

# green<sup>❄️</sup> cooling initiative

## Ghana's Greenhouse Gas Inventory and Technology Gap Analysis for the Refrigeration and Air Conditioning Sector.



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# ABBREVIATIONS

<b>AC</b>	Air Conditioning	<b>MAC</b>	Mobile Air Conditioning
<b>BAU</b>	Business as Usual	<b>MEPS</b>	Minimum Energy Performance Standard
<b>BMU</b>	German Federal Ministry for Environment, Nature Conservation and Nuclear Safety	<b>MESTI</b>	Ministry of Environment, Science, Technology and Innovation (Ghana)
<b>BTU</b>	British Thermal Unit	<b>MIT</b>	Mitigation scenario
<b>CCAC</b>	Climate and Clean Air Coalition	<b>MLF</b>	Multi-Lateral Fund
<b>CCGELS</b>	Climate Change and Green Economy Learning Strategy (Ghana)	<b>MRV</b>	Measuring, Reporting and Verification
<b>CEPS</b>	Customs Excise and Preventive Service	<b>NAMA</b>	Nationally Appropriate Mitigation Action
<b>CFC</b>	Chlorofluorocarbon	<b>NACODS</b>	National Committee on Ozone Depleting Substances
<b>COP</b>	Coefficient of Performance	<b>NARWOA</b>	National Association of Refrigeration Workshop Owners Association
<b>CTCN</b>	Climate Technology Centre and Network	<b>NCCC</b>	National Climate Change Committee (Ghana)
<b>DC</b>	Direct Current	<b>NCCP</b>	National Climate Change Policy (Ghana)
<b>EER</b>	Energy Efficiency Ratio	<b>NDC</b>	National Determined Contribution
<b>EPA</b>	Environmental Protection Agency	<b>NOU</b>	National Ozone Unit
<b>F-GAS</b>	Fluorinated Gas	<b>ODP</b>	Ozone Depleting Potential
<b>GHG</b>	Green House Gases	<b>ODS</b>	Ozone Depleting Substances
<b>GWP</b>	Global Warming Potential.	<b>RAC</b>	Refrigeration and Air Conditioning
<b>HC</b>	Hydrocarbon	<b>REDD+</b>	Reducing emissions from deforestation and forest degradation
<b>HCFC</b>	Hydrochlorofluorocarbon	<b>TEAP</b>	Technology and Economic Assessment Panel
<b>HEAT</b>	Habitat, Energy Application & Technology	<b>UNEP</b>	United Nations Environment Programme
<b>HFC</b>	Hydrofluorocarbon	<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>HPMP</b>	Hydrofluorocarbon Phase-out Management Plan	<b>VRF</b>	Variable Refrigerant Flow
<b>ICI/IKI</b>	International climate initiative/ Internationale Klimainitiative	<b>VRV</b>	Variable Refrigerant Volume
<b>INDC</b>	Intended nationally determined contributions		
<b>IPCC</b>	Intergovernmental Panel on Climate Change		

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- Association of Ghana Industries (AGI)
- Ghana Hotels Association







# EXECUTIVE SUMMARY

This report for the refrigeration and air conditioning (RAC) sector in Ghana has been prepared under the Green Cooling Africa Initiative (GCAI). GCAI has been co-funded by both the German Government through the German Green Cooling Initiative (GCI) and by the Climate Technology Centre and Network (CTCN). The Ghana inventory was fully funded through GCI. RAC appliances are rapidly spreading across Africa. With an emerging middle class and an increasing population, the total number of RAC appliances is estimated to more than double by 2030. This will contribute to increased energy needs in many African countries. This report firstly estimates the impact the RAC sector will have on greenhouse gas emissions and energy demand in Ghana in an inventory report. Secondly, the report presents a technology gap analysis to identify suitable technical options to reduce emissions and energy demand.

Over the recent years, Ghana has experienced growth of its RAC appliances in terms of volume despite several years of decline due to a devaluation of currency and energy shortage. The demand for air conditioning is further increasing due to population growth and increasing expendable income. Currently, the sector shows an average growth rate of approx. 4 %.

The inventory report shows that the energy demand for the RAC sector will increase continuously from 7.04 TWh in 2015 to 20.9 TWh in 2050. GHG emissions follow the same trend with an increase from 5.05 Mt CO<sub>2</sub>eq in 2015 to emissions as high as 12.8 Mt CO<sub>2</sub>eq in 2050.

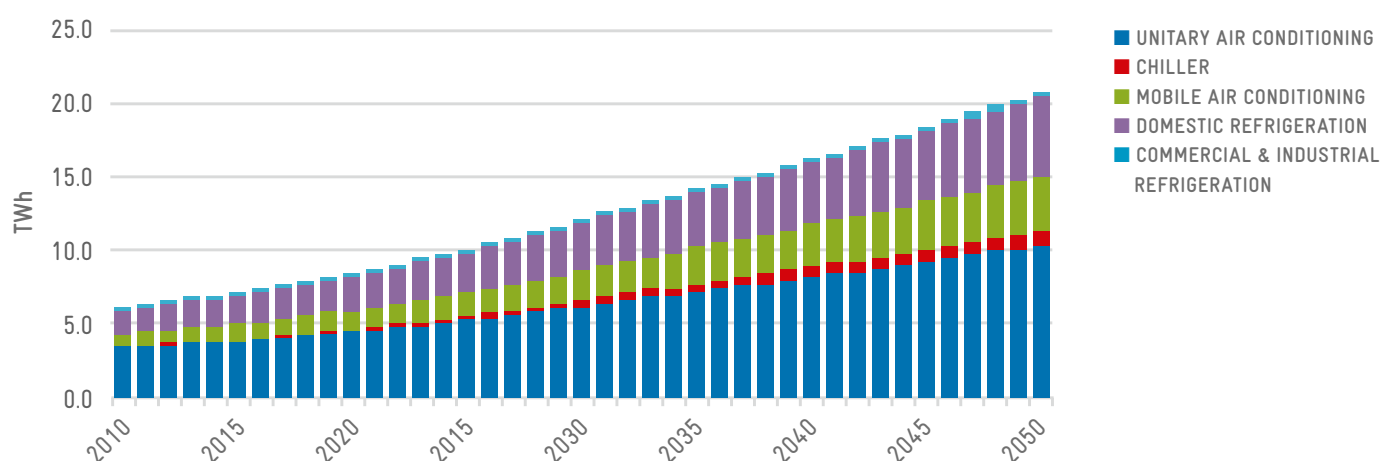


FIGURE 1: CURRENT AND PROJECTED ENERGY CONSUMPTION UNTIL 2050





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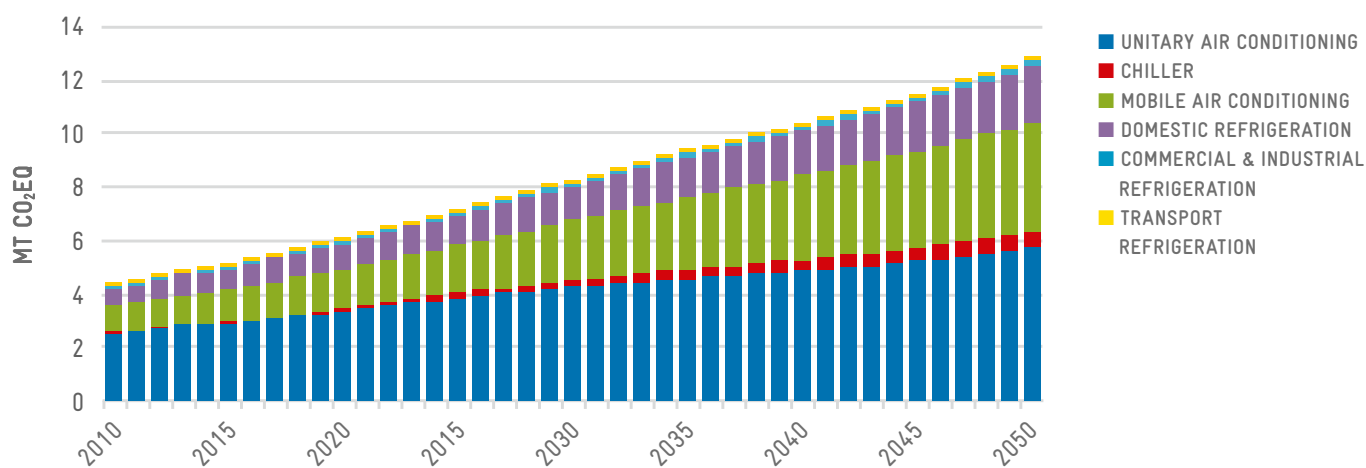


FIGURE 2: CURRENT AND PROJECTED TOTAL EMISSIONS UNTIL 2050

Unitary AC, mobile AC and domestic refrigeration account for the highest proportion of emissions. Considering different RAC sector appliances, split ACs have by far the highest contribution (nearly 60 %) to these emissions.

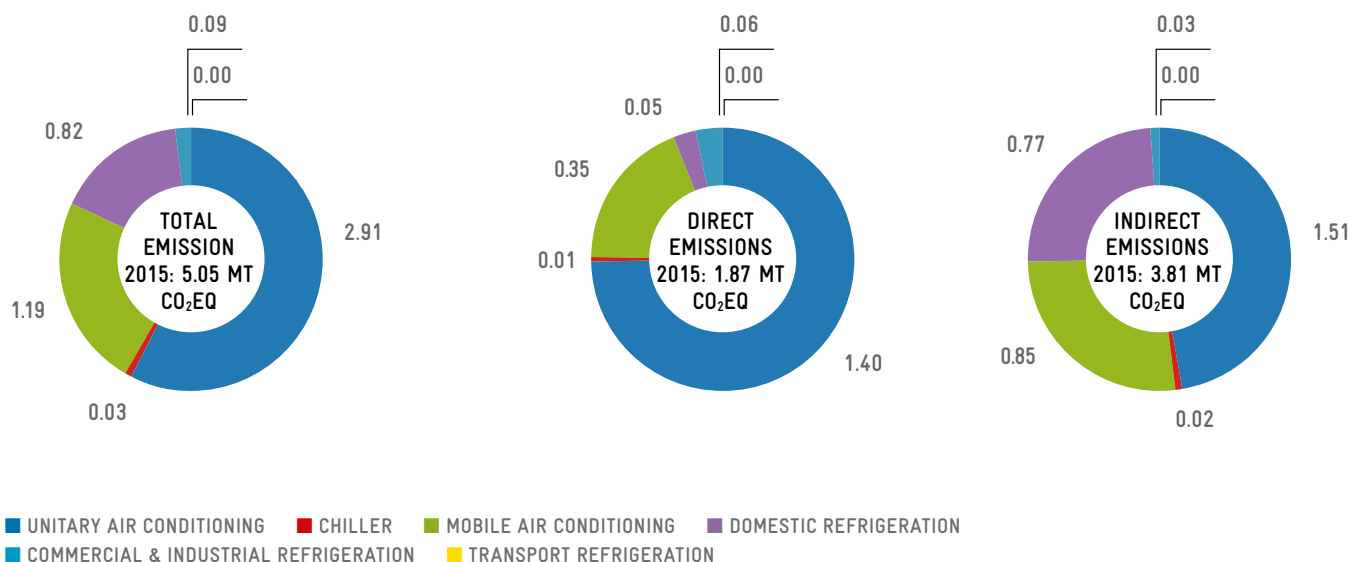


FIGURE 3: GHG EMISSIONS IN MT CO<sub>2</sub>EQ BREAKDOWN ACCORDING TO SUBSECTORS FOR THE GHANAIAN RAC INDUSTRY IN 2015



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HCFCs still contribute dominantly to direct emissions in Ghana. HFC emissions are expected to grow considerably over the next few years as the use of HCFCs is slowly phased -down under the Montreal Protocol.

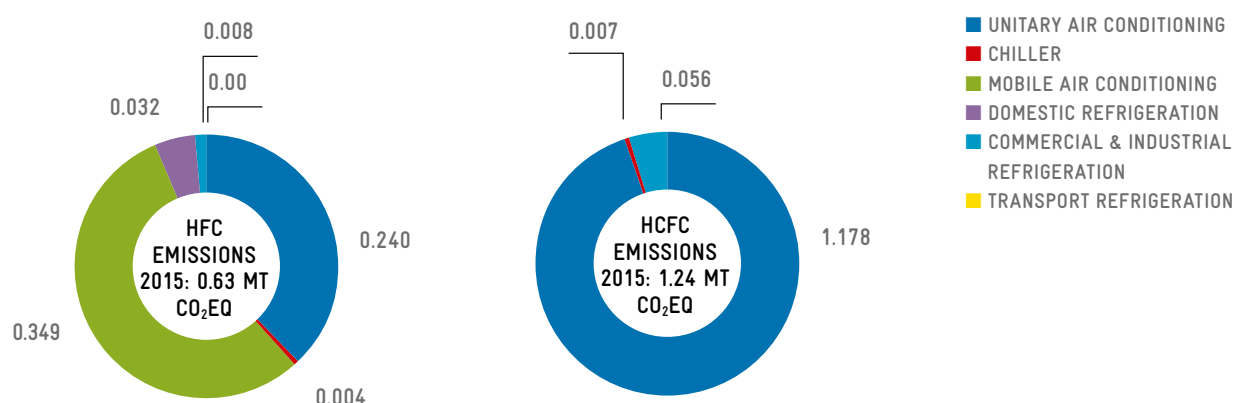


FIGURE 4: CONTRIBUTION OF HFC AND HCFC TO DIRECT EMISSIONS IN GHANA IN 2015 IN MT CO<sub>2</sub>EQ

Globally and in Ghana, there are different levels of availability for technologies with high energy efficiencies and low-GWP refrigerants (green cooling technologies). In Ghana, green cooling technologies for domestic refrigerators, stand-alone units, chillers and centralised systems are available. On the global market, green cooling technologies are also available for split ACs, and to a small extent for condensing units. More options for chillers and centralised systems are available in terms of the variety of natural refrigerants, higher energy efficiency and more varied application of these units.

Several barriers were identified for the uptake of green cooling technologies. Key identified barriers include lack of policy and of training for technicians. Technicians that have not received training to their full potential are more likely to make mistakes, which could result in high leakage rates and low energy efficiency. These technicians will also not be able to install RAC equipment with natural refrigerants, which are more environmentally friendly. Additional barriers are seen sometimes in the low availability of green cooling equipment.

Introducing best available technology to the Ghanaian market can lead to an emission reduction potential of up to 1.9 Mt CO<sub>2</sub>eq by 2030 and 4.3 Mt CO<sub>2</sub>eq by 2050 annually compared to the BAU scenario.

# 1 INTRODUCTION

## 1.1 PROJECT FRAMEWORK

Refrigeration and air conditioning are responsible for a significant share of global greenhouse gas emissions. Especially in developing and emerging countries, the demand for cooling equipment is rising. Low efficiencies and high leakage rates of refrigerant gases with high global warming potential will increase these emissions drastically. The goal of the Green Cooling Initiative is to accelerate the transfer of climate and environmentally friendly technologies in the refrigeration and air conditioning sectors to and within developing countries. It is believed that the exchange between technology suppliers and users, as well as between the industry, public institutions and civil society is crucial for the promotion of green cooling technologies. This report seeks to provide useful information, give access to knowledge and get partners/countries connected with others working on the same goal: Promoting green cooling technologies worldwide. The Green Cooling Initiative (GCI) is funded by the International Climate Initiative and implemented by GIZ Proklima.

### The International Climate Initiative

Since 2008, the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has been financing climate and biodiversity projects in developing and newly industrialising countries, as well as countries in transition. Based on a decision taken by the German parliament (Bundestag), a sum of at least 120 million euros is available for use by the initiative annually. For the first few years the IKI was financed through the auctioning of emission allowances, but it is now funded from the budget of the BMU. The IKI is a key element of Germany's climate financing and the funding commitments in the framework of the Convention on Biological Diversity. The Initiative places clear emphasis on climate change mitigation, adaption to the impacts of climate change

and the protection of biological diversity. These efforts provide various co-benefits, particularly the improvement of living conditions in partner countries.

The IKI focuses on four areas: mitigating greenhouse gas emissions, adapting to the impacts of climate change, conserving natural carbon sinks with a focus on reducing emissions from deforestation and forest degradation (REDD+), as well as conserving biological diversity.

New projects are primarily selected through a two-stage process that takes place once a year. Priority is given to activities that support creating an international climate protection architecture, to facilitate transparency, innovative and transferable solutions that have an impact beyond the individual project. The IKI cooperates closely with partner countries and supports consensus building for a comprehensive international climate agreement and the implementation of the Convention on Biological Diversity. Moreover, it is the goal of the IKI to create as many synergies as possible between climate protection and biodiversity conservation.

### GIZ Proklima

Proklima is a programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Since 2008 Proklima has been working successfully on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under its International Climate Initiative (ICI) to disseminate ozone- and climate-friendly technologies.

Proklima has been providing technical and financial support for developing countries since 1996, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) to implement the provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer.

## 1.2 THE REFRIGERATION AND AIR CONDITIONING SECTOR

The refrigeration and air conditioning (RAC) sector has a high negative impact on the environment. Firstly, the electricity consumption is high, particularly in climate zones with high ambient temperatures such as Ghana where equipment is often operated for long periods. Additionally, high leakage of synthetic refrigerants during use or at the end-of-life of equipment contributes considerably to greenhouse gas emissions because of their high global warming potential. In developing countries and emerging economies, the demand for cooling equipment is rising. Ghana's equatorial location, the related hot climate, its high population growth, rapid urbanization, widespread electrification, economic growth, growing industry and service sectors

in combination with an expanding middle class increase the demand for RAC equipment significantly. As a result, GHG emissions from the RAC sector are increasing.

Ghana's goal in the fight against climate change includes a transition of the RAC sector towards climate friendly technologies, which is included in Ghana's Intended Nationally Determined Contributions (INDC, 2015). This can be achieved by introducing energy efficient appliances using natural refrigerants with negligible or no GWP. Training and certification of technicians can further reduce leakages and improve the safety of RAC appliances. The RAC sector transformation to low GWP refrigerants and energy efficient appliances will enable Ghana in meeting several other benefits, many of which also serve to attain the Sustainable Development Goals:



Improved and sustainable income for workers and their families; energy efficient appliances save electricity costs for households;



Sustainable cold chains ensure quality and shelf life of food items;



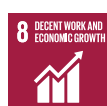
RAC technologies ensure safe storage and provision of medical goods, even in remote areas;



Teaching and qualification of technicians as well as capacity building among engineers, technicians trainers as well as policy-makers;



Introduction of innovative energy efficient technologies with low GWP refrigerants;



Creation and formalisation of jobs, the strengthening of local production and infrastructure with the use of green cooling technologies;



Introduction of innovative natural refrigerant technologies. There are no intellectual property rights associated with natural refrigerants and less patents on products using them compared to synthetic substances;



Sustainable technologies for human living environments, such as climate-friendly air-conditioning and building insulation. It also provides opportunities to move towards a circular economy;



Natural refrigerants have zero ODP, a negligible GWP and are part of the natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere;



Direct and indirect emissions of the cooling sector are reduced by the use of natural refrigerants and energy efficient appliances



Involvement of both the public and the private sector as well as multi-stakeholder partnerships;

In avoiding leakage of refrigerants with high GWP, a significant emission reduction can be achieved at an early stage as a contribution to the globally intended pre-2020 early climate actions (UNFCCC, 2016). Inventories not only give estimations of emissions, but also identify those sectors with the highest reduction potential and thereby contribute to the policy decision-making processes.

### 1.3 IMPORTANCE AND BENEFITS OF RAC SECTOR INVENTORIES

Inventories in the RAC sector that are based on estimated total numbers of equipment in different sub-sectors and their technical parameters provide a reliable database, and could serve as a starting point for all GHG emission reduction activities.

Equipment based RAC inventories can provide the following information:

- » Sales and stock per subsector as well as growth rates per subsector
- » Technical information about average energy efficiency, 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:

- » Identification of focus sectors with the highest GHG emissions as well as the highest emission reduction potential based on available technologies. RAC inventories are important steps in the planning, development and implementation of mitigation roadmaps

- » Support of countrywide GHG emission inventories that can be used for reporting under the UNFCCC. Based on the projections they give indications of how GHG emissions will develop in the future. Sectoral RAC mitigation plans based on GHG inventories and GHG emission projections can support the development of sectoral targets as part of Nationally Determined Contributions (NDC)
- » Provision of planning tools for mitigation actions, such as the formulation of Minimum Energy Performance Standards (MEPS) and labelling categories or formulation of policies targeting to ban refrigerants with high-GWP.
- » Give indication on the impact of legislation on stakeholders in different subsectors
- » Formation of a basis for a Measuring, Reporting and Verification (MRV) system or a product data base
- » Support of the development of project proposals with the aim of reducing GHG emissions in the RAC sector, such as nationally appropriate mitigation actions (NAMAs).
- » Important database support for the Montreal Protocol, as consumption and banks of ozone depleting substances (ODS) and ODS alternatives can be calculated and emissions can be assigned to subsectors.

Some end-users found the exercise very useful as they had never done monitoring of refrigerant and energy consumption. Inventories therefore increase the awareness of consumers on operating costs and environmental impact of their RAC equipment and highlight possibilities for reduction of costs and emissions.

RAC inventories are a time and cost intensive activity that cannot be repeated every year. As the data is extremely useful it is recommended to institutionalise the data collection exercise. An effective mean of institutionalisation of yearly updates of the inventory and GHG emission calculations goal is updating annual reporting of appliance sales into a product data base and the use of statistical information regarding vehicle registrations, household sizes and electrification rates.



Based on the advantages and different purposes of use, the following stakeholders can benefit from RAC inventories:

- » Climate departments/institutions and the focal points for planning GHG inventories under UNFCCC reporting (specifically on HFCs)
- » National entities (Environment ministries etc.) responsible for pollution control as well as waste collection systems
- » National ozone units for the control and planning of HCFC and HFC mitigation steps and the reporting requirements under the Montreal Protocol
- » National entities (Energy ministries etc.) responsible for the planning of energy use and conservation
- » Importers and retailers, manufacturers interested in the development of the sector in the country

### 1.3.1 A note on key subsectors

The IPCC defines “key sectors” based on a statistical analysis of the highest contributions to overall GHG emissions; please see the IPCC (2000) publication on “Good practice guidance and uncertainty management” in chapter 7 and the IPCC (2006) “Guidelines for national GHG inventories” in volume 1 chapter 4. Key sectors will then receive more resources to determine GHG emissions as accurately as possible. Other categories will be analysed on a lower level only. Once decided to integrate the RAC sectors in the national GHG inventory, we recommend covering all RAC subsectors at the same data level, independent of the subsector’s contribution to total RAC sector GHG emissions. “Key” or “focus” subsectors are then not tied to the statistical definition of the IPCC guidelines but those sectors where a quantitative assessment of emissions and a qualitative assessment of intervention options show a high potential for emission reductions.

## 1.4 OBJECTIVES AND SCOPE OF THIS REPORT

This inventory report for the RAC sectors in Ghana has been prepared under the Green Cooling Africa Initiative (GCAI). GCAI has been co-funded by both the German Government through the German Green Cooling Initiative (GCI) and by the Climate Technology Centre and Network (CTCN). The Ghana inventory was fully funded through GCI.

