Green Chillers NAMA Project Indonesia

Refrigeration and Air Conditioning Greenhouse Gas Inventory for Indonesia

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Jl. H.O.S Cokroaminoto No.91
Jakarta, 10310

Author

Dietram Oppelt; Herlin Herlianika; Irene Papst, HEAT GmbH

Reviewer

Edi Sartono; Ardian Marta Kusuma; Wisnu Adi Purwoko, EBTKE -KESDM

Evi Wahyuningsih; Denise Andres; Philipp Munzinger; Kai Berndt, GIZ

Adam Adiwinata, HEAT GmbH

Editor/Layout

Syifa Astarini Iskandar

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List of abbreviations

ASHRAE	American Association of Refrigeration Engineers
APEC-ASEAN	Asia Pacific Economic Cooperation - Association of Southeast Asian Nations
BAPPENAS	State Ministry of National Development Planning
BAT	Best Available Technologies
BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BOE	Barrel of Oil Equivalent
BSN	National Standardization Agency of Indonesia
CAGR	Compound Annual Growth Rate
ComRef	Commercial Refrigeration
DomRef	Domestic Refrigeration
GCI	Green Cooling Initiative
GEF	Grid Emission Factor
GEG	Good Environmental Governance
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GHG	Greenhouse Gas
GOI	The Government of Indonesia
GWP	Global Warming Potential
EPTS	Energy Performance Testing Standards
INDC	Intended Nationally Determined Contributions
HEAT	Habitat, Application and Technology (Heat GmbH)
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPMP	HCFC Phase-Out Management Plan
KLHK	Environmental Ministry
MEMR	Ministry of Energy and Mineral Resources
MEPS	Minimum Energy Performance Standards
MOF	Ministry of Finance
MOI	Ministry of Industry
MP	Montreal Protocol
MRV	Measuring, Reporting and Verification
MW	Megawatt
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contributions
NOU	National Ozone Unit
RAC	Refrigeration & Air Conditioning
RAN-GRK	National Action Plan for Greenhouse Gas Emissions Reduction
RAD-GRK	Local Action Plan for GHG Emission Reduction
RIKEN	National Energy Conservation Master Plan
SNI	Indonesian National Standard
UAC	Unitary Air Conditioning
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Organisation

Foreword

The energy sector is the second largest greenhouse gas (GHG) emitter in Indonesia and therefore holds the key to achieving the national emissions reduction target. As stated in the first Nationally Determined Contributions (NDCs) of Indonesia, along with renewable energy development, energy efficiency is one of the key measures to reduce GHG emissions from energy sector. In response to the national target for reducing GHG emissions, the Directorate General for New, Renewable Energy and Energy Conservation (DG NREEC) under the Ministry of Energy and Mineral Resources (MEMR) reinforces its efforts by establishing policies and programmes to support the implementation of mitigation actions in the energy sector. This is also particularly evident in the Refrigeration and Air Conditioning (RAC) sector, where significant mitigation potential could be materialized through the implementation of climate friendly technologies.

The inventory for the RAC sector of Indonesia, capturing emissions from both climate-damaging refrigerant and energy use, is the first of its kind and is a result of a comprehensive data collection and assessment process. This report has been developed to provide a basis for the further development of the Nationally Appropriate Mitigation Action (NAMA) in the RAC sector in contribution to Indonesia's climate targets set out in its Nationally Determined Contributions. This RAC Inventory was conducted as part of the Green Chillers NAMA Project funded by the International Climate Initiative (IKI) of the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and jointly implemented by Directorate General for New and Renewable Energy and Energy Conservation (DG NREEC) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

We would like to express our gratitude for the support of all the institutions, companies and other stakeholders, whose support and expertise were indispensable to the realization of this project.

Mrs. Ir. Ida Nuryatin Finahari M.Eng
Director for Energy Conservation
Directorate General for New and Renewable Energy and Energy Conservation (DG NREEC)

Mr. Kai Berndt
Principal Advisor
Green Chillers NAMA

Summary

Over the last few years, there has been tremendous growth in the Indonesian RAC industry. Especially due to rapid population growth and steady rise of ambient temperatures, the demand for air conditioning and refrigeration is also continuously rising. These findings show the emission from the RAC sector according to a business-as-usual (BAU) sector as well as the sector's mitigation potential, which can be achieved through technologically and economically feasible mitigation actions.

- In 2015, the RAC sector was responsible for 77.31 Mt CO_2eq of GHG emissions. This means that the RAC sector's share in overall energy-related emissions corresponds to approximately 15.4% of Indonesia's energy-related GHG emissions[1] (Edgar Emissions Database, 2017), which is comparable to the level of RAC-related emissions in the region[2].
- Following the current warming trend with a 2-2.5°C global temperature rise under the most optimistic Representative Concentration Pathway (RCP), the RCP 2.6, until 2100 (IPCC, 2014), the need for air conditioning and refrigeration will further rise. With the underlying growing demand for RAC appliances, the the resulting emissions from the Indonesian RAC sector are expected to rise to almost 218 Mt CO_2eq by the year 2050 (see Figure 1).

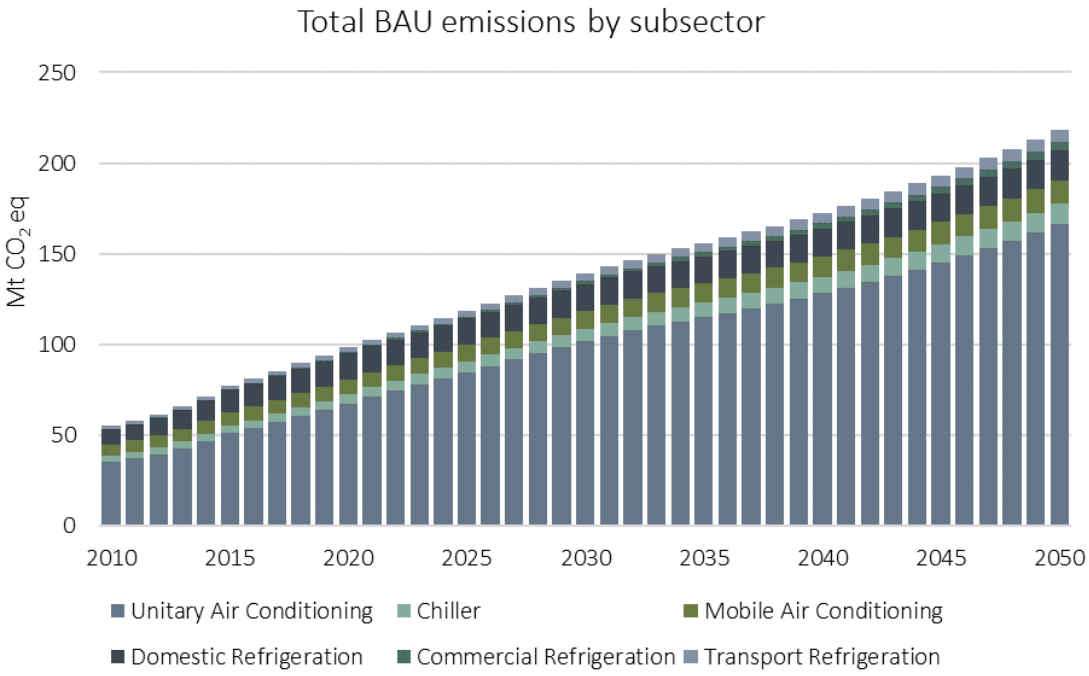

Figure 1. Projected business-as-usual scenario for GHG emissions in the RAC sector until 2050

- About 42.5 MtCO_2 can be reduced annually by 2050 as shown in Figure 2, where mitigation action addressing direct emissions can account for 17.7 MtCO_2 (dark green) and from indirect emissions can account for 25 MtCO2eq (light green).

[1] Based on 2015 energy related emissions from the Edgar database of 503 Mio tCO_2.
[2] See country specific GHG emissions of key RAC subsectors from www.green-cooling-initiative.org (accessed on 19.06.2017)

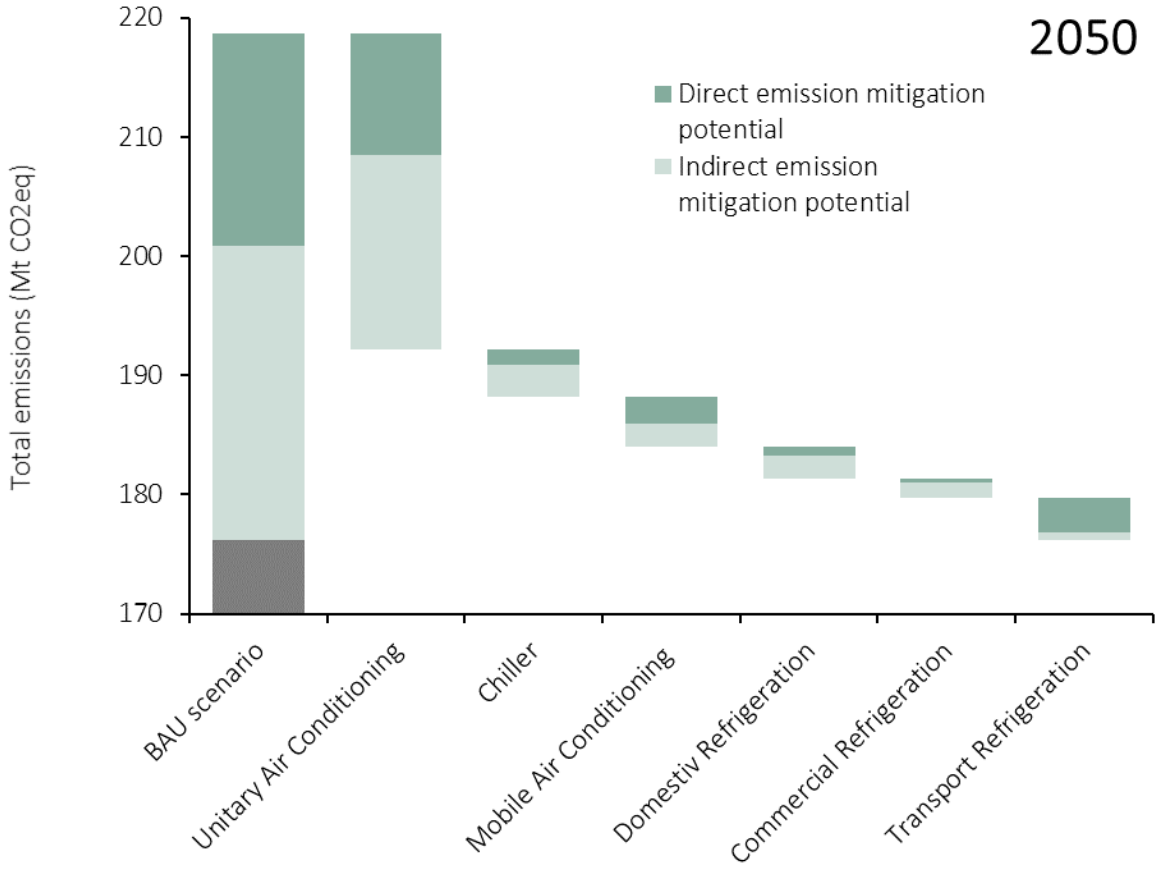

Figure 2. Mitigation potential of the Indonesian RAC sector in the year 2050[3]

The large GHG mitigation potential in the sector lies in transitioning from highly climate-damaging hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) to alternatives with low Global Warming Potential (GWP) values in a timely manner, ahead of the current HFC phase-down schedule stipulated in the Kigali amendment to the Montreal Protocol (Clark and Wagner, 2016). Figure 3 shows the RAC-related HFC consumption under the Business-as-Usual (BAU) scenario (blue line), the assumed consumption freeze and reduction steps under the Kigali Amendment (green line) and projected consumption under a more ambitious scenario as assumed under the mitigation scenario (MIT) in this inventory report (red line). Refrigerant consumption and emissions as shown in the Figures above are calculated based on the same model. The MIT scenario assumes the application of best available technologies (BAT) and the use of low GWP[4], natural refrigerants.

[3] Note: the grey color of the first column shows the unabated emissions. The next columns to the right of the first column show the emission mitigation potential of each subsectors both for direct (dark green) and indirect (light green) emissions. As it can be seen from this figure, the Unitary Air Conditioning subsector, has the most significant abatement potential.

[4] Note: Low GWP in this document is referred to refrigerants with a GWP below 10

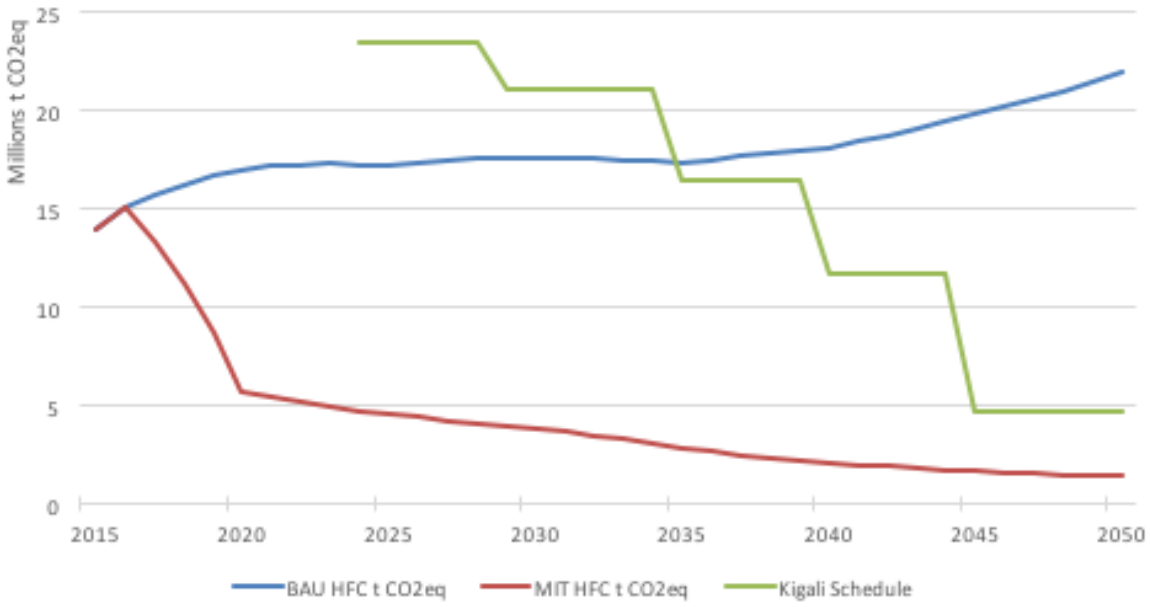

Figure 3. Scenarios on HFC BAU, MIT emissions and Kigali Schedule

Furthermore, the transition to low GWP refrigerants can also yield additional benefits along reducing GHG emissions. Some co-benefits are saving energy and costs through improved energy efficiency, creating local employment through use of refrigerants and appliances produced locally. Overall, reducing energy consumption also contributes to Indonesia's national energy security.

This RAC inventory showing direct, indirect, and total emissions from the sector is the first of its kind in Indonesia. Prior to this inventory, emissions for the RAC sector were not compiled and were also not included in Indonesia's national GHG reporting. Through the information provided by this inventory, Indonesia now has a robust basis to include RAC sector emissions in further NDC planning.

1. Introduction

1.1 Project framework

This GHG inventory was compiled within the framework of the project "Development of a NAMA for Energy-Efficient Cooling Systems and Cold Supply in Indonesian Industry and Commerce". This project was commissioned to the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for implementation by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) under the International Climate Initiative (IKI). The project supports the Indonesian Ministry of Energy and Mineral Resources (MEMR) in establishing parameters for increased energy efficiency in RAC technology, finding solutions for greener RAC technologies and fostering their marketability and local manufacturing. Also, the results of the project will be valuable for other developing countries with similar climate and economic prerequisites.

The project works closely with the following local authorities:

- Ministry of Energy and Mineral Resources (MEMR) - the Directorate of Energy Conservation is responsible for coordinating the project;
- Ministry of Environment and Forestry (KLHK);
- State Ministry of National Development Planning (BAPPENAS);
- Ministry of Industry (MoI);
- Ministry of Finance (MoF);

The purpose of the RAC GHG inventory is to obtain an overview of the current state of GHG emissions in the refrigeration and air conditioning (RAC) sector in Indonesia. Particularly, this report intends to provide information on the following topics:

- business-as-usual (BAU) GHG emissions resulting from refrigerant and energy consumption of the RAC sector
- potential market penetration of energy-efficient appliances with low-GWP refrigerants
- potential to mitigate GHG emissions from refrigerant use and energy consumption in the RAC sector and its subsectors

Further, this report describes the RAC appliances currently available on the Indonesian market as well as their energy consumption, refrigerants used and the respective GHG emissions. RAC technologies currently deployed are compared with the international best practice technologies in order to determine their GHG emissions mitigation potential. Future trends in each of the RAC subsectors are analysed with respect to both BAU and mitigation (MIT) scenarios.

1.2 Importance and benefits of RAC sector inventories

Inventories of the RAC sector that are based on estimated number of equipment in different subsectors as well as the average technical parameters per subsector provide a sound database. This serves as a reliable starting point for designing and implementing GHG emission reduction activities in the sector.

Equipment-based RAC inventories can provide the following information:

- Sales and stock per subsector as well as growth rates per key subsector
- Technical information about appliance data such as average energy efficiency, and refrigerant distribution and leakage rates
- GHG emissions on a RAC unit basis
- Total GHG emissions for the RAC sector, with a distinction between direct and indirect emissions
- Projection of future RAC GHG emissions
- Mitigation scenarios based on the introduction of different technical options

The collected information can be used for the following purposes:

- Identifying key subsectors with the highest GHG emissions as well as the highest emissions reduction potential based on available technologies. RAC inventories are important for the planning, development, and implementation of mitigation roadmaps.
- Supporting country-wide GHG emission inventories that can be used for reporting under the UNFCCC. The also indicate how GHG emissions will develop in the future, as demonstrated in the projections. Sectoral RAC mitigation plans based on GHG inventories and projections can support the development of sectoral targets as part of the Nationally Determined Contributions (NDC).
- Providing planning tools for mitigation actions, such as the formulation of Minimum Energy Performance Standards (MEPS) and labelling categories or formulating policies such as banning of refrigerants with high GWP.
- Giving indication on the impact of legislation on stakeholders in different subsectors
- Forming the basis of a Measuring, Reporting and Verification (MRV) system or a product database
- Supporting the development of proposals with the aim of reducing GHG emissions in the RAC sector, such as NAMAs.

