR	• Mandatory LRM practices for service contractors/ end users	• Mandatory LRM practices
MAC	• Mandatory LRM practices for formal service centres • Promote and incentivise RRR at informal service centres	• Mandatory LRM practices at end-of-life vehicle (ELV) recycling facilities

Source: Authors' analysis

In room air-conditioners, for instance, if leakage happens during its operational life, by the time the end user notices a significant drop in cooling and calls a technician, usually around 60–80 per cent of the gas has already leaked out. In that case, mandatory recovery may not be sensible. In addition, service technicians mostly travel by two-wheelers with all their tools. Carrying a recovery machine and additional cylinder(s) for the storage of recovered gas will be practically difficult. Thus, in the case of residential air conditioners, during installation and operational life, the focus should be on measures to avoid leakages rather than making recovery mandatory.

At the EOL of room air-conditioners, despite recent initiatives concerning formal e-waste recycling, a large proportion of products is currently dismantled and disposed of by informal scrap dealers and handlers. Therefore, in addition to making recovery and refrigerant management mandatory for formal e-waste recyclers, initiatives should also target formalising waste management and incentivising informal scrap dealers for effective refrigerant management. A similar approach is also recommended for the residential refrigeration sector.

The commercial air-conditioning and refrigeration sectors

In commercial air-conditioning and refrigeration, provision for mandatory recovery and refrigerant management is advisable at all lifecycle stages as

- Servicing and maintenance are mostly provided by formal enterprises having skilled technicians
- The quantity of refrigerants charged in a single unit in the commercial air-conditioning or refrigeration sector is multiple times more than that of a residential air-conditioning or refrigeration unit, which makes the recovery, recycling, and reuse of refrigerants in this sector more techno-economically viable
- There already exists a practice of refrigerant recovery and management to some extent.

> **By the time an end user notices a significant drop in cooling and calls a servicing technician, it is estimated that 60-80% of the gas has already leaked out.**

Mobile air-conditioning sector

In mobile air-conditioning, the vehicles are serviced and repaired at a workshop, whether formal or informal. Therefore, refrigerant management can be mandated at formal workshops; however, informal workshops would require incentives and support to adopt refrigerant management practices. At the EOL, with the new *Vehicle Scrappage Policy* in place, refrigerant management can be mandated at all EOL vehicle recycling facilities.

Proposed approaches for LRM in different sectors

The previous sections show that different approaches need to be adopted for LRM in different sectors. Further, for LRM, in addition to the recovery and processing of gases, a range of other interventions are required, such as in the design and manufacturing of products, training and certification of technicians, and nudging user behaviour.

The proposed approaches for LRM in different sectors that emerged in the discussions are highlighted in Table 6.

3.8 Prioritisation of refrigerant management in different sectors

The quantity and type of refrigerants used (including their ODP and GWP) vary from sector to sector. An assessment was done to prioritise the selected sectors based on the following parameters:

