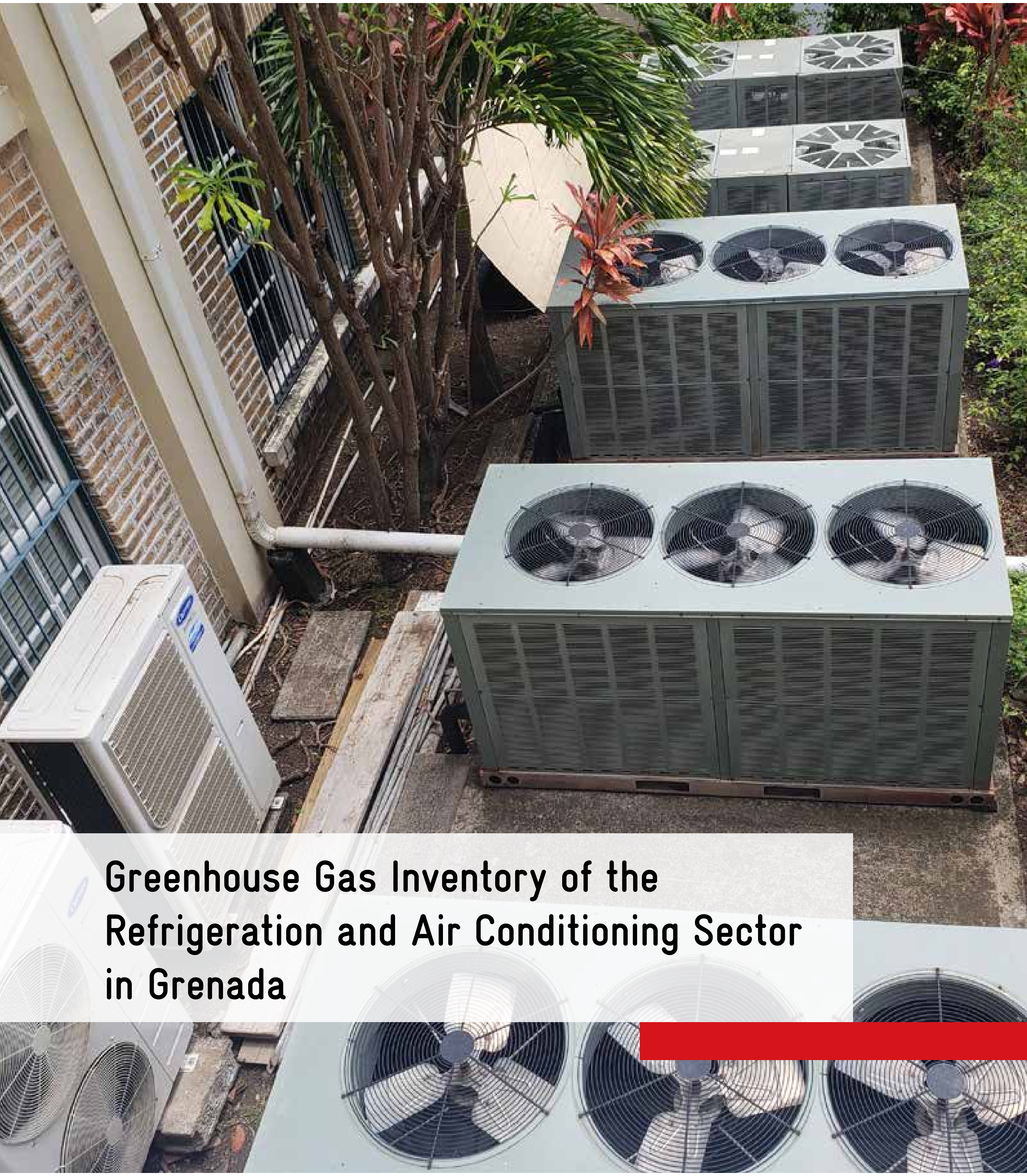

Greenhouse Gas Inventory of the Refrigeration and Air Conditioning Sector in Grenada

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

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LIST OF ABBREVIATIONS

AC	Air conditioner
BAU	Business-as-Usual
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
C4	Cool Contributions fighting Climate Change
CFC	Chlorofluorocarbons
EEI	Energy Efficiency Index
EER	Energy Efficiency Ratio
F-GAS	Fluorinated gas
GCI	Green Cooling Initiative
GDP	Gross Domestic Product
GEF	Grid Emission Factor
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GRENLEC	Grenada Electricity Services
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HEAT	Habitat, Energy Application and Technology GmbH
HFC	Hydrofluorocarbon
HFO	Unsaturated HFC or Hydrofluoroolefin
HVAC	Heating, Ventilation and Air Conditioning
IDB	Inter-American Development Bank
IKI	International Climate Initiative
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
MAC	Mobile Air Conditioning
MEPS	Minimum Energy Performance Standard
MIT	Mitigation scenario
MLF	Multilateral Fund of the Montreal Protocol
MRV	Measuring, Reporting and Verification
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contributions
NOU	National Ozone Unit

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ODP	Ozone depleting potential
ODS	Ozone depleting substances
RAC	Refrigeration and Air Conditioning
TAMCC	T.A. Marryshow Community College
TPMP	Terminal Phase-Out Management Plan
UAC	Unitary Air Conditioning
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Organization

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This report is the result of a comprehensive data collection and assessment process that has been carried out since January 2018 within the project "Cool Contributions fighting Climate Change (C4)" implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under the International Climate Initiative (IKI).

The greenhouse gas (GHG) inventory provides a detailed profile of GHG emissions resulting from refrigeration and air conditioning (RAC) in Grenada and may serve as a basis for the further development of emission reduction measures in the RAC sector in contribution to Grenada's climate targets. The results from this inventory can serve as a basis for further planning of Grenada's Nationally Determined Contributions (NDC) and hydrofluorocarbon (HFC) phase-down schedules in contribution to the Montreal Protocol's Kigali Amendment.

We would like to express our gratitude for the support of all the institutions, companies and other stakeholders in Grenada. We especially thank the National Ozone Unit (NOU) at Ministry of Finance and Energy whose expertise and collaboration were indispensable for the realization of this report. They provided access to relevant actors and facilitated workshops with the stakeholders. Likewise, our thanks go to Dr. John Telesford, who was assigned to carry out the data collection. His efforts were determining for the level and quality of data reached as basis for this inventory.

EXECUTIVE SUMMARY

In recent years, Grenada's refrigeration and air conditioning (RAC) sector has experienced significant growth. The growing demand for air conditioning and refrigeration is driven by the country's steady economic growth, moderate population growth and the rise in temperatures caused by climate change.

» In 2015, the RAC sector was responsible for 122 kt CO_2eq of greenhouse gas (GHG) emissions from refrigerant loss and energy consumption. This means that the RAC sector accounts for approximately 29%[1] of Grenada's total GHG emissions, which amounted to 406.6 kt CO_2eq in 2014[2].

» According to the current temperature trend (IPCC, 2014) resulting in a predicted temperature increase of 0.7 to 2.6°C by 2060 in Grenada (The World Bank Group, 2019), the need for air conditioning and refrigeration in Grenada increases. Due to the increasing use of air conditioning and refrigeration in Grenada, the resulting annual emissions in Grenada's RAC sector are expected to rise to 263 kt CO_2eq in the year 2050 (see Figure 2).

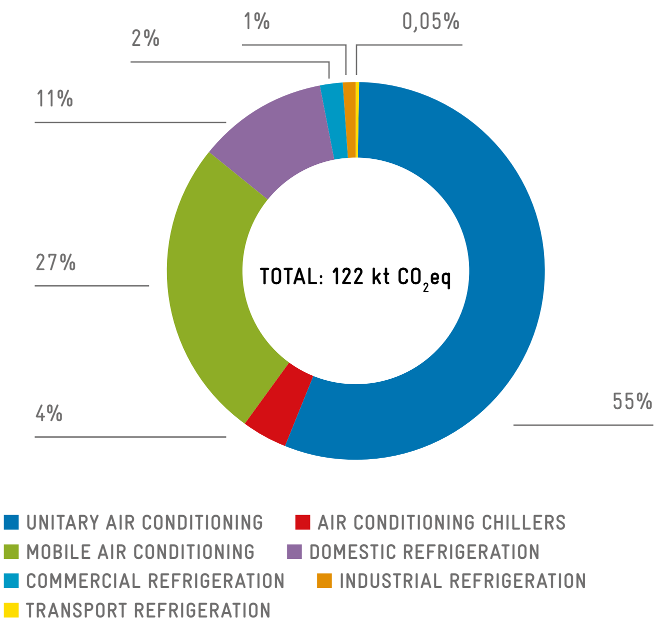

FIGURE 1: GRENADA'S GHG RAC EMISSIONS BY SUB-SECTORS IN 2015

Figure 1 presents the distribution of RAC sector related GHG emissions among all relevant sub-sectors for the year 2015. The total emissions are composed by 18% direct and 82% indirect emissions.

Figure 2 shows different scenarios for the development of Grenada's annual GHG emissions from the RAC sector. In the Business-as-Usual (BAU) scenario case, it is estimated that the annual GHG emissions in Grenada's RAC sector will exceed 200 kt CO_2eq of annual GHG emissions in 2033 and keep increasing at somewhat slower pace in the 2030s, amounting to annual GHG emissions of 263 kt CO_2eq in 2050. By continuously deploying climate-friendly and energy-efficient RAC appliances with increasing use of natural refrigerants, it is estimated that 111 kt CO_2eq can be avoided annually by 2050 (see mitigation (MIT) scenarios). 38% of these avoided emissions are related to the transition to low-GWP refrigerants (red line) and 62% to corresponding energy efficiency improvements which take the MIT scenario under consideration of all mitigation effects further down to the "Ref+EE" scenario (see green line).

The breakdown of emissions by sub-sector in Figure 3 shows that the largest share of emissions can be attributed to unitary air conditioning (UAC), with further significant contributions by mobile air conditioning (MAC). UAC is the main contributing RAC sub-sector to total GHG emissions, accounting for 55% of the total RAC sector emissions in 2015. Standing out for the highest growth rates of appliances, the UAC share of total RAC emissions is projected to increase to 76% by 2050 (66% in 2030).

1 Referring to RAC emissions of 119 kt CO_2eq in 2014;

2 This figure is indicated by Grenada's Second National Communication to the United Nations Framework Convention on Climate Change

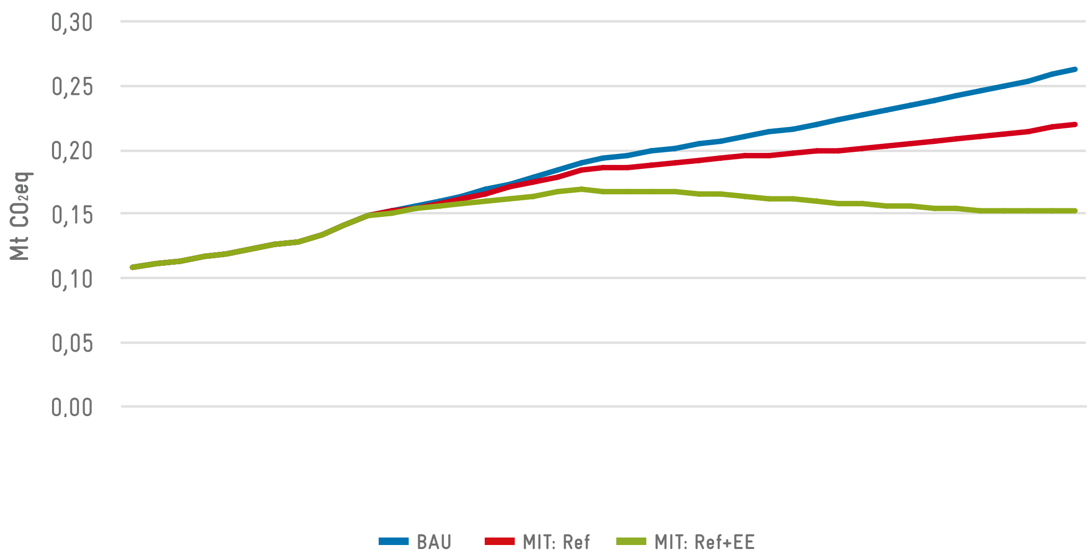

FIGURE 2: TOTAL ANNUAL GHG EMISSIONS FROM THE RAC SECTOR 2010-2050, BAU AND MITIGATION SCENARIOS

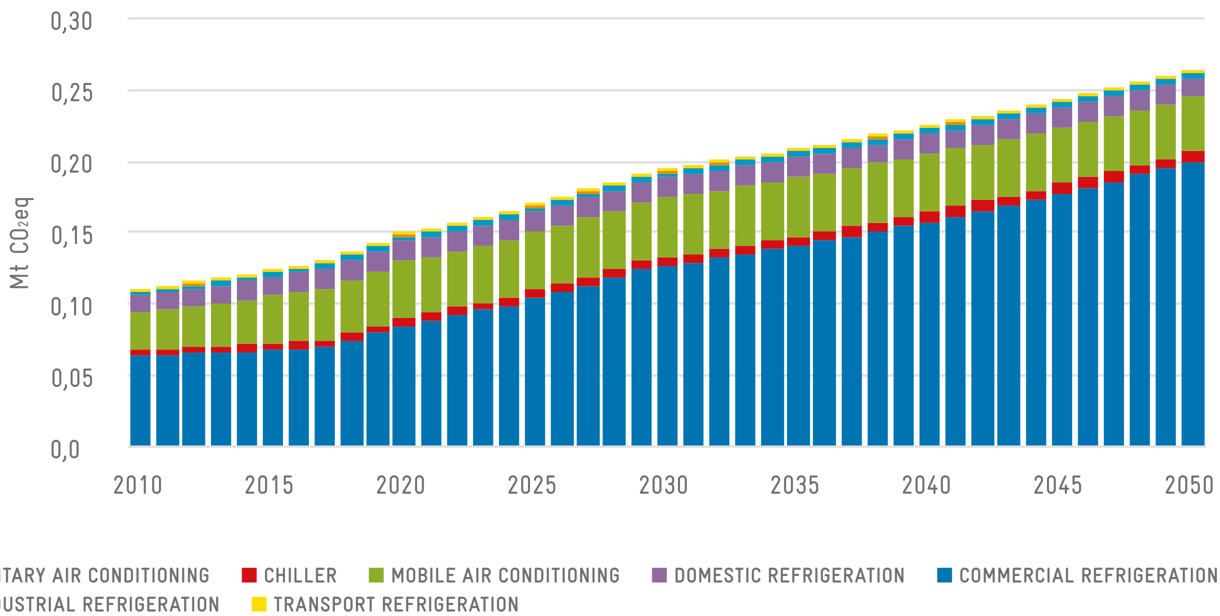

FIGURE 3: PROJECTED BUSINESS-AS-USUAL (BAU) SCENARIO FOR GHG EMISSIONS IN THE RAC SECTOR UNTIL 2050

In contrast, in the mitigation scenario shown in Figure 4, annual GHG emissions are projected to peak at nearly 170 kt CO_2eq in 2029 and then fall to 152 kt CO_2eq by 2050. The decrease of annual GHG emissions is lower in the decade 2040-2050, due to less additionality of reduction measures to the BAU scenario which is, at that point of time, assumed to be much more influenced by the restrictions of HFC refrigerant consumption as stipulated under the Kigali Amendment to the Montreal Protocol (further detail given in sub-chapter 3.4.3). Moreover, mitigation action competes against high growth rates, particularly in the UAC sub-sector.

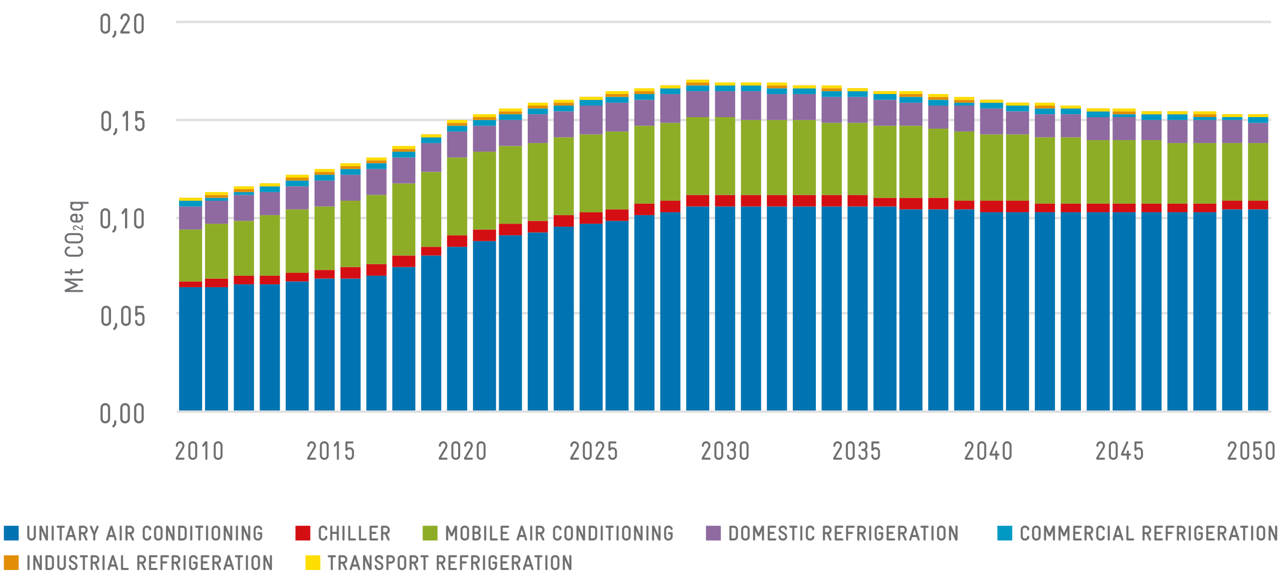

FIGURE 4: PROJECTED MIT SCENARIO FOR GHG EMISSIONS IN THE RAC SECTOR UNTIL 2050

The GHG inventory shows that the RAC sector holds a large GHG mitigation potential, particularly in the UAC sub-sector, which is achievable through technologically and economically feasible mitigation actions. Avoided emissions compared to BAU are expected in the magnitude of 25 kt CO_2eq in 2030, which could contribute approximately 6.3% to the targeted national emission mitigation efforts in 2030. From today's perspective with no mitigation compared to BAU before 2020, much greater emission mitigation potential has been identified in the RAC sector after 2030[3]. The annual mitigation potential by the RAC sector is expected to increase to 111 kt CO_2eq in 2050. The total accumulated mitigation potential until 2050 is estimated to add up to 1.5 Mt CO_2eq.

A large GHG mitigation potential lies in transitioning from highly climate-damaging hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) to alternatives with low global warming potential (GWP), ahead of the current HFC phase-down schedule stipulated in the Kigali Amendment to the Montreal Protocol (Clark and Wagner, 2016). For the facilitation of an effective and sustainable RAC sector technology transformation, it is recommended to take action by following a holistic approach under consideration of market incentives, capacity building, regulatory schemes and awareness raising related to energy efficiency and refrigerant use.

This RAC inventory is the first of its kind in Grenada, showing direct, indirect and total GHG emissions in the RAC sector, broken down to its sub-sectors and individual appliances, based on the stock of installed RAC appliances. As no data on RAC emissions for Grenada has been established prior to the compilation of this RAC emission inventory, RAC emissions have so far not been included in Grenada's National Determined Contributions (NDC) related to the Paris Agreement. With the information provided from this inventory, Grenada has a solid RAC sector emissions estimate as a basis for planning and implementing mitigation measures in the RAC sector as a part of its NDCs.

3 Assuming a national GHG emission reduction of 400 kt CO2eq in 2030 compared to BAU (NC2, Figure 87)

1 INTRODUCTION

1.1 PROJECT FRAMEWORK

This greenhouse gas (GHG) inventory was compiled in the frame of the project "Cool Contributions fighting Climate Change (C4)". This project was commissioned to the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH for implementation by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under the International Climate Initiative (IKI). The project aims to develop a GHG mitigation strategy in the refrigeration and air conditioning (RAC) sector as part of Grenada's Nationally Determined Contributions (NDCs), including establishing parameters for increased energy efficiency in RAC technology, finding solutions for greener RAC technologies and fostering their marketability.

The project works closely with the following public authorities:

» National Ozone Unit (NOU) under Ministry of Finance and Energy;

» Energy Division;

» Customs department;

» Department of Trade;

» Grenada Bureau of Standards;

» Physical Planning Unit;

» NDA (National designated Agency);

» Grenada Refrigeration Air-Conditioning and Ventilating Association (GRAVA)

» Grenada Electricity Services (GRENLEC);

» T.A. Marryshow Community College (TAMCC)

as well as other public institutions and private sector companies. Close coordination among these entities is considered essential to promote a coherent and sustainable development of Grenada's RAC sector.

The purpose of the RAC GHG inventory is to get an overview of the current state of the GHG emissions of the RAC sector in Grenada. More specifically, the report intends to provide information on the following topics:

» Business-as-Usual (BAU) GHG emissions resulting from refrigerant and energy consumption of the RAC sector

» Potential market penetration of energy-efficient appliances using refrigerants with low Global Warming Potential (GWP)

» Potential to mitigate GHG emissions from refrigerant use and energy consumption in the RAC sector

This report describes the currently installed RAC appliances in Grenada, their energy consumption, the refrigerants used and the respective GHG emissions. RAC technologies currently deployed are compared with international best practice technologies in order to determine the related emissions mitigation potential. Future trends in each of the RAC sub-sectors are analysed with respect to both BAU and MIT scenarios.

1.2 IMPORTANCE AND BENEFITS OF RAC SECTOR INVENTORIES

Inventories based on the stock of installed appliances and average technical parameters per appliance showing energy and refrigerant use as sources of GHG emissions provide a sound base for the calculation of GHG emissions and thus a starting point for all GHG emission reduction activities.

This appliance-based RAC inventory provides information on:

» sales and stock of appliances per sub-sector as well as growth rates per sub-sector;

» technical data on systems, which determines their GHG emissions such as average energy efficiency, refrigerant distribution and leakage rates;

- GHG emissions on a RAC unit basis;
- GHG emissions for the whole RAC sector including the distribution between direct and indirect emissions;
- future projections of RAC-related GHG emissions;
- mitigation scenarios based on the introduction of different technical options.

The collected information can be used for the following purposes:

- To identify key sub-sectors with the highest GHG emissions as well as the highest emission reduction potential based on available technologies. An RAC inventory is an important step in the planning, development and implementation of mitigation roadmaps.
- To provide the basis for country-wide GHG emission data that can be used for reporting under the UNFCCC.
- To project the GHG emissions development in the future.
- To inform sectoral RAC mitigation plans for the development of updated, more specific NDC targets[4].
- To provide the foundation for the development of effective policy instruments such as Minimum Energy Performance Standards (MEPS) and (energy) labelling, as well as bans on refrigerants with high GWP.
- To give an indication of the impact of legislation on stakeholders in different sub-sectors.
- To form the basis for a Measuring, Reporting and Verification (MRV) system or a product database.
- To support the development of project proposals with the aim of reducing GHG emissions in the RAC sector, such as Nationally Appropriate Mitigation Actions (NAMAs).

Based on the advantages and different purposes, the following Grenadian stakeholders can benefit from the RAC inventory:

- National Climate Change Committee: for GHG control and mitigation planning as well as the UNFCCC reporting on HFCs. The outcomes of this inventory can be used to support the F-gas reporting included in the National Communications and Biennial Update Reports. An independent verification of the assumptions used within the inventory is strongly recommended.
- The NOU: for the control and planning of HCFC phase-out and future reduction plans of the HFC phase-down as well as the reporting requirements under the Montreal Protocol.
- The RAC sector: by being able to comply with the HCFC and HFC consumption targets under the Montreal protocol through the timely transition to zero ozone depleting potential (ODP) and low-GWP refrigerants
- The energy sector, notably the Energy Division and Grenada Electricity Services Limited (GRENLEC): for the planning of energy use and conservation, as well as energy security.
- The Ministry of Finance: for support function of licensing and quota systems, monitoring of trade and providing fiscal incentives to facilitate the low GWP refrigerant transition process.
- The Grenada Bureau of Standards: for the establishment and enforcement of appropriate standards, codes and practices.