Based on these various advantages and purposes, the following stakeholders can benefit from RAC inventories:

- Climate departments/institutions and/or national focal point for GHG control and mitigation planning as well as UNFCCC reporting (specifically on HFCs)
- Environmental ministries for pollution control as well as for waste collection systems
- National ozone units for the control and planning of HCFC and HFC mitigation steps with reporting requirements under the Montreal Protocol
- Energy ministries for the planning of energy use and conservation

1.3 The refrigeration and air conditioning (RAC) sector in Indonesia

As a tropical country with the world's fourth largest population and a growing economy, Indonesia significantly contributes to the global GHG emissions with a substantial input from its RAC sector. Due to low energy prices (that have been subsidized for a long time), low or non-existing energy performance standards, and limited awareness on the efficient use of electricity, the energy consumption of RAC appliances in use is exceptionally high. In response to this development and in line with reduction of electricity subsidies in various tariff groups,

the Indonesian government has started introducing Minimum Energy Performance Standards (MEPS) and labelling for household refrigeration and air conditioning appliances (CLASP, 2017). For commercial RAC appliances, only non-mandatory recommendations exist so far (Oppelt, Yatim and Colbourne, 2016).

Current RAC appliances do not widely use energy efficiency features such as variable speed controls or inverter compressors, which automatically adjust the cooling supplied according to the cooling demand. Adopting energy efficiency features can reduce energy consumption and energy related emissions significantly. In addition, many other features (e.g. size of heat exchanger, piping, dimensioning and control engineering) need to be optimised to ensure the energy efficiency of a system.

Regarding refrigerants, Indonesia is currently phasing out ozone depleting substances, including HCFC-refrigerants in the RAC sector. As alternatives, both medium-high and high-GWP HFCs as well as low GWP non-HFCs are considered. Significant amounts of refrigerant-related (i.e. direct) emissions can be mitigated by directly transitioning to low GWP refrigerants.

Section 2.3 will analyse in greater detail the main historic and future growth drivers of Indonesia's RAC sector.

1.4 Factors influencing the growth of RAC appliances

The demand for RAC appliances in Indonesia is continuously growing. The current and future drivers of demand are namely: growing population and number of households (Oppelt, 2013), increasing urbanisation, economic growth and the fossil fuel based primary energy supply. Table 1 and Figure 4 (Ministry of Energy and Mineral Resources, 2016) illustrate the growth of factors contributing to the growing demand of RAC appliances and their resulting energy use and emissions. There is a strong demand in urban areas where 53.7% of the total population lives. The urbanisation grew strongly during recent years with a rate of 2.69%[5].

Table 1. Compound Annual Growth Rates (CAGR) of selected values for the years 2011-2015 (Ministry of Energy and Mineral Resources, 2016). CO_2 and GHG data from 2010-2015 and 2010-2013, respectively (Olivier *et al.*, 2016).

	GDP[6]	Population	Number of households	Primary energy supply	CO_2	GHG [CO_2eq]
CAGR [%]	**4.3**	**1.4**	**1.1**	**1.5**	**2.9**	**1.5**

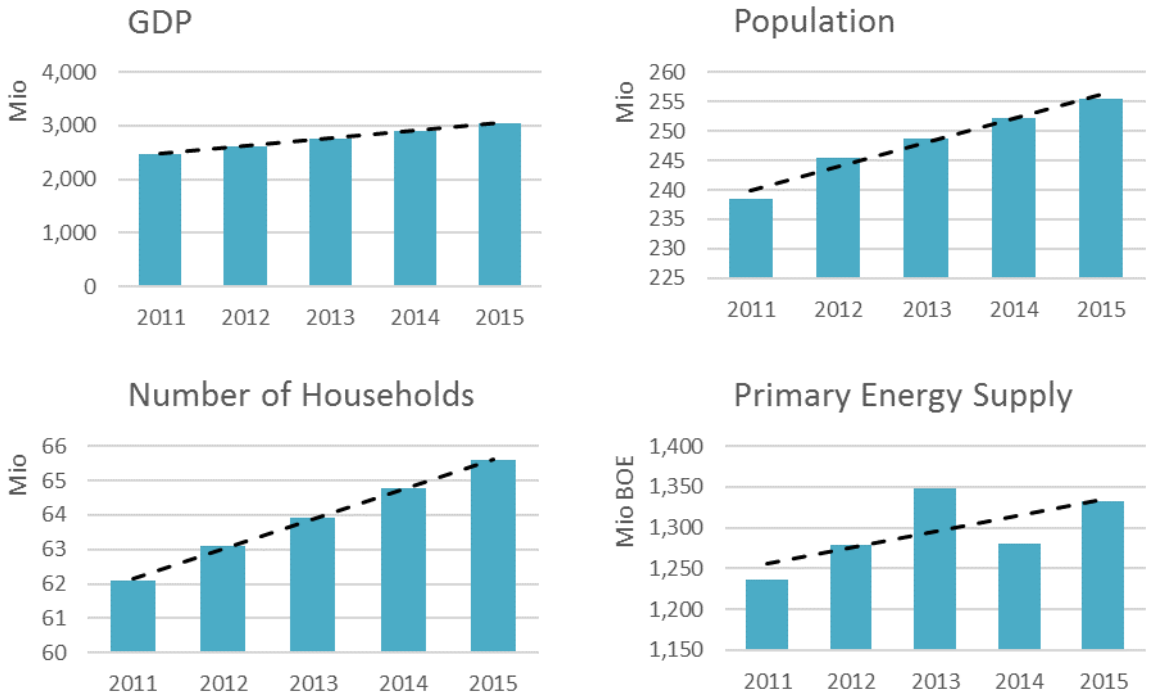

Figure 4. The changes in GDP, population, number of households and the primary energy supply for the years 2011-2015 for Indonesia (Ministry of Energy and Mineral Resources, 2016). The dashed line shows the CAGR trend line.

An additional driver will be increasing global temperatures. The climate of Indonesia is tropical with a distinct rainy season and a dry season, without any extremes The humidity is high throughout the year and temperatures range between 23°C and 32°C depending on the geographic location. The greatest variation in precipitation is due to the monsoon in the month

[5] https://www.cia.gov/library/publications/the-world-factbook/geos/id.html
[6] At constant prices for the year 2000.

November to March. With a reference temperature of 18°C, the cooling degree days (CDD) of Jakarta are 3880, triggering the use of air conditioners in most parts of Indonesia throughout the year. Climate change projections assuming a temperature rise of about 2-2.5°C for Indonesia over the coming decades (Gosling et al., 2011) imply even higher CDD, which in turn, will further increase the demand for air conditioning equipment (Oppelt, 2013). With higher global temperatures, the number of cooling degree days in Asia will increase between 30% and nearly 100% by 2100 under the climate reference scenarios RCP2.5 and RCP8.5, respectively (Hasegawa et al., 2016). With the rising temperatures, he demand for cooling food is also expected to rise and thereby presents an additional challenge.

1.5 Electricity generation from fossil fuels

As most of Indonesia's energy is still generated from fossil fuels (Figure 5), the growing demand for energy, where the RAC sector is a significant driver, will further increase Indonesia's GHG emissions. This will likely be the case, even as Indonesia aims for a greater proportion of renewable energy with up to 23% in the year 2025 (Tharakan, 2015).

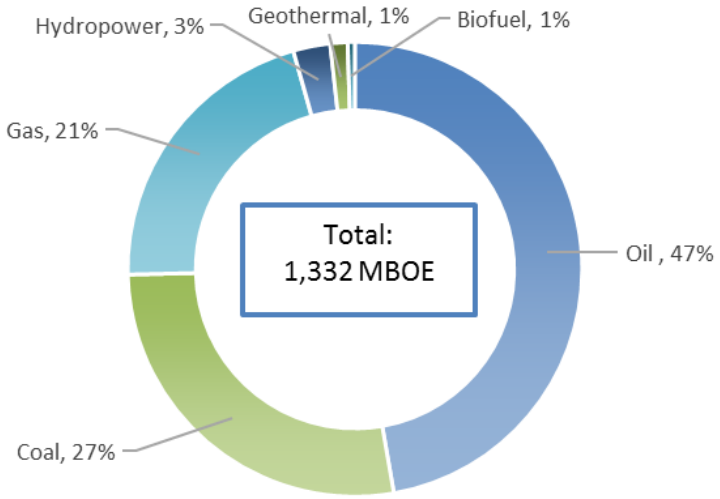

Figure 5. Primary energy supply by type (excluding biomass) as of 2015 (Handbook of Energy & Economic Statistics 2016).

In the last few years, the country has been progressively taking efforts to exploit renewable energy sources such as hydro- and geothermal power. Nevertheless, renewable resources account for only 5% of the electricity produced inland as of 2015. As shown in Figure 6, the household and the commercial sector account for about 36% of the energy consumption in Indonesia. Air conditioning often accounts for over 50% of the building related energy consumption (Neuber *et al.*, 2015). About 80% of Indonesia's households have access to the electricity grid. Many households have a contracted capacity limit of 450 W (Osumi, 2016).

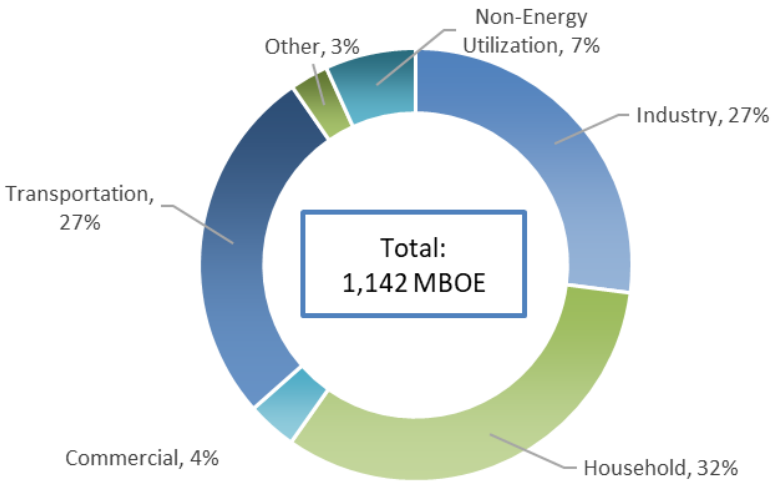

Figure 6. Share of final energy consumption by sector as of 2015 (Handbook of Energy & Economic Statistics 2017).

1.6 RAC stakeholders

Table 2 provides an overview of Indonesia's key government institutions relevant for the climate and energy conservation policy in the RAC sector as well as key non-state institutions and stakeholders in the sector.

Table 2. Overview of institutions relevant for the RAC sector

Ministry/Institution	Duties/Functions/Responsibilities
Ministry of Energy and Mineral Resources (MEMR)	• Responsible for affairs in the field of energy and mineral resources. • Offers support in renewable energy development • Enforces energy efficiency standards and administers labelling schemes • Responsible for the Green Chiller project
Directorate General of New Renewable Energy and Energy Conservation/ EBTKE under MEMR	• Revises the National Energy Conservation Master Plan (RIKEN), which includes energy conservation activities • Responsible for the energy policy of Indonesia
Ministry of National Development Planning/ BAPPENAS[7]	• Implements the National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GRK) until 2020. Within this framework, BAPPENAS deals with topics of measurement of RAN-GRK, Nationally Determined Contributions (NDCs) and the Nationally Appropriate Mitigation Actions (NAMA).
Ministry of Environment and Forestry/ KLHK *(Kementerian Lingkungan Hidup dan Kehutanan)*[8]	• Responsible for the national environmental policy and planning, implementation of climate change and ozone protection programs including HPMPs • Serves as the national focal point to the UNFCCC • Implements Measuring, Reporting and Verification (MRV) • Administers the Good Environmental Governance (GEG) programs to promote public empowerment and capacity building in local environmental management
Ministry of Industry (MoI)[9]	• Responsible for the implementation of product certification based on Indonesian National Standards (SNI) issued by the National Standardization Agency of Indonesia (BSN).
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	• The local chapter of ASHREA acts as an organisation that coordinates the RAC industry stakeholders and RAC engineers in Indonesia

[7] http://bappenas.go.id/profile1/
[8] http://www.menlh.go.id/
[9] http://www.kemendag.go.id/en/about-us/task-and-function/secretariat-general

The Cold Chain Association of Indonesia	• The Cold Chain Association represents the interest of key RAC actors, such as manufacturers of RAC appliances and operators along the cold chain including transport refrigeration, commercial refrigeration and cold stores, in policy discussions.
The Green Building Council of Indonesia	This independent organization, which is comprised of professionals in design and construction industry, promotes energy conservation in buildings – for example by including the definition of energy efficiency standards and the use of climate friendly and energy efficient RAC appliances.
Polytechnic Institutes of Bali, Bandung, Indramayu, Tanjung Balai, Sekayu	• Key institutions for the vocational training of RAC engineers and technicians with a regional focus.
UNDP, UNIDO, The World Bank	• Multilateral implementing agencies under the Multilateral Fund of the Montreal Protocol

1.7 RAC related policies

Regulatory frameworks are required to promote and enable changes towards environmentally friendly technology alternatives in the RAC sector. Indonesia has already committed to several international agreements and set internal goals relevant to the climate and the RAC sector in specific. Indonesia's energy consumption related emissions, for example, will be targeted within Indonesia's ambitions to mitigate GHG emissions as part of its NDCs under the UNFCCC and its Paris Agreement.

1.7.1 RAC related energy policies

The National Energy Policy (2014) and National Energy Conservation Master Plan (RIKEN) state that Indonesia aims to achieve energy elasticity of less than 1 by 2025 and decrease energy intensity by an average of 1% per year to 2025[10]. Between 2000 and 2009, there was a reduction of more than 1% per year. During 2010-2011, the reduction achieved was closer to 0.9%, largely due to the impacts of the slow growth and reduced investment in modern technologies. Indonesia's energy conservation targets (measured as energy intensity) until 2025 compared to 2011 as the base year can be detailled as follows[11]:

- Industry - 17%
- Commercial - 15%
- Transportation - 20%
- Household - 15%

In addition, the Government of Indonesia (GOI) plans to increase the share of **renewable energy** relative to fossil fuels. Government Regulation No. 79/2014 on National Energy Policy

[10] Energy intensity is measured in terms of the amount of energy required to produce one unit of GDP.

[11] Source: MEMR. 2011. Draft National Energy Conservation Master Plan (RIKEN).

set out an ambition to transform the primary energy supply mix with an increased share of renewable energies with at least 23% in 2025 and 31% in 2050.

A key measure to increase energy efficiency, specifically in the commercial and household sectors is the introduction of Minimum Energy Performance Standards (MEPS) and labelling. MEPS can effectively push energy inefficient appliances out of the market while labelling provides transparent information to the end users on different energy efficiency classes. Through this transparent information, a "pull effect" on the demand for more energy-efficient appliances is created. Indonesia has MEPS for selected electrical appliances, which are based on the Indonesian National Standard (Standar Nasional Indonesia, or SNI) and Energy Performance Testing Standards (EPTS) as illustrated in Table 4. These policies were introduced in 2008 and were formalized through the Government Regulation No. 70/2009. The purpose of the standards is to specify technical requirements regarding energy efficiency and safety as well as energy labelling. MEPS are applicable to residential and commercial sectors such as home appliances, lighting and equipment. Since August 2016, MEPS are mandatory for split ACs. The MEPs for ACs have been initially introduced with a COP of 2,5 (2016) and are planned to be upgraded to 2.64 (2018) and 2.93 (2020). Based on the current labelling scheme for ACs, four appliances in the market are rated with one star, 43 with two stars, 36 with three stars and 260 with four stars (MENR, 2017). MEPS for domestic refrigerators are planned to be introduced in the near term.

Table 3. Energy efficiency standards for domestic refrigerators in Indonesia (kW/year), where Vadj is adjusted volume

Star rating	Without freezing capacity	With freezing capacity
1 star	$<465 + 1.378*V_{adj}*1.15$	$<465 + 1.378*V_{adj}*1.55$
2 star	1 star*0.77	1 star*0.77
3 star	2 star*0.77	2 star*0.77
4 star	3 star*0.77	3 star*0.77

Table 4. International performance testing standards for selected appliances

Product	Standard
Room AC split type	ISO 5151
Room AC window	ISO 5151
Household refrigerators	SNI IEC 15502-2009

The APEC-ASEAN Harmonization of Energy Efficiency Standards for Air Conditioners Initiative was introduced in 2010 by ICA and UNEP with ACs selected as priority devices. Under this project, the testing standard SNI 19-6713 was introduced in 2002 to Indonesia. The project estimates that through the implementation of the newly established standards and use of energy-efficient air conditioning devices, energy savings could amount to 51.67 TWh in 2030 (Cazelles, 2015).

1.7.2 Underlying climate and energy policies

Within the National Action Plan for Greenhouse Gas Reduction (RAN-GRK) in 2010, the Government of Indonesia committed to reducing emissions by 26% compared against the BAU scenario until 2020. Beyond 2020, Indonesia has set an unconditional emissions reduction target (i.e. without international support) of 29% and conditional emissions reduction target (i.e. with international support) of up to 41 % compared to the business-as-usual scenario by 2030.

