Cool Up
Upscaling Sustainable Cooling

COOLING SECTOR PROSPECTS STUDY JORDAN:

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

March 2023

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Table of contents

Figures

Tables

Acronyms

AC	Air conditioning
BSRIA	Building Services Research and Information Association
CAPEX	Capital expenditure
CBJ	Central Bank of Jordan
CLASP	Collaborative Labelling and Appliance Standards Program
CO_2	Carbon dioxide
COP	Coefficient of performance
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
$MtCO_{2\,eq}$	Mega ton CO_2 equivalent
MW	Megawatt
NDC	Nationally Determined Contributions
NEEAP	National Energy Efficiency Action Plan
NOU	National Ozone Unit
ODS	Ozone-depleting substance(s)

OPEX	Operating expenditure
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
UEC	Unit energy consumption
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 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 – on average – approximate 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.

Jordan's climate varies between Mediterranean and desert and is generally very arid. Energy consumption and power demand in the country has steadily increased due to economic and population growth. With these increases, Jordan is facing rising energy demand, particularly in the residential sector. Lighting, cooling, and heating represent the largest share of energy consumption in the country, and the residential sector accounts for about half of electricity consumption in Jordan. More than 60% of energy consumed in households is used for heating and cooling[2].

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

[1] British Patrol 2018

[2] Source: Potentials and Barriers of Energy Saving in Jordan's Residential Sector through Thermal Insulation, I. Al Hinti, H. Al-Sallami, JJMIE,2017

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

1.2. 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. The cooling sector prospects report is based on the Cool Up programme Cooling Sector Status[3] and the Regulatory Analysis reports. 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 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 list the various input parameters used throughout the study.

[3] Cooling Sector Status Report Jordan: Analysis of the current market structure, trends, and insights on the refrigeration and air conditioning sector. Accessible online: https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-jordan/

2. Methodology

The first step in developing the cooling sector status report 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.[4]
- 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.[5]
- 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.[6]
- 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.[7]
- 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.
- Moderate to 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 to households and is a function of household income and Climate Maximum is a function of CDD.[8] 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,

[4] CFI Team 2022

[5] United Nations Environment Programme (UNEP) 2019

[6] Definition based on United Nations Environment Programme (UNEP) 2015

[7] Scott 2022; Brightly

[8] McNeil and Letschert 2007

sales are largely driven by replacements, increasing population (new constructions of buildings), and ownership of multiple appliances.[9]

- 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[10]
    - 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 provides 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 (multi-zone).[12]
    - 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. In detail, in VRF systems several outdoor units can support many indoor units (up to 64), 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:

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[9] Ibid.

[10] Industrial sector and transport refrigeration are out of the Cool Up Programme scope

[11] Primary sources for these definitions are:

United Nations Environment Programme (UNEP) Ozone Secretariat 2015c

United Nations Environment Programme (UNEP) Ozone Secretariat 2015d

United Nations Environment Programme (UNEP) Ozone Secretariat 2015e, 2015a

United Nations Environment Programme (UNEP) 2019

[12] CIELO 2019

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

Cool Up 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): Covers the three main types of equipment:[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/hypermarkets 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 also in 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 approach

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 Jordan. The interviews were conducted with a diverse set of experts representing manufacturers; assemblers; wholesalers; architects; mechanical, electrical, plumbing (MEP) consultants; and project developers.

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]

[13] United Nations Environment Programme (UNEP) Ozone Secretariat 2015b

[14] Bawaresh et al. 2022b, Cooling Sector Status Report Jordan: Analysis of the current market structure, trends, and insights on the refrigeration and air conditioning sector. Accessible online: https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-jordan/

[15] National Ozone Unit Lebanon 2021

[16] United Nations Industrial Development Organization (UNIDO) 2018

[17] The Building Services Research & Information Association (BSRIA) 2018

[18] Klinckenberg and Smith 2012
Waide et al. 2014

[19] Regional Center for Renewable Energy and Energy Efficiency (RCREEE) 2019

This data approach had limitations, such as partial lack of systematic approaches for data collection (e.g. data on HFC consumption, data basis for installed technologies, especially in the commercial refrigeration sector), difficulty accessing official data, missing background information to available data, and high ranges of data for the same point between different sources. Due the data situation in the mentioned RAC subsectors, this report acknowledges data gaps and data from different sources that results in discrepancies. To reduce the limitations, the Cool Up programme utilised various approaches such as analysis of different data sources, cross valuation, 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 different grade of uncertainty.

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
- 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
- AC and commercial refrigeration equipment development (stock and sales). See Annex I
- Final energy demand per subsector. See Chapter 4.1
- Indirect and direct emissions per subsector. See Chapter 4.2
- Total Annuity costs per subsector. See Chapter 4.3
- Electricity costs and potential cost savings. See Chapter 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.

[20] Intergovernmental Panel on Climate Change (IPCC) 2007

[21] International Energy Agency (IEA) 2018

[22] Campbell et al. 2018

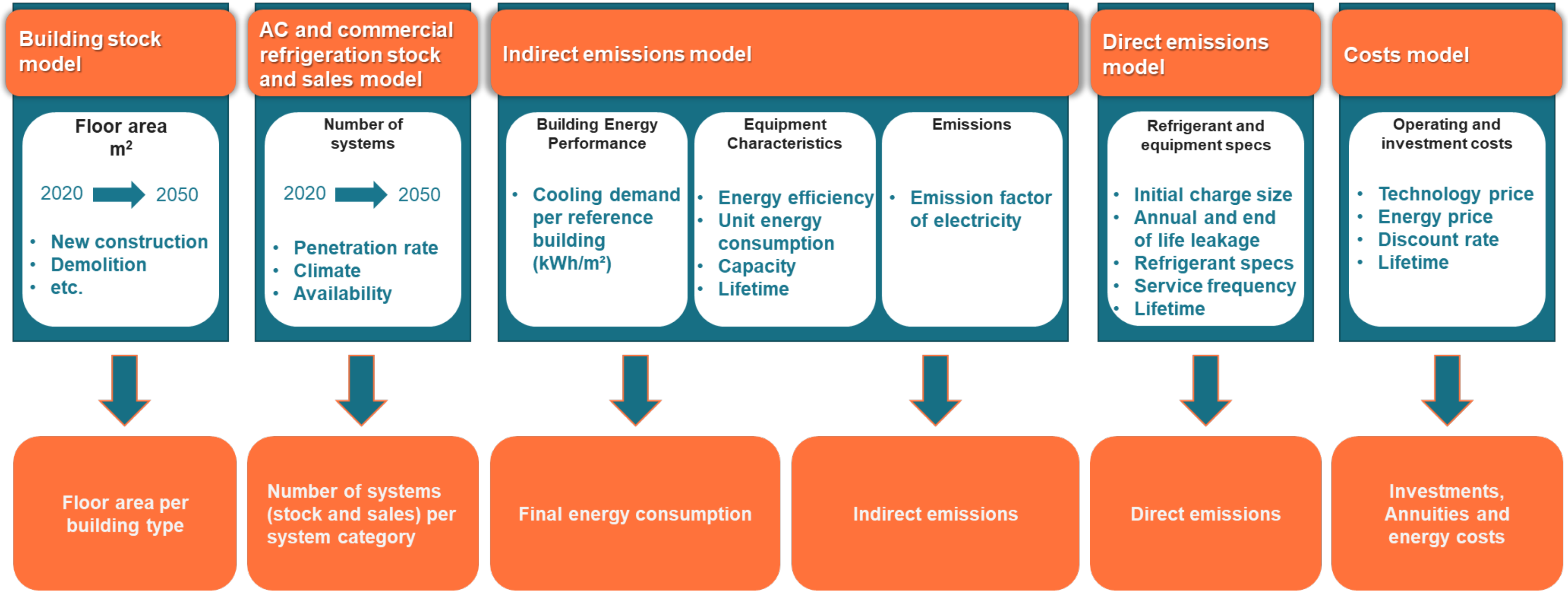
[23] Waide et al. 2014

[24] Green Cooling Initiative 2021. 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 2021

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 factors that influence their development on both aspects based on a country specific situation. 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 usually have a higher probability of owning 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 wealthy households will increase average dwelling size, make greater use of AC usually expressed in more or larger units working for a longer time but also increasing the share of floor area in the dwellings really cooled.
- 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 from 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 capacity, efficiencies, and refrigerant charge size ranges). According to the structure of the vintage 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
  - Central systems

[26] McNeil and Letschert 2007
[27] International Energy Agency (IEA) 2018
[28] McNeil and Letschert 2007

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 I.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 I.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 to compare 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 annuities 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 I.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 chapter 2.1). Annuities are estimated based on the sum of annual technology installations, technology price, interest rate, and annual technology price increase. (See Annex I.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 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 Jordan 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 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 scenario and the mitigation scenarios shows the potential impact of additional measures such as use of natural refrigerants, more ambitious efficiency (RAC and building performance) due to improved codes and standards related 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 the abatement potential, including refrigerant transition, decarbonization of power generation and further efficiency improvement in industry and buildings.

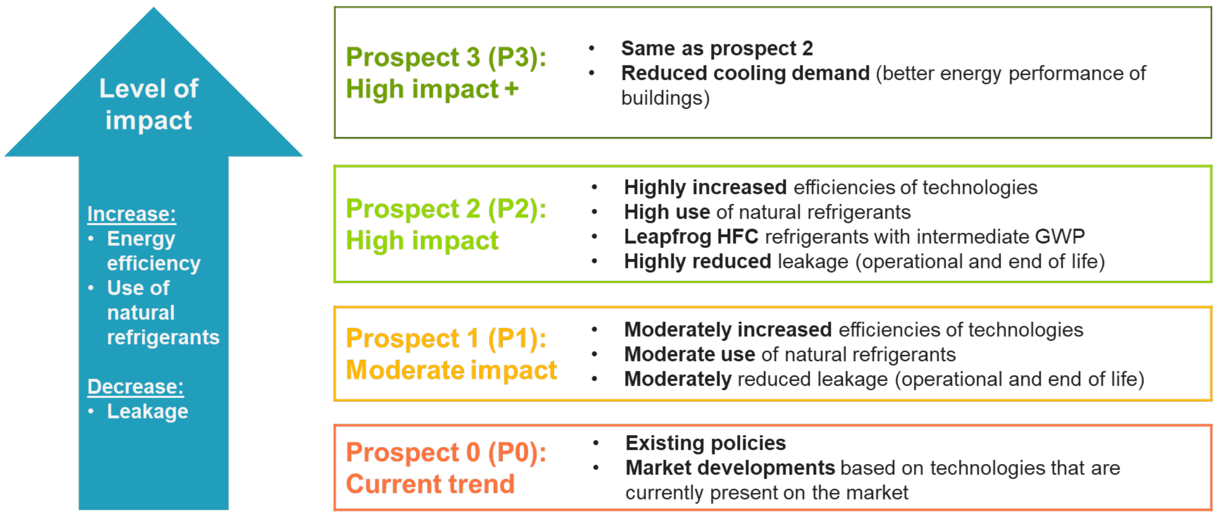


Figure 2 Cool Up programme prospects and mitigation actions

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

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 be more than 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.

3.2. Prospect (P0): Current trend

The current trend prospect (P0) considers existing implemented policies such as programs, laws, and other policy instruments such as codes and standards that are in force at the time of the study (June 2022), based on the regulatory analysis [29]. Jordan 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. At the level of the standards and Minimum Energy Performance Standards (MEPS), the standards on cooling appliances and systems are well implemented, monitored, and enforced. MEPS and labelling of AC systems are mandatory. In contrast, MEPS for commercial refrigeration systems are absent.

The current trend prospect considers these policy instruments (related to ODS phase out (R22) and standards and MEPs related to efficiency of AC systems.