Under the GCAI, four African countries (Ghana, Kenya, Mauritius and Namibia) target as a regional initiative the preparation of a transformational change towards sustainable cooling appliances. The four countries requested the CTCN to provide technical assistance to cover the following four activities:

- » Establishment of a robust GHG inventory
- » Analysis of the technological gap between business as usual (BAU) and internationally best available technological (BAT) options
- » Recommendations of policies and regulatory frameworks: review and updates on green cooling technologies
- » Regional and country specific technology roadmap recommendations, based on the three previous tasks.

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in consultation with the four countries developed a Response Plan. GIZ was awarded with the implementation of the Response Plan and implemented it in cooperation with Habitat, Energy Application & Technology (HEAT GmbH) as a technical consultant.

As part of the Response Plan, this report covers the first two outputs, the establishment of a RAC inventory and a technology gap analysis for Ghana as one of the GCAI countries.

The report has been prepared under the supervision of the Environmental Protection Agency (EPA) Ghana which is under the Ministry of Environment, Science, Technology & Innovation (MESTI). Ghanaian consultants Kwame Owusu-Achiaw and Herbert Bimpong as well as Johanna Gloel of HEAT GmbH in Germany compiled this report. Team members from GIZ and EPA reviewed the report accordingly.

The main objectives of this report are:

- » Getting an overview of the current state of the GHG emissions of the RAC sector in Ghana.
- » Presenting a comprehensive RAC inventory analysis, from which the current sector GHG emissions can be derived, as a BAU scenario, as well as the sector’s GHG mitigation potential until 2050. The emission and the mitigation potential cover both direct GHG emissions from refrigerants and indirect emissions from the energy consumption of RAC equipment. In this context,



the potential market penetration of energy-efficient appliances with low GWP refrigerants are analysed.

- » Identifying international best practice RAC technologies with low GWP refrigerants and high energy efficiency, suitable for Ghana to mitigate emissions in the RAC sector.

The first part of this report entails the inventory of RAC appliances, their used refrigerants, their energy use and the related GHG emissions. This is presented on a sub-sector basis, including data collected via questionnaires and secondary data (chapters 1–4). The second part, the technology gap analysis, describes internationally available green RAC technology and compares it with the currently dominant technology sold in Ghana (chapter 5). Additionally, potential GHG emission reductions resulting from technologically possible deployment of green RAC technology are presented.

The structure of this report is as follows:

- » Chapter 1 gives an introduction to inventories and the Ghanaian country background.
- » Chapter 2 outlines the methodology used for collecting data as well as the modelling approach.

» Chapter 3 shows the results of the inventory.

» Chapter 4 shows the expected emissions of the RAC sector.

» Chapter 5 includes a technology gap analysis comparing technical parameters of units in Ghana with international available best practice technology.

In a second step, the results from this report has been combined with the results from a policy analysis into a technology roadmap that suggests specific actions to reduce RAC GHG emissions. This includes the necessary policy framework for initiating the transformation as well as specific milestones targeting the RAC subsectors with the highest share of emissions.

## 1.5 COUNTRY BACKGROUND

### 1.5.1 Geographical location of Ghana and climatic conditions

Ghana is a West African country located near the equator. Ghana shares a coast of 540km with the Gulf of Guinea, directly at the Atlantic Ocean. Ghana borders Cote d'Ivoire in the west, Burkina Faso in the north and Togo in the east (Figure 5). Ghana covers a total land area of 239,000 sq. km.

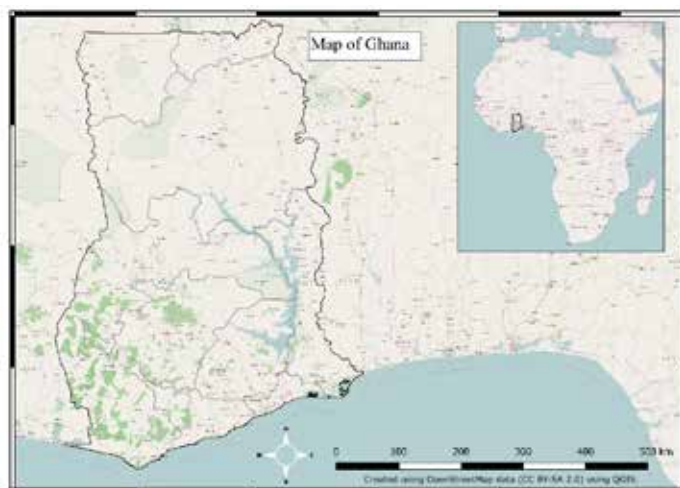


FIGURE 5: MAP OF GHANA

The climate is characterised as tropical, the typical type of vegetation is rainforest and savannah grasslands. The mean annual temperature ranges between 28–32°C. Depending on the region, the main precipitation falls in the rainy season between April to June and September to October with amounts of 1400–750mm (Figure 6 exemplary shows the climate chart for Kumasi). The humidity is about 90% during the wet season. During the remaining months, in the dry season, the temperatures decrease to 25–27°C and the humidity drops to 25%.

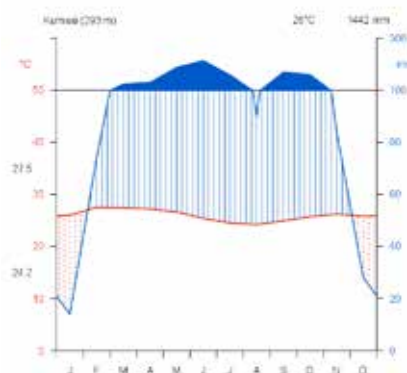


FIGURE 6: CLIMATE CHART FOR KUMASI, GHANA. SOURCE DATA: [HTTP://WWW.KLIMADIAGRAMME.DE/AFRIKA/KUMASI.HTML](http://www.klimadiagramme.de/afrika/kumasi.html)

### 1.5.2 Population and economic situation

Ghana has an estimated population of 28.3 million (GSS, 2016, based on a census in 2010), with a relatively high annual population growth rate of 2.4% compared to 1.6% for other lower-middle income countries, but in line with the 2.5% average for Sub-Saharan Africa. Ghana is divided into 10 administrative regions. The country has a diverse rich resource base that includes gold, timber, cocoa, diamond, bauxite and manganese. The economy is traditionally oriented towards agriculture, contributing immensely to the gross domestic product (GDP) and small domestic trading.

Ghana has recently gone through a slowdown in economic growth but is currently recovering. Whilst GDP growth was 8.7% in 2012, it fell to 4% in 2014, 3.7% in 2015 and is expected to have reached 5.8% in 2016 with a forecast of 8.7% for 2017<sup>1</sup>.

For over three years beginning in 2011, the nation went through load shedding (i.e. rotating planned electricity shutdown) to deal with the severe power deficit. This had a severe toll on all economic activity including demand for RAC products. Around the same period that the load shedding was having severe bite on economic activities, the local currency experienced serious depreciation. For example, the exchange rate of the Ghana cedi to the US dollar fell from 0.61 in 2011 to 0.29 in 2014 before stabilizing in 2015. The falling exchange rate affected general imports and a usual complaint among RAC importers at that time was that the quantity of goods they could import with their operating capital kept falling with each import. Once the power situation and the exchange rate began to stabilize in 2015, businesses began to pick up in all sectors including import of RAC products.

### 1.5.3 Energy and emissions profile

The installed electricity capacity of Ghana has doubled between 2000 (1,418 MW) and 2013 (2,850MW) and is seen as a key driver for Ghana's development (Energy Commission, 2014). Electricity in Ghana is generated by both hydropower and fossil fuels (Table 1, Figure 7). Ghana hosts the largest solar energy plant in West Africa, but the contribution is still very small. Prices for private customers rose from 0.017 GHS/kWh (0.024 US\$/kWh) to 0.307 GHS/kWh (0.156 US\$/kWh) over the same period of time. Higher efficiency of appliances is therefore an important topic for consumers. The carbon intensity of electricity is comparatively low at 0.39 kg/kWh (Personal communication, Energy Commission Ghana 2017) and less than the global average as Ghana has several hydropower stations. However, it has increased over the last years due to fossil fuel power stations being built to meet the rapidly rising electricity demand.

<sup>1</sup> <https://www.afdb.org/en/countries/west-africa/ghana/ghana-economic-outlook/>

TABLE 1: INSTALLED GRID ELECTRICITY GENERATION CAPACITY OPERATIONAL AS OF DECEMBER 2015. SOURCE: ENERGY COMMISSION, GHANA, 2016 ENERGY (SUPPLY AND DEMAND) OUTLOOK FOR GHANA

GENERATION PLANT	FUEL TYPE	CAPACITY (MW)				TOTAL GENERATION	
		Installed (name plate)	% Share	Average Dependable	Average Available	GW/h	% Share
<b>Hydro Power Plants</b>							
Akosombo	Hydro	1,020		900	375	4,156	
Bui	Hydro	400		340	330	870	
Kpong	Hydro	160		140	105	819	
<i>Sub-Total</i>		<i>1,580</i>	<i>49.8</i>	<i>1,380</i>	<i>760</i>	<i>5,845</i>	<i>50.86</i>
<b>Thermal Power Plants</b>							
Takoradi Power Company (TAPCO)	Oil/NG	330		300	300	1,784	
Takoradi International Company (TICO)	Oil/NG	330		320	320	1,336	
Sunon–Asogli Power (SAPP)	NG	200		180	180	1,185	
Tema Thermal Plant1 (TT1P)	Oil/NG	110		100	100	541	
Tema Thermal Plant2 (TT2P)	Oil/NG	49.5		45	30	215	
CENIT Energy Ltd (CEL)	Oil/NG	110		100	100	317	
Mines Reserve Plant	Oil/NG	80		70	40	170	
Takoradi T3 <sup>#</sup>	Oil	132		36	3.6	31	
Karpower*	HFO	250		225	225	64	
<i>Sub – Total</i>		<i>1,591.50</i>	<i>50.1</i>	<i>1,376</i>	<i>1,298.6</i>	<i>5,643</i>	<i>49.10</i>
<b>Renewables</b>							
VRA Solar	Solar	2.5		2	1	4	
<i>Sub – Total</i>		<i>2.5</i>	<i>0.1</i>				<i>0.04</i>
<b>Total</b>		<b>3,174</b>		<b>2,756</b>	<b>2,058.6</b>	<b>11,492</b>	

NG is Natural gas, \*Estimated.; # Takoradi T3 worked for two months; January and February.

Most of the electricity is consumed by the industrial sector (45%), followed by the residential sector (28%) and the non-residential sector (18%), Ghana's GHG emissions of 33.66 Mt CO<sub>2</sub>eq in 2012 arise from the combustion of fossil fuels for electricity production, industrial processes and transport as well as through land use changes, agricultural and waste management practices. Since 1990, GHG emissions are on the

rise, mainly driven by economic growth (National GHG inventory report, 2015). Agriculture, forestry and other land use contribute 45% of the total emissions, followed by energy combustion activities (40%), Waste (13.4%) and industrial processes (1.4%). In this inventory, HCFC emissions are not included and HFC emissions have not yet been considered.

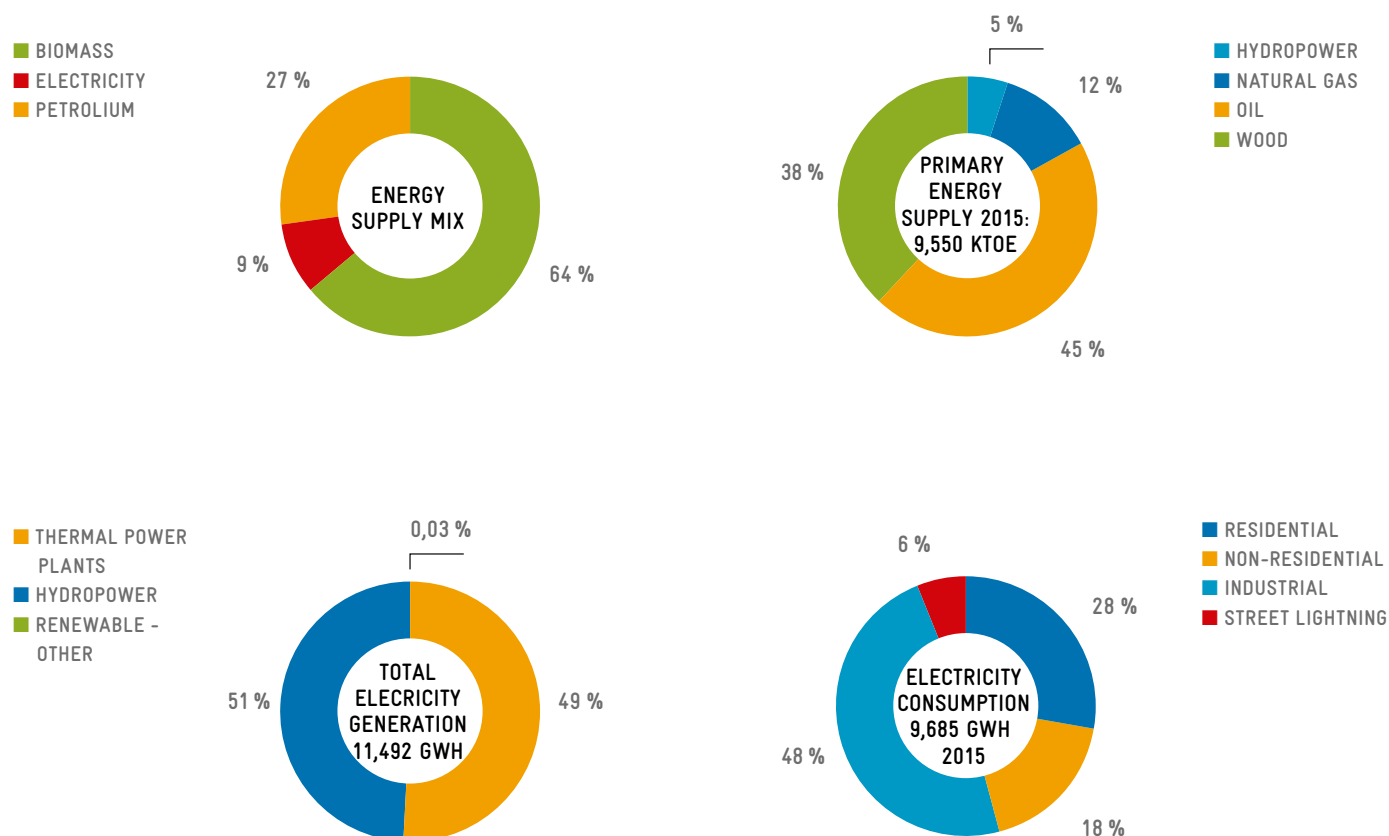


FIGURE 7: ENERGY SUPPLY MIX 2007 (GYAMFI ET AL., 2015) AND PRIMARY ENERGY SUPPLY IN 2015 ACCORDING TO SOURCES. (TOP PANEL). TOTAL ELECTRICITY GENERATION ACCORDING TO MEANS OF GENERATION AND ELECTRICITY CONSUMPTION ACCORDING TO MAIN CUSTOMERS, BOTH FOR 2015. (LOWER PANEL). SOURCE: NATIONAL ENERGY STATISTICS, 2016B

## 1.6 RAC RELATED LEGISLATION AND POLICY FRAMEWORK

Ghana has stayed with the international community in the fight against the use of substances considered harmful to the environment. Since ratifying the Vienna Convention and the Montreal Protocol to control the consumption of ODS, the country has successfully controlled and managed the consumption of ODS and is currently on course in the implementation of the HCFC Phase-out Management Plan (HPMP).

Following global concerns on climate change, Ghana became a signatory to the United Framework Convention on Climate Change (UNFCCC) and the country has initiated actions to mitigate global warming and adapt to climate change. In this regard, the country has put in place a National Climate Change Committee (NCCC) in 2012 and followed it up with the launching of a National

Climate Change Policy (NCCP) in 2014 to provide policy direction on the issues of climate change. A National Climate Change Adaptation Strategy (NCCAS) has also been developed in 2012. Furthermore, a Climate Change and Green Economy Learning Strategy (CCGELS) was launched in 2016 to promote climate change education, awareness and learning in Ghana. Ghana has submitted its INDC to the UNFCCC in October 2015 which outlines its commitment in fighting climate change. Currently, Ghana is putting in place an implementation plan for its NDC of which the RAC sector mitigation actions has been included. This document serves also as support to Ghana's blueprint in mitigating and adapting to the impacts of climate change. The EPA leads the drafting of the NDC in collaboration with MESTI and other key sector collaborators from different institutions. Ghana already implements a legislation to increase the energy efficiency of ACs and domestic refrigerators since 2008.

### 1.6.1 Institutional set up under the Montreal Protocol and the UNFCCC

As required for parties to the Montreal Protocol, a National Ozone Unit (NOU) was set up in Ghana in EPA which is under MESTI. The NOU is one of the 3 main departments of the Chemicals Control and Management Centre (CCMC) of the EPA. The NOU is responsible for the implementation of actions to protect the ozone layer. The key responsibilities of the NOU include

- » Coordination with other ministries, departments and the private sector, raising of public awareness and sensitisation of stakeholders
- » Act as a facilitator for implementing and funding agencies, processing of clearances for import/export of ozone depleting substances including refrigerants and alternatives
- » Report data and progress to the requisite UN institutions including the Multilateral Fund and the Ozone Secretariat

Under the country programme for the control and management of ODS, a National Committee on Ozone Depleting Substances (NACODS) was formed and works together with a variety of stakeholders, which include Ministries, Agencies, research institutions, private sector and NGOs. Involvement of the above mentioned organisations ensures ownership, cooperation, accountability and enables the EPA to contribute to the formulation of policies and implement strategies for the control of ODS use.

For the implementation of the UNFCCC, a national climate change committee was established in Ghana in 2012. Its members were drawn from all relevant ministries, agencies and planning commissions as well as NGOs, universities and international aid organisations (MESTI, 2013). It was hosted by MESTI. The committee was responsible for drafting national climate change policies and has been dissolved when the policy was launched in 2014. A National Climate Change Steering Committee has been formed in 2016 in order to implement the NCCP, led by MESTI.

There is a national climate change focal person in Ghana, based at the EPA. The main role of the focal person is to coordinate and implement climate change activities in the country and communicate to the UNFCCC.

### 1.6.2 Legislation in Ghana regarding the RAC sector

The following legislation supports the regulation of the RAC sector in Ghana:

#### a) Export and Import Act, 1995 (Act 503)

By this Act, the Minister of Trade and Industry is empowered to prohibit or restrict the exportation or importation of any goods such as ODS import management.

Another aspect of the Export and Import Act that facilitates the regulation of ODS imports is the requirement that the Import declaration form (IDF) must be completed and submitted to the appropriate agencies, which include the commissioner of customs, the inspector to be appointed by the minister and any other agency specified on the form.

#### b) CEPS (Management) Law, 1993 (PNDC L330)

The Customs Excise and Preventive Service (CEPS) Management Law acts as an omnibus law on import and export trade and could be used to address regulatory requirements of any of the agencies where such agency lacks adequate legal backing to do so.

#### c) EPA Act, 1994 (Act 490)

The Environmental Protection Act, 1994 maps the mandate, functions, structure and funding of the EPA. The mandate of the EPA includes formulating environmental policy and making recommendations for the protection of the environment.

#### d) Management of Ozone Depleting Substances and Products Regulations, 2005 (LI 1812)

The Management of ODSs and Products Regulations, 2005 (LI 1812) was enacted to enable the country to control ODS imports in order to meet its obligations under the Montreal Protocol, namely, that of progressive phase-out of ODS consumption.

#### e) Energy Commission - Energy Efficiency Regulation, 2008 (LI 1932)

In October 2008, the Minister of Energy, empowered by the Energy Commission Act 541, promulgated the Energy Efficiency Regulation 2008 (LI 1932) which prohibited importation and sale of used air conditioners, used refrigerators, used freezers and used combination refrigerator / freezer, among other products. The full effect of the LI came into effect on 1st January 2012. This LI was introduced as part of the campaign to flush out inefficient appliances from the market, which at the time was estimated by the Energy Commission to be causing about 30% loss in electricity consumption. Used fridges, used freezers, etc. imported into the country were invariably



appliances operating with CFC gases that had been discarded in the developed countries where consumption of the ODS had already been phased-out. Thus, the ban contributed to saving the environment by reduced carbon emission from banning energy-inefficient appliances and also eliminating additional introduction of CFC-based products into the country.

**f) Environmental Assessment Regulations, 1999 (LI 1652)**

The regulation lists activities, which require registration and issue of an environmental permit and the process of conducting environmental impact assessments.

**g) Hazardous and Electronic Waste Control Management Act, 2016, (Act 917.) and Hazardous, electronic and other wastes (classification), control and management regulations, 2016 (LI 2250)**

Act 917 was passed in parliament in 2016 and includes extended producer responsibility elements such as a levy on appliances to be used for their proper dismantling and disposal. Both ACs and domestic refrigerators are included in the document. The "Hazardous, Electronic and other Wastes Classification, Control and Management Regulations, 2016, L.I. 2550 are partly implementing Act 917.

**h) Other mechanisms to control ODS import**

Other mechanism and administrative procedures have been put in place to control and monitor importation of ODS.

**1.6.3 Activities under the HPMP and other programs targeting the RAC sector**

The refrigeration and air conditioning (RAC) sector is currently targeted by the activities outlined in the HCFC Phase-out Management Plan (HPMP) and other programs (e.g. technology transfer under the GCI), which are not linked to the legislation mentioned above. The HPMP is conducting the following activities, partly in line or implemented through legislation:

- » Licensing and quota system for HCFCs, bans on imports of new HCFC-based equipment and imports of HCFC-141b in bulk, in place since 1 January 2015

- » Training of customs officers on identification and control of import of ODS and ODS-based equipment

- » CEPS controls entry of goods into the country at all entry points (by sea, air and land). This makes CEPS a very strategic partner of the NOU/EPA in the control and management of imports of ODS into the country

- » Provision of refrigerant identifiers for ODS blends for border posts

- » Technician training on good service practices, use of hydrocarbon refrigerants (mainly R290 and R600a) and safety measures

Activities supported by other programs, e.g. funded by international climate change mitigation programs, include:

- » HFC Inventory GHANA 2011-2014 (CCAC)
- » Procurement of R290-based air conditioning units and further equipment for training and demonstration purposes
- » Technician training on good service practices, use of hydrocarbon refrigerants (mainly R290 and R600a) and safety measures
- » Awareness-raising activities including regular coordination meetings with stakeholders to create an enabling environment for HCFC phase-out and several newspaper advertisements on HCFC controls, licensing and quota system and phase-out targets
- » Completed take-back scheme "new for old" for domestic refrigerators to increase energy efficiency in the market and adequate dispose of refrigerants and blowing agents
- » Supporting the incorporation of HFCs into NDCs

## 2 METHODOLOGICAL APPROACH

The following chapter details the methodology that was used to collect and compile data. It also describes the difficulties encountered during data collection and assumptions made for calculations.

The adopted methodology for this report mainly relies on the following three publications:

- Penman, J., Gytarsky, M., Hiraishi, T., Irving, W., Krug, T. (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Geneva: Intergovernmental Panel on Climate Change (IPCC).
- Multilateral Fund for the Implementation of the Montreal Protocol (2016) Guide for Preparation of the Surveys of ODS Alternatives. Montreal: Interagency Coordination Meeting.