The Paris Agreement was ratified by Indonesia through Law 16/2016 und enacted on October 25, 2016. The First Intended Nationally Determined Contributions (INDCs) for Indonesia was submitted to the UNFCCC for ratification on September 24, 2015[12]. The document outlines the country's transition to a low-carbon and climate resilient future.[13]

The development of a NAMA Strategy is part of the implementation of Indonesia's climate action plan (Thamrin, 2011). As shown in Table 5, most of the emission mitigation actions are related to energy and forestry (with other minor contributions targeted for the waste treatment and agriculture sector). The energy-related counter measures under the CM1 (unconditional) and CM2 (conditional) scenarios target emission reductions of 314 and 389 $MtCO_2eq$ annually by 2030.

Table 5. Projected BAU and Counter measure mitigation scenarios for different sectors (EBTKE, 2017a)

Sector	GHG Emission Level 2010* Mt CO_2eq	GHG Emission Level 2030 Mt CO_2eq			GHG Emission Reduction				Annual Average Growth BAU (2010-2030)	Average Growth 2000-2012
					Mt CO_2eq		% of total BAU			
		BAU	CM1	CM2	CM1	CM2	CM1	CM2		
Energy*	453	1,669	1,355	1,271	314	398	11	14	6.7	4.5
Waste	88	296	285	270	11	26	0.4	1	6.3	4
Agriculture	111	120	110	116	9	4	0.3	0.1	0.4	1.3
Forestry**	646	714	217	64	497	650	17	23	0.5	2.7
TOTAL	**1,334**	**2,869**	**2,034**	**1,787**	**834**	**1,081**	**29**	**38**	**3.9**	**3.2**

*Including fugitives
**Including peat fire
CM1= Counter measure (unconditional mitigation scenario)
CM2= Counter measure (conditional mitigation scenario)

The unconditional emission reduction target of 314 $MtCO_2eq$ of the energy sector can be further subdivided into savings through specific measures, namely: application of renewable energies, energy conservation, and restoration of mined lands. Energy conservation accounts for about 100 $MtCO_2eq$ or one third of the total mitigation target. The respective estimated values and shares can be seen in Table 6.

Table 6. Specific measures for mitigation in the energy sector (EBTKE, 2017a)

Energy Sector mitigation targets (2030)	Million Tons	[%]
Renewable energy (electricity and non-electricity)	170.42	54.27%
Clean energy (power plant)	31.8	10.13%
Energy conservation	96.33	30.68%
Fuel switch (oil and gas)	10.02	3.19%

[12] http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx; Indonesia submitted its first NDC in November 2016.
[13] Further information in Indonesia's INDC submission: http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Indonesia/1/INDC_REPUBLIC%20OF%20INDONESIA.pdf (accessed on 3rd of April, 2017).

After mining reclamation	5.46	1.74%
Total	314.03	100%

The RAC sector is a major driver for the energy and electricity demand contributing to growing GHG emissions from the energy sector. This inventory report will demonstrate that significant savings in the energy sector can also be achieved through transition to more energy-efficient and environmentally friendly RAC-appliances.

1.7.3 RAC related policies under the Montreal Protocol

The refrigeration and air conditioning (RAC) sector is currently addressed by the activities outlined in the HCFC Phase-out Management Plan (HPMP). According to its commitment under the Montreal Protocol, Indonesia will reduce HCFC production and consumption by 97,5% until 2030 and phase them out completely by 2040. Indonesia has successfully implemented its targets under Stage I of its HPMP and is currently preparing for the implementation of Stage II. Target and key measures per stage are outlined in Table 7.

Table 7. HPMP Stages and objectives.[14,15]

	Duration	Implementing Agency	Target and key measures
Stage I	2012 - 2018	UNDP, Australia, World Bank, UNIDO	Reduce 80t or 20% of HCFCs by 2018 from a baseline of 403t HCFCs • Prohibition of the use of R22 and HCFC-141b in refrigeration and air conditioning and the assembly sectors • In the AC sector 5 out of 21 companies completed conversion from R22 to R32. • In the commercial sector 15 out of 27 companies stopped using HFCFs
Stage II[16]	2020 - 2023	UNDP, World Bank	• Reduce HCFC consumption as percentage of the baseline by 37,5% (2020) and 55% (2023) • Import ban on HCFC-141b in bulk and contained in imported pre-blended polyols

Indonesia agreed to the Kigali Amendment under the consensus principle followed by the Montreal Protocol, however, it made a reservation to seek national consensus for the first freeze date (UNEP, 2016b). Under the Kigali Amendment it was agreed to freeze HFC consumptions/productions starting from 2024 based on a GWP-weighted baseline of average HFC consumption in the year 2020-2022. HFCs are greenhouse gases with no ozone depleting potential but with a high global warming potential (GWP values ranging up to 14,800). The

[14] http://www.id.undp.org/content/dam/indonesia/Project%20Docs/hpmp/HPMP%20-IDN%20MP%20OLP%20v%2002.pdf?download

[15] http://www.multilateralfund.org/76/English/1/7636.pdf

[16] see reference: (UNEP, 2016a)

Kigali amendment starts with a freeze in 2024, provides a first reduction step of 90% of the baseline in 2029 and successive steps of 70% of the baseline in 2035, 50% in 2040 and 20% in 2045. The baseline for article 5 countries (in group 1)are determined from 65% of the HCFC baseline and average HFC consumption in the years 2020-2022.

The stipulations of the Kigali Amendment has a direct impact on the choice of refrigerants used in RAC appliances as the average GWP of refrigerants need to be substantially reduced. The phase-down will lead to a shortage in the supply of HFCs with higher GWP and consequently force an increase in prices. Any effort taken by Indonesia to phase down HFCs faster than agreed under the Kigali Amendment can contribute to the targets laid out in the country's NDCs to the Paris Agreement to mitigate GHG emissions. Hence, mid- and long-term strategies should consider sustainable solutions that reflect the obligations and future developments under the Kigali Amendment and the Paris Agreement.
Instead of replacing the HCFCs with HFCs, Indonesia could opt for more sustainable solutions straight away.

2 Scope of the inventory

The inventory covers GHG emissions from the RAC sector based on a stock model covering the major refrigeration and air conditions subsectors and their appliances. The current and future stock are derived from historic sales figures whereas historic growth trends and dynamics help to determine the future stock. The emissions are calculated for each subsector and appliance type based on critical technical parameters, determining the direct and indirect emissions.

More specifically, the inventory covers the following:

- For each of the subsectors and their respective appliance types (Table 16) an inventory of historic and future sales and stock unit data is established.
- For each appliance unit type the historic, current and future energy and refrigerants use and their respective emissions are estimated.
- Currently deployed RAC technologies are compared with international best practice technologies for their potential to mitigate GHG emissions on an appliance unit basis
- The scope covers the calculated mitigation potential of the RAC sector of Indonesia using the IPCC guidelines
- Future trends of RAC subsectors are analyzed both with respect to business as usual and mitigation scenarios.

The RAC subsectors and all appliances covered by the inventory are categorized according to key subsectors as outlined in the RAC NAMA Handbook (Heubes and Papst, 2014) and further illustrated in Table 17 and Table 18 of the Annex.

As outlined in the methodology below, the inventory is based on actual emissions gathered at the unit or appliance level as opposed to inventories based on the bulk refrigerant consumption across different sectors. The latter approach is usually applied for estimating emissions as part of Ozone Depleting Substances (ODS) alternative surveys.

2.1 Methodology

The methodology adopted for the report draws on the concepts outlined by Heubes et al. (Heubes and Papst, 2014) and Penman et al. (Penman *et al.*, 2006) and draws on the Tier 2 methodology from the IPCC 2006 Guidelines. To be noted, the word “system” is used interchangeably in this report with the words “appliance, equipment or unit”.

While alternative refrigerant inventories, such as ODS alternative surveys, are typically based on the Tier 1 methodology, this inventory is based on the IPCC Tier 2 methodology. This covers not only refrigerant related emissions and their mitigation options, but also GHG emissions from the energy use and their mitigation options. In addition, the Tier 2 methodology allows for the preparation of national GHG mitigation actions (such as NAMAs) in relevant RAC subsectors and thereby suitable for the purpose offurther NDC development and review as well. As Tier 2 inventories are based on unit appliances, a reliable MRV system can be established at the unit appliance level to track emissions as well as mitigation planning and efforts in the sector.

The difference between Tier 1 and Tier 2 methodologies can be summarized as follows[17]:

- Tier 1: emissions are calculated based on an aggregated sector based level (Heubes, 2013; Penman, 2006; IPCC 2006 Guidelines).
- Tier 2: emissions are calculated based on a disaggregated unit based level (Heubes, 2013; Penman, 2006, IPCC 2006 Guidelines). The difference between the Tier 1 and Tier 2 methodology are further illustrated in the following Figure 7.

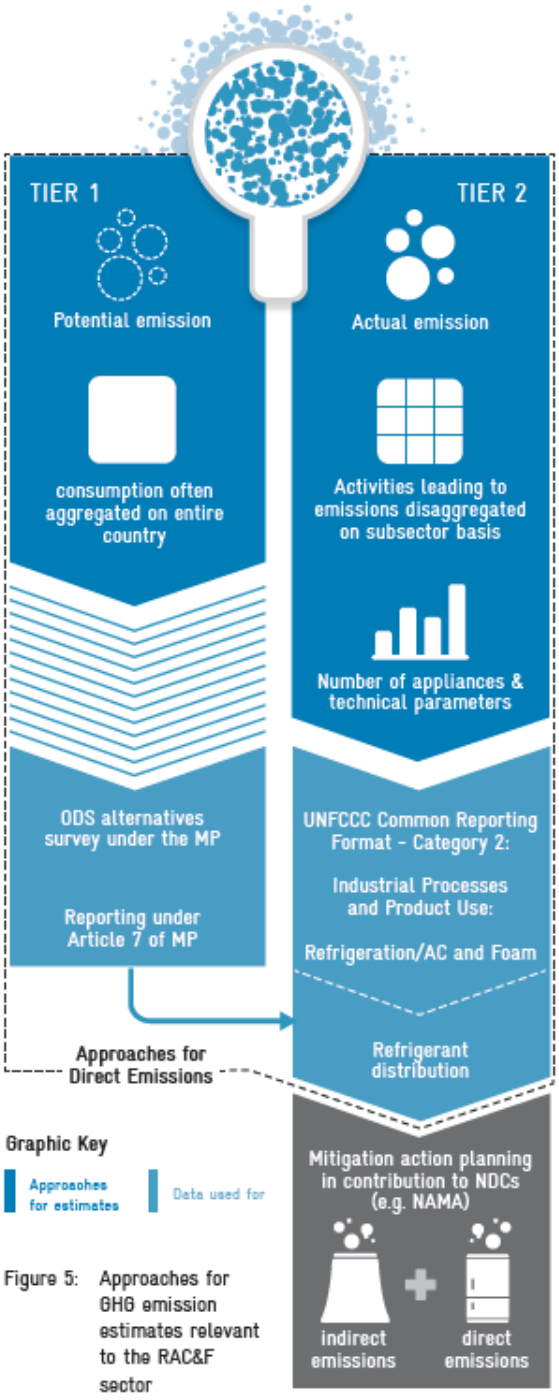

Figure 7. Approaches for GHG emission estimates relevant to the RAC&F sector (Munzinger *et al.*, 2016).

[17] Please note that sector, subsector and application here are used in the context of this report, where IPCC 2006 methodology refers to sector as application and application as sub-application.

The Tier 2 methodology used in this report accounts for direct and indirect emissions of the stock (or appliances in use) in manufacture, use, and disposal as illustrated in Figure 8. This data is gathered at the appliance unit level. Indirect CO_2 emissions result from electricity generation for cooling (annual electricity consumption and grid emissions factor) and direct refrigerant emissions from leakage of refrigerant gases during production, servicing/operation and at end-of-life of cooling appliances. With having a detailed calculation of the actual emissions on the appliance level, the Tier 2 approach offers a far greater detail and accuracy compared ot the Tier 1 approach. As the Tier 1 approach does not caculate emissions based on the stock of appliance in use, but rather applies deemed leakage rates of refrigerants which are applied accross various subsectors, in practice its very difficult or even impossible to reach a detailed and accurate estimate of actual emissions with the Tier 1 approach. In this context the Tier Tier 2 methodology goes beyond the Tier 1 approach. Importantly, the Tier 1 approach does not include the indirect emissions from the energy use of appliances.

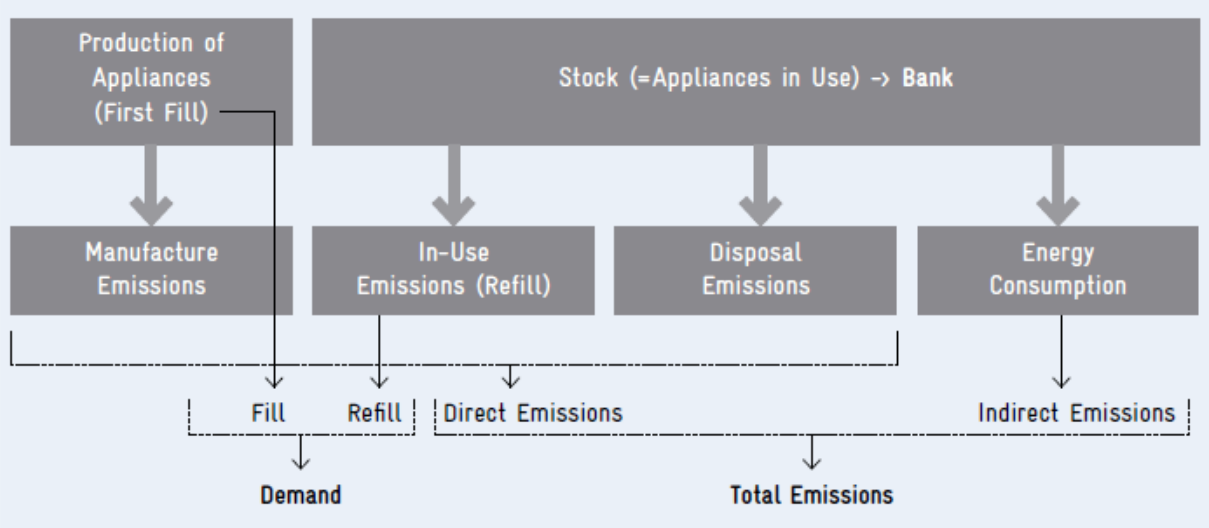

Figure 8. Overview RAC refrigerant demand versus RAC total emissions

Refrigerant consumption is accounted for at all stages during the product life of the equipment:

- Refrigerants that are filled into new manufactured products
- Refrigerants in operating systems (average annual stocks)
- Refrigerants remaining in products at decommissioning

2.2 Data collection process

The following **steps** were performed to collect and verify data for the complete inventory:

Step 1: National kick-off workshop with relevant stakeholder on April 13th, 2016.
Step 2: Preparation of questionnaires and list of stakeholders for each subsector.
Step 3: Sending questionnaires to stakeholders.
Step 4: Face to face interviews with stakeholders to explain the required data.
Step 5: Validation checks of primary data and gathering of complementary information from secondary and tertiary data, call-backs and compilation of data received through questionnaires into the master sheets from data entry forms.
Step 6: Verification of data during a national inventory workshop on March 7th, 2017.

The data for this inventory was collected from primary, secondary and tertiary sources. Specific activities carried out to obtain information were as follows:

- For **primary** data, a survey was carried out with different key stakeholders involved in the RAC sector, including key companies, local manufacturers and importers, placing RAC appliances on the market. These companies included Frigoglass Indonesia, PT Itu Airconco, PT Royal Sultan Agung, PT Gita Mandiri Teknik, PT Fata Sarana Makmur, PT Daikin Indonesia, Matur Nuwun Nusantara, and PT Hayati Indonesia. Further, direct interviews with air conditioning and refrigeration manufacturers were conducted. Information on supermarkets was also obtained from direct interviews by ASHRAE with the technical managers of supermarket chains.

- For **secondary** data, information was obtained among others from the following sources:
    - Building Services Research and Information Association (BSRIA) market studies (BSRIA, 2013, 2014).
    - Custom import data on air conditioning and refrigeration equipment, and compressors. The compressor import data was used to analyze the local production of refrigeration and air conditioning equipment (Directorate General of Custom and Excise)
    - NARAMA study on Chillers (PT. Narama Mandiri for GIZ, 2015)
    - Climate and Clean Air Coalition (CCAC) HFC alternative survey (Chakroun, 2016)
    - GAIKINDO data on vehicle production and sales in Indonesia
    - Japan Air Conditioning & Refrigeration News (JARN, 2012)
    - The Barrier Removal to the Cost-Effective Development and Implementation of Energy Efficiency Standards and Labeling (Indonesia, 2014) study by UNDP for domestic refrigeration (UNDP Indonesia, 2014)
    - Alfamidi for data on commercial refrigeration and supermarket distribution (Chakroun, 2016)
    - HPMP data and studies

- For **tertiary** data, information was mostly taken from the Green Cooling Iniative (GCI) Database[18] ('Green Cooling Initiative', 2013).

The inventory analysis was established with the support of the following key **stakeholders** (which include governmental institutions and private stakeholders, particularly RAC-related associations and companies):

- Ministry of Energy and Mineral Resources (MEMR) / EBTKE
- ASHRAE Indonesia
- RAC manufacturers, importers and suppliers
- The Cold Chain Association of Indonesia
- The Green Building Council of Indonesia

The following challenges were encountered during data collection for this inventory from primary data resources:

- Reluctance to provide any information (in a few companies) or willingness to provide only partial information due to the confidentiality policy of the companies
- Difficulties with filling out questionnaires on the part of the companies; questionnaires had to be simplified to get any information
- The raw data had to be collected at site, processed and entered the database for each company and category individually

[18] http://www.green-cooling-initiative.org/

2.3 Modelling parameters

For the analysis of this inventory the modelling parameters derived from primary and secondary data collection as shown in Table 8 were applied.

Table 8. Modelling Parameters for Business as Usual and Mitigation scenario (HEAT analysis)[19].