Currently no Jordanian 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 and 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 reaching an average system efficiency in 2050 in the order of magnitude of best available national technology today is assumed
- **Refrigerant transition**: Taking current market trends into account, the following is assumed:
  - Air-conditioning: Air-conditioning: Main refrigerants used and existing in the stock include R410A, R134a (in chillers) followed byR404A and still R22[30]. It is assumed that R410A is being phased down and replaced by lower GWP refrigerants (i.e. R32) which is evident from the market trend for VRF system and split units which shifting towards low GWP refrigerants. Taking the current industry trends into account, it is assumed that the share fluorinated intermediate GWP refrigerants will reach around 45% in 2050 for AC systems along with a minor share of 10% of natural refrigerants.
  - Commercial refrigeration: Commercial refrigeration: R404A is still the dominant refrigerant in commercial refrigeration systems followed by smaller shares of R134a. It is assumed that without any regulatory effect R404A will continue to be used and its share will decrease slowly up to 2050. Apart from R404A, R134a and R290 are being introduced to the market further[31]. In the current trend prospect, it is assumed that natural refrigerants shares will increase from 5% for standalone systems to 50% in 2050 respectively. (Shares mainly gained from R404A).
- **Leakage rate**: It is assumed that the RAC operational system's leakage rate slightly decreases overtime per technology up until 2050 (See **Table 7**).
- **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 8**).
- **Energy efficiency of buildings**: building envelope parameters and in specific the thermal transmittance (U-value) of the building surfaces (Walls, roof, floor and window) were taken from the Build_ME[32] project baseline values of the existing and new build standards of Multi Family

[29] Bawaresh et al. 2022a

[30] Expert Interviews 2021

[31] Expert Interviews 2021

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

Houses, Single Family Houses and Office buildings, as shown in Table 8. An enhancement of the building envelope of 10% (tighter U-value requirements) is assumed per decade until 2050.

Table 1 Baseline U- and G-values for existing, improved existing and new build for residential and non-residential buildings in Jordan

		Existing buildings			**Improved existing***			**New build**		
Parameter		Residential		Non-residential	Residential		Non-residential	Residential		Non-residential
		MFH	**SFH**	**Office**	**MFH**	**SFH**	**Office**	**MFH**	**SFH**	**Office**
U value	*Wall*	3.0	1.8	3.0	1.8	1.2	1.8	0.6	0.6	0.5
	Roof	2.0	1.5	2.0	1.3	1	1.3	0.6	0.6	0.5
	Floor	4.0	2.5	4.0	2.6	1.8	2.5	1.2	1.1	1.1
	Window	5.7	5.7	5.7	5.7	4.4	4.4	5.7	3.0	3.0
G value	*Window*	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.7

* Improved existing is taken as an average of old existing buildings (before 1990) and new build buildings (after 2010)

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 chapter), 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 Jordan MEPS are mandatory for residential AC systems. In general MEPS should reflect the progress made in energy efficiency of equipment placed on the market and MEPS 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 classes' 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 efficiency of international best available national technology today. E.g. for residential room air conditioners (decentral systems), in 2050 the efficiency is assumed to be around 30% higher than the assume efficiency in P0 in 2050. (See **Table 9**).

- **Refrigerant transition**
  - **Typical measures addressing refrigerant transition** are provisions that prohibit the placing on the market of high GWP refrigerant 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), R744 (CO2) are assumed to play an increasingly prominent role compared to P0. However, due to the absence of provisions that prohibit the placing on the market of high GWP refrigerants, potent greenhouse gases such as R410A or R404A can still be used in 2050 under this scenario. (see **Table 6**). 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 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[33]. Note: Increase in running costs are not taken into consideration throughout this study, see Section **2.4.6** for detailed costs description.

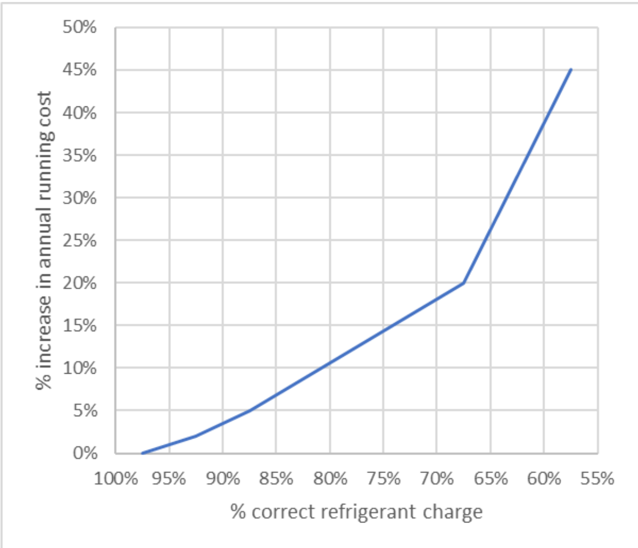


Figure 3 Relationship between Annual running costs and refrigerant leakage for small air-conditioning and commercial systems[34].

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

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

- **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 7**).

- **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 8**).

- **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 from 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 [IPPC AR4]).
    - 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 [IPPC AR4]). 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 7**).
- **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 8**).[35]
- **Energy efficiency of buildings**
  - P2 applies the same assumptions as P0

3.5. Prospect 3: 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 a significant enhancement of 30% of the building envelope parameters (tighter U-value requirements) compared to P2, P1 and P0. Other parameters are all equal to P2.

[35] Although their share is negligible in 2050

4. Results

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

- **Electricity demand** provides results on the development of energy demand up to 2050 resulting from AC and commercial refrigeration sectors.
- **GHG emissions** provides results of the corresponding direct and indirect emissions up to 2050 from 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 Jordan is projected to grow by fivefold from 706 thousand units in 2020 to approximately 3.5 million units in 2050. The stock of commercial refrigeration systems is expected to grow from approximately 95 thousand systems in 2020 to approximately 128 thousand systems in 2050. For details, see Appendix I.1 and I.2.

4.1. Electricity demand

4.1.1. Current trend prospect

This chapter 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 3.5-fold increase, reaching 3.6 TWh by 2050 from 1 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 2039.

The P0 trend expects electricity demand resulting from commercial refrigeration activities to exhibit a steady growth from 0.47 TWh in 2020 to 0.6 TWh in 2050, exhibiting 22% 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.

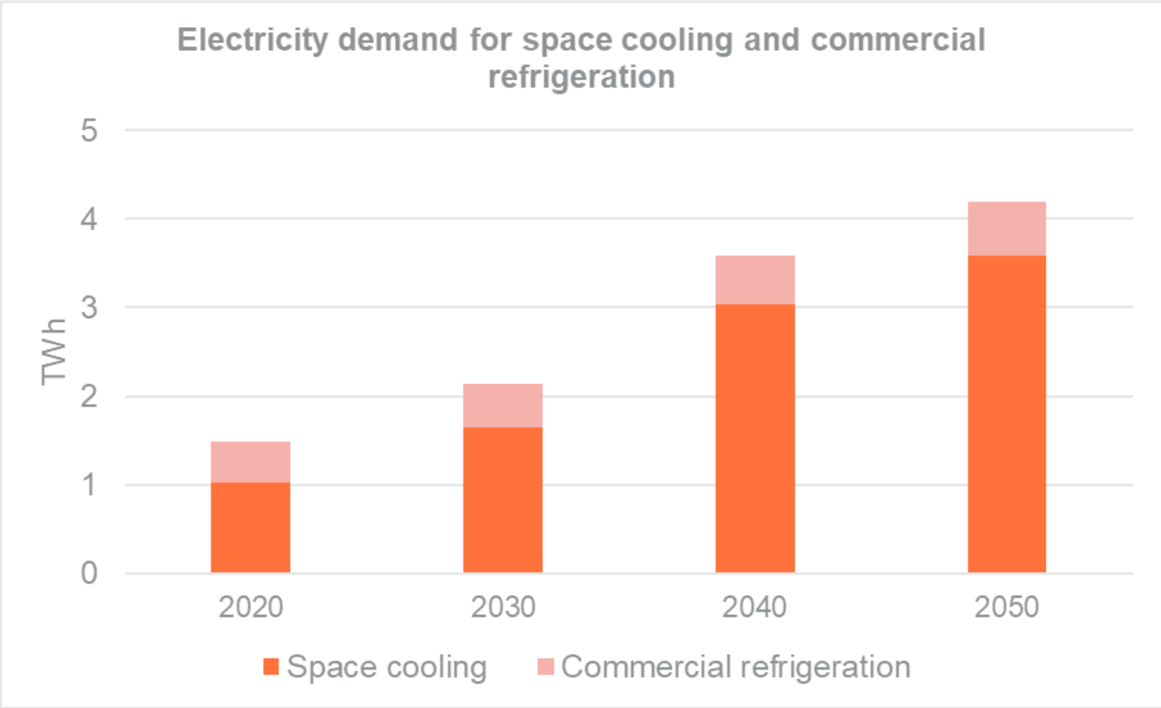


Figure 4 Current trend prospect - Electricity demand for space cooling and for commercial refrigeration 2020 - 2050

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

4.1.2. Mitigation prospects

This chapter 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 P 1 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 20% 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]

P1: Electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades from 1 TWh up to 2.8 TWh, meaning demand is expected to almost triple by 2050 compared to the starting year in 2020 and in 2050 savings of 23% are expected compared to P0.

P2: Electricity demand for space cooling (AC systems) is expected to increase rapidly over the next decades from 1 TWh up to 2.2 TWh, meaning demand is expected to more than double by 2050 compared to the starting year in 2020. In 2050 savings of around 38% and 15% 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.

[36] Bawaresh et al. 2022b, Cooling Sector Status Report Jordan: Analysis of the current market structure, trends, and insights on the refrigeration and air conditioning sector. Accessible online: https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-jordan/

[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.

P3: Electricity demand for space cooling (AC systems) is expected to increase over the next decades from 1 TWh up to 1.9 TWh, meaning demand is expected to almost double by 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 46% are predicted and 8% 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.

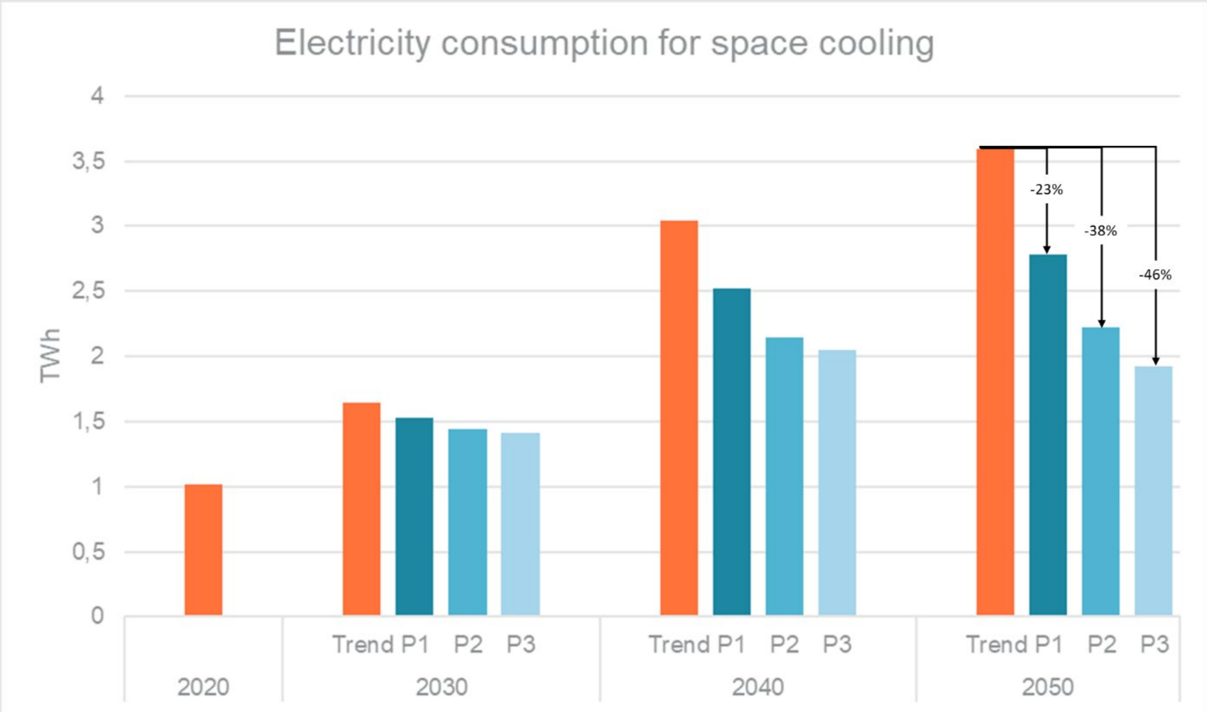


Figure 5 Mitigation prospects - Electricity consumption for space cooling 2020 - 2050

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 0.47 TWh up to 0.56 TWh, i.e. the demand is expected to increase by about 20% 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 keep relatively stable with 0.47 TWh in 2050. Compared to P0, in 2050 expected savings are 21% compared to P0, respective 13% compared to P1.