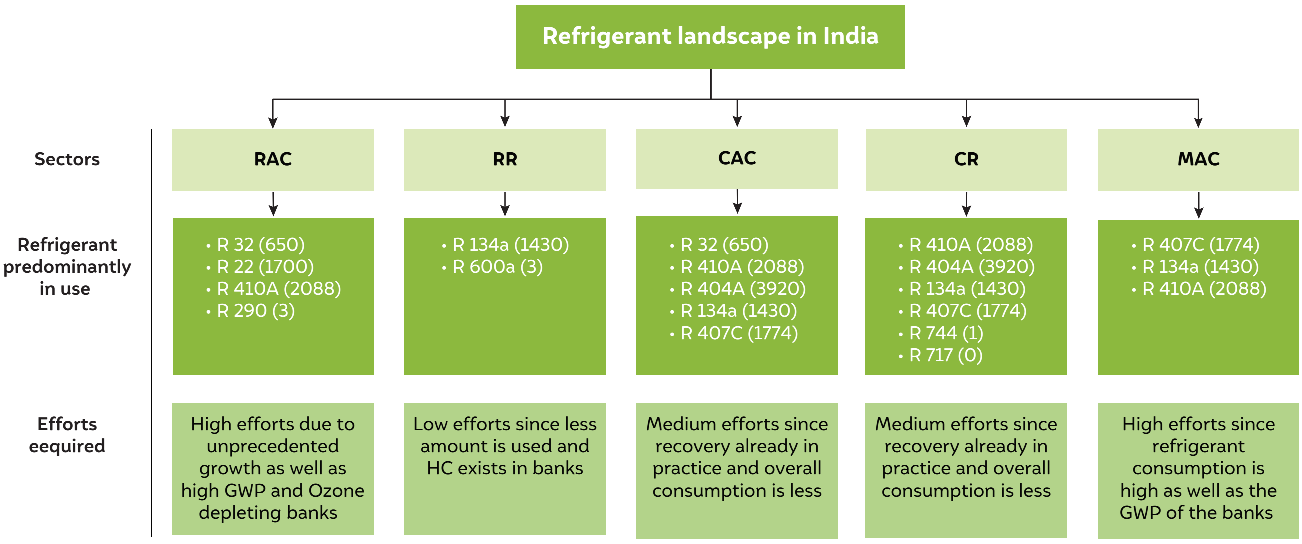
- Type and quantity of refrigerant (ODP and GWP) predominantly used
- Presence of refrigerant management practices in the sector and the availability of a skilled workforce

The outcomes of the assessment were as follows:

- **RAC and MAC sectors:** High priority and greater efforts are required for operationalising refrigerant management in these sectors. This is because larger quantities of gases with high GWP are being used, and refrigerant management practices are currently absent in these sectors.
- **CAC and CR sectors:** Medium priority and medium efforts are required for operationalising refrigerant management in these sectors. This is because relatively smaller quantities of gases are being used, and refrigerant management practices exist to some extent, along with the presence of skilled and formal workforces in these sectors.
- **RR sector:** Low priority and lower efforts are required for operationalising refrigerant management in this sector. This is because a relatively lower quantity of gases is being used, and low GWP gases have been in use over the past few years.

Figure 5 offers an overview of the assessment.

Figure 5 Prioritisation of refrigerant management in different sectors (the GWP value of the gas in parenthesis)



Source: Authors' analysis. GWP values are taken from AR6 (IPCC 2022)

4. Recommendations for LRM in India

LRM is a new concept for the Indian air-conditioning and refrigeration sectors. Substantial efforts are required to develop and establish policies, infrastructure, human resources, tools and equipment, standards, guidelines and SOPs. Initiatives are also required to educate and sensitise stakeholders in the refrigerant management value chain.

We recommend a multi-pronged approach for the effective operationalisation of LRM in India (Figure 6). The recommendations in this section have been developed based on inputs received from stakeholder consultations, a literature review, and learnings from global best practices.

4.1 Regulatory measures

With regards to regulatory measures, we recommend that the *Ozone Depleting Substances (Regulation and Control) Rules 2000*, *E-Waste (Management) Rules 2016*, and the *Vehicle Scrappage Policy 2021* be suitably amended to include provisions related to LRM.

Amendments to the Ozone Depleting Substances (Regulation and Control) Rules 2000 to include provisions for LRM

In particular, the amendments should make provisions for the following:

- Expand the scope of the *Ozone Depleting Substances (Regulation and Control) Rules 2000* to include high GWP HFCs (as specified under the Kigali Amendment to the Montreal Protocol).
- Recommend that venting of refrigerant gases (with ODS and high GWP) be avoided during servicing, installation, uninstallation, handling, dismantling, and recycling of products.
- Expand the reporting requirements for buyers and users of refrigerant gases to also include reporting on (a) refrigerant recovered, (b) refrigerant reclaimed, (c) refrigerant destroyed, and (d) the procurement and use of new and reclaimed refrigerant.
- Direct e-waste recycling and vehicle scrappage facilities to report on the quantity and types of refrigerants recovered and sent for reclamation.

