Cool Up
Upscaling Sustainable Cooling

COOLING SECTOR PROSPECTS STUDY EGYPT:

Energy and emission saving potential up to 2050 in the refrigeration and air conditioning sector

March 2023

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Guidehouse Germany GmbH
Albrechtstr. 10C
10117 Berlin, Germany
+49 (0)30 297735790
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© 2023 Guidehouse Germany GmbH

Authors

Lead authors:

Ahmed A. Hassan (Integrated Development Group)

Jan Grözinger, Nesen Surmeli-Anac, Mustafa Abunofal (Guidehouse)

Contributing authors:
Norhan El Dallal (Integrated Development Group)
Felix Heydel (Öko-Recherche)
Markus Offermann (Guidehouse)

Review:
Mohamed Salheen (Integrated Development Group)
Kjell Bettgenhäuser (Guidehouse)
Barbara Gschrey (Öko-Recherche)
Sanjeev Tamhane (Frankfurt School)

Date

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Contact

Contact us at info@coolupprogramme.org.
Visit us on the web at www.coolupprogramme.org.

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Acronyms

AC	Air conditioning
BSRIA	Building Services Research and Information Association
CAPEX	Capital Expenditures
CBE	Central Bank of Egypt
CFC	Chlorofluorocarbons
CLASP	Collaborative Labelling and Appliance Standards Program
CO_2	Carbon dioxide
COP	Coefficient of performance
DC	District cooling
EE	Energy efficiency
EER	Energy efficiency ratio
EOL	End of life
EU	European Union
EUR	Euro
GCI	Green Cooling Initiative
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
IEA	International Energy Agency
IKI	International Climate Initiative
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
m^2	Metres squared
MENA	Middle East and North Africa
MEP	Mechanical, engineering, and plumbing
MEPS	Minimum Energy Performance Standards
MP	Montreal Protocol
$MtCO_{2\,eq}$	Mega tonnes $CO_{2\,eq}$
MW	Megawatt
NDC	Nationally Determined Contributions

NEEAP	National Energy Efficiency Action Plan
NOU	National Ozone Unit
ODS	Ozone-depleting substance(s)
OPEX	Operational Expenditures
R134a	HFC-123a (tetrafluoroethane)
R22	HCFC-22 (chlorodifluoromethan)
R290	HC-290, Propane (hydrocarbon)
R32	HFC-32 (difluoromethane)
R404A	Mixture composed of HFCs: R143a (trifluoroethane), R125 (pentafluoroethane), R134a (tetrafluoroethane)
R407C	Mixture composed of HFCs: R32 (difluoromethane), R125 (pentafluoroethane), and 1,1,1,2-tetrafluoroethane
R410A	Mixture composed of HFCs: R32 (difluoromethane) and R125 (pentafluoroethan)
R600a	HC-600a, Isobutane (hydrocarbon)
R717	NH3-717, Ammonia (natural refrigerant)
R718	Water (natural refrigerant)
R744	Carbon dioxide
RAC	Refrigeration and air conditioning
RCREEE	Regional Center for Renewable Energy and Energy Policy
RE	Renewable Energy
RTOC	Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee
R&D	Research and development
UAC	Unitary Air Conditioning
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
VRF	Variable refrigerant flow
W	Watt

1. Introduction

With energy demand expected to increase 50% by 2040,[1] Middle East and North Africa (MENA) countries are facing a range of climate-change related challenges. The region's energy challenges include rapidly growing populations, urbanisation, and a heavily strained energy infrastructure. Cooling in air conditioning (AC)-equipped households already represents a major source of energy consumption in the region. The use of cooling is expected to grow further since, with an improved standard of living, more households are using air conditioning (AC) systems. There is large potential for energy saving as many of the space cooling and refrigeration systems in use have a low energy efficiency. An additional climate impact from cooling comes from the refrigerants still used in many of today's air conditioners and refrigerators. Such refrigerants with a high global warming potential are 2,000 times more potent for the climate (direct greenhouse gas emissions) than carbon dioxide and natural refrigerant alternatives. Without further policy intervention, direct and indirect emissions from cooling and refrigeration may rise 90% above 2017 levels by 2050, creating a vicious feedback loop.

1.1. The Cool Up programme

The Cool Up programme promotes accelerated technological change and early implementation of the Kigali Amendment to the Montreal Protocol and Paris Agreement in Egypt, Jordan, Lebanon, and Türkiye. The programme focuses on enabling natural refrigerants and energy efficient solutions to mitigate the effects of rising cooling demand. The Cool Up approach is based on four pillars: reducing cooling demand, phasing down hydrofluorocarbons (HFCs), replacing inefficient equipment and recycling refrigerants, and facilitating technical training and raising awareness.

The programme's cross-segment approach focuses on the residential and commercial AC (air conditioning) sector and on the commercial refrigeration sector.

The programme aims to develop lasting institutional capacity and increase the deployment of sustainable cooling technologies in the market. To enable a cooling market transformation towards sustainable cooling technologies, the Cool Up programme will:

- Enhance cross-sectoral dialogue between national actors to build ownership to support long-term impact.
- Develop policy actions to create a supportive regulatory environment.
- Develop financial mechanisms and funding structures to enable the cooling market transition.
- Support the commercial deployment and dissemination of existing and emerging technologies with natural refrigerants.
- Provide resources for capacity development on sustainable cooling in the four partner countries.

In Middle East and North Africa (MENA) countries, cooling constitutes a major source of energy consumption; it produces indirect greenhouse gas (GHG) emissions and contributes to ozone depletion and global warming. The Cool Up programme seeks to address this challenge in its partner countries by mitigating the adverse impacts of refrigerants through promoting accelerated technological change and facilitating early implementation of the Kigali Amendment and Paris Agreement.

The programme's activities cover the following three areas:

- Policy and regulation
- Technology and markets
- Financing and business models

[1] BP Energy Economics, "BP Energy Outlook 2018 Edition," https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2018.pdf

1.2. Aim and scope of this report

The cooling sector prospects report is one in a series of reports that has been produced by the Cool Up programme. There have already been reports published on four topics:[2]

- Status of the cooling sector
- Regulatory analysis
- Finance market assessment
- Catalogue of Technical Solutions for Sustainable Cooling

The data input for the cooling sector prospects report is based on the Cool Up programme Cooling Sector Status[3] and Regulatory Analysis reports.[4]

The Cool Up prospects study aims at developing one current trend and three mitigation prospects with different alternatives for transition. Its objectives include creating:

- an understanding of possible sustainable development pathways for the air conditioning (AC) sector and the commercial refrigeration sector, as well as
- the basis for the development of policy and finance measures

This study provides:

- a basis of current and future stocks of AC and commercial refrigeration systems
- emissions and final energy saving potentials in 2030, 2040 and 2050 as a result of mitigation prospects based on an increased uptake of sustainable and energy efficient applications compared to the current trend prospect
- associated costs and potential cost savings

The sectoral prospects report is structured as follows:

- Chapter 2 describes the methodology, baseline information and modelling approach.
- Chapter 3 describes the different prospects modelled and analysed throughout this study and the Cool Up Programme
- Chapter 4 presents the analysis results and modelling outcomes
- Chapter 5 summarizes the core findings and main conclusions

The sectoral prospects report is also supported by an Annex that lists the various input parameters used throughout the study.

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[2] "Cool Up Knowledge Base: Egypt," Cool Up Programme, https://www.coolupprogramme.org/knowledge-base/?filters%5Boverview%5D=knowledge-base&filters%5Bcountry%5D%5B%5D=219&filters%5Bcategory%5D%5B%5D=reports&page_size=8&_page=1

[3] Norhan El Dallal et al., "Cooling Sector Status Report Egypt: Analysis of the current market structure, trends, and insights on the refrigeration and air conditioning sector" (Cool Up Programme, 2022), https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-egypt/

[4] Norhan El Dallal, Eslam M. Mahdy Youssef, and Katja Dinges, "Regulatory Analysis Egypt: Analysis and recommendations for the regulatory and policy instruments governing the RAC sector" (Cool Up Programme, 2022), https://www.coolupprogramme.org/knowledge-base/reports/regulatory-analysis-egypt/

2. Methodology

The first step in developing the cooling sector prospects study was establishing an understanding of the status of the AC- and the commercial refrigeration sectors.

2.1. Definitions

The Cool Up programme uses the following definitions:

- Air conditioning (often referred to as AC) is the process of removing heat and moisture from the interior.
- Annuities are a series of payments made at equal intervals (annually) in which the net present value (NPV) of the investment in the corresponding year is equally distributed to all periods (lifetime of equipment) taking into account the time value of money.[5]
- Commercial refrigeration cold storage includes commercial-scale cold storage rooms, which are usually equipped with condensing or centralised units and have capacities of up to 200 kW. These applications serve as storage for food and beverage products and differ from industrial-scale cold storage, which is used for the processing and storage of food and beverages or in the manufacturing process of petrochemicals, chemicals, and pharmaceuticals. Industrial-scale cold storage systems can range in size up to 30 MW.[6]
- The commercial refrigeration scope includes stationary systems used to store and display food and beverages in retail (supermarkets, shops) and food service (restaurants, hotels) but not for processes concerning food processing. The United Nations Environment Programme (UNEP) defines commercial refrigeration systems as systems that usually include standalone, condensing, or centralised units that mostly do not exceed a capacity of 200 kW and keep temperatures between -25°C and 8°C.[7]
- Cooling degree days - a cooling degree day (CDD) is a measurement designed to quantify the demand for energy needed to cool buildings. It is the number of degrees that a day's average temperature is above 18° Celsius). It is calculated as follows: Mean daily temperature (MDT) = (Daily High Temp + Daily Low Temp)/2; CDD = MDT - 65°F.[8]
- Direct greenhouse gas (GHG) emissions are related to refrigerant losses on each appliance (refrigerant leakage, operational and at disposal after end of life).
- Energy efficiency ratio (EER) measures the energy efficiency of cooling devices cooling capacity. A higher EER rating corresponds to higher energy efficiency.
- Sustainable cooling is affordable and safe cooling that satisfies user needs with lowest possible impacts on the environment. Specifically, this implies the absence of environmentally harmful refrigerants (like fluorinated gases), a low energy demand (including a high efficiency), and at least readiness for a fully renewable energy supply.
- Indirect GHG emissions are those related to the generation of the electricity used for cooling.
- Low GWP refrigerants are used to describe refrigerants with GWP lower than 750 (e.g. R32)
- Market penetration: refers to the penetration rate of cooling equipment which is defined as the share of residential housing units and non-residential buildings with at least one AC system installed.
- Market saturation: Mc Neil defines market saturation as a function of availability (income) and climate (Cooling Degree days- CDD) where availability represents the affordability of air conditioning

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[5] CFI Team, "Equivalent Annual Annuity (EAA)," Corporate Finance Institute, https://corporatefinanceinstitute.com/resources/wealth-management/equivalent-annual-annuity-eaa/

[6] United Nations Environment Programme, "2018 Report of the Refrigeration, Air Conditiong and Heat Pumps Technical Options Committee: 2018 Assessment" (United Nations Environment Programme, Kenya, 2019), https://ozone.unep.org/sites/default/files/2019-04/RTOC-assessment-report-2018_0.pdf

[7] Definition based on United Nations Environment Programme, *Presession Documents: Workshop on Hydrofluorocarbon Management* (2015)

[8] Gordon Scott, "Cooling Degree Day (CDD)," Investopedia, https://www.investopedia.com/terms/c/colddegreeday.asp; "Understanding Heating and Cooling Degree Days," Brightly, https://help.dudesolutions.com/Content/Documentation/Energy/UtilityDirect/Reporting/Understanding%20Heating%20and%20Cooling%20Degree%20Days.htm

to households and is a function of household income and Climate Maximum is a function of CDD.[9] According to Mc Neil air conditioner ownership will approach a climate dependant maximum market saturation but never exceed it. For immature markets, the ownership rate is dominated by the dynamics of affordability (income). For mature markets, where ownership levels are near saturation, sales are largely driven by replacements, increasing population (new constructions of buildings), and ownership of multiple appliances.[10]

- Natural refrigerants are non-synthetic refrigerants that can be found in nature, but have to meet certain specifications (i.e., purity) before they can be used as refrigerants.
- Non-residential building sector includes public and private offices, education, health and social, hotel and restaurant, wholesale and retail trade, and other buildings (e.g., sports facilities). Industrial, agricultural and fishery buildings and warehouses are not included.
- RAC sector:
  - Refrigeration: Domestic, commercial, industrial, and transport refrigeration
  - AC: Residential and commercial AC (including chiller)
  - Servicing sector for RAC
- Residential building sector consists of single and multifamily buildings.
- Synthetic refrigerants are substances of anthropogenic origin (they do not occur naturally). These include HCFCs and HFCs, among others.

2.2. Building segments and equipment types

Air-conditioning sector

Cool Up focuses on the commercial and residential AC sector.

- Building segments: Focuses on residential buildings that cover single-family and multifamily buildings and on non-residential buildings, i.e. on public and private offices, education, health and social, hotel and restaurant, wholesale and retail trade, and other buildings (e.g. sports facilities).
- Equipment types (AC systems): Although there are many different technologies installed in the market, they can be clustered into the following key technology segments, which are used to depict the market characteristics.[11] AC systems can generally be divided into central and decentral systems.
  - Ducted air conditioning systems provide cooling (or heating) through a system of ducts. The central unit consists of a compressor, condenser, and an air handling unit, normally located in the attic or basement. Cool (or hot) air is distributed through a series of ducts and vents to the building. These systems are also called central air conditioning systems, which can be broadly segregated into two types, i.e., split central air conditioners (duct split) and packaged central air conditioners.[12]

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[9] Michael A. McNeil and Virginie E. Letschert, "Future Air Conditioning Energy Consumption in Developing Countriesand what can be done about it: The Potential of Efficiency in theResidential Sector," Conference: ECEEE Buildings Summer Study 2007, Colle SurLoup, France, June2-6, 2007 (Lawrence Berkeley National Lab. (LBNL), Berkeley, CA, 2007), https://www.osti.gov/servlets/purl/927342.

[10] Ibid.

[11] Primary sources for these definitions are:

United Nations Environment Programme (UNEP) Ozone Secretariat, "FACT SHEET 7 Small Self Contained Air Conditioning" (UNEP Ozone Secretariat, Bangkok, 2015)

United Nations Environment Programme (UNEP) Ozone Secretariat, "FACT SHEET 8 Small Split Air Conditioning" (UNEP Ozone Secretariat, Bangkok, 2015)

United Nations Environment Programme (UNEP) Ozone Secretariat, "FACT SHEET 9 Large Air-Conditioning (air-to-air)" (UNEP Ozone Secretariat, Bangkok, 2015); United Nations Environment Programme (UNEP) Ozone Secretariat, "FACT SHEET 10 Water chillers for air conditioning" (2015)

United Nations Environment Programme, "2018 Report of the Refrigeration, Air Conditiong and Heat Pumps Technical Options Committee"

[12] CIELO, "Ducted vs. Ductless Air Conditioning Systems," https://www.cielowigle.com/blog/ducted-vs-ductless-air-conditioning-systems/

- Splits units: Single split systems consist of an indoor and an outdoor unit and provide AC for one indoor zone.
- Multi-split and variable refrigerant flow (VRF) systems: Multi-split systems consist of one outdoor and several indoor units. VRF systems are sophisticated multi-split systems. Several outdoor units can support many indoor units, and the indoor units can be regulated individually.
- Packaged units (e.g., rooftop): All components are enclosed in a single box. Packaged units are typically located outside (rooftop, terrace) and provide cooling by delivering conditioned air to one or more indoor zones.
- Chillers: Central cold generation units as part of a central AC system, which can be categorised into three groups:
  1. Compression water-cooled chillers
  2. Compression air-cooled chillers
  3. Sorption (absorption or adsorption) chillers
  - Chillers are connected to water/brine distribution- and delivery systems (e.g. fan coil units or water/air heat-exchangers in air handling units).

Commercial refrigeration sector

The Cool Up programme only focuses on the commercial refrigeration sector. Domestic and industrial refrigeration are not included in the Cool Up programme scope.

- Building segments: Focuses on corner stores, restaurants, supermarkets, and hotels, including areas for cold storage.
- Equipment types (commercial refrigeration systems): three main types of equipment are covered:[13] standalone equipment, condensing units, and centralised systems (for supermarkets). The different equipment types are used in different building segments:
  - Most medium to large supermarkets prefer to use centralised systems because they are usually more energy efficient than condensing units and plug-in cabinets. The size of the sales area of supermarkets that use a centralised refrigeration system range from 400 m^2 to up to 20,000 m^2.
  - Condensing units are commonly used in medium and large stores and can often be found in fast food outlets, restaurants, bars, and convenience stores. In comparison to a centralised system, they allow fewer cabinets to be connected to the system, take up less space, and are usually easier to install.
  - Standalone refrigeration systems are typically self-contained systems such as ice cream freezers, display cases, and vending machines. They are often referred to as plug-in units because they are closed systems, which do not require extensive installation.

2.3. Data collection

The data for this prospect study was collected during the development of the cooling sector status report. The detailed approach and the various sources used are described in the cooling sector status report.[14]

Primary data was gathered through expert interviews in Egypt. The interviews were conducted with a diverse set of experts representing manufacturers; assemblers; wholesalers; architects; mechanical, electrical, plumbing (MEP) consultants; and project developers.

[13] United Nations Environment Programme (UNEP) Ozone Secretariat, "FACT SHEET 4 Commercial Refrigeration" (UNEP Ozone Secretariat, Bangkok, 2015)

[14] El Dallal et al. 2022a

Secondary data was obtained from a diverse set of publications covering national and international statistical sources and national documents (e.g. the National Cooling Plan Lebanon[15] or HFC inventory in Jordan from United Nations Industrial Development Organization (UNIDO)[16]), market research companies (e.g. Building Services Research and Information Association (BSRIA) for Egypt),[17] a literature review, and regional information such as the Collaborative Labelling and Appliance Standards Program (CLASP)[18] or the Regional Center for Renewable Energy and Energy Policy (RCREEE).[19]

This data approach had limitations, such as a partial lack of systematic approaches for data collection (e.g., data on HFC consumption, databases for installed technologies, especially in the commercial refrigeration sector), difficulty accessing official data, missing background information to available data, and large data ranges between different sources for the same points. Due to the data situation in the mentioned RAC subsectors, this report acknowledges that data gaps and data from different sources can result in discrepancies. To reduce the limitations, the Cool Up programme utilised various approaches such as analysis of different data sources, cross evaluation, reliability analysis, and use of expert opinions.