Equipment Type	Lifetime [years]	Main refrigerants	Initial charge [kg]	COP (2016)	Service emission factor[20]	Disposal emission factor
Self-contained AC	10	R407C; R410A	1	2.70	0.1	0.95
Split residential AC	8	R410A; R32	1.26	2.87	0.05	0.95
Split commercial AC	11	R410A; R32	1.72	2.87	0.1	0.8
Duct split residential AC	8	R407C; R410A	1.88	2.85	0.08	0.9
Commercial ducted splits	8	R407C; R410A	8	2.68	0.25	0.9
Rooftop ducted	11	R407C; R410A	20	2.68	0.1	0.75
Multi-splits	12	R407C; R410A	15.32	2.68	0.1	0.8
Air conditioning chillers	18	R407C; R134a, R22	60	3.10	0.1	0.95
Process chillers	16	R407C; R134a, R22	80	3.11	0.22	1
Car air conditioning	12	R134a	0.5	2.54	0.2	1
Large vehicle air conditioning	15	R134a	1	2.53	0.3	0.8
Domestic refrigeration	10	R134a; R600a	0.15	2.35	0.02	0.8
Stand-alone equipment	12	R404A; R134a	0.3	2.45	0.03	0.8
Condensing units	10	R22, R404A, R134a	9.67	1.89	0.3	0.85
Centralised systems (for supermarkets)	15	R22, R404A, R134a	210	1.88	0.38	0.9
Integral	10	R404A; R134a	0.5	1.88	0.05	0.8
Condensing units	15	R22, R404A, R134a	5	1.88	0.25	1

[19] Please note that the use ratio of car and large vehicle air conditioning is set to 0.1 and 0.3, respectively.
[20] Values taken from http://www.green-cooling-initiative.org and modified according stakeholder/industry consultation.

Centralised systems	15	R22; R404A; R717;R134a	500	1.88	0.4	1
Refrigerated trucks/trailers	15	R407C; R410A; R404A, R134a	6.5	2.20	0.25	0.5

The grid emission factor (GEF) is a measure of CO_2 emission intensity per unit of electricity generation in the total grid system. In the study presented we use a GEF of 0.808[21]. As there are no future predictions of a potential GEF, which can be implemented in our model, the data presented in this report uses the same GEF for the BAU and the MIT scenario.

The following sales growth rates (listed in Table 9) were derived from the history growth rates and trends and applied for modelling future unit sales in the respective subsectors.

Table 9. Assumed future appliance sales growth rates

Subsectors	Appliance types	Annual growth rates 2016-2050[22]
Unitary air conditioning	Self-contained air conditioners	4.0%
Unitary air conditioning	Split residential air conditioners	6.0%
Unitary air conditioning	Split commercial air conditioners	4.0%
Unitary air conditioning	Duct split residential air conditioners	4.0%
Unitary air conditioning	Commercial ducted splits	4.0%
Unitary air conditioning	Rooftop ducted	4.0%
Unitary air conditioning	Multi-splits	4.0%
Chillers	Air conditioning chillers	3.0%
Chillers	Process chillers	4.0%
Mobile AC	Car air conditioning	4.0%
Mobile AC	Large vehicle air conditioning	4.0%
Domestic refrigeration	Domestic refrigeration	5.0%
Commercial Refrigeration	Stand-alone equipment	15.0%
Commercial Refrigeration	Condensing units	4.0%
Transport Refrigeration	Refrigerated trucks/trailers	4.0%

According to information collected during the data collection, the growth rate of chiller sales is slightly lower than that of other subsectors. Some subsectors, such as standalone commercial refrigeration units grew during recent years with rates above GDP growth rates and other subsectors (Chakroun, 2016), for the future this report assumes that the growth rate of RAC sector will level out and grow along other subsectors and approach rate of the general economy.

[21] http://www.petromindo.com/bookstore/download.php?f=orderform-ruptl.pdf
[22] Growth rates are obtained from historic growth trends

3 Results

3.1 Subsector sales and stock data analysis

For the compilation of the report, the secondary data collection and review targeted the brands with the highest market share in each of the subsectors. These brands, covering over 90% of the total market share in each subsector are shown in Table 10..

Table 10. Companies with the highest market share in each subsector

Industry subsector	Top brands
Unitary Air Conditioning	Panasonic, Sharp, LG, Samsung, Daikin, Polytron, Midea, Haier, Mitsubishi H.I., Aux, Akari, Denpoo, Sanken, Gree, Electrolux, Toshiba, Mitsubishi, Aqua, Sanyo and others
Chillers	Carrier, Trane, Johnson Control (York), McQuay (Daikin), Mitsubishi, Dunhambush, Aicool
Mobile Air Conditioning	Denso, Sanden, Toyota, Daihatsu, Mitsubishi, Suzuki
Domestic Refrigeration	LG, Panasonic, Toshiba, Sharp, Polytron, Maspion, Sanken, Dast
Commercial Refrigeration	Sanden, AHT, Panasonic, Starcool, Rebecca
Industrial Refrigeration	Mycom, GEA, JCI (York), Yantai
Transport Refrigeration	Carrier Transicold, Thermo King, Mitsubishi, Mitsui, CCCL, Denso, Hwasungthermo, Prima Coldchain

In the following sub-chapters, the sales and stock development of the key subsectors are discussed. The analysis combines AC chillers, chillers for centralised units for commercial refrigeration, and process chillers for industrial refrigeration as most of the chillers are manufactured by the same type of manufacturers and the chillers have similar principal working conditions.
The stock analysis considers the phase in of new equipment driven by the sales development and the phase out of old equipment considering standardised assumptions for the lifetime of the equipment.
The analysis addressed the key subsectors. The transport refrigeration subsector is not analysed further in detail due to a lack of reliable primary and secondary data. Therefore, this subsector is not included in the emission analysis. It is typically assumed, that this subsector has a contribution to the total RAC-related GHG emissions of less than 5%.

3.1.1 UAC sales and stock data

The unitary air conditioning sales market is dominated by over 90% split-residential air conditioning systems. The remaining share is split between different air conditioning equipment as shown in Figure 9. The analysis draws on input provided by primary (company questionnaires) and secondary data collection, mainly industry studies and customs data.
Approximately 80% of AC units in the country are imported, while about 20% are manufactured inland. The share of inverter room air conditioners is below 5% (EBTKE, 2017b).

The current MEPS for a split ACs correspond to a Coefficient of Performance (COP) of 2.5. This value is intended to be raised to 2.64 by year 2018 and 2.93 by 2020 (EBTKE, 2017a).

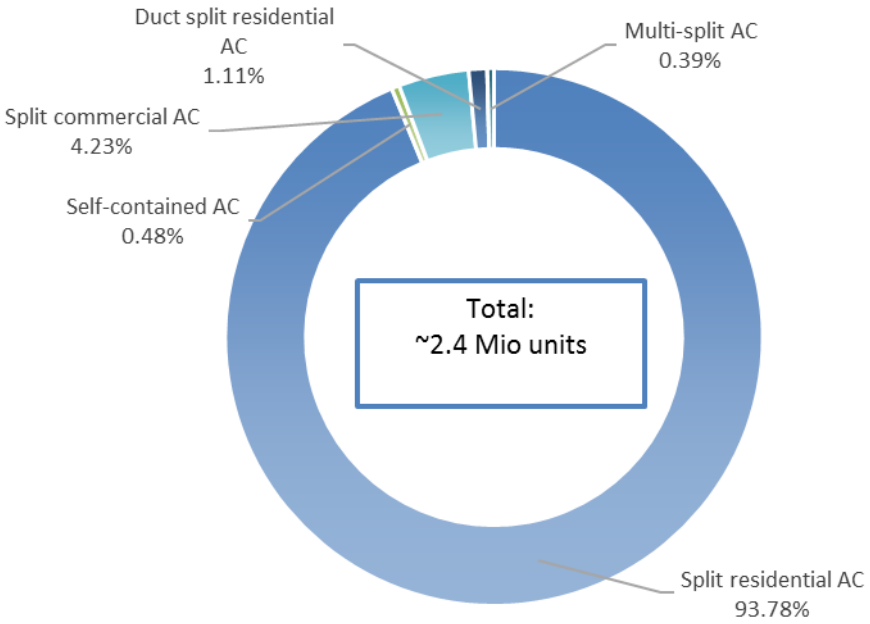

Figure 9: Market share of unitary air conditioning sales by type of appliance in Indonesia for the year 2015.

Figure 10 shows the development of sales of UAC appliances within the five years, from 2011 to 2015. It shows the development of each appliance type separately, that is, for residential split room air conditioners and other types of air conditioners such as multi-splits, rooftop ducted appliances, duct split residential ACs, split commercial and self-contained ACs.

The sales of room ACs were relatively low in 2015 due to the ban of units containing R22 as a refrigerant. In the following year, 2016, the market caught up. In 2016, the sold units containing R22 accounted for about 50% while the remaining 50% of sold units are accounted for by units containing R32 and R410.

Due to the contracted capacity limit of 450 W, 90% of room ACs sold have below 1 horse power (HP) or a cooling capacity of 2 to 4 KW[23]. Within this range, 0.5 HP, 0.75 HP, and 1.0 HP units account for 45%, 10%, and 35% of the market respectively. The market is dominated by four brands, namely: Sharp, LG, Panasonic and Samsung. Together, they account for about 70% of the market (Osumi, 2016). Other brands such Daikin, Mitsubishi Electric, Fujitsu General and Changhong, Midea, Gree, Haier and TCL are increasing their market share. Brands with local manufacturing or assembly include LG, Samsung, Panasonic and Sharp. Split ACs sold after August 2016 must carry an energy label and meet the new minimum energy efficiency standards (MEPS).

[23] the cooling capacity is depending on the individual system coefficient of performance (COP)

Figure 10. UAC unit sales in Indonesia in the years 2011 to 2015 (left - split residential subsector, right – other appliance types).

Figure 11. UAC subsector unit stock in Indonesia for the years 2011 to 2015 (left - split residential subsector, right – other appliance types).

With a stock of 13.5 million room air conditioners in 2015, the market penetration lies at 28% of households. This is considerably lower than that of other Asian countries such as China where the penetration rate is around 127%, i.e. more than one AC per household (Liu *et al.*, 2016).

3.1.2 Chillers sales and stock data

The data obtained on chiller sales draws on primary data collection from leading manufacturers including York, Trane, Daikin McQuay and Dunham-Bush as well as Chinese manufacturers Shuangliang, Broad, Midea and Gree (JARN, 2012). Chiller sales also draw from secondary data, collected from industry studies such and customs data. Figure 12 illustrates the growth rates of the chiller subsector observed during the last 5 years. The sales growth rate of process chillers was faster than that of AC chillers. However, AC chillers still dominate the chiller market with a market share of over 80% in 2015.

Figure 1212 illustrates the unit sales and stock numbers for chillers. The overall number of chillers installed in Indonesia exceeds 20,000 and the stock grew by 7% from 2011 to 2015.

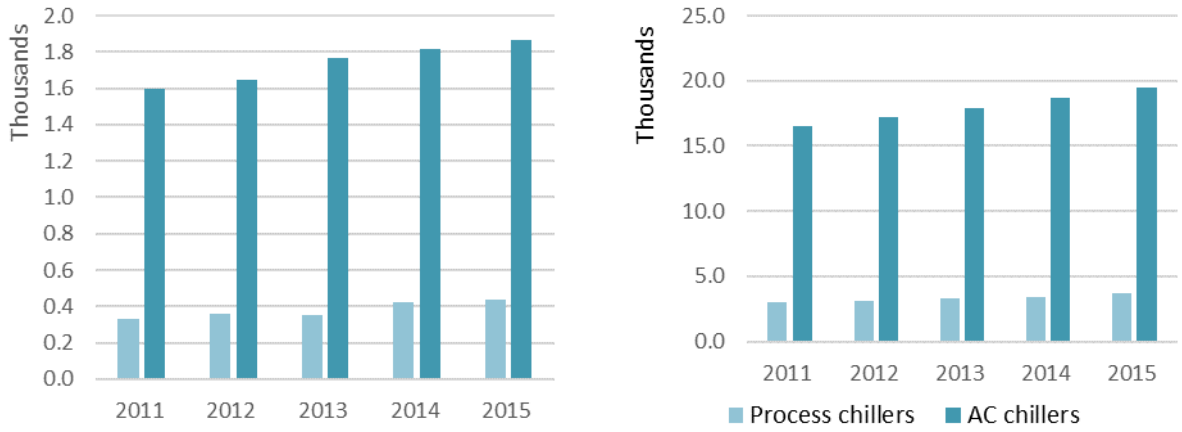

Figure 12: Chiller (process and AC) units sales (left) and unit stock (right) for the years 2011-2015.

The performance of an average chiller in Indonesia is currently about 1 kW/ton which approximately corresponds to a COP of 3.11 and corresponds to poor performance in comparison to modern standards in other countries. The recommend energy efficiency standard in Indonesia around 0.8-0.7 kW/ton or a COP of 4 for water cooled chillers (Oppelt, Yatim and Colbourne, 2016). Most Indonesian chillers have a cooling capacity of 250 to 500 kW (Nasir, 2017). As part of the Green Chiller project, the energy efficiency standards for chillers in Indonesia were reviewed and compared to the Australian standard.

3.1.3 Mobile air conditioning

From 2014 to 2015 the sales of the mobile AC subsector decreased, whilse the stock data still increased[24]. The CAGR between 2011 and 2015 from the large vehicle ACs show a different pattern, where the sales increase by 16.6% and the stock increases by 4.3%.

[24] Based on data received from Gaikindo, the Association of Indonesian Automotive Industries. The increase of the overall stock despite lower sales is due the lower rate of retiring cars with ACs.

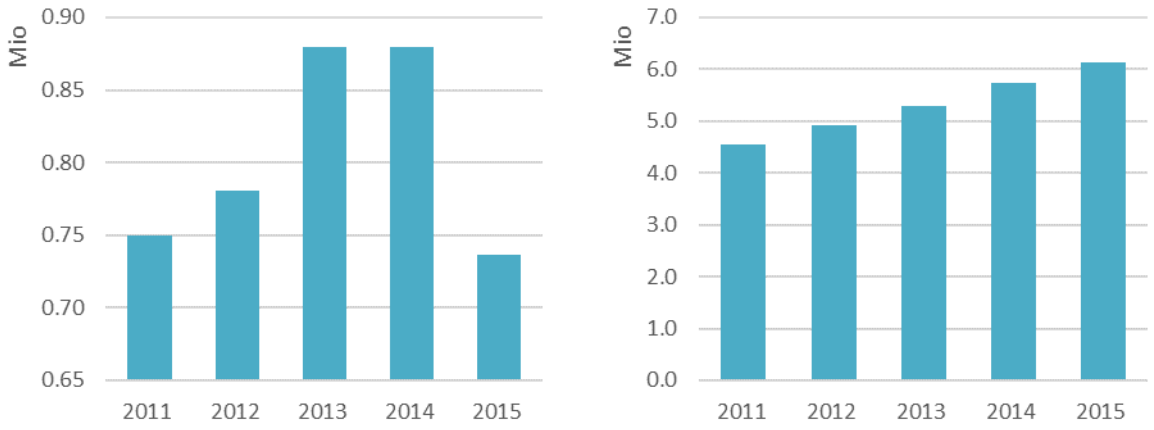

Figure 13: Passenger car air conditioning unit sales (left) and unit stock (right, CAGR: 6.2%) in Indonesia in the years 2011 to 2015.

There are approximately 17,000 ACs installed in trucks and over 2,000 ACs installed in busses.

3.1.4 Domestic Refrigeration

During the recent years, sales of domestic refrigerators increased strongly and this had a strong impact on the stock growth. With a current stock of approximately 33 million refrigerators, this subsector has a high market penetration with approximately half of all households owning one unit[25]. The stock of domestic refrigerators was taken from data of the Central Bureau of Statistics.

Figure 14: Domestic refrigeration unit sales (left) and stock (right) in the years 2011 to 2015. The CAGR 9.4% for the stock.

[25] The annual sales data were calculated back using the stock data provided by the Central Bureau of Statistics.

3.1.5 Commercial Refrigeration

The number of convenience stores grew by 16.8% between the years 2011 and 2015. The supermarkets and hypermarkets grew with a slower rate of 4.1% and 11.8%, respectively (Wright and Rangkuti, 2016).
Convenience stores are mostly equipped with stand-alone units (Chakroun, 2016). These can be further distinguished into reach-in showcases and freezers. A typical convenience store has 3-5 reach-in showcases and 3-5 freezers, with an average cooling capacity of 2.6 kW per unit for the showcases and 0.4 kW for the freezers. The common refrigerant used in these types of units are R404a and R134a. The stock of stand-alone equipment grew by 13% between 2011 and 2015, as illustrated in Figure 15. The condensing unit stock grew by approximately 4.2%.
The commercial subsector is probably underrepresented in the data since there are only some publications regarding the number of commercial stores (Wright and Rangkuti, 2016). Another issue is the configuration of a typical convenience store or a supermarket regarding the numbers of their equipment used for refrigeration and food storage (Chakroun, 2016). Based on the HFC Inventory report from 2010-2012 and information from Chakroun (2016), stock and sales data for this subsector were extrapolated.

