THE 2018 RTOC ASSESSMENT REPORT UNDER MONTREAL PROTOCOL

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1. INTRODUCTION

The Refrigeration Technical Options Committee (RTOC) under United Nations Environment (UNEP) Montreal Protocol (https://ozone.unep.org/) has released its 2018 Assessment Report in March 2019 (UNEP, 2018).

The RTOC is one of the five Technical Options Committees of the TEAP (Technology and Economic Assessment Panel), which assist parties to the Montreal Protocol in implementing the Protocol and its subsequent amendments, such as the Kigali Amendment that mandates a phase-down of HFCs (https://ozone.unep.org/science/overview).

The 2018 RTOC Assessment reports on the state of the art of Refrigeration, Air Conditioning and Heat Pump (RACHP) technologies in relation to the Montreal Protocol framework on phasing out ODS (Ozone Depleting Substances) and implementing non-ODS replacements.

2. THE REPORT

This 2018 Refrigeration, A/C and Heat Pumps Technical Options Committee Assessment Report (hereafter called “2018 RTOC Assessment Report”) forms part of the UNEP review pursuant to Article 6 of the Montreal Protocol. It is part of the 2018 assessment work of the Technology and Economic Assessment Panel.

The information collected (particularly in the form of the Key Messages and Executive Summaries) is also part of the 2018 Technology and Economic Assessment Report, as well as the overall 2018 Synthesis Report as composed by the three Assessment Panels[5] by April 2019. All the reports can be downloaded from the UNEP Montreal Protocol website (https://ozone.unep.org/science/assessment/teap).

The RTOC assessment report was developed by all full RTOC (reporting) members; as resource persons, the RTOC also had a small number of reviewing members. Each of the chapters was developed by 2-8 experts in the specific sector, and the chapter was chaired by a Chapter Lead Author (CLA) - who did the larger part of the drafting and the co-ordination.

Several drafts of the report were made, reviewed by the separate chapters and discussed in five RTOC meetings (2015-2018). Drafting and reviewing meetings were held in Paris, France (2015), Kingston, Jamaica (2016), Amman, Jordan (2017) and Bruges, Belgium (2017), as well as in Delhi, India (2018). A last meeting to discuss peer review comments and to decide on the final 2018 RTOC Assessment Report contents was held in Rome, Italy (December 2018).

The 2018 RTOC Assessment Report has been drafted in the form of a number of chapters. There are chapters on refrigerants and their properties, on the different RACHP application areas and there is one chapter on sustainable refrigeration. The structure of the report was decided to be more or less similar to the structure of the 2014 RTOC Assessment Report:

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[5] See: https://ozone.unep.org/science/overview

The following Table reports, for each single Chapter of the report, the list of Chapter Lead Authors and Co-Authors.

Chapter	Chapter Lead Authors	Chapter Co-Authors
Chapter 1, Introduction	L. Kuijpers (NL), R. Peixoto (BR), F. Polonara (IT)	
Chapter 2, Refrigerants	A.Vonsild (DK)	J.M.Calm (US), D. Colbourne (UK), L. Kuijpers (NL), S. Yana Motta (PE)
Chapter 3, Domestic Refrigeration	S. Devotta (IN)	M. Janssen (NL), R. DeVos (US)
Chapter 4, Commercial Refrigeration	R. Rajendran (US)	M. Janssen (NL), M. Kauffeld (DE), D. Mohan Lal (IN), P. Nekså (NO), P.H. Pedersen (DK), S. Yana Motta (PE)
Chapter 5, Industrial Refrigeration and Heat Pump Systems	A.Pachai (DK)	M.C. Britto Bacellar (BR), H. Nelson (JM), M. Alaa Olama (EG)
Chapter 6, Transport Refrigeration	R. Čermák (CZ)	H. König (DE), A. Pachai (DK), R. Lawton (UK), G. Rusignuolo (US)
Chapter 7, Air-to-Air Conditioners and Heat Pumps	D. Colbourne (UK)	S. Devotta (IN), S. Hamed (JO), T. Li (CN), T. Okada (JP), R. Rajendran (US), H. Yamaguchi (JP)
Chapter 8, Water and Space Heating Heat Pumps	M. Dieryckx (BE)	Guangming Chen (CN), R. Gluckman (UK), M. Grozdek (HR), P. Nekså (NO), T. Okada (JP)
Chapter 9, Chillers	D. Dorman (US)	J.M. Calm (US), M. Dieryckx (BE), S. Hamed (JO), A. Pachai (DK), G. Rusignuolo (US)
Chapter 10, Vehicle Air Conditioning	C. Malvicino (IT)	R. Čermák (CZ), Jiangping Chen (CN), D. Godwin (US), J. Köhler (DE), S. Yana Motta (PE)
Chapter 11, Energy Efficiency and Sustainability Applied to Refrigeration Systems	H. König (DE), P. Vodianitskaia† (BR)	R. DeVos (US), B. Elassaad (LB), D. Godwin (US), M. Kauffeld (DE), M. Mousa (SA), A. Pachai (DK)
Chapter 12, Not-In-Kind Technologies	M. Alaa Olama (EG)	Guangming Chen (CN), S. Devotta (IN), S. Hamed (JO), P. Vodianitskaia† (BR)
Chapter 13, High-Ambient-Temperatures Applications	B. Elassaad (LB)	D. Colbourne (UK), M. Dieryckx (BE), S. Hamed (JO), L. Kuijpers (NL), T. Li (CN), M. Mousa (SA), M. Alaa Olama (EG), A. Pachai (DK), R. Peixoto (BR)
Chapter 14, Modelling of RACHP Systems	L. Kuijpers (NL)	D. Godwin (US), M. Janssen (NL), M. Mousa (SA), R. Peixoto (BR), A. Vonsild (DK)