Several strategies were used to handle the data limitations. If no country-specific values were available, data gaps were closed by using information from global studies such as those from the Intergovernmental Panel on Climate Change (IPCC),[20] International Energy Agency (IEA),[21] Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee (RTOC), Rocky Mountain Institute,[22] and CLASP,[23] as well as by using data from a global model developed by the Green Cooling Initiative (GCI)[24] and by using knowledge from expert interviews.

The global model developed by GCI[25] estimates data on installed equipment in the stock and sales data and provides projections for AC systems (also chiller AC) and commercial refrigeration systems; other RAC subsectors are also covered. Due to the global model approach, the country-specific values are afflicted with a grade of uncertainty.

The observed lack of comprehensive data for current trends on the RAC market in the partner countries highlights the need for further assessments and systematic data collection.

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[15] National Ozone Unit Lebanon, "Guidance for Integrating Efficient Cooling in National Policies in Lebanon" (2021), https://www.lb.undp.org/content/lebanon/en/home/library/guidance-for-integrating-efficient-cooling-in-national-policies-.html

[16] United Nations Industrial Development Organization, "HFC Inventory of Jordan" (2018), https://www.ccacoalition.org/en/resources/jordan-hfc-inventory

[17] The Building Services Research & Information Association, "Split Systems 2018: Egypt" Report 61099/2 (BSRIA, Bracknell, 2018)

[18] Frank Klinckenberg and Winton Smith, "Scoping Study for Commercial Refrigeration Equipment: Mapping and Benchmarking Project - Results" (KLINCKENBERG CONSULTANTS; PUDDLE CONSULTANCY; Collaborative Labeling and Appliance Standards Program (CLASP), 2012)

Paul Waide, Sietze van der Sluis, and Thomas Michineau, "CLASP Commercial refrigeration equipment: mapping and benchmarking" (Waide Strategic Efficiency Ltd; CLASP, 2014)

[19] Regional Center for Renewable Energy and Energy Efficiency, "Field survey results for AC market in Egypt" (2019)

[20] Intergovernmental Panel on Climate Change, "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: Chapter 2: Changes in Atmospheric Constituents and in Radiative Forcing" (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007), https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf

[21] International Energy Agency, "The Future of Cooling - Opportunities for energy efficient air conditioning" (International Energy Agency (IEA), 2018)

[22] Iain Campbell, Ankit Kalanki, and Sneha Sachar, "Solving the Global Cooling Challenge: How to Counter the Climate Threat from Room Air Conditioners" (2018), https://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf

[23] Waide, van der Sluis and Michineau, "CLASP Commercial refrigeration equipment: mapping and benchmarking"

[24] Green Cooling Initiative, "Global greenhouse gases emissions from the RAC Sector," Green Cooling Initiative, accessed September 1, 2021, https://www.green-cooling-initiative.org/country-data/#!total-emissions/all-sectors/absolute. The model estimates data on installed equipment in the stock (as well as sales figures) for AC cooling equipment and for the commercial refrigeration sector.

[25] Green Cooling Initiative, "Global greenhouse gases emissions from the RAC Sector"

Key data parameters will be monitored throughout the programme duration and will be reflected in updates of programme activities and recommendations.

2.4. Calculation methodology

A multi-step bottom-Up modelling approach has been used throughout this study to calculate the following:

- AC and commercial refrigeration equipment development (stock and sales). See Annex I: Input parameters
- Final energy demand and efficiency impacts (including indirect emissions and savings)
- Direct emissions and savings (impact of switching to natural refrigerants and leakage reduction)
- Total equivalent annual costs (annual operational costs and capital costs (annuities))
- Potential costs savings across the different prospects

2.4.1. Overview of the calculation methodology and outputs

Multiple models have been used throughout the study to produce the following key-outputs:

- Building stock development (number of buildings and conditioned floor area). See Annex I: Input parameters
- AC and commercial refrigeration equipment development (stock and sales). See Annex I: Input parameters
- Final energy demand per subsector. See Section 4.1
- Indirect and direct emissions per subsector. See Section 4.2
- Total Annuity costs per subsector. See Section 4.3
- Electricity costs and potential cost savings. See Section 4.3

The used models provide the development of these outputs from 2020 until 2050 for four different prospects described in the following Chapter 3.

The following **Figure 1** provides an overview of the different models, main input parameters and their corresponding outputs.

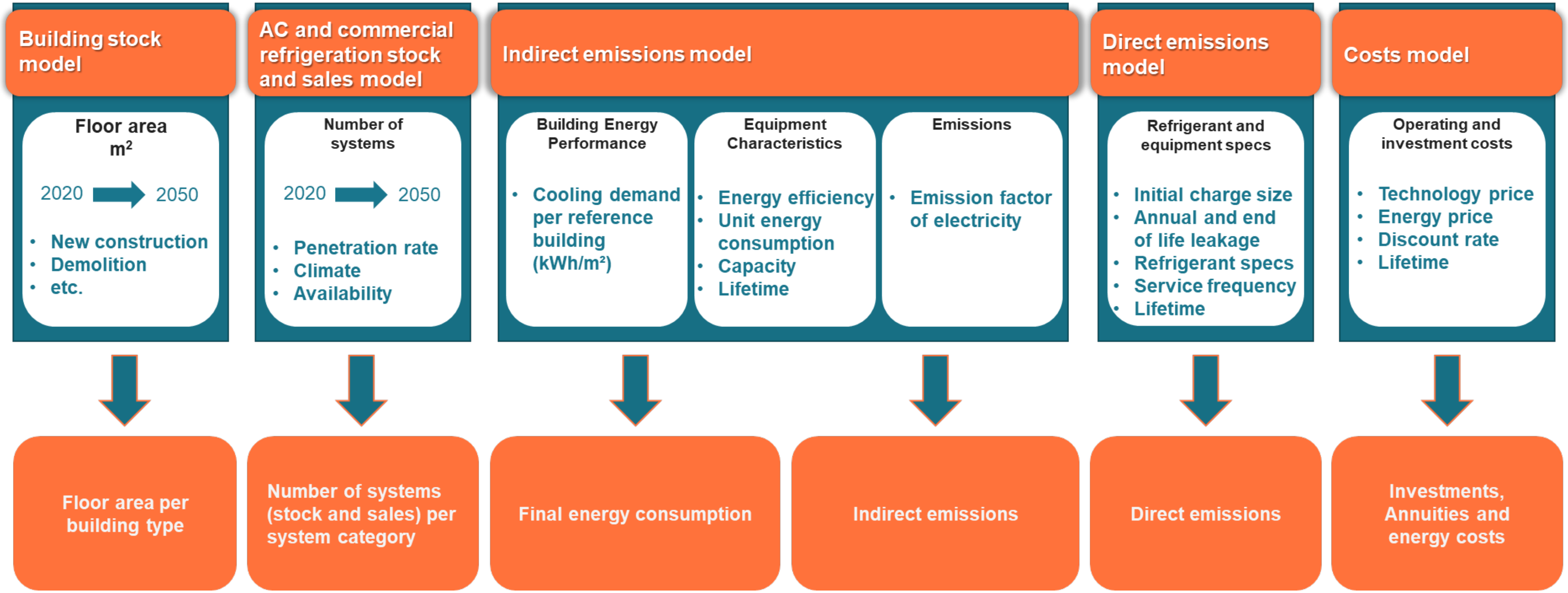

Figure 1 Calculation methodology, models, and corresponding outputs

2.4.2. Cooling demand drivers

Cooling demand and the need for air conditioning are subject to numerous country specific factors that influence their development. Throughout this study, the following key influencing factors were taken into consideration for the estimation of results:

- **Population growth** – influences the total number of households as well number of people per household, affecting cooling demand.
- **Rates of urbanisation** – Urban households are more likely to own an AC or refrigeration unit, as well as making greater use of these appliances.
- **Climate change** – As climate change takes hold, it is likely to increase temperatures in the region, causing increased demand for cooling.
- **Economic growth** – Increased economic growth will drive demand in the RAC sector as there is increased activity in the economy. Similarly, increasing household income will increase average dwelling size, this translates into increased AC use, usually expressed in more or larger units working for a longer time but also increasing the share of cooled floor area in the dwellings.
- With growing wealth, the **demand for indoor climate comfort** but also **design aspects of buildings** are increasing. Which in turn contributes to a constant growth of (central) systems.

2.4.3. Future RAC market and future building stock

In a first step, a projection of the future building stock and the future market for AC and commercial refrigeration systems was made. This entails forecasting sales and stock development including increasing sales and AC equipment installation, increased share of cooled floor area, and building stock and population growth. Annual AC demand is based on a bottom-up stock-accounting model. For projection of new AC demand a saturation forecast is used. The saturation overcast is based on macroeconomic drivers, considering affordability. According to Mc Neil[26] and International Energy Agency's (IEA) The Future of Cooling report,[27] the household ownership rate of ACs rises with economic development and household income. Furthermore, the maximum saturation is determined using a climate maximum saturation as presented by McNeil.[28] For mature markets, where new AC systems sales are near market saturation, sales are largely driven by replacements, population increase, and increased in cooled floor area per household. For developing countries, on the other hand, stock and shipments will be dominated by the dynamics of affordability. A second aspect is the climate dependency.

In a second step, typical AC and commercial refrigeration systems have been identified (including typical capacities, efficiencies, and refrigerant charge size ranges). According to the structure of the model used, the technologies were grouped in the following three main categories:

- **Residential sector AC**:
  - Decentral systems: room air conditioners; single split ductless systems
  - Central systems: ducted and ductless systems; single duct split, rooftop units, multi-split units
- **Non-residential sector AC**:
  - Decentral systems
  - Central systems
  - Chillers
- **Commercial refrigeration sector**
  - Standalone units: standalone refrigerators and freezers (plug-in)
  - Condensing units

[26] McNeil and Letschert, "Future Air Conditioning Energy Consumption in Developing Countries and what can be done about it: The Potential of Efficiency in the Residential Sector"

[27] International Energy Agency, "The Future of Cooling - Opportunities for energy efficient air conditioning"

[28] McNeil and Letschert, "Future Air Conditioning Energy Consumption in Developing Countries and what can be done about it: The Potential of Efficiency in the Residential Sector"

- Central systems

By customizing the input assumptions, a current trend prospect as well as hypothetical "what-if" prospects can be modelled to estimate the potential savings. Input assumptions such as current and future efficiency or refrigerant mix and the other key input assumptions are presented in Annex A.4.

2.4.4. Direct emissions

The model uses the annual installed stock, new equipment sales, and end-of-life (EOL) retirements of AC and commercial refrigeration equipment. Using a bottom-up accounting methodology, the model calculates annual HFC consumption based on quantities used for first fill of new equipment and the servicing of existing equipment (refill of leaked quantities); as well as annual refrigerant emissions to the atmosphere due to equipment leakage and emissions resulting from disposal at EOL retirement. As Global Warming Potential (GWP) of refrigerants the values of the Fourth IPCC Assessment Report (AR4) are considered.

2.4.5. Final energy demand

By applying average building sizes for air conditioning systems and floor area cooled per AC system, the model calculates the amount of floor area cooled in a specific year per building type. This parameter is then the basis for calculating energy demand.

Like the AC approach, sales and stock numbers of commercial refrigeration systems can then be combined with average energy demand per system.

2.4.6. Indirect emissions

The indirect emissions are calculated by multiplication of the energy demand with the emission factor for grid electricity. A future decrease of the emission factor has been considered. For details see Annex A.10.

2.4.7. Economic assessment and costs savings

The aim of the economic assessment is to determine the electricity cost savings, the cost of savings, i.e. the additional cost of implementing the mitigation prospects (annuities), and finally the total cost of the mitigation prospects in comparison with the current trend prospect. The total cost approach allows for a comparison of the total yearly costs of the implementation of the mitigation prospects. Total yearly costs are the sum of OPEX (electricity costs) and CAPEX (annuities). Annuities are investments broken down using yearly payments, considering lifetime, discount rate and price increase of technology. CAPEX costs refer to the annuity investments throughout this study. OPEX costs are limited to the electricity costs and do not include maintenance and labour costs.

The total cost of the prospects is calculated as follows:

- Electricity costs are estimated by taking the overall energy demand and the corresponding average electricity price per kWh per household for the residential sector, and similarly the average electricity price for the commercial sector (e.g., supermarkets, offices, etc.). (see Annex A.9 for electricity prices and annual price increase assumptions)
- Annuities are the investments of components broken down using yearly payments (annuities), considering lifetime and discount rate (see definition Section 2.1). Annuities are estimated based on the sum of annual technology installations, technology price, interest rate, and annual technology price increase. (See Annex A.8 for further details on exact technology costs and the assumed annual price increase)

Electricity costs savings, additional annuities as well as total costs difference are estimated based on the costs difference between the modelled mitigation prospects and the current trend prospect.

3. Prospects and mitigation actions

This study considers multiple prospects for the transition of the cooling sector market until 2050. For each mitigation prospect, energy savings, direct and indirect emissions reductions, and the total equivalent annuity costs were determined relative to a current trend prospect.

Four prospects have been modelled, specifically a current trend prospect (referred to as P0), a moderate impact prospect (referred to as P1), a high impact prospect (referred to as P2) and a high impact + prospect (referred to as P3).

The current trend prospect is based on technologies that are currently available on the markets in the country and on existing policies. Since Egypt is currently in a transition phase where national F-gas legislation, e.g., introducing measures such as a HFC phase down are still absent, the current trend prospect does not necessarily meet the targets set under the Kigali Amendment (see Annex I: Input parameters for detailed information on the underlying assumptions). The most ambitious modelling prospect ('high impact prospect') assumes a high penetration rate of systems with natural refrigerants combined with a further reduced cooling demand (compared to the current trend prospect). The transition from the current trend prospect (P0) to the more ambitious prospects (P1, P2, P3) is associated with an increase of cooling system efficiency, increased use of natural refrigerants and reduction in refrigerant leakage, both during the operation as well as at end of life during disposal (see **Figure 2**).

The comparison between the current trend prospect and the mitigation prospects shows the potential impact of additional measures such as the use of natural refrigerants, more ambitious efficiency (RAC and building performance) due to the improved related codes and standards and other policy instruments such as financing schemes having impact on the technical parameters.

Compared to the moderate prospect, the high impact prospect requires a swift, multi-faceted transition of the entire market and policy framework. Examples in the high impact prospect are ambitious policy measures targeting aspects that are relevant in terms of abatement potential, including refrigerant transition, decarbonization of power generation and further efficiency improvement in industry and buildings.

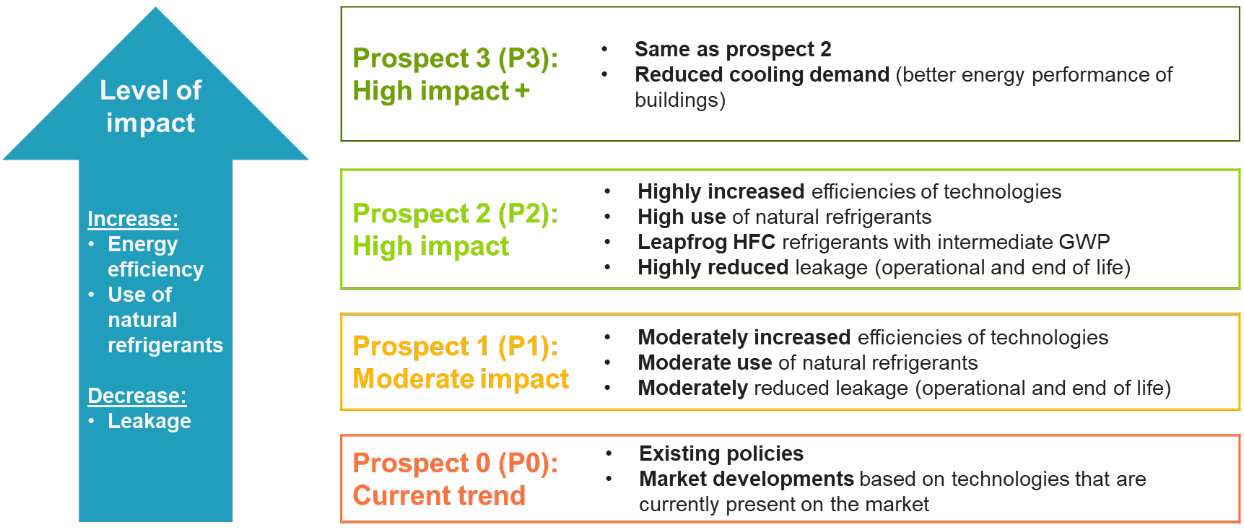

Figure 2 Cool Up programme prospects and mitigation actions

In depth description of the modelled prospects are highlighted in the following subsections.

3.1. Base year and general assumptions

The base year of input data such as equipment stock, sales, systems efficiencies etc. is 2020. The required data for establishing the base year was collected during the development of the cooling sector status and regulatory analysis reports. Based on the data collected, average efficiency values, the corresponding refrigerant mixes, annual and end of life leakage had been determined.

An underlying assumption for all prospects is that the emission factor in 2050 will halve compared to 2020 due to decarbonization of the grid.
Details on data sources and assumptions along with an overview of key parameters for the base year as well as for the different prospects is provided in Annex I: Input parameters.

3.2. Prospect (P0): Current trend

The current trend prospect (P0) considers existing policies such as programmes, laws, and other policy instruments like codes and standards that are in force (June 2022), based on the regulatory analysis report.[29] Egypt has successfully delivered on its commitments under the Montreal Protocol and its amendments through the implementation of several relevant programs, elaboration of laws, other plans, and codes and standards. The standards on cooling appliances and systems are well implemented, monitored, and enforced. MEPS and labelling of RAC systems are mandatory. In contrast, MEPS in buildings are currently only used as guidelines.
The current trend prospect considers these ODS phase-out policy instruments (specifically relating to R22) as well as standards and MEPs relating to efficiency of RAC systems.

Currently no Egyptian national regulations on F-gases exist (such as bans or annual checks of equipment) leaving room for improvement to develop the reduction of leakage, recovery of F-gases, appropriate treatment of used refrigerants, the transition to F-gas alternatives, technician training etc. Thus, no f-gas regulation is considered in current trend prospect.