- Heubes, J., Papst, I. (2013) NAMAs in the refrigeration, air conditioning and foam sectors. A technical handbook. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

### 2.1 CLASSIFICATION ADOPTED FOR THE RAC SUBSECTORS

According to Heubes (2013), the RAC sector includes (i) air conditioning and (ii) refrigeration. The subsectors and typical systems are listed in Table 2. In this report, the word “system” is used interchangeably with the words “appliance, equipment or unit”.

TABLE 2: REFRIGERATION AND AC SUBSECTORS (HEUBES ET AL. 2013)

	SUBSECTOR	TYPICAL EQUIPMENT
AIR CONDITIONING	Unitary air conditioning	Self-contained air conditioners Split 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
REFRIGERATION	Domestic refrigeration	Domestic refrigeration
	Commercial refrigeration	Stand-alone equipment Condensing units Centralised systems for supermarkets
	Industrial refrigeration	Stand-alone equipment Condensing units Centralised systems
	Transport refrigeration	Refrigerated trucks/trailers



For Ghana, the classification was adjusted to local conditions as follows (Table 3):

- » The differentiation between commercial and residential AC equipment was dropped as this does not play a role in everyday life and no distinction is made during import, sales and maintenance.

- » Equipment counted as commercial and industrial refrigeration was combined as there is very little or no technical difference between the subsectors

TABLE 3: RAC SUBSECTORS AND TYPICAL EQUIPMENT IN GHANA AFTER ADJUSTMENT OF CLASSIFICATION

	SUBSECTOR	TYPICAL EQUIPMENT
AIR CONDITIONING	Unitary air conditioning (Stationary AC)	Self-contained Single split (non-ducted) Single split (ducted) Rooftop ducted Multi-splits (VRV/VRF)
	Air Conditioning Chiller (Stationary AC)	AC Chiller
	Mobile air conditioning	Small vehicle (Saloon cars, light commercial) Large vehicle (bus)
REFRIGERATION	Domestic refrigeration	Refrigerator Freezer Combined refrigerator/freezer
	Commercial/Industrial refrigeration	Stand-alone equipment (e.g. display units, packaged units) Condensing units Centralised systems (e.g. cold stores, supermarkets) Process Chiller
	Transport refrigeration	Refrigerated trucks/trailers

## 2.2 GHG EMISSION CALCULATION TECHNIQUES – TIER 1 VS TIER 2 INVENTORIES

There are different approaches to conduct inventories:

- > In **Tier 1** inventories, potential (IPCC 1996)<sup>2</sup> or actual (Penman 2006) emissions are calculated. The 1996 method relies heavily on refrigerant consumption data and is widely used. The 2006 method is further based on annual sales, introduction year, generic emission factors and growth using generic assumptions to back-calculate the build-up of banks
- > In **Tier 2**, actual emissions are based on system- and country-specific refrigerant charge, lifetime and emission factors (Heubes, 2013; Penman, 2006). Data is collected on a disaggregate subsector or even system level.

(Heubes, 2013; Penman, 2006). Tier 1 requires less data and produces highly aggregated data that will give an overview e.g. of the consumption of a specific refrigerant at country level but does not give enough details to highlight which subsectors are responsible for the highest emissions.

<sup>2</sup> 1996 Good Practice guidelines.



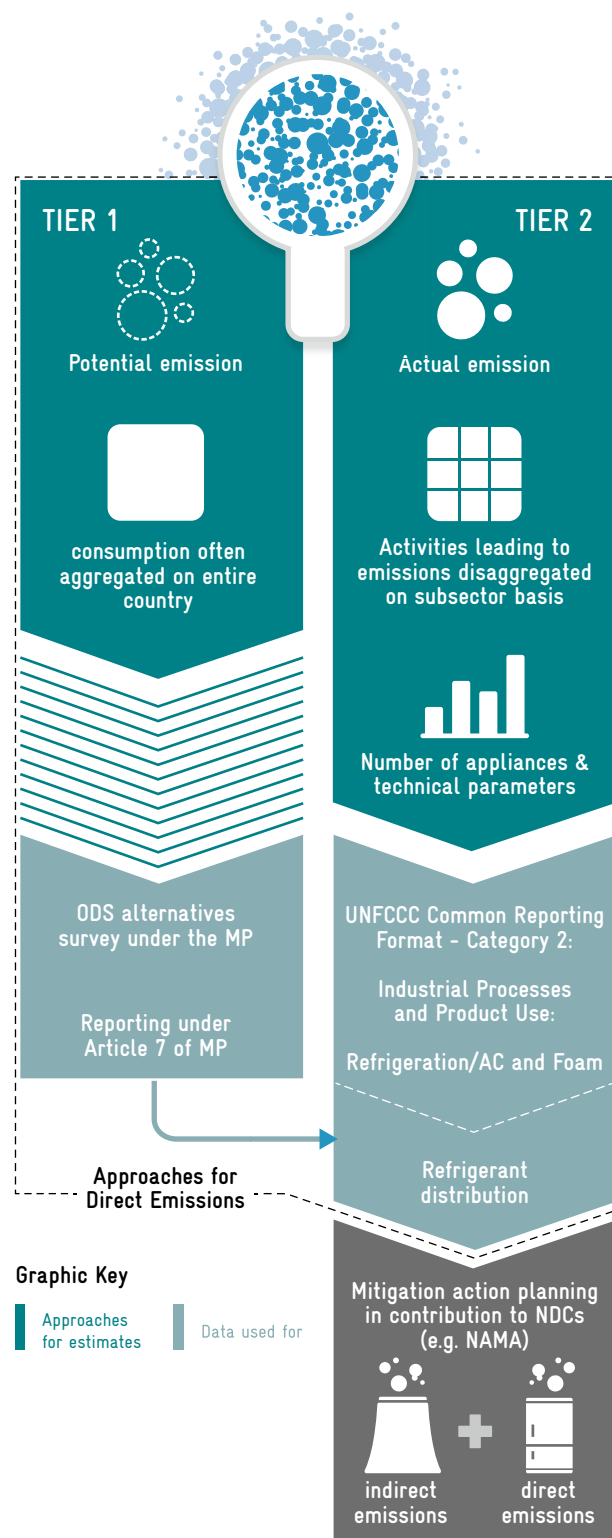


FIGURE 8: APPROACHES FOR GHG EMISSION ESTIMATES RELEVANT TO THE RAC SECTOR. SOURCE: GIZ PROKLIMA, 2016

The report at hand followed the Tier 2 methodology. Additionally, the applied approach did not only cover refrigerant related emissions, but also included GHG emissions from energy use. The following parameters were analysed for Ghana in order to conduct this inventory:

- » Total stock and annual sales of appliances.
- » Refrigerant distribution per subsector/appliance system.
- » Leakage rate during operational use and at decommissioning.
- » Energy efficiency and energy consumption on a unit basis.

This enabled us to calculate the unit based GHG emissions as well as the country-wide emissions for the RAC sector. For a more detailed methodology of this, please see chapter 1 and its annex of the NAMA handbook (Heubes et al., 2013).

The differences between Tier 1 and Tier 2 methodologies for direct emissions are further illustrated in Figure 8. Whilst indirect emissions are included in the calculation for this report, they are already included in the national GHG inventory of Ghana. These calculations will therefore only highlight the contribution of the RAC sector towards GHG emissions from electricity consumption.

## 2.3 DATA COLLECTION PROCESS

Data was collected from both primary and secondary data and whenever possible different sources were compared for validation purposes.

### 2.3.1 Review of secondary data

A desk study was conducted to review historical data on refrigerant imports into the country over the years as well as reports and documents on earlier RAC inventory work funded and carried out by the Hydrochlorofluorocarbon Phaseout Management Plan (HPMP), Climate and Clean Air Coalition (CCAC) and United Nations Environment Programme (UNEP). The secondary data serves to supplement possible data gaps from the primary data. Further, the secondary data serves to have a quality review and control of the primary data. The following documents were reviewed for the compilation of this report:

- » Customs data of Equipment imports (2012-2015).
- » Hydrochlorofluorocarbon Phase-out Management Plan (HPMP), UNDP, 2010.
- » HFC Inventory GHANA 2011-2014, Owusu-Achaw, 2015.
- » Comtrade data base (UNSD, 2004).

### 2.3.2 Primary data collection

Consultations were held with National Ozone Unit (NOU) at the Environmental Protection Agency (EPA) to deliberate on the terms of reference for the project, its objectives and scope of works and to develop a project plan.

Primary data was collected using a questionnaire. A draft questionnaire for the data collection exercise was prepared based on a template supplied by HEAT. Two versions of the questionnaire were used, one for importers/sales and one for end-users as there is no manufacturing sector in Ghana. Importers were asked primarily for the numbers of units brought into the country and sold on the domestic market. End-users, particularly of large units such as chillers and centralised systems, but also transport refrigeration were asked for technical parameters of their units. At first, a national stakeholder workshop was organized in Accra to present the project and the draft questionnaires to stakeholders in order to include their comments and input. The workshop was replicated in four other regional capitals.

Participants for the workshop were drawn from the National Association of Refrigeration Workshop Owners Association (NARWOA), CEPS, RAC equipment importers, RAC service providers and diverse end-users from hotels, restaurants, industry, commercial institutions, educational institutions and others. Members of NARWOA were involved in sensitizing RAC sector stakeholders about the inventory process and also provided valuable knowledge about the sector. CEPS was able to provide input regarding the import of ODS and ODS alternatives as well as equipment charged with these substances.

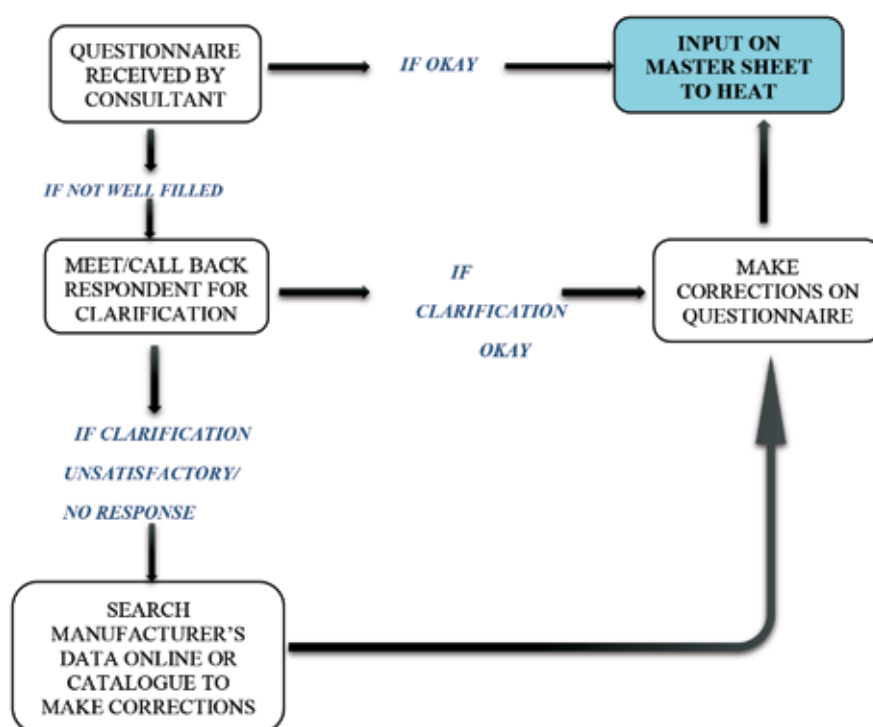
The questionnaire was adjusted according to the comments of the participants before being distributed widely to importers and end-users.

Measures were put in place to ensure data received from respondents were thoroughly checked to ensure a good data collection exercise. Figure 9 provides the quality control chart used to validate data received from respondents. The local consultant, after going through the validation process, fills and forwards the Master Sheet to HEAT for cross-checking.



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FIGURE 9: VALIDATION CHART FLOW, OWN REPRESENTATION



The validation process ended with a national validation workshop, which provided the opportunity to some key RAC stakeholders (EPA/NOU, CEPS, NARWOA, RAC equipment importers and end users) to comment and

agree on the inventory data. Changes to the data were made according to these comments. Details are included in the results section. Key stakeholders for the inventory process are summarised in Table 4.

TABLE 4: KEY STAKEHOLDERS AND THEIR ROLES IN THE ESTABLISHMENT OF THE RAC INVENTORY

STAKEHOLDER	ROLE
NATIONAL OZONE UNIT (NOU)	Consultation to develop project methodology and work plan, organizing of stakeholder workshop, data on imports, reviewing of Draft and Final Report
CEPS	Providing historical data on imports of ODS and ODS alternative substances and equipment
IMPORTERS	Providing import data
NARWOA	Sensitize members to support data collection exercise
END-USERS	Providing data on equipment and consumption of ODS alternative.

## 2.4 DATA COLLECTION CHALLENGES

Response to questionnaire was generally slow and insufficient and is summarised as follows:

A total of 305 questionnaires were sent out to end-users (275) and importing agencies (30), from which 216 completed questionnaires were received, representing 70 % response. Most of the questionnaires were poorly filled and had to be followed up for correction (Table 5).



TABLE 5: NUMBER OF SUBMITTED AND RECEIVED QUESTIONNAIRES

NO	SECTOR	END-USER SUBMITTED	RECEIVED	IMPORT SUBMITTED	RECEIVED	CUSTOMS IMPORT
1	STATIONARY AC	135	99	11	5	26
2	DOMESTIC REFRIGERATION	93	64	6	1	15
3	COMMERCIAL REFRIGERATION	35	35			1
4	TRANSPORT REFRIGERATION	0	0	3	1	0
5	INDUSTRIAL REFRIGERATION	12	6			0
6	MOBILE AC	0	0	10	5	0
	TOTAL	275	204	30	12	42

- » Most respondents delayed filling the questionnaire and had to be repeatedly prompted by phone calls before eventually filling and returning the questionnaire.
- » End-users were not prepared to disclose their annual energy consumption. This was a "no-go area" and the mere mentioning of that request made respondents suspicious and not interested in the exercise.
- » There was general complaint about the technical complexity of the questionnaire regarding inputs such as EER<sup>3</sup>/COP<sup>4</sup> and annual kWh consumption.
- » Many of the big importers of unitary AC and domestic refrigeration equipment were reluctant to give out their import volumes data on the suspicion that the information may fall into the hands of their competitors to their disadvantage.
- » Among the commercial end-users, poor record keeping was a very visible problem as many could not provide ready information of their refrigerant consumption over the past years.
- » Major multi-national processing industries displayed lukewarm attitude to the questionnaire for two reasons:
  - (i) Existing company policies did not allow to disclose information of their operation
  - (ii) Suspicion that the EPA was using the survey to identify companies that were still using banned substances in order to levy penalties against them.
- » RAC equipment in the fishing vessels could not be covered under this survey. EPA/NOU is limited in terms of capacity to monitor and enforce compliance in this sub-sector though it has plans to do so in the immediate future.

3 Energy Efficiency Ratio. Ratio of cooling capacity to the power input.

4 Coefficient of Performance. Ratio of cooling provided to work.

# 3 RESULTS AND ANALYSIS

## 3.1 REFRIGERANT CONSUMPTION

Ghana reports HCFC import to the Ozone and multilateral fund (MLF) secretariats as part of their national data reporting obligations (HPMP, 2010). Additionally, an

ODS alternatives survey was conducted in 2014/2015, reporting imports of HFCs (CCAC, 2014). Here, there are no production and export hence it was considered that import equals consumption. Results are compiled in Table 6.

TABLE 6: HCFC AND HFC IMPORTS IN GHANA. SOURCES: EPA, OWUSU-ACHAW (2015)

YEAR	REFRIGERANT IMPORTS [IN MT]								
	HCFC-22	HCFC-406	HFC-134A	HFC-404A	HFC-410A	HFC-407C	HFC-507	R600A	R290
2008	335		612	9					
2009	353	943	922	9	972	13	2	3	
2010	161	95	37	3	2	1	1	4	
2011	324	212	43	13	0.7	14	902	12	
2012	261	125	111	64	13.1	14.5	15.7	36.8	0.15
2013	361	89	123	22.5	18.5	17.8	4.5	8.6	
2014	155	81	61.4	11.7	19.9	4.2	0.06	19.9	1.5
2015	139	107	108	33	11	47	4	5	
2016	297	39	78	22	12	5	0.5	20	

According to the Montreal Protocol requirements, imports of HCFC have started to decrease over the last years, whereas HFC imports have on average increased over the same period. The aforementioned economic instability in the years 2011–2015 can also be seen in the imports of refrigerant. Some fluctuations exist due to the fact that consumption of imported substances does not necessarily have to happen in the same year. If annual import and consumption volumes do not match up, high import volumes in one year can lead to lower import volumes in the following year.

## 3.2 EQUIPMENT BASED RESULTS

### 3.2.1 Annual refrigerant leakage rates

In order to determine direct emissions, annual refrigerant leakage rates were considered. This information was collected from end-user questionnaires on the frequency of servicing and the average amount of refilled refrigerant per servicing. The following information was collected:

- » Annual leakage rates for unitary AC were found to be very high, in the range of 80 % for single split units and up to 280 % for units such as multi-splits with plenty of connections. Other equipment leakage rates were also reported to be very high.

Several problems were encountered:

- » The expert validation workshop reported occasional very high leakage rates, but did not confirm these high leakage rates for the whole country.
- » It is not clear if every servicing event also includes a refill of refrigerant.
- » An estimation of annual consumption of refrigerants with the annual leaked amount also does not confirm the extremely high values from questionnaires. The consumption of refrigerant in Ghana is not high enough to justify these rates unless leakage is considerably smaller in newer units or different sectors.

» However, a second analysis was done where the reported annual refill of refrigerant was compared to the initial charge of equipment, seemed to confirm the high leakage rates.

» A study by the Technology and Economic Assessment Panel (TEAP) (UNEP/OzL.Pro/ExCom/71/56) reports leakage rates for single split units in the range of 29–79% in developing countries.

For the calculation of emissions, the following leakage rates and end-of-life emissions were used with the knowledge that a better understanding and more knowledge is necessary.

TABLE 7: COMPARISON OF ANNUAL LEAKAGE RATES BASED ON END-USER QUESTIONNAIRES AND DEFAULT VALUES BASED ON LITERATURE ANALYSIS. BOLD BLACK VALUES WERE CONFIRMED BY THE EXPERT VALIDATION MEETING. VALUES MARKED WITH A \* WERE ASSUMED AS LIKELY RATES IN THE VALIDATION WORKSHOP UNTIL FURTHER ANALYSIS IS CONDUCTED

	RESULT BASED ON END-USER QUESTIONNAIRE	DEFAULT VALUES BASED ON LITERATURE ANALYSIS	USED FOR CALCULATIONS
SELF-CONTAINED	109 %	10 %	25 %*
SPLIT (DUCTLESS)	83 %	10 %	23 %*
SPLIT (DUCTED)	96 %	10 %	20 %*
ROOFTOP DUCTED	136 %	10 %	31 %*
MULTI-SPLITS, VRF/VRV	280 %	25 %	35 %*
AIR CONDITIONING CHILLERS	56 %	22 %	22 %
PROCESS CHILLERS	23 %	22 %	22 %
CAR AIR CONDITIONING	Not given	20 %	20 %
LARGE VEHICLE AIR CONDITIONING	Not given	30 %	30 %
DOMESTIC REFRIGERATION	1 %	2 %	2 %
COMM/IND STAND-ALONE EQUIPMENT	1 %	3 %	3 %
COMM/IND CONDENSING UNITS	95 %	30 %	30 %
COMM/IND CENTRALISED SYSTEMS	Not given	38 %	38 %
REFRIGERATED TRUCKS/TRAILERS	Not given	25 %	25 %





### 3.2.2 Stationary air conditioning

#### 3.2.2.1 Data collection and validation

There is no production of stationary ACs in Ghana. Data was collected through questionnaires from importers. However, only 5 filled questionnaires were received. Customs data of a total of 26 companies was therefore analysed for the years 2009-2014 to fill the data gaps.

For the categories of “Self-contained, Single split (ducted), Rooftop ducted and Multi-splits (VRV/VRF)”, RAC experts in the validation workshop in Accra approved the data in March 2017.

Imports of “Single split (non-ducted)”, the major category, were still considered too low with 55,000 units for 2015. The final data was obtained by comparing the confidentially disclosed market shares of one major and one minor importer. The resulting number was about twice as high as the reported customs data. The final data set was therefore obtained by multiplying available customs data by 2 for the entire data set. It cannot be said why the disparity is so high. Undeclared import was only estimated to be in the range of 6-7%.

A 2008 survey in preparation of the HPMP estimates stock of residential and commercial split units to be as high as 1.8 million. This high number of stock could not be verified by reported import numbers and was declared unrealistic.

Very little feedback was given on imports for AC Chillers. These units are only sometimes brought into the country by importers as most chillers are installed in hotels, malls or other big international companies, who import directly. There is also no customs database for chillers. The stock was therefore estimated by RAC experts in the validation workshop based on their extensive knowledge of the installed units in the country as well as from one importer (personal information, no questionnaire submitted). The 2008 survey assessed the number of chillers to be 613 in that year, which appears to be overestimated.

#### 3.2.2.2 Technical parameters

Both importers and end-users reported average cooling capacity, initial refrigerant charge size, refrigerant distribution and average energy efficiency ratios. The information was not significantly different with the exception of refrigerant distribution where the HCFC phase-out has led to lower charges of R22 in some sub-sectors. Very little information from questionnaires was not confirmed in the workshop. Energy efficiency was highest for single split units (EER of 3.04) where MEPS have been implemented and multi-splits (EER of 3.64) where units are generally using the newest technology including the inverter technology.

TABLE 8: AVERAGE TECHNICAL PARAMETERS AND UNIT COSTS FOR STATIONARY AC EQUIPMENT, DEDUCTED FROM QUESTIONNAIRES

	INITIAL CHARGE [KG]	COOLING CAPACITY [KW]	ENERGY EFFICIENCY RATIO [W/W]	UNIT COST [USD]	REFRIGERANT DISTRIBUTION IMPORTERS	REFRIGERANT DISTRIBUTION END-USERS
SELF-CONTAINED	0.80* (2.25)	6.47	2.72	360	95 % R22 5 % R410A	77 % R22 9 % R410A 14 % R134a
SINGLE SPLIT (NON-DUCTED)	1.68	5.3	3.04	500	53 % R22 12 % R407C 35 % R410A	79 % R22 1 % R407C 20 % R410A 0.3 % R290
SINGLE SPLIT (DUCTED)	3.14	19.92	2.77	726	68 % R22 1 % R407C 31 % R410A	89 % R22 1 % R134a 10 % R410A
ROOFTOP DUCTED	10.23	14.73	2.71	17,333	8 % R22 25 % R407C 66 % R410A	86 % R22 3 % R407C 11 % R410A
MULTI-SPLITS (VRV/VRF)	21.95	62.87	3.64	17,777	6 % R22 92 % R410A	3 % R22 90 % R410A 7 % R407C
AC CHILLER	84		2.44	134,222		23 % R410A 77 % R134a
*default values from the GCI data base						

### 3.2.2.3 Sales and Stock

An extrapolated summary of sold units is given in Table 9. Single splits are by far the most common units with nearly 115,000 units being sold in 2016. The decrease

in 2013 due to the economic situation is felt most in this sector. From 2015, there was a profound increase in multi-split systems.