4 NDCs have been formulated, but overall targets are not yet broken down into individual sectors

1.3 FACTORS INFLUENCING THE GROWTH OF RAC APPLIANCES

The demand for RAC appliances in Grenada is growing. Current and future demand drivers include economic growth, a growing population and number of households and a growing urbanisation (Oppelt, 2013). These factors are listed in Table 1 and indicate future growth of Grenada's RAC sector.

An additional driver for future demand is the expected increase of temperature. Grenada's climate is characterised by an already high annual average temperature of 26 °C. Future scenarios project an increase in average by 0.7°C to 2.2°C by the 2050s and by 1 to 3.7°C by the 2080s[6]. The climate predictions suggest an increasing demand for air conditioning (AC) equipment and for refrigerated food.[7]

TABLE 1: STATISTICAL DATA OF GRENADA (CIA, 2019)

GDP GROWTH [%] (2017 EST.)	POPULATION (2018 EST.)	POPULATION GROWTH RATE [%] (2018 EST.)	NUMBER OF HOUSEHOLDS (2017 EST.)	URBANISATION [%] (2017)	CO_2 [MT] (2017 EST.)	GHG [T CO_2EQ] (2014)[5]
5.1	112,207	0.42	40,070	36.3	0.28	406,600

1.4 THE RAC SECTOR IN GRENADA

There is no domestic production of oil or refrigerant in Grenada, so these products are imported. Grenada is therefore dependent on the availability of refrigerants on the international market. The refrigerants predominantly used in Grenada include the ozone-depleting HCFC R22 and the non-ozone depleting HFCs and HFC blends, such as R134a, R404A, R407C and R410A, all of which have high GWP greater than 1,000. Import data from 2015 registered the approximate amounts of R22 (3.9 metric tonnes), R134a (3.5 metric tonnes), R404A (0.9 metric tonnes), R407C (0.9 metric tonnes) and R410A (1.8 metric tonnes) used as refrigerants in the RAC sector. The low-GWP natural refrigerants R717 (ammonia), R744 (CO_2) and the hydrocarbon refrigerants R600a and R290 are currently used in small amounts, but with an increasing trend. R717 is primarily used for cold storage and food processing, R744 for commercial refrigeration and R600a for domestic refrigeration. The first 30 split AC systems using R290 have recently been installed in Grenada as part of the C4 country programme implemented by GIZ. The most recent trends show that split ACs based on the refrigerants R290 and R32 are entering Grenada's market as two local suppliers are already commercialising such appliances.[7]

The recirculation of recovered refrigerants is possible in principle. Recovery units were supplied and their use has been demonstrated in CFC and HCFC phase-out activities under the HPMP. Twenty collection points have been set up by the NOU. However, a lack of reclamation or disposal and destruction infrastructure leads to the accumulation of refrigerants in individual workshops, with high risks of leaking to the environment.

1.5 ENERGY PRODUCTION AND CONSUMPTION

In 2014, Grenada's electricity generation had an installed capacity of 53.3 MW, with diesel-based generation dominating the energy production. Around 1 MW of Grenada's installed power capacity is based on renewable energy sources (mainly solar PV and wind energy). The slow development in the solar PV installations has repeatedly pushed back Grenada's goal for renewable energy share (IDB, 2015). According to a CARICOM member states survey by the Worldwatch Institute in 2015, Grenada aimed to produce 20% of its electricity from renewables by 2017 and targets 100% by 2030 (IDB, 2015), representing a significant challenge. Grenada's energy production needs are projected to grow rapidly, expected to double from 2015 until 2027. Mitigation measures in the RAC sector resulting in lower energy consumption can therefore significantly contribute to alleviate the pressure on the national power supply and energy security.

The majority of Grenada's total energy consumption in 2013 can be attributed to the transportation sector, followed by the residential sector and the commercial sector (see Figure 5). Industry plays a subordinate role in electricity consumption, while other consumption includes street lighting and government consumption.

5 Grenada's Second National Communication to the UNFCCC

6 Grenada's Second National Communication to the UNFCCC

7 Collection and analysis of data for this inventory had been conducted from year 2017 until early 2019. The most recent trends indicate higher R290 and R32 shares of split ACs than the assumptions made in the inventory model.

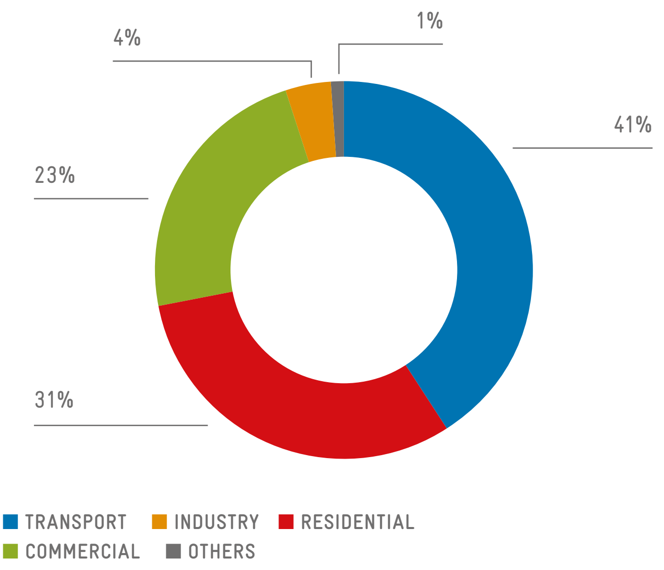

FIGURE 5: ENERGY CONSUMPTION BY SECTOR. SOURCE: IDB, 2015

1.6 RAC STAKEHOLDERS

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

TABLE 2: OVERVIEW OF INSTITUTIONS RELEVANT FOR THE RAC SECTOR

MINISTRY/INSTITUTION	DUTIES/FUNCTIONS/RESPONSIBILITIES
NATIONAL OZONE UNIT GRENADA UNDER MINISTRY OF ENERGY AND FINANCE	The NOU is responsible for the implementation of the program and activities under the Montreal Protocol in phasing out the production and consumption of all Ozone depleting substances.
NATIONAL CLIMATE CHANGE COMMITTEE (NCCC)	Its objective is to facilitate awareness raising and mainstreaming climate change considerations in national development plans.
MINISTRY OF CLIMATE RESILIENCE AND THE ENVIRONMENT	Responsible for the coordination of all environmental protection activities
DEPARTMENT OF ECO-NOMIC AND TECHNICAL COOPERATION	Responsible for Resource mobilisation
GRENADA REFRIGERATION, AIR CONDITIONING AND VENTILATING ASSOCIATION (GRAVA)	Representation of companies and individuals providing services in the RAC sector.
CARIBBEAN COMMUNITY (CARICOM)	The Caribbean Community (CARICOM) is an organisation of fifteen Caribbean nations and dependencies whose main objective is to promote economic integration and cooperation among its members, to ensure that the benefits of integration are equitably shared, and to coordinate foreign policy.
ORGANISATION OF EASTERN CARIBBEAN STATES (OECS)	An international inter-governmental organisation dedicated to economic harmonisation and integration, protection of human and legal rights, and the encouragement of good governance among independent and non-independent countries in the Eastern Caribbean.
ALLIANCE OF SMALL ISLAND STATES (AOSIS)	Alliance of Small Island States (AOSIS) is an intergovernmental organization of low-lying coastal and small island countries. Established in 1990, the main purpose of the alliance is to consolidate the voices of Small Island Developing States (SIDS) to address global warming.

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1.7 RAC-RELATED LEGISLATIVE AND POLICY NETWORK

Regulatory frameworks are required for the implementation of most changes towards more environmentally-friendly technology alternatives in the RAC sector. Grenada has committed to a low emission development pathway through several international agreements. Compliance with these is expected to bring significant economic benefit and reduce Grenada's carbon footprint. This process is currently under way and thus offers an opportunity to include emission reduction targets for the RAC sector.

Policies targeting the RAC sector so far are mainly driven by the HPMP which focuses on capacity development and technology conversion in the RAC and foam sectors for the phase-out of HCFCs. Specific actions and objectives are outlined below.

1.7.1 Energy policy

Grenada's National Energy Policy serves as the main guide for the government to achieve sustainable energy and low carbon development. It establishes and enables a dynamic incentive regime, both in a regulatory and an institutional way, to achieve a more diversified and sustainable energy sector. Grenada's NDC includes actions to reduce the level of vulnerability of its energy sector, while aiming at using existing and emerging technologies. Grenada's energy supply is highly dependent on importing fossil fuels. But more recently, efforts are ongoing to introduce and expand alternative technologies, such as solar and geothermal energy. Grenada is also providing incentives to use solar technologies, which encourage both businesses and individuals to further explore its potential. A geothermal power potential of 15 MW was estimated. However, the anticipation of increasing electricity consumption and the lack of a mandatory energy labelling scheme are considered as hindrances in the fight against climate change.

Until now, no Minimum Energy Performance Standard (MEPS) have been established for RAC equipment in Grenada. However, CARICOM has established the CARICOM Renewable Energy Efficiency Building Code (CREEBC) and a regional standard for energy-efficient labels for refrigerators. A similar energy-efficient labelling standard is being developed for air-conditioners. The Grenada Bureau of Standards has already established Technical Committees (TC) for the establishment of the energy labels for RAC equipment and the CREEBC. The TC for the energy labels for refrigerators have submitted the draft standard to the Commission of the Bureau of Standards for its approval before submitting for public comments. Similarly, CARICOM is also developing MEPS for member states to adopt and implement. There is also an Organisation of Eastern Caribbean States (OECS) Building Code that has been established and should be in operation in the OECS territories. To guide the market to more energy-efficient products and ban less efficient units, the introduction of mandatory MEPS is recommended. Introduction of MEPS pushes the average market energy-efficient towards higher values. More specific targets will help to streamline the process. The following policies are already established:

- » The Grenada Climate change policy (2017-2021) provides exemptions on VAT on renewable energy and energy-efficient technologies.
- » Energy policies spanning from MEPS and labelling requirements to incentive programs to accelerate the uptake of high energy-efficient equipment are in the early stages of development (Energy Efficiency Act).
- » The Electricity supplies Act (2016) enabling the implementation of new methodologies in renewable energy and energy efficiency programs.

1.7.2 RAC-related climate policies and agreements

The current NDC includes a GHG emissions reduction target of 30% of the 2010 level by 2025, with an indicative reduction of 40% of the 2010 level compared to the BAU scenario by 2030. To achieve this goal, Grenada plans to increase electricity production from renewable energy sources and enhance energy efficiency. Those pledged reductions will not be possible without taking measures in the RAC sector.

Whilst the NDC states this as an economy-wide target, the RAC sector or its sub-sectors are not explicitly mentioned. Grenada has committed to the reduction of its GHG emissions by signing several international and regional initiatives and expressing commitment to United Nations processes related to Climate Change. Grenada's past and current adaptation actions have been formulated in the National Climate Change Policy and Action Plan (NCCPAP – 2007-2011), which is currently being reviewed. Moreover, Grenada's Cabinet has already approved the National Climate Change Adaptation Plan (NAP) 2017-2021 for Grenada, which sets out a number of measures to mitigate against the impact of climate change in key sectors.

Specific refrigerant-related measures have been carried out under the Montreal Protocol's Terminal Phase-out Management Plans (TPMP) for chlorofluorocarbons (CFCs) and HCFC Phase-out Management Plans (HPMP). Imports of ODS refrigerants and their alternatives are monitored, but there is no mandatory reporting or monitoring on where the refrigerants are used and if they are collected for reuse or destruction. Technician training on proper refrigerant handling exists for fluorinated substances and is presently extended to cover natural refrigerants, as well. Until now, there are no nationally adopted refrigerant standards. However, the NOU has worked along with the Grenada Bureau of Standards to establish voluntary standards for "*Requirements for Labelling: Labelling of Refrigerant containers*" (GDS 135:2016) and a "*Code of Practice for the Safe Use, Handling, Storage and Transportation of Refrigerants including Flammable Refrigerants*" (GDS139:2018). The absence of safety standards for flammable or toxic refrigerants additionally creates uncertainty on what is considered a safe installation. The following strategies could be adopted in the Grenadian RAC market:

- » The transition to low-GWP refrigerants by favouring the use of systems with low-GWP through lowering import tax or other incentives, banning high-GWP refrigerants.
- » Ensuring proper installation and service of equipment to maintain safety and improve energy efficiency by adapting regulations to international safety and energy design standards as well as capacity building measures.
- » Efforts on expanding the capacity of skilled technicians working on natural or other low-GWP refrigerants is being undertaken in Grenada and is also anchored in the vocational training scheme. Further, establishing a compulsory certification scheme would benefit the fast transition to emissions mitigation and improved energy efficiency.

Considering the large share of the RAC sector in the country's overall GHG emissions, Grenada's future NDC reflects the significant potential of the RAC sector and covers all RAC appliances with direct and indirect emissions. In addition, with regard to the Grenadian HFC phase-down schedule set out in the Kigali Amendment of the Montreal Protocol, the government may consider to thoroughly explore different technology options and take near-term decisions in terms of how and when to switch to low-GWP refrigerants in order to ensure a non-disruptive and cost-effective transition. Grenada was one of the early countries to ratify the Kigali Amendment in May 2018, underlining its commitment to a timely HFC phase-down.

The transition towards natural refrigerants will yield lower direct emissions, and simultaneously allow progress on energy efficiency of key appliances, which will result in reduced indirect emissions. Hence, with an integrated policy approach covering both the transition to low-GWP refrigerants and improvement of energy efficiency in the RAC sector, Grenada can avoid up to 111 kt CO_2eq annually by 2050 (see sub-chapter 3.4 for detailed information).

2 SCOPE OF THE INVENTORY

The inventory covers GHG emissions from the RAC sector based on a stock model covering the major RAC sub-sectors and their appliances. The inventory is based on stock data and assumptions, while historic growth trends and dynamics help to determine the future stock. Emissions are calculated for each sub-sector and appliance type based on critical technical parameters determining direct and indirect emissions.

This inventory covers

» The calculated mitigation potential of the RAC sector of Grenada, applying the Tier 2, 2006 methodology of the Intergovernmental Panel on Climate Change (IPCC);

» For each of the sub-sectors and their respective appliance types (Table 3), an inventory of historic and future unit sales and stock data is established;

» For each appliance type, the historic, current and future energy and refrigerant use and their respective emissions are estimated;

» Currently deployed RAC technologies are compared with international best practice technologies with view to their GHG mitigation potential on a unit basis;

» Future trends of RAC sub-sectors are analysed both with respect to BAU and MIT scenarios.

The RAC sub-sectors and all appliances covered by the inventory are categorised according to key sub-sectors as outlined in the RAC NAMA Handbook, Module 1: Inventory (Heubes and Papst, 2014).

TABLE 3: RAC SUB-SECTORS AND RELATED SYSTEMS

SUB-SECTOR	SYSTEMS
UNITARY AIR CONDITIONING	Self-contained air conditioners Split residential air conditioners Split commercial air conditioners Duct split residential air conditioners Commercial ducted splits Rooftop ducted Multi-splits
CHILLERS	Air conditioning chillers Process chillers
MOBILE AIR CONDITIONING	Car air conditioning Large vehicle air conditioning
DOMESTIC REFRIGERATION	Domestic refrigerators
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

Out of the above-mentioned appliances, process chillers and large vehicle AC have not been included as separate classification in this inventory, but they are contained in the respective overall sub-sector. Self-contained air conditioners have not been found relevant in Grenada's unitary AC sub-sector. As outlined in the methodology below, the inventory is based on actual emissions gathered at the unit or appliance level as opposed to inventories based on the bulk refrigerant consumption across different sectors. The latter approach is usually applied for estimating emissions as part of ozone depleting substances (ODS) alternative surveys.

Future projections have been included, mostly using growth rates from expert judgements or projections derived from economic and population growth.

2.1 METHODOLOGY

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

While alternative refrigerant inventories, such as ODS alternative surveys, are typically based on the Tier 1 methodology, this inventory is based on the IPCC Tier 2 methodology to cover not only refrigerant related emissions and their mitigation options, but also GHG emissions from the energy use and their mitigation option. In addition, the Tier 2 methodology allows for the preparation of GHG mitigation actions (such as NAMAs) in relevant RAC sub-sectors and further NDC development and review. As Tier 2 inventories are based on unit appliances, a MRV system of mitigation efforts can be established at the unit level.

Tier 1 and Tier 2 methodologies have the following basic differences[8]:

» Tier 1: emissions are calculated based on an aggregated sector-based level (Heubes and Papst, 2014; Penman, 2006).

» Tier 2: emissions are calculated based on a disaggregated unit-based level (Heubes and Papst, 2014; Penman, 2006).

The difference between the Tier 1 and Tier 2 methodology are further illustrated in Figure 6.

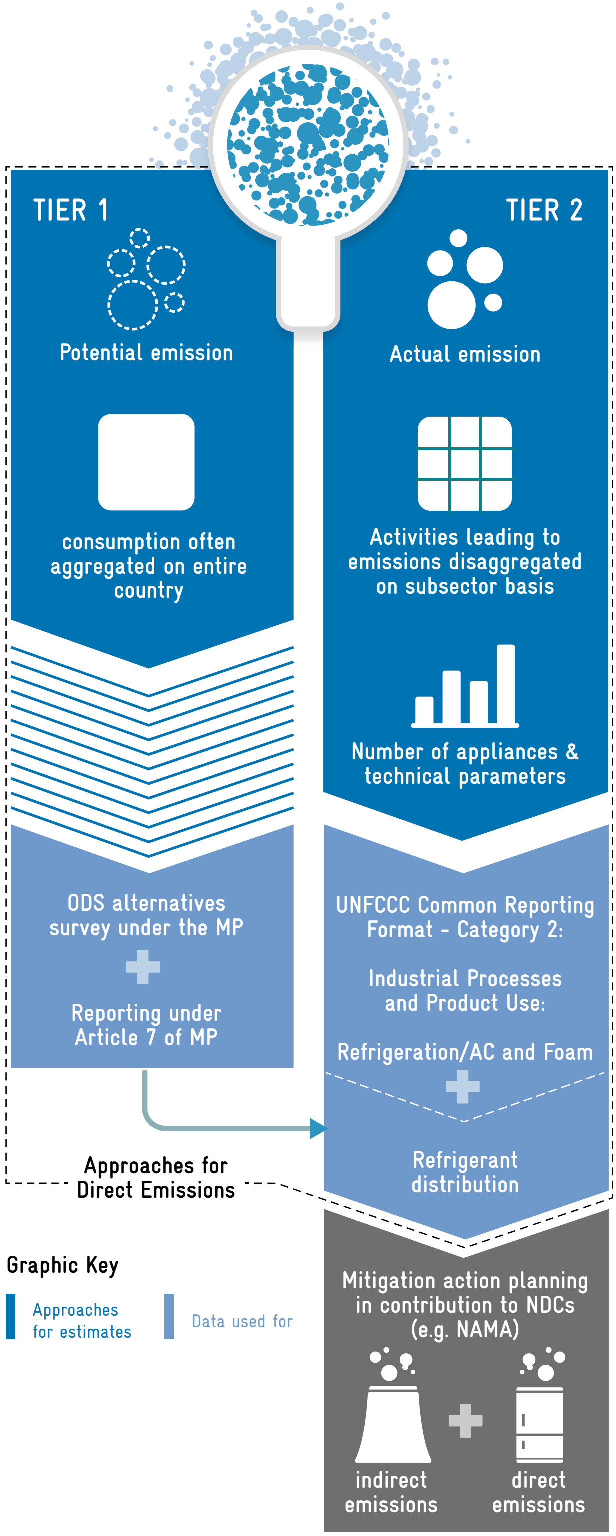

FIGURE 6: APPROACHES FOR GHG EMISSION ESTIMATES RELEVANT TO THE RAC&F SECTOR (MUNZINGER ET AL., 2016)

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

The Tier 2 methodology used in this report accounts for direct and indirect emissions at the unit level as illustrated in Figure 7 for the stock of appliances in use, their manufacturing and disposal emissions. Indirect emissions result from electricity generation for cooling, considering the annual electricity consumption and Grenada's grid emission factor (GEF). Direct emissions include refrigerant emissions from leakage of refrigerant gases during manufacture, servicing, operation and at end-of-life of cooling appliances. The Tier 2 methodology goes beyond the Tier 1 approach which only focuses on the demand and use of refrigerants. The Tier 1 approach does not include indirect emissions from the energy use of appliances.

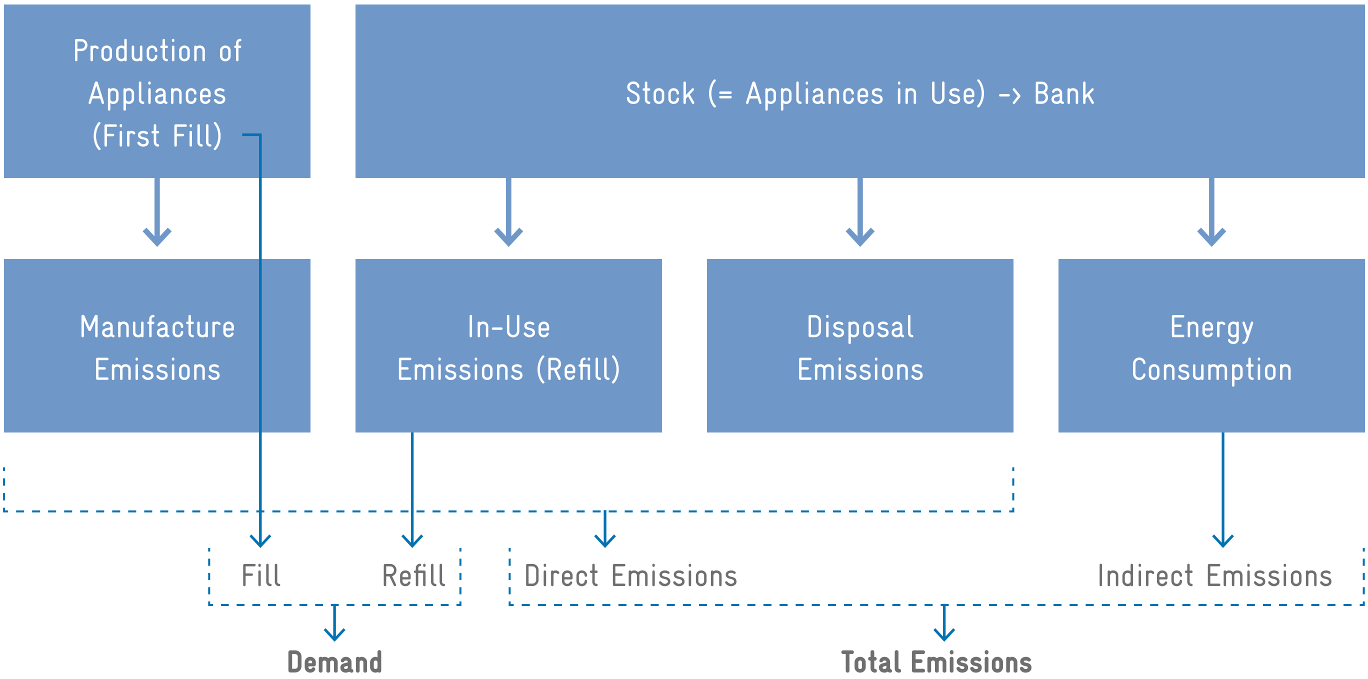

FIGURE 7: OVERVIEW RAC REFRIGERANT DEMAND VERSUS RAC TOTAL EMISSIONS

Refrigerant consumption is accounted for in all stages during the product life of the equipment, ranging from

» Refrigerants that are filled into newly manufactured products;

» Refrigerants in operating systems (average annual stocks);

» Refrigerants remaining in products at decommissioning.

2.2 DATA COLLECTION PROCESS

The following steps were taken to complete the inventory:

Step 1 National kick-off workshop with relevant stakeholders.

Step 2 Preparation of questionnaires and list of stakeholders for selected sub-sectors.

Step 3 Sending questionnaires to stakeholders.

Step 4 Interviews with stakeholders to explain the required data.

Step 5 Validation checks of primary data and gathering of complementary information from secondary and tertiary data, call-backs and compilation of data received through questionnaires into the master sheets from data entry forms.

Step 6 Verification of data during a stakeholder workshop on 18 July 2018.

The data for this inventory were collected mainly from primary and secondary sources.