The current trend prospect considers technologies currently available on the market and current trends with respect to use of certain refrigerants. Current trends with regards to refrigerants are derived from what is actually sold in the market, based on interviews. It considers:

- **Energy efficiency of systems**: from 2020 to 2050 a slow and steady but minor increase in system efficiencies is assumed, reaching an average system efficiency in 2050 in the order of magnitude of best available national technology today.
- **Refrigerant transition**: Taking current market trends into account, the following is assumed:
  - Air-conditioning: Main refrigerants used and existing in the stock include R410A, R134a (mainly in chillers) and R22 which is the most significant refrigerant used in the stock. It is assumed that the market share of R22 is decreasing in manufacturing and is being phased out but still being used in servicing. Already today, for split units and VRF systems, the market is shifting towards refrigerants with a lower GWP (e.g., R32). Considering current industry trends, it is assumed that the share of fluorinated intermediate GWP refrigerants will increase and reach 50% in AC manufacturing in 2050.
  - Commercial refrigeration: R22 is by far the dominant refrigerant in the commercial refrigeration systems stock. However, in terms of new systems sold, R134a is gaining momentum, and it is assumed that without any regulatory action, R134a will continue to be used and its share will decrease only slowly till 2050. Apart from R134a, R404A and R22 are also used (R22 only for servicing purposes). It is assumed that natural refrigerants enter the market and have market shares of 40% for condensing and central systems and around 50% for standalone systems in 2050. (Shares mainly gained from R134a and R404A).
- **Leakage rate**: It is assumed that the RAC operational system's leakage rate slightly decreases overtime for each of the considered technologies up until 2050 (See **Table 6**).
- **End of life recovery of fluorinated refrigerants**: It is assumed that the RAC system's end of life recovery of fluorinated refrigerants increases moderately for each of the considered technologies up until 2050 (See **Table 7**).
- **Energy efficiency of buildings**: Building envelope parameters and in particular the thermal transmittance (U-value) of the building surfaces (Walls, roof, floor and window) were taken from

[29] El Dallal, Mahdy Youssef and Dinges (2022)

the Build_ME[30] project baseline values of the existing and new build standards. An enhancement of the building envelope of 10% (tighter U-value requirements) is assumed per decade until 2050.

3.3. Prospect 1 (P1): Moderate impact

The moderate impact prospect presents a pathway where the transition of the cooling sector is happening at a faster rate, with an increase in energy efficiency of the technologies, an increase in the use of natural refrigerants, an increase in end-of-life recovery of emissions, and a decrease in leakage rate compared to the current trend prospect. The improvements might result from moderately ambitious policy measures such as additional regulations or support schemes and from a moderate acceleration of implementation. In contrast to the high impact prospects (see next Section), in P1 single measures of lower ambition are implemented.

- **Energy efficiency of systems**
  - **Typical measures addressing improvement of energy efficiency** are the implementation of MEPS (and labels) and their continuous review and upgrading. In Egypt MEPS are mandatory for AC systems. In general MEPS should reflect the progress made in energy efficiency of equipment placed on the market and are normally updated every 2-5 years to provide clear guidance to industry as well as sufficient time to react. Labels, i.e., the label class characteristics, are reconsidered once a significant proportion of the market (e.g., over 15-20%) is represented in highest labelling classes.
  - **In P1 the energy efficiency of systems** is considered to moderately increase compared to P0. It is assumed that the average efficiency in 2050 reaches the order of magnitude of the international best available technology today, in terms of efficiency. For example, for residential room air conditioners (decentral systems), in 2050 the efficiency is assumed to be around 30% higher than the assumed efficiency in P0 in 2050. (See **Table 8**).

- **Refrigerant transition**
  - **Typical measures addressing refrigerant transition** are provisions that prohibit placing high GWP refrigerants on the market and market incentive programmes.
  - **In P1 the transition of refrigerants** used in equipment placed on the market (originating from imports or local manufacturing) is primarily driven by market incentive programmes. As a result, low GWP solutions such as R290 (propane) and, R744 (CO_2) are assumed to play an increasingly prominent role compared to P0. However, due to the absence of provisions that prohibit placing high GWP refrigerants on the market, potent greenhouse gases such as R410A or R404A can still be used in 2050 in this prospect (see **Table 5**). Specific assumptions in P1 are:
    - AC sector: It is assumed that natural refrigerants have a 'moderate' increase in the overall market share compared to the current trend prospect and the high impact prospect. Compared to the current trend prospect, the market share of the current standard refrigerant (R410A) will decrease faster, the penetration of intermediate refrigerants (such as R32 or other fluorinated (low) GWP refrigerants) is assumed to be slower and stay at a lower level. The share of natural refrigerants is expected to increase faster and to reach a higher penetration in 2050.
    - Commercial refrigeration sector: Compared to the current trend prospect, the use of R134a and R404A in newly sold systems is further decreased, and the share of natural refrigerants reaches 70% in 2050 for condensing units and central systems.

- **Leakage rate operational**
  - **Typical measures for addressing the improvement of leakage are** stricter leakage checks and capacity building to improve the skills of technicians handling equipment during servicing as well as at the end of life. Particularly for high GWP refrigerants, these measures are vital in reducing

[30] Build_ME. "Towards a Low-Carbon Building Sector in the MENA Region." https://www.buildings-mena.com/.

direct F-gas emissions from cooling equipment. In addition to reducing direct emissions, indirect emissions also decrease when reducing leakage rates. The electricity efficiency of cooling systems is drastically reduced when the refrigerant charge in the system falls below approximately 70% of the original charge size, as shown in **Figure 3**. Thus, an increase in indirect emissions, goes hand in hand with an increase in running costs[31]. Note: Increase in running costs are not taken into consideration throughout this study, see Section 2.4.7 for detailed costs description.

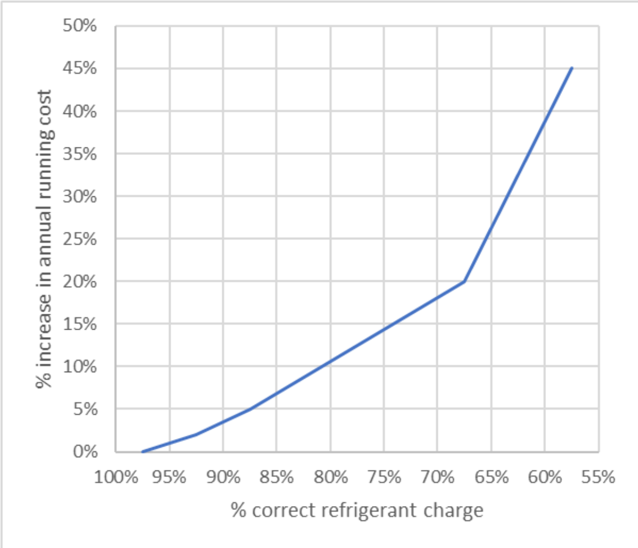

Figure 3 Relationship between Annual running costs and refrigerant leakage for small air-conditioning and commercial systems.[32]

- **In P1** it is assumed that the RAC operational system's leakage rate moderately decreases overtime for each of the considered technologies up until 2050 when compared to P0 (see **Table 6**).

- **End of life recovery of fluorinated refrigerants**
  - **Typical measures for addressing the end-of-life recovery of fluorinated refrigerants** are provisions on containment and recovery together with provisions on training and certification and labelling. These are assumed to lead to reductions in emission rates, both over the lifetime and the end-of-life of equipment, especially for the sectors of refrigeration and stationary air conditioning. As a result, it is assumed that service personnel are better qualified to reduce emissions during servicing and have a higher awareness of the negative environmental consequences of F-gas emissions. Further, improvements in the tightness of new equipment, due to technological developments, are supposed to occur, led by an increased incentive to reduce leakage rates.

    In the EU, where reclaimed HFCs are not subject to the limits of the HFC phase-down, reclaimed gases can ensure the availability of essential HFCs on the market going forward, especially as the phase-down gets tighter.
  - **In P1** it is assumed that the RAC system's end of life recovery of fluorinated refrigerants increases moderately for each of the considered technologies up until 2050 compared to P0 (see **Table 7**).

[31] 2020, ICF Incorporated, Supermarket Emission Reduction Analysis. Accessible online at https://www.nrdc.org/sites/default/files/supermarket-emission-reduction-analysis.pdf

[32] 2020, ICF Incorporated, Supermarket Emission Reduction Analysis. Accessible online at https://www.nrdc.org/sites/default/files/supermarket-emission-reduction-analysis.pdf

- **Energy efficiency of buildings**:
  - **In P1** no improvements compared to P0 are assumed

3.4. Prospect 2 (P2): High impact

The high impact prospect presents a pathway where the transition of the cooling sector is happening faster compared to the moderate prospect. The improvements are assumed to – inter alia - result from increasingly harmonised implementation of measures, including policies addressing F-gases, financing schemes promoting the uptake of natural refrigerants, increasing awareness, and specifically addressing skills of technicians and an acceleration of the implementation. The high impact prospect considers:

- **Energy efficiency of systems**
  - **P2** assumes a highly increased efficiency of technologies compared to P0 and P1. It is assumed that the average efficiency in 2050 will be more efficient than the efficiency of international best available technology today.
- **Refrigerant transition**
  - **P2 assumes high ambitious measures,** such as prohibitions on certain types of refrigerants. In P2 prohibitions are included to facilitate an effective reduction of the use of high GWP refrigerants in equipment on the market. Additionally, P2 assumed a high use of natural refrigerants and its accelerated implementation compared to P1. The acceleration is implemented through leapfrogging intermediate refrigerants such as R32 or other fluorinated (low) GWP refrigerants, i.e., it is assumed that the current standard refrigerant will be directly substituted with natural refrigerants and fluorinated (low) GWP refrigerants are not used as a bridge technology (refrigerant). Specific assumptions for each sector are given below:
    - AC sector: compared to the P1 it is assumed that natural refrigerants have an accelerated increase in the overall share and 100% in 2050, except chillers. The share of the current standard refrigerant (R410A) will decrease faster compared to P1 as a result to a ban on use of refrigerants with a GWP higher than 2000 in new AC applications (in effect prohibiting the use of R410A with a 100-year GWP of 2088.[33]
    - Commercial refrigeration sector: Compared to the moderate prospect, the use of R134a and R404A is further reduced by implementing the following provisions: Prohibit the use of refrigerants with a GWP higher than 2500 in new central commercial refrigeration applications (including condensing units) (in effect prohibiting the use of R404A with a 100-year GWP of 3922.[34] Prohibiting the use of refrigerants with a GWP higher than 1000 in new stand-alone (hermetic) commercial refrigeration appliances (in effect prohibiting the use of R134a with a 100-year GWP of 1430 [IPPC AR4]). Compared to P0 and P1 the share of natural refrigerants reaches 100% in 2050 for all systems in the commercial refrigeration sector.
- **Leakage rate**
  - P2 assumes that the RAC operational system's leakage rate highly decreases overtime per technology up until 2050 (See **Table 6**).
- **End of life recovery of fluorinated refrigerants**
  - P2 assumes that the RAC system's end of life recovery of fluorinated refrigerants increases significantly for each of the considered technologies up until 2050 (See **Table 7**).[35]
- **Energy efficiency of buildings**
  - P 2 applies the same assumptions as P0

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[33] Intergovernmental Panel on Climate Change, "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change"

[34] Intergovernmental Panel on Climate Change, "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change"

[35] Although their share is negligible in 2050

3.5. Prospect 3 (P3): High impact +

P3 builds upon P2 and additionally considers a reduced cooling demand, i.e., a highly increased energy performance of buildings resulting in significantly reduced cooling needs compared to P2. The further improvements will require significantly more ambitious policy packages regarding the building efficiency for new build and ambitious building renovation over the decades from 2020 to 2050

P3 assumes an enhancement of 30% of the building envelope parameters compared to P2, P1 and P0. All other parameters are equal to P2.

4. Results

The following chapter provides modelling results in three categories as follows:

- **Electricity demand** provides results on the development of energy demand up to 2050 resulting from the AC and commercial refrigeration sectors.
- **GHG emissions** provides results of the corresponding direct and indirect emissions up to 2050 from the AC and commercial refrigeration sectors.
- **Economic assessment** provides results on the overall expected investment costs, corresponding annuities discounted over the lifetime of the project and up to 2050 and on the expected costs savings of the different prospects compared to the trend prospect.

The results are based on different aspects as described in the previous chapters. The expected extreme growth of the air-conditioned floor area must be explicitly mentioned when looking at these results.

The stock of AC systems in Egypt is projected to grow nearly sevenfold from 7.8 million units in 2020 to approximately 53 million units in 2050. The stock of commercial refrigeration systems is expected to grow from approximately 1.1 million systems in 2020 to approximately 1.4 million systems in 2050. For details, see Annex A.1 and A.2.

4.1. Electricity demand

4.1.1. Current trend prospect

This section elaborates on the current trend prospect (P0) regarding the electricity demand as well as the AC and commercial refrigeration sectors.

Under the current trend prospect, electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades, exhibiting a more than 5-fold increase, reaching 152 TWh by 2050 from 28 TWh in 2020 (**Figure 4**). This significant growth can be attributed directly to the increase in the conditioned floor area per building and the corresponding growing demand for AC equipment (see **Figure 22**). The decelerated growth noticed between 2040 and 2050 is a consequence of the expected efficiency improvements in the upcoming decades and the maximum market saturation achieved around 2036.

The P0 trend expects electricity demand resulting from commercial refrigeration activities to exhibit a steady growth from 5.3 TWh in 2020 to 6.6 TWh in 2050, exhibiting 25% increase (**Figure 4**). This growth is related to the stock growth development of commercial refrigeration equipment (see **Figure 23**). System efficiency improvements only damp the growth but do not reverse the trend.

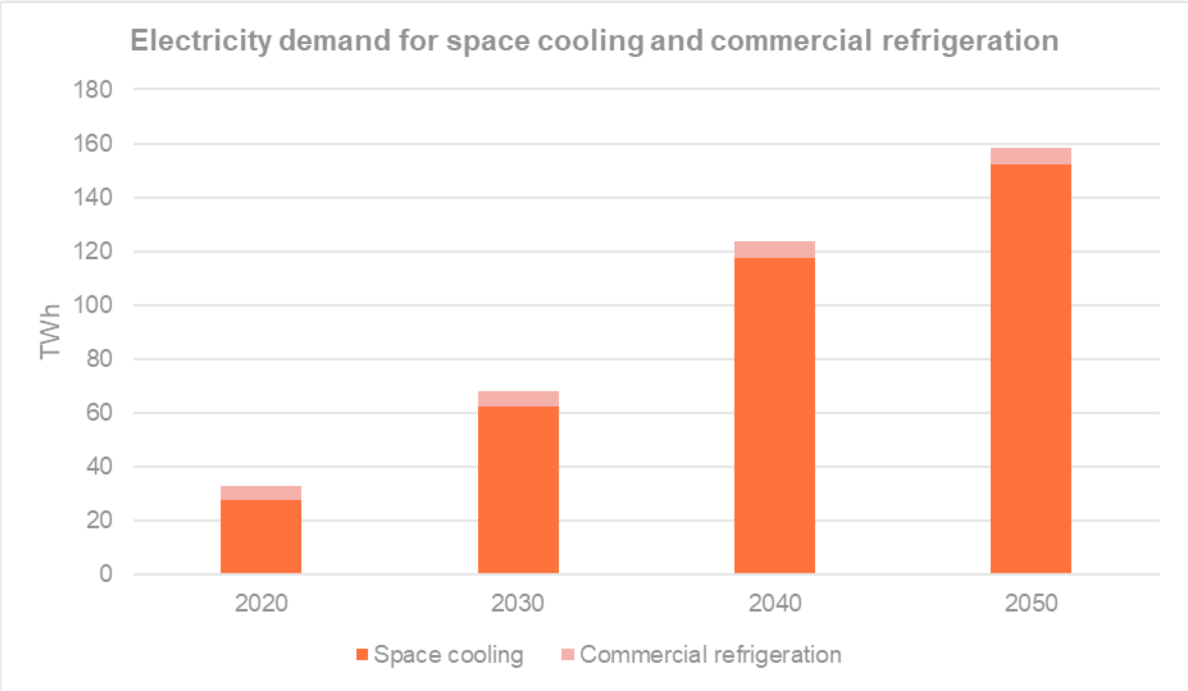


Figure 4 Current trend prospect - Electricity demand for space cooling and for commercial refrigeration 2020 – 2050

The expected increase of electricity demand would lead to the need for significant additional electricity generation capacities.

4.1.2. Mitigation prospects

This section elaborates on the electricity demand mitigation potential. It summarizes the expected savings of the mitigation prospects (P1, P2 and P3) compared to the current trend prospect (P0). It also shows the expected electricity demand in 2050 compared to the starting year in 2020 per prospect.

Figure 5 shows that all prospects (P0, P1, P2 and P3) show a higher electricity demand in 2050, compared to base conditions in 2020. The electricity demand for space cooling is predicted to steadily grow in all prospects between 2020 and 2040 and in the decade between 2040 and 2050 the growth is expected to slow down in P1 and P2 and almost stabilize in P3. The predicted upward trend between 2020 and 2050 is the consequence from a strong growing building stock combined with an assumed strong increase of the average cooled floor area, especially in residential buildings which increases from 27% in 2020[36] to 50% in 2050. The lower increase after 2040 is the effect of reaching a saturated market which leads to reduction in AC system sales in the residential sector compared to previous years.[37]

It is expected that in 2050, significant additional generation capacity is needed in all prospects. Depending on prospect the increase is about 3-5-fold compared to 2020. Compared to the current trend prospect this would avoid significant additional generation capacity in the range.

P1: Electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades from 28 TWh up to 115 TWh, meaning demand is expected to quadruple by 2050 compared to the starting year in 2020 and in 2050 savings of 24% are expected compared to P0.

P2: Electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades from 28 TWh up to 92 TWh, meaning demand is expected to more than triple by 2050 compared

[36] El Dallal et al., "Cooling Sector Status Report Egypt"

[37] In a saturated market the main driver for sales are first time installations in new buildings and replacement of dysfunctional equipment in existing buildings.

to the starting year in 2020. In 2050 savings of around 39% and 19% are expected compared to P0 and P1 respectively. The assumed strong penetration of highly efficient AC systems in P2 is sufficient to further slowdown the growth of electricity demand in the RAC sector compared to P1.

P3: Electricity demand for space cooling (AC systems) is expected to increase over the next decades from 28 TWh up to 80 TWh, meaning demand is expected to almost triple by 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 48% are predicted and 15% compared to P2. These additional savings in P3 compared to P2 are the consequence of additional improvements of the building envelope between 2020 and 2050.