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 shows even a stable electricity demand compared to base conditions in 2020 despite the expected growth in cooling demand, showing the potential achievement by different policy measures.

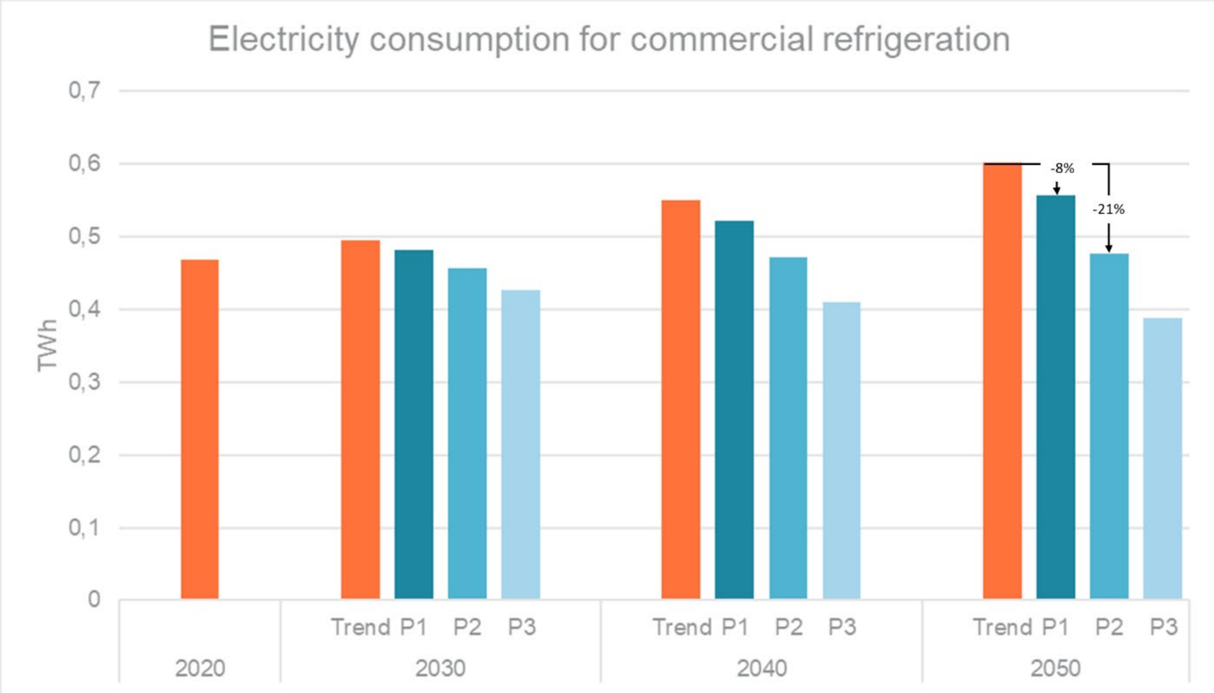


Figure 6 Mitigation prospects - Electricity consumption for commercial refrigeration 2020 – 2050

4.2. Indirect and direct greenhouse gas emissions

4.2.1. Current trend prospect

This chapter 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 1.3 $MtCO_{2\,eq}$ of which slightly more than 52% (0.68 $MtCO_{2\,eq}$) account for indirect and 48% (0.62 $MtCO_{2\,eq}$) account for direct emissions. In the AC sector the total emissions account for 0.8 $MtCO_{2\,eq}$ of which 58% account for indirect and 42% for direct emissions. In the commercial refrigeration sector, the total emissions account for 0.5 $MtCO_{2\,eq}$, of which 43% account for indirect and 57% for direct emissions. This signifies that the indirect emissions constitute the larger share of emissions for the AC sector unlike the commercial refrigeration sector where direct emissions are responsible for the larger emissions share. 1.

In 2050, the total emissions (both AC and commercial refrigeration sector) are expected to increase by a factor of about 1.25 and reach 1.61 $MtCO_{2\,eq}$., even with the considered decarbonization of the electricity grids. Of these, indirect emissions account for 48% and direct emissions for 52%, indicating that the share of direct emissions are expected to increase (from 48 to 52%) compared to 2020.

In 2050 the total emissions of the AC sector are expected to increase by a factor of 1.6 to reach 1.31 $MtCO_{2\,eq}$. The total emissions in the commercial refrigeration sector are expected to drop until 2050 to reach around 0.3 $MtCO_{2\,eq}$. Compared to 2020 the share of the AC sector emissions of the total emissions of the considered sectors increases from 61% to more than 81%. 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 42% to 50% and in the commercial refrigeration sector from 57% to 63%.

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 $CO_{2\,eq}$ 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.

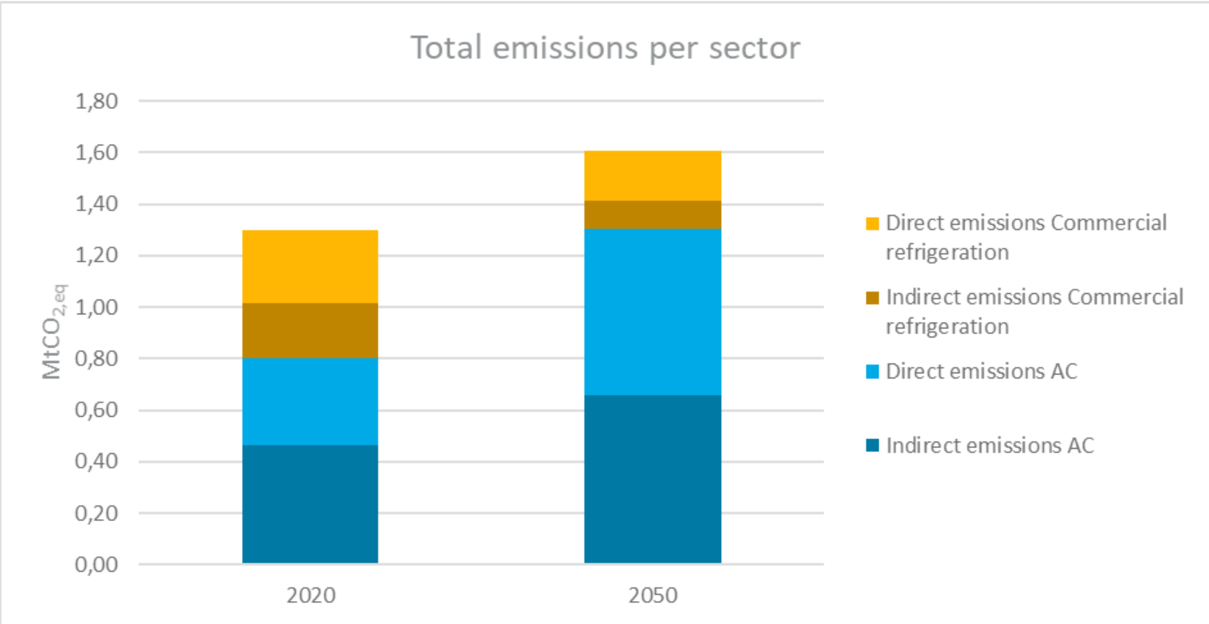


Figure 7 Overview of the total indirect and direct emissions, of the total emissions in AC and in commercial refrigeration sector and of direct and indirect emissions disaggregated by the AC and commercial refrigeration sector

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 65% of the emissions of the considered sectors and groups in 2050. The non-residential AC sector is expected to be responsible for about 16% of the emissions of the technology groups.

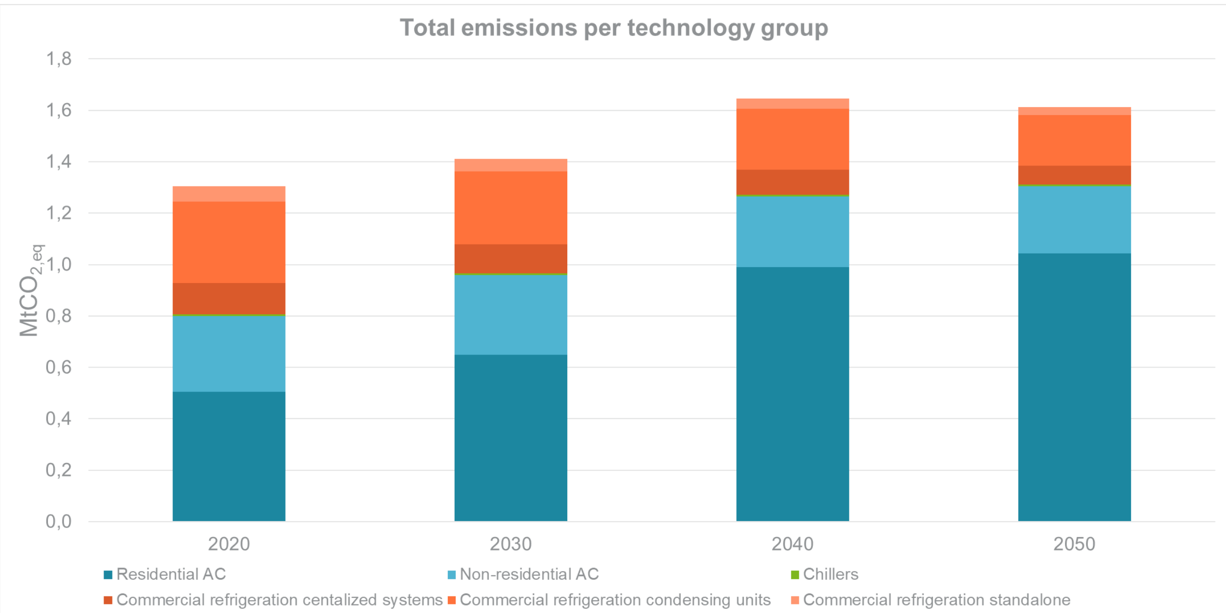


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Figure 8 Current emissions trend disaggregated by technology groups 2020 - 2050

Direct emissions in the building segments and by technology groups

Direct emissions resulting from AC (incl. chillers) and commercial refrigeration sector were around 0.62 $MtCO_{2\ eq}$ in 2020. AC and chillers are responsible for more than 54% of the direct emissions of the technology groups.

By 2050, direct emissions of the technology groups are expected to increase by around 26% and reach around 0.84 $MtCO_{2\ eq}$. AC and chillers, with 0.65 $MtCO_{2\ eq}$ constitute more than 77% of the total direct emissions, indicating that the relative importance of the AC system for direct emissions in Jordan 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 0.17 $MtCO_{2\ eq}$ in 2020 to 0.47 $MtCO_{2\ eq}$ in 2050. The results are illustrated in **Figure 9**.