The following activities were carried out to obtain information:

» For **primary** data, a survey was conducted. Grenada's major end users of RAC equipment were identified and contacted. 30% of the identified actors (22 out of 72) provided data[9]. However, not all of the requested information was filled out, especially regarding technical data of the RAC appliances. Sales numbers have been partially provided[10], which is the reason why our model is based on stock units. In order to reach a satisfactory data level, an analysis of the supermarket stock and a survey for transport refrigeration have been conducted. The total stock was then calculated from the retrieved data and a scaling factor to close the gap from the number of users included in the data survey to the countrywide total of end users for each sub-sector. Few information has been specified by RAC technicians and servicing companies. Data gaps on technical and other sector-relevant information were filled by secondary and tertiary data, use of a global RAC data base and estimations.

» **Secondary** data shared by the NOU for public buildings provided input regarding the unitary AC sub-sector. Additionally, a study of Grenada's split AC sector within the C4 programme by GIZ Proklima (2018) was used for energy efficiency characteristics of split ACs.

» **Tertiary** data was used from statistical sources. A previous survey by the NOU under the Ministry of Finance and Energy reported the number of refrigerators used in households. The total number of households also served as an indicator for residential unitary AC (assumption of 27% AC use applied to the latter). Data on registered vehicles by the Traffic Department of the Royal Grenada Police Force was used to estimate the number of mobile AC (MAC) in cars.

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

» Reluctance of relevant actors to participate in the survey and difficulties in filling out questionnaires.

» Despite feedback loops, questionnaires returned incomplete. Especially the technical data and sector indicators remained full of gaps (e.g. substances used on the servicing of equipment, electricity consumption of facilities and knowledge of the number of systems installed in many facilities).

» No comprehensive primary data could be obtained for technical data in many cases. The sources mentioned above were used to fill the gaps.

» Lack of comprehensive data on technicians in the informal sector and lack of servicing records by these technicians.

Due to those difficulties, the primary data collected was incomplete. For this reason, data from statistics and registered vehicles were often used instead of – or as supplements to – the collected data. The assumptions are presented in detail in the following chapters.

2.3 MODELLING PARAMETERS

For the data modelling of this inventory the parameters were derived as average values from primary data collection as shown in Table 4.

The modelling parameters are derived from questionnaires and complementary sources where possible gaps were filled with default values obtained from the Green Cooling database. Among others, the assumption of leakage rates (service and disposal emission factors) required comprehensive use of default values. A small number of actors provided basic information in this area, but the indications given do not reach a reliable extent that would justify their use in this model.

9 A list of responding companies is provided in the Annex, see section 5.1

10 Response rate of 43% (3 out of 7), full of gaps and not representative enough to build the model on these figures.

TABLE 4: MODELLING PARAMETERS FOR BAU AND MIT SCENARIO

EQUIPMENT TYPE	LIFETIME [YEARS]	MAIN REFRIGER-ANTS[10]	INITIAL CHARGE (IC) [KG]	COOLING CAPACITY (KW)	SERVICE EMISSION FACTOR[11] [% OF IC]	DISPOSAL EMISSION FACTOR [% OF IC]
RESIDENTIAL SPLIT AC	15*	R410A, R32	1.25*	3.5	0.2*	0.95*
COMMERCIAL SPLIT AC	15*	R410A, R32	1.5	5.2	0.2*	0.8*
DUCTED SPLIT AC	10*	R410A	5.8	30*	0.2*	0.9*
ROOFTOP DUCTED	10*	R410A	21.5	36	0.3*	0.75*
MULTI-SPLITS	15*	R22, R407C, R410	4.6	4.9	0.2*	0.8*
AIR CONDITIONING CHILLERS	20*	R134a, R407C, R410A	134	264	0.2*	0.95*
CAR AIR CONDITIONING	15*	R134a (R1234yf)	0.6*	5.0*	0.25*	1.0*
DOMESTIC REFRIGERA-TION	20*	R134a, R600a	0.175*	0.20	0.1*	0.8*
STAND-ALONE EQUIP-MENT	15*	R134a, R404A	0.4*	0.80	0.1*	0.8*
CONDENSING UNITS	20*	R404A		0,20	0,02*	0,8*
CENTRALISED SYSTEMS FOR SUPERMARKET	20*	R22, R134a, R404A	5.9	8.8	0.3*	0.85*
INTEGRAL UNITS (INDUSTRIAL)	15*	R717	230*	100*	0.3*	0.9*
INDUSTRIAL CONDENS-ING UNITS	20*	R404A	45	2.8	0.3*	0.8*
CENTRALISED SYSTEMS	30*	R717	7.5	11.6	0.3*	1.0*
REFRIGERATED TRUCKS/TRAILERS	15*	R134a	6.5*	3.0	0.25*	0.5*

*** default values from the Green Cooling Initiative database**

The energy efficiency ratio (EER) values of all equipment types are calculated assuming a stepwise increase based on increments of 5 to 10 years as shown in Table 5 and Table 6 for BAU and MIT scenario, respectively. The current EER averages are taken from the inventory, where adequate data have been provided. Otherwise, default value from the Green Cooling Initiative database are used. Current EER values for ductless split AC (both residential and commercial) were oriented on the results from the study of Grenada's split AC sector within the C4 programme (GIZ Proklima, 2018).

11 Numbers in brackets are relevant for the future projection only

12 This value corresponds to the annual refrigerant leakage rate during the useful life of the appliance. Values taken from http://www.green-cooling-initiative.org and modified according to stakeholder/industry consultation..

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TABLE 5: ENERGY EFFICIENCY RATIO (EER[13]) PARAMETERS FOR BAU SCENARIO (SALES)

EQUIPMENT TYPE	2017	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	3.20	3.26	3.31	3.36	3.46	3.56
COMMERCIAL SPLIT AC	3.30	3.36	3.41	3.46	3.56	3.66
DUCTED SPLIT AC	3.35	3.41	3.45	3.48	3.51	3.53
ROOFTOP DUCTED	2.61	2.66	2.71	2.76	2.82	2.90
MULTI-SPLITS	3.45	3.51	3.59	3.66	3.82	3.90
AIR CONDITIONING CHILLERS	2.95	3.02	3.09	3.14	3.22	3.31
CAR AIR CONDITIONING	2.81	2.86	2.93	3.02	3.20	3.36
DOMESTIC REFRIGERATION	2.00	2.06	2.14	2.19	2.28	2.34
STAND-ALONE EQUIPMENT	1.47	1.48	1.52	1.56	1.60	1.64
CONDENSING UNITS	2.16	2.17	2.19	2.20	2.26	2.34
CENTRALISED SYSTEMS FOR SUPERMARKET	2.08	2.11	2.14	2.16	2.19	2.25
INTEGRAL UNITS	2.18	2.21	2.27	2.29	2.35	2.43
INDUSTRIAL CONDENSING UNITS	2.08	2.11	2.14	2.16	2.23	2.25
CENTRALISED SYSTEMS	3.35	3.41	3.52	3.56	3.62	3.69
REFRIGERATED TRUCKS/TRAILERS	2.33	2.34	2.35	2.36	2.41	2.46

13 Please note that EER values have been used for this inventory. These should not to be confused with the SEER (seasonal energy efficiency ratio). The SEER takes local conditions including the climate into account and therefore cannot be converted into EER by a fixed conversion number.

TABLE 6: ENERGY EFFICIENCY (EER) PARAMETERS FOR MITIGATION (MIT) SCENARIO (SALES)

EQUIPMENT TYPE	2017	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	3.20	3.26	4.40	5.00	6.00	6.60
COMMERCIAL SPLIT AC	3.30	3.36	4.50	5.10	6.10	6.70
DUCTED SPLIT AC	3.35	3.41	3.68	3.92	4.39	4.62
ROOFTOP DUCTED	2.61	2.66	2.87	3.17	3.56	3.74
MULTI-SPLITS	3.45	3.76	4.11	4.43	4.92	5.33
AIR CONDITIONING CHILLERS	2.95	3.02	3.27	3.61	4.12	4.58
CAR AIR CONDITIONING	2.81	2.86	2.98	3.29	3.86	4.60
DOMESTIC REFRIGERATION	2.00	2.06	2.22	2.44	2.91	3.44
STAND-ALONE EQUIPMENT	1.47	1.48	1.90	2.34	2.98	3.63
CONDENSING UNITS	2.16	2.17	2.74	2.86	3.27	4.14
CENTRALISED SYSTEMS FOR SUPERMARKET	2.08	2.11	2.16	2.24	2.62	2.91
INTEGRAL UNITS	2.18	2.21	2.24	2.28	2.41	2.51
INDUSTRIAL CONDENSING UNITS	2.08	2.11	2.27	2.51	2.70	2.79
CENTRALISED SYSTEMS	3.35	3.41	3.61	3.76	4.08	4.35
REFRIGERATED TRUCKS/TRAILERS	2.33	2.34	2.41	2.49	2.62	2.73

The GEF is a measure of CO_2 emission intensity per unit of electricity generation in the total grid system. In the modelling of GHG emissions we use a GEF of 0.6244 kg CO_2/kWh. The GEF is assumed to remain constant for the BAU and regular MIT scenario. Reduction of the GEF would lower indirect emissions and thus result in a decrease of total emissions and the total mitigation potential.

Historic growth rates as well as population and economic growth trends were considered for modelling future unit sales in the respective sub-sectors as listed in Table 7. Expert judgments drawn from experiences in recent market trends played a primary role particularly for the UAC sub-sector.

TABLE 7: ASSUMED ANNUAL FUTURE GROWTH RATES OF APPLIANCE SALES

SUB-SECTORS	APPLIANCE TYPES	2016-2020	2021-2030	2031-2050
UNITARY AIR CONDITIONING	Split residential air conditioners	10.0%	7.0%	3.5%
UNITARY AIR CONDITIONING	Split commercial air conditioners	7.0%	2.3%	1.2%
UNITARY AIR CONDITIONING	Ducted splits	7.0%	2.3%	1.2%
UNITARY AIR CONDITIONING	Rooftop ducted	7.0%	2.3%	1.2%
UNITARY AIR CONDITIONING	Multi-Splits	7.0%	2.3%	1.2%
CHILLERS	Air conditioning chillers	4.0%	1.3%	0.7%
MOBILE AIR CONDITIONING	Car air conditioning	3.0%	1.0%	0.5%
DOMESTIC REFRIGERATION	Domestic refrigeration	1.7%	0.6%	0.3%
COMMERCIAL REFRIGERATION	Stand-alone equipment	3.0%	1.0%	0.5%
COMMERCIAL REFRIGERATION	Condensing units	3.0%	1.0%	0.5%
COMMERCIAL REFRIGERATION	Centralised systems for supermarkets	3.0%	1.0%	0.5%
INDUSTRIAL REFRIGERATION	Integral units	3.0%	1.0%	0.5%
INDUSTRIAL REFRIGERATION	Industrial condensing units	3.0%	1.0%	0.5%
INDUSTRIAL REFRIGERATION	Centralised systems	3.0%	1.0%	0.5%
TRANSPORT REFRIGERATION	Refrigerated trucks/trailers	4.0%	1.3%	0.7%

3 RESULTS

3.1 SUB-SECTOR SALES AND STOCK DATA ANALYSIS

Data collection and data review of secondary data targeted the stock of installed RAC equipment. Primary data were collected from 22 end-users across several branches from the commercial sector (supermarkets, hotels, food processing, one shopping mall) and the public sector (office buildings, one university). Few responses were received from the servicing sector. The RAC stock installed in the residential sector was estimated by utilisation of national statistics.

The sales and stock development of the key sub-sectors was analysed. The stock analysis considers the phase-in of new equipment driven by sales development and the phase-out of old equipment using parameters collected in the survey or standardised assumptions for the lifetime of the equipment.

Primary data collection with questionnaires and stakeholder interviews were undertaken for UAC, domestic, commercial and industrial refrigeration. The fleet of refrigerated vehicles was estimated by sector experts. Due to the unavailability of national data, the numbers of MAC in cars and large vehicles were estimated from the total vehicle stock.

3.1.1 UAC sales and stock data

For UAC, it was assumed that currently 11,000 households (27% of total) and all 5,000 small commercial energy consumers (shops and offices) use one ductless split AC appliance each. Split AC systems in hotels and public buildings were considered additionally based on the received inventory data. Ductless splits were divided into 62% residentially used and 38% commercially used units in 2017. However, stronger growth rates are assumed for residential split AC so that its share is expected to rise up to 73% in 2030 and 81% in 2050. The UAC sub-sector is composed mainly by ductless split AC systems, completed by a combined share of ducted split, rooftop ducted and multi-splits of around 2%. Self-contained AC systems (e.g. window type) have not been identified in Grenada.

The resulting stock and sales numbers for the 2010-2050 timeline are presented in Figure 8. The UAC stock is projected to more than quadruple in this period, from around 15,500 units in 2010 to 69,000 units in 2050. This corresponds to an average annual growth rate of 4% over the 40-year time period. The growth is highest in the current period from 2018 to 2020 but continues strong growth thereafter (see also Figure 7). The calculated sales increase over the data collection period 2010-2016 from about 1,300 to more than 1,600 units.

3.1.2 Chillers sales and stock data

AC chillers are commonly used in large commercial and public buildings. Within the survey, the General Hospital, hotels and a university in Grenada have been identified as operators of chillers. Process chillers which are commonly used for food processing or other industrial purposes have not been registered. As a result, the calculation was done using a current stock of 21 AC chillers (in 2017) and annual sales of around 2 chillers (Figure 9). The stock is estimated to increase to 27 chillers in 2030 and 31 chillers in 2050.

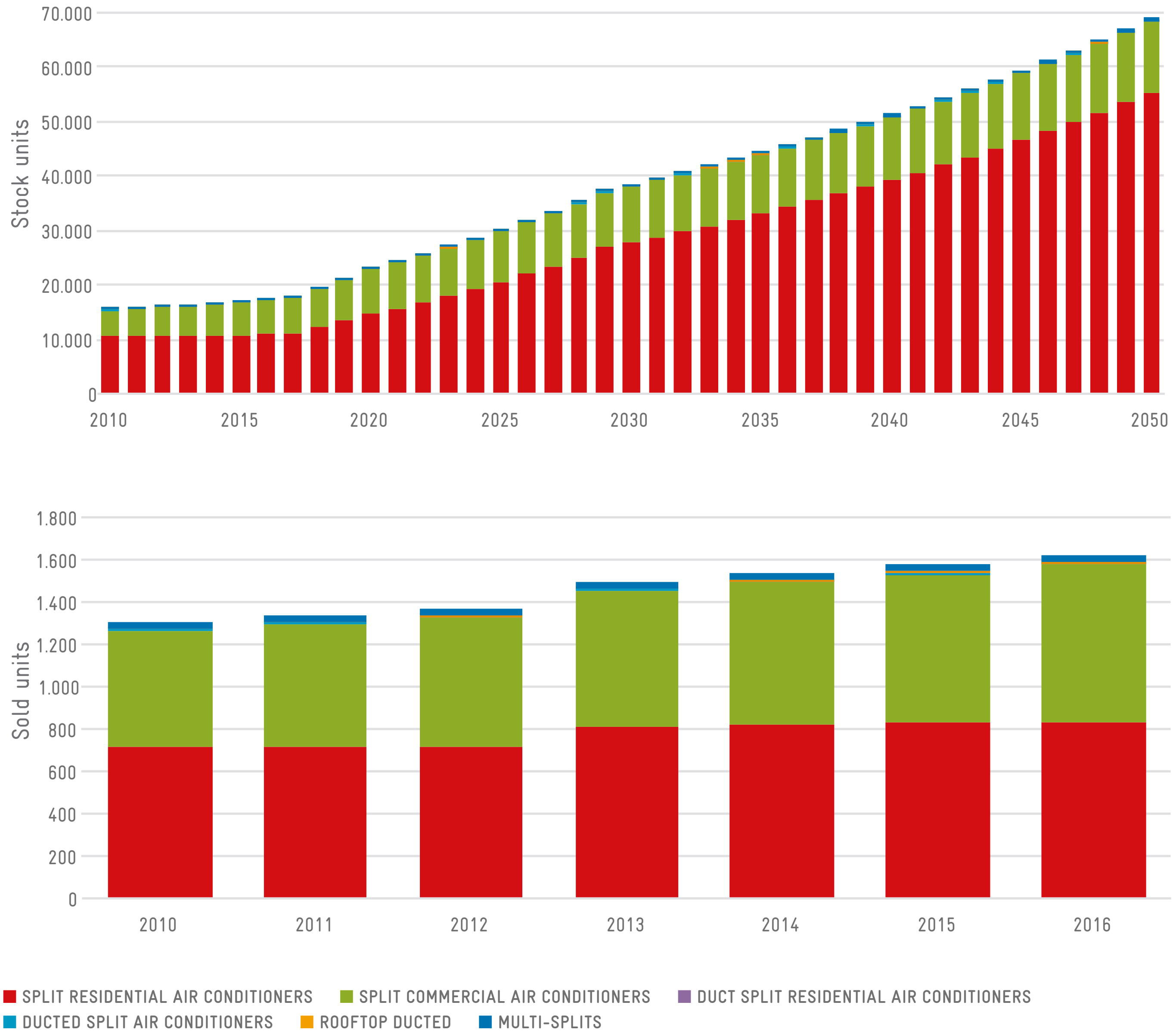
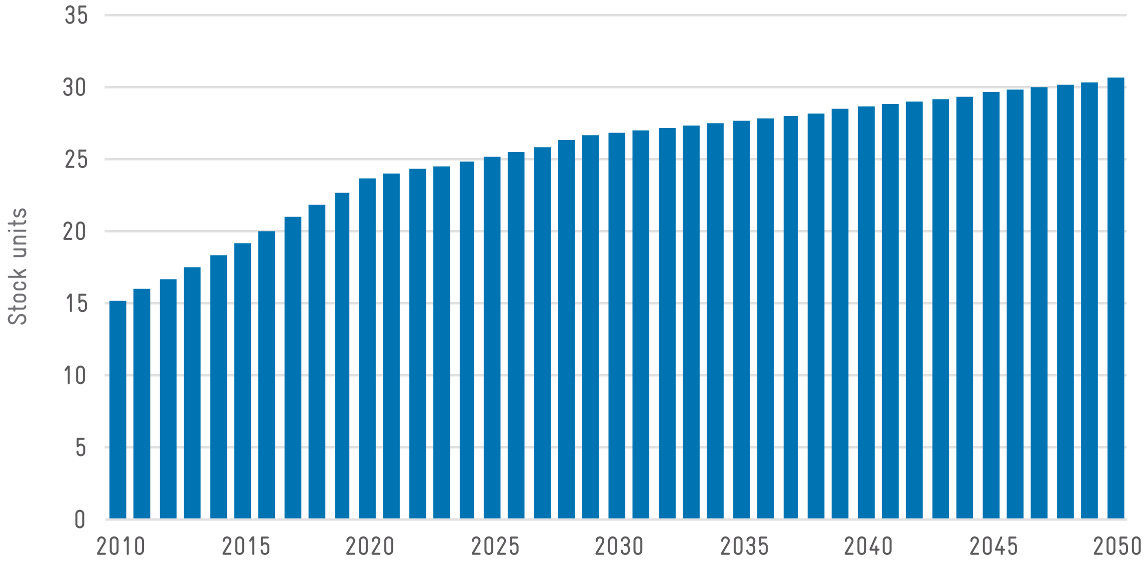


FIGURE 8: UAC STOCK NUMBERS (2010-2050) AND CALCULATED UAC SALES NUMBERS (2010-2016)



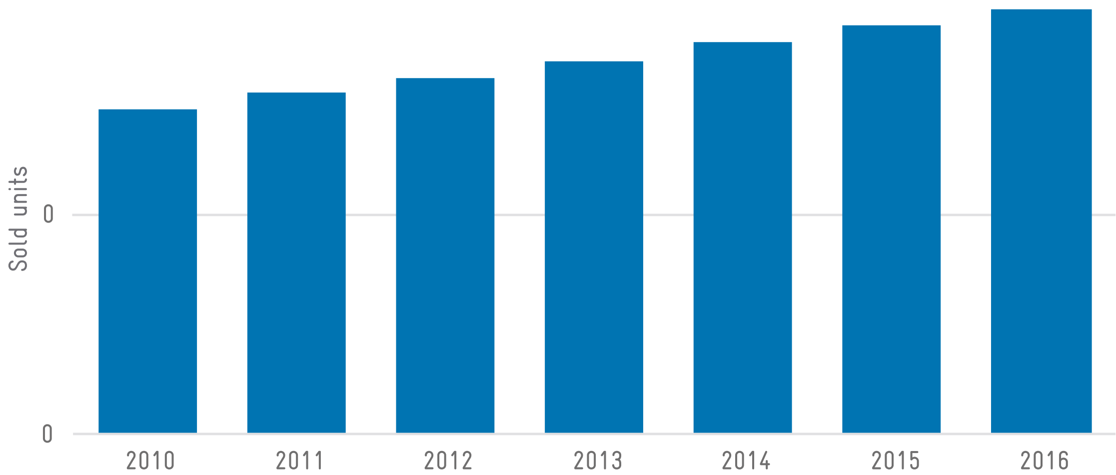


FIGURE 9: AC CHILLER STOCK NUMBERS (2010-2050) AND CALCULATED SALES NUMBERS (2010-2016)

3.1.3 Mobile air conditioning

For MAC systems used in vehicles, the country's vehicle fleet was estimated from data collected from the registration and licensing system of the Royal Grenada Police Force/Traffic Department. Based on the derived stock of 26,104 vehicles in 2017, sales and the projection of future stock were calculated (Figure 10). With annual sales in a range between 2,500 and 3,000 units, the stock of MAC is estimated to reach more than 31,000 air-conditioned vehicles in 2030 and almost 35,000 in 2050. As the contribution by larger vehicles is unknown and presumably low, all MAC systems have been calculated in the passenger car category.

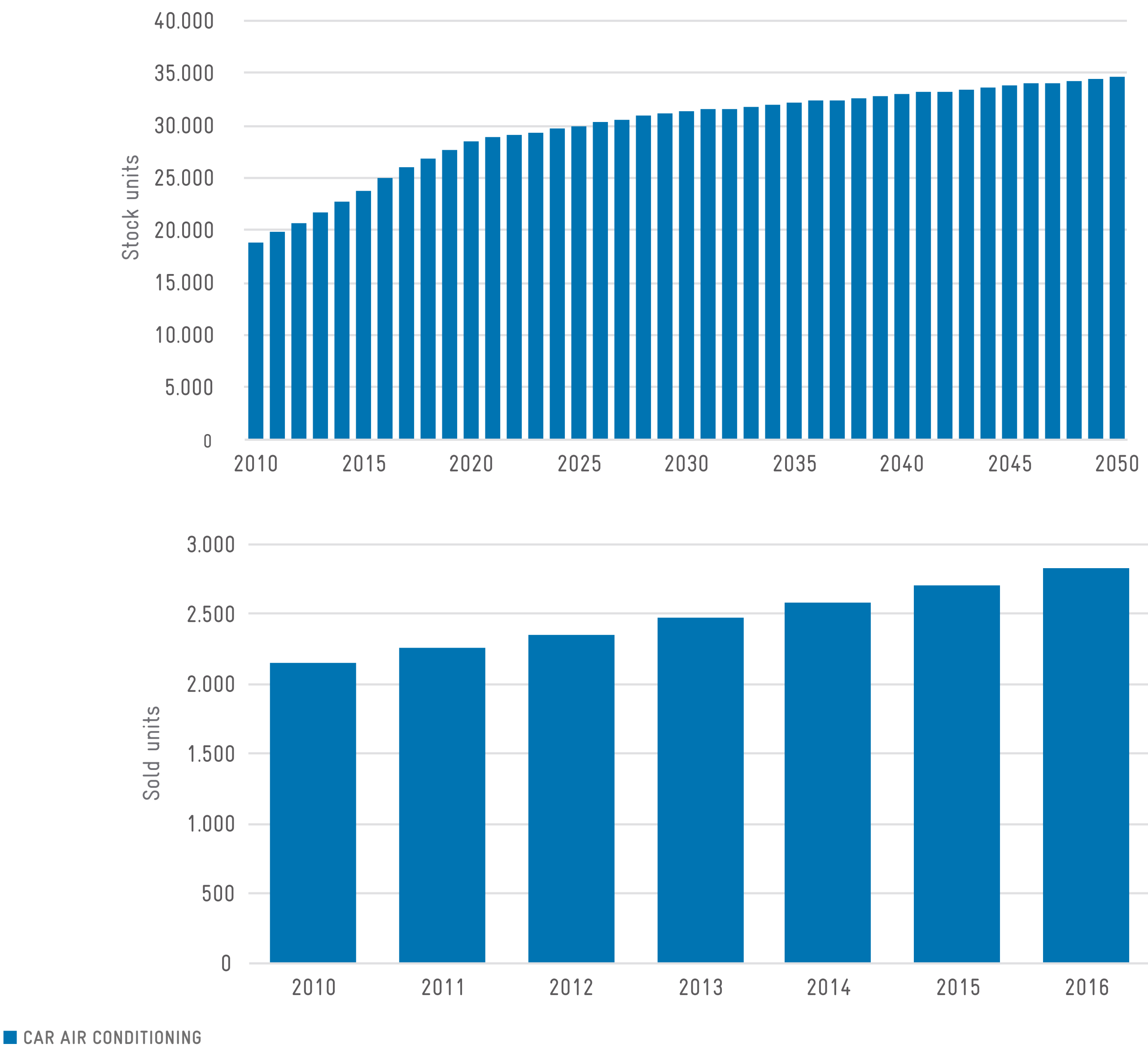


FIGURE 10: MAC STOCK NUMBERS (2010-2050) AND CALCULATED SALES NUMBERS (2010-2016)

3.1.4 Domestic refrigeration

Domestic refrigeration data are based on a national survey for Grenada conducted by the National Ozone Unit of the Ministry of Finance and Energy, resulting in a stock number of 40,472 refrigerators in 2015 (Figure 11). The projected stock is expected to reach more than 45,000 refrigerators in 2030.