TABLE 9: ESTIMATED SALES NUMBERS FOR AIR CONDITIONING PRODUCT GROUPS, DEDUCTED FROM CUSTOM DATA, QUESTIONNAIRES AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
SELF-CONTAINED	537	560	585	840	492	514	536
SINGLE SPLIT (NON-DUCTED)	137,492	136,808	161,070	76,284	106,864	110,000	114,858
SINGLE SPLIT (DUCTED)	2,531	2,643	2,760	2,840	2,980	3,200	3,341
ROOFTOP DUCTED	21	42	91	46	127	134	140
MULTI-SPLITS (VRV/VRF)	19	13	402	92	265	1,942	2,028
AC CHILLER	10	10	10	32	28	70	73



The resulting estimated stock of the equipment is shown in Table 10. The number of single splits is estimated to be nearly 1.5 million in 2016.

TABLE 10: ESTIMATED STOCK NUMBERS FOR AIR CONDITIONING PRODUCT GROUPS, DEDUCTED FROM CUSTOM DATA, QUESTIONNAIRES AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
SELF-CONTAINED	4,693	4,916	5,149	5,391	5,871	5,972	6,087
SINGLE SPLIT (NON-DUCTED)	1,328,531	1,377,454	1,422,432	1,488,673	1,465,712	1,474,862	1,486,538
SINGLE SPLIT (DUCTED)	22,139	23,195	24,292	25,432	26,577	27,785	29,133
ROOFTOP DUCTED	194	202	231	306	332	437	542
MULTI-SPLITS (VRV/VRF)	108	116	118	508	549	759	2,625
AC CHILLER	99	104	109	113	140	161	223

### 3.2.2.4 Projection until 2050

Expected growth factors for the next five years were obtained from the corresponding data provided in the filled-out questionnaires from importers (Table 11). Data until 2050 was extrapolated. Growth factors were

confirmed in the validation workshop. Growth factors are estimated to be about 4.4 to 4.6% until 2030 and about 2.2 to 2.3% from 2030 to 2050 based on the assumption that the market will reach saturation at one point.

TABLE 11: ANNUAL GROWTH FACTORS [IN %] DEDUCED FROM QUESTIONNAIRES (2015-2020) AND EXTRAPOLATION

PRODUCT GROUP	2016-2020	2021-2030	2031-2050
SELF-CONTAINED	4.42	4.42	2.21
SINGLE SPLIT (NON-DUCTED)	4.42	4.42	2.21
SINGLE SPLIT (DUCTED)	4.42	4.42	2.21
ROOFTOP DUCTED	4.42	4.42	2.21
MULTI-SPLITS (VRV/VRF)	4.42	4.42	2.21
AC CHILLER	4.58	4.58	2.29

Applying these growth factors leads to the stock projection until year 2050 as shown in Figure 10. Single splits are expected to increase from about 1.5 million today to 2 million in 2030 and 3.5 million in 2050. Whilst the number of units for multi-splits and AC chiller stays

relatively low, with just over 20,000 in 2030 and nearly 50,000 in 2050 for multi-splits and about 1,000 units in 2030 and 2,700 units in 2050 for AC chiller, their installed capacity (Figure 10 lower panel) will gain importance due to higher cooling capacity per unit.

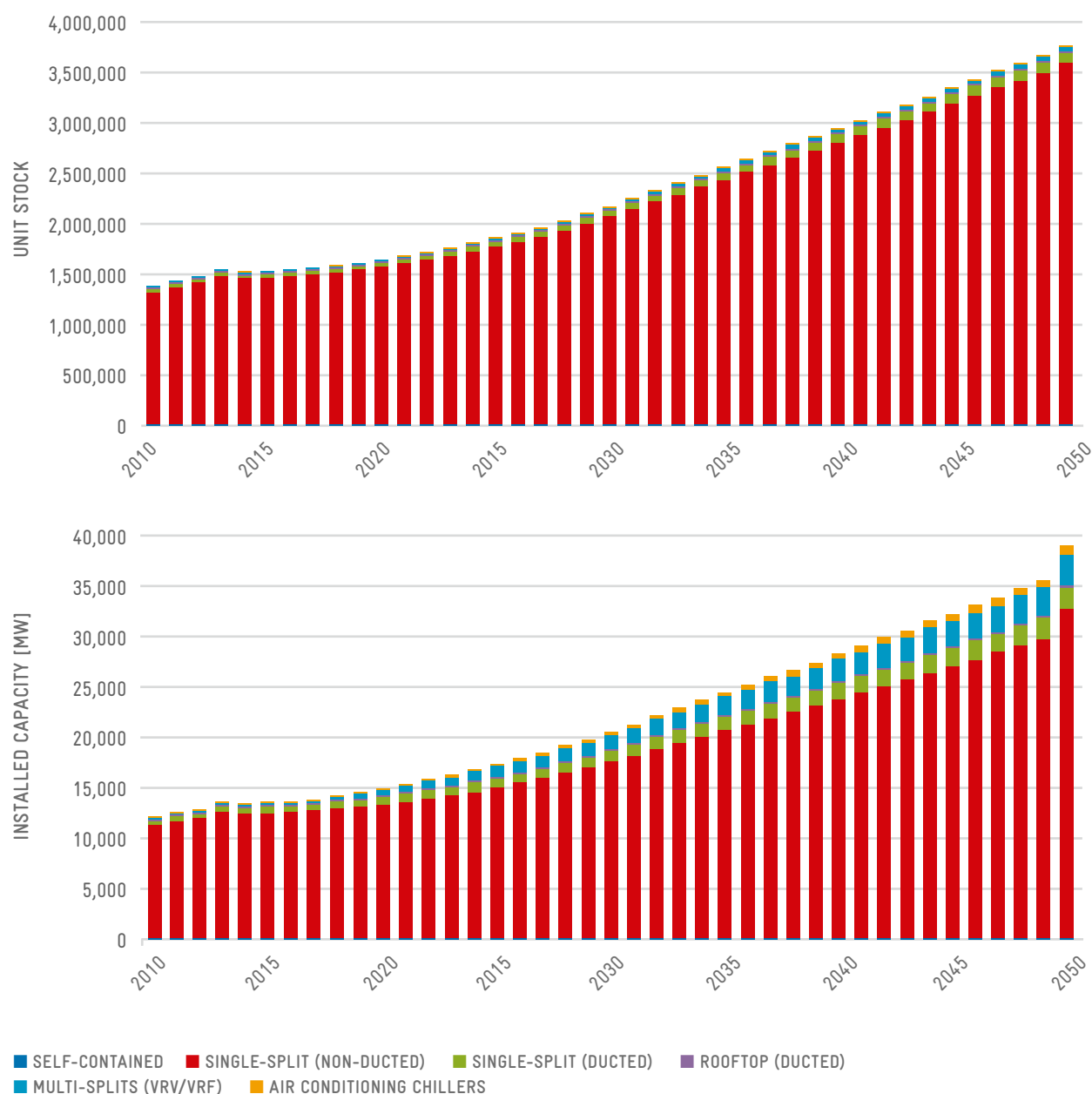


FIGURE 10: PROJECTION OF AC EQUIPMENT STOCK UNTIL 2050 BASED ON UNITS (UPPER PANEL) AND INSTALLED CAPACITY (LOWER PANEL)

### 3.2.2.5 Characterisation

Comfort air conditioning of offices and other indoor work places as well as residential homes has become a standard feature of modern lifestyle in the country. With increasing estate development, stationary air conditioning has become a fast growing subsector. The sector is dominated by unitary air conditioners of which the single split has the largest market share. This is presumably because of their ease of installation and relatively low cost. The multi-split system, variable refrigerant volume, VRV (aka variable refrigerant flow, VRF) has become popular for complex office application, especially due to its higher energy efficiency.

R22 and R410A dominate the unitary AC market. R22 split AC units continue to be patronized on the market due to its lower price both in cost of the unit and cost of the refrigerant compared to R410A. Energy efficiencies of these units are generally low and close to Ghanaian MEPS of 2.8. R410A is common in new units with higher energy efficiency, which have inverter technology in about 30–50% of cases and is dominating the Multi-split sector.



Natural refrigerants currently only play a minor role (reported by 0.3 % of end-users). Some installed units are converted to the hydrocarbon refrigerant R290. However, originally manufactured R290 based units are not available on the market yet.

The use of chiller AC system is limited to a few high-rise buildings and hotels due to its relatively high initial cost as well as its perceived complexity among local AC technicians, which poses maintenance challenges. Many chiller AC installations are known to have broken down after the first couple of years in operation and eventually become replaced with split units.

### 3.2.3 Mobile air conditioning

#### 3.2.3.1 Data collection and validation

Questionnaires collected from a small number of importers of cars gave important information about the technical parameters of mobile AC units in Ghana. The number of cars in Ghana was derived from the yearly number of vehicles registered in Ghana from 2000–2014 (565,295) and reports of the total number of vehicles on Ghanaian roads<sup>56</sup> (1.2 million). The higher number was found to be more realistic in the validation workshop and was therefore used. However, it was considered that only 60 % of vehicles on the road have functioning AC units. If ACs are installed in cars, but never used (e.g. taxis), this is not counted, because the refrigerant would never be recharged, therefore not leading to an increase in emissions.

#### 3.2.3.2 Technical parameters

Technical data was obtained from questionnaires. If no information was given, default values were used (Table 12). Data in Ghana generally follows the global trend.

TABLE 12: AVERAGE TECHNICAL PARAMETERS AND REFRIGERANT DISTRIBUTION FOR MOBILE AC (AS INDICATED: QUESTIONNAIRE OR DEFAULT VALUES, SOURCE: GCI)

	INITIAL CHARGE [KG]	COOLING CAPACITY [KW]	ENERGY EFFICIENCY RATIO [W/W]	UNIT COST [USD]	REFRIGERANT DISTRIBUTION
PASSENGER CARS	0.58	3.52	2.5*	N/A	100 % R134a
LARGE VEHICLES	4*	10*	2.5*	N/A	100 % R134a
*default values from the GCI data base					
*no data was obtained and default values seemed too high. Therefore, 50 % of the default value was applied.					

5 <https://www.modernghana.com/news/153214/one-million-motor-vehicles-on-ghanas-roads.htm>.

6 <https://www.newsghana.com.gh/the-number-of-cars-in-ghana-increases-by-23/>.

### 3.2.3.3 Sales and Stock

An extrapolated summary of sold units is given in Table 13. The number of newly registered large vehicles is thereby about 20 % of passenger cars.

TABLE 13: ESTIMATED SALES NUMBERS FOR MOBILE ACS, DEDUCTED FROM VEHICLE REGISTRATION NUMBERS AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
PASSENGER CARS	57,207	59,953	62,831	65,847	69,139	72,164	75,321
LARGE VEHICLES	9,506	9,922	10,356	10,809	11,282	11,776	12,291

The resulting estimated MAC equipment stock values are shown in Table 14.

TABLE 14: ESTIMATED STOCK NUMBERS FOR MOBILE ACS, DEDUCTED FROM VEHICLE REGISTRATION NUMBERS AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
PASSENGER CARS	575,422	594,268	614,603	636,460	659,876	685,023	711,519
LARGE VEHICLES	71,925	76,636	81,449	86,375	91,426	96,612	101,947

### 3.2.3.4 Projection until 2050

Even though the vehicle population is reported by the DVLA (Driver, Vehicle and Licensing Authority, Ghana) to grow at the rate of 23 % since 2013, lower numbers obtained from returned questionnaires were used for the

projection. Expected growth factors for the coming five years were obtained from the corresponding data provided in the filled-out questionnaires (Table 15). Later data was extrapolated. Growth factors were confirmed in the validation workshop.

TABLE 15: ANNUAL GROWTH FACTORS MAC DEDUCTED FROM QUESTIONNAIRES (2015-2020) AND EXTRAPOLATION

PRODUCT GROUP	2016-2020	2021-2030	2031-2050
PASSENGER CARS	5.00 %	4.38 %	2.19 %
LARGE VEHICLES	4.38 %	4.38 %	2.19 %

Applying these growth factors leads to the stock projection until year 2050 as shown in Figure 11. MAC units are expected to reach 1.2 million in 2030 and 2.3 million in 2050. The number could be even higher if the proportion of vehicles using their AC is increasing. This was not considered here.

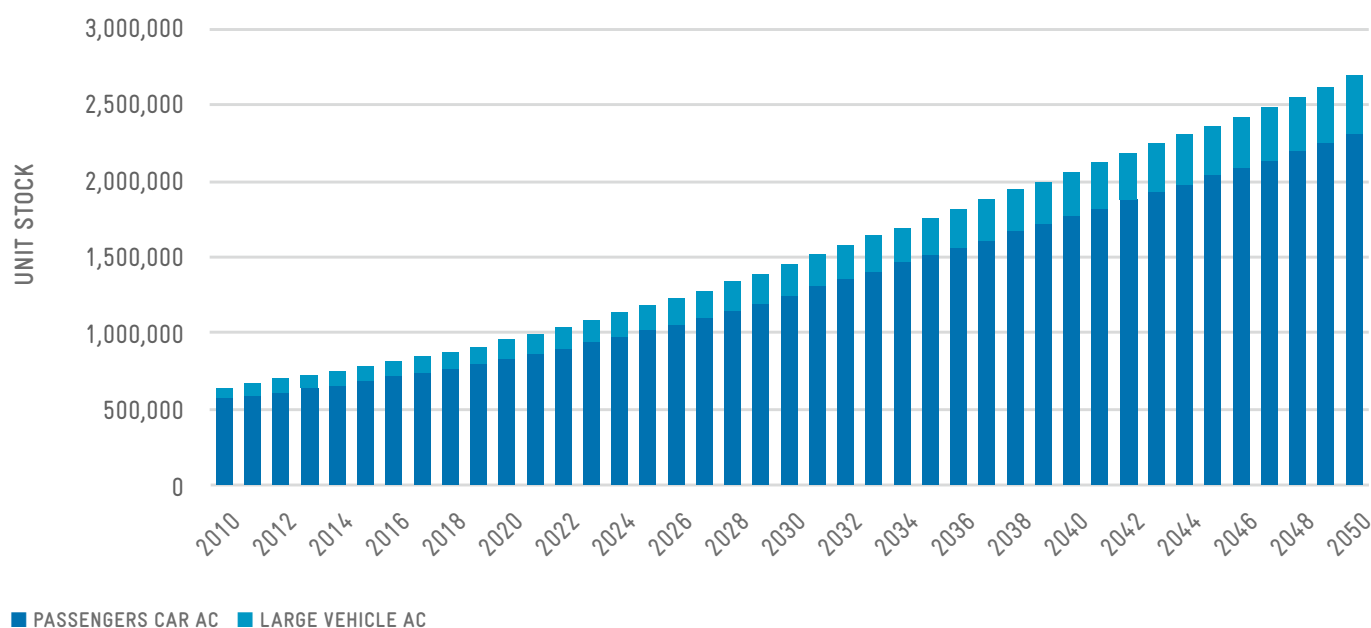


FIGURE 11: PROJECTION OF MAC UNITS UNTIL 2050

### 3.2.3.5 Characterisation

The MAC sector is rapidly expanding, driven by improving standard of living and rapidly increasing vehicle population. The dominant refrigerant in the sector is R134a. A few new cars, lately imported into the country are fitted with MACs charged with HFO1234yf but this is negligibly small. Servicing of MAC units is carried out by private workshops operated by refrigeration service technicians.

## 3.2.4 Domestic refrigeration

### 3.2.4.1 Data collection and validation

Only one questionnaire was returned from importers. Customs delivered import data for 15 companies. The reported import for 2009 to 2014 (343,266 – 426,069) resulted in an estimated stock of 4.2 million in 2015, which was considered too low by the present experts in the validation workshop. Different sources (e.g. Amoyaw-Osei et al. (2011), UNSD (2004)) resulted in a possible range of 3.8–7.5 million units installed in the country. The following calculation was conducted using statistical data (GLSS6 (2014)) for validation: Out of 6.6 million households, 60.94% live in an urban and 39.6% in a rural environment. The electrification rate is at 86.6% in urban areas and 48.3% in rural areas. The assumption is that all households with electricity have one refrigerator and a further 50% have a second one. For rural areas, the assumption is that every household that has access to electricity also owns a refrigerator. This results in the stock of refrigerators to be just over

6 million units. Customs data was therefore multiplied with a factor of 1.35. Similar to the split AC sector, it is not clear where the disparity between customs data and expert opinion/statistical data comes from as the laws regarding illegal imports are very strict in Ghana and generally well enforced.

### 3.2.4.2 Technical parameters

Technical data was obtained from questionnaires as much as possible. If no information was given, default values were used (Table 16).



TABLE 16: AVERAGE TECHNICAL PARAMETERS AND REFRIGERANT DISTRIBUTION FOR DOMESTIC REFRIGERATORS (AS INDICATED: QUESTIONNAIRE OR DEFAULT VALUES, SOURCE: GCI)

	INITIAL CHARGE [KG]	COOLING CAPACITY [KW]	ENERGY EFFICIENCY RATIO [W/W]	UNIT COST [USD]	REFRIGERANT DISTRIBUTION IMPORTER	REFRIGERANT DISTRIBUTION END-USER
DOMESTIC REFRIGERATORS	0.08	0.2*	1.85	431	40 % R134a 60 % R600a	63 % R134a 37 % R600a
*default values from the GCI data base						

### 3.2.4.3 Sales and Stock

An extrapolated summary of sold units is given in Table 17.

TABLE 17: ESTIMATED SALES NUMBERS FOR DOMESTIC REFRIGERATORS, DEDUCTED FROM CUSTOMS DATA

	2010	2011	2012	2013	2014	2015
DOMESTIC REFRIGERATORS	483,877	505,249	527,564	550,865	575,194	600,599

The resulting estimated equipment stock values are shown in Table 18 with values ranging from 4.8 million in 2010 to 6.2 million in 2015.

TABLE 18: ESTIMATED STOCK NUMBERS FOR DOMESTIC REFRIGERATORS, DEDUCTED FROM CUSTOMS DATA

	2010	2011	2012	2013	2014	2015
DOMESTIC REFRIGERATORS	4,865,309	5,105,921	5,355,874	5,615,644	5,885,726	6,166,634

### 3.2.4.4 Projection until 2050

Expected growth factors for the coming five years were obtained from the corresponding data provided in the filled-out questionnaires (Table 19). Data for later years

was extrapolated. Growth factors were confirmed in the validation workshop. Growth factors are slightly lower compared to other subsectors as the market has reached saturation in urban areas.

TABLE 19: GROWTH FACTORS DEDUCTED FROM QUESTIONNAIRES (2015-2020) AND EXTRAPOLATION

PRODUCT GROUP	2016-2020	2021-2030	2031-2050
DOMESTIC REFRIGERATORS	3.8 %	3.8 %	1.9 %

Applying these growth factors leads to the stock projection until year 2050 as shown in Figure 12. The number of refrigerators in the country is expected

to reach 12 million in 2030 and double again to reach just over 23 million in 2050.



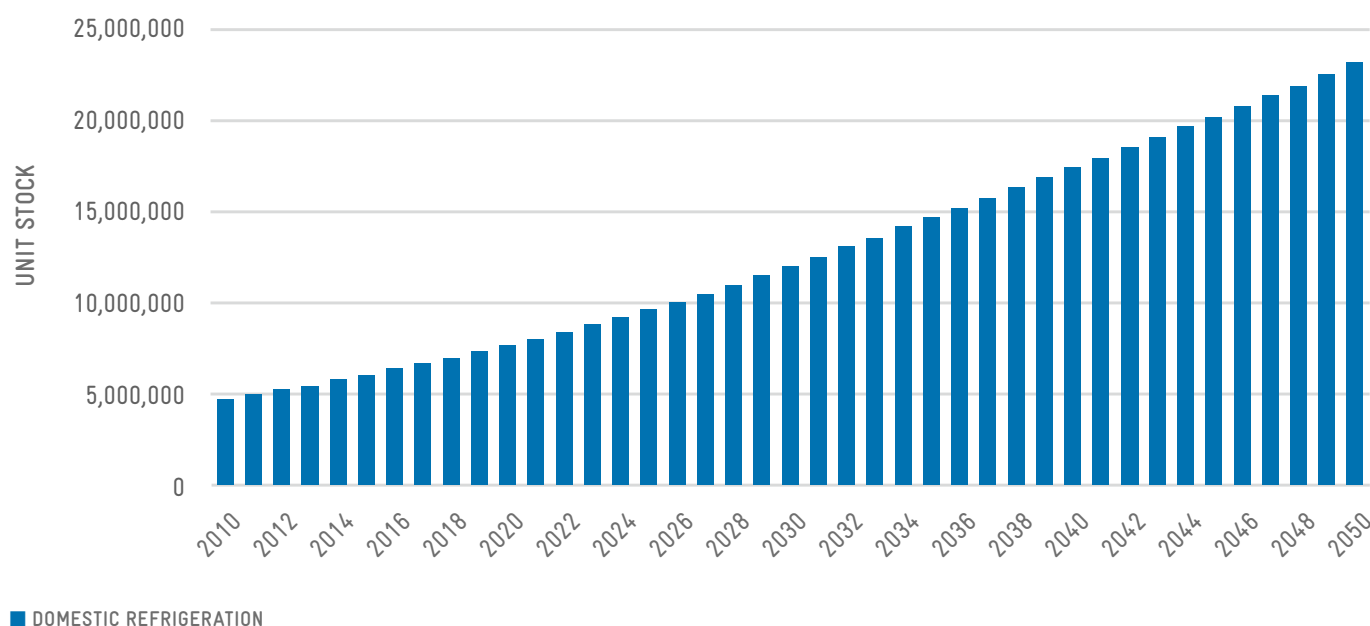


FIGURE 12: PROJECTION OF DOMESTIC REFRIGERATION STOCK UNTIL 2050

### 3.2.4.5 Characterisation

Following the sustained rural electrification programme, which has brought power to a large proportion of rural communities and resulted in increasing urbanization and improved standard of living, the dissemination of domestic refrigerators and freezers in the country is very high. This led to a fast growth of the domestic refrigeration sector. The irregular trend around the year 2014 because of power outages and depreciating Ghana Cedi is clearly visible. The domestic refrigeration subsector was additionally affected by the ban on second-hand refrigerator imports that took effect on January 1, 2013. The sector is still expected to grow as electrification in rural areas will continue and population growth is currently 2.2%. The expected decrease of household size will further increase the overall number of households and therefore total number of refrigerators will also increase in the country.

R134a is the dominating refrigerant in this sector followed by increasing use of R600a. The market share of new units is 60%. Ghana has chosen to replace the synthetic refrigerants with climate-friendly hydrocarbons and has carried out training for refrigerator technicians on conversion of refrigerators to R600a while addressing the hazards of hydrocarbon use due to its flammability

character. In addition, the NOU has initiated the preparation of user safety guidelines as part of this campaign to encourage the shift to hydrocarbon use in the RAC sector. R406A is also a popular replacement for R134a among the refrigerator repairers because it cost about 25% less than R134a on the local market. However, it was not reported in the questionnaires of end-users and therefore does not appear in the inventory.

The government is actively trying to improve the energy efficiency of units with the introduction of minimum energy efficiency standards and labelling as well as with communication campaigns and a take back scheme.

## 3.2.5 Commercial and industrial refrigeration

### 3.2.5.1 Data collection and validation

No information about imported units was obtained from the commercial and industrial refrigeration sectors, but 41 questionnaires were received from end-users.