Figure 6 A multi-pronged approach needed for operationalising LRM in India

Source: Authors' analysis

- Mandate recovery of refrigerant gases during uninstallation and dismantling/recycling of cooling equipment in the RAC and RR sectors, and recycling/reclamation of gases for reuse or destruction.
- Mandate recovery of refrigerant gases during installation and commissioning, servicing, maintenance, repairs, and uninstallation of cooling equipment in the CAC, CR, and MAC sectors, and recycling/reclamation of gases for reuse or destruction.
- Mandate recovery, reclamation, destruction, and handling of refrigerants to be performed by certified technicians and as per relevant standards such as those established by the Bureau of Indian Standards (BIS) or Petroleum and Explosives Safety Organisation (PESO).
- Mandate the certification of reclamation and destruction facilities by the National Accreditation Board for Testing and Calibration Laboratories (NABL) or an equivalent agency, and mandate that reclaimed gases be tested to ensure quality control.

Amendments to the E-waste (Management) Rules, 2022

We recommend the following provisions to be included in the *E-Waste (Management) Rules, 2022*:

- Mandate the recovery of refrigerant gases at e-waste recycling facilities and storage of gases according to refrigerant types.
- Ensure that the recovery, handling, and storage of refrigerants are performed by certified technicians and as per prevalent standards (BIS, PESO).
- Assign to e-waste recycling facilities the responsibility of transporting recovered gases to reclamation facilities with the cost to be covered under existing EPR.
- Mandate record-keeping and reporting of refrigerants recovered (by type) and transported to reclamation facilities.

> **Recovery of refrigerant gases must be mandatory during un-installation and dismantling/recycling of cooling devices in the RAC and RR sectors.**

Amendments to the Vehicle Scrappage Policy 2021 and its guidelines

We recommend the following provisions to be included in the *Vehicle Scrappage Policy, 2021*:

- Mandate recovery of refrigerant gases at vehicle scrappage facilities and storage of gases according to refrigerant type.
- Ensure that the recovery, handling, and storage of refrigerants are performed by certified technicians and as per prevalent standards (BIS, PESO).
- Assign to vehicle scrappage facilities the responsibility of transporting recovered gases to reclamation facilities with the cost to be covered under the existing vehicle scrappage cost.
- Mandate record-keeping and reporting on refrigerants recovered (by type) and transported to reclamation facilities.

4.2 Standards and guidelines

LRM involves several tools, equipment, and processes that require standards and guidelines for maintaining the quality of these tools and their performance. We recommend that India develops or adopts the existing AHRI/ ISO standards and guidelines for the following:

- Standards for tool and equipment
  - Recovery machines
  - Reclamation equipment
  - Recycling machines
  - Gas storage and transportation cylinders
- Standards for processes
  - Recovery process
  - Recycling process
  - Reclamation process
  - Destruction process
  - Storage and handling
- Safety standards/guidelines for handling flammable/toxic refrigerants.

4.3 Training and certification

The existing training and skill development programmes under the *National Skill Development Mission* (NSDM) for technicians in the air-conditioning and refrigeration sectors are primarily focused on the installation, servicing, and repair of the equipment. The training programmes conducted under the *HCFC Phaseout Management Plan* focused on some aspects of refrigerant management, however, the reach of these training programs was limited to a few thousand technicians only. We recommend the inclusion of modules relating to LRM, such as recovery, recycling, and reclamation, which are currently absent in existing training programmes. The proposed training and certification initiative aims to:

- Expand the scope of existing training and certification programmes to create a larger skilled workforce to cater to the growing demand, and
- Develop and deliver training and certification programmes for the skill sets that are absent in existing programmes but are required for refrigerant management.