All chapters drafted key messages as well as executive summaries. These key messages, derived from the summaries, as well as the summaries have been put together and form the first part of the 2018 RTOC Assessment Report. They are elaborated upon in the following.

3. KEY MESSAGES

Refrigerants

- Since the publication of the RTOC 2014 Assessment Report (UNEP, 2014), 35 new refrigerants have received a standard designation and safety classification and five are single-compound refrigerants.
- There is not a single “ideal” refrigerant. Refrigerant selection is a balanced result of several factors which include: suitability for the targeted use, availability, cost of the refrigerant and associated equipment and service, energy efficiency, safety, ease of use, and environmental issues.
- The HFC phase-down under the Kigali Amendment, as well as regional and national regulations, are driving the industry towards the use of low GWP refrigerants. Alternatives to high GWP refrigerants exist and new lower GWP refrigerants have been proposed, which creates a challenge to finding the best

refrigerant for each application. Many of these newly introduced refrigerants are expected to play only an interim role in the phase-down process, as their GWP may still be high for the average future application.
- Refrigerants with low direct impact on climate change are often flammable and may have higher toxicity. In order to maintain the current safety levels new technologies are being developed and an increased level of training will be needed.

Domestic appliances
- HC-600a (predominantly) or HFC-134a continue to be the refrigerant options for new production and currently, more than 1 billion domestic refrigerators use HC-600a. None of the other new refrigerants has matured to become an energy-efficient and cost competitive alternative.

Commercial refrigeration
- Lower GWP HFC/HFO blends and non-halocarbon options like R-744, HC-290, HC-600a and R-717 are growing in use, especially as research and development continues into improving system performance; this trend will increase once new safety standards and codes go into effect in the next few years.

Industrial refrigeration and heat pump systems
- In larger industrial refrigeration plants, R-717 has been extensively used for more than 150 years. Current technological advances enable the use of low charge R-717 systems, as well as cascade systems using R-717 together with R-744, opening up new opportunities.

Transport refrigeration
- In some regions, a significant migration from R-404A to lower GWP has occurred since the last assessment. Today, R-404A has been completely replaced by R-452A in new truck and trailer equipment in Europe. This trend might extend across the rest of the world.
- R-744 and R-513A have been introduced in intermodal container applications. R-744 is being field tested on trucks and trailers.

Air-to-air air conditioners and heat pumps
- The phase out of HCFC-22 in non-Article 5[6] parties is essentially complete and is progressing in Article 5[7] parties.
- There is an almost continuous introduction of new refrigerants for use in air-to-air air conditioners and heat pumps, but few match or exceed the performance of HCFC-22 regardless of the GWP. Component and system optimization can be a design challenge.
- Despite the reported low risk for certain applications, safety standards remain restrictive to several low GWP flammable refrigerants in certain product types, but are under revision for all refrigerants. There remains no large-scale shift to low GWP refrigerants as yet.

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[6] "non-Article 5" are those countries not included in Article 5 of Montreal Protocol (see https://ozone.unep.org/classification-of-parties)

[7] "Article 5" parties are those developing countries included in Article 5 of Montreal Protocol (see: https://ozone.unep.org/montreal-protocol-substances-deplete-ozone-layer/79722/22 and https://ozone.unep.org/classification-of-parties)

Water and space heating heat pumps

- Water and space heating heat pumps are a dynamic market with a number of options. Low GWP refrigerant HC-290 and the medium GWP refrigerant HFC-32 are commercially available, and other medium and low-GWP HFC blends may become commercially available. R-744 based water heating heat pumps have been mainly developed and commercialized in Japan, where around 6 million units have been installed since 2001. In Europe, commercial sized units are being installed for multi-family houses and hotels.

Chillers

- The phase-out of ozone depleting refrigerants in new chillers is nearly complete. HCFC-22 in new, small chillers has been phased out in non-Article 5 parties, but limited production continues in Article 5 parties.
- Since the HFCs in use today are considered to have a high GWP, there is global pressure to change to lower GWP refrigerants. Research for alternative refrigerants with lower GWP are nearly over and have yielded several acceptable alternatives.