Stand-alone imports were taken from the Comtrade data base for the years 2000 to 2013 (UNSD (2004)) and numbers were confirmed by experts in the validation workshop.

The number of condensing units installed in hotels, supermarkets, mini-shops (e.g. petrol stations) and restaurants from end-users was given to be around 200. Experts in the validation workshop estimated this number to be closer to 400 as not every establishment was covered by the end-user survey. Additionally, 200 condensing units in morgues were recorded in the country. These numbers were confirmed by the validation workshop.

Centralised systems were counted mainly in cold stores and the number was estimated to be 14 in the whole country by the validation workshop.

Process chiller stock was similar to AC chillers estimated by RAC experts in the validation workshop based on their extensive knowledge of the installed units in the country as well as by one importer/servicing company (personal information, no questionnaire submitted).

### 3.2.5.2 Technical parameters

Technical data was obtained from end-user questionnaires as much as possible. If no information was given, default values were used (Table 20). Higher efficiencies in the process chiller subsector compared to the AC chiller subsector can be explained since process chillers are generally water-cooled and therefore more efficient.

TABLE 20: AVERAGE TECHNICAL PARAMETERS AND REFRIGERANT DISTRIBUTION FOR COMMERCIAL AND INDUSTRIAL REFRIGERATION (AS INDICATED: QUESTIONNAIRE OR DEFAULT VALUES, SOURCE: GCI)

	INITIAL CHARGE [KG]	COOLING CAPACITY [KW]	ENERGY EFFICIENCY RATIO [W/W]	UNIT COST [USD]	REFRIGERANT DISTRIBUTION
STAND-ALONE EQUIPMENT	0.28	1.07	2.0*	N/A	82 % R134a 18 % R600a
CONDENSING UNITS	20.92	23	1.1	N/A	10 % R22 84 % R404A 6 % R502
CENTRALISED SYSTEMS	6,424	236	1.7	N/A	100 % R717
PROCESS CHILLER	159	650	4.0	N/A	9 % R22 9 % R407C 27 % R717 55 % R134a
*default values from the GCI data base					

### 3.2.5.3 Sales and Stock

An extrapolated summary of sold units is given in Table 21. Both commercial and industrial condensing units and centralized systems are considered. The number of industrial condensing units is approximately one third of the total sales and stock. There is only one known commercial and a low number of industrial centralized systems in Ghana.

TABLE 21: ESTIMATED SALES NUMBERS FOR COMMERCIAL AND INDUSTRIAL REFRIGERATION, DEDUCTED FROM CUSTOMS DATA, QUESTIONNAIRES AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
STAND-ALONE EQUIPMENT	2,686	2,710	3,881	2,148	3,292	3,437	3,589
CONDENSING UNITS	33	21	42	50	40	60	65
CENTRALISED SYSTEMS	1	1	1	1	1	1	1
PROCESS CHILLER	5	2	3	16	14	35	37

The resulting estimated equipment stock values are shown in Table 22.

TABLE 22: ESTIMATED STOCK NUMBERS FOR COMMERCIAL AND INDUSTRIAL REFRIGERATION, DEDUCTED FROM CUSTOMS DATA, QUESTIONNAIRES AND EXPERT OPINION

	2010	2011	2012	2013	2014	2015	2016
STAND-ALONE EQUIPMENT	20,491	21,810	23,066	25,410	25,864	27,431	28,895
CONDENSING UNITS	245	266	274	302	337	360	402
CENTRALISED SYSTEMS	12	12	13	13	13	14	14
PROCESS CHILLER	45	48	47	48	61	72	104

### 3.2.5.4 Projection until 2050

No information about subsector growth rates was obtained for these categories. As the growth factors for all other subsectors (with the exception of domestic refrigeration, which shows a different dynamic with already high penetration of units) were consistently around 4 %, the same values were assumed here.

TABLE 23: ASSUMED GROWTH FACTORS FOR THE COMMERCIAL AND INDUSTRIAL REFRIGERATION SUBSECTORS

PRODUCT GROUP	2016-2020	2021-2030	2031-2050
COMMERCIAL AND INDUSTRIAL REFRIGERATION	4.42 %	4.42 %	2.21 %

Applying these growth factors leads to the stock projection until year 2050 as shown in Figure 13 upper panel. This sector experiences a steady growth from 20,000 units in 2010 to more than 100,000 units in 2050. Majority of units are of the stand-alone type. Based on installed cooling capacity (Figure 13 lower panel), process chillers have by far the highest share

and condensing units are gaining importance compared to stand-alone units until 2050. In 2010, the installed capacity of condensing units was far less than half of the installed capacity of stand-alone units. In 2050 it is predicted to be nearly three quarters of the capacity of stand-alone units.

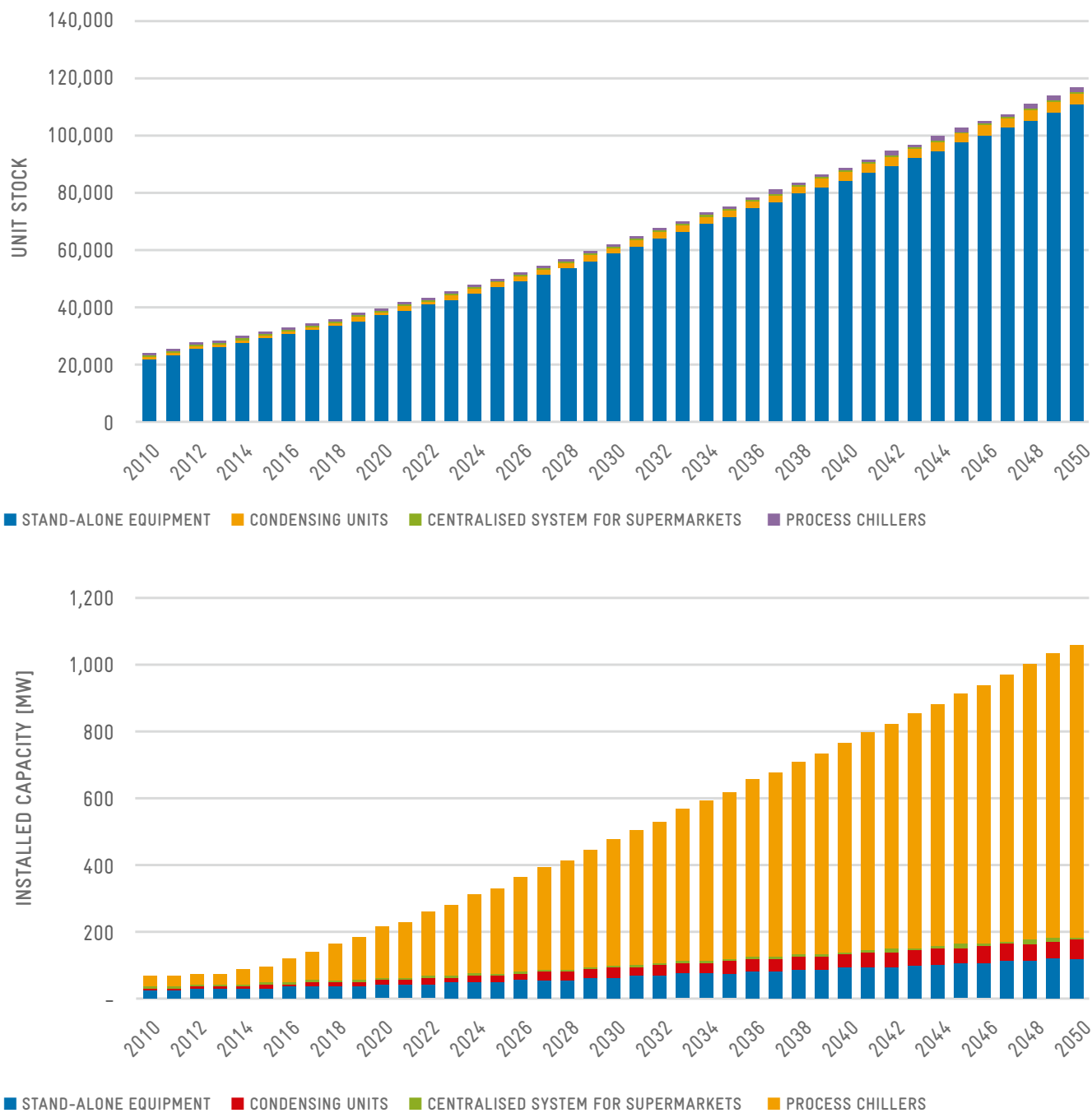


FIGURE 13: PROJECTION OF AC EQUIPMENT STOCK UNTIL 2050 BASED ON UNITS (UPPER PANEL) AND INSTALLED CAPACITY (LOWER PANEL)

### 3.2.5.5 Characterisation

The commercial refrigeration subsector is also fast growing in Ghana. Standalone plug-in drink dispensers in shops and display cabinets in super markets have become a common feature in the growing urban communities across the country. The dominating refrigerants are R134a, R600a and R404A. Use of condensing units in commercial refrigeration is predominant in the cold store activity. They are used in all sizes of cold stores, from small walk-in cold rooms in hotels, catering services, institutions etc. to large frozen depots. For example, some with storage capacity over 6,000 Mt for frozen fish storage in the Tema fishing harbour. R404A is the dominating refrigerant in this subsector. However, a large number of cold stores using R22 and R507A still exists in small to medium range all over the country.

In the 1970-1980s, large cold stores in the country were predominantly equipped with centralized ammonia plants. When the usage of condensing units started for large cold stores, it virtually knocked out the use of centralized ammonia plants because of the lower initial cost of the condensing unit systems. Centralized ammonia plant in large cold stores is slowly returning into the competition with about four such cold stores constructed in the last three years in the Tema fishing harbour enclave.

The industrial refrigeration sector is not always easy to be distinguished from the commercial refrigeration sector.

Industrial activities in Ghana declined since the 1980s, partly due to strong competition from cheaper imports from China. Poor power supply and the high tariff rate during the last three years exacerbated this situation. As a result, the total number of industrial refrigeration applications has considerably decreased. The big users of industrial refrigeration in the country are currently the breweries and processing factories (food processing, cocoa processing, etc.). The existing refrigeration plants are a mix of large capacity plants such as ammonia chillers and R134a centrifugal chillers on the one hand and low capacity chiller units operating with R407C and other HFC blend on the other hand. Condensing units are also used in the morgues of the country, which is considered part of the industrial refrigeration subsector.

## 3.2.6 Transport refrigeration

### 3.2.6.1 Data collection and validation

Even though only one importer returned a questionnaire, their market share of transport refrigeration was considered to be accurate by the experts present at the validation workshop and used for all calculations.

### 3.2.6.2 Technical parameters

Technical data was obtained from questionnaires as much as possible. If no information was given, default values were used (Table 24). Average data for initial charge and cooling capacity indicate that the units are of small capacity, probably for installations in vans.

TABLE 24: AVERAGE TECHNICAL PARAMETERS AND REFRIGERANT DISTRIBUTION FOR TRANSPORT REFRIGERATION UNITS (AS INDICATED: QUESTIONNAIRE OR DEFAULT VALUES, SOURCE: GCI)

	INITIAL CHARGE [KG]	COOLING CAPACITY [KW]	ENERGY EFFICIENCY RATIO [W/W]	UNIT COST [USD]	REFRIGERANT DISTRIBUTION IMPORTER	REFRIGERANT DISTRIBUTION END-USER
TRANSPORT REFRIGERATION	5.7	3.66	2.1*	-	60 % R134a 40 % R404A	16 % R134a 84 % R404A

\*default values from the GCI data base

### 3.2.6.3 Sales and Stock

An extrapolated summary of sold units is given in Table 25. Because of the small number of units sold, the high variation of 9 to 60 sold units per year is assumed to be a real effect.



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TABLE 25: ESTIMATED SALES NUMBERS FOR TRANSPORT REFRIGERATION UNITS FOR 2010-2015, DEDUCTED FROM QUESTIONNAIRES

	2010	2011	2012	2013	2014	2015
TRANSPORT REFRIGERATION	9	9	10	10	60	20

The resulting estimated equipment stock values are shown in Table 26. The numbers are slowly increasing towards a total amount of 150 units in 2015.

TABLE 26: ESTIMATED STOCK NUMBERS FOR TRANSPORT REFRIGERATION UNITS FOR 2010-2015, DEDUCTED FROM QUESTIONNAIRES

	2010	2011	2012	2013	2014	2015
TRANSPORT REFRIGERATION	82	86	89	93	97	150

#### 3.2.6.4 Projection until 2050

Expected growth factors for the next five years were obtained from the corresponding data provided in the filled-out questionnaire (Table 27). Later data was extrapolated. Growth factors were confirmed in the validation workshop. Considering the currently very

low population of refrigerated transport vehicles, future health regulations requiring refrigerated transport of perishable goods. This could cause the growth factor to be considerably higher.



TABLE 27: GROWTH FACTORS DEDUCTED FROM QUESTIONNAIRES (2015-2020) AND EXTRAPOLATION

PRODUCT GROUP	2016-2020	2021-2030	2031-2050
DOMESTIC REFRIGERATION	3.8 %	3.8 %	1.9 %

Applying these growth factors leads to the stock projection until year 2050 as shown in Figure 14. The current stock of around 170 refrigerated vehicles is expected to double by 2032 and reach nearly 600 in the year 2050.

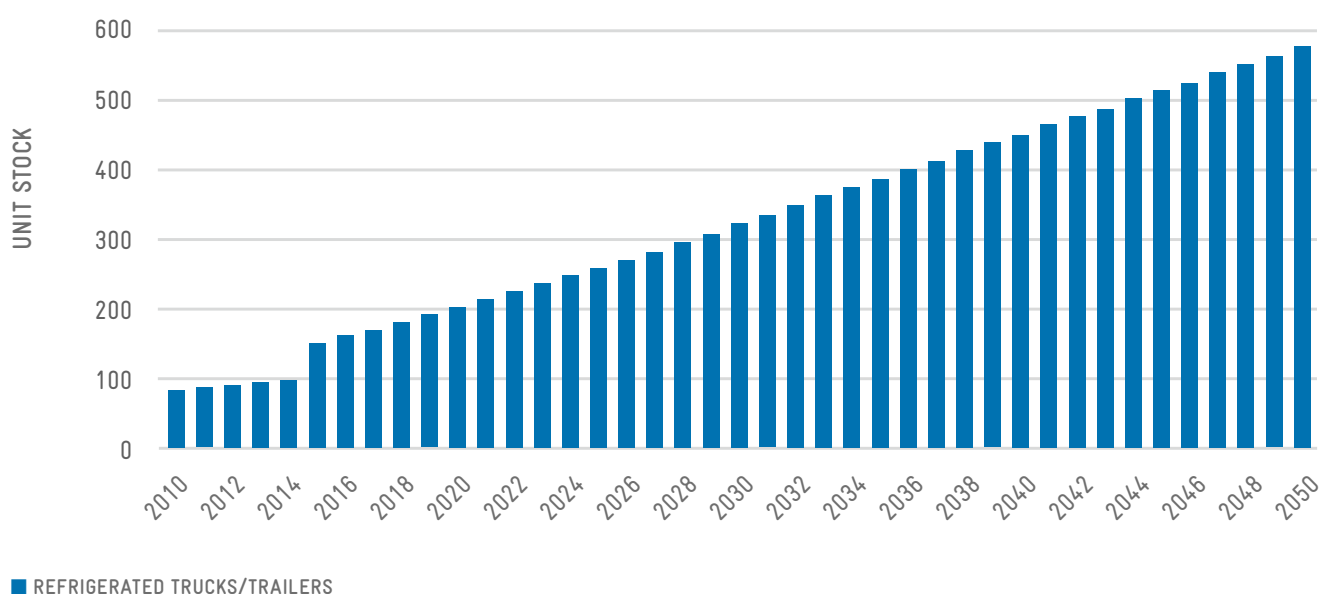


FIGURE 14: PROJECTION OF TRANSPORT REFRIGERATION UNIT STOCK UNTIL 2050

### 3.2.6.5 Characterisation

Growth in this sector has been stagnant in the country for several years now. In the 1970s, the state-owned State Fishing Corporation (SFC) operated a fleet of refrigerated trailers to distribute fish from its Tema harbour base to their cold store depots in all the regional capitals. With the collapse of the SFC in the early 1980s, the refrigerated trailer fleet also collapsed. Currently, Fan Milk Factory in Accra is the only company that operates a fleet of refrigerated trailers to distribute their products nationwide, followed by a second company, Blue Sky, that also operates a couple of refrigerated

trucks to transport fruit juice from their factory on the outskirts of the capital and to the airport for airfreight to overseas market. In the last couple of years, a local agent of Thermo King, a leading manufacturer of transport refrigeration equipment, has started installing imported Thermo King units in small vans. This has received attention from the catering services, pharmaceutical industry for drugs distribution and the aquaculture industry. The units operate predominantly with R134a and R404A, following the globally preferred refrigerant trend in this subsector.

# 4 RESULTS AND CURRENT AND PROJECTED GHG EMISSIONS FOR THE GHANAIAN RAC INDUSTRY

Using the data presented in the chapters above, energy use and resulting indirect emissions as well as direct emissions were estimated and projected until the year 2050.

## 4.1 ENERGY CONSUMPTION

Figure 15 shows the current and the projected energy consumption for the RAC-sectors in Ghana. The unitary air conditioning subsector is the one with the highest energy consumption, followed by domestic refrigeration. In third place is the mobile AC subsector. It must be

mentioned, that here fuel consumption has been used to calculate the equivalent consumption in TWh. This subsector does not put a strain on the electricity grid and could be neglected for certain analyses. The total energy consumption associated with Ghana's RAC sector rises from 7.04 TWh in 2015 to 20.9 TWh in 2050. Energy consumption was 5.92 TWh in 2010 and is expected to rise to 8.43 TWh in 2020 and 11.6 TWh in 2030. Not regarding the mobile AC subsector, the electricity demand from the RAC sector in 2015 is estimated to be 5.98 TWh.

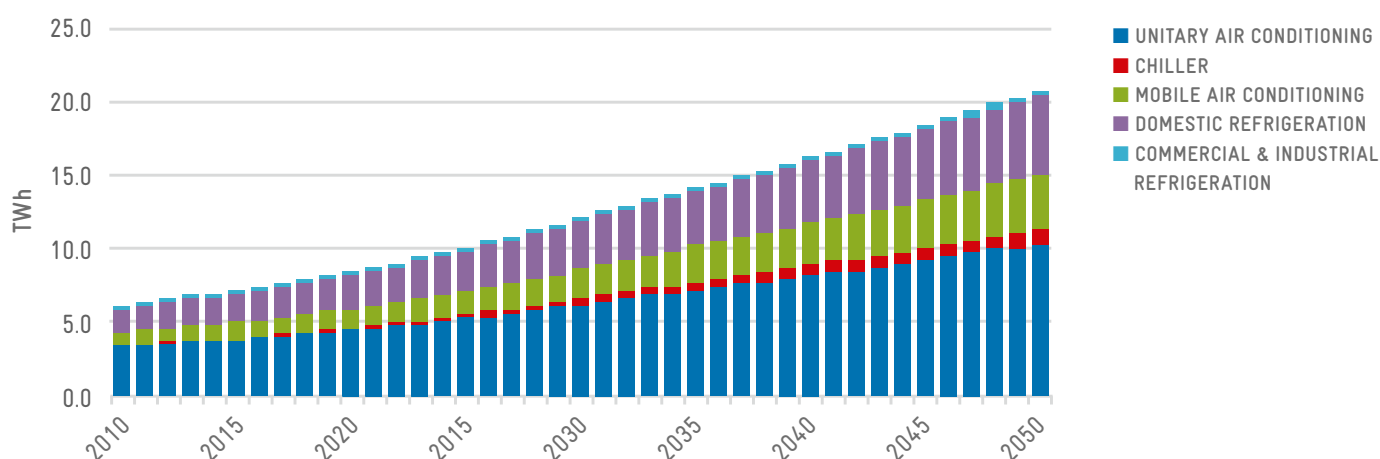


FIGURE 15: CURRENT AND PROJECTED ENERGY CONSUMPTION UNTIL 2050

The electricity consumption shown here for the RAC sector thereby contributed about 60 % of the total electricity consumption of Ghana in 2015 (estimated at 9.685 TWh in the Ghanaian National Energy Statistics (Energy Commission, 2017), see also chapter 1.5.3), which is considered to be very high. Reports from large Asian cities show electricity consumption from ACs to be as high as half of total consumption, but Ghana has

a large rural part where the RAC sector is expected to play a smaller part. All numbers used for the calculation were discussed and verified by industry experts and government representatives in the country. Therefore, the results are presented here as they were derived. The following theoretical explanations can be given for the disproportionately high energy consumption of the RAC sector:



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- » The annual runtime for the units could be overestimated and not take into consideration the frequent blackouts.
- » Many hotels, hospitals and private companies are using their own generators in case of varying electricity supply. This energy use would not appear in the overall statistic under electricity use. Because of the Tier 2 approach, this energy consumption is included in our calculations.
- » Sales and stock numbers as well as dimensions of the units could include overestimations.
- » The electricity consumption could be higher than reported as smaller plants or imports might not be considered. Generator use is also not counted as electricity consumption.

However, all possible steps have been taken to ascertain the accuracy of the data displayed in this report. This also has to be taken into consideration when looking at direct refrigerant emissions, which will be accordingly lower.

## 4.2 TOTAL GHG EMISSIONS

The same pattern is visible in Figure 16 and in Figure 17 in the total emissions until 2050, where the unitary AC subsector is responsible for most of the emissions, followed by the domestic refrigeration and the mobile AC sectors, with total emissions in 2015 of 5.05 Mt CO<sub>2</sub>eq rising to 12.8 Mt CO<sub>2</sub>eq in 2050.

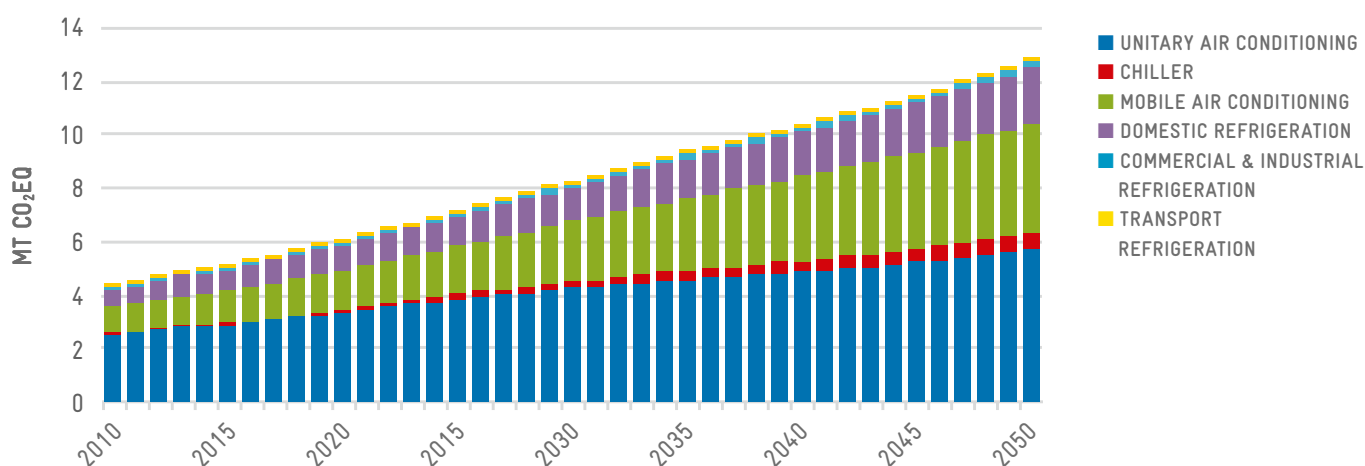


FIGURE 16: CURRENT AND PROJECTED TOTAL EMISSIONS UNTIL 2050

In the analysis on the appliance level (Figure 17), it can be seen that split ACs are by far the most dominant source of emissions, contributing more than half of the total RAC sector emissions in 2015. Whilst emissions from the MAC sector are increasing considerably until

2050, the emissions for the domestic refrigeration subsector show a lower growth. Multi-splits contribute very little to RAC sector emissions today, but this will increase to a significant part by 2050.