Training and certification are particularly needed for the following skill sets that would be required for refrigerant management:

- Good installation practices (especially in RAC)
- Good servicing practices
- Recovery of gases
- Reclamation of gases
- Storage and handling of gases
- Gas quality testing
- Uninstallation and decommissioning of devices/ cooling systems

In place of conventional classroom-based training programmes, multiple alternative options should be available for receiving training in a particular skill, such as on-the-job training or video modules. There should be a robust and independent assessment and certification system to assess and certify the skills of a technician. The certification should be based on the skill set one possess, and it should not be dependent upon the methods of training one has received. We recommend a periodic renewal of the certificate to keep pace with advancements in technology and align skill sets with technological improvements.

4.4 Help create supportive ecosystems for refrigerant management

In addition to policy and regulatory measures, substantial efforts are required to establish the requisite infrastructure and a reverse supply chain for refrigerant management.

Support establishing a network of reclamation centres for pilot and demonstration

A network of reclamation centres across different regions of the country would be required to meet the demand for reclamation facilities for refrigerant management. We recommend the establishment of a few reclamation centres in the initial stages as a pilot for demonstrating the technical feasibility and business case for these centres. The focus should not be on establishing mini-reclamation centres that have limitations in terms of the quantity and types of gases that can be reclaimed daily.

Support indigenous manufacturing of tools and equipment required in refrigerant management

We recommend establishing a few micro, small, and medium enterprises (MSME) for the indigenous manufacture of the required tools and equipment. Indigenisation helps reduce equipment costs and establish new MSMEs, which create jobs.

Applied research and development

Some of the areas in need of R&D that emerged during interactions with the stakeholders are:

- Reuse of recovered refrigerant blends after recycling/reclamation is generally avoided and not recommended by OEMs due to overall efficiency concerns.
- Destruction efficiency at destruction facilities (such as cement kilns) for HFCs and HCFCs is unknown and needs an assessment.

> **There should be a robust and independent assessment and certification system to assess and certify the skills of a technician.**

- Leakages due to corrosion are typical in areas near open sewerages or corrosive environments.
- Reclamation and separation of a mix of different refrigerant gases stored together need further study.

Enhance synergies and cooperation among relevant government agencies

The Ozone Cell of the Ministry of Environment, Forest, and Climate Change (MoEFCC) has constituted various committees to provide guidance and support in implementing the *Ozone Depleting Substances (Regulation and Control) Rules* and *HPMP Plans*. We recommend that the government should focus on enhancing synergies and collaborative capacities between these existing committees in the Ozone Cell drawn from the following departments and ministries for greater impact on controlling refrigerant emissions:

- Ozone Cell, Ministry of Environment, Forest, and Climate Change (MoEFCC)
- Central Pollution Control Board (CPCB)
- Ministry of Electronics and Information Technology (MEITY)
- Ministry of Labour
- Ministry of Chemicals and Fertilisers
- Council of Scientific Industrial Research (CSIR)
- Petroleum and Explosives Safety Organisation (PESO)
- Ministry of MSME
- Ministry of Skill Development and Entrepreneurship (MSDE)
- Bureau of Indian Standards (BIS)
- Bureau of Energy Efficiency (BEE)
- Department of Science and Technology (DST)

While these agencies and ministries are already part of various committees, efforts should be made to strengthen collaboration and coordination between and among them. With enhanced synergies and cooperation among them, the committees can achieve significant success in implementing regulations focused on LRM.

4.5 Nudging end-user behaviour to enhance participation in refrigerant management

We recommend that consumers be educated on the harmful impacts of refrigerant emissions and encouraged to participate in the refrigerant management process. They could do so by adopting good installation and servicing practices or proactively handing over discarded cooling products or vehicles to an authorised waste recycler. In particular, consumers could be nudged to participate in LRM through:

- Awareness generation on the impacts of improper waste disposal and gas venting. This will encourage end users to opt for proper servicing and upkeep of their devices to prevent leakages. It will also help in improving efficiencies and reducing the energy cost of running devices.
- Nudging end users to participate in formal waste management through replacement schemes (replacement with more efficient systems with cleaner refrigerants).
- Awareness generation for the adoption of good servicing and installation practices

Image: iStock

End-of-life cooling devices containing refrigerants should be handled carefully and separately from the other e-waste to avoid refrigerant leakage and ensure its recovery.