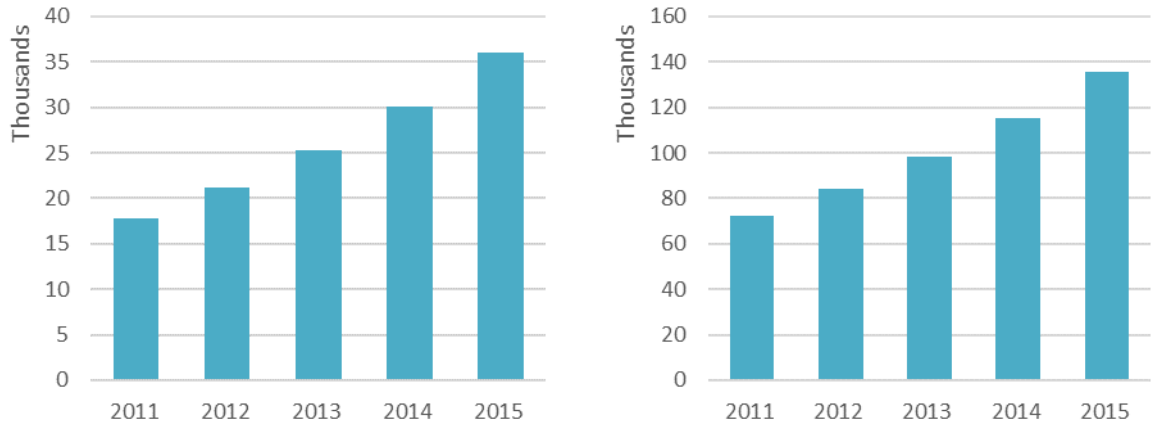

Figure 15: Stand-alone equipment sales (left) and stock (right, CAGR: 13.5%) in the years 2011 to 2015.

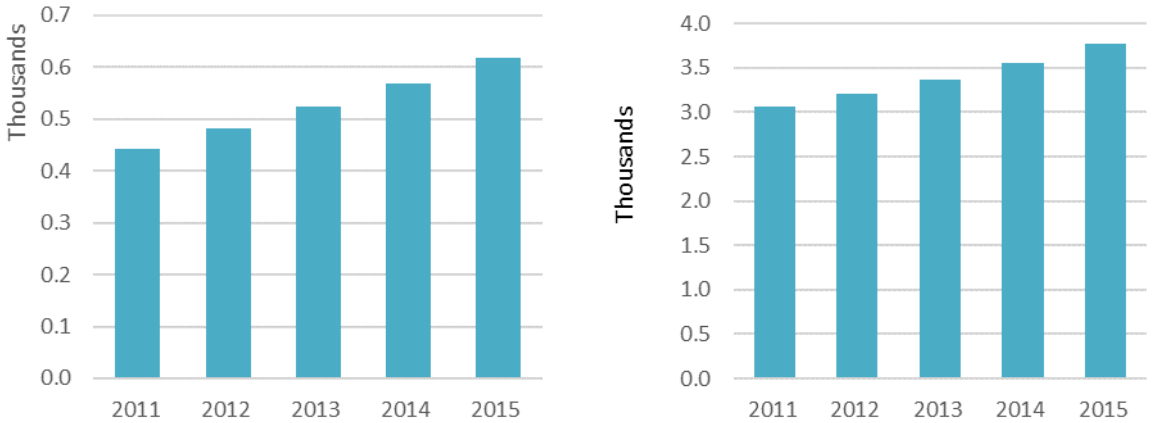

Figure 16: Condensing units estimated sales (left) and calculated stock (right, CAGR: 4.2%) in the years 2011 to 2015.

3.1.6 Transport refrigeration

For the assessment of the transport refrigeration subsector, an interview with the Cold Chain Association of Indonesia was carried out, in which it was pointed out that there is a great need to further develop the cold chain in Indonesia. For example, Indonesia's seafood industry alone requires some 14 million tons of cold storage facility with a corresponding need for transport refrigeration. Currently, only half of the demand is met with appropriate cooling facilities. For poultry, only 1.5 million tons refrigerated facilities are available while there is demand for over 5 million tons. For fruits and vegetables, the demand is for over 30 million tons and only 1.5 million tons are provided.

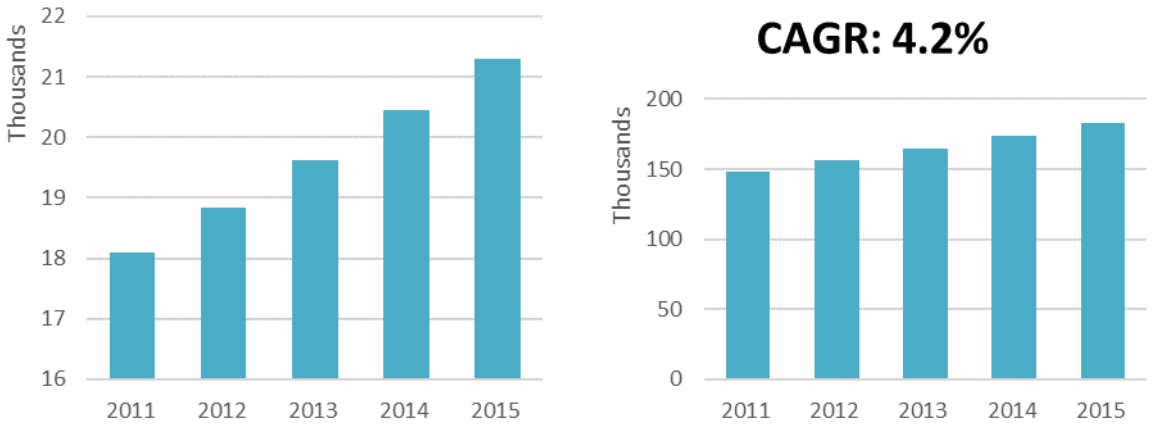

Figure 17: Estimates unit sales (left) and stock (right) of refrigerated trucks in Indonesia in the years 2011 to 2015.

3.2 BAU Emissions and Projections in the RAC sector

From the installed stock of RAC appliances outlined in Chapter 3.1, the current GHG emissions in the RAC sector in Indonesia were estimated applying the methodology described in Chapter 2. The resulting total GHG emissions in 2015 are 77.31 Mt CO2eq which represents over 15.4% of Indonesia's total energy related GHG emissions (Edgar Emissions Database, 2017).
As illustrated in Figure 1818, about 51% of the emissions are related to the UAC subsector followed in the sequence of relevance by the domestic refrigeration, the mobile air conditioning, ,chillers, transport subsector and the commercial refrigeration subsectors.

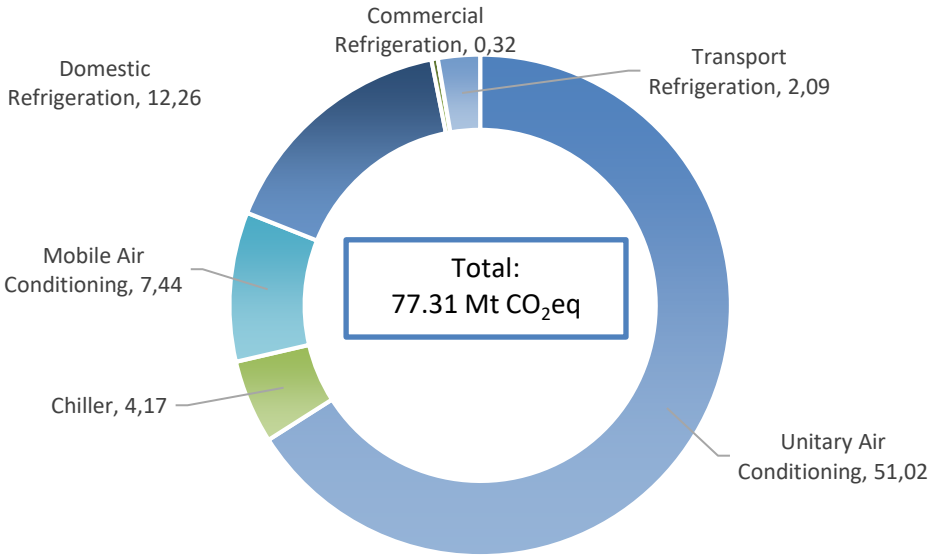

Figure 18: Total BAU GHG emissions for the Indonesian RAC sector by subsector in 2015

As illustrated in Figure 19 and Figure 20, about 11.3 Mt CO_2eq or 14.6% of the total GHG emissions in the RAC sector in Indonesia result from direct, refrigerant-related GHG emissions and 66 Mt CO_2eq are coupled with direct, energy-related GHG emissions, corresponding to 85% of the overall emissions in the sector. Almost 56% of the direct emissions are caused by the unitary air conditioning subsector.

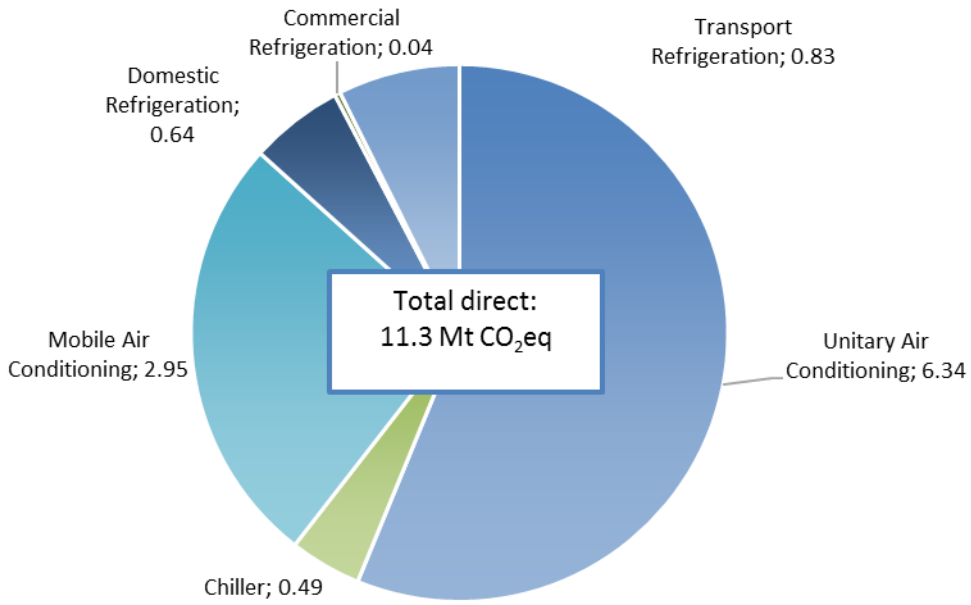

Figure 19: Direct GHG emissions of the RAC subsectors in 2015

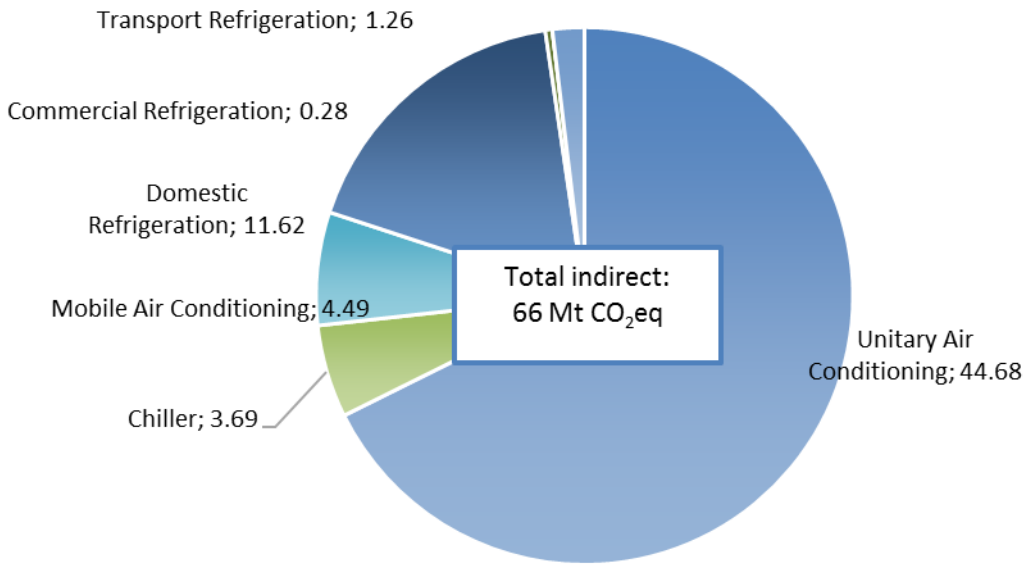

Figure 20: Indirect GHG emissions of the RAC subsectors in 2015

Indonesia currently has very low penetration rates of RAC appliances per household and per capita compared with both the global benchmark and the benchmark in developing countries (Oppelt, 2013). It is estimated that with the growing average wealth per capita, increasing urbanization, and rising ambient temperatures, the GHG emissions in Indonesia's RAC sector will grow from 77.31 Mt CO_2eq in 2015 to almost 218.6 Mt CO_2eq by 2050 in the BAU case.

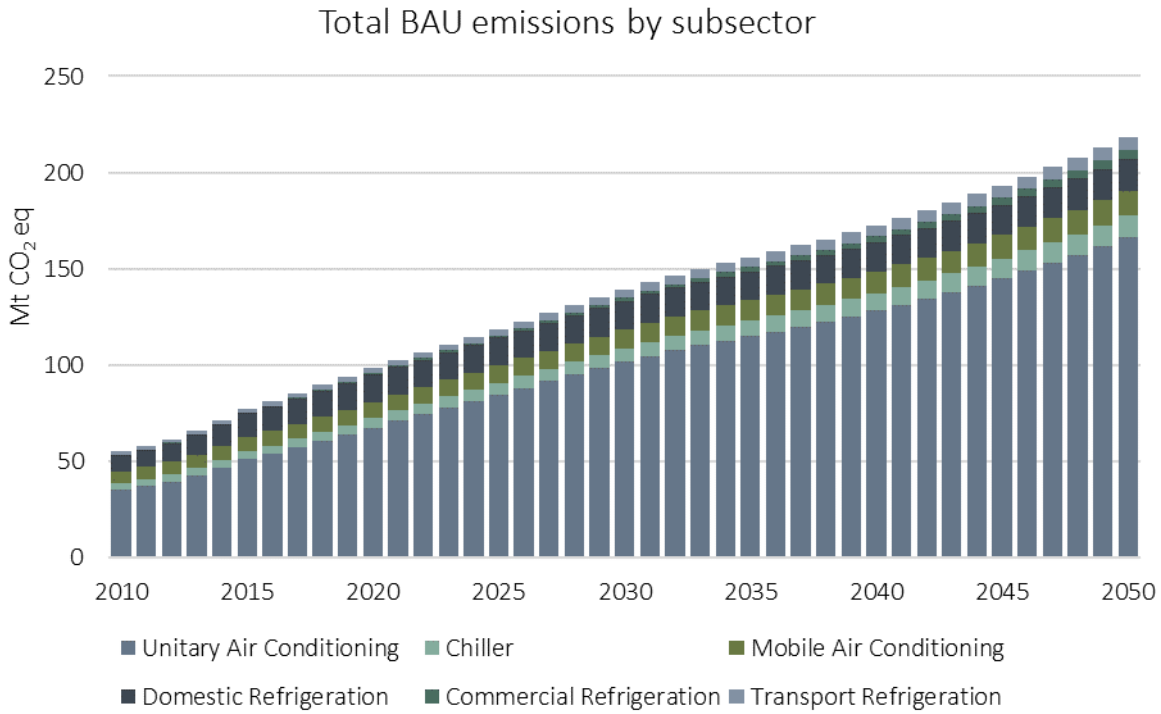

Figure 21: Projected business-as-usual scenario for GHG emissions in the RAC sector until year 2050

3.3 Alternative technologies

Building on local circumstances, chapter 3.3 analyses the potential to lower the GHG emissions in Indonesia's RAC sector by deploying available climate-friendly and highly energy-efficient RAC technologies.

3.3.1 Overview on energy efficiency and refrigerants in a BAU scenario

Table 11 shows the energy efficiencies and refrigerants used in typical applications installed and sold in the market. As outlined in the introduction, electricity prices were subsidized over a long time in Indonesia, which contributes highly to the delayed deployment of highly energy efficient appliances. Also, mainly high GWP refrigerants, including HFCs, are used in RAC appliances.

Table 11. List of HFCs and energy efficiencies common for Indonesia in the RAC subsectors (CCAC and UNDP, 2014, data from personal interviews with experts from ASHRAE and Thermoking)

Subsector	Energy efficiencies (average)[26]	Main refrigerants
Unitary Air Conditioning (residential, commercial)	~2.7	R-410A, R-407C
Chillers	3.1	R-407C, R-134A, R404A

[26] COP (ratio of useful cooling provided to work (electricity) required) unless otherwise stated

Mobile Air Conditioning	2.5	R-134a
Domestic Refrigeration	> 300 kWh/ year	R-134a
Commercial Refrigeration	< 1.5	R-134a, R-404A, R-507C
Industrial Refrigeration	< 3	R-404A, R-507C
Transport Refrigeration	< 2	R-404A
Transport Air Conditioning	< 1.5	R-134a
Industrial Air Conditioning	< 3	R-134a, R-410a, R-407c

3.3.2 Transition to high energy efficiency RAC technologies

The gradual increase of electricity prices and the need to comply with Minimum Energy Performance Standards (MEPS) and labelling requirements can lead to a substantial improvement in energy efficiency as well as reduced GHG emissions in the RAC sector. Best available RAC technologies in terms of efficiency, applicable to nearly all RAC appliances and their components, include:

- variable speed inverter-driven compressors, which adjust to the required cooling load
- improved evaporator or compressor heat exchangers
- variable auxiliary components such as pumps and vans
- sensor-linked controllers with smart adjustment functions and better insulation systems to lower the required cooling loads

3.3.3 Transition to low GWP refrigerants

With the signing of the Kigali Amendment, most developed and developing countries (A5 countries under the Montreal Protocol), signalled their willingness towards a gradual phase down of HFCs. The F-Gas Regulation in the European Union (EU) drives the transition from high-GWP to low-GWP refrigerants. Further advanced or best practice policy instruments developed by the EU can also serve as a basis for designing policy tools in developing countries for the implementation of the Kigali Amendment or additional measures for an enhanced phase out of HFCs (such as refrigerant bans or GWP based tradeable quotas).

In nearly all RAC subsectors there are now alternative technologies available which operate without HFCs and are based on refrigerants with very low- to zero-GWP. In the following sections, the report will highlight the most suitable low-GWP refrigeration systems for Indonesia as well as the best low-GWP refrigerants for each subsector.