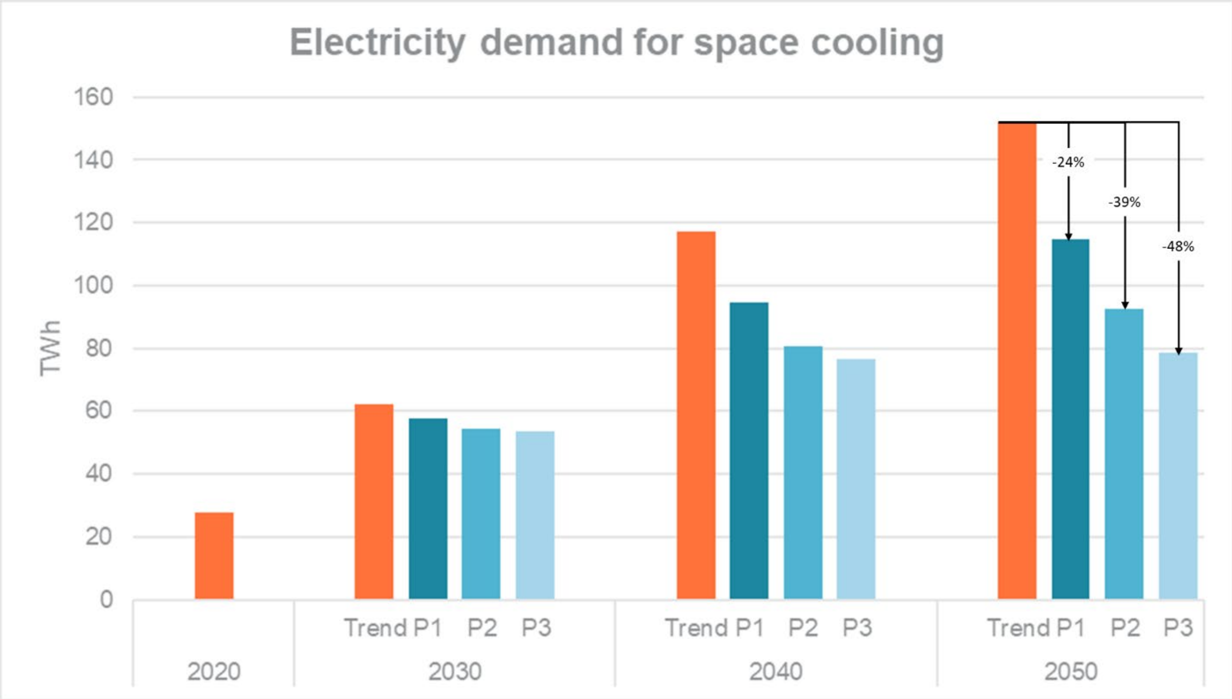


Figure 5 Mitigation prospects - Electricity demand for space cooling 2020 - 2050

Figure 6 shows that the electricity demand for commercial refrigeration is expected to steadily grow for P0 and P1 until 2050. P2 shows an almost stable electricity demand due to a stronger penetration of highly efficient technologies compared to P0 and P1.

P1: Electricity demand for commercial refrigeration is expected to increase steadily and slowly over the next decades from 5.3 TWh up to 6.1 TWh, meaning the demand is expected to increase by about 15% in 2050 compared to starting year 2020. Compared to P0, in 2050 savings of 8% are expected.

P2: Electricity demand for commercial refrigeration is expected to decrease slightly over the next decades from 5.3 TWh in 2020 down to 5.2 TWh in 2020. In 2050, savings of 21% and 15% are expected compared to P0 and P1 respectively.

The developments in the commercial refrigeration sector are shaped by stock development (e.g. new construction of supermarkets that drive installation of new commercial refrigeration equipment) and the increase of technologies efficiency.

In contrast to the AC sector, the commercial refrigeration sector has a much lower increase in electricity demand in 2050 compared to 2020. P2 in 2050 even shows a slightly lower electricity demand compared to base conditions in 2020 despite the expected growth in cooling demand, showing the potential achievement by different policy measures.

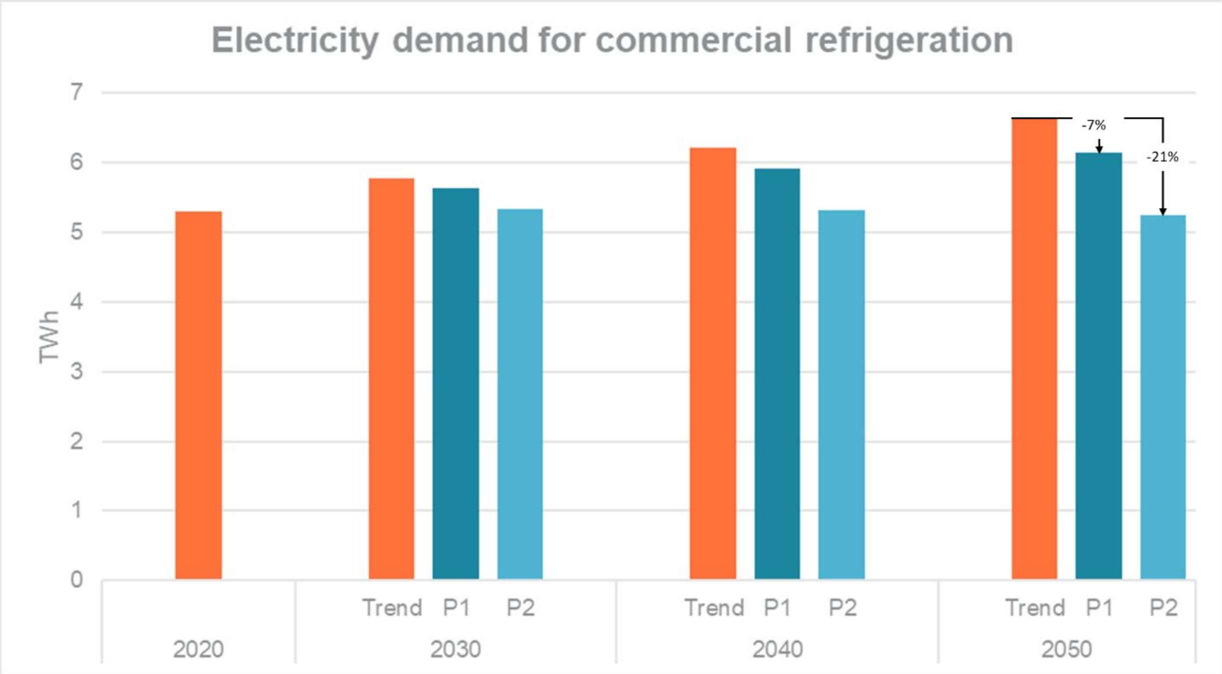


Figure 6 Mitigation prospects - Electricity demand for commercial refrigeration 2020 – 2050

4.2. Indirect and direct greenhouse gas emissions

4.2.1. Current trend prospect

This section elaborates on the emissions in the current trend prospect (P0), comparing 2020 and 2050. It provides an overview of the share of indirect and direct emissions, of the total emissions in the AC and in the commercial refrigeration sector and it shows direct and indirect emissions disaggregated across these two sectors.

In 2020, total emissions (both AC and commercial refrigeration sector) were calculated to amount to 27 $MtCO_{2\,eq}$ of which 73% (20 $MtCO_{2\,eq}$) account for indirect and 27% (7 $MtCO_{2\,eq}$) account for direct emissions. In the AC sector the total emissions account for 22 $MtCO_{2\,eq}$ of which 82% account for indirect and 18% for direct emissions. In the commercial refrigeration sector, the total emissions account for 5 $MtCO_{2.eq}$, of which 69% account for indirect and 31% for direct emissions. In both, the AC as well as the commercial refrigeration sector the indirect emissions constitute the larger share of the emissions.

In 2050, the total emissions (both AC and commercial refrigeration sector) are expected to increase by a factor of about 2,7 and reach 72 $MtCO_{2\,eq}$., even with the considered decarbonization of the electricity grids. Of these, indirect emissions account for 68% and direct emissions for 32%, indicating that the share of direct emissions are expected to increase (from 27 to 32%) compared to 2020.

In 2050 the total emissions of the AC sector are expected to more than triple up to 67 $MtCO_{2\,eq}$. The total emissions in the commercial refrigeration sector are expected to stay stable until 2050 (around 5 $MtCO_{2.eq}$). Compared to 2020 the share of the AC sector emissions of the total emissions of the considered sectors increases from 80% to more than 90%. This is mainly due to the higher growth of the AC sector (increase in cooled floor area) compared to the commercial refrigeration sector.

In the AC sector, compared to 2020, the share of direct emissions is expected to increase until 2050 from 24% to 31% and in the commercial refrigeration sector from 33% to 43%.

The increase of the share of direct emissions in the total emissions is a consequence of the interplay of various factors such as the expected decreasing CO_2 factor of the grid electricity, the increase in efficiency, the change in the refrigerant types used and reductions in operational leakage and in recovery of refrigerants at the disposal stage.

Figure 7 provides an overview of the total indirect and direct emissions disaggregated by the AC and commercial refrigeration sectors.

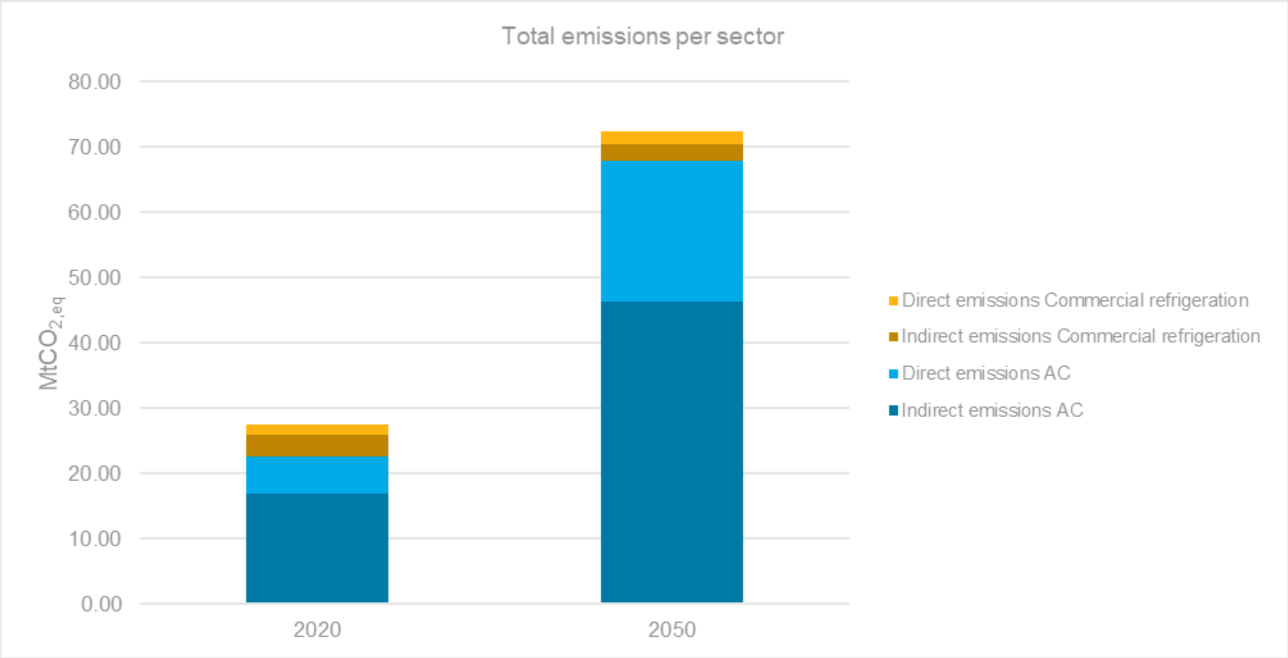


Figure 7 Overview of the total indirect and direct emissions disaggregated across the AC and commercial refrigeration sector

Total emissions in the building segments and by technology groups

Following the growth trend in emissions, the relative emissions contribution broken down per technology group vary over the years. **Figure 8** depicts the resulting emissions from different technology groups per decade up until 2050. It is expected that the residential AC will exhibit the highest growth and will be responsible for more than 71% of the emissions of the considered sectors and groups in 2050. The non-residential AC sector is expected to be responsible for about 20% of the emissions of the technology groups.

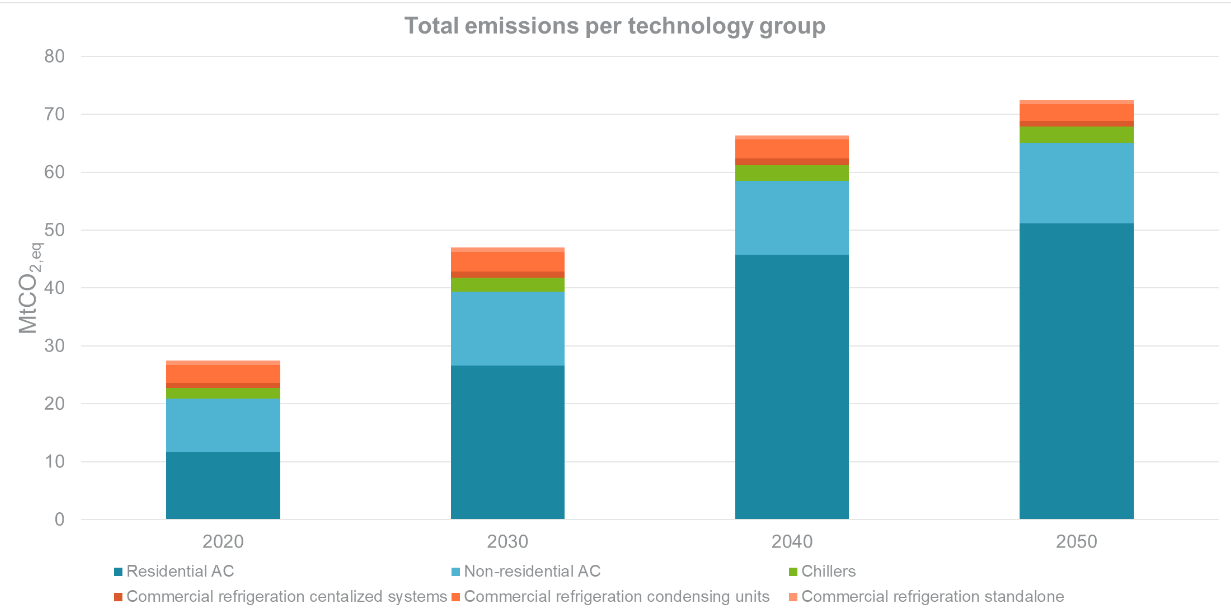


Figure 8 Current emissions trend disaggregated by technology groups 2020 - 2050

Direct emissions in the building segments and by technology groups

Direct emissions resulting from AC (incl. chillers) and commercial refrigeration sector were around 7 $MtCO_{2,eq}$ in 2020. AC and chillers are responsible for more than 75% of the direct emissions of the technology groups.

By 2050, direct emissions of the technology groups are expected to more than triple and reach 23 $MtCO_{2,eq.}$ AC and chillers, with 21 $MtCO_{2\ eq}$, constitute more than 90% of these direct emissions, indicating that the relative importance of the AC system for direct emissions in Egypt still increases over time.

The direct emission resulting from AC in the residential sector has the highest growth in absolute numbers with a growth from around 2 $MtCO_{2\ eq}$ in 2020 to 15 $MtCO_{2\ eq}$ in 2050. The results are illustrated in **Figure 9**.

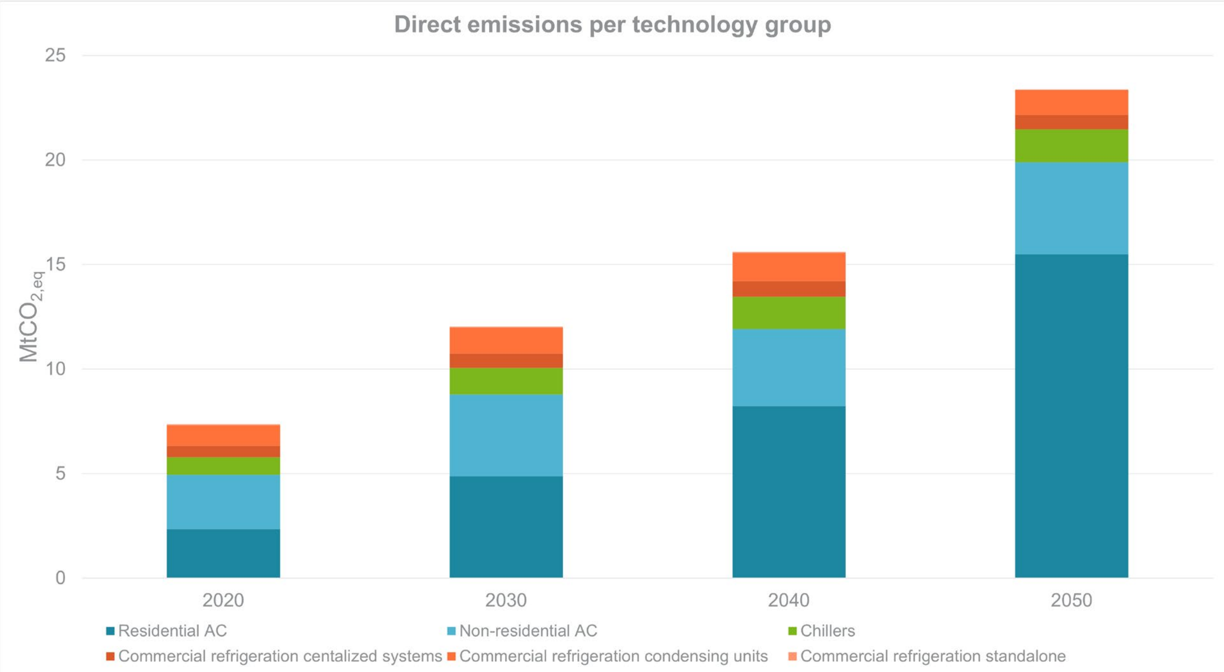


Figure 9 Current direct emissions trend disaggregated by technology groups 2020 - 2050

Indirect emissions in the building segments and by technology groups

Indirect emissions resulting from AC (incl. chillers) and commercial refrigeration sector were around 20 $MtCO_{2,eq}$ in 2020. At 17 $MtCO_{2,eq}$, AC and chillers are responsible for around 85% of the indirect emissions of the technology groups.

By 2040, indirect emissions of the technology groups are expected to increase more than 2-fold and reach 50 $MtCO_{2\ eq}$. Between 2040 and 2050 the emissions slightly decrease by 1 $MtCO_{2\ eq.}$ AC and chillers with 46 $MtCO_{2\ eq}$ constitute more than 90% of these indirect emissions, indicating that the relative importance of the AC system for indirect emissions in Egypt is increasing over time. The highest growth can be observed in the residential AC sector, where emissions almost quadruple from 9 to 35 $MtCO_{2\ eq.}$ The results are illustrated in **Figure 10**.

The decrease between 2040 and 2050 is the sum of effects of the projected improvements of the CO_2 factors of the electricity grid, the efficiency improvements over the next decades, and the slowdown in AC systems stock growth after achieving the maximum market saturation.