4.6 Finance and investment

A key pillar of LRM is finance and investment. There are many interventions or activities that would require financial support, and there are multiple avenues for availing that support. This section discusses the various funding options that can be accessed for different interventions. At the time of initiating LRM, appropriate options can be finalised in consultation with the concerned stakeholders (Table 7).

Table 7 Options for finance for the recommended interventions

Finance needed for	Potential funding avenues
Cost of various processes in refrigerant management • Recovery, recycling, reclamation, destruction, storage, transportation., testing	Private sector • EOL in RAC, RR, & MAC – existing EPR on the producer • EOL or servicing in CAC & CR – end user to pay • EOL or servicing in CAC & CR – unlocking carbon credits for the GHG emission mitigated
Infrastructure (to support a few pilot & demo units) • Reclamation centre (collection, testing, and reclamation facilities) • Destruction facility • Indigenous manufacturing of tools and equipment	• MLF/international grants • National Clean Energy and Environment Fund (NCEEF) • Government grant/subsidy • Industry contribution (refrigerant manufacturers & importers, OEMs) – Voluntary/CSR – Tax/fee charged by the government
Other support activities • Awareness campaigns • Training and certification • Replacement schemes	• Through the government's existing programmes on awareness and skilling • Industry participation (e.g., CSR) in skilling, awareness generation, and replacement schemes

Source: Authors' analysis

4.7 Institutional arrangement for the implementation of proposed interventions

Table 8 highlights the responsibilities of relevant authorities in implementing the recommended interventions.

4.8 Conclusion

LRM is vital for achieving the intended objectives of refrigerant transition initiatives. It can potentially mitigate a cumulative or around 2 billion tonnes of CO_2 eq. emissions by 2050 in the RAC, RR, and MAC sectors alone, which would otherwise be produced in the absence of refrigerant management. In addition, LRM offers several other environmental, social, and economic benefits, such as:

- Introduction of circularity in refrigerant use and reducing reliance on the production and use of virgin refrigerants.
- Creation of new MSMEs and jobs resulting from the infrastructure and reverse supply chain that would be established for refrigerant management (network of reclamation facilities, collection centres, test facilities, logistics, etc.).
- Formalisation of the servicing and waste management sectors as part of initiatives aimed at training and certifying technicians and widening the implementation of formal e-waste management.
- Increased private-sector investments in the waste and refrigerant management sectors driven by successful business models showcased by the proposed LRM pilots.
- Avoiding GHG emissions through LRM practices will contribute to achieving India's net-zero goals.

Table 8 Proposed interventions and responsibilities

Proposed interventions for operationalisation of refrigerant management	Responsibility
Amendments in Ozone Depleting Substances (Regulation and Control) Rules 2000	Ozone Cell, MoEFCC
Amendments in E-Waste Management Rules 2022	Central Pollution Control Board (CPCP), in consultation with Ozone Cell
Amendments to the Vehicle Scrappage Policy 2021 and its guidelines	MoRTH, in consultation with Ozone Cell
Standards and guidelines for tools, equipment, and processes	BIS & PESO
Training and certification	Electronics Sector Skills Council of India (ESSCI), in consultation with the Ozone Cell
Creating supporting ecosystem	Ozone Cell (through its steering committee) and relevant authorities (MoMSME and DST)
Awareness and end-user behaviour	Ozone Cell (through its steering committee) and relevant authorities (CPCB and BEE)
Finance and investment	Ozone Cell (through its steering committee), in consultation with relevant stakeholders

Source: Authors' analysis

- LRM will contribute to achieving the goals of some of the government's flagship initiatives, including
  - *Mission LiFE* (nudging to change end-user behaviour towards minimising refrigerant emission and its climate impacts);
  - *ICAP* (minimising refrigerant emissions and their climate impacts through LRM);
  - *Make in India* (initiatives towards supporting indigenous manufacturing of tools and equipment needed for LRM);
  - Commitments under the Montreal Protocol and Kigali Amendment (use of recycled/reclaimed refrigerant will reduce the demand for virgin refrigerants and hence help achieve phase-out/ phase-down targets under these protocols).