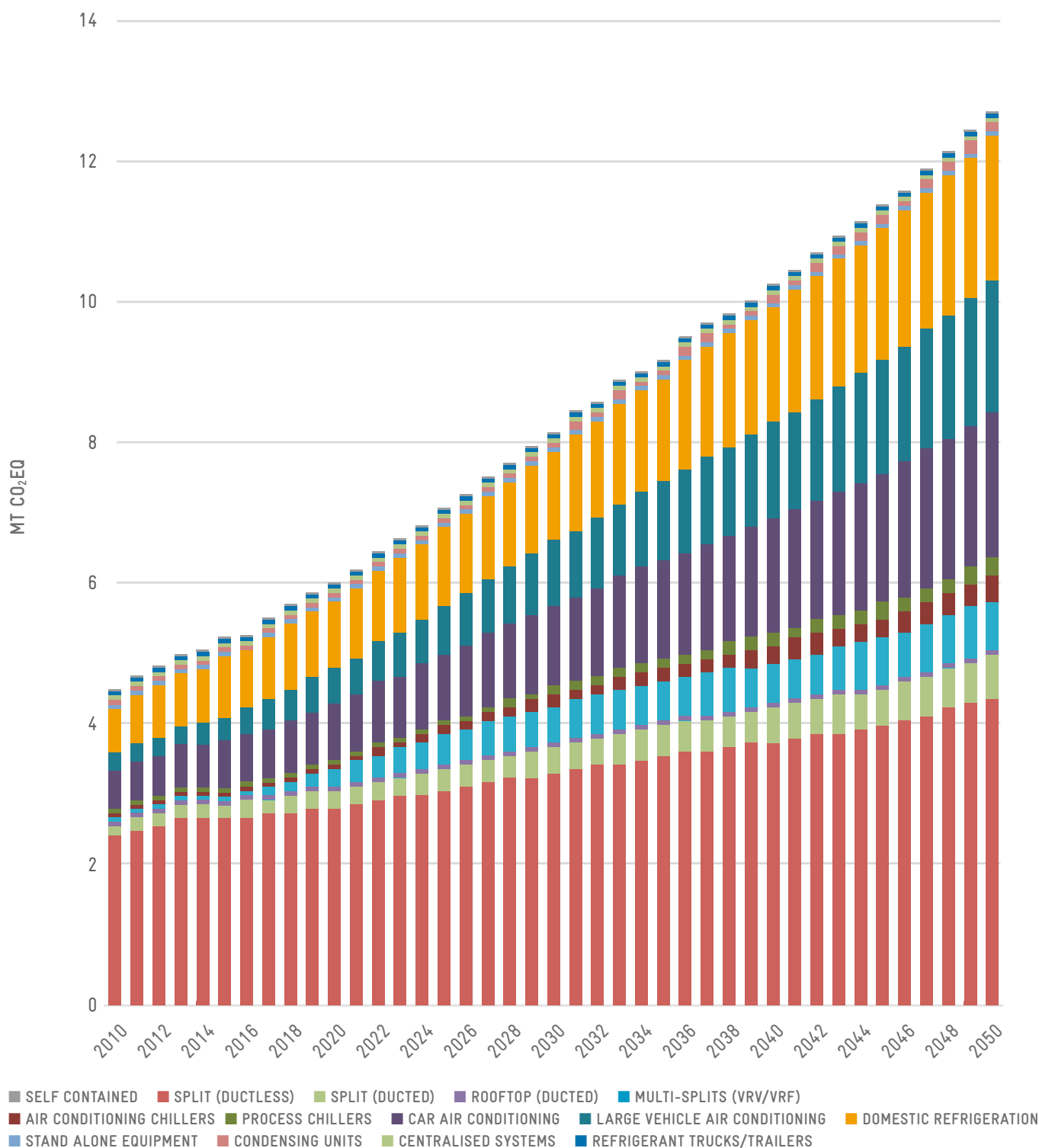


FIGURE 17: CURRENT AND PROJECTED TOTAL EMISSIONS UNTIL 2050, BY EQUIPMENT TYPE



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For more detail, Table 28 gives the relative contribution per subsector and product group to total emissions in 2015.

TABLE 28: EMISSIONS ATTRIBUTED TO SUBSECTORS AND PRODUCT GROUPS FOR 2015 (SOURCE: HEAT ANALYSIS)

SUBSECTOR	PRODUCT GROUP	RELATIVE EMISSION CONTRIBUTION PER PRODUCT GROUP	RELATIVE EMISSION CONTRIBUTION PER SUBSECTOR
UNITARY AIR CONDITIONING	Self-contained	0.1 %	57.6 %
	Split (ductless)	52.8 %	
	Split (ducted)	3.9 %	
	Rooftop ducted	0.1 %	
	Multi-splits, VRF/VRV	0.6 %	
CHILLER	Air conditioning chillers	0.4 %	0.7 %
	Process chillers	0.3 %	
MOBILE AIR CONDITIONING	Car air conditioning	13.1 %	23.7 %
	Large vehicle air conditioning	10.6 %	
DOMESTIC REFRIGERATION	Domestic refrigeration	16.2 %	16.2 %
COMMERCIAL & INDUSTRIAL REFRIGERATION	Stand-alone equipment	0.4 %	1.9 %
	Condensing units	0.5 %	
	Centralised systems	1.0 %	
TRANSPORT REFRIGERATION	Refrigerated trucks/trailers	0.02 %	0.02 %



Figure 18 shows the breakdown of emissions according to subsectors for the year 2015 for total, direct and indirect emissions. The high contribution of the UAC subsector becomes apparent, especially for direct emissions. The domestic refrigeration subsector contributes

considerably more to indirect than to direct emissions. Direct and indirect contributions are about equal for commercial and industrial refrigeration. Chiller and transport refrigeration contribute very little to overall emissions.

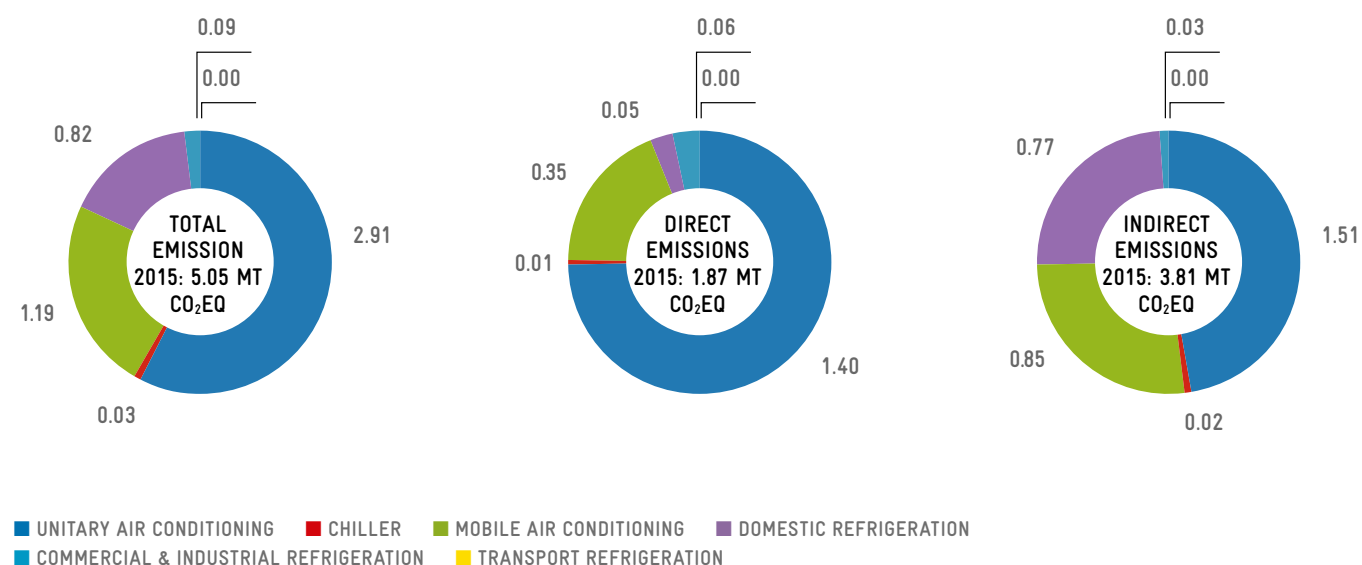


FIGURE 18: GHG EMISSIONS IN MT CO<sub>2</sub>EQ BREAKDOWN ACCORDING TO SUBSECTORS FOR THE GHANAIAN RAC INDUSTRY IN 2015

Figure 19 shows the split between indirect emissions (blue) and direct emissions (red). The share of direct emissions compared to total emissions goes down from 37% in 2015 to 33% in 2030 decreases further to 24% until 2050. This is due to the increase of lower GWP refrigerants, even in the BAU scenario. As already

mentioned in chapter 1.4.2, the grid emission factor has increased in recent years due to higher fossil fuel use in the electricity generation. Further increase, which could lead to a higher contribution of indirect emissions, is possible, but not predictable until 2050.





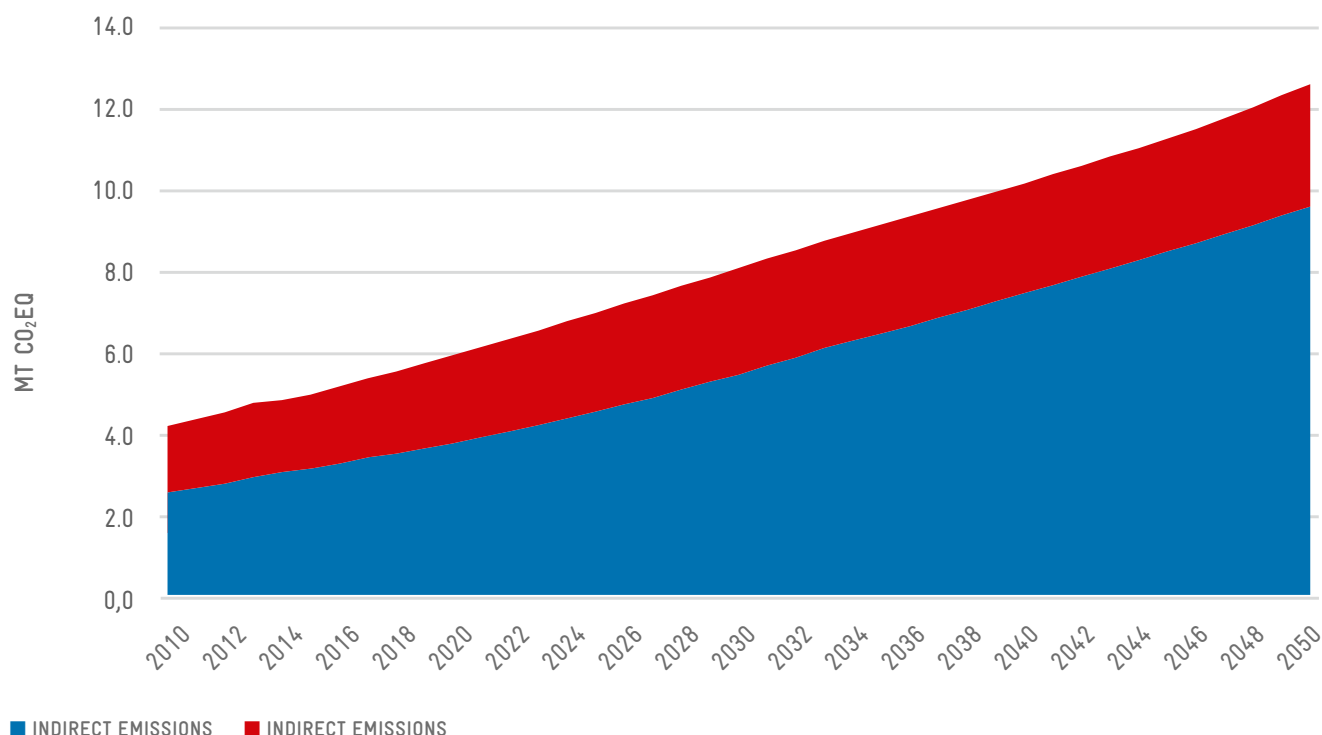


FIGURE 19: RAC SECTOR EMISSION PROJECTION UNTIL 2050 FOR INDIRECT (BLUE) AND DIRECT (RED) EMISSIONS

HCFCs still contribute about 20% to direct emissions in Ghana (Figure 20), with UAC having by far the highest share. HFCs are mainly used in mobile AC systems, followed by UAC and domestic refrigeration. Many sectors do not use HCFCs anymore.

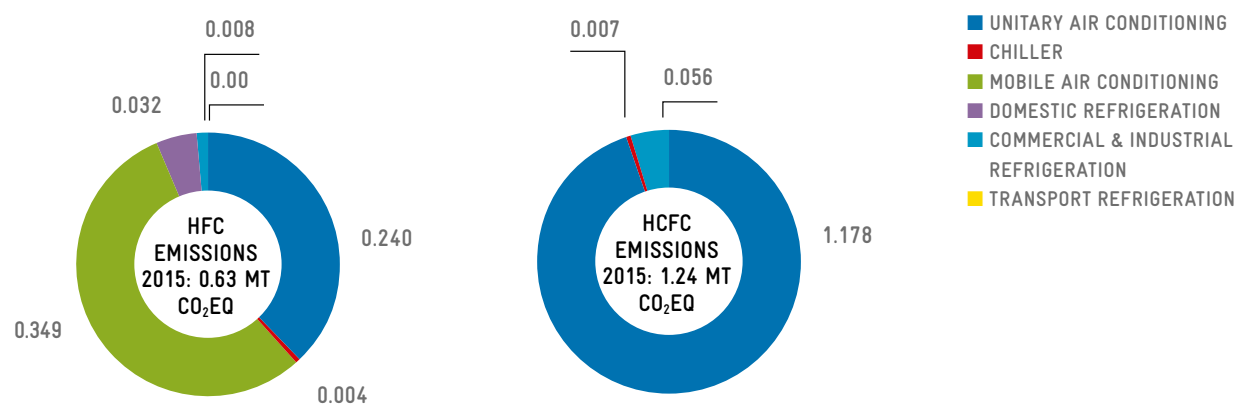


FIGURE 20: CONTRIBUTION OF HFC AND HCFC TO DIRECT EMISSIONS IN GHANA IN 2015 IN MT CO<sub>2</sub>EQ

# 5 TECHNOLOGY GAP ANALYSIS

This chapter compares the technological gap between currently installed units in Ghana and internationally available best technology that is readily available on the market. The chapter ends with a comparison of the emissions forecasted in the Ghanaian BAU scenario and the possible emissions reductions forecasted in a hypothetical mitigation scenario (MIT) where internationally available best technology are introduced. The aim of this exercise is to make recommendations regarding the suitability and applicability of such technologies for Ghana. The technical roadmap analyses the transformation roadmap towards a more climate friendly RAC sector in Ghana.

Existing technologies are compared with internationally available green cooling technologies with high energy efficiency and low-GWP refrigerants suitable to mitigate emissions. Air conditioning and refrigeration equipment with low-GWP refrigerants and design aspects that lower the energy consumption, such as for example inverter technologies, will serve as a reference for this comparison. An in-depth analysis will be provided for each focus subsector. Further, a barrier analysis report will be presented, which will identify key issues to be addressed to allow for a wider dissemination of climate friendly green cooling solutions.

Both direct and indirect emissions will be analysed, looking at the aspects of refrigerants and energy efficiency.

## 5.1 ENERGY EFFICIENCY

Development towards more efficient appliances is driven by legislation such as minimum energy performance standards (MEPS). MEPS have been adopted by many countries to reduce the country-wide electricity consumption. For larger equipment, such as chiller or centralized systems, the demand for energy efficient system also stems from the requirement of companies to reduce high operating costs.

Improvements in energy efficiency in the RAC sector are for example, achieved by the following design aspects:

- » 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 fans
- » Sensor-linked controllers with smart adjustment functions
- » Efficient propeller fan with low noise
- » Electric expansion valve
- » Using refrigerants with good thermodynamic properties

Higher efficiency can also be reached by improving demand side management:

- » Energy management and optimization controls
- » High performance insulation (ex. prefabricated insulation panels for cold store) to lower the required cooling loads

After experiencing perennial power deficit in the last three decades, energy conservation in Ghana is seriously encouraged. In the RAC sector, this was demonstrated by the introduction of energy labelling and MEPS of appliances to enable consumers to make informed choices of the appliance to buy. In addition, the ban on used fridges in 2013 was aimed primarily at checking the influx of old inefficient domestic fridges/freezers, which also carried the risk of containing banned CFC gas. However, the potential to increase energy efficiency in Ghana is still very high.



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## 5.2 REFRIGERANTS

Over the last decades, the Montreal Protocol has driven the global RAC industry towards refrigerants with no ozone depleting potential (ODP). Once ratified, the recent Kigali Amendment will be the start of the significant phase-down of HFCs and thereby increase the volume of refrigerants with low GWPs on the market. In most developed countries, such as member countries of the EU, Australia, New Zealand, Japan and the USA, a phase-down of high-GWP HFCs has already started because of national or regional legislation, with increased technical developments.

The most climate and environmentally friendly refrigerants are natural refrigerants such as hydrocarbons (R290, R600a, R1270), CO<sub>2</sub> (R744) and ammonia (R717). Based on production cost and the fact that there are no intellectual property rights, these refrigerants can also be very cheap. Availability is sometimes the factor that drives prices high. Low-GWP natural refrigerant solutions are available for almost every subsector. Because of their characteristics, such as flammability, lower toxicity or higher pressure in the system, they might have a slightly different technological set-up compared to HCFC or HFC equipment and require a specific skill set of RAC engineers and technicians. Technical differences might include different compressors, a secondary loop system or specific risk reducing measures (e.g. eliminating sources of ignition).

In the following sections, the most suitable low-GWP refrigeration systems as well as appropriate low-GWP refrigerants for each subsector in Ghana are highlighted.

Ghana has settled on adopting hydrocarbons where applicable as the preferred natural refrigerant.

## 5.3 ANALYSIS OF ALTERNATIVE, LOW-GWP RAC APPLIANCES AND THEIR RESPECTIVE COST-BENEFIT IMPLICATIONS

In the following section, the relevant low-GWP, energy-efficient technologies and the improvement potential of the current installed stock of equipment for each subsector are discussed.

For applications where all data was available, i.e. self-contained and split AC and domestic refrigerators, a cost-benefit calculation was conducted. To provide information on the economic benefit potentially resulting from employing best available technology (BAT), the net present value<sup>7</sup> of each unit is calculated with a discount rate of 8%. With available data, the annual electricity cost was determined by multiplying the annual energy consumption with an electricity cost of 0.147 US cents/kWh<sup>8</sup>. Investment costs for currently employed units in Ghana are average values taken from questionnaires' results. BAT investment costs are based on European prices, since local prices were not available. Those prices can only provide an approximate price range, as cost calculations by global suppliers are subject to many factors. Efforts were undertaken to estimate the energy consumption of BAT technologies under Ghanaian climate conditions. Results are presented as part of the tables in the following sub-chapters.

<sup>7</sup> Net present value (NPV) of a project is the potential change in an investor's wealth caused by that project while time value of money is being accounted for. It equals the present value of net cash inflows generated by a project less the initial investment on the project. It is one of the most reliable measures used in capital budgeting because it accounts for time value of money by using discounted cash flows in the calculation. (<http://accountingexplained.com/managerial/capital-budgeting/npv>, accessed 16.3.2017).

<sup>8</sup> [energycom.gov.gh/files/National%20Statistics\\_2016.pdf](http://energycom.gov.gh/files/National%20Statistics_2016.pdf).

### 5.3.1.1 Unitary AC systems

Hydrocarbons can be used for most unitary air conditioning systems, particularly portable and ductless split systems. Portable units utilising R290 are available worldwide and window units using R290 are in production in Asia. Split air conditioning systems using R290 are in production in India and China. China has completed the conversion of 18 production lines from R22 to R290 as part of their HPMP. Efforts are underway to better assess the risks and establish standards and best practices of using hydrocarbons in larger charge systems. According to technical experts from HEAT, R290 can be safely handled for cooling capacities up to 10 kW.

For ducted and multi-split systems, the use of hydrocarbons requires the use of ducted systems, either with air or with water as a heat transfer medium inside buildings. With appropriate design modifications, energy efficiency improvements of up to 10% can be achieved also for indirect systems compared to the currently installed systems using R410 or R404A and R407C for ducted air conditioning systems.

Table 29 compares the current technology as derived in the inventory to best practice technology in terms of refrigerant and energy efficiency. For unitary AC, this is mainly the hydrocarbon R290 in direct or secondary loop applications. The table also includes the potential market penetration for alternative systems and product example.

TABLE 29: CURRENT AND BEST PRACTICE UNITARY AC (SOURCE: HEAT ANALYSIS)

UNITARY AC		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	POTENTIAL MARKET PENETRATION FOR ALTERNATIVE SYSTEMS			PRODUCT EXAMPLES
				CURRENT	2020	2030	
SELF-CONTAINED AIR CONDITIONERS	Refrigerant	R22	R290	0%	50%	60%	Midea MPPC-11 CRN7-QB6G1
	Equipment energy efficiency	2.72	>3.2				
SPLIT AIR CONDITIONERS	Refrigerant	R22, R410A	R290	<1%	50%	70%	Midea MSAECU-18HRFN7-QRD0GW / Godrej GSC FG 6 BOG
	Equipment energy efficiency	3.04	>3.9				
DUCTED AIR CONDITIONING SYSTEMS	Refrigerant	R22, R410A	R290 (+liquid secondary)	0%	50%	70%	Geoclima
	Equipment energy efficiency	2.77	>3.5				
MULTI-SPLITS	Refrigerant	R410A, R407C	R290 (+liquid secondary)	0%	30%	70%	Eco Chill Stratos S-Type and V-Type
	Equipment energy efficiency	3.64	4				

Comparing the available self-contained AC unit with the BAT, about 25% efficiency improvement can be achieved. Considering a lifetime of 10 years, the higher investment costs are compensated by reduced energy costs. For split systems, a Midea R290 based unit is about 15% more efficient than its corresponding size split unit installed in Ghana. Since the Midea R290 unit is not yet

available on the market, investment cost is estimated based on the assumption that they cost the same as an HFC unit. The higher investment price compared to current price in Ghana is compensated by the lower energy cost over the lifetime. Table 30 shows the details of the comparison.