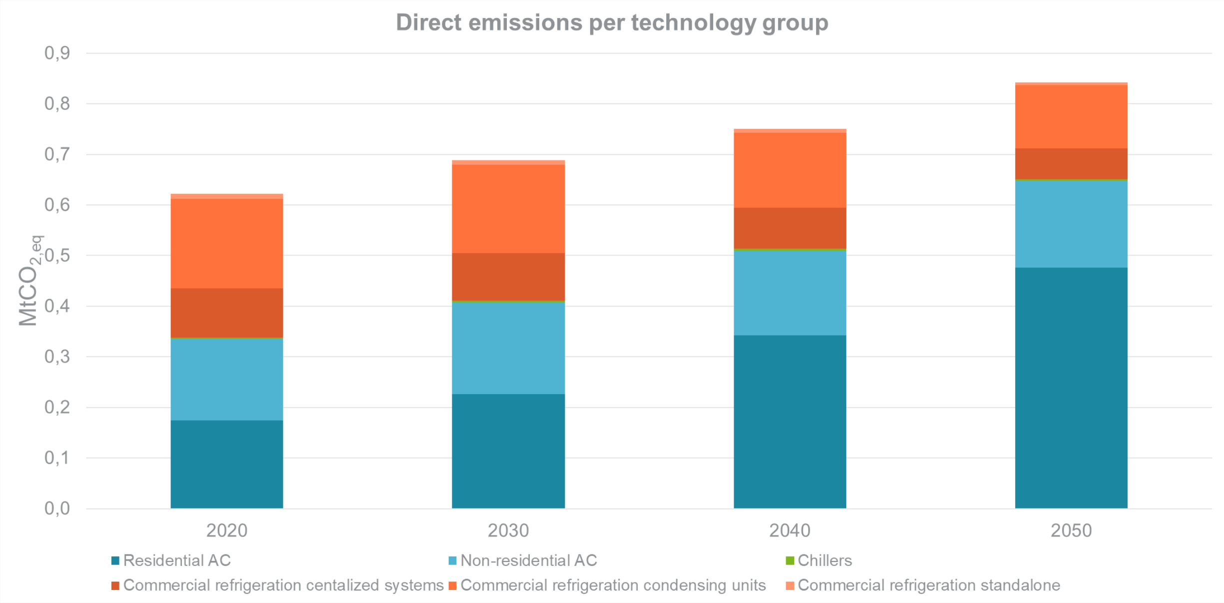


Figure 9 Current direct emissions trend disaggregated by technology groups 2020 - 2050

Indirect emissions in the building segments and by technology groups

Indirect emissions resulting from AC and commercial refrigeration sector accounted for slightly less than 0.7 $MtCO_{2\ eq}$ in 2020. At 0.47 $MtCO_{2\ eq}$ AC and chillers are responsible for around 70% of the indirect emissions of the technology groups.

By 2040, indirect emissions of the technology groups are expected to increase by a factor of 1.3 and reach 0.9 $MtCO_{2\ eq}$. Between 2040 and 2050 the emissions slightly decrease by 0.13 $MtCO_{2\ eq.}$ AC and chillers with 0.66 $MtCO_{2\ eq}$ constitute more than 86% of these indirect emissions, indicating that the relative importance of the AC system for indirect emissions in Jordan is increasing over time. The highest growth can be observed in the residential AC sector, where emissions almost double from 0.33 to 0.57 $MtCO_{2\ eq.}$ The results are illustrated in **Figure 10**.

The decrease between 2040 and 2050 is the sum of effects of the projected improvements of the $CO_{2\ eq}$ 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 around 2040.

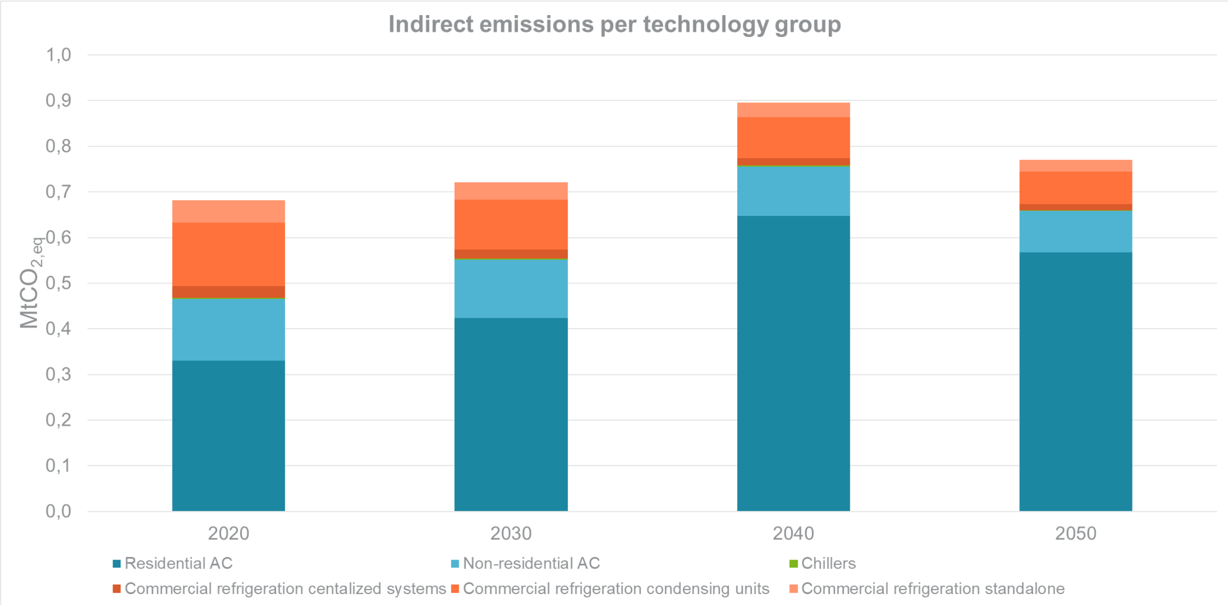


Figure 10 Current indirect emissions trend disaggregated by technology groups 2020 - 2050

4.2.2. Mitigation prospects

This chapter 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 chapter 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 subchapter 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 subchapters 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 growth (P1), decrease (P2) and strongly decrease (P3) between 2020 and 2050. In 2050, compared to the P0 all mitigation prospects (P1, P2, P3) show significant savings, ranging from 45% to 73%.

P1: Total emissions are expected to increase from 1.3 to 1.61 $MtCO_{2\ eq}$, meaning the total emissions are expected to increase by a factor 1.25 in 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 45% are expected.

P2: The total emissions in 2050 are expected to decrease from 1.3 to 0.9 $MtCO_{2\ eq}$, i.e. approximately 30% reduction in 2050 compared to the starting year in 2020. Compared to P 0, in 2050 savings of 69% are expected respective 24% compared to P1.

P3: the total emissions in 2050 are expected to decrease from 1.3 to 0.4 $MtCO_{2\ eq}$, i.e. a reduction of about 70% compared to 2020. Compared to P0, in 2050 savings of 73% are predicted, respective 4% 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.

Between 2030 and 2040 the emissions are starting to decrease slightly and accelerate decreasing between 2040 and 2050. 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).

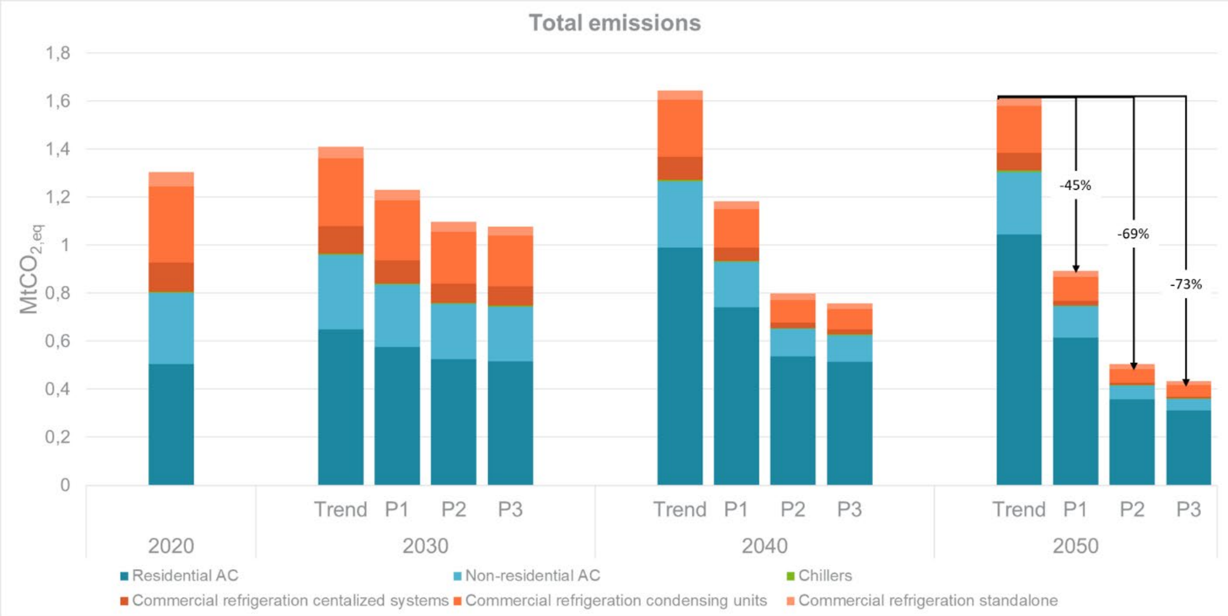


Figure 11 Total emissions development per prospect 2020 – 2050

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

This subchapter 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 decrease already by more than 67% in P1 in 2050 compared to starting year 2020. In P2 significant savings are expected in 2050 compared to 2020. Compared to P0, in 2050 all mitigation prospects (P1, P2, P3) show significant savings, ranging from 67% to 99%, The savings potentials start to become evident already in 2030 and increases significantly throughout 2040. The significant reductions are mostly driven by the switch to natural refrigerants.

P1: Direct emissions are expected to start decreasing from 0.62 $MtCO_{2\ eq}$ in 2020 to 0.28 $MtCO_{2\ eq}$ in 2050. Between. The main reason for the reductions 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: Direct emissions are expected to start decreasing from 0.62 $MtCO_{2\ eq}$ in 2020 to 0.008 $MtCO_{2\ eq}$ in 2050. The reductions are almost negligible in comparison to the starting point in 2020, mainly because of the use of natural refrigerants. In 2050 savings of around 99% and 32% are expected compared to P0 and P1 respectively.

P3: Direct emissions are expected to start decreasing from 0.62 $MtCO_{2\ eq}$ in 2020 to 0.007 $MtCO_{2\ eq}$ in 2050. The reductions are almost negligible in comparison to the starting point in 2020, mainly because of the use of natural refrigerants. In 2050 savings of around 99.2%, 31.8% and 0.2% 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 6**). 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.

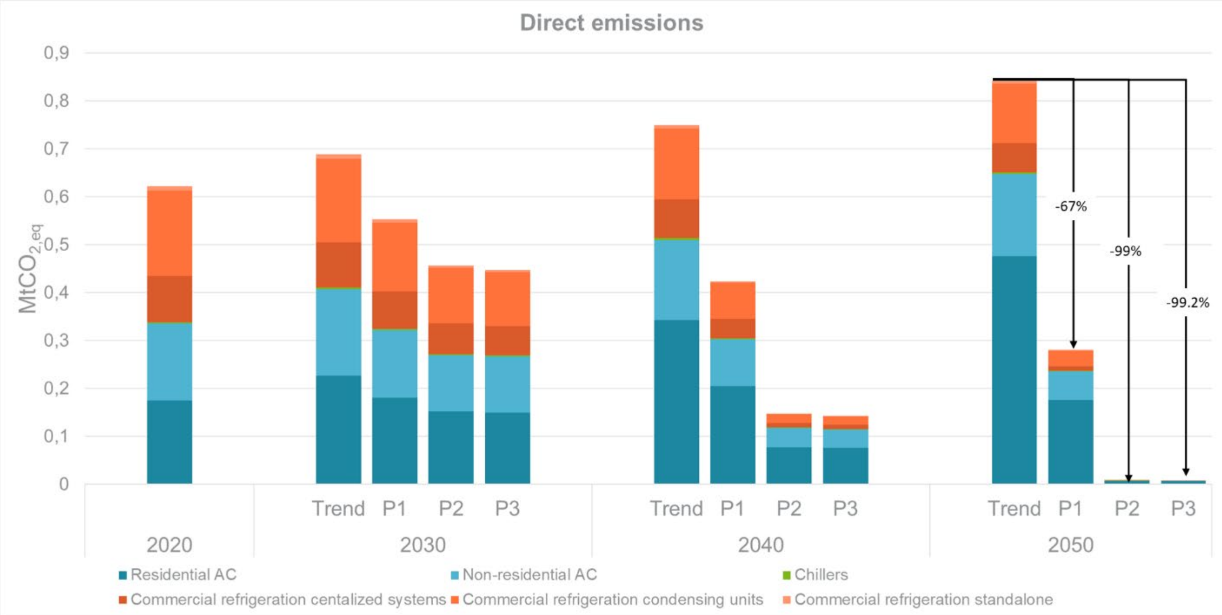


Figure 12 Direct emissions development per prospect 2020 - 2050

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

This subchapter 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 are expected to be higher compared to the starting year in 2020 in P0 but lower in all mitigation prospects. Compared to the direct emissions savings the indirect emissions savings are significantly less which will increase the relative importance of indirect emissions in the future. 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 enough to counterbalance the upward trend in indirect emissions from 2020 to 2050 driven by the 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 Annex I) it is expected that indirect emissions will also exhibit a reduction in their share in the overall emissions of the considered sectors in the future with the exception of P1 which will exhibit an increase until 2040 before reversing the trend and exhibiting further reduction. 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 20% to 45% (see **Figure 13**).