A comprehensive LRM plan will help prevent the environmental impacts caused by emission of the refrigerant gases, and fast-track achieving the phase-down targets. For effective implementation of the LRM plan to accomplish the intended benefits, a concerted effort on multiple fronts will be required.

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Acronyms

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AI	artificial intelligence
BAU	business-as-usual
CAC	commercial air-conditioning
CAGR	compound annual growth rate
CCAC	Climate and clean air coalition
CFC	chlorofluorocarbon
CO_2	carbon dioxide
CO_2 eq.	carbon dioxide equivalent
CPCB	Central Pollution Control Board
CR	commercial refrigeration
EOL	end-of-life
EPR	extended producer responsibility
ESSCI	Electronics Sector Skills Council of India
F-gas	fluorinated gas
FGD	focus group discussions
GHG	greenhouse gases
GT	giga tonnes
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbons
HPMP	HCFC Phaseout Management Plan
HVAC	heating, ventilation, and air-conditioning
ICAP	India Cooling Action Plan
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
LiFE	lifestyle for environment
LRM	lifecycle refrigerant management
MAC	mobile air-conditioning
MLF	Multilateral fund
MMT	million metric tonnes
MoEFCC	Ministry of Environment, Forest, and Climate Change
MT	metric tonnes
NABL	National Accreditation Board for Testing and Calibration Laboratories
NCEEF	National Clean Energy and Environment Fund
NSDM	National Skill Development Mission
ODP	ozone depletion potential
ODS	ozone depletion substances
OEM	original equipment manufacturers
PRO	producer responsibility organisations
R&D	research and development
RAC	residential air-conditioning
RASSS	Refrigeration and Air-Conditioning Servicing Sector Society
RATA	Refrigeration and Air-Conditioning Trades Association
RR	residential refrigeration
SIAM	Society of Indian Automobile Manufacturers
SLCP	short-lived climate pollutants
SOP	standard operating procedure
TEAP	Technology and Economic Assessment Panel
UNEP	United Nations Environment Programme

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"LRM presents an opportunity to potentially avoid 2 billion tonnes of CO2 eq. emissions, and fast track achieving the phasedown targets set under the Kigali Amendment of the Montreal Protocol. To tap this potential, initiatives on multiple fronts would be required – policy, capacity building, consumer awareness, and finance. This report is an attempt to break-down and analyse the challenges, and recommend a comprehensive set of measures for effective LRM implementation."

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"Recovering and reusing the potent refrigerants will not only help in mitigating the adverse environmental impact, but its effective implementation will reduce dependency on virgin refrigerants, which are subject to regulation under the Montreal Protocol"

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"By adopting a pragmatic approach to lifecycle refrigerant management, we have the potential to minimise the demand for virgin refrigerants and significantly mitigate their environmental impact. This report underscores the importance of a collaborative and holistic strategy in effectively managing refrigerants and unlocking their value through the principles of the circular economy."

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"With low penetration, high GDP growth, aspirations of people, growth in tourism, pharma, precision manufacturing, food security the cooling and refrigeration products demand is bound to increase multifold. With this increase as a country we need to have a balanced approach to ensure that the environmental impacts are minimised. Refrigerants have high GWP and EOL management is critical phase in the life cycle management. This report looks to take holistic approach and will help in formation of mitigation policy."

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"The AC and cooling sector in India is growing rapidly and is set to be one of the biggest in the world. It is therefore crucial to make this sector as sustainable as possible. This involves the use of energy efficient equipment containing refrigerants with low environmental footprints. Equally important is the lifecycle management of refrigerants already in use or by decommissioning, which is the focus in this second cooperation project between CEEW and the NEA. Norway is pleased to cooperate with the very professional team at CEEW and we hope that the Norwegian experience can contribute to finding the right solutions for India."

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