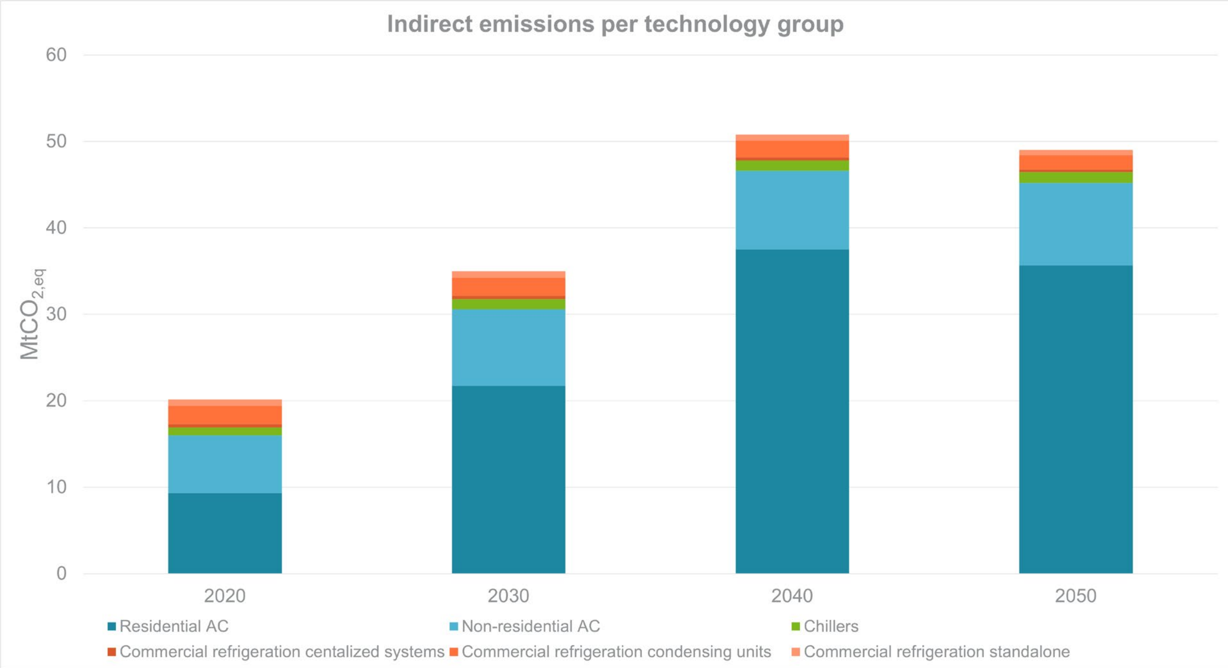


Figure 10 Current indirect emissions trend disaggregated across technology groups 2020 - 2050

4.2.2. Mitigation prospects

This section elaborates on $CO_{2\ eq}$ emissions mitigation potential. It shows the relative expected $CO_{2\ eq}$ emissions savings of P1, P2 and P3 compared to the current trend prospect (P0). It summarizes the expected savings of the mitigation prospects (P1, P2 and P3) compared to the current trend prospect (P0). It also shows the expected emissions in 2050 compared to the starting year in 2020 per prospect. The section is structured in three parts, elaborating on the a) total, b) direct and c) indirect emissions.

Total emissions in the building segments and by technology groups per modelled prospect

This subsection provides an overview of the total emissions in the AC and commercial refrigeration sectors disaggregated across the building segments, residential and non-residential sector. The two following subsections follow the same structure and provide an overview of the direct and indirect emissions respectively, also disaggregated across the building segments, residential and non-residential.

Figure 11 shows that the total emissions are predicted to grow (P1), slightly grow (P2) and slightly decrease (P3) between 2020 and 2050. In 2050, compared to the P0 all mitigation prospects (P1, P2, P3) show significant savings, ranging from 36% to 64%.

P1: Total emissions are expected to increase from 27 $MtCO_{2\ eq}$ up to 45 $MtCO_{2\ eq}$, meaning the total emissions are expected to increase by a factor 1.7 in 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 36% are expected.

P2: The total emissions in 2050 are expected to increase slightly by approximately 10% in 2050 compared to the starting year in 2020. In 2050 savings of 57% and 21% are expected compared to P0 and P1 respectively. Between 2040 and 2050 the total emissions are expected to decrease.

P3: It is the only prospect in which in 2050 the total emissions are slightly lower compared to the starting year 2020 (around 7% lower). In 2050 savings of 64% and 7% are predicted compared to P0 and P2 respectively. These additional savings in P3 compared to P2 are the consequence of additional improvements of the building envelope between 2020 and 2050.

Between 2030 and 2040 emissions start to decrease slightly, decreasing more rapidly between 2040 and 2050. The main reasons for this development are the accelerated implementation of natural refrigerants and avoiding lock-in effects, as well as the early implementation of highly efficient technologies.

Despite the already described effect of strong growth of the building stock combined with an assumed strong increase of the average cooled floor area, especially in residential buildings, P3 is expected to result in lower emissions compared to the starting year in 2020. This shows the potential and need for strong and ambitious policy packages and their harmonised implementation, including policies addressing F-gases, financing schemes enhancing the uptake of natural refrigerants and increase awareness, specifically addressing skills of technicians. Additionally, policies regarding the building efficiency for new buildings and ambitious building renovation over the decades from 2020 to 2050 show great potential (see also Chapter **3**).

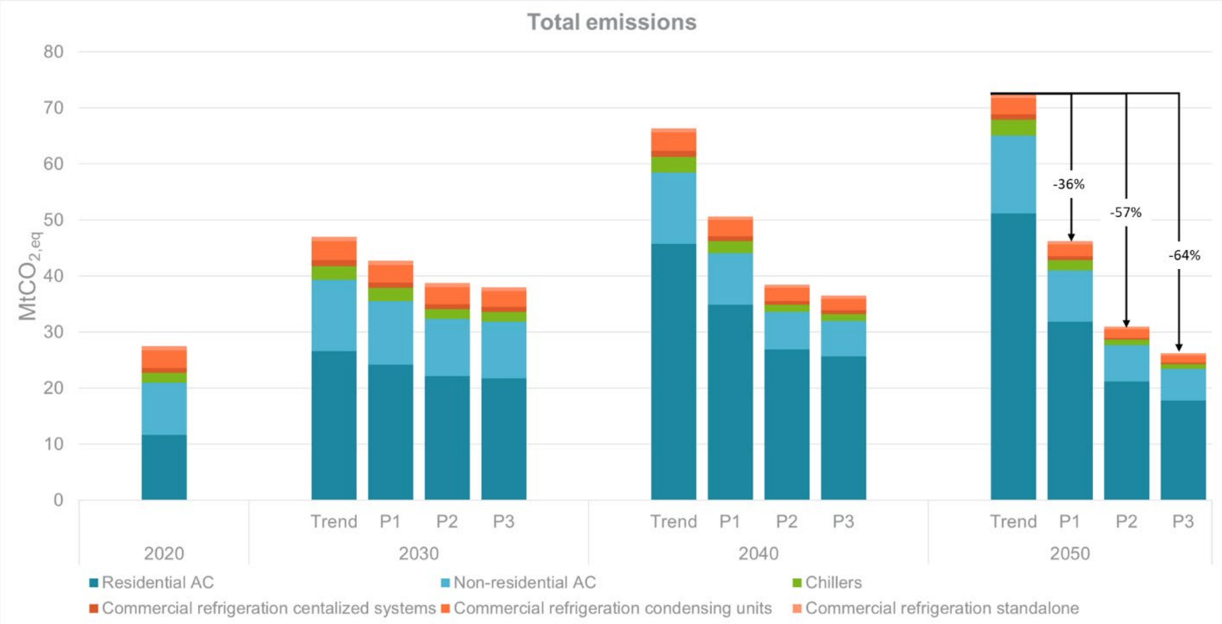


Figure 11 Total emissions development per prospect 2020 – 2050

Direct emissions in the building segments and by technology groups per prospect

This subsection provides an overview of the direct emissions in the AC and the commercial refrigeration sector disaggregated by the building segments residential and non-residential sector. Direct emissions savings are mainly a result of the switch to intermediate (low GWP) and natural refrigerants as well as measures that reduce leakage (operational as well as end of life leakage).

Figure 12 shows that direct emissions are expected to increase slightly in P1. In contrast, a significant reduction in P2 in 2050 compared to 2020 is expected. Compared to P0, in 2050 all mitigation prospects (P1, P2, P3) show significant emission reductions, ranging from 62% to 98%, compared to the P0. The reduction potentials start to become evident already in 2030 and increase significantly throughout 2040. The significant reductions are mostly driven by the switch to natural refrigerants.

P1: Direct emissions are expected to increase between 2020 and 2030 and then start decreasing slightly up to 2050. Between 2020 and 2050 there is still a slight increase from 7 to 8 $MtCO_{2\ eq}$. The main reason that direct emissions reach their peak around 2030 is the assumed switch from high GWP refrigerants to intermediate refrigerants with lower GWP and to natural refrigerants. Another factor is the improvement on leakages.

P2: Between 2020 and 2030 the emissions increase very slightly and between 2030 to 2040 the emissions start decreasing. Between 2040 and 2050 the emissions decrease to zero, mainly because of the use of natural refrigerants. In 2050 savings of around 97% and 35% are expected compared to P0 and P1 respectively.

P3: Between 2020 and 2030 the emissions stay stable and between 2030 to 2040 the emissions start decreasing. Between 2040 and 2050 the emissions decrease to zero, mainly because of the use of natural refrigerants. In 2050 savings of around 98%, 36% and 1% are expected compared to P0, P1 and P2 respectively. The slight reduction in comparison to P2 is a result of the improved building envelope that results in reduced need for cooling and thus avoiding further operation.

The measures in P1 already assume a high share of natural refrigerants in 2050, but compared to P2, the implementation is slower and the share of natural refrigerants in 2050 is lower (see **Table 5**). The results show that early implementation is key to avoid lock – in effects. The main reasons for the additional savings in P2 compared to P1 is the accelerated implementation of natural refrigerants, including leapfrogging intermediate refrigerants and thus avoiding lock-in effects and of the early implementation of highly efficient technologies. Additionally enhanced measures in controlling leakage rates and end of life disposal contribute to the emission reduction potential of P2 compared to P1.

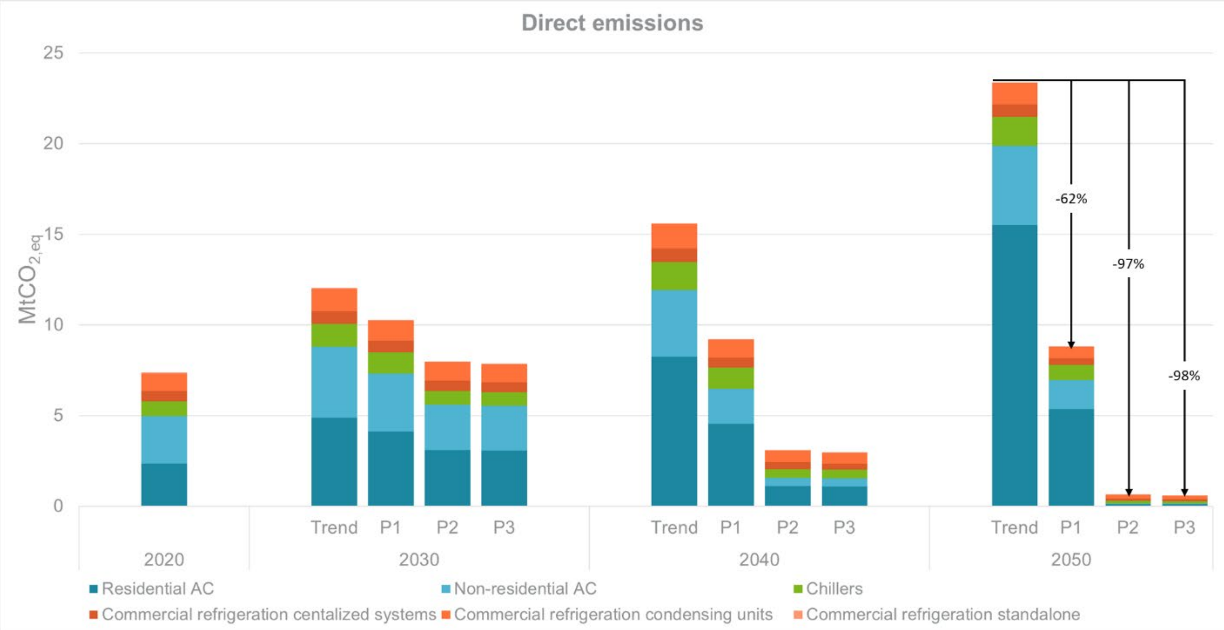


Figure 12 Direct emissions development per prospect 2020 – 2050

Indirect emissions in the building segments and by technology groups per modelled prospect

This subsection provides an overview of the indirect emissions in the AC and the commercial refrigeration sector disaggregated by the building segments residential and non-residential sector. Indirect emissions savings are mainly a result of increased system efficiency and grid decarbonization efforts.

Figure 13 shows that indirect emissions in 2050 will be higher compared to the starting year in 2020 in all mitigation prospects. The main reason for the increase is strong market growth. The savings in indirect emissions in the mitigation prospects through an increase in efficiency of the technologies and the assumed decarbonization of the grid is not enough to offset the upward trend in indirect emissions from 2020 to 2050 driven by high market growth.

This contrasts with the direct emissions in 2050 where all prospects were significantly lower compared to the starting year 2020, with P2 and P3 almost fully eliminating direct emissions. Based on the assumptions (see Table **8** and Table **13**) it is expected that indirect emissions increase their share in the overall emissions of the considered sectors in the future. Compared to the current trend prospect (P0) the mitigation prospects show a potential of indirect emissions reduction in 2050 compared to 2020, that ranges from 24% to 48% (see **Figure 13**).

Throughout all mitigation prospects the indirect emissions increase until 2040 and only decrease in the decade between 2040 and 2050. This is due to a slower market growth and a further increase in efficiency of the technologies.

P1: The indirect emissions increase from 20 $MtCO_{2\ eq}$ to 37.5 $MtCO_{2\ eq}$, meaning an increase by a factor of 1.8 between 2020 and 2050. The indirect emissions peak around 2040 and then start decreasing slightly. The main reason for the strong increase in the next decades is the high market growth. Compared to P0, in 2050 savings of 24% are expected.

P2: The indirect emissions increase from 20 $MtCO_{2\ eq}$ to 30 $MtCO_{2\ eq}$ between 2020 and 2050, meaning an increase by a factor of about 1.5, slightly less than in P1. Between 2040 and 2050 the indirect emissions start decreasing slightly. From 2040 onwards, market growth is decreasing. The effects of indirect emissions savings through efficiency measures and the assumed decarbonization of the grid become larger than the additional emissions caused by the market growth which leads to an overall decrease in indirect emissions.

In 2050 savings of around 38% and 14% are expected compared to P0 and P1 respectively. Main reason for the additional savings of P2 compared to P1 is the accelerated implementation of best available technology.

P3: The indirect emissions increase from 20 $MtCO_{2\ eq}$ to 25.7 $MtCO_{2\ eq}$ between 2020 and 2050, meaning an increase by a factor of about 1.3, slightly less than in P1 and P2. Like in the other prospects, the indirect emissions increase up to 2040. Between 2040 and 2050 the indirect emissions start decreasing more rapidly than in P2.

In 2050, savings of around 48% and 10% are expected compared to P0 and P2. The 10% additional savings compared to P2 is the consequence of additional improvements of the building envelope between 2020 and 2050.

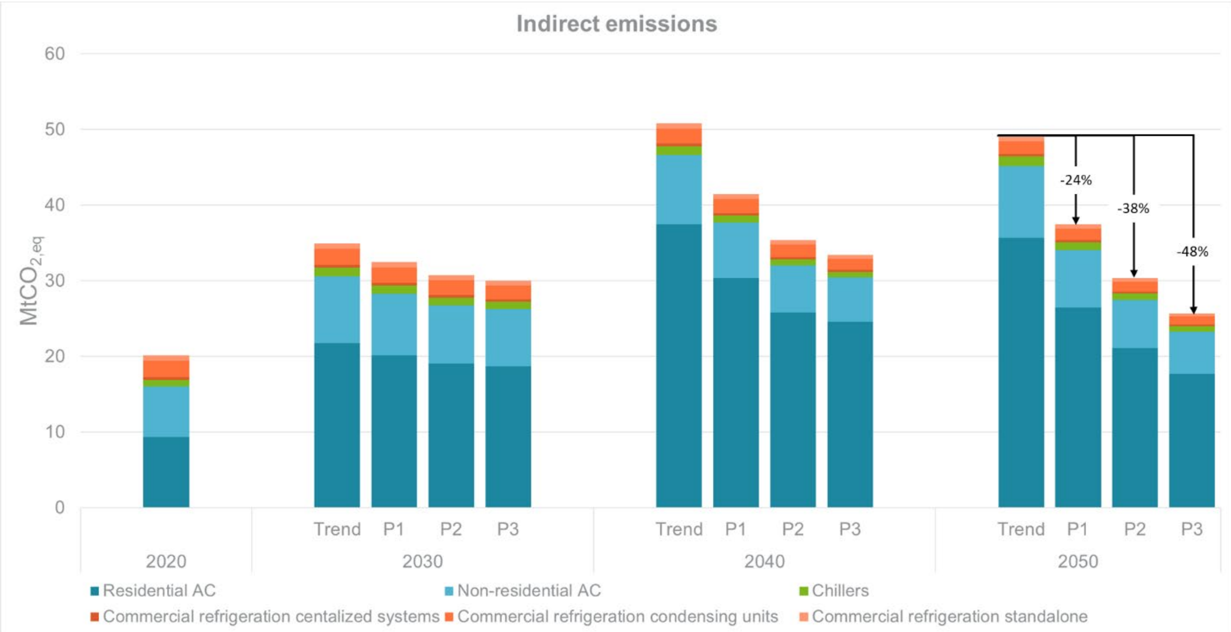


Figure 13 Indirect emissions development per prospect 2020 – 2050

4.3. Economic assessment and cost savings

Compared to the current trend prospect, the mitigation prospects lead to electricity cost savings but also require additional investments to implement sustainable technologies (higher efficiency and technologies using natural refrigerants). In this section the investments have been broken down using yearly payments (annuities), considering lifetime, technology price increase and discount rate (see section 2.4.7).

This section elaborates on the electricity costs and CAPEX (annuities) in the current trend prospect P0. It illustrates the electricity cost savings as well as the costs of the mitigation prospect and finally analyses the total costs of the mitigation prospects compared to the current trend prospect. All costs and annuities mentioned below are specified as nominal values[38].