Overall the reduction exhibited in the emissions reduction by all prospects is due to a slower market growth and a further increase in efficiency of the technologies.

P1: The indirect emissions decrease from 0.68 $MtCO_{2\ eq}$ to 0.61 Mt $CO_{2\ eq}$, i.e. increase of around 13% between 2020 and 2050. The indirect emissions peak around 2040 and then start decreasing slightly. The main reason for the increase in the next decades is the high market growth. Compared to P0, in 2050 savings of 20% are expected.

P2: The indirect emissions decrease from 0.69 Mt $CO_{2\ eq}$ to 0.5 Mt $CO_{2\ eq}$ between 2020 and 2050, meaning a decrease by 28%. Compared to P0, in 2050 savings of 36% respective of 16% compared to P1 are expected. 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.

P3: The indirect emissions decrease from 0.69 $MtCO_{2\ eq}$ to 0.4 $MtCO_{2\ eq}$ between 2020 and 2050, i. e. decrease by more than 40%. Between 2040 and 2050 the indirect emissions start decreasing more rapidly than in P2.

In 2050, savings of around 45% and 9% are expected compared to P0 and P2. The additional savings compared to P2 is the consequence of additional improvements of the building envelope between 2020 and 2050.

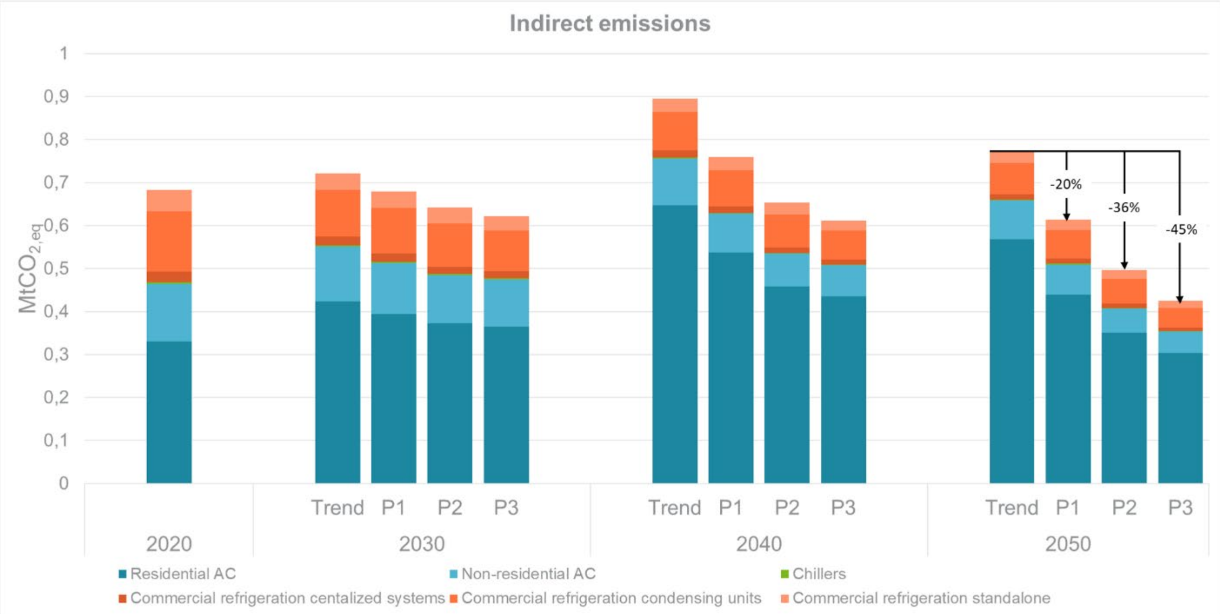


Figure 13 Indirect emissions development per prospect 2020 – 2050

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 the chapter the investments have been broken down using yearly payments (annuities), considering lifetime, technology price increase and discount rate (see chapter 2.4.6).

This chapter 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).

Electricity costs

Under P0, electricity costs for space cooling and commercial refrigeration are expected to increase rapidly over the next decades, exhibiting a 10-fold increase, reaching EUR 2.1 billion by 2050 (**Figure 14**). This significant increase is directly correlated with the increase in electricity consumption for space cooling and commercial refrigeration (see chapter 4.1.1.) and the assumed annual electricity price increase after 2023.

[38] Including an annual inflation of 3 %

Residential AC share of the total costs paid for electricity is expected to increase from almost 45% in 2020, estimated around EUR 94 million, to around 71% by 2050 estimated around EUR 1.5 billion. On the other hand, non-residential AC are also growing steadily, however their shares are slowing down from 21% in 2020 to 13% 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 70 million in 2020 to around EUR 335 million in 2050, however their total shares also slowing down from 33% in 2020 to around 16% in 2050.

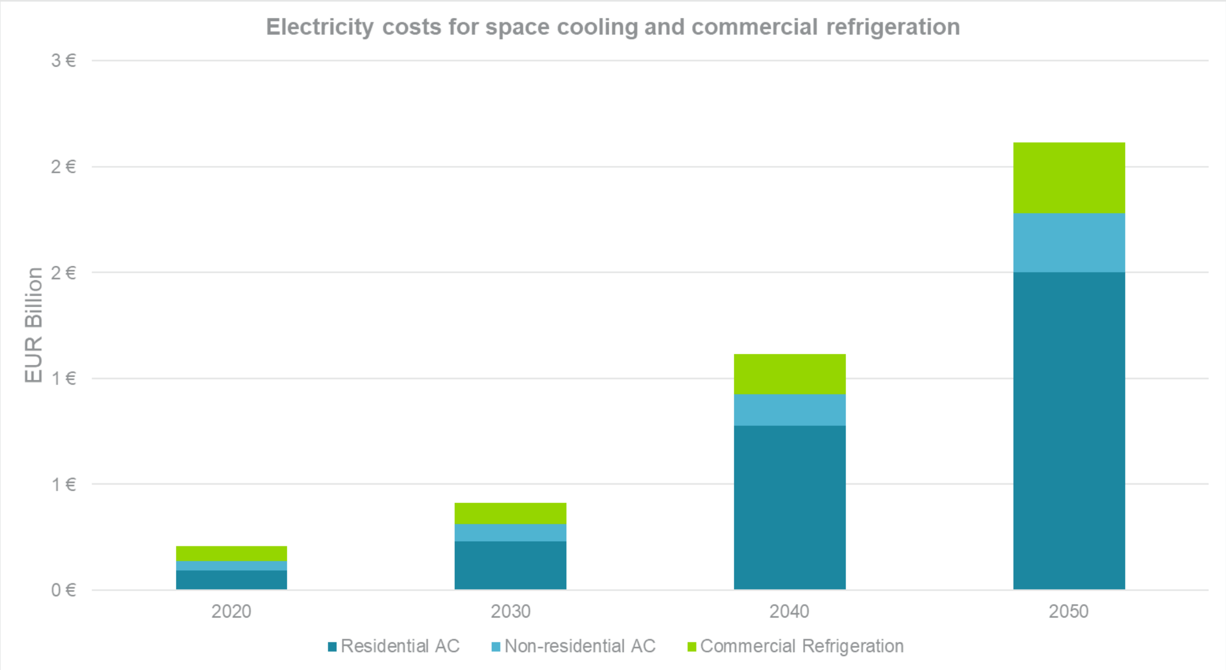
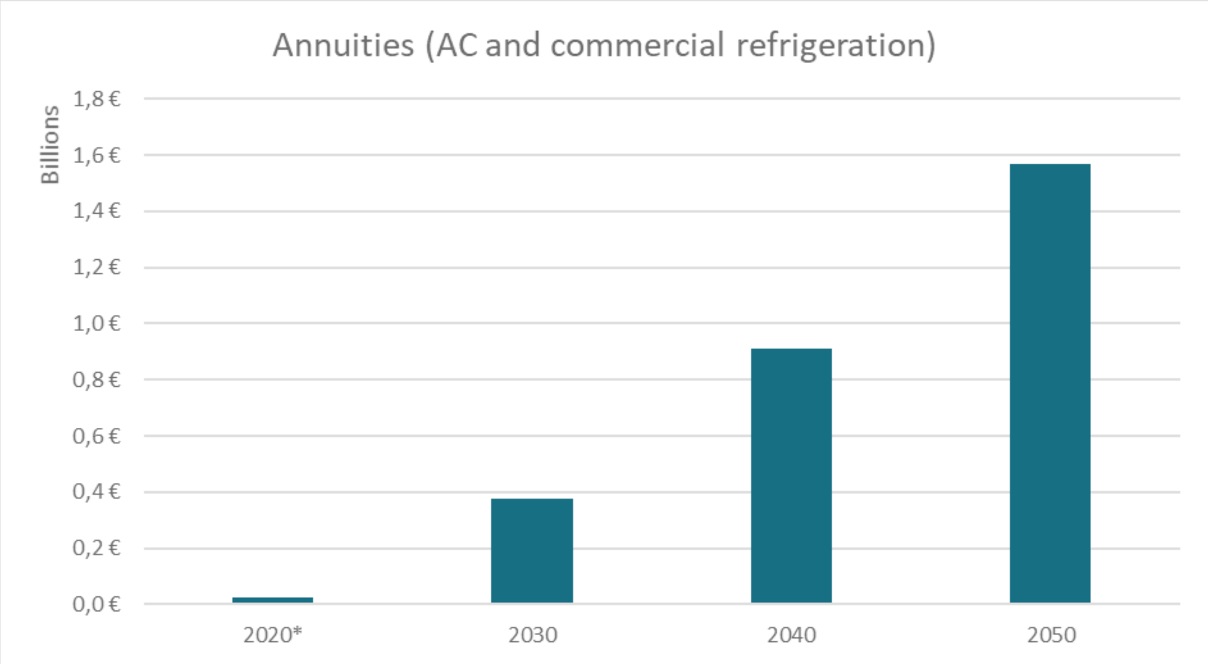


Figure 14 Current trend - Energy costs for space cooling and commercial refrigeration 2020 - 2050

Annuities for investments

As a result of the large growth of cooling demand and the associated significant increase in AC and to less extend 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 chapter 2.4.6).

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 1.57 billion in 2050 as demonstrated in **Figure 16**.



* 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 57% in 2050. Total costs resulting from air conditioning and refrigeration sectors are expected to go up to EUR 3.7 billion in 2050 signalling a significant increase from 2020 as shown in **Figure 16**.