Accelerating the transition to RAC systems with low-GWP refrigerants, particularly to systems using negligible GWP refrigerants with a GWP less than 10 hold several benefits for Indonesia.[27]

[27] Refrigerants with GWP below 10 are mainly natural refrigerants, including non-fluorinated hydrocarbons, CO_2 and NH3, and unsaturated hydrofluorocarbons named as HFOs. The classification of refrigerants refers to the classification suggested through the Technical Assessment Panel of the Montreal Protocol (UNEP, 2016c)

These benefits include:

- Avoidance of direct emissions due to low GWP refrigerants with GWP <10.
- Contribution to Indonesia's GHG mitigation efforts under its NDCs
- Saving energy. For example, many natural refrigerants, particularly R717 and hydrocarbons as suggested by the Green Chiller project in Indonesia, have high thermodynamic properties, which lead to higher energy efficiency and, consequently, energy savings. With well-designed R717 and hydrocarbon systems, it is possible to save 10 to 15 % of energy against convetional systems with HCFC or HFCs. Considering the warm climatic conditions in Indonesia, in contrast to the colder climate of Europe, use of R744 as a refrigerant is less recommendable. R744 has a low critical temperature, implying that the heat transfer for condensation is inhibited at higher ambient temperatures.
- Employment creation. The safe handling of systems using natural refrigerants requires skilled, educated, and qualified technicians to install, operate, and maintain the systems. The qualification of technicians creates additional employment and allows for safe, efficient handling of RAC appliances.

3.3.4 UAC systems

Transitions to low GWP UAC systems includes UAC appliances with improved energy efficiency and the use of low GWP refrigerants.

The most important improvement of the energy efficiency in room air conditioners can be achieved through the transition to inverter type UAC systems. Due to past energy subsidies, inverter room air conditioners only make up less than 5% of annual sales. Also, customers lack education on the benefits of inverter technologies and their potential energy savings and lower total cost of ownership. Inverter driven UACs can adjust their thermal output, i.e. the cooling effect, dynamically to the cooling demand. The resulting energy efficiency gains are in the range of 20-25% (Shah, Phadke and Waide, 2013).

Using hydrocarbons as low GWP refrigerants in UACs can also result in improved energy efficiencies of the appliances. Given relatively high ambient temperatures in Indonesia, hydrocarbons[28] can be used with improved energy efficiency for many unitary air-conditioning systems, including portable and ductless split systems[29]. Portable units utilizing R290 are available worldwide and window units using R290 are in production in Asia[30]. Split air-conditioning systems using R290 are already produced in India and China.

[28] Hydrocarbon refrigerants have favorable performance parameters as refrigerants, mainly relatively better thermodynamic parameters compared to most HFCs.

[29] Compared to many other refrigerants, e.g. R32 or HFC-410, hydrocarbons have a higher critical temperature which results in favorable thermodynamic properties at higher ambient temperatures, i.e. with increasing ambient temperatures the COP is relatively and higher

[30] i.e. with Godrej India
http://hydrocarbons21.com/articles/3087/indian_manufacturer_launches_r290_ac_production_line , last accessed 21.04.2017

Most split-type room air conditioners in Indonesia have small capacities of below 1 HP with consequently possible low charge sizes of below 140 to 480g of R290[31]. With these low charge sizes, the risk level of even using highly flammable refrigerants is very low.

The benefit of using R290 refrigerants in portable and split systems are typical energy efficiency improvements of 10 to 20 % compared to R410 refrigerant systems (Patel, Kapadia and Matawala, 2016).

For ducted and multi-split systems, the use of low GWP A2L and A3 refrigerants[32] typically requires the utilization of ducted systems, either with air or water as a heat exchange carrier inside the buildings. With appropriate design options, energy efficiency improvements of up to 10% can be achieved even for these indirect systems compared to direct expansion systems with R410, R404A or R407C as refrigerants.

Table 12. Current and best practice in UAC appliances

		Current technology	Best practice technology	Potential market penetration for alternative systems		
				Current	2020	2030
Self-contained air conditioners	Refrigerant	R410A, R407c	Low GWP < 10	< 5%	50%	60%
	Equipment energy efficiency	2.7	>3.2			
Spilt air conditioners	Refrigerant	R410A, R32	Low GWP < 10	< 5%	50%	70%
	Equipment energy efficiency	2.87	>3.7			
Ducted air conditioning systems	Refrigerant	R410A, R404A, R407C	Low GWP < 10 low GWP with liquid secondary	< 5%	40%	80%
	Equipment energy efficiency	2.85	>3.5			
Multi-splits	Refrigerant	R410A	Low GWP < 10 or low GWP with ducted split	< 5%	30%	70%
	Equipment energy efficiency	2.68	>3.5			

[31] There is around 70 to 120g R290 required per kW. Dependent on the COP the cooling capacity of a 1 HP system ranges from 2-4 KW with a corresponding average refrigerant charge of 140 to 480 g. Information obtained from Daniel Colbourne, HEAT GmbH.

[32] According to international refrigerant safety classification ISO 817

3.3.5 Chillers – AC and process chillers

Stationary air-conditioning and refrigeration chiller systems are used for residential, commercial and industrial cooling. Generally, chillers are in a machinery room or outdoors, making it easier to deal with safety issues related to toxicity and flammability of low-GWP refrigerants. For hot ambient temperature conditions, both R717 and hydrocarbon (R290 and R1270) refrigerants are very energy efficient with energy efficiency properties often superior to those of HFC-based chiller systems.

Driven by the requirements of the EU F-Gas Regulation, the number of manufacturers producing R290-chillers in Europe and other regions has been increasing. In Europe, HC-chillers have been manufactured and safely operated for many years, including large systems with up to 1 MW capacity. R717 chillers have been manufactured, installed and operated worldwide for decades, with focus on the large-scale industrial refrigeration systems. Due to the F-Gas regulation, R717 chillers are increasingly being used for AC purposes in Europe. In combination with screw compressors, very high energy efficiencies can be achieved with both R290- and R717-chiller systems, particularly in high ambient temperature environments. As for the large systems, R717 systems are very cost-competitive, regarding the combination of upfront and operating costs. Industrial process chillers with R717 as refrigerant are a well established technology in many countries. Hydrocarbon chiller systems are suitable for systems in the range of 10 – 500 kW.

A comparison of the current and best practice technology is shown in Table 13 for chiller systems. Current RAC chillers in Indonesia mainly operate with HFC R134a and R410A, both refrigerants with a high GWP. With the adaptation of an alternative technology using hydrocarbon refrigerants such as R290, energy efficiency improvements in the range of 10-20 % are to be expected (Patel, Kapadia and Matawala, 2016).

Through the Green Chiller NAMA Project, several R290 AC chillers will be demonstrated in Indonesia for their safe and energy-efficient use. R290 AC chillers was previously not used for larger scale chiller applications in Indonesia. The project will be fully implemented by the end of 2018.

Energy efficiency for chillers will be increasingly important in the future. So far, Indonesia only has a recommended energy efficiency standard SNI 6390:2011. In a standard proposal developed under the Green Chiller project, the introduction of more ambitious MEPS for chillers is suggested (Oppelt, Yatim and Colbourne, 2016).

Table 13. Current and best practice in RAC chillers

		Current technology	Best practice technology	Potential market penetration for alternative systems		
				Current	**2020**	**2030**
Air conditioning chillers	Refrigerant	R22, R32, R134a, R407c, R410a	Low GWP < 10 (R290, R717, HFO)	< 5%	30%	70%
	Equipment energy efficiency	3.10	>4			

Process chillers	Refrigerant	R134a, R407a, R404a	Low GWP < 10 (R290, R717, HFO)	< 5%	40%	60%
	Equipment energy efficiency	3.11	>4			
Centralized systems for supermarkets	Refrigerant	R22, R134a, R 404a, R507	Low GWP < 10 (R290, R717, HFO, R744 cascade)	< 5%	20%	80%
	Equipment energy efficiency	1.88	>4			

3.3.6 Refrigeration – Domestic and Commercial Stand-alone Systems and Commercial Condensing Units

With the drive to lower F-gas consumption, for example with the EU F-Gas Regulation (EU, 2014), alternative refrigerants are increasingly used in RAC appliances for domestic and commercial refrigeration. In the stand-alone equipment (bottle coolers, ice coolers and display cases up to 3.75m) category, appliances with hydrocarbon as a refrigerant have reached significant market share in several markets such as Europe and China and were successfully introduced to the Indonesian market.

Commercial refrigeration systems in supermarkets can also be upscaled, linking multiple stand-alone units, which release their condensation heat into a water circuit. Condensing units that use hydrocarbon refrigerants are also available. Currently, the updated draft of the IEC standard 60335-2-89 suggests charge size can be increased from 150g to 500g hydrocarbons, which will allow for their even more widespread application.

The use of R600a and R290 instead of the currently available R134a and R410a is estimated to yield energy efficiency gains of over 10% (Gerwen van and Colbourne, 2012).

Table 14. Current and best practice in standalone and condensing units

		Current technology	**Best practice technology**	**Potential market penetration for alternative systems**		
				Current	**2020**	**2030**
Domestic refrigeration	Refrigerant	R600a, R134a	R600a	N/A	95%	95%
	Equipment energy efficiency	>300 kWh/year	< 150 kWh/year			
Stand-alone equipment	Refrigerant	R134a	R290	<5%	85%	85%
	Equipment energy efficiency	2.45	>3.5			

Condensing units	Refrigerant	R410A	Low GWP < 10 to low GWP with liquid secondary	none	40%	60%
	Equipment energy efficiency	1.89	>3.5			

3.3.7 Refrigeration – Transport Refrigeration Systems

For transport refrigeration, there are emerging technology alternatives for refrigeration systems with low GWP refrigerants. The leading manufacturer of transport refrigeration systems in South Africa, Transfrig is currently testing a prototype which uses R290. The prototype testing of the units has been highly successful with energy efficiency improvements of 20-30% as compared to the HFC-systems. This technology can be relevant for Indonesia, considering the good performance of hydrocarbons in its climatic conditions. It would allow Indonesia to avoid direct emissions in the transport refrigeration subsector and save fuels for powering the systems.

Table 15. Current and best practice in transport refrigeration units

		Current technology	**Best practice technology**	**Potential market penetration for alternative systems**		
				Current	**2020**	**2030**
Refrigerated trucks/trailers	Refrigerant	R407C	R290	none	40%	80%
	Equipment energy efficiency	2.2	no data			

A change from the current R407C to an alternate low-GWP R290 in the transport refrigeration subsector is forecasted to result in a significant improved market share of 80% by the end of 2030.

3.3.8 Mobile AC

MAC systems can be categorized into two types:

- Mobile air-conditioning (MAC) systems used in passenger vehicles
- Transport air-conditioning systems used in other vehicles (e.g., trucks, trains, airplanes and buses).

Currently installed mobile air-conditioning systems in Indonesia use R134a as a refrigerant. Alternative systems with HFO-1234yf and R744 have been developed in Europe, where refrigerants are required to have a GWP less than 150, according to EU law (EuropeanUnion, 2006).

Hydrocarbons are not yet considered as a viable refrigerant option by car manufacturers due to flammability concerns. Nevertheless, hydrocarbons can be an option for electric vehicles with

hermetically sealed refrigerant systems. For large vehicles, R744 MAC systems are available for buses and trains, for example in Germany.

The most energy efficient and environmentally sound solution in the passenger car category would be using hermetically sealed refrigerant systems in electric cars with refrigerants with a GWP below 10. In such systems, R290 systems should work efficiently and safe. However, such development need to be adopted by the global car industry with the increasing emergence of energetically optimized electric cars.

Table 16. Current and best practice in mobile AC units (Source: HEAT analysis)

		Current technology	Best practice technology	Potential market penetration for alternative systems		
				Current	2020	2030
Car air conditioning	Refrigerant	R134a	R744 HC for hermitically sealed refrigerant systems.	<5%	30%	60%
	Equipment energy efficiency	2.5	no data			
Large vehicle air conditioning	Refrigerant	R134a	R744	none	5%	15%
	Equipment energy efficiency	2.5	no data			

3.4 Mitigation scenario emissions for Indonesian RAC sector

As evident from the data modelling in this report, with technologically and economically feasible mitigation actions, it is possible to reduce GHG emissions significantly by 35 $MtCO_2eq$ and 26.6 TWh annually by 2030. This corresponds to

- about 11 percent of the unconditional national total target of energy-related GHG emissions mitigations of 314 Mt CO_2eq;
- about one third of the energy conservation related target;s and
- 8.8 percent of the conditional target of 398 Mt CO_2, where the conditional target assumes that foreign investment is required for the transition to modern technologies in the RAC sector.

APEC-ASEAN Harmonization of Energy Efficiency Standards for Air Conditioners Initiative estimated energy savings of about 51.7 TWh for the split AC subsector while the model applied here predicts energy savings of about 20.4 TWh for the split AC subsector. A potential reason for this deviation may be that the standards aimed for in the project are higher than the ones assumed for in the present model, which are closer to the current situation.

In the following section, the energy saving potential as well as the mitigation scenario are described in more detail. Figure 22 and Figure 23 show the total emission mitigation potential for the years 2030 and 2050, respectively. The direct emissions are plotted together with the

indirect emissions for the individual subsectors. Direct refrigerant emissions are a result of the use of the appliance, while the indirect emissions result from the electricity generation used for cooling. Comparing to the BAU scenario with its total emission of 139 Mt CO_2eq, the total savings of the mitigation scenario are 35 Mt CO_2eq shared by the individual sectors (Figure 22). In the year 2050, the emissions of the BAU scenario are 218.6 Mt CO_2eq with the mitigation scenario applied, the total savings could be as high as 42.5 Mt CO_2eq, shared by the individual sectors (Figure 23).

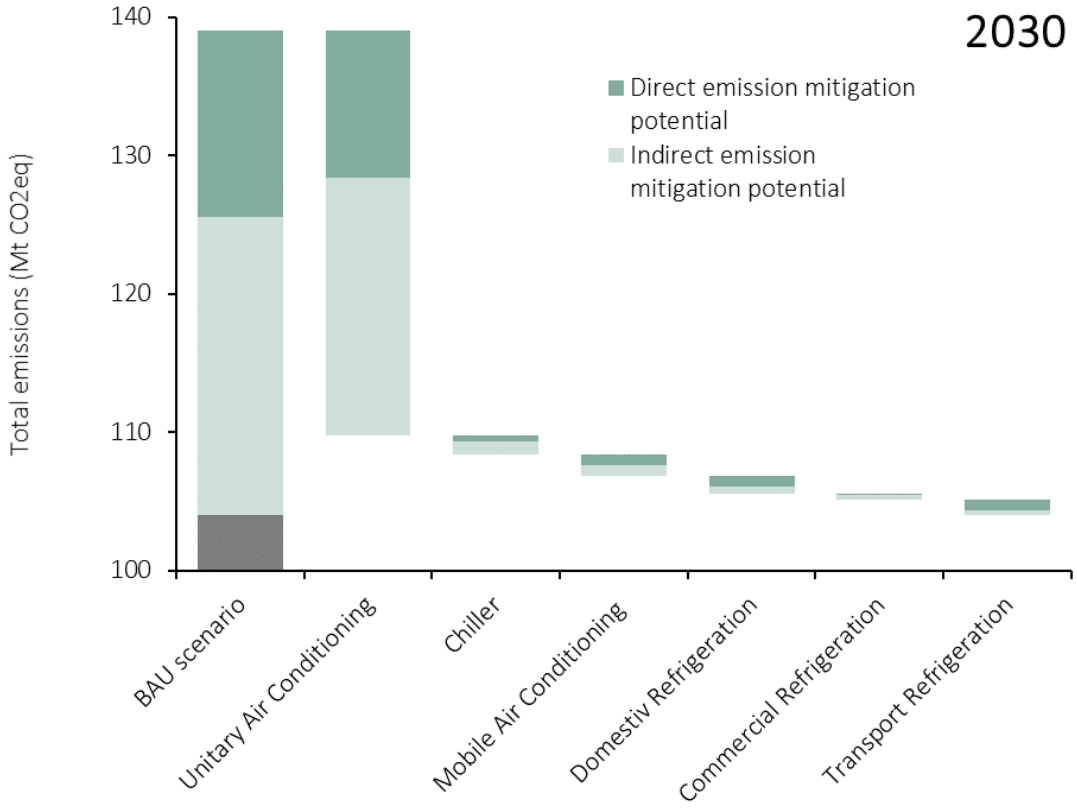

Figure 22. Direct and indirect mitigation potential for the year 2030[33].