Vehicle air conditioning

- At present, more than one refrigerant is used for new car and light truck air conditioning: HFC-134a will remain widely accepted world-wide while, due to regulations, the use of HFO-1234yf will continue expanding mainly in the US, Europe and Japan. R-744, currently available for very few car models, is expected to be considered as an option for electrified vehicles, when used at the same time for a heat pump function.

Energy efficiency and sustainability applied to refrigeration systems

- Industry and policymakers may consider the methods, tools and incentives described in this RTOC assessment report chapter to stimulate and support improvements on energy efficiency and sustainability. A wider range of relevant environmental and social aspects is briefly described in this chapter while keeping focus on possible environmental impacts of refrigeration systems.
- Comprehensive sustainable selection criteria for refrigerants have been introduced. They address energy efficiency, impact on climate and hydrosphere, usage of renewable energy, and other options to reduce GHG emissions and consumption of natural resources, adaptability for thermal energy storage, costs, technological development level, safety, flammability and liability.

Not-in-Kind technologies

- Not-In-Kind (NIK) technologies do not primarily use mechanical vapour compression (MVC) technology to produce air conditioning or refrigeration.
- These technologies can be classified as “widely commercially available”, “commercially available” or “emerging and R&D”. They are divided into three groups: (1) thermal, (2) solid-state, and (3) electro-mechanical technologies.
- Thermal technologies are predominantly available commercially; solid-state technologies are mostly available commercially with one technology in the R&D stage; electro-mechanical technologies are mostly in the R&D stage. The last ones are assumed to become the NIK technologies of the near future, with expected higher EERs compared to other NIK technologies.
- NIK technologies are expected to provide savings in operating costs. Their unique ability to use waste and renewable energy sources makes their application potentially highly energy efficient.

High Ambient Temperatures (HAT) Applications

- Research done at HAT conditions reveals viable low-GWP refrigerant alternatives that can be effectively used.
- There is more awareness of the challenges faced at HAT conditions in the design, implementation, and even servicing of equipment using low-GWP refrigerants that are capable of delivering a high level of energy efficiency.

Modelling

- Determination of current and future refrigerant demand has been a task for RTOC experts when involved in recent Task Force reports. The demand follows from "bottom-up" calculations of banks and emissions that give good insight into future developments, albeit that these imply assumption of a large amount of parameters. This includes economic growth, equipment base and composition, leakage, end-of-life characteristics, recovery and recycling.
- The methodology used by the RTOC to model banks and emissions from the global sector transitions is described in significant detail for the first time in this assessment report.

4. REVIEW

After the meeting in India (March 2018) a peer review draft was developed and was ready for review by the end of August 2018. This draft was subsequently peer reviewed by a number of institutions and associations (twenty in total); each of them reviewed (via their experts) the different chapters in a co-ordinated effort. This took place between late August 2018 and early October 2018 (see the Table below for the organisations involved). As a result, a total of 2000 comments were received.

1 AICARR	IT	Ass. Italiana Condizionamento dell'Aria Riscaladamento e Refrigerazione
2 AIRAH	AU	Australian Institute of Refrigeration, Air Conditioning and Heating
3 ASHRAE	US	American Society of Heating, Refrigeration and AC Engineers
4 CAR	CN	Chinese Association of Refrigeration
5 CARB	US	California Air Resources Board
6 CHEAA	CN	China Household Electric Appliances Association
7 CRAA	CN	Chinese Refrigeration and Air Conditioning Association
8 CSE	IN	Center for Science and Environment, CSE India
9 DKV	DE	German Refrigeration Association
10 EHPA	EU	European Heat Pump Association
11 EIA	US	Environmental Investigation Agency
12 EPEE	EU	European Partnership for Environment and Energy
13 eurammon	EU	European Industry - Association for Ammonia etc
14 IIR		International Institute of Refrigeration
15 IOR	UK	Institute of Refrigeration, UK
16 ISHRAE	IN	Indian Society Heating Refrigeration Air Conditioning Engineers
17 JRAIA	JP	Japanese Refrigeration and Air-conditioning Industry Association
18 NIST	US	National Institute of Standards and Technology
19 SAE	US	SAE Interior Climate Control Steering Committee
20 shecco		R/AC Market Development Expert Organization Brussels

During the December Rome meeting, RTOC members decided in separate chapter meetings (and thereafter in plenary) on whether and how to amend the draft chapter texts on the basis of all the peer review comments received. This resulted in semi-final drafts of the chapters which were put together and formatted into one complete, consistent report, after which the report was once more reviewed by the RTOC CLAs and co-authors. After that all final comments had been inserted the report was submitted to UNEP in the course of February 2019. The Key Messages of the RTOC Assessment Report are part (as in the case for the Key Messages from all TOC reports) od the TEAP 2018 Assessment Report which was reviewed during the TEAP meeting in April 2019.

5. REFERENCES

UNEP, 2014. 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, available at: https://ozone.unep.org/science/assessment/teap?page=3. Accessed April 26, 2019

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