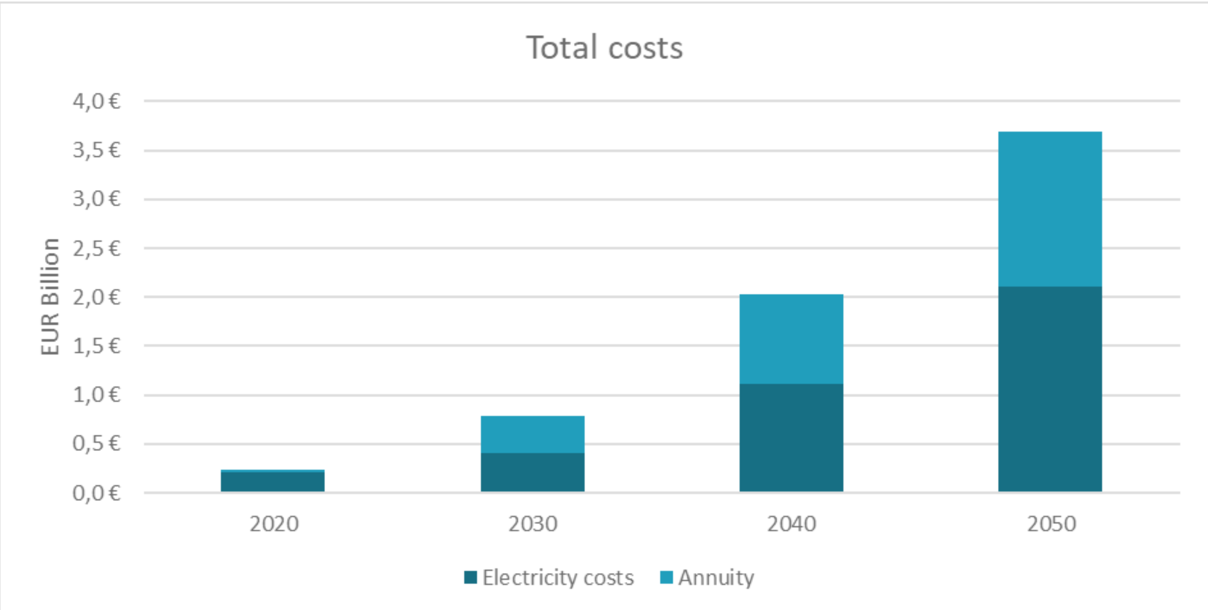


Figure 16 Current trend prospect – Total yearly costs development 2020 – 2050

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 chapter 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 (chapter 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 close up 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 10, in P1 approximately 8, in P2 slightly higher than 6.5. and in P3 slightly more than 5.5. In 2050, compared to the P0 all mitigation prospects (P1, P2, P3) show significant savings, ranging from 20% to 45%.

P1: Electricity costs are expected to increase from EUR 208 million to EUR 1.7 billion meaning the total electricity costs are expected to increase by a factor of around 8 in 2050 compared to the starting year in 2020. Compared to P0, in 2050 savings of 20% are expected.

P2: Electricity costs are expected to increase from EUR 208 million to EUR 1.37 billion meaning the total electricity costs are expected to increase by a factor of slightly higher than 6.5 in 2050 compared to the starting year in 2020. In 2050 savings of 35% and 15% are expected compared to P0 and P1 respectively.

P3: Electricity costs are expected to increase from EUR 208 million to EUR 1.17 billion meaning the total electricity costs are expected to increase by a factor of slightly more than 5.5 in 2050 compared to the starting year in 2020. In 2050 savings of 45% and 10% are expected compared to P0 and P2 respectively.

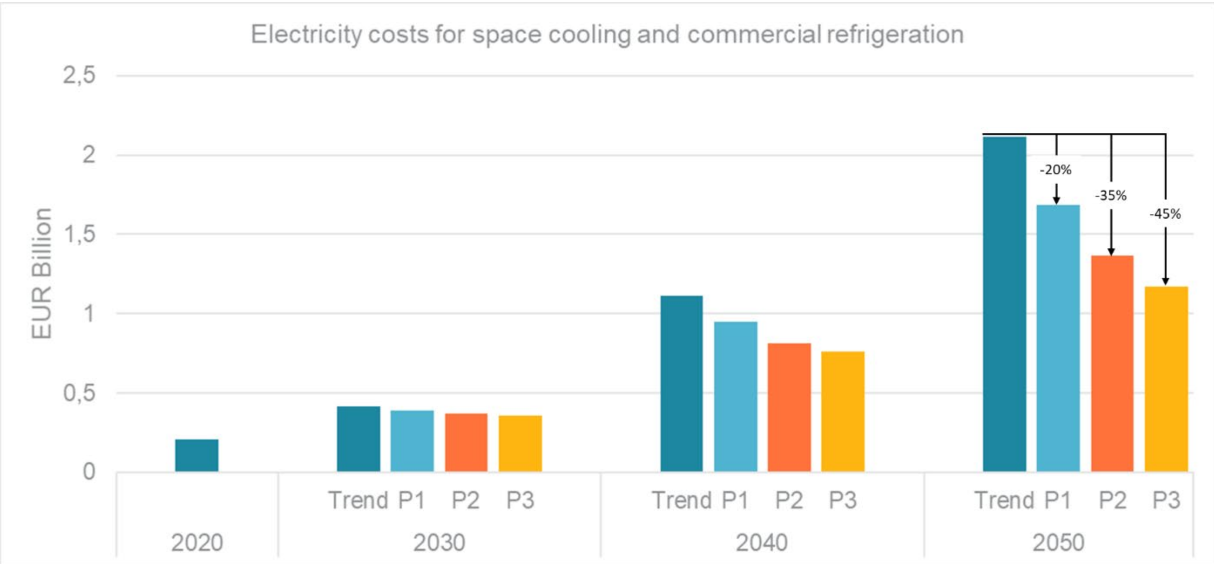


Figure 17 Mitigation prospects - Electricity costs development 2020 – 2050

The following **Figure 18** provides a close up 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 EUR 426 million to around EUR 746 million 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 19**) to keep the total cost on the same level through all mitigation prospects.

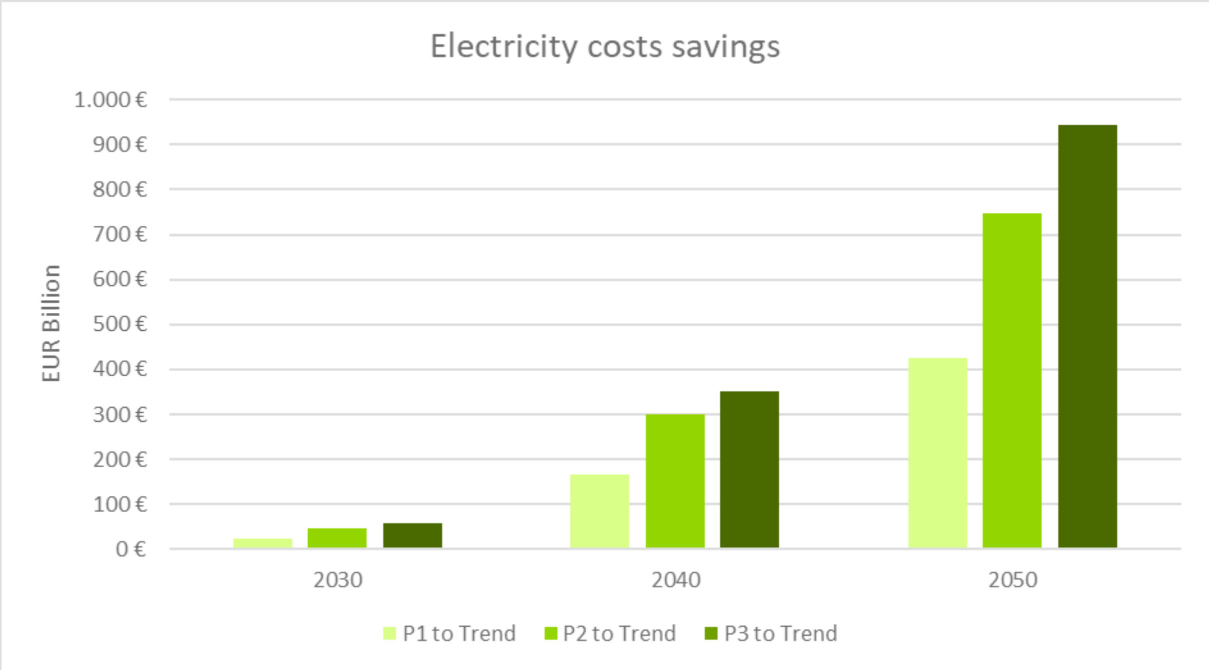


Figure 18 Annual electricity costs savings 2030 – 2050

Total cost of savings

The CAPEX (annuities) of implementing the mitigation prospects (P1 and P2) adds up to 1.7, respective 2 billion EUR in 2050. Compared to current trend prospect P0, this corresponds to additional annuities of 205 million EUR or 12% in P1 respective of 437 million EUR or 22% in P2 in 2050 (assumptions on additional costs for improved technologies, see annex I).

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.

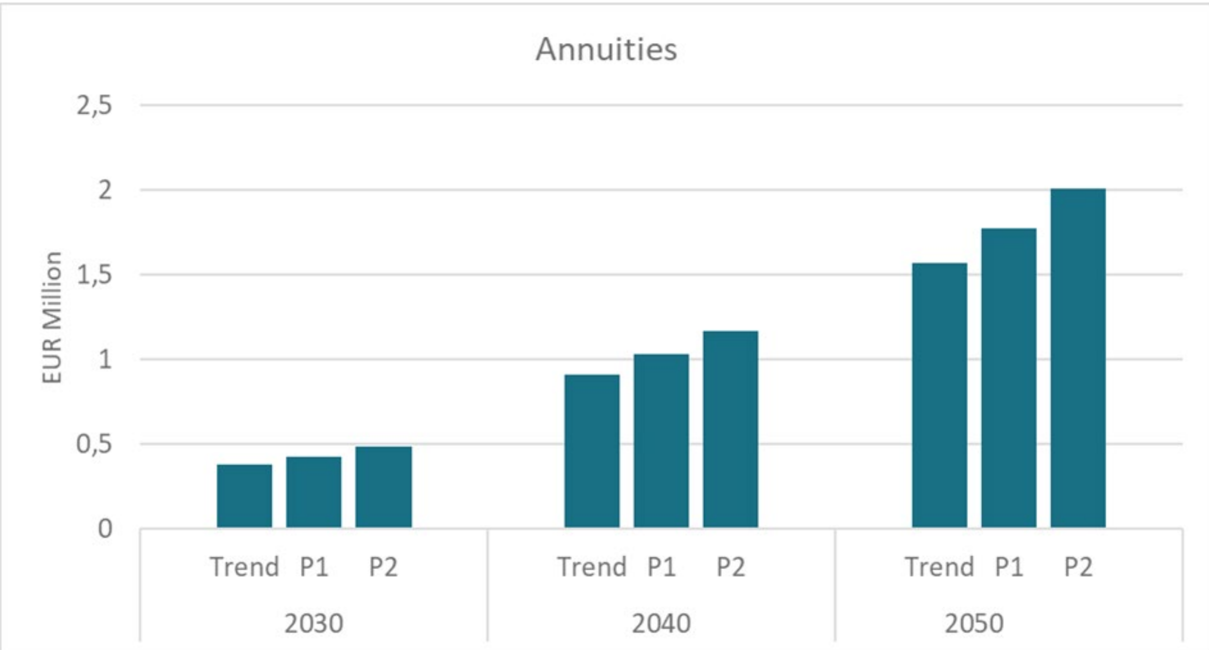


Figure 19 Mitigation prospects - Annuity for investments development 2020 - 2050

As outlined in the previous section, the electricity cost savings in the mitigation prospects sum up to EUR 426 million in P1, respective to EUR 746 million in P2 compared to P0 in 2050.

The total cost of the mitigation prospect is 6% lower in P1 and 8% lower in P2 than the total cost of the current trend prospect in 2050.