TABLE 30: COST COMPARISON BETWEEN CURRENT AND BEST PRACTICE UNITARY AC APPLIANCES (SOURCE: HEAT ANALYSIS)

			CURRENT TECHNOLOGY	BEST AVAILABLE TECHNOLOGY	PRODUCT EXAMPLES
UNITARY AIR CONDITIONING	Self-contained air conditioners	Refrigerant	R22	R290	DeLonghi Pinguino Air to Air PAC EX 100 SILENT
		Equipment energy efficiency	2.72	3.6	
		Investment cost (USD)	\$360	\$719	
		Annual electricity cost (USD)	\$770	\$668	
		<b>Cost (Net present value, USD)</b>	<b>\$6,954</b>	<b>\$6,438</b>	
	Split air conditioners	Refrigerant	R410A/R22	R290	Midea MSAECU-18HRFN7- QRD06W
		Equipment energy efficiency	3.04	3.5 (SEER=7)	
		Investment cost (USD)	\$500	\$719	
		Annual electricity cost (USD)	\$947	\$865	
		<b>Cost (Net present value, USD)</b>	<b>\$8606</b>	<b>\$8044</b>	

### 5.3.1.2 AC and process Chillers

AC and process chiller systems are used for residential, commercial and industrial cooling. Generally, chillers are located 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 conditions, both R717 and hydrocarbon (R290 and R1270) refrigerants have very good thermodynamic properties that can lead to high energy efficient chiller systems, which are often superior to those based on HFC.

Driven by the requirements of the EU F-Gas Directive, 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 the main focus on large-scale industrial refrigeration systems. Due to the F-Gas directive, R717 chillers are increasingly being used for AC purposes in Europe. In combination with screw com-

pressors, 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, both with regard to upfront and operating costs. Industrial process chillers are the state-of-the-art condition in many countries. Hydrocarbon chiller systems are suitable for systems in the range of 10 – 500 kW. As R717 is toxic and hydrocarbons are flammable, particular consideration and technical skills are required for the installation, operation and maintenance of these systems.

A comparison of current and BAT is presented in Table 31.

Process chiller in Ghana are already highly efficient with the average energy efficiency per unit reported by end-users being as high as 4 (W/W). Only about 30% of installed chillers use the natural refrigerant R717 and 50% using R134a. In terms of installed capacity, over 95% is already covered by R717. Therefore, it seems that the highest technology gap exists with small R134a

chillers. As R717 chillers are mainly used for application where a cooling capacity of 500 kW and higher is required, R290 chiller might be the better substitute for these small R134a chillers.

Current AC chiller in Ghana mainly operate with the HFCs R134a and R410A at a comparatively low average efficiency (EER) of 2.44. Alternatively, R290 or R717 technologies could improve the energy efficiency by up to 40 %.

TABLE 31: CURRENT AND BEST PRACTICE CHILLERS (SOURCE: HEAT ANALYSIS)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	POTENTIAL MARKET PENETRATION FOR ALTERNATIVE SYSTEMS			PRODUCT EXAMPLES
				CURRENT	2020	2030	
AIR CONDITIONING CHILLERS	Refrigerant	R134a, R410A	R290, R717	0 %	30 %	50 %	Eco Chill Stratos S-Type and V-Type
	Equipment energy efficiency	2.44	>4				
PROCESS CHILLERS	Refrigerant	R134a, R717	R717, R290	20 %	30 %	50 %	There are many R717 chiller available worldwide; Haffner-Muschler, Futron
	Equipment energy efficiency	4.0	>4				

### 5.3.1.3 Commercial refrigeration

The commercial refrigeration sector has been targeted specifically by the EU F-Gas Directive, which pushes the development of energy efficient units using low-GWP natural refrigerants. In the stand-alone category (bottle coolers, ice coolers and display cases up to 3.75m), refrigerants with a GWP higher 150 are forbidden. Appliances using hydrocarbon refrigerants have reached significant market shares. Stand-alone equipment can also be used for refrigerating whole supermarkets. This is done by combining multiple stand-alone units, which release their condensation heat into a water circuit.

Currently, the updated draft of the IEC standard 60335-2-89<sup>9</sup> suggests, that the charge size can be increased from 150g to 500g hydrocarbons, allowing an even more widespread application. The use of R600a and R290 instead of the currently available R134a is estimated to result in energy efficiency gains of over 10 %.

Condensing units mainly use R404a and R22 in Ghana. Currently, both R290 and R744 are slowly entering the market. Ambient temperatures in Ghana might be too hot for the R744 units to reach their full efficiency potential. Alternatively, some shops or small supermarkets are installing small chiller-type units using R290.

Centralised systems in Ghana already use R717 as refrigerant, however, the reported energy efficiency of 1.7 is very low compared to available best practice technology efficiency of at least 3. A comparison of current and BAT for commercial refrigeration is presented in Table 32 below.

<sup>9</sup> IEC (International Electrotechnical Commission) 60335-2-89: Household and similar electrical appliances – Safety – Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor.



TABLE 32: CURRENT AND BEST PRACTICE TECHNOLOGIES IN THE COMMERCIAL REFRIGERATION SECTOR (SOURCE: HEAT ANALYSIS)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	POTENTIAL MARKET PENETRATION FOR ALTERNATIVE SYSTEMS			PRODUCT EXAMPLES
				CURRENT	2020	2030	
STAND-ALONE EQUIPMENT	Refrigerant	R134a, (R600a)	R290, R600a	18 %	85 %	85 %	AHT, Athen XL ECO
	Equipment energy efficiency	No data	>3.5				
CONDENSING UNITS	Refrigerant	R404A, R22	R290 (+liquid secondary), R744	0 %	40 %	60 %	Futron, Sanden, Carrier
	Equipment energy efficiency	2.1	>3.5				
CENTRALIZED SYSTEMS	Refrigerant	R717	R717; R290 + liqu. sec. for MT and CO <sub>2</sub> cascade for LT,	100 %	100 %	100 %	Usually tailor-made systems
	Equipment energy efficiency	1.7	>3				

#### 5.3.1.4 Domestic refrigeration

Domestic refrigerators using hydrocarbon R600a as a refrigerant are state of the art in Europe and Asia and already constitute the majority of new imports in Ghana. Efficiency improvements are driven by labelling and

MEPS, both in Europe and Ghana. In Europe, the rating A+++ is the highest category and fridges, below A rated appliances are banned from the market. Table 33 provides current and best practice technologies in the domestic refrigeration sector.

TABLE 33: CURRENT AND BEST PRACTICE TECHNOLOGIES IN THE DOMESTIC REFRIGERATION SECTOR (SOURCE: HEAT ANALYSIS)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	POTENTIAL MARKET PENETRATION FOR ALTERNATIVE SYSTEMS			PRODUCT EXAMPLES
				CURRENT	2020	2030	
DOMESTIC REFRIGERATION	Refrigerant	R600a, R134a	R600a	60 %	67 %	100 %	many fridges with Energy rating A+++
	Equipment energy efficiency	>400 kWh/year	139 kWh/year				

A cost comparison between current and best practice technology shows that the low annual electricity costs set off the higher investment costs of the more efficient domestic refrigerator model (Table 34). Units that are more efficient are not necessarily more expensive than other units.

TABLE 34: COST COMPARISON BETWEEN CURRENT AND BEST PRACTICE TECHNOLOGY FOR DOMESTIC REFRIGERATION (SOURCE: HEAT ANALYSIS)

			CURRENT TECHNOLOGY	BEST AVAILABLE TECHNOLOGY	PRODUCT EXAMPLES
DOMESTIC REFRIGERATION	Domestic refrigeration	Refrigerant	R134a (40 %)	R600a	Siemens Fridge-Freezer, A+++
		Equipment energy efficiency	> 400 kWh/year	139 kWh/year	
		Investment cost (USD)	\$431	\$629	
		Annual electricity cost (USD)	\$73	\$29	
		Cost (Net present value, USD)	\$1,056	\$878	

### 5.3.1.5 Mobile AC

The automobile industry has always chosen a single refrigerant solution for the global market in the past. Currently, alternative systems have been developed with the HFO R1234yf and R744 for Europe and the US where refrigerants are required to have a GWP less than 150. Both technologies are currently more expensive than the standard R134a because of higher refrigerant costs in the case of the HFO and higher development costs in the case of R774. Car repair shops will have to adapt their technicians' skill as well as equipment before maintenance can be conducted on these units.

Car manufacturers, due to flammability concerns, do not yet consider hydrocarbons as a viable refrigerant option. A potential future application are hydrocarbons for electric vehicles with hermitically sealed secondary loop refrigerant systems. These systems would also work well in the reverse cycle for heating. For example in Germany, large vehicles using R744 systems are available for buses and trains.

It is expected that environmentally friendly natural solutions will enter the Ghanaian market after 2030.

TABLE 35: CURRENT AND BEST PRACTICE 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.	0 %	0 %	0 %
	Equipment energy efficiency	no data	no data			
LARGE VEHICLE AIR CONDITIONING	Refrigerant	R134a	R744	0 %	0 %	0 %
	Equipment energy efficiency	no data	no data			

### 5.3.1.6 Transport refrigeration

There are currently no marketed low-GWP refrigerant solutions available in this sector. The leading manufacturer of transport refrigeration systems in South Africa, Transfrig, is currently field testing a prototype which uses R290. The prototype has been highly successful with energy efficiency improvements of 20–30 %

as compared to the HFC-systems. It can be expected that potentially the units may be commercially available in Ghana. Carrier is currently conducting field tests in Europe using R744.

For the Ghanaian climate, the R290 unit is expected to be more efficient and applicable.

TABLE 36: CURRENT AND BEST PRACTICE TRANSPORT REFRIGERATION UNITS (SOURCE: HEAT ANALYSIS)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	POTENTIAL MARKET PENETRATION FOR ALTERNATIVE SYSTEMS		
				CURRENT	2020	2030
REFRIGERATED TRUCKS/TRAILERS	Refrigerant	R404A, R134a	R290	none	40 %	80 %
	Equipment energy efficiency	no data	no data			

## 5.4 MAIN BARRIERS AND SOLUTION SUGGESTIONS

Concerning the transition to low-GWP RAC systems, there are a number of technical, market- and policy-related barriers to be addressed. The policy and market-related barriers and possible financial solutions in particular will be analysed under the remaining activities of the GCAI CTCN Response Plan, precisely the RAC Policy Gap Analysis as well as the RAC Technology Roadmap Recommendations. As a further step, appropriate solutions need to be identified and implemented to surmount these barriers. Table 37 provides a detailed review of the most significant barriers and possible solutions.

Ghana has already made the decision to include hydrocarbons as the preferred low-GWP refrigerants to replace ODS and high-GWP substances in the RAC sector. A number of barriers needs to be removed to fully realise this.

Passing legislation is necessary to secure the safe design, application, handling, transportation and control of HCs because of the risk they pose to humans and property, due to their flammable nature. Training and certification of RAC practitioners as prerequisite for handling HC system will need to be strictly enforced to minimize flammability risk. Policy and market-related barriers need to be analysed to identify appropriate and financial assistance sought under GCAI-CTCN.



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TABLE 37: OVERVIEW OF BARRIERS TO THE INTRODUCTION OF CLIMATE FRIENDLY TECHNOLOGIES AS WELL AS POSSIBLE SOLUTIONS TO OVERCOME THESE

TOPIC	BARRIER	POSSIBLE SOLUTIONS
REFRIGERANTS	Lack of technical capacity for qualified technicians, specifically in the handling of flammable refrigerants	<p>Define qualification levels and implement mandatory training and certification/licensing of RAC technicians;</p> <p>Increase training activities by offering country-wide training courses, also in the handling of flammable refrigerants</p> <p>Offer training for HC refrigerant vendors</p>
	Lack of leakage controls and information about refrigerant use	<p>Implement mandatory reporting for the use of (high) GWP refrigerants (refrigerant registry) and leakage testing for operators and service companies;</p> <p>Include training on leakage reduction and reporting</p> <p>The following data should be registered: servicing record, breakdown repairs and refrigerant top-up charge. Unless proper record is kept of plant operation and maintenance, it becomes difficult to evaluate whether it is operating efficiently.</p>
	Lack of availability of low-GWP refrigerants	<p>Low-GWP refrigerants, such as R290 and R600a, are generally available in Ghana. Import and sales are currently controlled to increase safety. Import activities could be widened, but further stipulations regarding the safe storage and handling as well as knowledge about risks need to be considered.</p>
	Lack of safety standards for the safe handling of low-GWP/ flammable refrigerants	<p>The transition to low-GWP refrigerants, will in many cases, result in the introduction of refrigerants with higher flammability to the market. The safe handling of flammable refrigerants requires that RAC appliance are conform to international best practice standards on safety for the installation, operation and the maintenance of the equipment; technicians have to be trained and certified/licensed to comply with such standards.</p>
	Safe retrofit	<p>Retrofit could potentially result in lowering refrigerants leakage related emissions. However, it is risky to make a general recommendation towards retrofitting units, since few appliances are suitable and safe handling cannot be safeguarded in many cases.</p>
	Lack of control for high GWP refrigerants	<p>Ban of high GWP refrigerants or pre-charged units for RAC subsectors that can use low-GWP alternatives are necessary. Further information on the impact of the Montreal Protocol and Kigali Amendment needs to be given to importers.</p>

TOPIC	BARRIER	POSSIBLE SOLUTIONS
ENERGY EFFICIENCY	Lack/low Minimum Energy Efficiency (MEPS) Standards and Labels	MEPS are a great tool to reduce energy consumption. Ghana has already implemented MEPS and labels for split AC and domestic refrigerators. However, these are low compared to international best practice levels. It is recommended to increase the MEPS of the mass appliances widely used in the country and to include further product groups that show high growth rates or particularly low efficiencies.
	Lack of effective Monitoring, Verification and Enforcement (MVE)	MEPS and Labels are only effective with a robust MVE regime. Appliance testing facilities should be further developed and regular checking should be increased. A product data base for imports is a tool for keeping track of all products both for the government and end-users.
	Lack of availability of low-GWP RAC appliances and components;	Low-GWP RAC appliances need to be introduced to the market as an attractive investment; Green government procurement programmes can be an effective instrument to introduce low-GWP RAC appliances with low-GWP refrigerants and high energy efficiency to the market. Importers can be encouraged financially or with structural support to increase the import of green cooling technologies. Technician training would increase the trust of manufacturers to sell their products in a foreign market.
	Lack of knowledge/awareness about optimum appliance type	Lower investment costs and lower complexity have led to the increased use of multi-split and condensing units instead of chillers e.g. in the comfort cooling and cold store sectors. Increased awareness about the potential for reduced leakage and energy consumption as well as improved training and education for technicians could increase their use again.
	Poor servicing leads to high power consumption	Increase training activities for servicing technicians and sales personnel. Regular cleaning and refrigerant top-up as well as leakage reduction will lead to more efficient units.
	Lack of insulation and insufficient building design increases necessary cooling capacity	Introduce regulations regarding the insulation quality of cold rooms, refrigerated trucks, refrigerators and buildings. Introduce courses for architects focusing on design for climate responsive buildings (e.g. avoid massive sunlit glazing) and green building codes.
APPLIANCES IN GENERAL	Lack of coordinated policy approach	The GHG emissions of the RAC sector are most effectively addressed if policies on energy efficiency and low-GWP refrigerants are closely coordinated. A central product data base register for RAC appliances and refrigerants can be an effective policy monitoring instrument. Through a central RAC registry, the progress of mitigating related GHG emissions can be closely monitored and reviewed and the results could be included in the country's NDCs.
	Lack of financing for the implementation of an integrated policy approach	Through an integrated and comprehensive approach and proposal, Ghana could potentially attract international donors to support the establishment of an enabling framework and adequate incentives for the transition to low-GWP RAC appliances. Such a sectoral plan can be accompanied by appropriate funding with international support.

## 5.5 GHANAIAN MITIGATION SCENARIO

Applying the technical solutions presented in the technology gap analysis, total emissions could be reduced from 8.2 MtCO<sub>2</sub>eq to 6.3 MtCO<sub>2</sub>eq by 2030 and

from 12.8 to 8.5 MtCO<sub>2</sub>eq by 2050 (Figure 21). This means that about 1.9 MtCO<sub>2</sub>eq could be avoided in 2030, which is 23% of the projected BAU emissions. In 2050, the mitigation could amount to 4.3 MtCO<sub>2</sub>eq, which accounts for 33% of the total emissions.

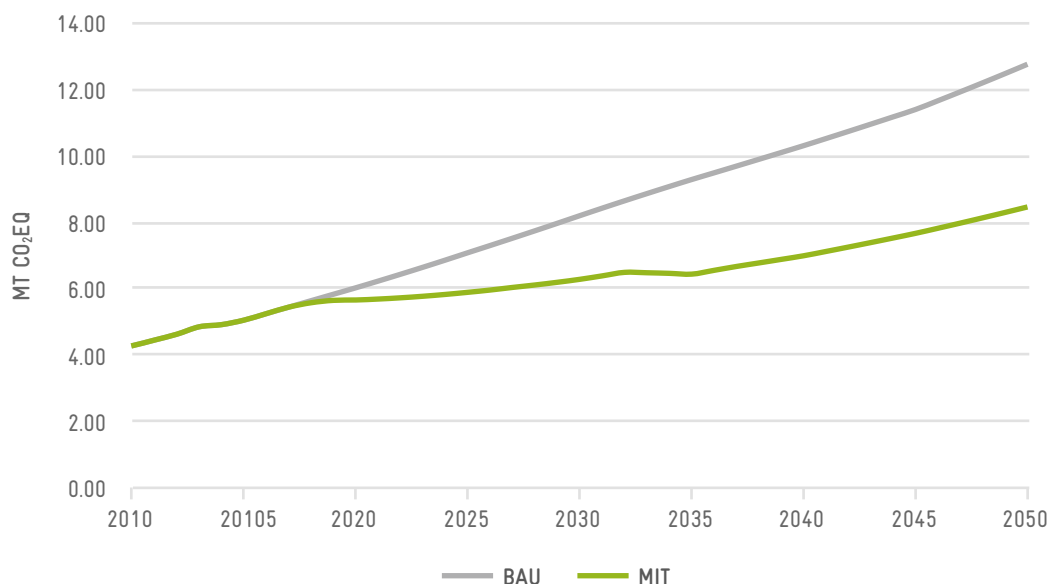


FIGURE 21: COMPARISON BETWEEN BAU AND MIT SCENARIO. THE MIT SCENARIO ASSUMES THAT ALL TECHNICAL OPTIONS PRESENTED ARE IMPLEMENTED

A comparison between BAU and MIT for direct and indirect emissions (Figure 22) shows that the reduction of indirect emissions is higher than that of direct emissions with a share of about 60% from indirect and

40% from direct emissions. The lower increase of direct emissions is visible because a reduction of GWP is already assumed in the BAU scenario due to international regulations.

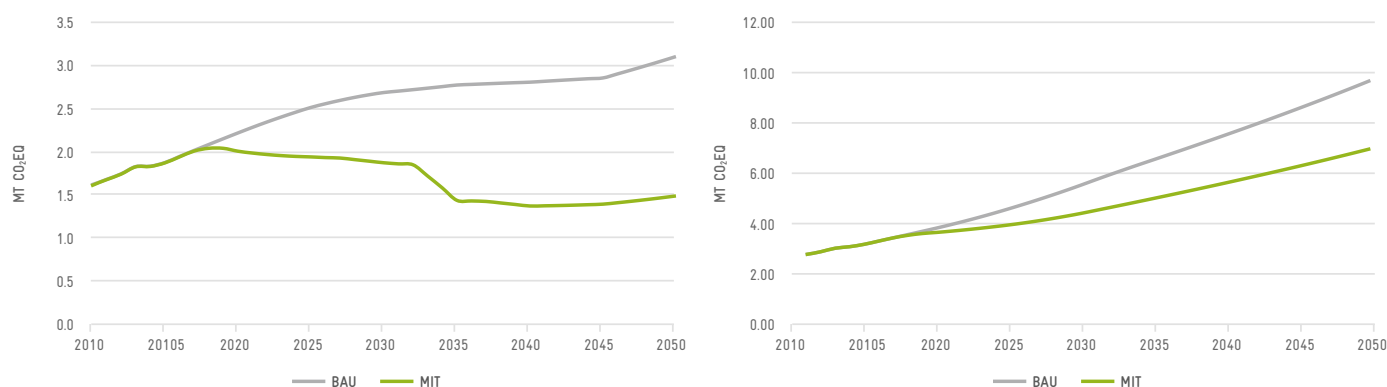


FIGURE 22: DIRECT EMISSION BAU AND MIT FOR BOTH SCENARIOS (LEFT PANEL). INDIRECT EMISSIONS BAU AND MIT FOR BOTH SCENARIOS (RIGHT PANEL)



A breakdown of the emission contribution according to subsectors as well as the emission reduction according to product groups is given in Table 38. The table shows that there is a difference between the appliances with the highest absolute potential of mitigation, which are also those with the highest number of units (e.g. split AC, multi-splits and MAC) and those where the mitigation relative to BAU is specifically high (rooftop ducted and multi-splits, AC and process chiller as well as refrigerated trucks). High absolute mitigation potentials

are generally related to the high number of units in the country whereas high relative reductions to the BAU scenario indicate a high potential for improvement, often through the avoidance of direct emissions with high GWP refrigerants.

Table 38 further shows (see also Table 28) the relative contribution each of the subsectors has towards total emissions.

TABLE 38: RELATIVE EMISSION CONTRIBUTION TO TOTAL EMISSION IN 2015 AND MITIGATION POTENTIAL RELATIVE TO BAU IN 2020 AND 2030

SUBSECTOR		PRODUCT GROUP	2020		2030	
	RELATIVE EMISSION CONTRIBUTION TO TOTAL EMISSIONS		MITIGATION POTENTIAL [KT CO <sub>2</sub> EQ]	REDUCTION RELATIVE TO BAU	MITIGATION POTENTIAL [KT CO <sub>2</sub> EQ]	REDUCTION RELATIVE TO BAU
UNITARY AIR CONDITIONING	57.6 %	Self-contained	0.2	4 %	1.3	17 %
		Split (ductless)	177.8	6 %	767.6	23 %
		Split (ducted)	11.7	5 %	68.8	20 %
		Rooftop ducted	1.3	14 %	3.9	25 %
		Multi-splits, VRF/VRV	86.8	29 %	419.2	71 %
CHILLER	0.7 %	Air conditioning chillers	7.8	13 %	48.8	32 %
		Process chillers	2.8	7 %	19.9	20 %
MOBILE AIR CONDITIONING	23.7 %	Car air conditioning	22.4	3 %	186.8	16 %
		Large vehicle air conditioning	13.9	2 %	123.8	11 %
DOMESTIC REFRIGERATION	16.2 %	Domestic refrigeration	38.9	4 %	246.4	19 %
COMMERCIAL & INDUSTRIAL REFRIGERATION	1.9 %	Stand-alone equipment	1.4	6 %	8.0	24 %
		Condensing units	3.4	8 %	20.2	29 %
		Centralised systems	0.1	0 %	0.8	3 %
TRANSPORT REFRIGERATION	<1 %	Refrigerated trucks/trailers	0.1	10 %	0.7	43 %



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## 5.6 PROPOSED SPECIFIC MITIGATION ACTIONS

In terms of highest GHG emission reductions, it is effective to target those product groups, which contribute most to the total emissions and where alternative technologies exist. Other possible targets are groups with a high expected growth in the near future where interventions can lead to a development of banks of environmentally harmful substances and those with a high potential of reduction per unit.