4.3.1. Current trend prospect

This section provides an overview of total electricity costs (of installed technologies), annuities and finally the total yearly costs for the equipment of the considered sectors in the current trend prospect (P0).

[38] Including an annual inflation of 5 %

Electricity costs

Under P0, electricity costs for space cooling and commercial refrigeration are expected to increase rapidly over the next decades, exhibiting almost a 17-fold increase, reaching EUR 47 billion by 2050 (**Figure 14**). This significant increase is directly correlated with the increase in electricity consumption for space cooling and commercial refrigeration (see Section 4.1.1.) and the assumed annual electricity price increase after 2024.

Residential AC share of the total costs paid for electricity is expected to increase from almost 44% in 2020, estimated around EUR 1.2 billion, to around 72% by 2050 estimated around EUR 34 billion. On the other hand, non-residential AC are also growing steadily, however their shares are slowing down from 39% in 2020 to 24% in 2050. This is directly attributed to the stronger increase in demand for residential space cooling as demonstrated in Section 4.1.1. Similar to non-residential AC, commercial refrigeration electricity costs are also growing steadily from around EUR 475 million in 2020 to around EUR 1.36 billion in 2050, however their total shares also slowing down from 17% in 2020 to around 4% in 2050.

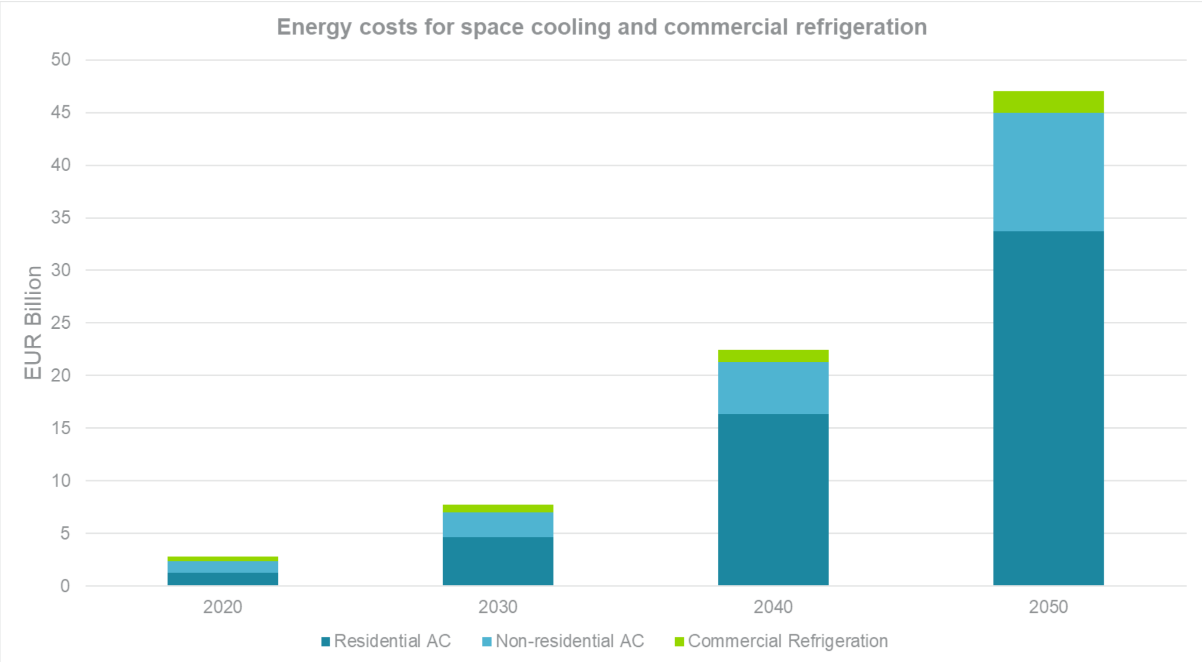
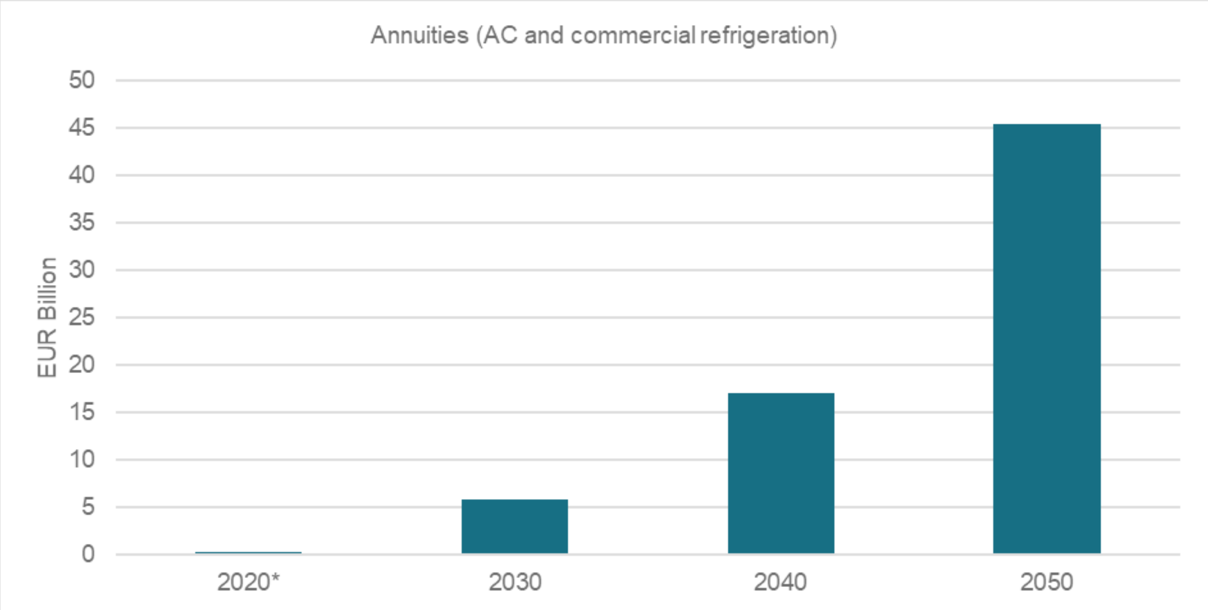


Figure 14 Current trend - Energy costs for space cooling and commercial refrigeration 2020 - 2050

Annuities for investments

As a result of the large growth of cooling demand and the associated significant increase in AC and to a lesser extent also of commercial refrigeration equipment installations, large investments are required. The investments have been broken down using yearly payments (annuities), considering lifetime and discount rate (see Section 2.4.7).

In the current trend prospect P0, the annuity cost payments are expected to increase steadily and significantly due to the growth in AC stock and due to the cumulative nature of annuity payments to reach around EUR 45 billion in 2050 as demonstrated in **Figure 15**.



* Annuity payments in 2020 are low as they include the very first payment of the required investment in that year that has been discounted over the technologies' lifetime. Historical investments annuities were not taken into consideration.

Figure 15 Current trend prospect – Annuity for investments development 2020 – 2050

Total costs

Total costs are calculated as the summation of annuity costs payments and the annual electricity costs. The share of OPEX in the total cost is about 51% in 2050. Total costs resulting from air conditioning and refrigeration sectors are expected to go up to EUR 92 billion in 2050 signalling a significant increase from 2020 as shown in **Figure 16**.

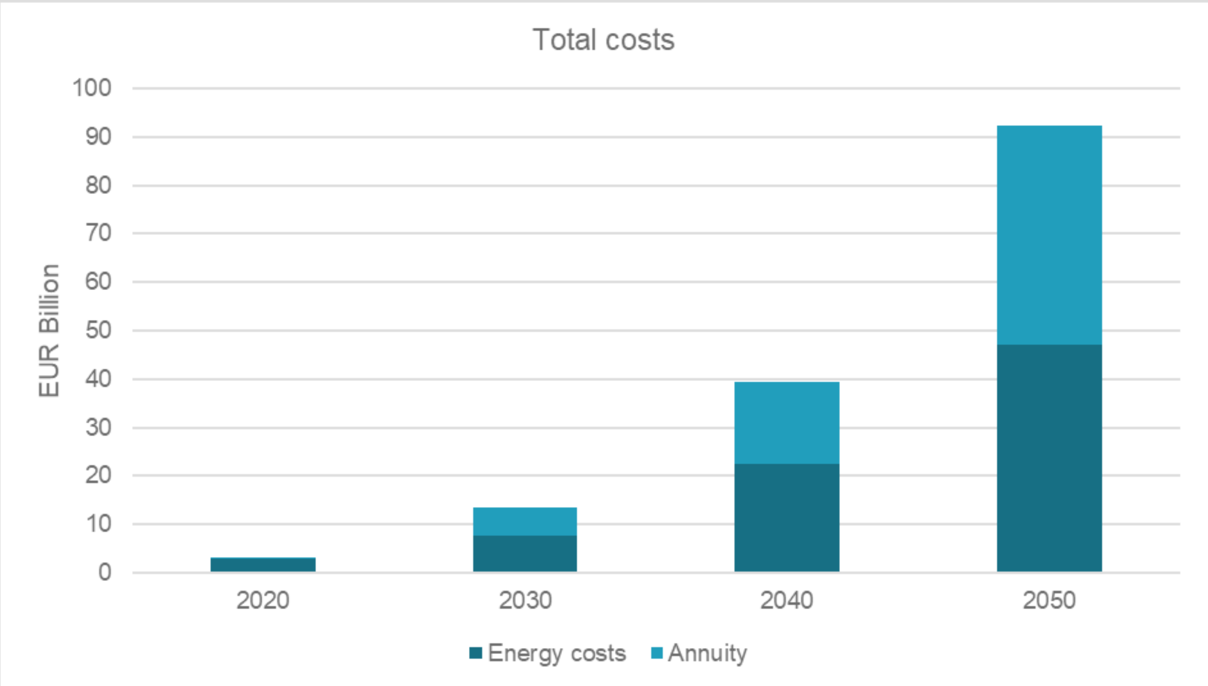


Figure 16 Current trend prospect – Total yearly costs development 2020 – 2050

4.3.2. Mitigation prospects

In the mitigation prospects, compared to current trend prospect P0 the investment costs and thus annuities are higher due to increased prices of more efficient technology and the total electricity costs are lower due to electricity cost savings. This section provides an overview of electricity cost savings, comparing the mitigation prospects P1 and P2 to P0 prospect.

Electricity costs and electricity cost savings

Similar to the resulting energy demand (Section 4.1.2), significant electricity costs saving can be achieved in the mitigation prospects compared to the current trend prospect. **Figure 17**, provides and overview of the energy costs development of the modelled prospects over the period of 2020 – 2050 and **Figure 18** provides a closeup to the numerical potential energy costs savings over the period of 2030 – 2050.

Figure 17 shows that the electricity costs are predicted to grow in any prospect growth between 2020 and 2050, whereas the growth factor in P0 is higher than 17, in P1 approximately 13, in P2 slightly higher than 10. and in P3 slightly more than 8.7. In 2050, compared to the P0 all mitigation prospects (P1, P2, P3) show significant savings, ranging from 24% to 48%.

P1: Electricity costs are expected to increase from EUR 2.8 billion to EUR 36 billion meaning the total electricity costs are expected to increase by a factor higher than 13 in 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 24% are expected.

P2: Electricity costs are expected to increase from EUR 2.8 billion to EUR 29 billion meaning the total electricity costs are expected to increase by a factor of about 10 in 2050 compared to the starting year in 2020. In 2050 savings of 38% and 14% are expected compared to P0 and P1 respectively.

P3: Electricity costs are expected to increase from EUR 2.8 billion to EUR 24,6 billion meaning the total electricity costs are expected to increase by a factor of about 8.7 in 2050 compared to the starting year in 2020. In 2050 savings of 48% and 10% are expected compared to P0 and P2 respectively.

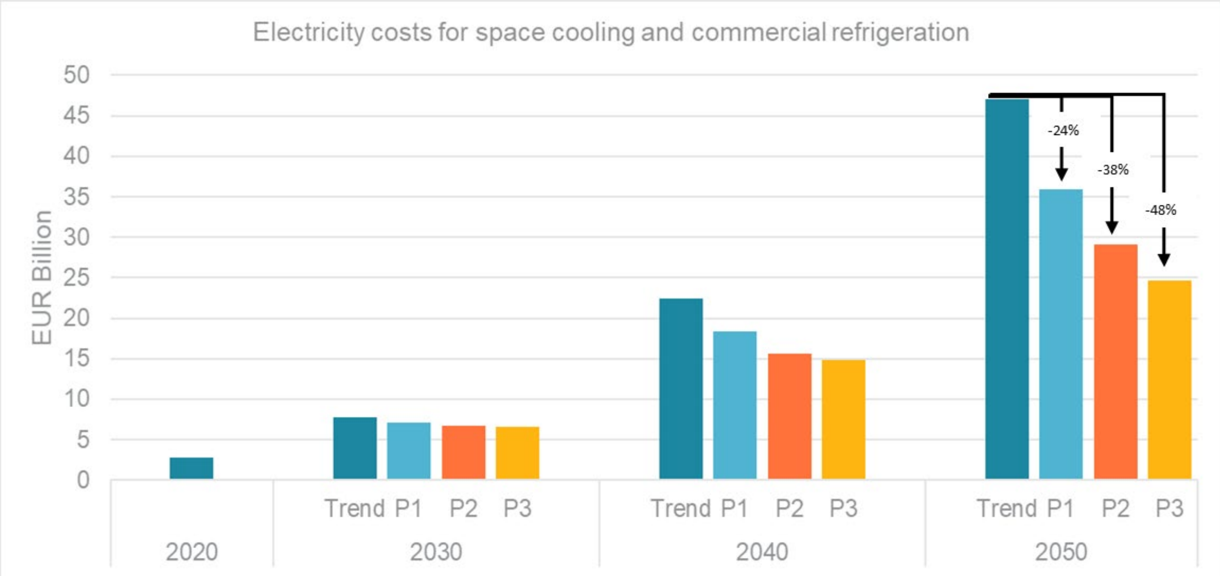


Figure 17 Mitigation prospects - Electricity costs development 2020 – 2050

The following **Figure 18** provides a closeup and highlights the electricity cost savings order of magnitude between the mitigation prospects P1 and P2 and the current trend prospect P0. Between 2030 and 2050 the cost savings reach between 11 to around EUR 18 billion whereas the savings in P2 are almost two times higher than in P1.

As described before the electricity cost savings (**Figure 18**) correspond to the allowable additional annuities (see **Figure 20**) to keep the total cost on the same level through all mitigation prospects.

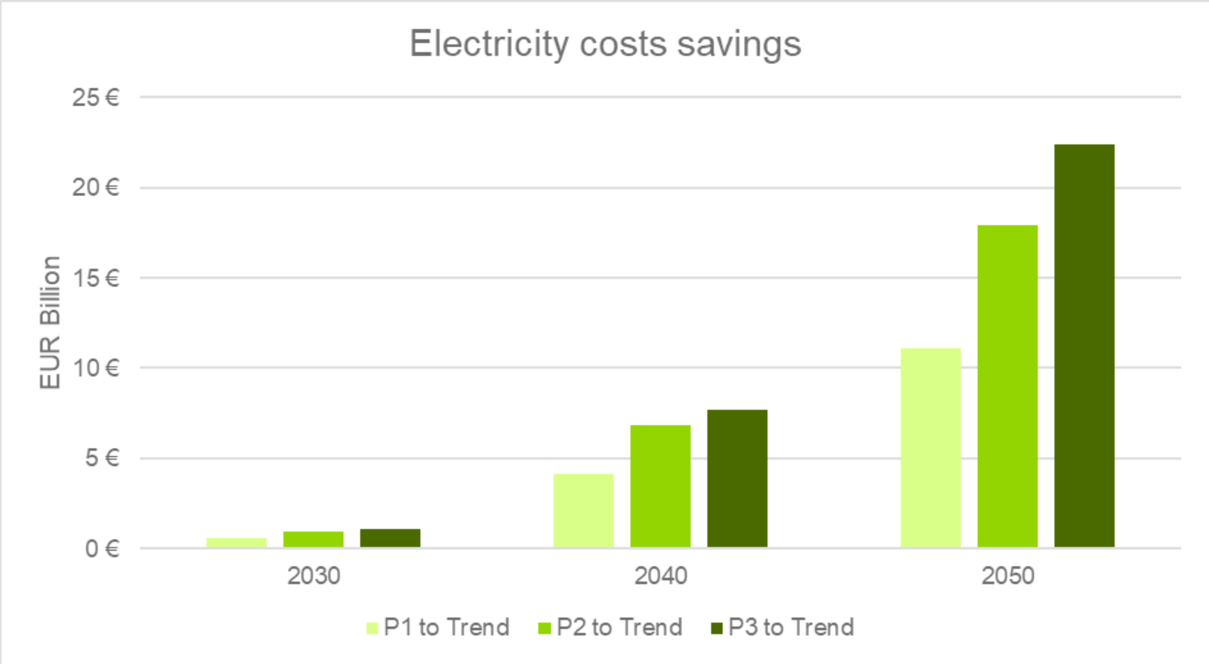


Figure 18 Annual electricity costs savings 2030 – 2050

Total cost of savings

The CAPEX (annuities) of implementing the mitigation prospects (P1 and P2) adds up to 52 Billion EUR, respective 57 Billion EUR in 2050. Compared to current trend prospect P0, this corresponds to additional annuities of 6.8 Billion EUR or 15% in P1 respective of 11.3 Billion EUR or 30% in P2 in 2050 (assumptions on additional costs for improved technologies, see Annex A.8).

The additional investments are expected to be in the same order of magnitude as the additional annuities, assuming constant investments over time. **Figure 19** highlights the development of annuity payments for the modelled prospects between 2020 and 2050.