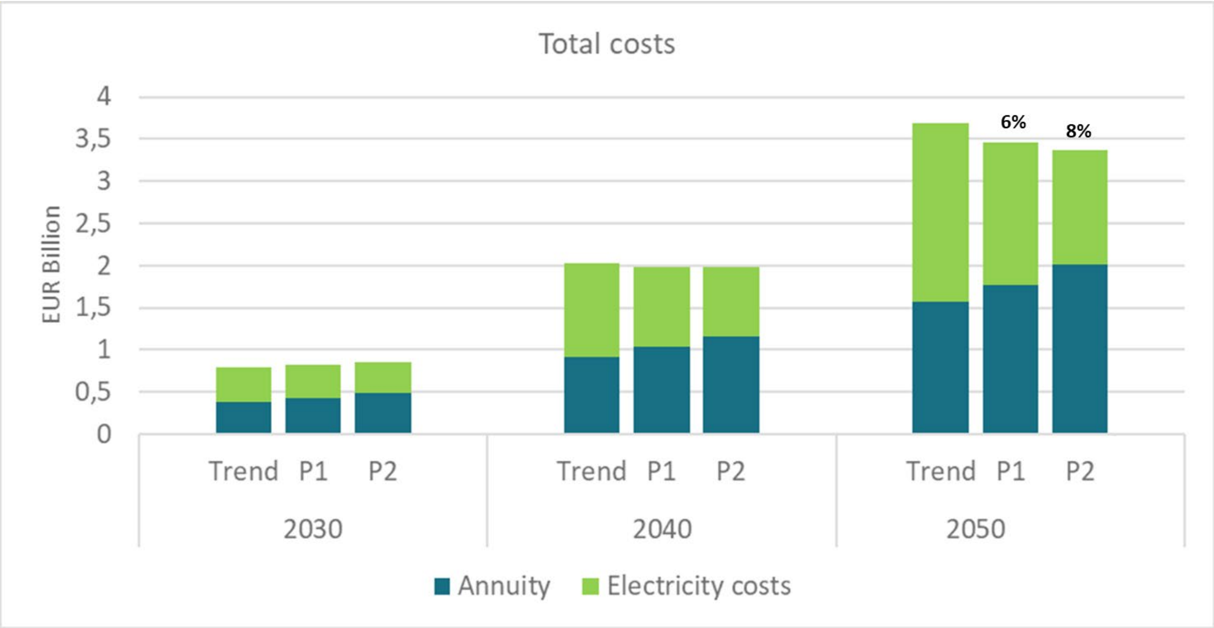


Figure 20 Mitigation prospects - Total yearly costs development 2020 – 2050

5. Summary of key findings

This study analyses several prospects of the development of the RAC sector in Jordan. 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 Jordanian market

- *The RAC market in Jordan is currently growing fast and has large market potential, the residential AC sector is expected to growth with a factor of 4.5 until 2050.*
- *The expected market growth leads to a strong increase in refrigerant and in electricity demand under current conditions.*
- *It is expected that in the current trend prospect (P0) the total emissions increase with a factor of about 1.2 and the electricity demand increase with a factor of 3.5 until 2050 compared to 2020.*
- *The expected increase in electricity demand would require significant additional generation capacity.*
- *Direct emissions a significant share of about 50 % in the overall emissions*[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 conditioned floor area. This translates directly to a large market potential for the AC sector in Jordan. 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 4.5 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 3.5-fold from 1 to 3.6 TWh by 2050.
- Indirect emissions are projected to increase until 2050 from 0.68 $MtCO_{2\ eq}$ to 0.77 $MtCO_{2\ eq}$.
- Direct emissions are expected to significantly increase by a factor of 1.4 until 2050 from 0.62 $MtCO_{2\ eq}$ to 0.84 $MtCO_{2\ eq}$.

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 Jordan which makes it vulnerable to global availability and price changes.
- Compliance with climate targets as well as future Kigali targets could be difficult as Jordan'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

- *All modelled prospects result in a reverse of 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 a significant emission saving in 2050 at 73%.*
- *To achieve high savings, a combination of ambitious measures and strong enforcement is needed.*

Moderate, ambitious and high ambitious prospects -P1, P2 and P3- all result in significant emissions savings of 45%, 69% and 73% by 2050, respectively. Such savings result in the reversing of the upward trend of emissions as opposed to the current trend prospect, which highlight the importance of further ambitious measures.

The high impact prospect illustrates that high savings are possible by implementing a set of high ambitious measures. In specific 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 directly influences systems efficiency
- Enhancement of building envelopes in newly built buildings and renovation of existing ones as well as the adoption of passive cooling measures

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

Regarding the improvement of leakage, certain measures covering periodic leak checks on systems and equipment containing F-gases appears critical to limit 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
- It is expected that in 2050, significant additional generation capacity is needed. Depending on prospect the increase is about 2-3-fold compared to 2020.
- Significant electricity savings are expected in the mitigation prospects by 2050 compared to P0

[40] Environmental Investigation Agency 2017, 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

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 23-46% 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 into 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 emissions savings as early as possible and avoid long-term lock in effects
  - To avoid lock in effects of equipment with HFC refrigerants (e.g. R 410A, R 134a) and support to achieve 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 to / increase lock-in effects.

An early market transformation has two positive effects. Regarding direct emissions, an early implementation of natural refrigerant colling 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[41].

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[42]. 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.[43]

In case of a full grid decarbonization[44] prospects P2 and P3 would enable Jordan to get climate neutral by 2050.

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[41] A quantification of corresponding savings were out of the scope of this study

[42] Cooling Post

[43] 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)

[44] CO_2 factor of grid electricity 0 g/kg 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 5.5-10 between 2020 and 2050.
- In 2050, 20% to 45% electricity costs savings are expected in the mitigation prospects P1 and P2 compared to the current trend prospect P0.
- 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 in all prospects with a factor between 5.5 and 10. That is dependent on prospect.

Comparing the prospects in 2050, significant electricity costs savings can be achieved in the mitigation prospects by 2050. More than EUR 426 million, EUR 746 million and EUR 943 million 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 based on the degree of increase in electricity price over the coming decades according to the current trend of increasing 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 1.7 billion, respective EUR 2 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 CAPEX (annuities) 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 costs 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.

Final remarks

The results and conclusions of this study strongly depend on the input data. Despite the lack of available data, 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 Annex I), to enable the reader to judge the effects of potential derivation of different input parameters.

Annex I: Input parameters

I.1 Building stock development

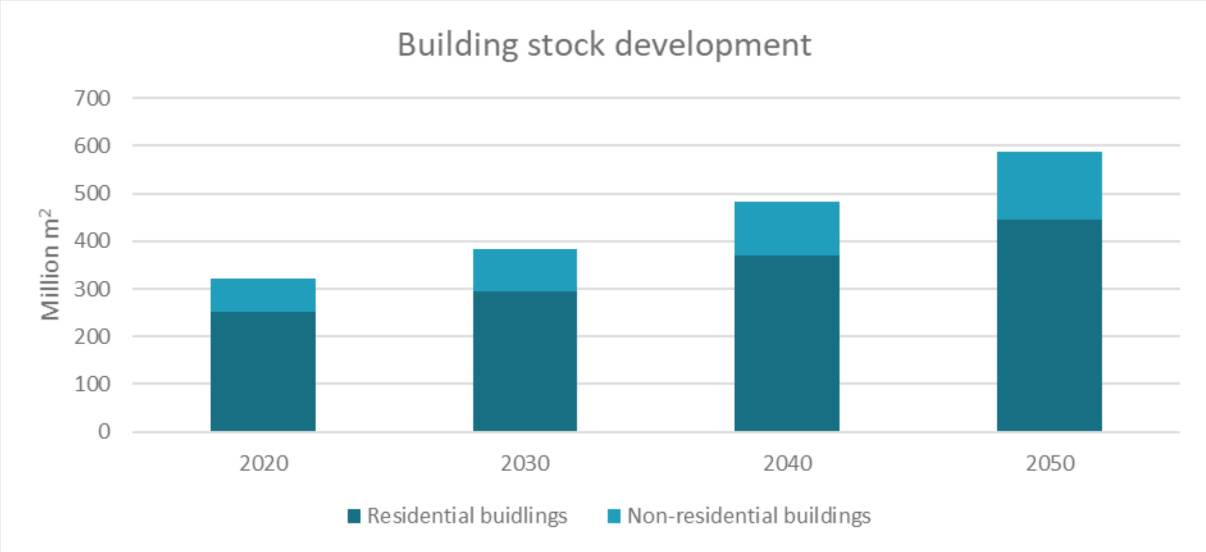


Figure 21 Building stock development 2020 - 2050

In 2020, building stock in Jordan was estimated to be around 320 million m^2 out of which 78% were of residential buildings estimated around 252 million m^2 and the remaining 22% with around 69 million m^2 were of non-residential buildings.

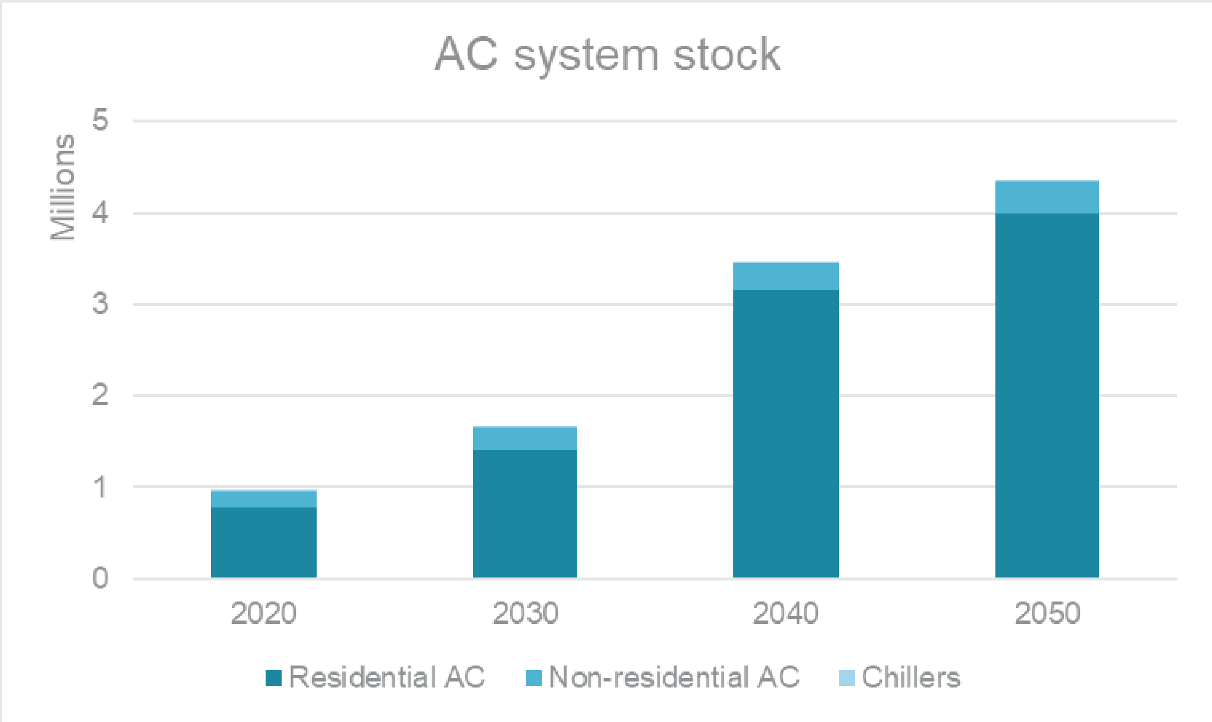
In 2050, building stock in Jordan is expected to exhibit significant growth with around 1.8 folds increase reaching around 590 million m^2. Non-residential buildings share is expected to grow higher and reach around 143 million squared meter which constitutes a total share of around 24% of the total building stock and the remaining 76% share are for residential buildings with around 445 m^2 meters as demonstrated in **Figure 21**.

I.2 AC and commercial refrigeration stock

The stock of AC systems in Jordan is expected to grow from roughly 1 million units in 2020 to approximately 4.5 million units in 2050. Main driver for this development is a significant growth of the building stock combined with increasing economic wealth[45]. 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 2039[46]. Market growth after this point however still takes place due to new building installations and still growing share of floor area cooled in dwellings that still will require additional AC cooling capacities.