It can be seen that in Ghana the following subsectors contribute mainly to RAC GHG emissions:

- » Unitary Air Conditioning
- » Mobile Air Conditioning
- » Domestic Refrigeration

The following product groups thereby show the highest emission share:

- » Split (ductless) (57.6 %)
- » Vehicle air conditioning (23.7 %)
- » Domestic refrigeration (16.2 %)

The following product groups show the highest absolute potential for mitigation in 2020 and in 2030:

- » Split (ductless) (177.8 kt CO<sub>2</sub>eq)
- » Multi-splits, VRF/VRV (86.8 kt CO<sub>2</sub>eq)
- » Car/large vehicle AC (22.4 kt CO<sub>2</sub>eq)
- » Domestic refrigerators (38.9 kt CO<sub>2</sub>eq)

The following product groups show the highest relative potential for mitigation compared to BAU in 2020:

- » Multi-splits, VRF/VRV (29 %)

- » Rooftop ducted (14 %)

- » Air conditioning chillers (13 %)

The following product groups show the highest relative potential for mitigation compared to BAU in 2030:

- » Multi-splits, VRF/VRV (71 %)

- » Air conditioning chillers (32 %)

- » Condensing units (29 %)

- » Refrigerated trucks/trailers (43 %)

The following product groups, low-GWP refrigerant and/or energy efficient units are already introduced to the Ghanaian market:

- » Process chillers
- » Domestic refrigeration
- » Stand-alone equipment

In the following product groups, low-GWP refrigerant and/or energy efficient units are introduced on international markets, but no or very few units can be found in Ghana:

- » Self contained
- » Split (ductless)
- » Air conditioning chillers
- » Process chillers
- » Centralised systems

Depending on the goal and available policy measures different mitigation actions can be advised.

## 6 CONCLUDING REMARKS

The inventory has shown that the highest contributions to the RAC sector's GHG emissions come from the UAC, MAC and domestic refrigeration subsectors. Even though the emissions are high in the mobile AC subsector, mitigation is difficult because the international automobile industry has not moved to low-GWP refrigerants and leakage reduction measures.

The UAC and domestic refrigeration subsectors are a good target of mitigation action as green cooling technologies with high energy efficiency and low-GWP refrigerants are available on the global and partly even on the Ghanaian market. Their increased application can be targeted by policy measures in order to reach substantial GHG emission reductions.

Both direct and indirect emissions are derived and included in the analysis. After discussion with EPA, direct emissions of

HCFCs and HFCs could be included in the national inventory of GHG emissions that is the basis for the NDC development. Whilst Ghana already accounts for emissions from electricity use, it was so far not possible to allocate these specifically to the RAC sector. Knowing the contribution of the RAC sector can support devising effective policy measures to reduce GHG emissions.

The results of this inventory report and technology gap analysis will be further included in a policy analysis that aims at identifying the optimal policy framework to initiate the transformation of the RAC sector towards a lower environmental impact. Finally, all results will be combined in a RAC sector technology roadmap, specifying milestones and emission reduction targets in the RAC sector until 2030 and beyond.

Results from these analyses are further used in the development of Ghana's NDCs.

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# ANNEX A: SUBSECTOR DEFINITIONS

## AIR CONDITIONING EQUIPMENT

SUBSECTOR	PRODUCT GROUP	DESCRIPTION
UNITARY AIR CONDITIONING	Self-contained	<ul style="list-style-type: none"> <li>All components of the system are located within one housing</li> <li>Examples are window or "through-the-wall" units, portable air conditioners</li> </ul>
	Split residential and commercial (duct-less)	<ul style="list-style-type: none"> <li>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. Both units are connected via refrigerant piping (duct-less split)</li> <li>Residential units: applied in private households</li> <li>Commercial units: applied in offices or other commercial buildings</li> <li>This product group refers to "single" split systems, i.e., one indoor unit is connected to one outdoor unit. Please, when reporting unit numbers, avoid double counting and regard systems as a whole.</li> </ul>
	Ducted split, residential and commercial	<ul style="list-style-type: none"> <li>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.</li> <li>Residential units: applied in private households</li> <li>Commercial units: applied in offices or other commercial buildings</li> <li>Ducted splits are mainly used to cool multiple rooms in larger buildings (incl. houses).</li> </ul>
	Rooftop ducted	<ul style="list-style-type: none"> <li>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.</li> </ul>
	Multi-split, VRF/VRV	<ul style="list-style-type: none"> <li>Multi-splits: similar to ductless single-split systems (residential/commercial single splits, see above), although usually up to 5 indoor units can be connected to one outdoor unit.</li> <li>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.</li> <li>When reporting unit numbers (multi-splits, VRF/VRV), please refer to outdoor units alone</li> </ul>
CHILLER, AIR CONDITIONING	Chillers (AC)	<ul style="list-style-type: none"> <li>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.</li> <li>AC chillers are mainly applied for commercial and light industrial purposes.</li> </ul>
MOBILE AIR-CONDITIONING	Small: Passenger cars, light commercial vehicle, Pick-up, SUV	<ul style="list-style-type: none"> <li>Air conditioning in all types of vehicles, such as passenger cars, trucks or buses. Mostly, a single evaporator system is used.</li> </ul>
	Large: Busses, Trains, etc.	



## REFRIGERATION EQUIPMENT

SUBSECTOR	PRODUCT GROUP	DESCRIPTION
DOMESTIC REFRIGERATION	Refrigerator/freezer	<ul style="list-style-type: none"> <li>The subsector includes the combination of refrigerators and freezers as well as single household refrigerators and freezers</li> </ul>
COMMERCIAL REFRIGERATION	Stand-alone	<ul style="list-style-type: none"> <li>"plug-in" units built into one housing (self-contained refrigeration systems)</li> <li>Examples: vending machines, ice cream freezers and beverage coolers</li> </ul>
	Condensing unit	<ul style="list-style-type: none"> <li>These refrigerating systems are often used in small shops such as bakeries, butcheries or small supermarkets.</li> <li>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.</li> <li>The unit usually comes pre-assembled.</li> </ul>
	Centralised systems (for supermarkets)	<ul style="list-style-type: none"> <li>Used in larger supermarkets (sales are greater than 400 square meters).</li> <li>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.</li> <li>The system is assembled on-site</li> </ul>
INDUSTRIAL REFRIGERATION	Stand-alone (integral) unit	<ul style="list-style-type: none"> <li>"plug-in" units built into one housing (self-contained refrigeration systems)</li> <li>Examples: industrial ice-makers</li> </ul>
	Condensing unit	<ul style="list-style-type: none"> <li>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.</li> <li>The unit usually comes pre-assembled.</li> <li>Example: cold storage facilities</li> </ul>
	Centralised systems	<ul style="list-style-type: none"> <li>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.</li> <li>The system is assembled on-site</li> </ul>
	Chillers, Process	<ul style="list-style-type: none"> <li>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.</li> </ul>
TRANSPORT REFRIGERATION	Trailer, van, truck	<ul style="list-style-type: none"> <li>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).</li> <li>Per road vehicle, usually one refrigeration unit is installed.</li> </ul>

# ANNEX B: APPLIED PARAMETERS

## REFRIGERANT EMISSION FACTORS, EQUIPMENT LIFETIME AND INITIAL CHARGES

	MANUFACTURING EMISSIONS [KG/KG]	ANNUAL LEAKAGE RATE [KG/KG]	2030 FINAL EMISSIONS [KG/KG]	LIFETIME [YEARS]
SELF-CONTAINED	0.01	0.25	0.95	15
SPLIT (DUCTLESS)	0.02	0.23	0.95	15
SPLIT (DUCTED)	0.02	0.2	0.8	15
ROOFTOP DUCTED	0.05	0.31	0.9	15
MULTI-SPLIT, VRF/VRV	0.05	0.35	0.9	10
AIR CONDITIONING CHILLERS	0.01	0.22	0.95	20
PROCESS CHILLERS	0.01	0.22	1	20
CAR AIR CONDITIONING	0.01	0.2	1	15
LARGE VEHICLE AIR CONDITIONING	0.02	0.3	0.8	15
DOMESTIC REFRIGERATION	0.01	0.02	0.8	20
STAND-ALONE EQUIPMENT	0.01	0.03	0.8	15
CONDENSING UNITS	0.05	0.3	0.85	20
CENTRALISED SYSTEM	0.05	0.38	0.9	20
REFRIGERATED TRUCKS/TRAILERS	0.02	0.25	0.5	15

## ASSUMED GROWTH FOR BUSINESS AS USUAL AND MITIGATION SCENARIO (GIZ/ HEAT ANALYSIS)

	2015	2020	2025	2030	2035	2040	2045	2050
SELF-CONTAINED	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
SPLIT (DUCTLESS)	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
SPLIT (DUCTED)	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
ROOFTOP DUCTED	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
MULTI-SPLITS, VRF/VRV	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
AIR CONDITIONING CHILLERS	4.58 %	4.58 %	4.58 %	4.6 %	2.3 %	2 %	2 %	2 %
PROCESS CHILLERS	4.58 %	4.58 %	4.58 %	4.6 %	2.3 %	2 %	2 %	2 %
CAR AIR CONDITIONING	4.38 %	4.38 %	4.38 %	4.4 %	2.2 %	2 %	2 %	2 %
LARGE VEHICLE AIR CONDITIONING	4.38 %	4.38 %	4.38 %	4.4 %	2.2 %	2 %	2 %	2 %
DOMESTIC REFRIGERATION	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
STAND-ALONE EQUIPMENT	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
CONDENSING UNITS	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
CENTRALISED SYSTEMS	4.42 %	4.42 %	4.42 %	4.4 %	2.2 %	2 %	2 %	2 %
REFRIGERATED TRUCKS/TRAILERS	3.80 %	3.80 %	3.80 %	3.8	1.9 %	2 %	2 %	2 %

## ASSUMED AVERAGE ENERGY EFFICIENCY RATIOS [W/W] FOR THE BAU SCENARIO (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	2000	2010	2020	2030	2040	2050
SELF-CONTAINED	2.70	2.70	2.82	2.90	2.90	2.90
SPLIT (DUCTLESS)	2.61	2.90	3.08	3.08	3.08	3.08
SPLIT (DUCTED)	2.73	2.73	3.04	3.06	3.08	3.10
ROOFTOP DUCTED	2.71	2.71	2.77	2.77	2.77	2.77
MULTI-SPLITS, VRF/VRV	3.01	3.64	3.76	4.13	4.17	4.17
AIR CONDITIONING CHILLERS	2.43	2.43	2.43	2.53	2.53	2.53
PROCESS CHILLERS	3.94	3.94	4.12	4.12	4.12	4.12
CAR AIR CONDITIONING	2.48	2.52	2.57	2.57	2.57	2.57
LARGE VEHICLE AIR CONDITIONING	2.48	2.52	2.57	2.57	2.57	2.57
DOMESTIC REFRIGERATION	1.79	1.84	2.02	2.14	2.35	2.56
STAND-ALONE EQUIPMENT	1.98	1.98	2.06	2.12	2.12	2.12
CONDENSING UNITS	1.15	1.15	1.20	1.21	1.21	1.21
CENTRALISED SYSTEMS	1.69	1.69	1.87	1.89	1.89	1.89
REFRIGERATED TRUCKS/TRAILERS	2.16	2.19	2.24	2.24	2.24	2.24

## ASSUMED AVERAGE ENERGY EFFICIENCY RATIOS [W/W] FOR THE MITIGATION SCENARIO (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	2020	2030	2040	2050
SELF-CONTAINED	3.56	3.91	4.12	4.29
SPLIT (DUCTLESS)	3.90	4.29	4.29	4.29
SPLIT (DUCTED)	3.40	3.42	3.56	3.56
ROOFTOP DUCTED	2.82	2.90	2.90	2.90
MULTI-SPLITS, VRF/VRV	4.45	4.59	4.59	4.59
AIR CONDITIONING CHILLERS	3.12	3.28	3.41	3.55
PROCESS CHILLERS	4.24	4.48	4.67	4.87
CAR AIR CONDITIONING	2.97	3.33	3.50	3.65
LARGE VEHICLE AIR CONDITIONING	2.97	3.33	3.50	3.65
DOMESTIC REFRIGERATION	3.58	3.69	3.77	3.93
STAND-ALONE EQUIPMENT	3.40	3.58	3.68	3.74
CONDENSING UNITS	2.66	2.76	2.92	2.92
CENTRALISED SYSTEMS FOR SUPERMARKETS	2.93	3.06	3.26	3.36
REFRIGERATED TRUCKS/TRAILERS	2.58	2.89	3.05	3.17

## ASSUMED AVERAGE ENERGY EFFICIENCY RATIOS [W/W] FOR THE BAU SCENARIO (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	BAU							MIT			
	REFRIGERANT	2000	2010	2020	2030	2040	2050	2020	2030	2040	2050
SELF-CONTAINED AIR CONDITIONERS	R22	100 %	98 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SELF-CONTAINED AIR CONDITIONERS	R290	0 %	0 %	30 %	30 %	30 %	30 %	50 %	60 %	60 %	60 %
SELF-CONTAINED AIR CONDITIONERS	R410A	0 %	3 %	50 %	20 %	20 %	20 %	0 %	0 %	0 %	0 %
SELF-CONTAINED AIR CONDITIONERS	R32	0 %	0 %	20 %	50 %	50 %	50 %	50 %	40 %	40 %	40 %
SPLIT AIR CONDITIONERS	R22	100 %	77 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SPLIT AIR CONDITIONERS	R290	0 %	0 %	0 %	5 %	10 %	15 %	50 %	70 %	70 %	70 %
SPLIT AIR CONDITIONERS	R407C	0 %	6 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SPLIT AIR CONDITIONERS	R410A	0 %	18 %	70 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SPLIT AIR CONDITIONERS	R32	0 %	0 %	30 %	95 %	90 %	85 %	50 %	30 %	30 %	30 %
DUCT SPLIT AIR CONDITIONERS	R22	100 %	84 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DUCT SPLIT AIR CONDITIONERS	GWP 150 HFC	0 %	0 %	0 %	20 %	20 %	20 %	50 %	70 %	70 %	70 %
DUCT SPLIT AIR CONDITIONERS	R407C	0 %	1 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DUCT SPLIT AIR CONDITIONERS	R410A	0 %	16 %	70 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DUCT SPLIT AIR CONDITIONERS	R32	0 %	0 %	30 %	80 %	80 %	80 %	50 %	30 %	30 %	30 %
ROOFTOP DUCTED	R22	100 %	54 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
ROOFTOP DUCTED	GWP 150 HFC	0 %	0 %	0 %	20 %	20 %	20 %	50 %	70 %	70 %	70 %
ROOFTOP DUCTED	R407C	0 %	13 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
ROOFTOP DUCTED	R410A	0 %	33 %	70 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
ROOFTOP DUCTED	R32	0 %	0 %	30 %	80 %	80 %	80 %	50 %	30 %	30 %	30 %
MULTI-SPLITS	R22	100 %	53 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
MULTI-SPLITS	R134a	0 %	1 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
MULTI-SPLITS	R410A	0 %	46 %	70 %	20 %	20 %	20 %	10 %	0 %	0 %	0 %
MULTI-SPLITS	GWP 10 HFC	0 %	0 %	0 %	0 %	0 %	0 %	40 %	80 %	80 %	80 %
AIR CONDITIONING CHILLERS	R22	100 %	50 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
AIR CONDITIONING CHILLERS	R407C	0 %	0 %	30 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %
AIR CONDITIONING CHILLERS	R410A	0 %	12 %	30 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %
AIR CONDITIONING CHILLERS	R290	0 %	0 %	0 %	4 %	4 %	4 %	30 %	70 %	70 %	70 %
AIR CONDITIONING CHILLERS	R134a	0 %	39 %	40 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %



## CALCULATED STOCKS (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	BAU							MIT			
	REFRIGERANT	2000	2010	2020	2030	2040	2050	2020	2030	2040	2050
PROCESS CHILLERS	R22	100 %	55 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
PROCESS CHILLERS	R407C	0 %	5 %	30 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %
PROCESS CHILLERS	R717	0 %	10 %	30 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %
PROCESS CHILLERS	R290	0 %	0 %	0 %	4 %	4 %	4 %	30 %	70 %	70 %	70 %
PROCESS CHILLERS	R134a	0 %	30 %	40 %	32 %	32 %	32 %	0 %	0 %	0 %	0 %
CAR AIR CONDITIONING	R134a	100 %	100 %	93 %	80 %	80 %	80 %	70 %	40 %	40 %	40 %
CAR AIR CONDITIONING	R744	0 %	0 %	0 %	0 %	0 %	0 %	30 %	60 %	60 %	60 %
CAR AIR CONDITIONING	R1234yf	0 %	0 %	7 %	20 %	20 %	20 %	0 %	0 %	0 %	0 %
LARGE VEHICLE AIR CONDITIONING	R744	0 %	0 %	0 %	0 %	0 %	0 %	5 %	15 %	15 %	15 %
LARGE VEHICLE AIR CONDITIONING	R134a	100 %	100 %	98 %	95 %	95 %	95 %	95 %	85 %	85 %	85 %
LARGE VEHICLE AIR CONDITIONING	R1234yf	0 %	0 %	2 %	5 %	5 %	5 %				
DOMESTIC REFRIGERATION	R134a	80 %	60 %	27 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DOMESTIC REFRIGERATION	R600a	20 %	40 %	73 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
STAND-ALONE EQUIPMENT	R404A	50 %	25 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
STAND-ALONE EQUIPMENT	R290	0 %	0 %	0 %	20 %	20 %	20 %	45 %	45 %	45 %	45 %
STAND-ALONE EQUIPMENT	R134a	50 %	66 %	70 %	40 %	40 %	40 %	15 %	15 %	15 %	15 %
STAND-ALONE EQUIPMENT	R744	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
STAND-ALONE EQUIPMENT	R600a		9 %	30 %	40 %	40 %	40 %	40 %	40 %	40 %	40 %
CONDENSING UNITS	R22	100 %	60 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
CONDENSING UNITS	R404A	0 %	38 %	30 %	20 %	20 %	20 %	0 %	0 %	0 %	0 %
CONDENSING UNITS	R290	0 %	0 %	5 %	10 %	10 %	10 %	40 %	60 %	60 %	60 %
CONDENSING UNITS	R134a	0 %	3 %	65 %	70 %	70 %	70 %	60 %	40 %	40 %	40 %
CENTRALISED SYSTEMS	R22	100 %	50 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
CENTRALISED SYSTEMS	R717	0 %	50 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
REFRIGERATED TRUCKS/ TRAILERS	R407C	25 %	13 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
REFRIGERATED TRUCKS/ TRAILERS	R410A	25 %	13 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
REFRIGERATED TRUCKS/ TRAILERS	R404A	25 %	33 %	40 %	40 %	40 %	40 %	0 %	0 %	0 %	0 %
REFRIGERATED TRUCKS/ TRAILERS	R134a	25 %	43 %	60 %	60 %	60 %	60 %	60 %	20 %	20 %	20 %

## CALCULATED SALES BY EQUIPMENT TYPE (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	2010	2015	2020	2025	2030	2035	2040	2045	2050
SELF-CONTAINED	537	514	638	791	982	1,096	1,222	1,363	1,521
SPLIT (DUCTLESS)	137,492	110,000	136,534	169,469	210,349	234,624	261,700	291,900	325,586
SPLIT (DUCTED)	2,531	3,200	3,972	4,930	6,119	6,825	7,613	8,492	9,472
ROOFTOP DUCTED	21	134	166	206	256	286	319	356	397
MULTI-SPLIT, VRF/VRV	19	1,942	2,410	2,992	3,714	4,142	4,620	5,153	5,748
AIR CONDITIONING CHILLERS	10	70	88	110	137	154	172	193	216
PROCESS CHILLERS	0	0	0	0	0	0	0	0	0
MOBILE AC	57,207	72,164	89,393	110,735	137,172	152,846	170,311	189,772	211,457
MOBILE AC	9,506	11,776	14,587	18,069	22,383	24,941	27,791	30,967	34,505
DOMESTIC REFRIGERATION	483,877	600,599	745,476	925,300	1,148,502	1,281,042	1,428,877	1,593,773	1,777,698
STAND-ALONE EQUIPMENT	2,710	3,437	4,267	5,296	6,573	7,332	8,178	9,122	10,174
CONDENSING UNITS	34	100	124	154	191	213	238	265	296
CENTRALISED SYSTEM	1	1	1	2	2	2	2	3	3
REFRIGERATION TRUCKS/ TRAILERS	9	20	24	29	35	38	42	46	51

## CALCULATED STOCKS (GIZ/HEAT ANALYSIS)

EQUIPMENT TYPE	2010	2015	2020	2025	2030	2035	2040	2045	2050
SELF-CONTAINED	4,693	5,972	6,700	7,812	9,338	11,121	12,903	14,746	16,698
SPLIT (DUCTLESS)	1,328,531	1,474,862	1,573,533	1,771,014	2,069,257	2,430,555	2,797,808	3,182,130	3,592,875
SPLIT (DUCTED)	22,139	27,785	35,067	43,936	54,825	66,903	78,696	90,663	103,168
ROOFTOP DUCTED	194	437	954	1,475	2,038	2,619	3,166	3,705	4,255
MULTI-SPLITS, VRF/VRV	108	759	9,214	16,321	23,142	29,632	35,307	40,714	46,199
AIR CONDITIONING CHILLERS	99	161	473	802	1,167	1,554	1,931	2,311	2,702
PROCESS CHILLERS	5	35	44	55	69	77	86	96	108
LARGE VEHICLE AIR CONDITIONING	575,422	685,023	831,878	1,018,663	1,253,493	1,516,803	1,775,168	2,038,242	2,313,804
MOBILE CONDITIONING	71,925	96,612	125,001	158,615	199,154	243,692	286,965	330,682	376,206
DOMESTIC REFRIGERATION	4,865,309	6,166,634	7,752,976	9,699,621	12,098,541	14,804,666	17,526,754	20,333,683	23,287,113
STAND-ALONE EQUIPMENT	21,810	28,895	36,994	46,718	58,554	71,626	84,365	97,269	110,737
CONDENSING UNITS	391	610	969	1,366	1,821	2,316	2,803	3,296	3,808
CENTRALISED SYSTEM FOR SUPERMARKETS	12	14	16	18	22	26	30	35	39
TRANSPORT REFRIGERATION	82	150	201	257	320	386	449	510	573

# ANNEX C: CUSTOMS CODES DESCRIPTION

## REFRIGERANT EMISSION FACTORS, EQUIPMENT LIFETIME AND INITIAL CHARGES

CUSTOM CODE	DESCRIPTION
841510	Air Conditioning Machines, Window or Wall Types, Self-contained
841520	Air conditioning machines of a kind used for
841581	A Refrigerating Unit, a Valve for Reversal of the Cooling/heat Cycle
841582	Other Air Conditioning Machines, Incorporating a Refrigerating Unit
841583	Air Conditioning Machines, Not Incorporating a Refrigerating Unit
841590	Parts of Air Conditioning Machines
841810	Combined refrigerator-freezers, fitted with separate external doors
841821	Household refrigerators, compression type
841829	Other household refrigerators
841830	Freezers of the chest type, capacity<=800L
841840	Freezers of the upright type, capacity<=900L
841850	Other refrigerating or freezing chests, cabinets, display counters, show-cases & similar refrigerating or freezing furniture



# green<sup>❄️</sup> cooling initiative



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