[33] Note: the grey color of the first column shows the unabated emissions

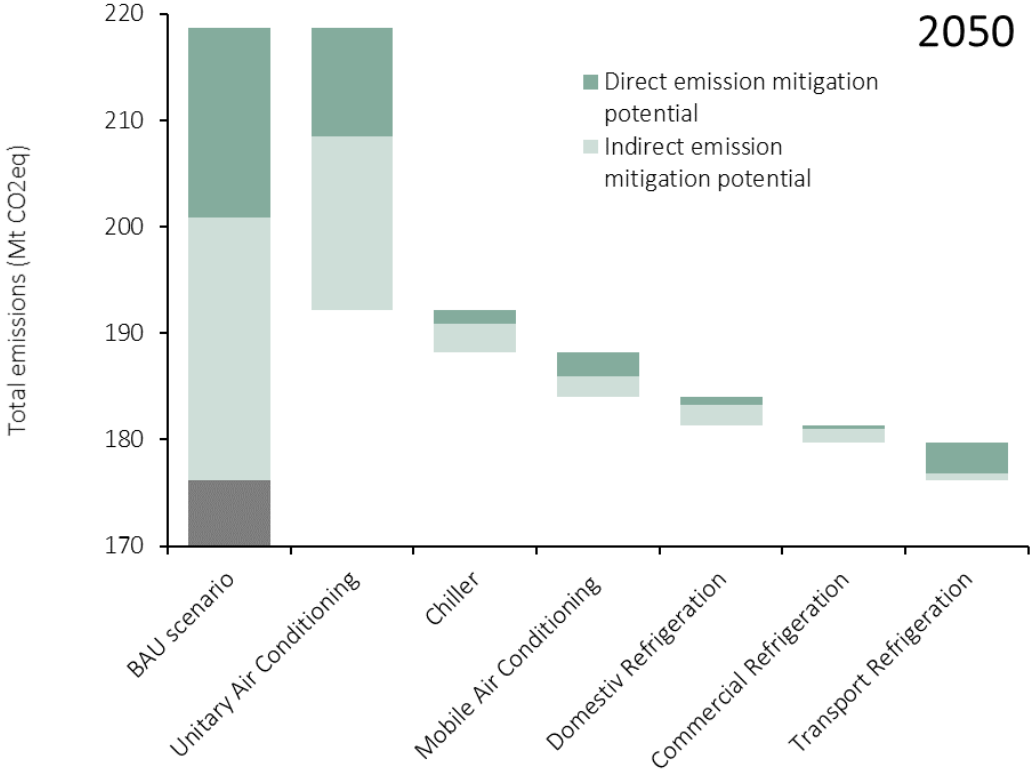

Figure 23.Direct and indirect mitigation potential for the year 2050.

3.4.1 Energy saving potential

The cumulative energy saving potential of 219 TWh until the year 2030 stems mainly from the unitary air conditioning subsector. Up to 90% energy can be saved solely in this subsector. The remaining 16% are shared by the other subsectors as shown in Figure 24. Until the year 2050, a total of 744 TWh energy can be saved. The main subsector with the highest saving potential remains the unitary air conditioning subsector (80%). Second most amount of energy savings can be achieved in the mobile air conditioning subsector, followed by chillers and the domestic and commercial refrigeration subsectors as shown in Figure 25.

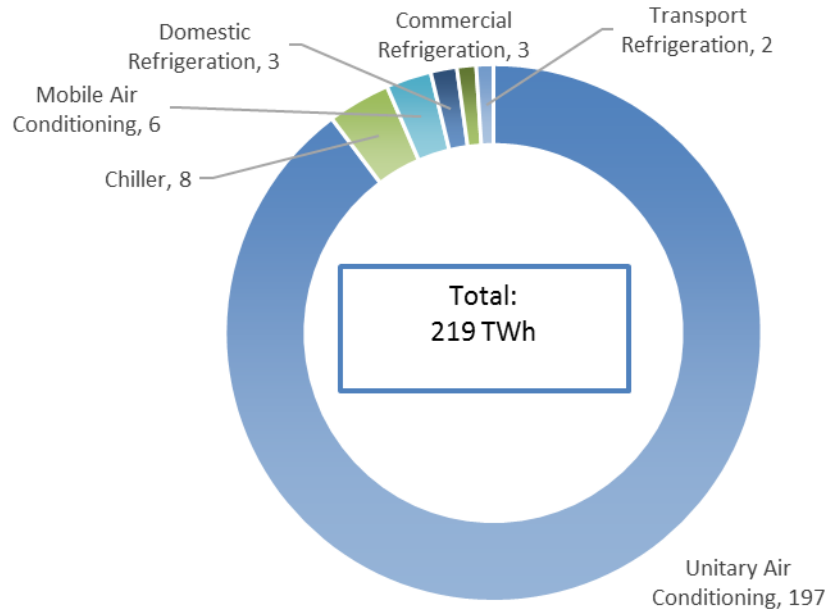

Figure 24. Total cumulative energy saving potential (219 TWh) of the Indonesian RAC sector until 2030.

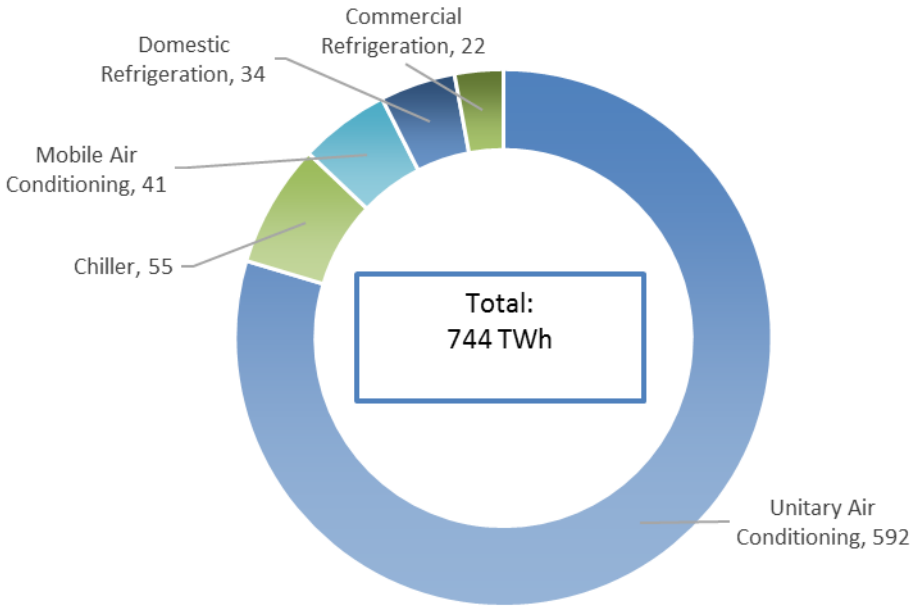

Figure 25. Total cumulative energy saving potential (744 TWh) of the Indonesian RAC sector until 2050.

3.4.2 Total emissions

By deploying climate-friendly and energy-efficient RAC appliances, ideally using natural refrigerants, we estimated that by 2050, emissions of over 42.5 Mt CO_2eq can be avoided annually as illustrated in Figure 26. About 50% of these avoided emissions are related to energy efficiency improvements and 50% through the transition to low-GWP refrigerants. Particularly, the transition to low GWP refrigerants can be achieved as an initial action with large savings to be achieved by 2030 as shown in Figure 26.

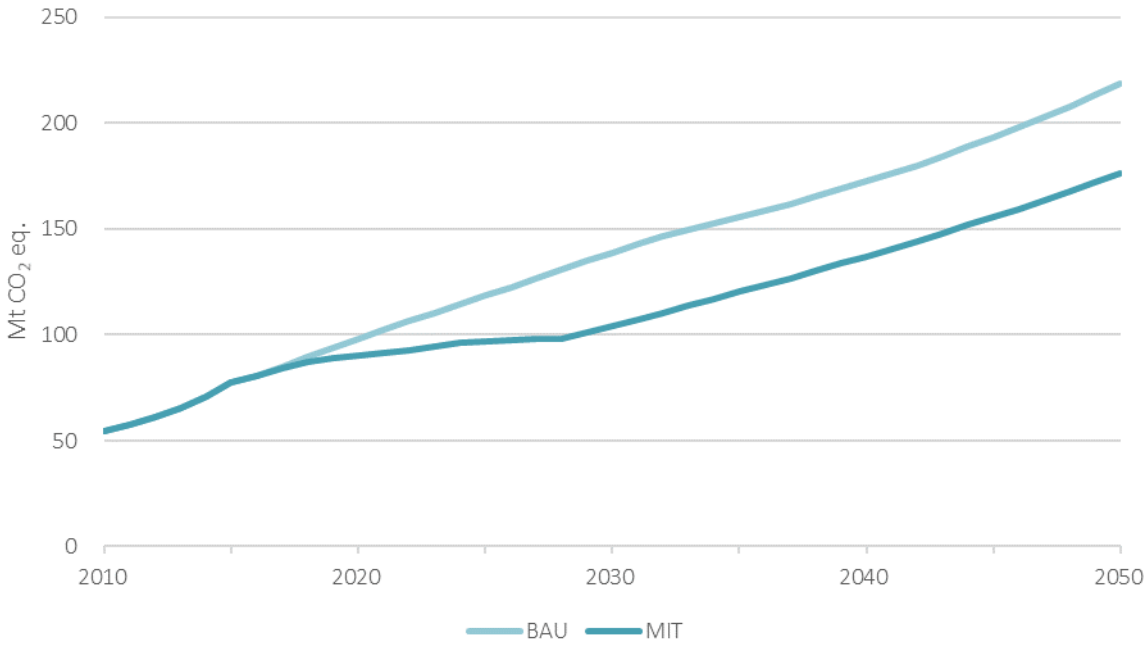

Figure 26. Total emissions from the RAC sector, business-as-usual and mitigation scenario

The drop in total emissions during the five-year period until 2030 in the mitigation scenario can be explained by:

- High-GWP refrigerants such as R22 will have been phased out and the lifetime of respective appliances will end at that point in time.
- In the AC subsector, lower-GWP R32 or low GWP-R290 systems should replace higher-GWP HFCs such as R410a
- In mobile air conditioning low GWP should replace R134a

3.4.3 Use of low GWP refrigerants

As described in Chapter 2.6.3, with the ratification of the Kigali amendment, GHG emissions from HFCs will be limited and reduced in the future. Figure 28 shows the RAC related HFC consumption under the BAU scenario (blue line), the assumed consumption freeze and reduction steps under the Kigali Amendment (green line) and possible mitigated consumption under a more ambitious scenario as assumed under the mitigation scenario (MIT) in this inventory report (red line). For better comparison to the Kigali schedule, the BAU and MIT scenario are shown as consumption, not emissions, as in most other figures in this report.

Under the BAU scenario, the growth of refrigerant consumption is first stagnant in the period from about 2020 to 2040. While the underlying demand for refrigerants continues to grow with

the continued growth of appliances, the GWP-weighted consumption from the refrigerants are stagnant due to the replacement of medium to high GWP refrigerants such as HFC-32[34]. From 2040 onwards, the underlying growth of appliance outweighs the replacement effect from high to medium-high refrigerants[35] and consequently, the total RAC related GHG consumption starts continuing to grow.

Under the Kigali Amendment, the GWP based consumption baseline is calculated from 2020 to 2022. The baseline is calculated from the GWP weighted HCFC and HFC consumption. For the A5 Group 1, to which Indonesia belongs, the first reduction step takes place in 2029 with 90% of the baseline and successive steps of 70% of the baseline in 2035, 50% in 2040 and 20% in 2045 as illustrated in Figure 27.

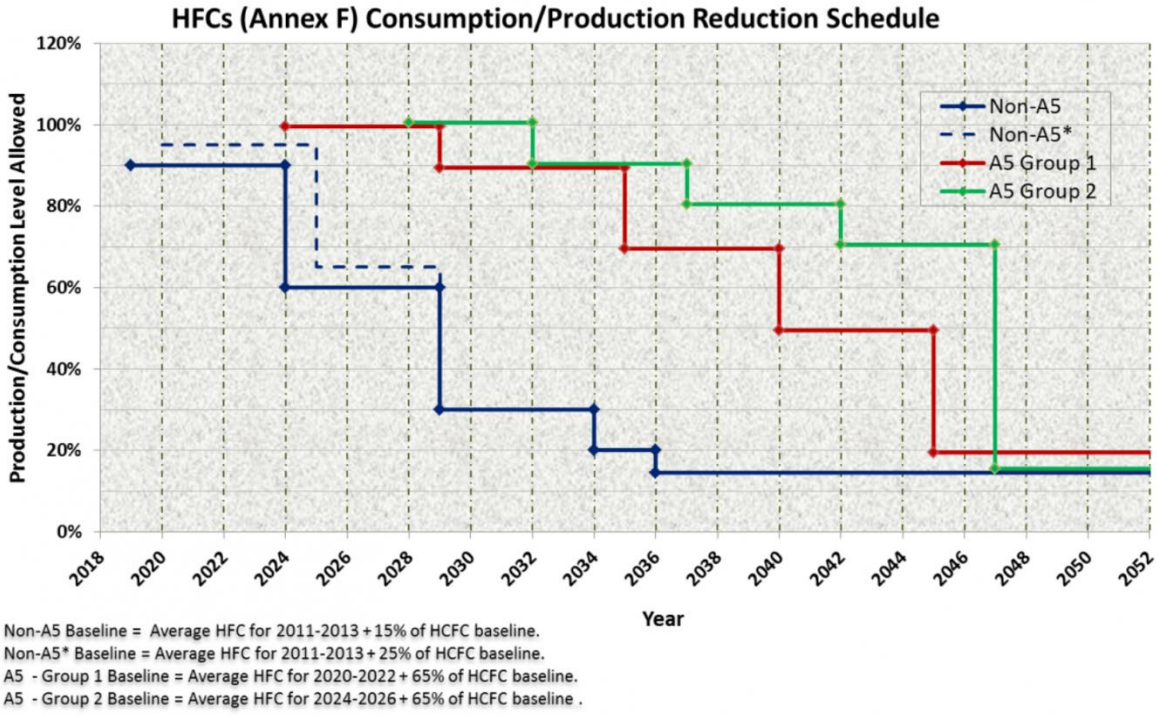

Figure 27- HFC reduction steps for different groups of parties according to the Kigali Amendment (Source: UNEP[36])

As Figure 28 shows, under the assumed scenarios, the Kigali Amendment would force to undertake mitigation action, i.e. the transition to low GWP refrigerants, from 2035 onwards. The onset of the Kigali schedule by 2035 can be explained by the baseline calculations used in the amendment. The baseline is calculated using the average HFC consumption of the years 2020-2022 and 65% of the HCFC baseline.

A large GHG mitigation potential lies in transitioning from highly climate-damaging hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) to low GWP alternatives in a timely manner, ahead of the current HFC phase-down schedule stipulated in the Kigali amendment to the Montreal Protocol (Clark and Wagner, 2016). Figure 28 shows the RAC related HFC consumption under the Business as Usual (BAU) scenario (blue line), the assumed

[34] see classification of the Technical Assessment Panel of the Montreal Protocol (UNEP, 2016c)
[35] The replacement of high to medium-high refrigerants takes place i.e. through the replacement of HFC-410a with HFC-32.
[36] Taken from UNEP Ozone website, see http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/41744, last accessed 19.06.2017

consumption freeze and reduction steps under the Kigali Amendment (green line) and possible mitigated consumption under a more ambitious scenario as assumed under the mitigation scenario (MIT) in this inventory report (red line). Refrigerant consumption and emissions as shown in the Figures above are calculated based on the same model. The MIT scenario assume the application of best available technologies and the use of very low GWP, natural refrigerants.

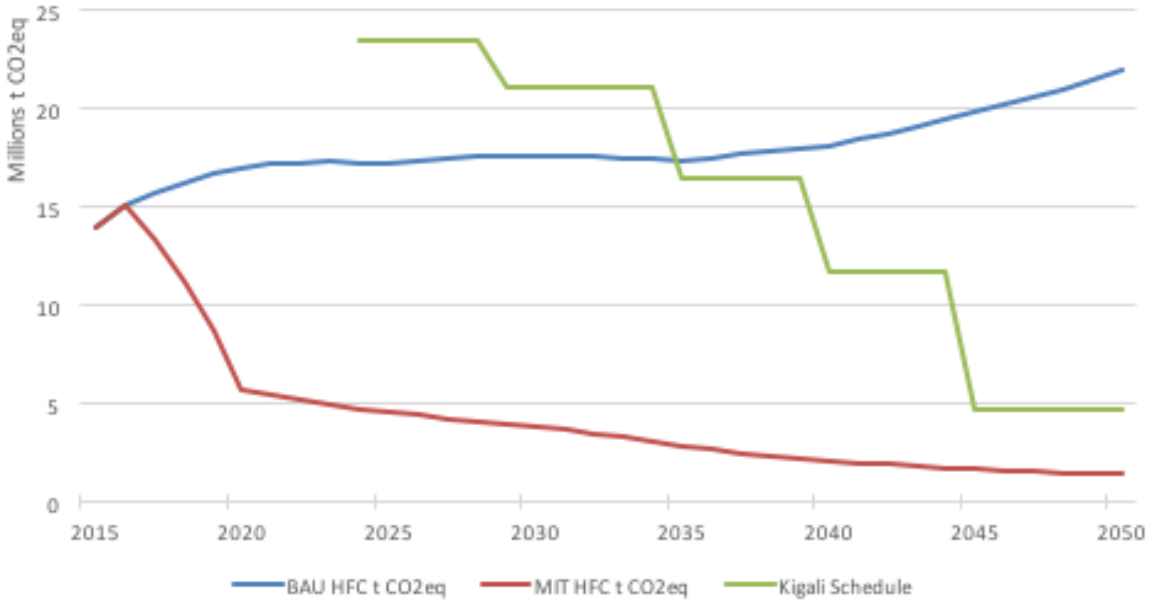

Figure 28. BAU and MIT emissions of HFC, and Kigali Schedule

The mitigation scenario (MIT) assumes a faster uptake of low GWP refrigerants with a GWP below 10 through the application of low GWP refrigerants such as hydrocarbons (e.g. R290 and R600a) and HFOs. As illustrated in Figure 27, there will be a very fast reduction in emissions until 2020 to 2022, assuming leapfrogging from high GWP refrigerants such as R22 and R410a to low GWP refrigerants in key subsectors, particularly in room ACs. Thereafter, there would be a more gradual replacement in subsectors where low GWP refrigerants would have a slower assumed uptake.

As Figure 28 shows, the faster transition to low GWP refrigerants under the mitigation scenario (MIT) will result to significant additional GHG consumption savings of over 10 to 15 $MtCO_2eq$ from 2020 to about after 2040 or accumulated sum of 200 to 300 $MtCO_2eq$ GHG consumption savings.

3.4.4 Unitary Air conditioning emissions

The split residential AC subsector has the biggest influence on GHG mitigation with nearly 26.4 Mt CO_2 savings potential annually by 2050. Figure 29 shows the total emission of the unitary air conditioning subsector, with split residential room AC as the most important appliance type. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the significant emission reduction that can be achieved through the transition to low-GWP R290 refrigerants, mostly for split room air conditioners. Another 10 Mt CO_2eq can be achieved from using highly efficient inverter type RAC room ACs.