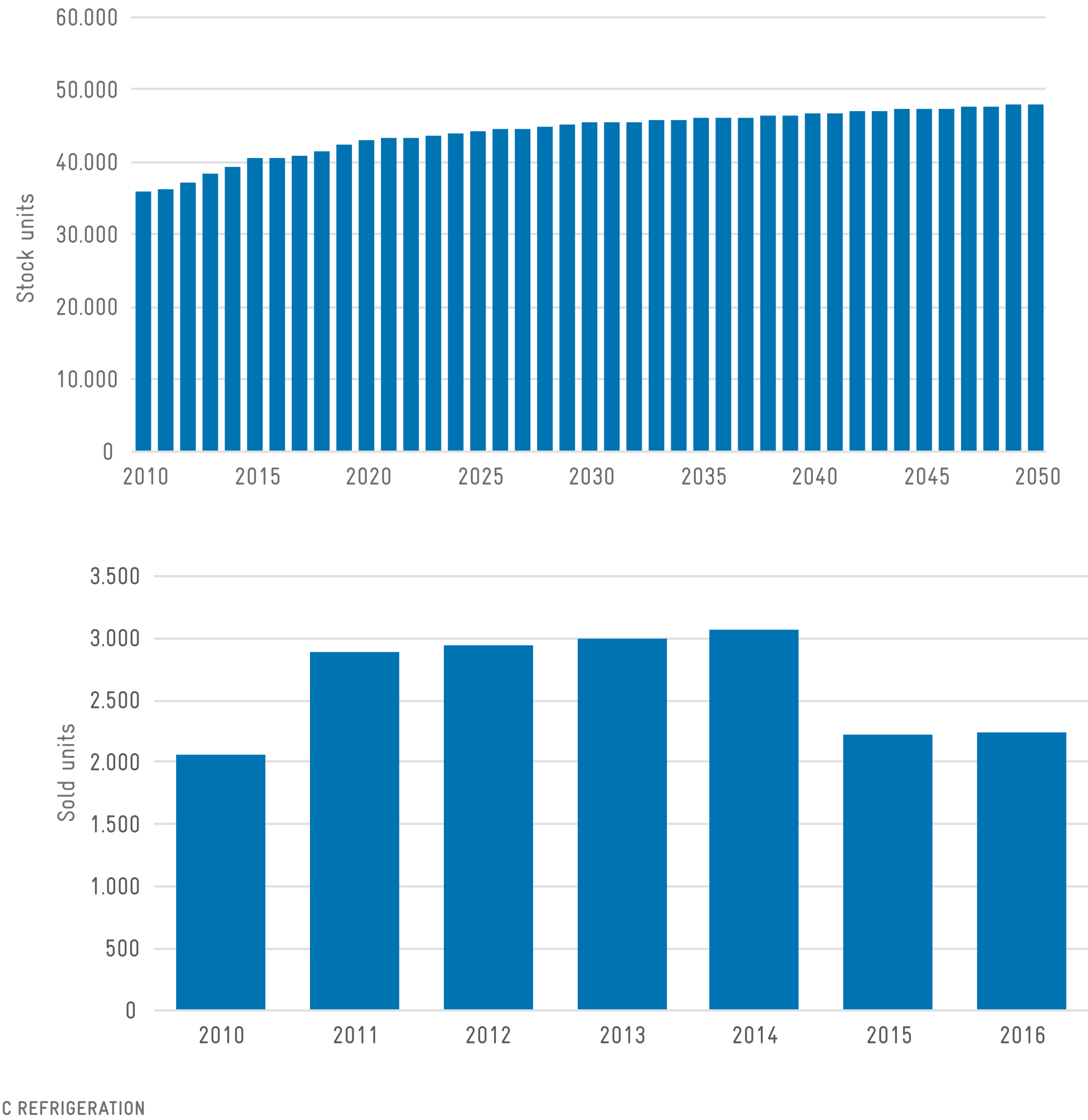


FIGURE 11: DOMESTIC REFRIGERATION STOCK NUMBERS (2010-2050) AND CALCULATED SALES NUMBERS (2010-2016)

3.1.5 Commercial refrigeration

Commercial refrigeration has been broken down into three appliance types. Based on the end user data collected for this inventory and an upscaling factor (i.e. to scale up from collected data to the total stock estimated from all end users), a stock of 198 stand-alone units, 126 condensing units and 1 centralised system for supermarkets was calculated for 2017 (Figure 12).

The total of 331 commercial refrigeration appliances in 2017 is assumed to increase to around 400 units in 2030. Calculated sales reach from 16 to 21 stand-alone appliances and 9 to 12 condensing units within the 2010-2016 data collection period, while sales of centralised systems for supermarkets are negligible.

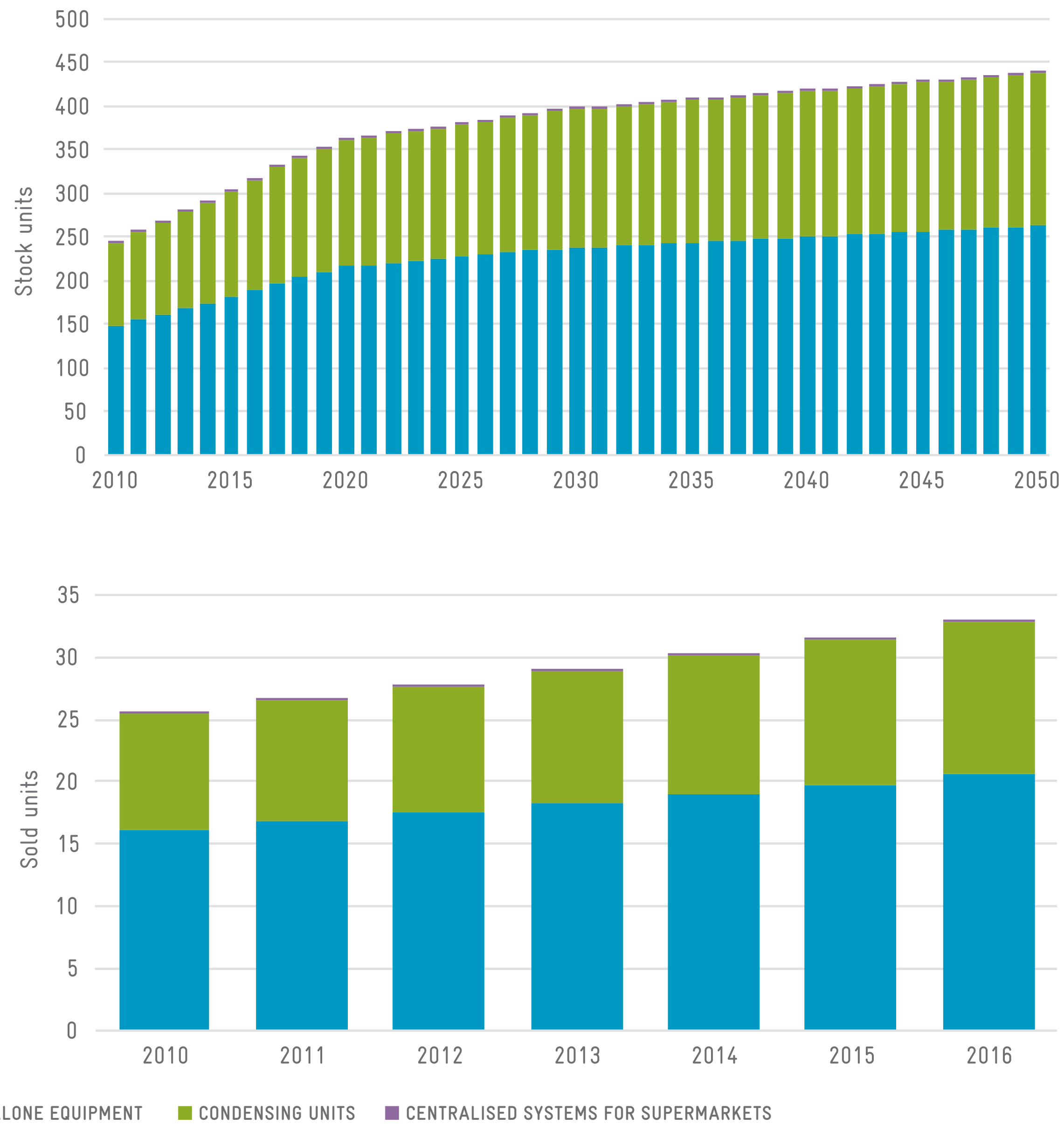


FIGURE 12: COMMERCIAL REFRIGERATION STOCK NUMBERS (2010-2050, ABOVE) AND CALCULATED SALES NUMBERS (2010-2016)

3.1.6 Industrial refrigeration

In the industrial refrigeration sub-sector, the natural refrigerant R717 (ammonia) plays a dominant role across all appliance types. Based on collected end user data, the current stock (2017) consists of 8 integral units, 15 industrial condensing units and 3 centralised systems (Figure 13), projected to reach 31 altogether in 2030.

3.1.7 Transport refrigeration

The figures for transport refrigeration were derived through an estimated stock of 13 units contained in trucks and vans for 2017, and are projected to grow to 17 units in 2030 and 19 units in 2050 (Figure 14).

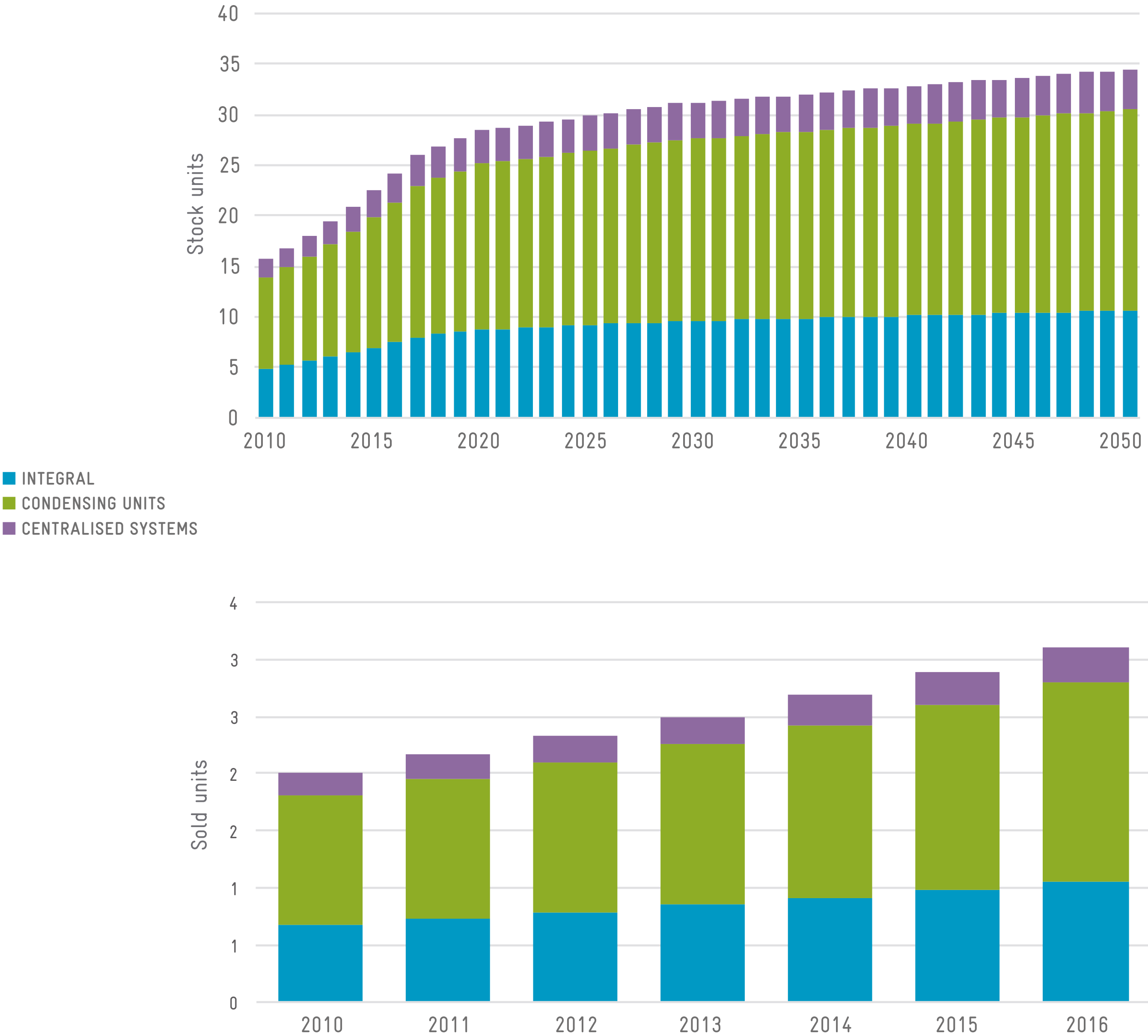


FIGURE 13: INDUSTRIAL REFRIGERATION STOCK NUMBERS (2010-2050) AND CALCULATED SALES NUMBERS (2010-2016)

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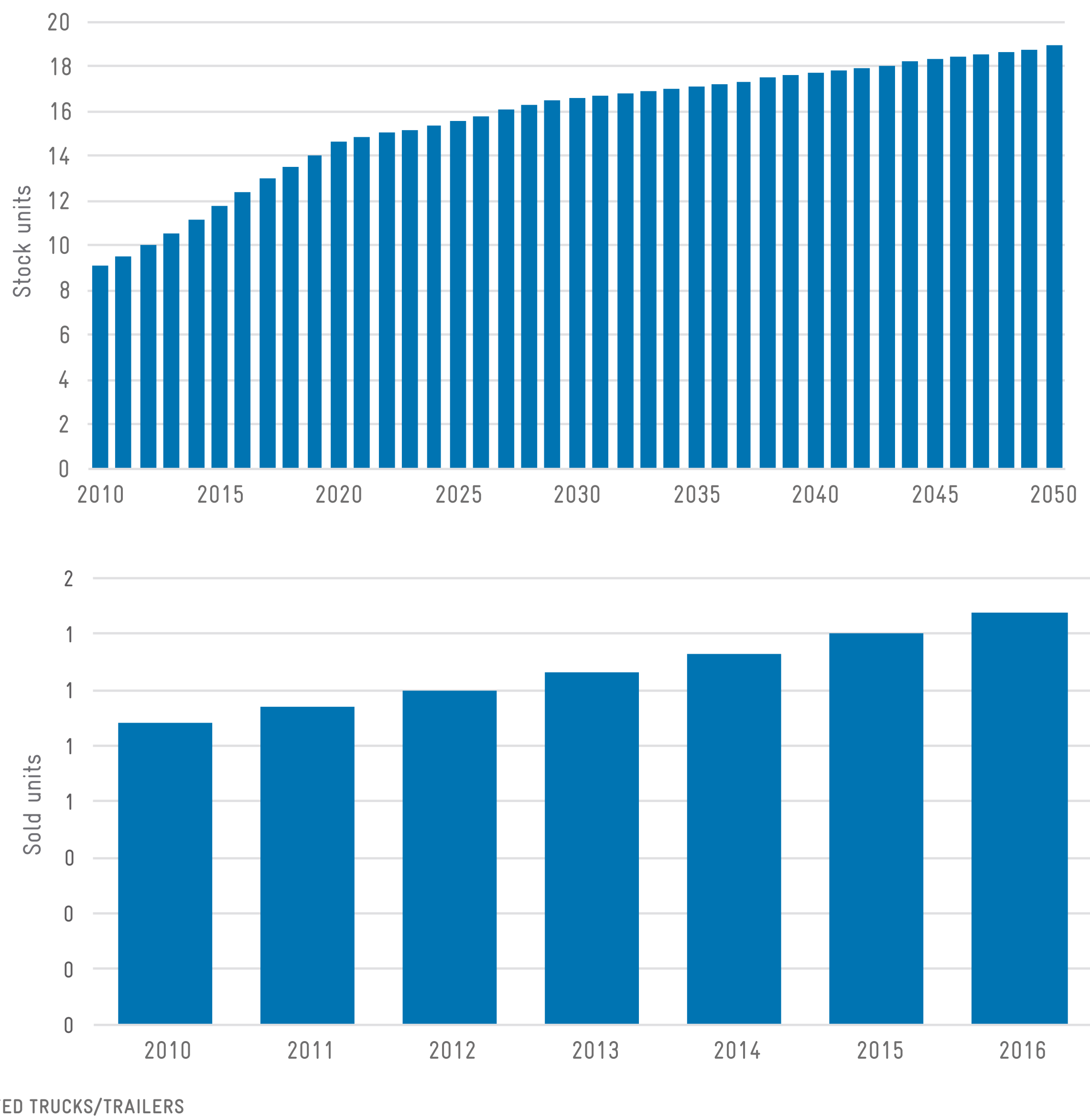

FIGURE 14: TRANSPORT REFRIGERATION STOCK NUMBERS (2010-2050) AND CALCULATED SALES NUMBERS (2010-2016)

3.2 STATUS QUO AND BAU PROJECTIONS IN THE RAC SECTOR

In this subchapter, the current state of GHG emissions and refrigerant banks in the RAC sector is analysed and a BAU projection until 2050 is provided.

3.2.1 BAU emissions and projections in the RAC sector

As shown in Figure 15, Grenada's RAC sector was responsible for 122 kt CO_2eq of GHG emissions from refrigerant emissions and energy use in 2015. 55% of the total emissions from Grenada's RAC sector are related to UAC, followed by MAC with 27% and domestic refrigeration with 11%. Chillers (4%) and the remaining refrigeration sub-sectors (<3%) contribute minor shares.

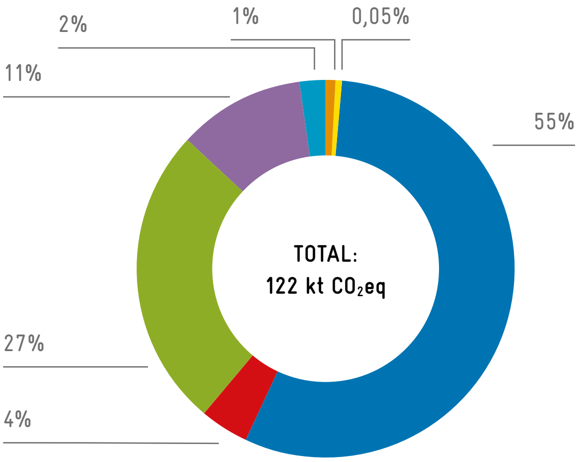

FIGURE 15: TOTAL BAU GHG EMISSION FOR GRENADA'S RAC SECTOR BY SUB-SECTORS IN 2015

The total emissions consist of about 18% direct and 82% indirect emissions. The following graphs illustrate the distribution among the RAC sub-sectors for direct emissions (Figure 16) and indirect emissions (Figure 17), both dominated by UAC.

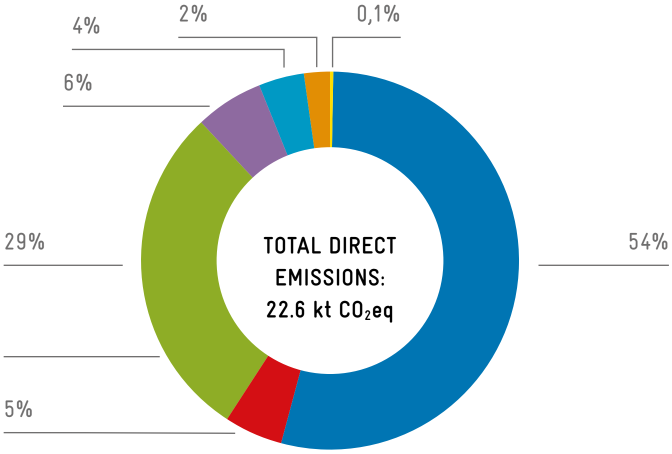

FIGURE 16: DIRECT GHG EMISSIONS OF THE RAC SUB-SECTORS IN 2015

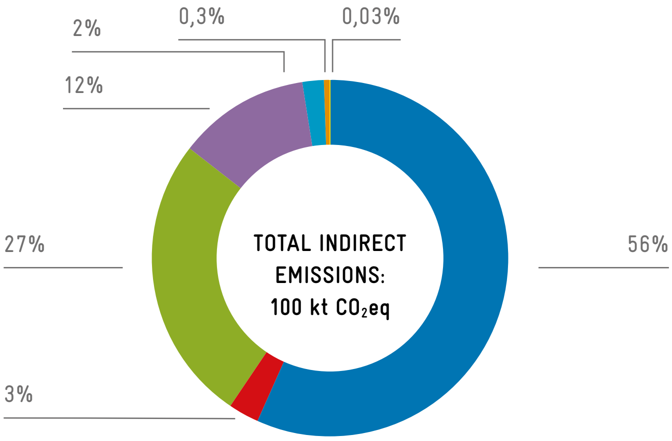

FIGURE 17: INDIRECT GHG EMISSIONS OF THE RAC SUB-SECTORS IN 2015

UNITARY AIR CONDITIONING, AIR CONDITIONING CHILLERS, MOBILE AIR CONDITIONING, DOMESTIC REFRIGERATION, COMMERCIAL REFRIGERATION, INDUSTRIAL REFRIGERATION, TRANSPORT REFRIGERATION

In the projection of the BAU scenario case, it is estimated that annual total GHG emissions in Grenada's RAC sector will grow continuously, up to 193 kt CO_2eq in 2030 and reach 263 kt CO_2eq in 2050 (Figure 18). The main driver of the growing GHG emissions is the UAC sub-sector, with some relevance also by the MAC sub-sector. In contrast, Grenada's domestic refrigeration market is relatively saturated, with about one fridge per household. Therefore, the assumed growth is low in this sub-sector. The remaining sub-sectors have minor shares of total RAC and relatively low growth rates.