[45] Bawaresh et al. 2022b, Cooling Sector Status Report Jordan: Analysis of the current market structure, trends, and insights on the refrigeration and air conditioning sector. Accessible online: https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-jordan/

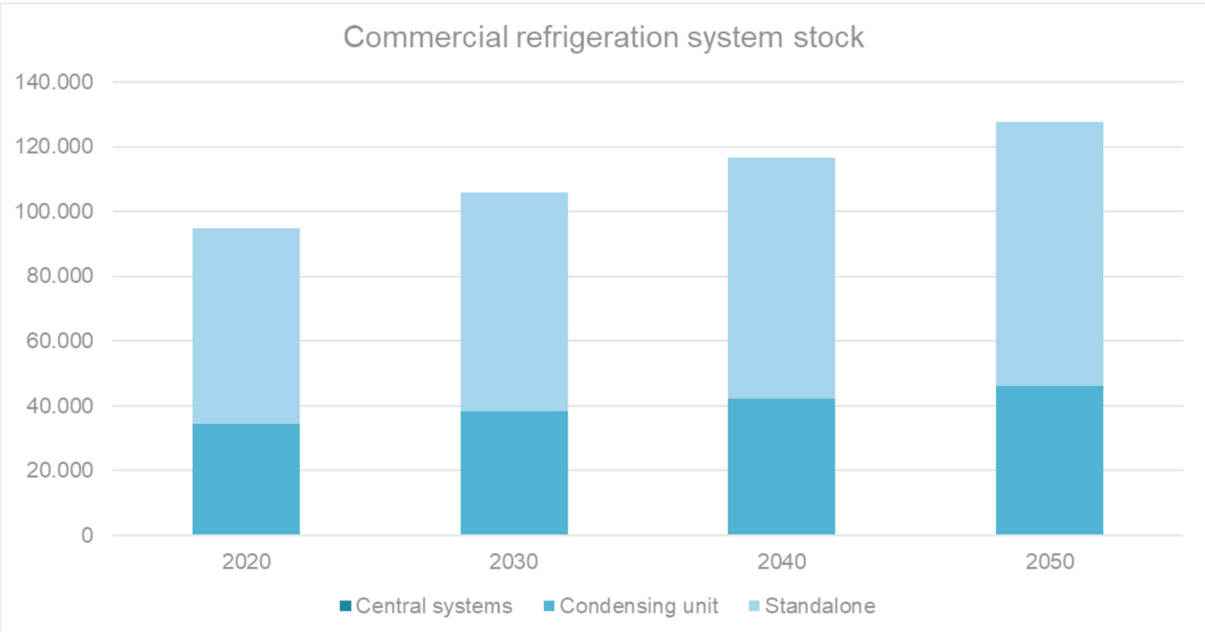
[46]The saturation model according to Mc Neil et al. assumes that air conditioner ownership will approach a climate dependant maximum but never exceed it. Saturation is a function of availability (income) and climate (Cooling Decree days- CDD) (further explanation see definition). For immature markets, 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.



* Chillers numbers are insignificant in comparison to AC and commercial refrigeration stock, however the stock doubles by 2050

Figure 22 AC stock development 2020-2050 in Jordan

Figure 23 shows the expected development of the commercial refrigeration system stock in Jordan, split by system type. The stock is expected to grow from approximately 95 thousand systems in 2020 to approximately 128 thousand systems in 2050[47]. The main driver is population increase and new construction of buildings where commercial refrigeration is installed, such as supermarkets.



* Central systems numbers are insignificant in comparison to standalone and condensing units stock, however the stock increases by a factor of 1.35 by 2050

Figure 23 Commercial refrigeration stock development 2020-2050 in Jordan

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

I.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 2 Technical parameters for considered AC and commercial refrigeration systems

System	Capacity [kW][48]	Unit energy consumption [UEC][49]	Initial refrigerant charge size [kg][50]	Lifetime [Years][51]
Residential decentral AC	3-7	-	0.9 - 2	10
Residential central AC	15	-	6.0	10
Non-residential decentral AC	3-7	-	0.9 - 2	10
Non-residential central AC	78	-	40	10
Chiller	175	-	35	15-20
Standalone refrigerators & freezers (plug-in)	-	1800	0.4	15
Condensing systems	-	9000	5	20
Central systems	-	175200	200	25

* Unit energy consumption is the amount of electricity that an electric utility customer use and is typically measured in kilowatthours (kWh)

I.4 Refrigerant mix

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

Table 3 Refrigerant mix in current technology stock

Current refrigerant mix (in 2020)							
Sector	**Refrigerant mix**						
	R22	R410A	R134a	R407c	R404a	Mid-Low GWP fluorinated refrigerants[52]	Natural refrigerants
Existing systems installed in stock[53]							
AC except chillers	30%	60%		10%			

[48] Expert Interviews 2021

[49] Cool Coalition Model

[50] 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

[51] Expert Interviews 2021

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

[53] Expert Interviews 2021

Current refrigerant mix (in 2020)							
Chillers			80%		20%		
Standalone refrigerators & freezers (plug-in)			20%		80%		
Condensing units and central systems			20%		80%		
New systems (sold in 2020)							
AC except chillers		85%				15%	
Chillers		20%	80%				
Standalone refrigerators & freezers (plug-in)			75%		20%		5%
Condensing units and central systems			80%		20%		

Table 4 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	HFC's (R410A, R134a, R407C, R404A, etc.)	Mid-Low GWP fluorinated refrigerants [54]	Natural refrigerants
Current trend prospect				
AC except chillers		55%	40%	5%
Chillers		95%		5%
Standalone refrigerators & freezers (plug-in)		80%		20%
Condensing units and central systems		80%		20%
Prospect 1				
AC except chillers		55%	25%	20%
Chillers		75%		25%
Standalone refrigerators & freezers (plug-in)		40%		60%
Condensing units and central systems		60%		40%

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

Future refrigerant mix of new sold systems in 2030				
Prospect 2				
AC except chillers		55%	10%	35%
Chillers		55%		45%
Standalone refrigerators & freezers (plug-in)				100%
Condensing units and central systems		40%		60%

Table 5 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	HFC's (R410A, R134a, R407C, R404A, etc.)	Mid-Low GWP fluorinated refrigerants [55]	Natural refrigerants
Current trend prospect				
AC except chillers		45%	45%	10%
Chillers		85%		15%
Standalone refrigerators & freezers (plug-in)		60%		40%
Condensing units and central systems		70%		30%
Prospect 1				
AC except chillers		45%		55%
Chillers		47%		53%
Standalone refrigerators & freezers (plug-in)		30%		70%
Condensing units and central systems		50%		50%
Prospect 2				
AC except chillers				100%
Chillers		10%		90%

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

Standalone refrigerators & freezers (plug-in)				100%
Condensing units and central systems		30%		70%

Table 6 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	HFC's (R410A, R134a, R407C, R404A, etc.)	Mid-Low GWP refrigerants	Natural refrigerants
Current trend prospect				
AC except chillers		45%	45%	10%
Chillers		80%		20%
Standalone refrigerators & freezers (plug-in)		50%		50%
Condensing units and central systems		60%		40%
Prospect 1				
AC except chillers		22%	23%	55%
Chillers		40%		60%
Standalone refrigerators & freezers (plug-in)		25%		75%
Condensing units and central systems		30%		70%
Prospect 2				
AC except chillers				100%
Chillers				100%
Standalone refrigerators & freezers (plug-in)				100%
Condensing units and central systems				100%

I.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 7 Assumed leakage rates across technology groups and prospects

System	Base year[56]	Current trend prospect			Prospect 1			Prospect 2		
	2020	2030	2040	2050	2030	2040	2050	2030	2040	2050
AC except chillers	8%	8%	7%	6%	7%	6%	5%	6%	3%	2%
Chillers	8%	8%	7.5%	6.5%	7.5%	6.8%	5.5%	7%	5.5%	3%
Central systems	40%	40%	38%	34%	38.4%	34.2%	27%	36.8%	29.4%	17%
Condensing units	25%	25%	24%	21.5%	24%	21.5%	17%	22.5%	18.3%	11%
Standalone	5%	5%	5%	4.5%	5%	4.3%	3.3%	4.3%	3.4%	2.3%

I.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 8 End of life refrigerant emission 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	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%

I.7 Systems efficiency

AC systems[58]

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.

[56] Expert Interviews 2021

[57] Expert Interviews 2021

[58] 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

Table 9 Assumed efficiency level across sector and prospect

System		Unit	Base year[59]	Current trend prospect			Prospect 1			Prospect 2		
			2020	2030	2040	2050	2030	2040	2050	2030	2040	2050
Residential	Decentral	EER	**3** (2.5-4.5)	3	3.8	4.5	4	5.3	6.5	4	5.5	6
	Central	EER	**3.5** (3.0-5.0)	3.7	3.8	4	4	4.5	5	4	5	5.5
Non-residential	Decentral	EER	3 (2.5-4.5)	3	3.8	4.5	4	5.3	6.5	4	5.5	6
	Central	EER	**3** (2.5-4.0)	3.7	3.8	4	4	4.5	5	4	5	5.5
Chillers	Chiller	EER	**3.5** (3.0-5.0)	3.5	3.8	4	4	5.1	6.1	4	5.2	5.7

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 10 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%	0,60%	1,20%
Condensing systems	Annual improvement in %	0,25%	0,50%	1,00%
Standalone	Annual improvement in %	0,25%	0,50%	1,00%

I.8 Technology prices

The following table provides information on the average prices 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[60]. Commercial refrigeration systems prices are based on average costs in the region for the capacities considered throughout the study[61]. A nominal annual technology price increase of 3% was assumed.[62]
The assumption on the future price increase of the technologies is based on the expert's estimation and experience in the Build_ME project.[63]

[59] Expert Interviews 2021

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

[61] Expert Interviews 2021

[62] Technology price increase is based on average inflation rate in Jordan for the past 20 years as disclosed by the worldbank. Future developments of inflation rate are not considered in the context of this study. The real technology prices are assumed to be stable.

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

Table 11 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)	EUR 450- 730	15%	30%
Residential AC central system (e.g. multisplit)	EUR 3,900 - 4,745		
Non-residential AC central system (e.g. packaged unit)	EUR 17,700 – 20,708		
Chillers	EUR 50,000-75,000		
Central systems	EUR 100,000		
Condensing units	EUR 7,500		
Standalone	EUR 1,400		

Table 12 Interest rate

	2022
Interest rate	5.25%
Source	Central Bank of Jordan[64]

I.9 Electricity prices

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

Table 13 Electricity price and assumed price development

		2020
Electricity prices	Residential	0.13 €/kWh
	Non-residential	0.15 €/kWh
	Source	Based on new electricity tariffs for Jordan from 2022. It was determined based on the expected consumption level

	2020- 2030[65]	2030-2040	2040-2050
Real annual price increase[66]	2020-2024: 0% 2024-2030: 5%	5%	5%
Source	Expert guess from expert interviews[67]		

[64] Central Bank of Jordan 2022, latest disclosed interest rate dating 25.09.2022 accessible online at https://www.cbj.gov.jo/Pages/viewpage.aspx?pageID=259

[65] Price increase assumed starting from 2024 as the current electricity tariff is valid without any potential change until the end of 2023 according to expert interviews

[66] This reflects the real price increase which is in line with the assumptions for the general inflation (3%) and a 2% increase for the energy prices on top. Any further price increase will lead to higher electricity cost saving in the mitigation prospects.

[67] Expert Interviews 2021

I.10 Emissions factor

The following table provides information on the starting CO2 emissions factor for electricity generation and the assumed new factor in 2050.

Table 14 Emission factor

	2020	2050
Emission factor	458.5 $gCO_{2,eq}$/kWh	183.9 $gCO_{2,eq}$/kWh
Source	RSS	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 15 Assumed emission factor development

	2020- 2030	2030-2040	2040-2050
Annual emission factor reduction	3%	3%	3%

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