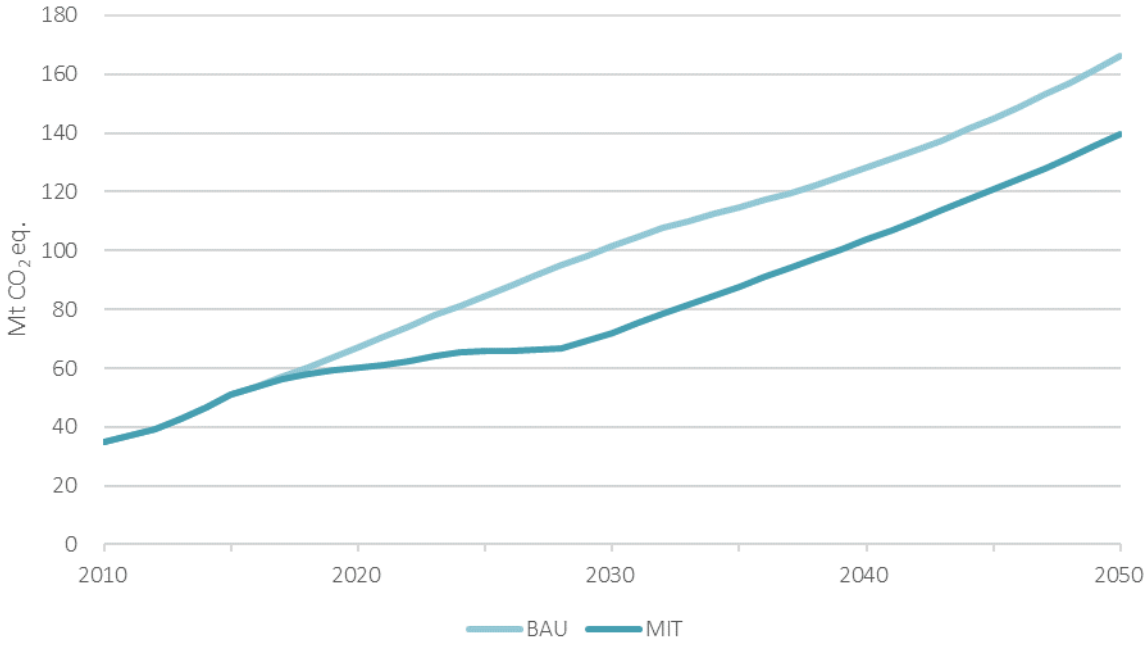

Figure 29. Projected GHG emissions of the unitary air conditioning subsector for the years 2010-2050.

3.4.5 Total Chiller emissions

The potential mitigation effect for the chiller subsector amounts to approximately 4 Mt CO_2eq by 2050. About 50% of these emission reductions or 2.3 Mt CO_2eq can be achieved by using low GWP refrigerants, most of which can be realized by 2030. The remaining reduction would result from chillers with high energy efficiency, e.g. with variable speed components and highly efficient heat exchangers.

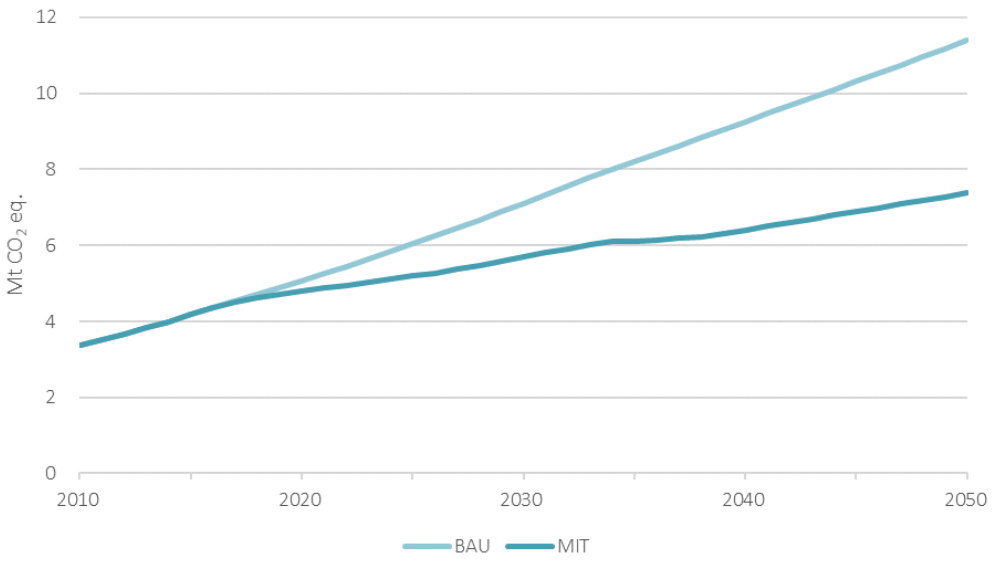

Figure 30: Projected GHG emissions of the chiller subsector for the years 2010-2050

3.4.6 Refrigeration emission mitigation potential

In this section, we show data for the emission mitigation potential in the refrigeration, which includes the domestic and the commercial refrigeration subsectors. The potential energy savings are about 4.3 Mt CO_2eq. This implies that already in the BAU scenario, the transition to R600 and R290 refrigerants for domestic and commercial plug-in units will happen. For example, Unilever has already introduced hydrocarbons for commercial refrigeration in many countries. Further mitigation effects will be achieved through the application of ambitious MEPS and labels.

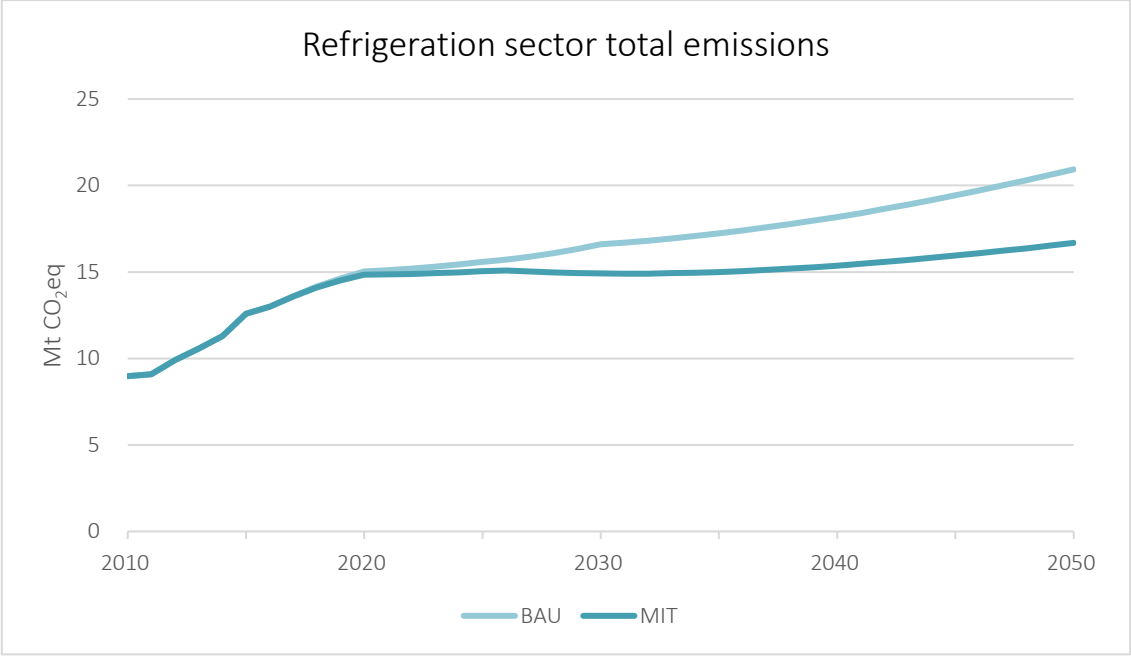

Figure 31: Total emission of the refrigeration subsector for the years 2010-2050.

3.4.7 Mobile air conditioning emission mitigation potential

There is a significant emissions saving potential in the mobile air conditioning subsector, both from improved energy efficiencies and the transition to low-GWP refrigerants with GWP below 10. There seems to be a good possibility that the potential can be realised in the future, with the update of electric-mobility, the transition to hermetically sealed and electrically driven AC systems with low-GWP refrigerants such as R290. Figure 32 shows the combined mobile AC subsector scenarios (e.g. passenger cars and large vehicles as well as buses and trucks).

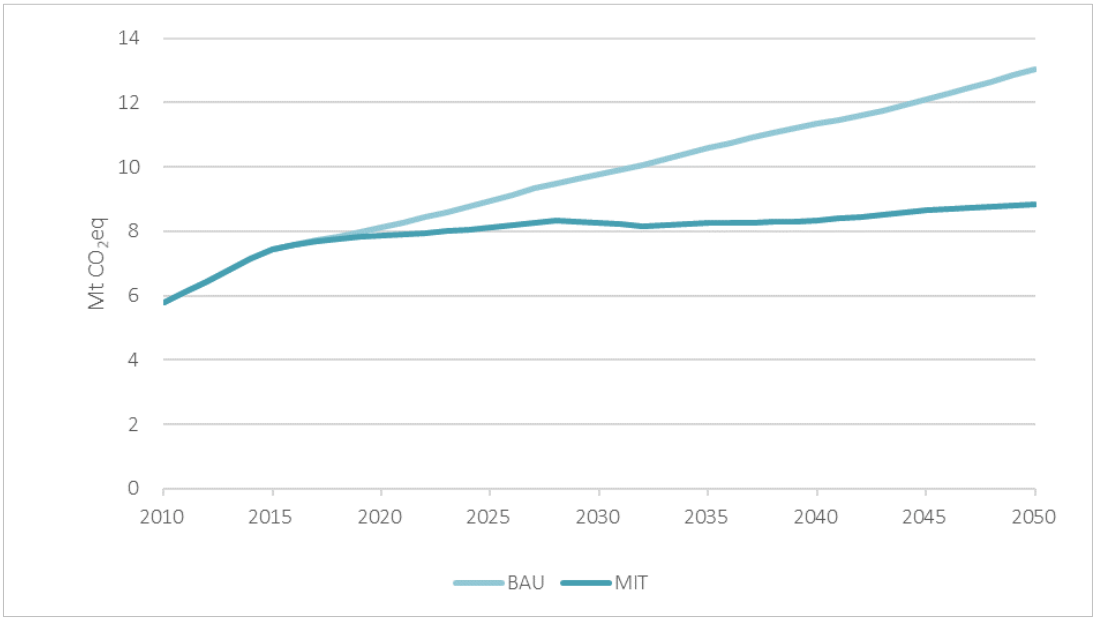

Figure 32. Projected GHG emissions of the mobile air conditioning subsector for the years 2010-2050.

3.4.8 Transport refrigeration emission mitigation potential

Transport refrigeration is a system where there could be an early adoption of low GWP refrigerants such as the prototypes which have now been positively tested in South Africa with R290 and significant energy efficiency improvements. With such transitions, the direct emission impact for the subsector could be avoided by 2030 to 2040. Similar as described above in the section for mobile air conditioning, further energy conservation benefits can be realized by moving from mechanically to electrically driven systems. Electrically driven systems will increasingly become common with the change from combustion to electrical power trains for transport refrigeration.

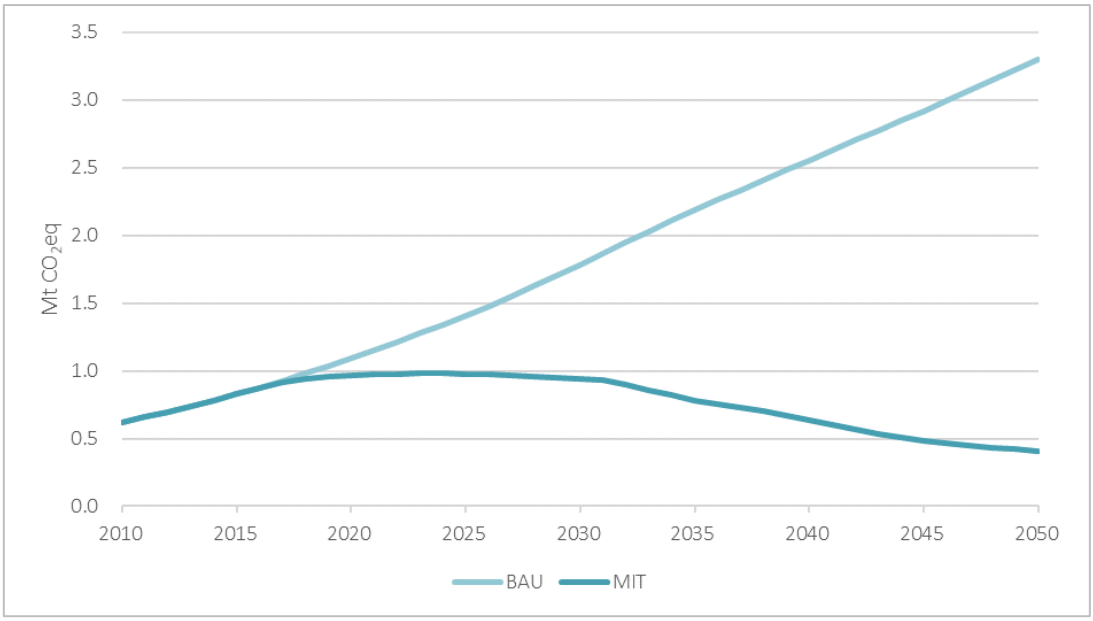

Figure 33. Total emissions saving potential for the transport subsector for the years 2010-2050

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5 Annex

Table 17: RAC subsectors and related systems

Subsector	Systems
Unitary Air Conditioning	Self-contained air conditioners
	Split residential air conditioners
	Split commercial air conditioners
	Duct split residential air conditioners
	Commercial ducted splits
	Rooftop ducted
	Multi-splits
Chillers	Air conditioning chillers
	Process chillers
Mobile Air Conditioning	Car air conditioning
	Large vehicle air conditioning
Domestic Refrigeration	Domestic refrigeration
Commercial Refrigeration	Stand-alone equipment
	Condensing units
	Centralized systems (for supermarkets)
Industrial Refrigeration	Stand-alone equipment
	Condensing units
	Centralized systems
Transport Refrigeration	Refrigerated trucks/trailers

Table 18: Overview of air conditioning subsectors

RAC subsector	Product group	Description
Unitary air conditioning	Self-contained	• All components of the system are located within one housing
	Split residential and commercial (duct-less)	• The systems consist of two elements: (1) the condenser unit containing the compressor mounted outside the room and (2) the indoor unit (evaporator) supplying cooled air to the room. • Residential units: applied in private households Commercial units: applied in offices or other commercial buildings • This product group refers to "single" split systems, i.e., one indoor unit is connected to one outdoor unit.
	Ducted split, residential	• Systems consist of an outdoor unit (condenser) containing the compressor which is connected to an indoor unit (evaporator) to blow cooled air through a pre-installed duct system. • Residential units are mainly used in domestic context

	and commercial	• Commercial units: applied in offices or other commercial buildings • Ducted splits are mainly used to cool multiple rooms in larger buildings (incl. houses).
	Rooftop ducted	• Single refrigerating system mounted on the roof of a building from where ducting leads to the interior of the building and cool air is blown through. •
	Multi-split, VRF/VRV	• Multi-splits: like ductless single-split systems (residential/commercial single splits, see above), although usually up to 5 indoor units can be connected to one outdoor unit. • VRF/VRV (variable refrigerant flow/volume) systems: Type of multi-split system where a 2-digit number of indoor units can be connected to one outdoor unit. Used in mid-size office buildings and commercial facilities.
Chiller, air-conditioning	Chillers (AC)	• AC Chillers usually function by using a liquid for cooling (usually water) in a conventional refrigeration cycle. This water is then distributed to cooling - and sometimes heating - coils within the building. • AC chillers are mainly applied for commercial and light industrial purposes.

Table 19 Overview of refrigeration sub-sectors

RAC subsector	Product group	• Description
Domestic refrigeration	Refrigerator/freezer	• The subsector includes the combination of refrigerators and freezers as well as single household refrigerators and freezers
Commercial refrigeration	Stand-alone	• "plug-in" units built into one housing (self- contained refrigeration systems) • Examples: vending machines, ice cream freezers and beverage coolers
	Condensing unit	• These refrigerating systems are often used in small shops such as bakeries, butcheries or small supermarkets. • The "condensing unit" holds one to two compressors, the condenser and a receiver and is usually connected via piping to small commercial equipment located in the sales area, e.g., cooling equipment such as display cases or cold rooms. The unit usually comes pre-assembled.
	Centralised systems (for supermarkets)	• Used in larger supermarkets (sales are greater than 400 square meters). • Operates with a pack of several parallel working compressors located in a separate machinery room. This pack is connected to separately installed condensers outside the building. • The system is assembled on-site.

Industrial refrigeration	Stand-alone (integral) unit	• "plug-in" units built into one housing (self- contained refrigeration systems) • Examples: industrial ice-makers
	Condensing unit	• The "condensing unit" holds one to two compressors, the condenser and a receiver and is usually connected via piping to small commercial equipment located in the sales area, e.g., cooling equipment such as display cases or cold rooms. The unit usually comes pre-assembled. Example: cold storage facilities
	Centralised systems	• Operates with a pack of several parallel working compressors located in a separate machinery room. This pack is connected to separately installed condensers outside the building. The system is assembled on-site
	Chillers, process	• Chillers used for cooling (heating) in industrial refrigeration, including process cooling, cold storage, electronic fabrication, moulding, etc. Typically, the same technology as chillers used for air conditioning.
Transport refrigeration	Trailer, van, truck	• Covers refrigeration equipment that is required during the transportation of goods on roads by trucks and trailers (but also by trains, ships or in airborne containers). • Per road vehicle, usually one refrigeration unit is installed.