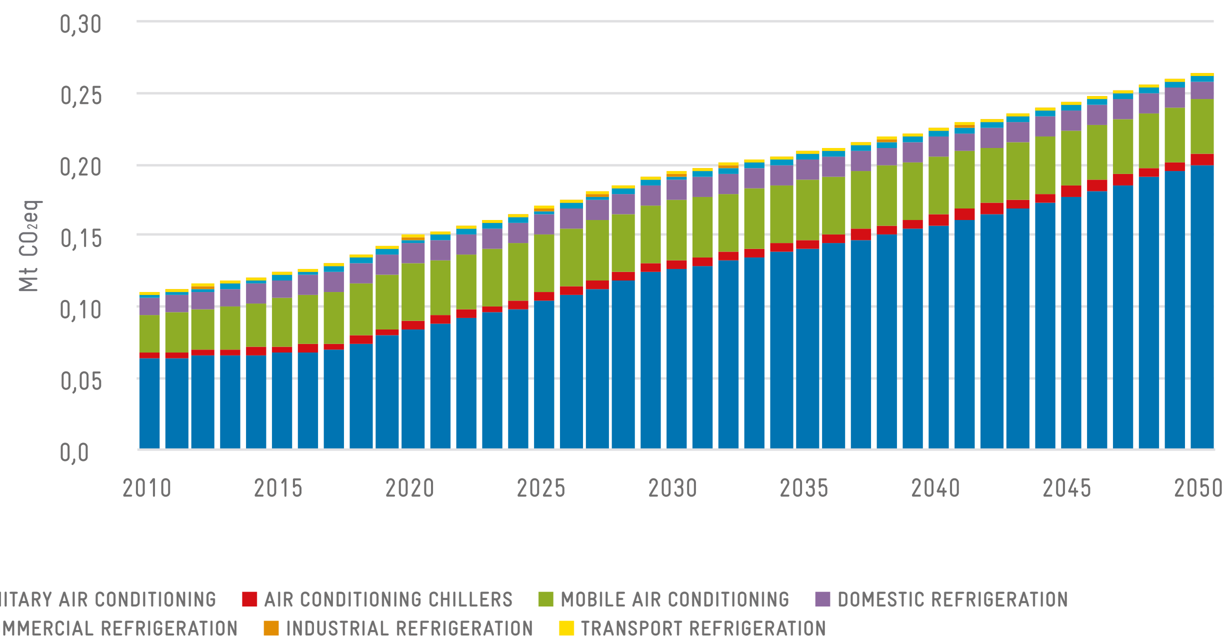

FIGURE 18: PROJECTED BAU GHG EMISSIONS IN THE RAC SECTOR FOR THE YEARS 2010-2050

3.2.2 Refrigerant consumption in the RAC sector

The imported amounts of bulk refrigerant in 2015 are shown in Table 8. With 3.9 metric tonnes, the ozone-depleting HCFC refrigerant R22 was the most imported substance, followed closely by the HFC R134a (3.5 metric tonnes), with R410A in the third place (1.8 metric tonnes).

TABLE 8: IMPORT OF BULK REFRIGERANTS, YEAR 2015.
SOURCE: NOU GRENADA

SUBSTANCE	IMPORTED AMOUNT (METRIC TONNES)
HCFC-22	3.936
HFC-134a	3.547
HFC-404A	0.861
HFC-407C	0.874
HFC-410A	1.828
OTHER	0.011
TOTAL	11.057

The projected refrigerant consumption (i.e. for first fills[14] and refills) indicates an increase in HFC consumption from 10.4 metric tonnes in 2015 up to 21.9 metric tonnes in 2030 and 31.3 metric tonnes in 2050. HCFCs are decreasing steadily from 4.5 metric tonnes in 2015 and expected to fall below 2 metric tonnes in 2027 (below 1 metric tonne in 2037, see Figure 19).

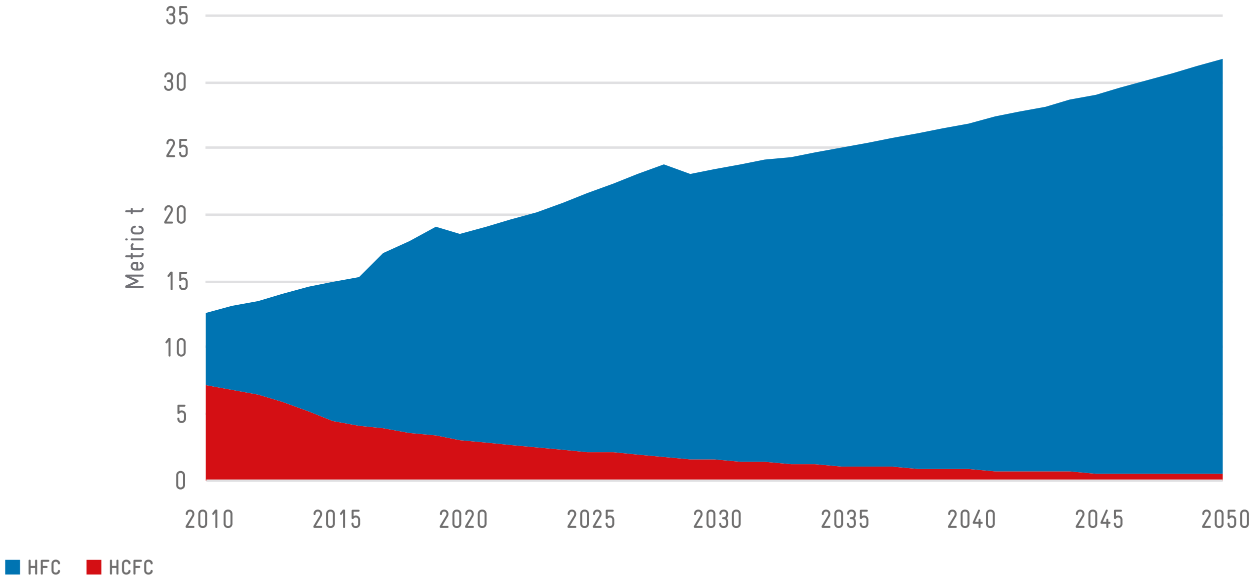

FIGURE 19: PROJECTED BAU REFRIGERANT CONSUMPTION OF HFCS AND HCFCS BY GRENADA´S RAC SECTOR, 2010-2050 BAU SCENARIO

14 Large RAC appliances are commonly charged on site during the installation, whereas smaller appliances such as the most common AC systems and domestic refrigerators are typically pre-charged by the manufacturer.

3.2.3 ODS and HFC banks and projections in the RAC sector

The total number of refrigerant banks amounted to 52.9 metric tonnes at a stock of about 83,600 appliances in 2016 (Table 9). With 22.0 tonnes attributed to 62,690 stock units, R134a contributed 42% to the total refrigerant banks, R22 shared 38% with 20.0 tonnes (12,365 units) and HFC-410A ranks third with 15% with 8.16 tonnes (5,320 units). The relation between refrigerant banks and stock units varies largely among the refrigerants due to different charge sizes by the relevant RAC appliance types. The projected development of refrigerant banks and stock units up from year 2019 until 2028 is presented in the Annex (see Table 27 and Table 28).

The refrigerant bank of RAC appliances across all refrigerant types is estimated to grow continuously, reaching 87.6 metric tonnes in 2030 (116,000 units), and rising up to 130 metric tonnes in 2050 which corresponds to more than 152,000 units (Figure 20). R134a has the largest number of refrigerant banks due to its dominant use in MAC and refrigerators. However, use of R134a is expected to decline after 2025, mainly due to its replacement in domestic refrigeration with R600a and increasing penetration of R1234yf in mobile AC (MAC). The number of units with R600a is growing quickly and expected to take the lead of stock units after 2045.

TABLE 9: REFRIGERANT BANKS AND STOCK UNITS BY SUBSTANCE, YEAR 2016

SUBSTANCE	REFRIGERANT BANKS (TONNES OF SUBSTANCE)	STOCK UNITS
HCFC-22	20.0	12,365
HFC-134a	22.0	62,690
HFC-404A	0.62	204
HFC-407C	0.66	61
HFC-410A	8.16	5,320
HFO-1234yf	0.02	28
R600a	0.51	2,934
R717	0.93	7
TOTAL	52.9	83,609

R410A refrigerant banks and stock units are expected to pass R22 in 2019. Regarding stock units, R290 plays a minor role in the BAU scenario, as do R32, R717 and R744. Increasing shares of R717 as well as R407C and R404A are more visible in refrigerant banks as these refrigerants are used in RAC appliances with relatively large charge sizes.

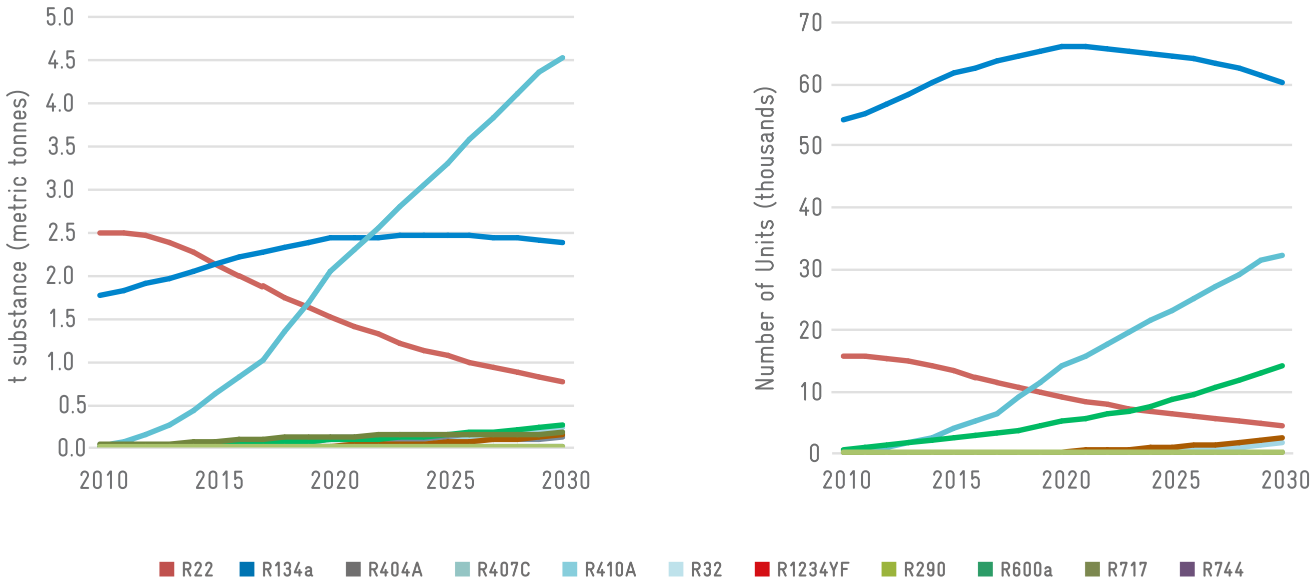

FIGURE 20: ESTIMATED HCFC AND HFC REFRIGERANT BANKS (LEFT SIDE) AND STOCK UNITS (RIGHT SIDE) IN GRENADA'S RAC SECTOR, 2010-2030 BAU SCENARIO

Under consideration of the lifetime parameters for all RAC appliances (see Table 4), refrigerant banks and units at the end of life (EoL) of the RAC appliances amounted to 3.3 metric tonnes at about 4,900 units in 2016. As shown in Table 10, R22 and R134a largely dominate while R410A and many other refrigerants do not reach significant shares yet, due to their more recent market penetration. The projected development of EoL refrigerant banks and EoL units until 2028 is presented in the Annex (see Table 29 and Table 30).

Figure 21 shows the development of EoL refrigerant banks and related units including their projection until 2030. R134a continues to grow while R22 strongly declines after 2025, and is mainly substituted by R410A as indicated by its increasing shares, in the second half of the 2020s. At the same time R600a also gains minor shares of EoL units. However, the corresponding R600a refrigerant amounts attributed to EoL refrigerant banks are negligible due to low refrigerant charges. Likewise, the remaining refrigerants are barely visible due to relatively low RAC market. EoL banks of R32, R1234yf and R744 appear after 2030, which is the reason that they are not displayed in the figure.

TABLE 10: END-OF-LIFE (EOL) REFRIGERANT BANKS AND UNITS BY SUBSTANCE, YEAR 2016

SUBSTANCE	EOL-REFRIGERANT BANKS (TONNES OF SUBSTANCE)	EOL-UNITS
HCFC-22	1.96	1,198
HFC-134a	1.36	3,697
HFC-404A	0.001	1.3
HFC-407C	0.004	0.3
HFC-410A	0.006	0.4
R-717	0.006	0.0
TOTAL	3.33	4,896

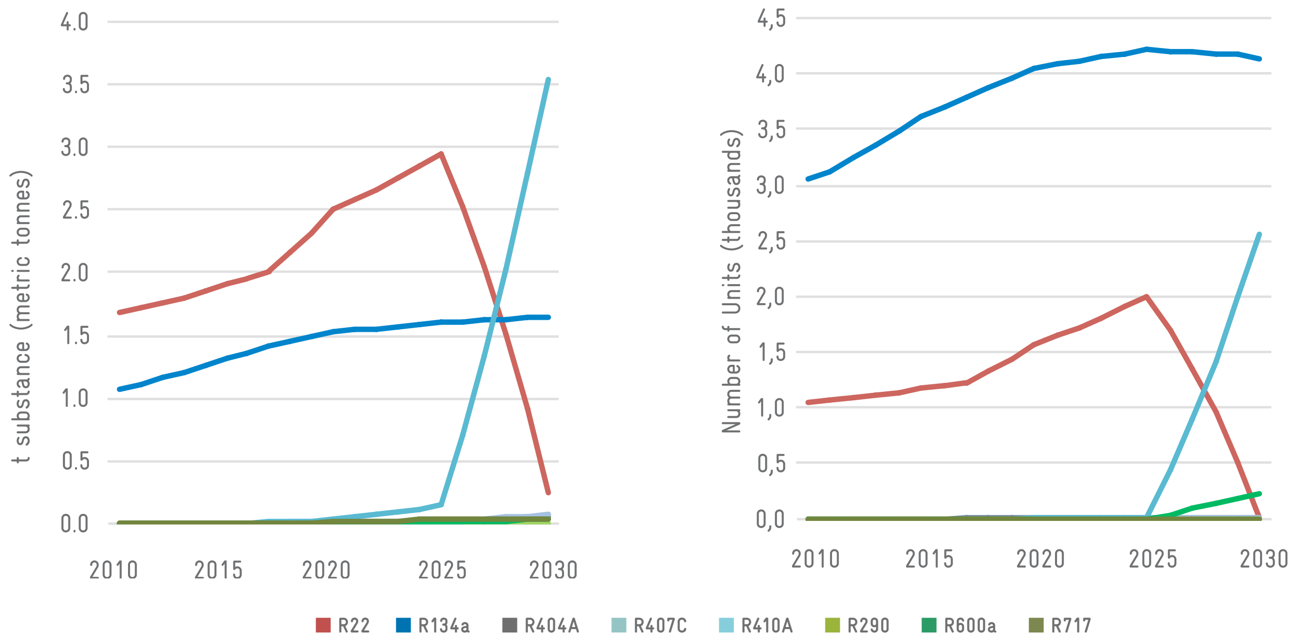

FIGURE 21: ESTIMATED END-OF-LIFE (EOL) REFRIGERANT BANKS (LEFT SIDE) AND EOL UNITS (RIGHT SIDE) IN GRENADA'S RAC SECTOR, 2010-2030

ANALYSIS OF ODS BANKS MANAGEMENT

The steps involved in the ODS management start with the development of a suitable set of policy measures, laws and regulations and other fiscal measures which define the scope and setting of objectives based on the countries situation and priorities along with identification of all stakeholders and institutions in the field including intervention areas given by the HCFC phase out management plans (HPMP). A sector analysis is conducted to identify the available ODS amounts, to analyse the respective reduction potential and to determine the technical feasibility for ODS recovery.

A sustainable enforcement of the policy measures involves a financing mechanism which is closely linked to the establishment of a collection scheme and a regulatory framework. The various options to receive financial aid for ODS bank management include the Multilateral Fund (MLF), climate programmes, the Green Climate Fund (GCF), Global Environmental Facility (GEF) and World Bank. Moreover, it is also important to integrate the policy-defined measures into an existing environmental policy framework. In the next step, an effective collective collection mechanism is established. It starts with an assessment of existing policy framework to analyse whether a waste electric and electronic equipment (WEEE) regulation is in place and addresses all relevant issues of the collection scheme. Another key success factor is widely applying extended producer responsibility (EPR) schemes as a solution to avoid shifting all the financial burden associated with ODS collection and destruction to the end-user, technicians or the informal sector. All these processes are accompanied by other support process such as

» the compilation of an ODS bank inventory;

» the establishment of a monitoring, reporting and verification (MRV) systems;

capacity building, such as technicians training to properly recover ODS from equipment

ODS management can be integrated into a waste management system. For establishing a functioning recycling and destruction infrastructure, the steps shown in figure 22 should be followed. Accountable for the ODS amount under Step 1 are:

» reachable ODS banks (amount of ODS in the country, apart from landfills);

» remaining charge of RAC equipment at decommissioning;

» amount captured by the collection scheme (determined by recovery rates and effectiveness of the collection scheme).

Re-use of ODS should be prioritised along the ODS management processes (Step 2). In this context, it is important to distinguish between the following terms:

» Recovery: removing of refrigerant in any condition from a system and storing in an external container

» Recycling: reduction of contamination in used refrigerant with the aim of reutilisation thereafter

» Reclamation: processing recovered refrigerant to new product specifications under quality verification

For Grenada, exporting ODS for destruction to another country is the only feasible option as there are no local destruction facilities and only a limited amount of ODS is available for destruction. Otherwise, the cost assessment of such ODS would be considered in Step 3 to find the more viable option. The transport of ODS is subject to the 'Basel Convention of the Control of Transboundary Movements of Hazardous Wastes and their Disposal' (Step 4). As a first indication, approximate cost in the range of USD 10 per kg of substance can be expected for destruction and shipment of Grenada's ODS banks[15]. For the transportation of the reclaimed refrigerant, it is recommended to cooperate with neighbouring countries. Only if critical amounts of ODS were available, establishing a local destruction plant could be the more cost-effective solution.

15 Cost indication taken from MLF demo project Colombia / Brazil

For more information on ODS management and destruction, please refer to Heubes, Gloel and Papst (2017).

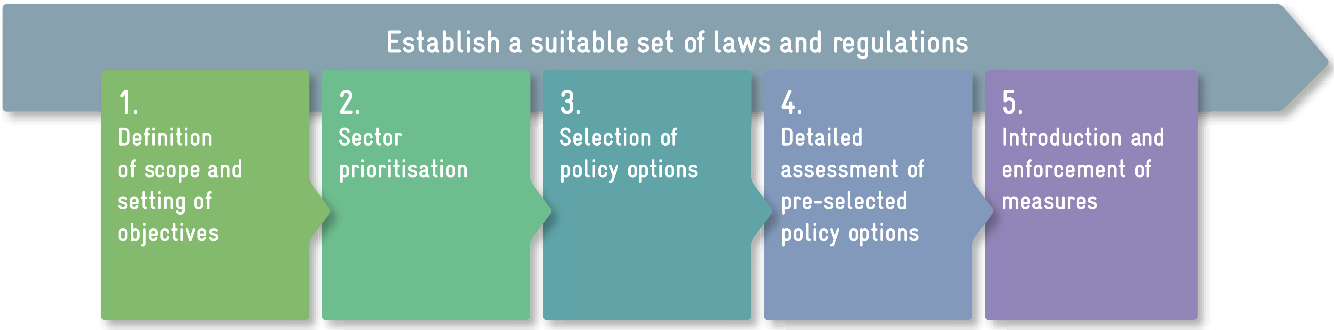

FIGURE 22: KEY STEPS FOR ESTABLISHING A FUNCTIONING RECYCLING AND DESTRUCTION INFRASTRUCTURE. SOURCE: HEUBES, 2017

3.3 ALTERNATIVE TECHNOLOGIES

Building on locally derived data where possible, this chapter analyses the potential to lower the GHG emissions in Grenada's RAC sector by deploying available climate-friendly and highly energy-efficient RAC technologies.

3.3.1 Overview on energy efficiency and refrigerants in a BAU scenario

Table 11 shows the energy efficiencies and refrigerants used for typical applications currently sold in the market. Mainly high-GWP refrigerants, including HFCs, are used in RAC appliances at moderate energy efficiency levels.

TABLE 11: LIST OF HFCS AND ENERGY EFFICIENCIES COMMON FOR GRENADA IN THE RAC SUB-SECTORS

SUB-SECTOR	ENERGY EFFICIENCY RATIO (EER) [W/W](AVERAGE)[15]	MAIN HFC REFRIGERANTS
UNITARY AIR CONDITIONING (RESIDENTIAL, COMMERCIAL)	>3.0	R410A, R407C, R22
ROOFTOP DUCTED	>2.5*	
AIR CONDITIONING CHILLERS	3.0*	R134a, R410A
MOBILE AIR CONDITIONING	2.5*	R134a
DOMESTIC REFRIGERATION	>400 kWh/year	R134a, R600a
COMMERCIAL REFRIGERATION	>2,5*	R134a, R404A
Centralised systems for supermarkets	>1,8*	
INDUSTRIAL REFRIGERATION	>2.0*	R404A, R717
TRANSPORT REFRIGERATION	>2.2*	R134a

* default estimates

16 EER (ratio between provided useful cooling and required work (electricity) in W/W) unless otherwise stated

3.3.2 Transition to high energy efficiency RAC technologies

Compliance with progressive MEPS and labelling requirements, which are regularly updated according to international best practices, can lead to a substantial improvement in energy efficiency as well as reduced GHG emissions in the RAC sector.

The best available RAC technologies in terms of energy efficiency, applicable to nearly all RAC appliances and their components, include

» variable speed inverter-driven compressors, which adjust to the required cooling load;

» improved evaporator or compressor heat exchangers;

» variable auxiliary components such as pumps and fans;

» sensor-linked controllers with smart adjustment functions and better insulation systems to lower the required cooling loads.

3.3.3 Transition to low-GWP refrigerants

With the signing of the Kigali Amendment, most developed and developing countries (A5 countries under the Montreal Protocol) signalled their willingness on a gradual phase-down of HFCs. The phase-down schedule of the F-Gas Regulation in the European Union (EU) is driving the development of low-GWP alternatives. There are many advanced or best practice policy instruments developed by the EU, which can be adopted by developing countries for the implementation of the Kigali Amendment or additional measures for an enhanced phase-out of HFCs (such as refrigerant bans for selected applications or GWP-based tradeable quotas).

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

Accelerating the transition to RAC systems with low-GWP refrigerants, particularly to systems using refrigerants with a GWP <10[17], holds several benefits for Grenada.

These benefits include:
Avoidance of direct emissions due to low-GWP refrigerants with a GWP <10, thereby contributing to Grenada's climate targets (NDC).

» **Energy saving.** Many natural refrigerants, particularly R717 and hydrocarbons have very favourable thermodynamic properties, which lead to higher energy efficiency and, consequently, energy savings. With well-designed R717 and hydrocarbon systems, energy savings of 10 to 15% are possible.

» **Employment creation.** The safe handling of systems using natural refrigerants requires skilled, educated and qualified technicians to install, operate and maintain the systems. The qualification of technicians creates additional employment and allows for safe, efficient handling of RAC appliances.

3.3.4 Low-GWP unitary AC systems

Transitions to low GWP UAC systems include UAC appliances with improved energy efficiency and the use of low GWP refrigerants (Table 12).

Regarding energy efficiency, the most important improvement of room ACs can be achieved through the transition to inverter type UAC systems. For room ACs, inverter appliances have now reached a share above 70% [17]. Customers lack education on the benefits of inverter technologies such as their energy saving potential and lower total cost of ownership. Inverter driven unitary ACs can adjust their supplied thermal output, i.e. the cooling effect, dynamically to the cooling demand. The resulting energy efficiency gains are in the range of 20-25% (Shah, Phadke and Waide, 2013).

17 GIZ Webinar, "Cost, energy and climate performance assessment of Split Air Conditioners" (27/06/2018)

Using hydrocarbons as low-GWP refrigerants in UACs can also result in improved energy efficiencies of the appliances. Given relatively high ambient temperatures in Grenada, hydrocarbons[18] can be used with improved energy efficiency for many UAC systems, including room AC, portable and ductless split systems[19]. Split AC systems using R290 are in production in India and by several manufacturers in China. The first 30 split AC units running on R290 refrigerant have recently been installed in Grenada within the scope of the C4 country programme. The Godrej R290 AC split units are now commercially available in Grenada through two local importers. The initial uptake indicates great promise for further expansion in the market.

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

For ducted and multi-split systems, the use of low GWP A2L and A3 refrigerants[20] typically requires the utilization of indirect systems, either with air or water as a heat exchange carrier inside the buildings. With appropriate design options, energy efficiency improvements of up to 10% can be achieved even for these indirect systems compared to direct expansion systems with R410, R404A or R407C as refrigerants.