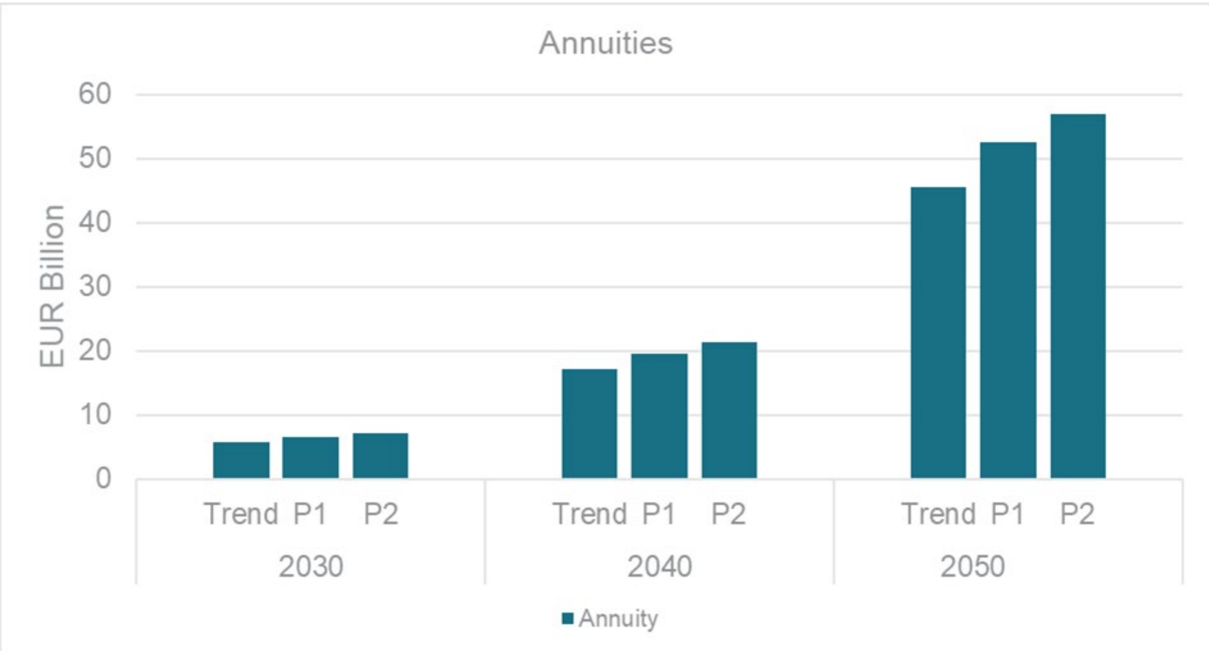


Figure 19 Mitigation prospects - Annuity for investments development 2020 - 2050

As outlined in the previous section, the electricity cost savings in the mitigation prospects sum up to EUR 11 Billion in P1, respective to EUR 22 Billion in P2 compared to P0 in 2050.

The total cost of the mitigation prospect is 6% lower in P1 and 7% lower in P2 than the total cost of the current trend prospect in 2050.

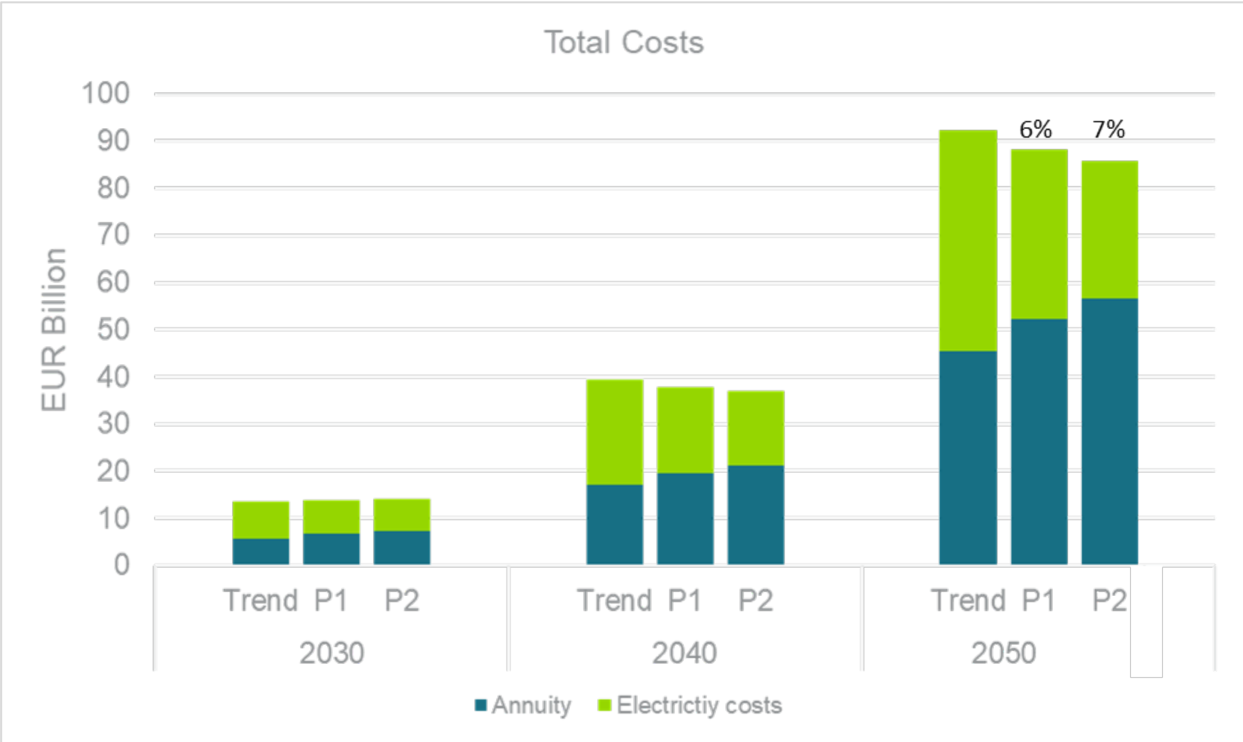


Figure 20 Mitigation prospects - Total yearly costs development 2020 – 2050

5. Summary of key findings

This study analyses several prospects of the development of the RAC sector in Egypt. It provides a basic understanding of the current situation and future developments in the RAC sector, especially the development of future quantities of AC and commercial refrigeration systems. By investigating different mitigation prospects, it also provides emission and final electricity saving potential in 2030, 2040 and 2050 based on increased uptake of sustainable, natural refrigerants-based, and energy efficient RAC equipment compared to the current trend prospect (P0). The study also provides an order of magnitude of additional annuities and cost savings for the analysed mitigation prospects.

Conclusion 1: High growth of the RAC market represents challenges and opportunities for the Egyptian market

- *The RAC market in Egypt is currently growing fast and has large market potential, the residential AC sector is expected to grow by a factor of 6.5 until 2050.*
- *The expected market growth leads to a strong increase in refrigerant and electricity demand under current conditions.*
- *It is expected that in the current trend prospect (P0) the total emissions increase by a factor of about 2.7 and the electricity demand increase by a factor of 5 until 2050 compared to 2020.*
- *The expected increase in electricity demand would require significant additional generation capacity.*
- *Direct emissions already have a significant share of 27% in the overall emissions in 2020 which increases to approx. 32 % in 2050.*[39]

Significant population growth coupled with improvement in the economic situation and societal welfare leads to an increase in built area along with an increase in air-conditioned floor area. This translates directly to a large market potential for the AC sector in Egypt. The highest increase in demand for AC equipment is expected to be in the residential sector, with an increase by a factor of up to 6.5 by 2050.

Under current conditions in the considered current trend prospect (P0) the strong growing demand for AC equipment has significant effects on the considered sectors, compared to 2020:

- Electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades, more than 5-fold from 28 to 152 TWh by 2050.
- Indirect emissions are projected to increase by a factor of 2.5 until 2050 from 20 $MtCO_{2\ eq}$ to 49 $MtCO_{2\ eq}$.
- Direct emissions are expected to significantly increase by a factor of more than 3 until 2050 from 7 $MtCO_{2\ eq}$ to 23 $MtCO_{2\ eq}$.

The forecasted significant increase in electricity demand in P0 results in an energy supply challenge which translates into:

- The need for significant additional electricity generation capacity.
- Increased usage of the power grid infrastructure and the possible need for further expansion and strengthening of the grid.

Furthermore, increased cooling and refrigeration demand is coupled with increased refrigerant demand that could pose a challenge as:

- Refrigerants are mostly imported in Egypt which makes it vulnerable to global availability and price changes.
- Compliance with climate targets as well as future Kigali targets could be difficult as Egypt's RAC sector is a fast-growing market.

[39] If the electricity would faster decarbonize as assumed the already high importance of direct emissions would increase further

Conclusion 2: Significant emission reduction and reversing the upward trend is possible by ambitious and timely measures

- *The effect of moderate impact prospect (P1) is limited in changing the upward trend of emissions significantly.*
- *Only the high impact prospect (P3) is expected to reverse the upward trend.*
- *Early action is key to implement highly efficient and sustainable cooling technologies to avoid lock-in effects.*
- *Compared to the current trend prospect, the high impact prospect (P3) shows significant emission savings in 2050 of 64%.*
- *To achieve high savings, a combination of ambitious measures and strong enforcement is needed.*

The moderate impact prospect (P1) already shows noticeable savings. However, P1 is not expected to reverse the upward trend. Only the high impact prospects (P2 and P3) based on very ambitious underlying policy measures are expected to break the upward trend and stabilize or lower emission levels in 2050 below the starting year 2020. Compared to P2, the assumed improvements of the building envelope show an additional 7% emissions reduction in P3 compared to P2.

The high impact prospect (P3) illustrates that high savings are possible by implementing a set of ambitious measures.

Specifically, the high direct emission savings can be achieved through:

- High use of natural refrigerants
- Strongly reduced operational leakage
- Strongly reduced end of life emissions

Similarly high indirect emissions savings are possible through demand reduction measures:

- Installing and replacing inefficient RAC equipment with best available highly efficient equipment
- Further measures to reduce the leakage rates which influences systems efficiency
- Enhancement of building envelopes in newly built buildings and renovation of existing ones

With the high market growth and the switch to natural refrigerants, the indirect emissions share will be growing in the future underlining the importance of efficiency.

Regarding the improvement of leakage, certain measures covering periodic leak checks on systems and equipment containing F-gases appear critical to limiting the release of high GWP F-gases into the atmosphere. For example, the current EU F-gas Regulation supported with two implementing acts dealing with leakage checking in RACHP and fire protection sectors (which were issued based on Regulation 842/2006 but are still valid) seeks to strengthen the control regime on unintended leakages.

Especially leakage rates in the commercial refrigeration sector, which can potentially be monitored and controlled effectively due to the lower number of units concerned, are known to be significant.[40] Capacity building, training, and certification of qualified personnel as well as increase in recovery rates are possible accompanying measures.

Conclusion 3: Significant electricity savings are possible by ambitious measures

- *All prospects show a higher electricity demand in 2050, compared to base conditions in 2020.*

[40] EIA Chilling Facts VII summarising data obtained from 22 retailers submitting data covering the 2015 calendar year from supermarkets across 37 countries. URL: https://eia-international.org/wp-content/uploads/Chilling-Facts-VII-FINAL-1.pdf

- *It is expected that in 2050, significant additional generation capacity is needed. Depending on prospect the increase is about 3-5-fold compared to 2020.*
- *Significant electricity savings are expected in the mitigation prospects by 2050 compared to P0.*

The predicted upward trend between 2020 and 2050 is the consequence from a strong growing building stock combined with an assumed strong increase of the average cooled floor area. It is not expected that the upward trend will reverse in any mitigation prospect. The potential success of policy measures and regulatory control would be to decelerate the expected growth of electricity demand as observed in P1, P2, and P3. Significant electricity saving of 24-48% are expected in 2050 compared to P0. This would lead to significant avoided generation capacity in the mitigation prospects compared to P0.

Conclusion 4: Early action and swift reduction is key to implement highly efficient technologies with natural refrigerants and avoid lock-in effects.

- *A fast transformation of the RAC sector towards more efficient technologies and natural refrigerants is key:*
  - *To counteract the fast-increasing emissions because of the market growth.*
  - *To accelerate significant indirect and direct emission reductions as early as possible and avoid long-term lock in effects.*
  - *To avoid lock in effects of equipment with standard refrigerants (e.g., R 410A, R 134a) and support the achievement of Kigali targets.*
- *Additional benefits of early action are increased refrigerant price security, availability of refrigerants and environmental benefits*

Considering the strong market growth and large market potential especially in the AC sector early action is key to implement low GWP practices and highly efficient systems before further market growth occurs. A delay in market transition to sustainable technologies will lead an increase in lock-in effects.

An early market transformation has two positive effects. Regarding direct emissions, an early implementation of natural refrigerant cooling technologies supports the country in achieving Kigali targets by lowering the refrigerant demand-based emissions. The implementation of highly efficient technology lowers the electric demand and saves costs.

The early action also has positive side effects. It increases the security of refrigerant availability. Natural refrigerants are in many cases locally available and there is no dependence on international shipments and suppliers.

Early and fast implementation of natural refrigerants increases the price stability and has a positive impact on the economic sustainability of business in the cooling sector since price changes occur at a much lower order of magnitude. During the last eight years of data collection by the EU commission, stable refrigerant prices have been observed for the case of natural refrigerants.

Based on data collected by the European Commission since 2014, the phase down of the quantity of HFCs allowed on the EU market has strong effects on the prices of synthetic refrigerants with a medium to high GWP. In short, word-wide, refrigerant prices will likely increase as a result of joint action on HFC under the Montreal Protocol. In the EU, price increases have been observed for conventional (high GWP) HFCs refrigerants that fall under the HFC phase down (e.g., on R134a R410A, and R407C). Prices of low GWP refrigerants such as natural refrigerants, in turn, appear to be more stable, indicating that the quota is strongly affecting market prices of the refrigerants affected by the phase down. Recently, on a global scale, refrigerant production volumes by non-EU suppliers appear to have been reduced, inter alia as a result of the Kigali Amendment to the Montreal Protocol. Especially regarding refrigerants produced in the US, international regulatory pressure on HFC production volumes appears to already be affecting the available quantity in the first HFC phase down step. This supply reduction has already led to increases in refrigerant prices on the European market.[41]

[41] Cost effects of refrigerants were not considered in this study. It would be expected that considering costs of refrigerants would result in even higher cost saving potentials as indicated for the ambitious prospects (P2 and P3)

In case of a full grid decarbonization[42] prospects P2 and P3 would enable Egypt to get climate neutral by 2050.

Conclusion 5: Significant electricity cost savings are possible by ambitious measures

- *The electricity costs are expected to increase, depending on prospect between a factor of 9-17 between 2020 and 2050.*
- *In 2050, 24% to 48% electricity costs savings are expected in the mitigation prospects compared to the current trend prospect.*
- *Cost savings allow for investment in efficient, sustainable cooling technologies.*

In all prospects the upward trend of electricity costs is expected to highly increase from 2020 to 2050 by a factor between 9 and 17, depending on which prospect.

Comparing the prospects in 2050, significant electricity costs savings can be achieved in the mitigation prospects by 2050. More than 11€bn, 18€bn and 22€bn in electricity cost savings can be achieved in P1, P2 and P3 in 2050 compared to P0 respectively. Such electricity costs savings not only allow for further flexibility to allocate the savings towards other decarbonization efforts, but it allows room for further investment in even more efficient, natural refrigerant-based equipment.

The electricity cost savings can be even higher when taking into consideration the exponential growth of the electricity prices in Egypt in a more thorough way. Another effect for instance, the electricity prices have increased by a factor of 200% over the past 10 years (2011 – 2021), with an increase of 15% on average alone in 2019 (in the modelling a conservative annual price increase of 5% starting from 2025 is assumed). The significant growth is mainly a result of the subsidies waiver from electricity prices.

A societal benefit of increasingly efficient appliances and thus electricity savings are avoided investments in electricity grid strengthening and expansion and avoided investments for additional power generation capacity, particularly peaking plants.

Conclusion 6: Cost of savings: the additional annuities to implement the mitigation prospects are lower than the achieved electricity cost savings

- *The CAPEX (annuities) of implementing the mitigation prospects adds up to EUR 52 billion, respective EUR 57 billion in 2050*
- *The CAPEX (annuities) costs of the mitigation prospects are 15% respective 30% higher than the current trend prosect in 2050.*
- *The additional annuities to implement the mitigation prospects are lower than the achieved electricity cost savings, the mitigation prospects result in net savings.*

The implementation of the mitigation prospects has additional CAPEX (annuities) because of the higher technology price of sustainable cooling technologies (higher efficiency and using natural refrigerants). Comparing the mitigation prospects with the current trend prospect, the additional annuities add up to 15% in P1 respective 30% in P2 in 2050, compared to P0.

The electricity cost savings in the mitigation prospects are higher than the required additional annuities to implement the mitigation prospects. Thus, the total cost of the mitigation prospects are lower than the total costs of the current trend prospect which means that the mitigation prospects result in net savings compared to the current trend prospect.

[42] CO_2 factor of grid electricity 0 g/kg by 2050

Final remarks

The results and conclusions of this study strongly depend on the input data. Therefore, Cool Up spent high efforts and care to get as reliable data and resilient prognoses as possible. Furthermore, Cool Up tried to make the input data as transparent as possible (see appendix), to enable the reader to judge the effects of potential derivation of different input parameters.

Annex I: Input parameters

A.1 Building stock development

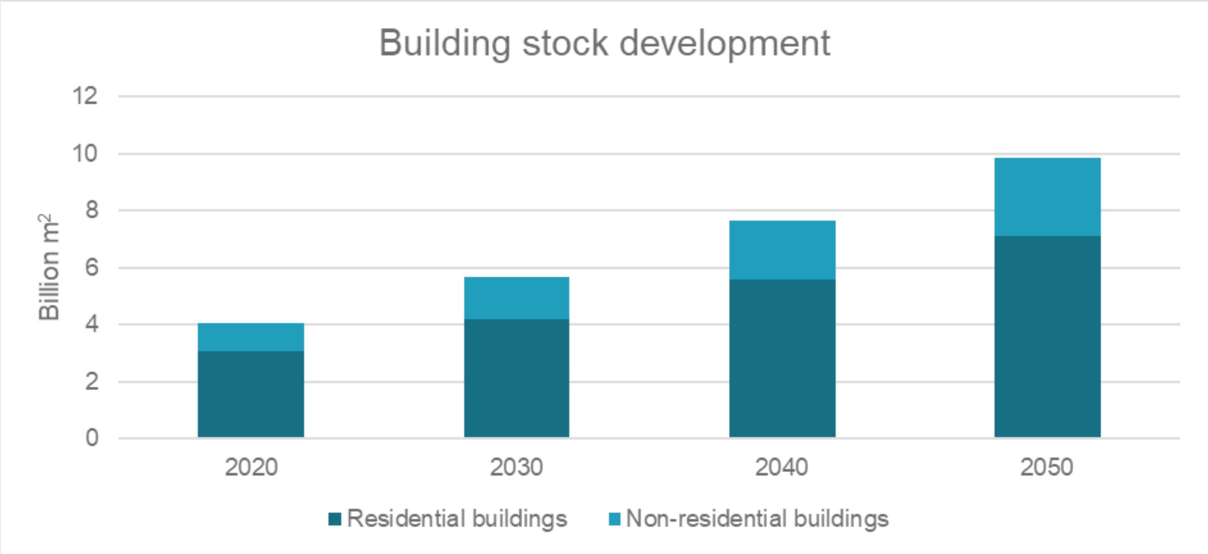


Figure 21 Building stock development 2020 - 2050

In 2020, building stock in Egypt was estimated to be around 4 billion squared meters out of which 75% were of residential buildings estimated around 3 billion squared meters and the remaining 25% with around 1 billion squared meters were of non-residential buildings.