TABLE 12: CURRENT AND BEST PRACTICE UNITARY AC APPLIANCES (SOURCE: HEAT GMBH)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	MARKET PENETRATION POTENTIAL FOR ALTERNATIVE SYSTEM		
				CURRENT	2020	2030
SELF-CONTAINED AC	Refrigerant	R410A	Low GWP <10	<5%	50%	60%
	Energy efficiency	3.2	>3.7			
DUCTLESS SPLIT	Refrigerant	R410A, R32	Low GWP <10	<5%	50%	70%
	Energy efficiency	3.4	>5			
DUCTED SPLIT	Refrigerant	R410A, R407C	Low GWP <10, Low GWP with secondary fluid	<5%	40%	80%
	Energy efficiency	3.4	>3.65			
MULTI-SPLIT	Refrigerant	R410A, R407C	Low GWP <10 or low GWP with ducted split	<5%	30%	70%
	Energy efficiency	3.3	>4.4			

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

19 Compared to many other refrigerants, e.g. HFC-32 or HFC-410A, hydrocarbons have a higher critical temperature which results in favorable thermodynamic properties at higher ambient temperatures, i.e. with increasing ambient temperatures the COP is relatively and higher

20 According to international refrigerant safety classification ISO 817

3.3.5 Low-GWP chillers – AC, process and commercial chillers

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Stationary AC and refrigeration chiller systems are used for commercial and industrial cooling. Generally, chillers are in a machinery room or outdoors, making it easier to deal with safety issues related to toxicity and flammability of low-GWP refrigerants. For hot ambient conditions, both R717 and hydrocarbon (R290 and R1270) refrigerants are very energy-efficient with energy efficiency properties often superior to those of HFC-based chiller systems (Table 13).

TABLE 13: CURRENT AND BEST PRACTICE RAC CHILLERS (SOURCE: HEAT GMBH)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	MARKET PENETRATION POTENTIAL FOR ALTERNATIVE SYSTEM		
				CURRENT	2020	2030
AC CHILLERS	Refrigerant	R410A, R134a, R407C	Low GWP <10 (R290, R717, HFO)	<5%	30%	70%
	Energy efficiency	3.0	>3.6			
PROCESS CHILLERS	Refrigerant	R134a, R407C, R404A, R717	Low GWP <10 (R290, R717, HFO)	<5%	40%	60%
	Energy efficiency	3.3	>3.7			
CENTRALISED SYSTEMS FOR SUPERMARKETS	Refrigerant	R134a, R404A, R507	Low GWP <10 (R290, R717, HFO, R744 cascade)	<5%	20%	80%
	Energy efficiency	2.0	>2.2			

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

A comparison of the current and best practice technology is demonstrated in Table 13. Current RAC chillers in Grenada mainly operate with R22, R134a or R410A, which are refrigerants with a high GWP. With the adaptation of an alternative technology using hydrocarbon refrigerants such as R290, energy efficiency improvements in the range of 10-20% are to be expected (Patel, Kapadia and Matawala, 2016).

3.3.6 Refrigeration – Domestic and commercial stand-alone systems and commercial condensing units

With the drive to lower consumption of fluorinated gases (F-gases), resulting for example from the EU F-Gas Regulation (EU, 2014), alternative refrigerants are increasingly used in RAC appliances for domestic and commercial refrigeration. In the stand-alone equipment category (bottle coolers, ice coolers and display cases up to 3.75m), appliances with hydrocarbon refrigerants have reached significant market share in several markets such as Europe and China and were successfully introduced to Grenada's market although at minor amounts up to date.

Commercial refrigeration systems in supermarkets can also be upscaled, linking multiple stand-alone units, which release their condensation heat into a water circuit. Condensing units that use hydrocarbon refrigerants are available as well. The recently accepted update of the IEC standard 60335-2-89 permits a charge size up to 500g of hydrocarbon, which will allow for their more widespread application. A comparison of the current and best practice technology is demonstrated in Table 14.

The use of R600a and R290 instead of the currently available R134a and R410A is estimated to cause energy efficiency gains above 10% (Gerwen van and Colbourne, 2012).

TABLE 14: CURRENT AND BEST PRACTICE STATIONARY REFRIGERATION UNITS (SOURCE: HEAT GMBH)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	MARKET PENETRATION POTENTIAL FOR ALTERNATIVE SYSTEM		
				CURRENT	2020	2030
DOMESTIC REFRIGERATION	Refrigerant	R134a, R600a	R600a	<5%	95%	95%
	Energy efficiency	1.8	>2.5			
STAND-ALONE UNITS	Refrigerant	R134a	R290	<5%	85%	85%
	Energy efficiency	1.6	>2.6			
CONDENSING UNITS	Refrigerant	R134a, R404A	Low GWP <10 to low GWP with secondary fluid	none	40%	60%
	Energy efficiency	2.0	>3.1			

3.3.7 Refrigeration – Transport refrigeration systems

For transport refrigeration, there are emerging technology alternatives for refrigeration systems with low-GWP refrigerants. The leading manufacturer of transport refrigeration systems in South Africa, Transfrig, has successfully developed a prototype which uses R290 with energy efficiency improvements of 20-30% as compared to HFC-systems with the same cooling capacity. This technology can be relevant to Grenada, considering the good performance of hydrocarbons in its climatic conditions. It would allow the country to avoid direct emissions in the transport refrigeration sector and save fuel for powering the systems. A comparison of the current and best practice technology is demonstrated in Table 15.

TABLE 15: CURRENT VS. BEST PRACTICE TRANSPORT REFRIGERATION UNITS (SOURCE: HEAT GMBH)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	MARKET PENETRATION POTENTIAL FOR ALTERNATIVE SYSTEM		
				CURRENT	2020	2030
REFRIGERATED TRUCKS / TRAILERS	Refrigerant	R404A, R134a, R407C	R290, R744, R1234yf (HFO)	N/A	20%	75%
	Energy efficiency	2.3	>2.3			

3.3.8 Mobile air conditioning (MAC)

MAC systems can be categorized into two types:

- » MAC systems used in passenger vehicles
- » Transport AC systems used in other vehicles (e.g., trucks, buses, trains, airplanes).

Currently installed MAC systems in Grenada use R134a as the refrigerant. Alternative systems with R1234yf (HFO) and R744 have been developed in Europe, where according to EU law refrigerants are required to have a GWP less than 150 (EU, 2006). Several other car manufacturers that export cars to Grenada have transitioned to the low GWP HFOs (R1234yf) as the refrigerant used in these mobile AC systems. A comparison of the current and best practice technology is demonstrated in Table 16.

TABLE 16: CURRENT AND BEST PRACTICE MAC UNITS (SOURCE: HEAT GMBH)

		CURRENT TECHNOLOGY	BEST PRACTICE TECHNOLOGY	MARKET PENETRATION POTENTIAL FOR ALTERNATIVE SYSTEM		
				CURRENT	2020	2030
CAR AC	Refrigerant	R134a	R744 HC for hermitically sealed refrigerant systems. HFO	<5%	20%	50%
	Energy efficiency	2.8	>3.5			
LARGE VEHICLE AC	Refrigerant	R134a	R744, R290	N/A	85%	85%
	Energy efficiency	2.5	>3			

Hydrocarbons are not yet considered a viable refrigerant option by car manufacturers due to flammability concerns. Still, hydrocarbons can be an option for electric vehicles with hermetically sealed refrigerant systems. For large vehicles such as buses and trains, R744 systems are in some parts of Europe, such as Germany.

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

3.4 MITIGATION SCENARIO EMISSIONS FOR GRENADA'S RAC SECTOR

Results of data modelling for this RAC GHG inventory show that it is both technologically and economically feasible to reduce the GHG emissions of Grenada's RAC sector by up to 25 kt CO_2eq annually and achieve energy savings of around 27 GWh annually by 2030. By 2050, GHG emissions of 111 kt CO_2eq can be mitigated annually and energy savings of up to 110 GWh can be achieved, see green line ("MIT Ref+EE") in Figure 23. These mitigation targets require continuous deployment of climate-friendly and energy-efficient RAC appliances, ideally using natural refrigerants.

62% of these avoided emissions are related to energy efficiency improvements and 38% to the transition to low-GWP refrigerants. The latter contribution is presented in the refrigerant scenario (red line in Figure 23).

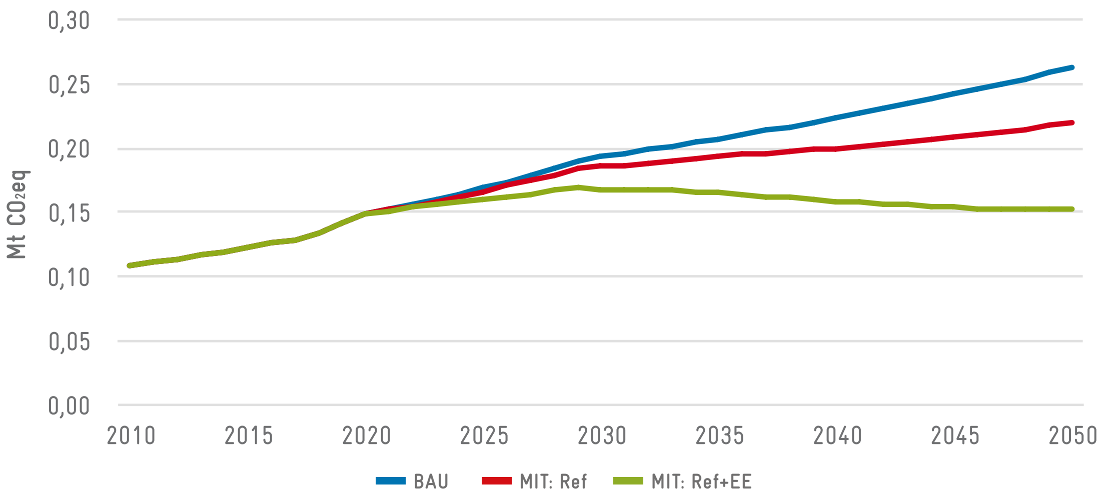

FIGURE 23: TOTAL ANNUAL EMISSIONS FROM THE RAC SECTOR, BAU AND MITIGATION SCENARIOS

The underlying parameters for the BAU and mitigation (MIT) scenarios are shown in section 2.3 (energy efficiency, see Table 5 and Table 6 for BAU and MIT, respectively) and include the exact distribution of refrigerant use (Table 23 and Table 24)) for both scenarios in section 5.4 of the Annex.

In the following section, the mitigation scenarios for direct and indirect emissions and the corresponding energy saving potential are described in more detail.

3.4.1 Energy consumption

The energy consumption development per sub-sector following the BAU scenario is presented in Figure 24. In 2015, UAC was responsible for 56% of the energy consumption by the total RAC sector, followed by MAC (27%) and domestic refrigeration (12%). The total RAC energy consumption is estimated to increase from 160 GWh in 2015 to 242 GWh in 2030 and 335 GWh in 2050.

The electricity consumption amounted to approximately 117 GWh in 2015, i.e. only considering the stationary sub-sectors which are operating on electrical energy and not considering the sub-sectors supplied directly by fossil fuels (MAC and transport refrigeration).

The RAC electricity consumption is estimated to have contributed 64% to the total national electricity consumption in 2013[21], with increasing trend in the future, largely due to high growth of the UAC sub-sector.

By assuming stepwise energy efficiency improvements for RAC appliances, energy consumption may be reduced to the growing curve as shown in Figure 25. With projected annual energy consumption of 113 GWh in 2050 (108 GWh in 2030), UAC remains the strongest consumer but demonstrates the highest saving potential. The presented energy saving potential corresponds with the "Ref+EE" scenario in the following analysis of GHG emissions.

3.4.2 GHG emission mitigation

The mitigation scenario projects the peak of GHG emissions in Grenada's RAC sector at 168 kt CO_2eq around 2029, with GHG emissions subsequently falling to 152 kt CO_2eq by 2050. Compared to BAU, about 111 kt CO_2eq can be reduced annually by 2050 (25 kt CO_2eq in 2030). The total accumulated mitigation potential until 2050 is estimated to add up to 1.5 Mt CO_2eq. The emission reduction potential is dominated by UAC which is estimated at 96 kt CO_2eq annually in 2050 (21 kt CO_2eq in 2030).

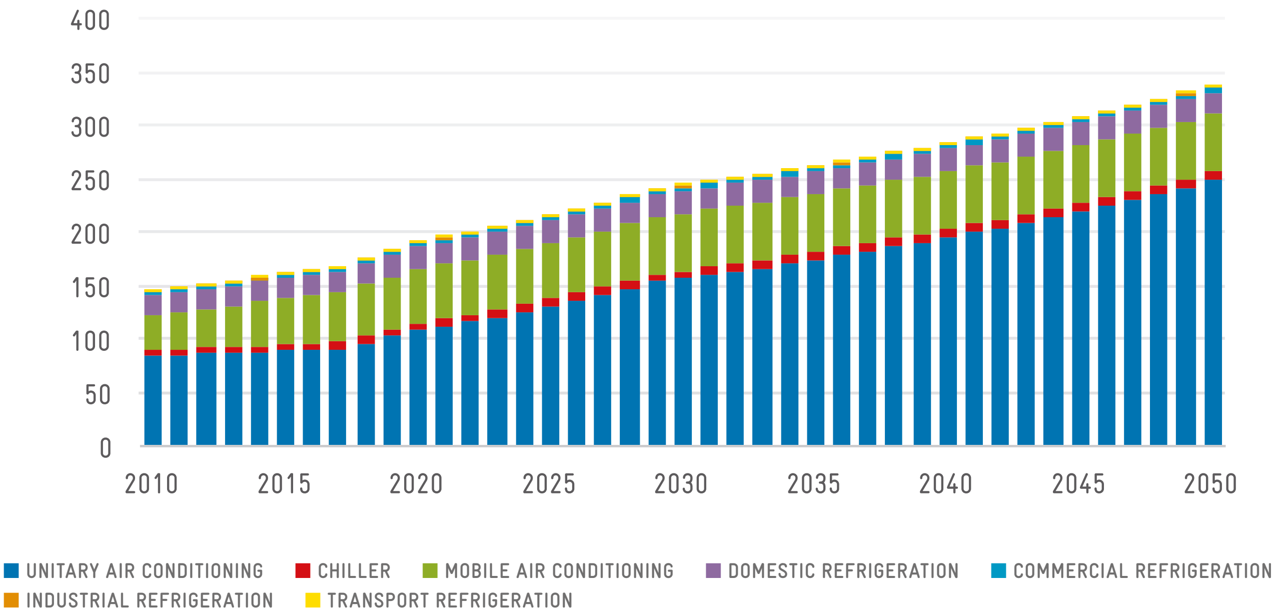

FIGURE 24: PROJECTED BAU ENERGY CONSUMPTION IN THE RAC SECTOR FOR THE YEARS 2010-2050

21 Based on 113 GWh RAC electricity consumption in 2013 against total electricity consumption of 176 GWh in Grenada according to IDB, 2015

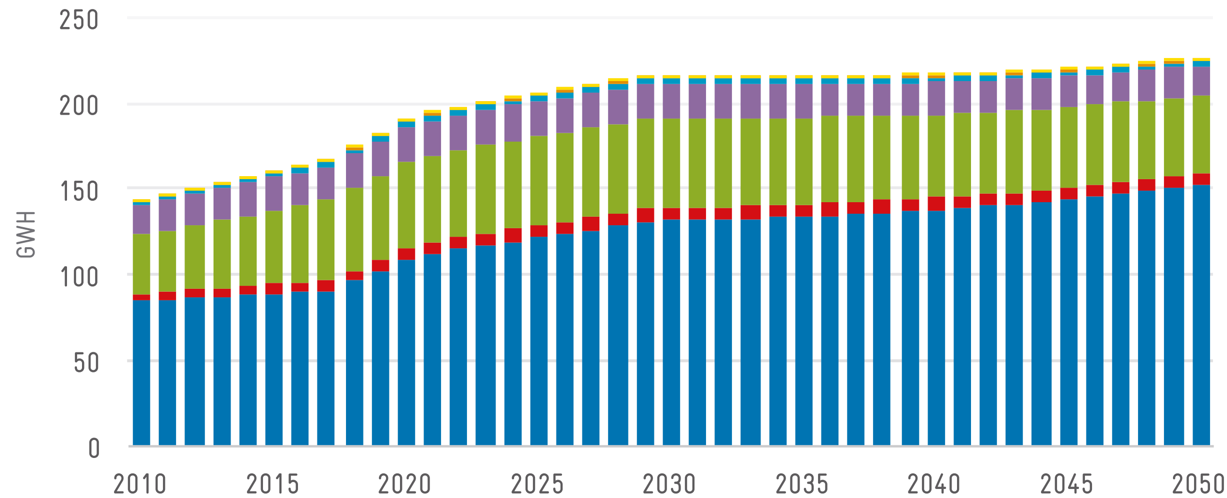

FIGURE 25: PROJECTED MIT ENERGY CONSUMPTION IN THE RAC SECTOR FOR THE YEARS 2010-2050

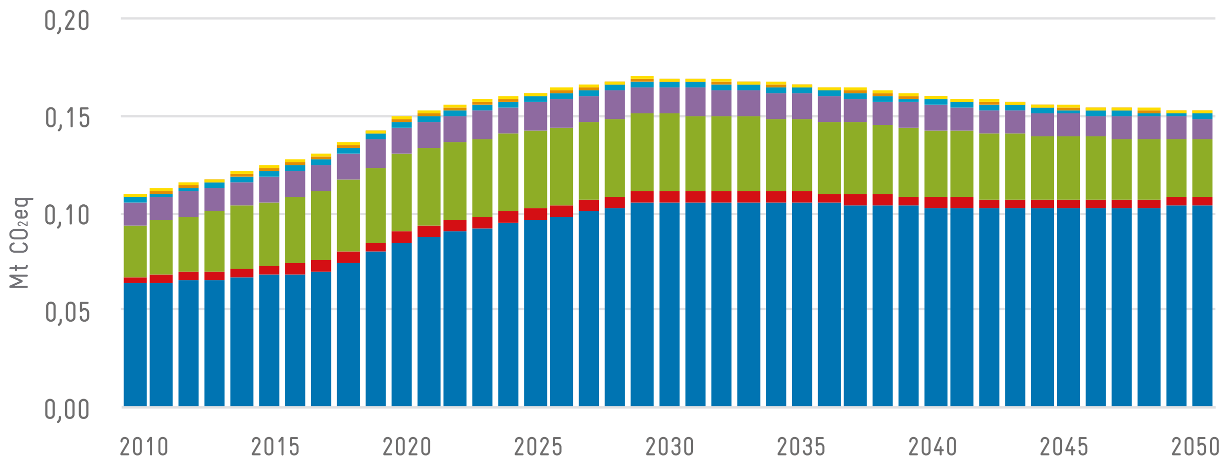

FIGURE 26: TOTAL GHG EMISSIONS FROM PROJECTED MIT SCENARIO IN THE RAC SECTOR UNTIL 2050

UNITARY AIR CONDITIONING · CHILLER · MOBILE AIR CONDITIONING · DOMESTIC REFRIGERATION · COMMERCIAL REFRIGERATION · INDUSTRIAL REFRIGERATION · TRANSPORT REFRIGERATION

3.4.3 Use of low-GWP refrigerants

With the ratification of the Kigali amendment, HFC consumption will be limited and reduced in the future. Figure 27 shows the RAC-related HFC consumption under the BAU scenario (blue line), the assumed consumption freeze and reduction steps under the Kigali Amendment (green line) and possible mitigated consumption under a more ambitious scenario as assumed under the MIT scenario in this inventory report (red line). For better comparison to the Kigali schedule, the BAU and MIT scenario are shown as refrigerant consumption (still in Mt CO_2eq) instead of emissions. Total BAU consumption will grow continuously. In contrast, under the MIT scenario more low-GWP refrigerants will be used (see also Annex section 5.4) so that it is currently close to its peak (years 2018-2019), with no significant increase thereafter, and will decrease after 2028 and in the coming decades.

Under the Kigali Amendment, the GWP based consumption baseline for the A5 Group 1 (including Grenada), is calculated from the 2020-2022 average HFC consumption plus 65% of the HCFC baseline consumption, both GWP-weighted. After the freeze from 2024-2028, the first reduction step takes place in 2029 with 90% of the baseline and successive steps of 70% of the baseline in 2035, 50% in 2040 and 20% in 2045, as illustrated in Figure 27. The BAU scenario is projected to exceed the stipulated 50% reduction step in 2035, whereas the MIT scenario is expected to comply with the requirements of the Kigali Amendment, with the only exception of a negligible excess in 2045.

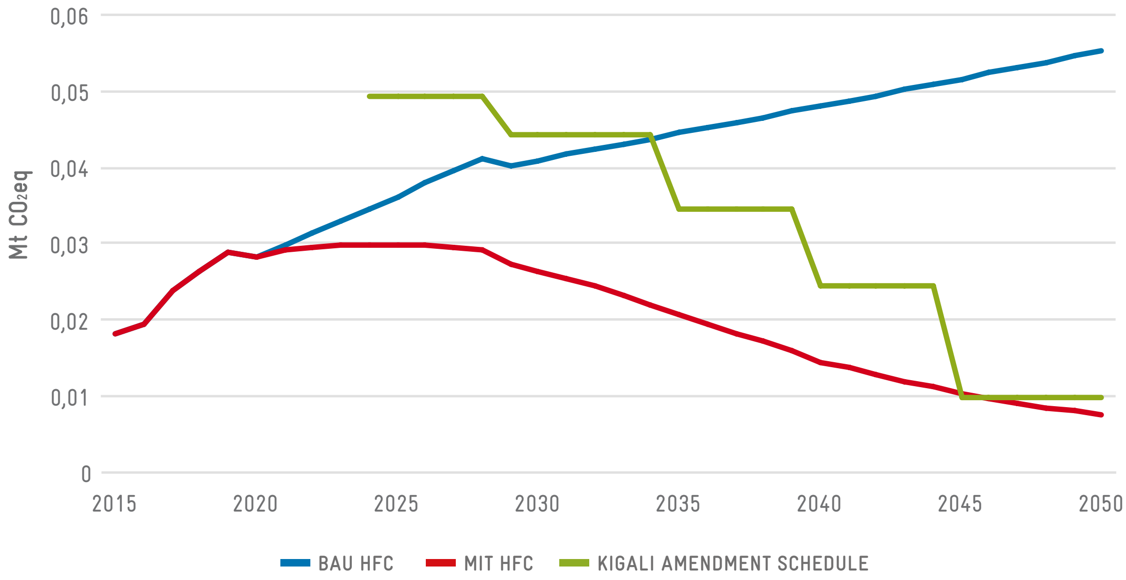

FIGURE 27: HFC CONSUMPTION UNDER BAU AND MIT SCENARIO AND THE KIGALI AMENDMENT SCHEDULE, KIGALI PHASE-DOWN BASED ON BAU SCENARIO

The great divergence between BAU and MIT scenario shows the large GHG mitigation potential by transitioning from highly climate-damaging HCFC and HFC to alternatives with low GWP in a timely manner, ahead of the current HFC phase-down schedule stipulated in the Kigali Amendment to the Montreal Protocol (Clark and Wagner, 2016).

3.4.4 Unitary air conditioning emission mitigation potential

The estimated emissions from UAC for different scenarios are shown in Figure 28. BAU emissions are expected to increase from 68 kt CO_2eq in 2015 to 200 kt CO_2eq in 2050. By progressive transition to low-GWP equipment from year 2020 onward, emissions are forecasted to come down to 163 kt CO_2eq in 2050 (red line). Simultaneous improvement of energy efficiency[22] by the new units on the market will enable significant further mitigation of GHG emissions, pushing total UAC emissions down to 104 kt CO_2eq in 2050 (green line). The resulting mitigation potential adds up to approximately 96 kt CO_2eq in 2050 (21 kt CO_2eq in 2030).

22 For the parameters used for energy efficiency improvement, please see Table 6 / further underlying parameters given in sub-chapter 2.3

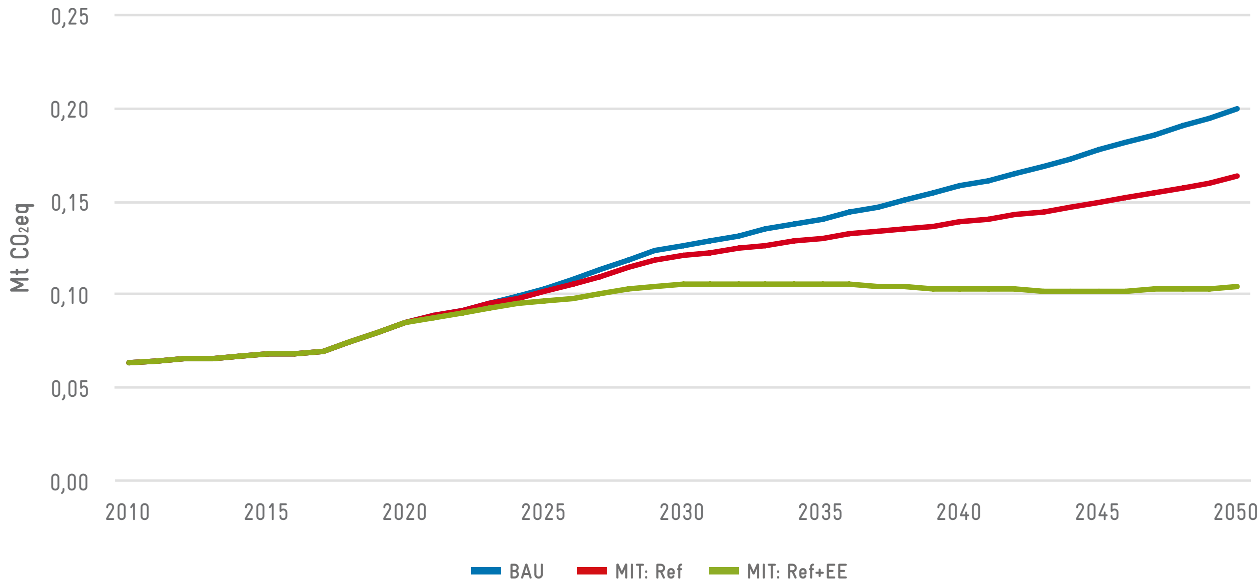

FIGURE 28: TOTAL ANNUAL EMISSIONS FROM UAC 2010-2050, BAU AND MITIGATION SCENARIOS

3.4.5 Chiller emission mitigation potential

The estimated annual mitigation potential for the chiller sub-sector (AC chillers) increases to 2.4 kt CO_2eq in 2050. The higher share of this mitigation is attributed to direct emissions by using low-GWP refrigerants. Currently operating AC chiller systems predominantly use the HFC refrigerants R134a, R407C and R410A.

The remaining reduction will result from chillers with high energy efficiency by using variable speed components and highly efficient heat exchangers[23].

Large-scale refrigeration systems working with R717 refrigerant are attributed to industrial condensing units and centralised systems under industrial refrigeration (see section 3.4.9).

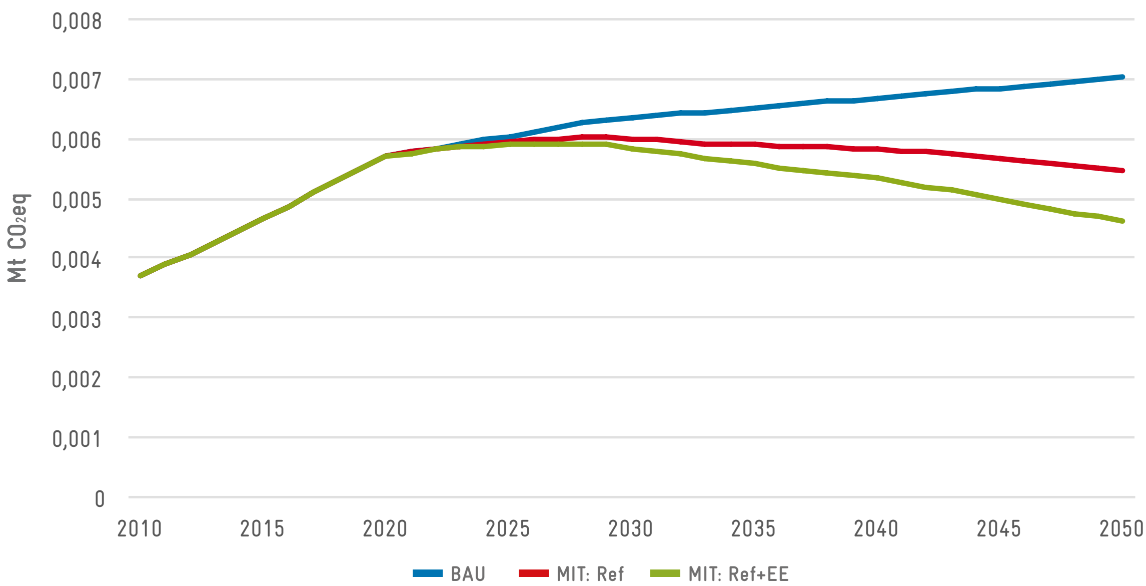

FIGURE 29: TOTAL ANNUAL EMISSIONS FROM CHILLERS 2010-2050, BAU AND MITIGATION SCENARIOS

23 For the parameters used for energy efficiency improvement, please see Table 6 / further underlying parameters given in sub-chapter 2.3

3.4.6 Mobile air conditioning emission mitigation potential

The estimated mitigation potential by the MAC sub-sector amounts to 8.5 kt CO_2eq annually in 2050. The mitigation of direct emissions (see red line: "MIT: Ref") is attributed to a conversion to CO_2 (R744) with a short influence period of HFO refrigerant (R1234yf), while a conversion to entirely using R1234yf by 2050 is assumed in the BAU scenario[24]. As visible in Figure 30 by the green line ("MIT: Ref+EE"), the higher mitigation impact is expected from indirect emissions reduction through energy efficiency improvements in addition to BAU. Even greater reduction potential could be explored with the uptake of electric mobility, if the therefore required driving energy is provided by electricity supply with higher renewable energy shares in the future.

3.4.7 Domestic refrigeration emission mitigation potential

As refrigerators are usually tight systems and have low refrigerant charge sizes, most emission mitigation potential for domestic refrigeration lies in the improvement of energy efficiency of refrigerators[25]. The estimated emission savings are around 2.1 kt CO_2eq annually in 2050. The mitigation scenarios basically represent an amplification of the already initiated technology uptake of R600a refrigerators which is why the expected reduction potential of direct emissions is marginal. The transition to R600a refrigerants for domestic units over the next decades can be considered as BAU. The additional mitigation potential can be achieved through the application of ambitious energy efficiency MEPS and labels.

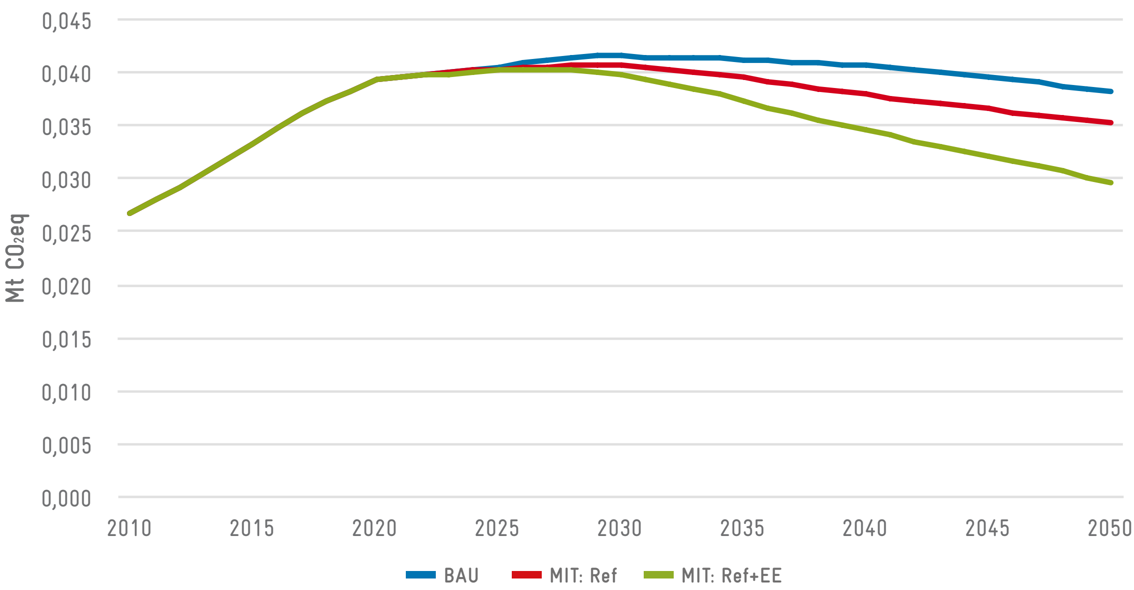

FIGURE 30: TOTAL ANNUAL EMISSIONS FROM MOBILE AC 2010-2050, BAU AND MITIGATION SCENARIOS

24 For the parameters used for refrigerant conversion, please see Table 4 / further underlying parameters given in sub-chapter 2.3

25 For the parameters used for energy efficiency improvement, please see Table 6 / further underlying parameters given in sub-chapter 2.3

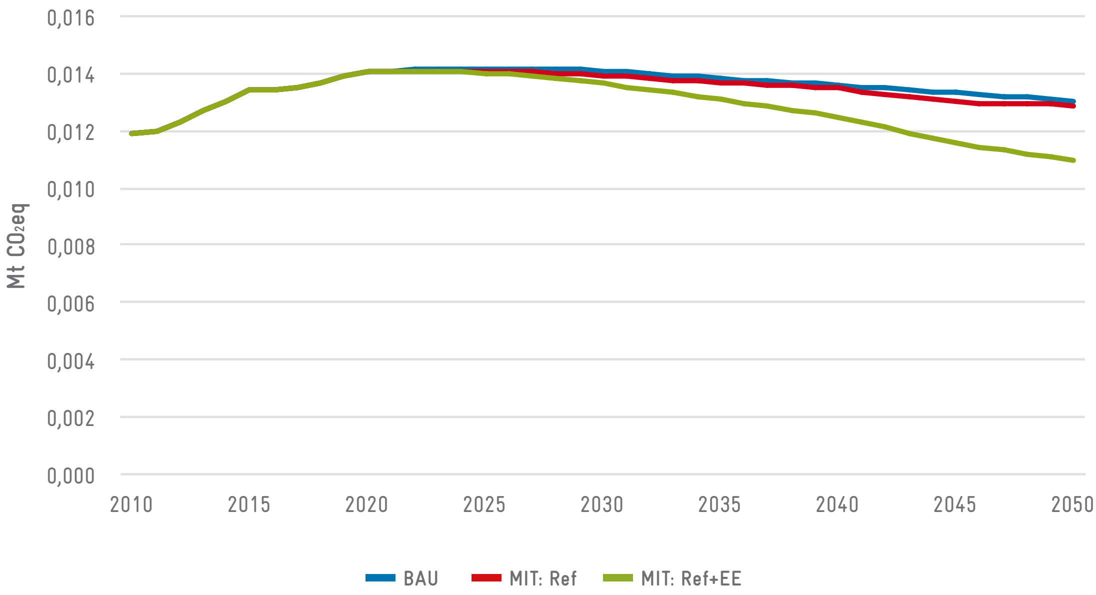

FIGURE 31: TOTAL ANNUAL EMISSIONS FROM DOMESTIC REFRIGERATION 2010-2050, BAU AND MITIGATION SCENARIOS

3.4.8 Commercial refrigeration emission mitigation potential

The emission saving potential for commercial refrigeration technology amounts to 1.7 kt CO_2eq per year by 2050. The MIT scenario includes emission savings from increased uptake of technology using the low-GWP refrigerants R290 and R600a which at the same time brings energy efficiency improvements, due to the advantageous physical properties of hydrocarbon refrigerants requiring lower refrigerant charges. Further mitigation effects could be achieved through a more progressive transition to low-GWP refrigerants and energy efficiency improvements[26] facilitated by the application of ambitious MEPS and labels.

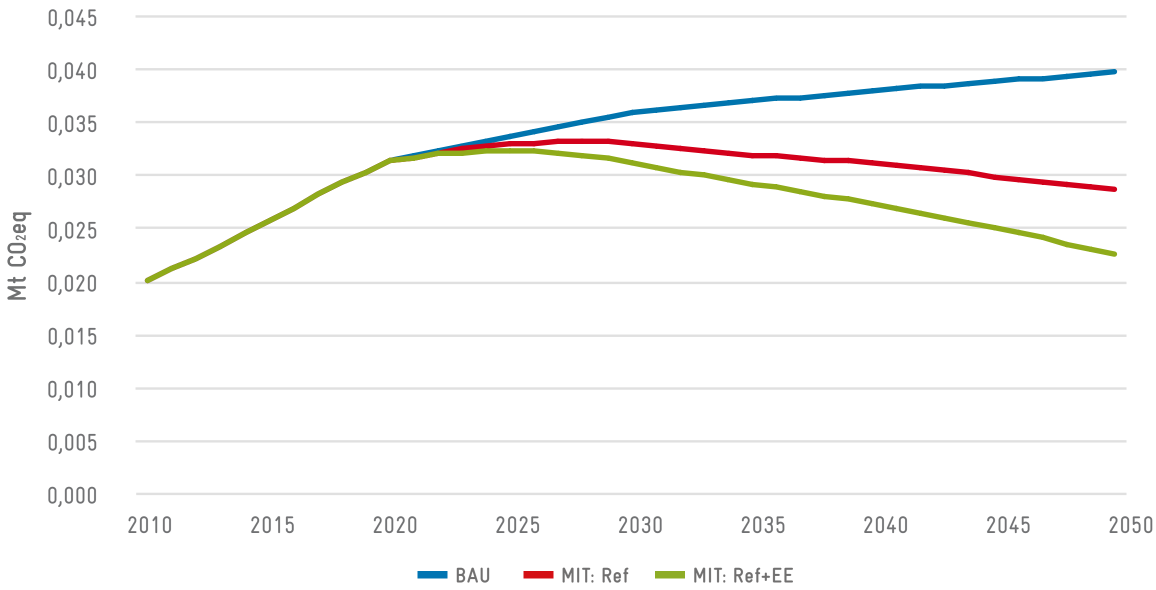

FIGURE 32: TOTAL ANNUAL EMISSIONS FROM COMMERCIAL REFRIGERATION 2010-2050, BAU AND MITIGATION SCENARIOS

26 For the parameters used for refrigerant conversion, please see Table 4 / for energy efficiency improvement, please see Table 6 / further underlying parameters given in sub-chapter 2.3

3.4.9 Industrial refrigeration emission mitigation potential

The expected emission mitigation potential per year in industrial refrigeration is of around 0.2 kt CO_2eq in 2050. The low reduction potential is also due to the low appliance stock in this sub-sector. The mitigation will mainly be achieved by transitioning to low-GWP refrigerants for condensing units with moderate additional energy efficiency improvements[27]. Other appliances in this sub-sector (integral units and centralised systems), despite of high individual refrigerant charges, only contribute to indirect emissions. This is due to the exclusive use of the zero-GWP refrigerant R717. For this reason, the related appliances only offer mitigation potential for indirect emissions by means of energy efficiency improvements.

3.4.10 Transport refrigeration emission mitigation potential

With a stock of 13 appliances in 2017, the estimated mitigation potential in transport refrigeration is marginal. Nonetheless, it is possible to mitigate direct emissions by uptake of appliances using low-GWP refrigerants such as R290.

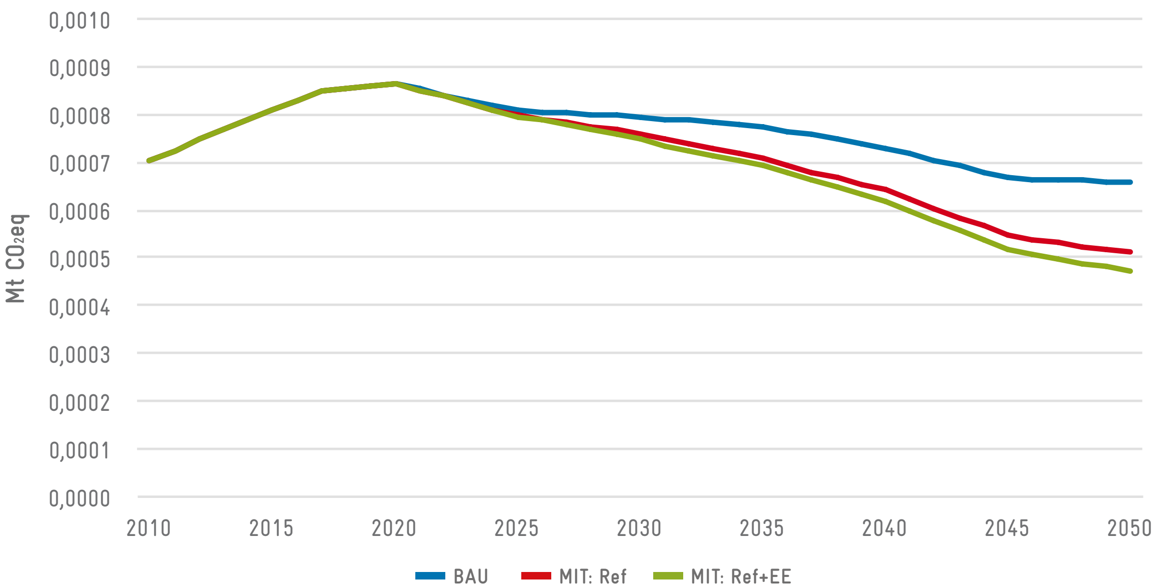

FIGURE 33: TOTAL ANNUAL EMISSIONS FROM INDUSTRIAL REFRIGERATION 2010-2050, BAU AND MITIGATION SCENARIOS

27 For the parameters used for refrigerant conversion, please see Table 4 / for energy efficiency improvement, please see Table 6 / further underlying parameters given in sub-chapter 2.3

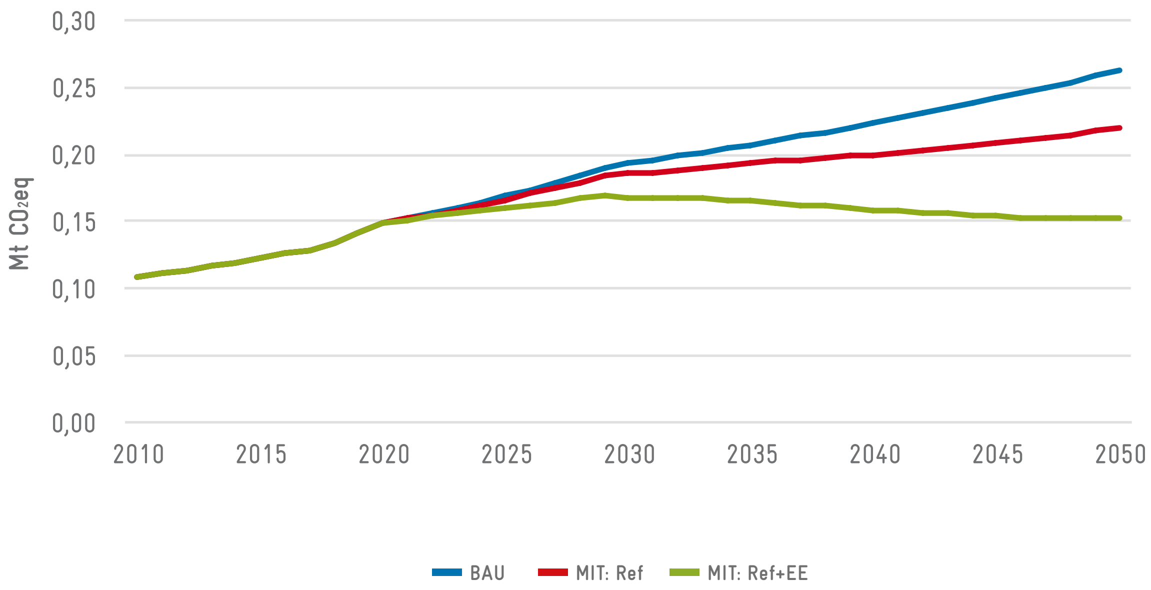

FIGURE 34: TOTAL ANNUAL EMISSIONS FROM TRANSPORT REFRIGERATION 2010-2050, BAU AND MITIGATION SCENARIOS

3.5 CONCLUSION

The sub-sector which contributes most to GHG emissions in Grenada's RAC sector is unitary air conditioning (UAC), followed by mobile AC (MAC) which is used to climatize vehicles. UAC is also projected to undergo the strongest growth in the next decades.

The mitigation scenario, which involves the enactment of regulatory measures to trigger technological advances concerning refrigerant choice and energy efficiency, is expected to achieve substantial emission reduction compared to business as usual (BAU) of approximately 111 kt CO_2eq annually by 2050 (25 kt CO_2eq annually by 2030) and thus contribute to Grenada's overall GHG reduction targets (30% reduction by 2025, and the indicate target of a 40% reduction by 2030 compared to a 2010 baseline). Because of its high unit numbers and strongly increasing market demand, UAC shows by far the largest emission mitigation potential.

Despite a contribution ranging between 18 and 22% of total emissions in the observation period 2010-2050, direct emissions stand out for a relatively high mitigation potential. The impact by direct emission mitigation contributes 38% to the total mitigation potential in 2050 (30% in 2030). This correlation is largely due to the large gap between different GWP levels. Most currently used refrigerants are high-GWP refrigerants with GWP values between 1,300 and 4,000, while low-GWP refrigerants have GWPs below 10 and make up the more progressive technology transition in the refrigerant mitigation scenario ("MIT: Ref").

With further relevance to direct emissions, it is assumed that Grenada has high refrigerant leakage rates in RAC appliances in general (between 20% and 30% assumed for most equipment types, see also Table 4). Due to their high refrigerant charges, larger AC units including chillers, commercial refrigeration and industrial refrigeration are most affected. A reduction in leakage can be achieved through more training and certification of RAC technicians in Good Refrigeration Practices.

The positive impact of the technology uptake of high energy efficiency equipment is not only reflected in the mitigation of indirect emissions, but also contributes to increasing energy security and reducing the load of the public power grid.

According to the BAU scenario, an increase in energy demand suggests an additional average energy consumption of 3% every year until 2030, whereat the additional energy consumption for UAC alone amounts to 6% every year until 2020 and 4% in average in the next decade. This additional demand on the national power grid would require the expansion of renewable energy capacity, the increase of power plants running on fossil fuels, or both. It is therefore essential to take appropriate energy efficiency measures in the RAC sector, including MEPS, labelling and other legislation, standards and codes.

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5 ANNEX

5.1 CONTACTED COMPANIES VIA QUESTIONNAIRES OF UNITARY AIR CONDITIONING AND REFRIGERATION SUB-SECTORS

TABLE 17: LIST OF RESPONSIVE ACTORS TO THE RAC GHG INVENTORY WITHIN THE C4 COUNTRY PROGRAMME

INDEX	COMPANY / FACILITY	CLASSIFICATION
1	St. George's University (SGU)	RAC end user
2	Bruce Street Mall	RAC end user
3	Coyaba Beach Resort	RAC end user
4	Grenada Trade Centre	RAC end user
5	Huggins Distribution	RAC end user
6	Radisson Hotel	RAC end user
7	Rex Grenadian Hotel	RAC end user
8	Sandals La Source	RAC end user
9	Spice Isle Beach Resort	RAC end user
10	True Blue Bay Resort	RAC end user
11	Gouyave Fish Market	RAC end user
12	Grenville Fish Market	RAC end user
13	Melville St. Fish Market	RAC end user
15	Food Fair Supermarket	RAC end user
16	Foodland Melville St.	RAC end user
17	SOG Supermarket	RAC end user
18	Southern Fishermen Association	RAC end user
19	Spice Isle Fish House	RAC end user
20	General Hospital	RAC end user
21	Food Fair Supermarket	RAC end user
22	Cooling Tech Limited	RAC distributor / servicing
23	Jonas Browne & Hubbards (Gda) Limited	RAC distributor / servicing

5.2 SUB-SECTOR DEFINITIONS

TABLE 18: OVERVIEW OF AIR CONDITIONING SUB-SECTORS

RAC SUB-SECTOR	PRODUCT GROUP	DESCRIPTION
UNITARY AIR CONDITIONING	Self-contained	• All components of the system are located within one housing
	Split residential and commercial (duct-less)	• The systems consist of two elements: (1) the condenser unit containing the compressor mounted outside the room and (2) the indoor unit (evaporator) supplying cooled air to the room. • Residential units: applied in private households • Commercial units: applied in offices or other commercial buildings • This product group refers to "single" split systems, i.e., one indoor unit is connected to one outdoor unit.
	Ducted split, residential and commercial	• Systems consist of an outdoor unit (condenser) containing the compressor which is connected to an indoor unit (evaporator) to blow cooled air through a pre-installed duct system. • Residential units are mainly used in domestic context • Commercial units: applied in offices or other commercial buildings • Ducted splits are mainly used to cool multiple rooms in larger buildings (incl. houses).
	Rooftop ducted	• Single refrigerating system mounted on the roof of a building from where ducting leads to the interior of the building and cool air is blown through.
	Multi-split, VRF/VRV	• Multi-splits: like ductless single-split systems (residential/commercial single splits, see above), although usually up to 5 indoor units can be connected to one outdoor unit. • VRF/VRV (variable refrigerant flow/volume) systems: Type of multi-split system where a 2-digit number of indoor units can be connected to one outdoor unit. Used in mid-size office buildings and commercial facilities.
CHILLERS, AIR-CONDITIONING	Chillers (AC)	• AC chillers usually function by using a liquid for cooling (usually water) in a conventional refrigeration cycle. This water is then distributed to cooling – and sometimes heating – coils within the building. • AC chillers are mainly applied for commercial and light industrial purposes.
MOBILE AIR CONDITIONING	Small: Passenger cars, light commercial vehicle, Pick-up, SUV Large: Busses, Trains, etc	• Air conditioning in all types of vehicles, such as passenger cars, trucks or buses. Mainly a single evaporator system is used.