In 2050, building stock in Egypt is expected to exhibit significant growth with around 2.5 folds increase reaching 10 billion squared meters. Non-residential buildings share is expected to grow higher and reach 2.8 billion squared meter which constitutes a total share of around 28% of the total building stock and the remaining 72% are residential buildings with around 6.2 billion squared meters as demonstrated in **Figure 21**.

A.2 AC and commercial refrigeration stock

The stock of AC systems in Egypt is expected to grow from 7.8 million units in 2020 to approximately 53 million units in 2050. Main driver for this development is a significant growth of the building stock combined with increasing economic wealth.[43] In the period 2020-2040, the stock growth is higher than thereafter (see **Figure 22**), which is due to the fact that the residential market reaches its maximum saturation in 2036.[44] Market growth after this point however still takes place due to new building installations and the growing share of floor area cooled in dwellings that will require additional AC cooling capacities.

[43] El Dallal et al. (2022)

[44] The forecasting air conditioning ownership model according to Mc Neil et al. assumes that air conditioner ownership will approach a climate dependant maximum but never exceed it. Saturation is a function of availability (income) and climate (Cooling Decree days- CDD) (further explanation see definition). For immature markets, the ownership rate is dominated by the dynamics of affordability (income). For mature markets, where ownership levels are near saturation, sales are largely driven by replacements, increasing population (new constructions of buildings), and ownership of multiple appliances.

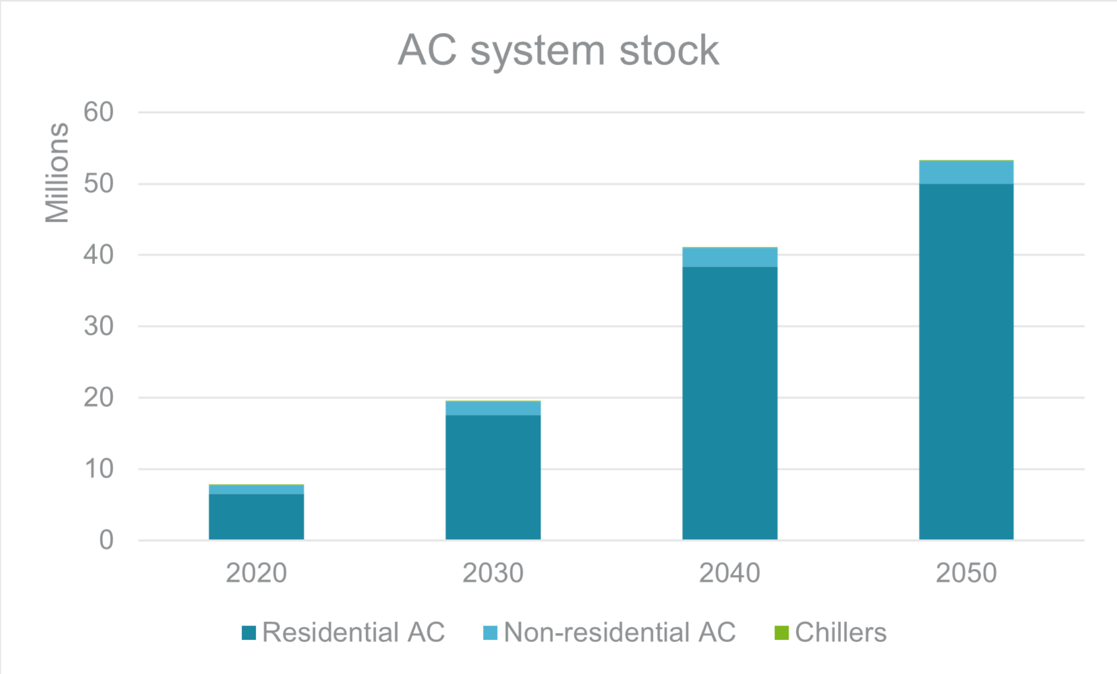


Figure 22 AC stock development 2020-2050 in Egypt

Figure 23 shows the expected development of the commercial refrigeration system stock in Egypt, divided by system type. The stock is expected to grow from approximately 1.1 million systems in 2020 to approximately 1.4 million systems in 2050.[45] The main driver is population increase and new construction of buildings where commercial refrigeration is installed, such as supermarkets.

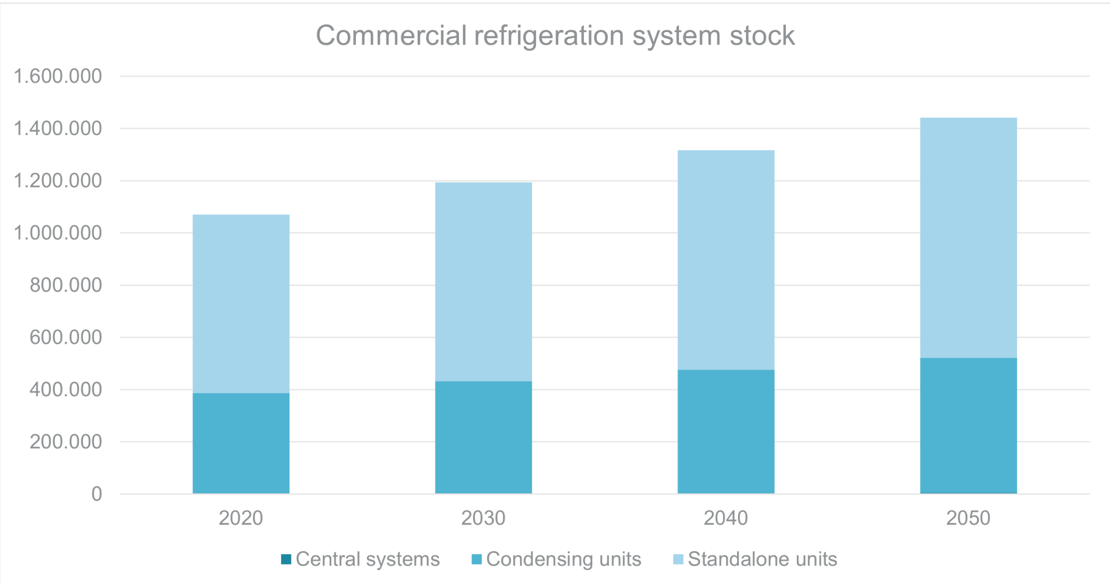


Figure 23 Commercial refrigeration stock development 2020-2050 in Egypt

[45] No national data available for the commercial refrigeration sector and the presented data were based on the global model of the Green Cooling Initiative

A.3 Technical parameters

The following table provides information on the different technical parameters for the considered AC and commercial refrigeration systems throughout the study.

Table 1 Technical parameters for considered AC and commercial refrigeration systems

System	Capacity [kW][46]	Unit energy consumption [UEC][47]	Initial refrigerant charge size [kg][48]	Lifetime [Years][49]
Residential decentral AC	3.4 - 7	-	0.9 - 2	10
Residential central AC	15	-	6.0	10
Non-residential decentral AC	3.4 - 7	-	0.9 - 2	10
Non-residential central AC	78	-	40	10
Chiller	175	-	35	20
Standalone refrigerators & freezers (plug-in)	-	1800	0.4	15
Condensing systems	-	9000	5	20
Central systems	-	175200	200	25

[46] Expert interview 2021

[47] Cool Coalition Model

[48] As simplification an average refrigerant charge size has been assumed, independent from the type of refrigerant. As systems with natural refrigerants or other (ultra)low GWP refrigerants typically have lower charge sizes the overall error by this assumption is small compared to other uncertainties

[49] Expert guess based on local interviews

A.4 Refrigerant mix

The following tables provide information on the current refrigerant mix in the existing stock for the technology groups as well as the new shares development over the decades and for each of the modelled prospects.

Table 2 Refrigerant mix in current technology stock

Current refrigerant mix (in 2020)									
Sector	**Refrigerant mix**								
	R22	R410A	R134a	R407c	R404a	Low GWP fluorinated refrigerants[50]	R290	R718[51]	R717
Existing systems installed in stock[52]									
AC except chillers	70%	30%							
Chillers		20%	70%	10%					
Standalone refrigerators & freezers (plug-in)	80%		20%						
Condensing units and central systems	80%		15%		5%				
New systems (sold in 2020)									
AC except chillers	5%	95%							
Chillers		20%	70%	10%					
Standalone refrigerators & freezers (plug-in)	10%		81%				9%		
Condensing units and central systems	20%		56%		24%				

[50] Low GWP refrigerants with a GWP below 750 (e.g. R32, etc)

[51] Water as refrigerant used in sorption chillers

[52] Expert interviews 2921

Table 3 Future refrigerant mix of new sold systems in 2030 under different prospects

Future refrigerant mix of new sold systems in 2030									
Sector	**Refrigerant mix**								
	R22	R410A	R134a	R407C	R404A	Low GWP fluorinated refrigerants[53]	R290	R718[54]	R717
Current trend prospect									
AC except chillers		50%				50%			
Chillers		20%	70%	5%			5%		
Standalone refrigerators & freezers (plug-in)			80%				20%		
Condensing units and central systems			60%		25%		15%		
Prospect 1									
AC except chillers		45%				25%	30%		
Chillers		17.5%	55%	2.5%			10%	7.5%	7.5%
Standalone refrigerators & freezers (plug-in)			40%				60%		
Condensing units and central systems			45%		17.5%		37.5%		
Prospect 2									
AC except chillers		25%				15%	60%		
Chillers		15%	40%				15%	15%	15%
Standalone refrigerators & freezers (plug-in)							100%		
Condensing units and central systems			30%		10%		60%		

[53] Low GWP refrigerants with a GWP below 750 (e.g. R32, etc)
[54] Water as refrigerant used in sorption chillers

Table 4 Future refrigerant mix of new sold systems in 2040 under different prospects

Future refrigerant mix of new sold systems in 2040									
Sector	**Refrigerant mix**								
	R22	R410A	R134a	R407c	R404a	Low GWP fluorinated refrigerants[55]	R290	R718[56]	R717
Current trend prospect									
AC except chillers		50%				50%			
Chillers		15%	65%	5%			15%		
Standalone refrigerators & freezers (plug-in)			60%				40%		
Condensing units and central systems			50%		20%		30%		
Prospect 1									
AC except chillers		25%				25%	50%		
Chillers		10%	35%	2.5%			22.5%	15%	15%
Standalone refrigerators & freezers (plug-in)			30%				70%		
Condensing units and central systems			35%		10%		55%		
Prospect 2									
AC except chillers							100%		
Chillers		5%	5%				30%	30%	30%
Standalone refrigerators & freezers (plug-in)							100%		
Condensing units and central systems			20%				80%		

[55] Low GWP refrigerants with a GWP below 750 (e.g. R32, etc)

[56] Water as refrigerant used in sorption chillers

Table 5 Future refrigerant mix of new sold systems in 2050 under different prospects

Future refrigerant mix of new sold systems in 2050									
Sector	**Refrigerant mix**								
	R22	R410A	R134a	R407c	R404a	Low GWP refrigerants	R290	R718	R717
Current trend prospect									
AC except chillers		50%				50%			
Chillers		15%	60%	5%			20%		
Standalone refrigerators & freezers (plug-in)			50%				50%		
Condensing units and central systems			45%		15%		40%		
Prospect 1									
AC except chillers		25%				25%	50%		
Chillers		7.5%	30%	2.5%			27.5%	15%	17.5%
Standalone refrigerators & freezers (plug-in)			25%				75%		
Condensing units and central systems			22.5%		7.5%		70%		
Prospect 2									
AC except chillers							100%		
Chillers							35%	30%	35%
Standalone refrigerators & freezers (plug-in)							100%		
Condensing units and central systems							100%		

A.5 Leakage rate

The following table provides information on the assumed leakage rates and their future development per technology group considered throughout this study for each of the modelled prospects.

Table 6 Assumed leakage rates across technology groups and prospects

System	Base year[57]	Current trend prospect			Prospect 1			Prospect 2		
	2020	2030	2040	2050	2030	2040	2050	2030	2040	2050
AC except chillers	8%	8%	7%	6%	8%	6%	5%	7%	3%	2%
Chillers	20%	20%	19%	17%	20%	18%	14%	13.5%	9.2%	3.5%
Central systems	40%	40%	38%	34%	38.4%	34 %	27%	36.8%	29.4%	17%
Condensing units	25%	25%	24%	21.5%	25%	23%	17.5%	25%	20.5%	12%
Standalone	5%	5%	5%	4.5%	5%	4.4%	3.3%	3.7%	2.6%	1.2%

A.6 End of Life refrigerant emissions rates

The following table provides information on the assumed shares of end-of-life emissions and their future development per technology group considered throughout this study for each of the modelled prospects.

Table 7 End of life refrigerant emission rates across technology groups and prospects

System	Base year[58]	Current trend prospect			Prospect 1			Prospect 2		
	2020	2030	2040	2050	2030	2040	2050	2030	2040	2050
AC except chillers	95%	83%	71%	70%	64%	42%	40%	55%	23%	20%
Chiller	95%	83%	71%	70%	57%	42%	40%	48%	23%	20%
Central systems	95%	83%	71%	70%	64%	42%	40%	55%	23%	20%
Condensing systems	95%	83%	71%	70%	64%	42%	40%	55%	23%	20%
Standalone refrigerators & freezers (plug-in)	95%	83%	71%	70%	57%	42%	40%	48%	23%	20%

[57] Expert interviews 2021

[58] Expert interviews 2021

A.7 Systems efficiency

AC systems[59]

The following table provides information on the assumed efficiency levels and their future development per AC system type considered throughout this study for each of the modelled prospects.

Table 8 Assumed efficiency level across sector and prospect

System		Unit	Base year[60]	Current trend prospect			Prospect 1			Prospect 2		
			2020	2021-2030	2031-2040	2041-2050	2021-2030	2031-2040	2041-2050	2021-2030	2031-2040	2041-2050
Residential	Decentral	EER	**3** (2.4-4.2)	4.0	4.5	5.0	4.0	5.3	6.5	4.0	6.5	7.2
	Central	EER	**3**	4.0	4.5	5.0	4.0	4.5	5	4.0	5	5.5
Non-residential	Decentral	EER	**3** (2.4-4.2)	4.0	4.5	5.0	4.0	5.3	6.5	4.0	6.5	7.2
	Central	EER	**3.5** (3.5-4.5)	4.0	4.5	5.0	4.0	4.5	5	4.0	5	5.5
Chillers	Chiller	EER	**3** (2.4-4)	4.0	4.5	5.0	4.0	5.1	6.1	4.0	6.1	6.7

Commercial refrigeration

The following table provides information on the assumed annual efficiency improvement levels for all commercial refrigeration systems considered throughout this study for each of the modelled prospects.

Table 9 Assumed annual efficiency improvement levels for commercial refrigeration technologies across prospects

System	Unit	Current trend prospect	Prospect 1	Prospect 2
Central systems	Annual improvement in %	0.25%	0,50%	1,20%
Condensing systems	Annual improvement in %	0.25%	0,50%	1,00%
Standalone	Annual improvement in %	0.25%	0,50%	1,00%

A.8 Technology price

The following table provides information on the average costs per conventional system for each of the technology group throughout this study.

AC systems prices are based on the findings of Build_ME project and expert interviews.[61] Commercial refrigeration systems prices are based on average costs in the region for the capacities considered throughout the study. [62] A nominal annual technology price increase of 5% was assumed.[63]

The assumption on the future price increase of the technologies is based on the expert's estimation and experience in the Build_ME project.[64]

[59] As simplification an average efficiency pers system has been assumed, independent from the type of refrigerant. Systems with natural refrigerants or other (ultra)low GWP refrigerants nowadays have typically have higher efficiencies than conventional systems with HFCs

[60] Expert interviews 2021

[61] Build_ME. "Towards a Low-Carbon Building Sector in the MENA Region." https://www.buildings-mena.com/.

[62] Expert interviews 2021

[63] Technology price increase is based on the most recent inflation rate in Egypt for 2020 as disclosed by the worldbank. Future developments of inflation rate are not considered in the context of this study. (reference). The real technology prices are assumed to be stable.

[64] Build_ME. "Towards a Low-Carbon Building Sector in the MENA Region." https://www.buildings-mena.com/, expert interviews 2021

Table 10 Technology prices and the assumed price increase

System	Unit price (without installation)	Price increase	
	Standard case	Moderate improvement	High improvement (best available)
Decentral system (split unit, non-inverter)	450- 730 €	15%	30%
Residential AC central system (e.g. multisplit)	3,900 €		
Non-residential AC central system (e.g. packaged unit)	17,700 €		
Chillers	50,000-75,000 €		
Central systems	100,000 €		
Condensing units	7500 €		
Standalone	1400 €		

Table 11 Interest rate

	2022
Interest rate	11.75%
Source	Central Bank of Egypt[65]

A.9 Electricity prices

The following table provides information on the considered electricity price throughout the study.

Table 12 Electricity price and assumed price development

	2020
Electricity price	0.08 €/kWh
Source	Egyptian Standard No. 3795: Energy Efficiency Label Requirements for Air Conditioner

	2020- 2030[66]	2030-2040	2040-2050
Nominal annual price increase[67]	2020-2024: 0% 2025-2030: 5%	5%	5%
Source	Expert guess (taking into account the planned phaseout of electricity subsidies by 2025) in addition to the electricity price increase of more than 200% over the past 10 years		

[65] Central Bank of Egypt latest disclosed discount rate dating 22.05.2022 accessible online at https://www.cbe.org.eg/en/EconomicResearch/Statistics/Pages/DiscountRates.aspx

[66] Price increase assumed starting from 2025 as the current electricity tariff is valid until the end of 2024

[67] This reflects the nominal price increase. The assumed price increase is in line with the assumptions for the general inflation (5%). The real electricity prices are assumed to be stable. This is considered a conservative approach; any further price increase will lead to higher electricity cost saving in the mitigation prospects.

A.10 Emissions factor

The following table provides information on the starting CO_2 emissions factor for electricity generation and the assumed new factor in 2050.

Table 13 Emission factor

	2020	2050
Emission factor	611 $gCO_{2\,eq}$/kWh	333 $gCO_{2\,eq}$/kWh
Source	IDG	Modelling result

The following table provides information on the assumed annual reduction of the emissions factor for electricity generation per decade. The same reduction levels were considered for all the modelled prospects throughout the study.

Table 14 Assumed emission factor development

	2020- 2030	2030-2040	2040-2050
Annual emission factor reduction	2%	2%	2%

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