TABLE 19: OVERVIEW OF REFRIGERATION SUB-SECTORS

RAC SUB-SECTOR	PRODUCT GROUP	DESCRIPTION
DOMESTIC REFRIGERATION	Refrigerator/freezer	• The sub-sector includes the combination of refrigerators and freezers as well as single household refrigerators and freezers
COMMERCIAL REFRIGERATION	Stand-alone	• "plug-in" units built into one housing (self-contained refrigeration systems) • Examples: vending machines, ice cream freezers and beverage coolers
	Condensing unit	• These refrigerating systems are often used in small shops such as bakeries, butcheries or small supermarkets. • The "condensing unit" holds one to two compressors, the condenser and a receiver and is usually connected via piping to small commercial equipment located in the sales area, e.g., cooling equipment such as display cases or cold rooms. The unit usually comes pre-assembled.
	Centralised systems (for supermarkets)	• Used in larger supermarkets (sales are greater than 400 square meters). • Operates with a pack of several parallel working compressors located in a separate machinery room. This pack is connected to separately installed condensers outside the building. • The system is assembled on-site.
INDUSTRIAL REFRIGERATION	Stand-alone (integral) unit	• "plug-in" units built into one housing (self-contained refrigeration systems) • Examples: industrial ice-makers
	Condensing unit	• The 'condensing unit' holds one to two compressors, the condenser and a receiver and is usually connected via piping to small commercial equipment located in the sales area, e.g., cooling equipment such as display cases or cold rooms. The unit usually comes pre-assembled. Example: cold storage facilities
	Centralised systems	• Operates with a pack of several parallel working compressors located in a separate machinery room. This pack is connected to separately installed condensers outside the building. The system is assembled on-site
TRANSPORT REFRIGERATION	Trailer, van, truck	• Covers refrigeration equipment that is required during the transportation of goods on roads by trucks and trailers (but also by trains, ships or in airborne containers). • Per road vehicle, usually one refrigeration unit is installed.

5.3 INVENTORY STOCK DATA

The following table shows the assumed stock data based on the collected data from primary (questionnaires) and secondary data sources.

TABLE 20: COLLECTED STOCK DATA

SUB-SECTOR	PRIMARY DATA	SECONDARY DATA	REFERENCE YEAR
DUCTLESS RESIDENTIAL SPLIT		11,000	2017
DUCTLESS COMMERCIAL SPLIT	1,679	5,000	2017
DUCTED SPLIT	73		2017
ROOFTOP DUCTED	20		2017
MULTI-SPLIT, VRF/VRV	314		2017
AIR CONDITIONING CHILLERS	21		2017
CAR AC		26,104	2017
DOMESTIC REFRIGERATION		40,472	2015
STAND-ALONE UNITS	198		2017
INTEGRAL UNITS	8		2017
CONDENSING UNITS	132		2017
CENTRALISED SYSTEMS FOR SUPERMARKETS	1		2017
INDUSTRIAL CONDENSING UNITS	15		2017
CENTRALISED SYSTEMS	3		2017
REFRIGERATED TRUCKS/TRAILERS		13	2017

5.4 APPLIED MODELLING PARAMETERS AND RESULTS OF MODEL CALCULATIONS

TABLE 21: ASSUMED AVERAGE ENERGY EFFICIENCY RATIOS IN EQUIPMENT STOCK FOR THE BUSINESS-AS-USUAL SCENARIO

EQUIPMENT TYPE	2017	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	3.20	3.26	3.31	3.36	3.46	3.56
COMMERCIAL SPLIT AC	3.30	3.36	3.41	3.46	3.56	3.66
DUCTED SPLIT AC	3.35	3.41	3.45	3.48	3.51	3.53
ROOFTOP DUCTED	2.61	2.66	2.71	2.76	2.82	2.90
MULTI-SPLITS	3.45	3.51	3.59	3.66	3.82	3.90
AIR CONDITIONING CHILLERS	2.95	3.02	3.09	3.14	3.22	3.31
CAR AIR CONDITIONING	2.81	2.86	2.93	3.02	3.20	3.36
DOMESTIC REFRIGERATION	2.00	2.06	2.14	2.19	2.28	2.34
STAND-ALONE EQUIPMENT	1.47	1.48	1.52	1.56	1.60	1.64
CONDENSING UNITS	2.16	2.17	2.19	2.20	2.26	2.34
CENTRALISED SYSTEMS FOR SUPERMARKET	2.08	2.11	2.14	2.16	2.19	2.25
INTEGRAL UNITS	2.18	2.21	2.27	2.29	2.35	2.43
INDUSTRIAL CONDENSING UNITS	2.08	2.11	2.14	2.16	2.23	2.25
CENTRALISED SYSTEMS	3.35	3.41	3.52	3.56	3.62	3.69
REFRIGERATED TRUCKS/ TRAILERS	2.33	2.34	2.35	2.36	2.41	2.46

TABLE 22: ASSUMED AVERAGE ENERGY EFFICIENCY RATIOS IN EQUIPMENT STOCK FOR THE MITIGATION SCENARIO

EQUIPMENT TYPE	2017	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	3.20	3.26	4.40	5.00	6.00	6.60
COMMERCIAL SPLIT AC	3.30	3.36	4.50	5.10	6.10	6.70
DUCTED SPLIT AC	3.35	3.41	3.68	3.92	4.39	4.62
ROOFTOP DUCTED	2.61	2.66	2.87	3.17	3.56	3.74
MULTI-SPLITS	3.45	3.76	4.11	4.43	4.92	5.33
AIR CONDITIONING CHILLERS	2.95	3.02	3.27	3.61	4.12	4.58
CAR AIR CONDITIONING	2.81	2.86	2.98	3.29	3.86	4.60
DOMESTIC REFRIGERATION	2.00	2.06	2.22	2.44	2.91	3.44
STAND-ALONE EQUIPMENT	1.47	1.48	1.90	2.34	2.98	3.63
CONDENSING UNITS	2.16	2.17	2.74	2.86	3.27	4.14
CENTRALISED SYSTEMS FOR SUPERMARKET	2.08	2.11	2.16	2.24	2.62	2.91
INTEGRAL UNITS	2.18	2.21	2.24	2.28	2.41	2.51
INDUSTRIAL CONDENSING UNITS	2.08	2.11	2.27	2.51	2.70	2.79
CENTRALISED SYSTEMS	3.35	3.41	3.61	3.76	4.08	4.35
REFRIGERATED TRUCKS/ TRAILERS	2.33	2.34	2.41	2.49	2.62	2.73

TABLE 23: REFRIGERANT DISTRIBUTION IN SALES FOR BUSINESS-AS-USUAL SCENARIO

EQUIPMENT TYPE	REFRIGERANT	2015	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	R410A	100%	100%	95%	90%	80%	70%
RESIDENTIAL SPLIT AC	R32	0%	0%	5%	10%	20%	30%
COMMERCIAL SPLIT AC	R410A	100%	100%	95%	90%	80%	70%
COMMERCIAL SPLIT AC	R32	0%	0%	5%	10%	20%	30%
COMMERCIAL DUCTED SPLIT AC	R410A	100%	100%	100%	100%	100%	100%
ROOFTOP DUCTED	R410A	100%	100%	100%	100%	100%	100%
MULTI-SPLITS	R22	35%	0%	0%	0%	0%	0%
MULTI-SPLITS	R407C	32.5%	50%	50%	50%	50%	50%
MULTI-SPLITS	R410A	32.5%	50%	50%	50%	50%	50%
AC CHILLERS	R134a	34%	34%	34%	34%	34%	34%
AC CHILLERS	R407C	33%	33%	33%	33%	33%	33%
AC CHILLERS	R410A	33%	33%	33%	33%	33%	33%
CAR AIR CONDITIONING	R134a	100%	95%	90%	80%	40%	0%
CAR AIR CONDITIONING	HFO 1234yf	0%	5%	10%	20%	60%	100%
DOMESTIC REFRIGERATION	R134a	80%	70%	50%	20%	0%	0%
DOMESTIC REFRIGERATION	R600a	20%	30%	50%	80%	100%	100%
STAND-ALONE EQUIPMENT	R404A	50%	50%	50%	40%	20%	20%
STAND-ALONE EQUIPMENT	R290	0%	0%	0%	10%	30%	30%
STAND-ALONE EQUIPMENT	R134a	50%	50%	50%	50%	50%	50%
CONDENSING UNITS	R404A	100%	100%	100%	100%	100%	100%
CENTRALISED SYSTEMS FOR SUPERMARKET	R22	47.5%	0%	0%	0%	0%	0%
CENTRALISED SYSTEMS FOR SUPERMARKET	R134a	8%	15%	15%	15%	15%	15%
CENTRALISED SYSTEMS FOR SUPERMARKET	R290	2.5%	5%	5%	5%	5%	5%
CENTRALISED SYSTEMS FOR SUPERMARKET	R404A	39%	74%	74%	74%	74%	74%
CENTRALISED SYSTEMS FOR SUPERMARKET	R744	3%	6%	6%	6%	6%	6%
INTEGRAL	R717	100%	100%	100%	100%	100%	100%
INDUSTRIAL CONDENSING UNITS	R404A	100%	100%	100%	100%	100%	100%

TABLE 23: REFRIGERANT DISTRIBUTION IN SALES FOR BUSINESS-AS-USUAL SCENARIO

EQUIPMENT TYPE	REFRIGERANT	2015	2020	2025	2030	2040	2050
CENTRALISED SYSTEMS	R717	100%	100%	100%	100%	100%	100%
REFRIGERATED TRUCKS/ TRAILERS	R134a	100%	100%	100%	100%	100%	100%

TABLE 24: REFRIGERANT DISTRIBUTION IN SALES FOR MITIGATION SCENARIO

EQUIPMENT TYPE	REFRIGERANT	2015	2020	2025	2030	2040	2050
RESIDENTIAL SPLIT AC	R290	0%	0%	30%	50%	90%	100%
RESIDENTIAL SPLIT AC	R410A	100%	100%	65%	40%	0%	0%
RESIDENTIAL SPLIT AC	R32	0%	0%	5%	10%	10%	0%
COMMERCIAL SPLIT AC	R290	0%	0%	30%	50%	90%	100%
COMMERCIAL SPLIT AC	R410A	100%	100%	65%	40%	0%	0%
COMMERCIAL SPLIT AC	R32	0%	0%	5%	10%	10%	0%
COMMERCIAL DUCTED SPLIT AC	R410A	100%	100%	60%	10%	10%	10%
COMMERCIAL DUCTED SPLIT AC	GWP 150 HFC	0%	0%	40%	90%	90%	90%
ROOFTOP DUCTED	R410A	100%	100%	60%	10%	10%	10%
ROOFTOP DUCTED	GWP 150 HFC	0%	0%	40%	90%	90%	90%
MULTI-SPLITS	R22	35%	0%	0%	0%	0%	0%
MULTI-SPLITS	R407C	32.5%	50%	0%	0%	0%	0%
MULTI-SPLITS	R410A	32.5%	50%	60%	10%	10%	10%
MULTI-SPLITS	GWP 150 HFC	0%	0%	40%	90%	90%	90%
AC CHILLERS	R134a	34%	34%	20%	0%	0%	0%
AC CHILLERS	R407C	33%	33%	20%	0%	0%	0%
AC CHILLERS	R410A	33%	33%	20%	0%	0%	0%
AC CHILLERS	R290	0%	0%	30%	80%	80%	80%
AC CHILLERS	R744	0%	0%	10%	20%	20%	20%
CAR AIR CONDITIONING	R134a	100%	95%	70%	40%	0%	0%
CAR AIR CONDITIONING	R744	0%	0%	15%	45%	100%	100%
CAR AIR CONDITIONING	HFO 1234yf	0%	5%	15%	15%	0%	0%

TABLE 24: REFRIGERANT DISTRIBUTION IN SALES FOR MITIGATION SCENARIO

EQUIPMENT TYPE	REFRIGERANT	2015	2020	2025	2030	2040	2050
DOMESTIC REFRIGERATION	R134a	80%	70%	0%	0%	0%	0%
DOMESTIC REFRIGERATION	R600a	20%	30%	100%	100%	100%	100%
STAND-ALONE EQUIPMENT	R404A	50%	50%	30%	0%	0%	0%
STAND-ALONE EQUIPMENT	R290	0%	0%	20%	50%	50%	50%
STAND-ALONE EQUIPMENT	R134a	50%	50%	30%	0%	0%	0%
STAND-ALONE EQUIPMENT	R600a	0%	0%	20%	50%	50%	50%
CONDENSING UNITS	R290	0%	0%	20%	45%	45%	45%
CONDENSING UNITS	R404A	100%	100%	60%	10%	10%	10%
CONDENSING UNITS	R134a	0%	0%	20%	45%	45%	45%
CENTRALISED SYSTEMS FOR SUPERMARKET	R22	47.5%	0%	0%	0%	0%	0%
CENTRALISED SYSTEMS FOR SUPERMARKET	R134a	8%	15%	15%	0%	0%	0%
CENTRALISED SYSTEMS FOR SUPERMARKET	R290	2.5%	5%	20%	50%	50%	50%
CENTRALISED SYSTEMS FOR SUPERMARKET	R404A	39%	74%	45%	0%	0%	0%
CENTRALISED SYSTEMS FOR SUPERMARKET	R744	3%	6%	20%	50%	50%	50%
INTEGRAL	R717	100%	100%	100%	100%	100%	100%
INDUSTRIAL CONDENSING UNITS	R290	0%	0%	20%	45%	45%	45%
INDUSTRIAL CONDENSING UNITS	R404A	100%	100%	60%	10%	10%	10%
INDUSTRIAL CONDENSING UNITS	R744	0%	0%	20%	45%	45%	45%
CENTRALISED SYSTEMS	R717	100%	100%	100%	100%	100%	100%
REFRIGERATED TRUCKS/ TRAILERS	R134a	100%	100%	50%	30%	0%	0%
REFRIGERATED TRUCKS/ TRAILERS	R290	0%	0%	50%	70%	100%	100%

TABLE 25: CALCULATED STOCK

EQUIPMENT TYPE	2010	2015	2020	2025	2030	2035	2040	2045	2050
SELF-CONTAINED AIR CONDITIONERS	0	0	0	0	0	0	0	0	0
SPLIT RESIDENTIAL AIR CONDITIONERS	10,535	10,781	14,641	20,535	27,859	33,088	39,298	46,673	55,433
SPLIT COMMERCIAL AIR CONDITIONERS	4,768	6,066	8,182	9,182	10,187	10,795	11,440	12,123	12,847
DUCT SPLIT RESIDENTIAL AIR CONDITIONERS	0	0	0	0	0	0	0	0	0
COMMERCIAL DUCTED SPLITS	59	69	82	88	93	96	100	103	106
ROOFTOP DUCTED	16	19	22	24	26	26	27	28	29
MULTI-SPLITS	204	277	353	377	401	414	428	443	458
AIR CONDITIONING CHILLERS	15	19	24	25	27	28	29	30	31
PROCESS CHILLERS	0	0	0	0	0	0	0	0	0
CAR AIR CONDITIONING	18,912	23,808	28,525	29,980	31,353	32,145	32,956	33,788	34,642
LARGE VEHICLE AIR CONDITIONING	0	0	0	0	0	0	0	0	0
DOMESTIC REFRIGERATION	35,848	40,472	42,998	44,230	45,370	46,016	46,672	47,337	48,011
STAND-ALONE EQUIPMENT	149	182	216	227	238	244	250	256	263
CONDENSING UNITS	96	120	144	152	159	163	167	171	175
CENTRALISED SYSTEMS FOR SUPERMARKETS	1	1	1	1	1	1	1	1	1
INTEGRAL	5	7	9	9	10	10	10	10	11
CONDENSING UNITS	9	13	16	17	18	18	19	19	20
CENTRALISED SYSTEMS	2	3	3	3	4	4	4	4	4
REFRIGERATED TRUCKS/TRAILERS	9	12	15	16	17	17	18	18	19

TABLE 26: CALCULATED SALES

EQUIPMENT TYPE	2010	2015	2020	2025	2030	2035	2040	2045	2050
SELF-CONTAINED AIR CONDITIONERS	0	0	0	0	0	0	0	0	0
SPLIT RESIDENTIAL AIR CONDITIONERS	713	828	2,001	2,806	2,832	3,364	3,995	4,745	5,636
SPLIT COMMERCIAL AIR CONDITIONERS	553	704	736	826	798	846	896	950	1,006
DUCT SPLIT RESIDENTIAL AIR CONDITIONERS	0	0	0	0	0	0	0	0	0
COMMERCIAL DUCTED SPLITS	8	9	9	10	10	10	11	11	11
ROOFTOP DUCTED	2	2	3	3	3	3	3	3	3
MULTI-SPLITS	27	36	28	30	29	30	31	32	34
AIR CONDITIONING CHILLERS	1	2	1	2	2	2	2	2	2
PROCESS CHILLERS	0	0	0	0	0	0	0	0	0
CAR AIR CONDITIONING	2,152	2,709	2,187	2,298	2,247	2,304	2,362	2,422	2,483
LARGE VEHICLE AIR CONDITIONING	0	0	0	0	0	0	0	0	0
DOMESTIC REFRIGERATION	2,056	2,226	2,394	2,462	2,397	2,431	2,466	2,501	2,537
STAND-ALONE EQUIPMENT	16	20	17	17	17	17	18	18	19
CONDENSING UNITS	9	12	9	9	9	9	9	9	10
CENTRALISED SYSTEMS FOR SUPERMARKETS	0	0	0	0	0	0	0	0	0
INTEGRAL	1	1	1	1	1	1	1	1	1
CONDENSING UNITS	1	2	1	1	1	1	1	1	1
CENTRALISED SYSTEMS	0	0	0	0	0	0	0	0	0
REFRIGERATED TRUCKS/TRAILERS	1	1	1	1	1	1	1	1	1

TABLE 27: REFRIGERANT BANKS IN TONNES OF SUBSTANCE, 2019-2028

REFRIGERANT	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
R22	16.20	15.07	14.05	13.11	12.23	11.41	10.64	9.93	9.27	8.65
R134a	23.80	24.32	24.41	24.48	24.53	24.55	24.56	24.53	24.46	24.35
R404A	0.79	0.85	0.88	0.91	0.94	0.96	0.99	1.02	1.04	1.07
R407C	1.05	1.19	1.27	1.35	1.42	1.49	1.56	1.63	1.70	1.77
R410A	16.96	20.61	23.10	25.60	28.09	30.60	33.14	35.70	38.30	40.95
R32	0.00	0.00	0.04	0.11	0.23	0.39	0.59	0.84	1.15	1.50
R1234yf	0.15	0.22	0.29	0.36	0.44	0.54	0.64	0.76	0.91	1.07
R290	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
R600a	0.78	0.89	0.99	1.10	1.23	1.36	1.51	1.67	1.86	2.06
R717	1.23	1.31	1.35	1.39	1.43	1.46	1.50	1.54	1.57	1.61
R744	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ANNUAL TOTAL	60.97	64.46	66.38	68.41	70.54	72.78	75.15	77.65	80.28	83.06
CUMULATIVE TOTAL	60.97	125.43	191.81	260.22	330.76	403.54	478.69	556.34	636.62	719.68
R22 CUMULATIVE	16.20	31.27	45.32	58.43	70.66	82.06	92.70	102.64	111.90	120.55

TABLE 28: STOCK UNITS BY SUBSTANCE, 2019-2028

REFRIGERANT	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
R22	9,923	9,202	8,556	7,955	7,396	6,877	6,394	5,945	5,527	5,139
R134a	65,325	66,130	65,995	65,774	65,471	65,089	64,630	64,026	63,280	62,399
R404A	234	243	247	251	254	258	262	265	268	271
R407C	104	123	133	142	152	161	170	179	187	196
R410A	11,488	14,085	15,917	17,751	19,594	21,452	23,333	25,242	27,187	29,173
R32	0	0	28	86	174	296	451	644	876	1,151
R1234yf	251	370	478	602	741	896	1,065	1,272	1,514	1,790
R290	0	0	0	0	0	0	0	0	1	2
R600a	4,470	5,104	5,665	6,300	7,005	7,778	8,617	9,570	10,632	11,799
R717	9	9	10	10	10	10	11	11	11	11
R744	0	0	0	0	0	0	0	0	0	0
ANNUAL TOTAL	91,805	95,266	97,028	98,870	100,797	102,816	104,933	107,153	109,484	111,932
CUMULATIVE TOTAL	91,805	187,071	284,099	382,968	483,766	586,582	691,515	798,668	908,152	1,020,084
R22 CUMULATIVE	9,923	19,126	27,681	35,636	43,032	49,909	56,302	62,247	67,775	72,914

TABLE 29: END-OF-LIFE REFRIGERANT BANKS IN TONNES OF SUBSTANCE, 2019-2028

REFRIGERANT	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
R22	2.32	2.50	2.58	2.66	2.75	2.85	2.95	2.52	2.04	1.51
R134a	1.49	1.53	1.54	1.56	1.57	1.59	1.60	1.61	1.62	1.63
R404A	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05
R407C	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05
R410A	0.02	0.03	0.05	0.07	0.10	0.12	0.15	0.71	1.33	2.02
R32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1234yf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R290	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R600a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02
R717	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.04
R744	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANNUAL TOTAL	3.85	4.08	4.21	4.34	4.48	4.63	4.79	4.96	5.13	5.31
CUMULATIVE TOTAL	3.85	7.93	12.14	16.48	20.96	25.59	30.39	35.34	40.47	45.79
R22 CUMULATIVE	2.32	4.82	7.40	10.06	12.81	15.66	18.61	21.13	23.17	24.68

TABLE 30: END-OF-LIFE UNITS BY SUBSTANCE, 2019-2028

REFRIGERANT	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
R22	1,443	1,566	1,644	1,726	1,814	1,907	2,007	1,697	1,346	952
R134a	3,961	4,053	4,084	4,115	4,147	4,179	4,211	4,201	4,190	4,179
R404A	6	7	9	12	14	17	19	19	18	17
R407C	1	2	2	3	3	4	4	6	7	8
R410A	2	3	5	8	11	14	17	437	903	1,422
R32	0	0	0	0	0	0	0	0	0	0
R1234yf	0	0	0	0	0	0	0	0	0	0
R290	0	0	0	0	0	0	0	0	0	0
R600a	0	0	0	0	0	0	0	44	89	135
R717	0	0	0	0	0	1	1	1	1	1
R717	0	0	0	0	0	1	1	1	1	1
ANNUAL TOTAL	5,413	5,631	5,745	5,864	5,990	6,121	6,260	6,403	6,555	6,714
CUMULATIVE TOTAL	5,413	11,044	16,788	22,653	28,642	34,763	41,023	47,426	53,981	60,695
R22 CUMULATIVE	1,443	3,009	4,652	6,378	8,192	10,099	12,107	13,803	15,149	16,101

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