CHAPTER 7

EMISSIONS OF FLUORINATED SUBSTITUTES FOR OZONE DEPLETING SUBSTANCES

[Parts in yellow – comments from Authors]

[Parts shaded in grey – the unchanged text from *2006 IPCC Guidelines*]

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7.1 INTRODUCTION

7.1.1 Chemicals and relevant application areas covered

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs), are serving as alternatives to ozone depleting substances (ODS) being phased out under the Montreal Protocol. Current and expected application areas of HFCs and PFCs include (IPCC/TEAP, 2005):

- refrigeration and air conditioning;
- fire suppression and explosion protection;
- aerosols;
- solvent cleaning;
- foam blowing; and
- other applications[1].

These major groupings of current and expected usage are referred to in this chapter as *applications* within the ODS substitutes category. This introduction (Section 7.1) provides a general framework for estimating emissions from ODS substitutes, and subsequent sections (Sections 7.2 through 7.7) provide more specialised guidance on the individual applications introduced above. Some of these applications themselves encompass products or uses with diverse emission characteristics, and countries will produce more rigorous estimates if they account for this diversity through the adoption of disaggregated assessments (higher tier). Additionally, the use of HFCs and PFCs in some applications, specifically rigid foam (typically closed-cell foam), refrigeration and fire suppression, can lead to the development of long-lived *banks* of material. The emission patterns from these uses can be particularly complex and methods employing disaggregated data sets are essential to generate accurate emissions estimates. Other applications, such as aerosols and solvent cleaning may have short-term inventories of stock but, in the context of emission estimation, can still be considered as sources of prompt emission. This statement also applies to flexible foams (typically open-cell foam).

[Update/Elaboration]

With respect to the 2006 guidelines, a major change occurred in the policy framework regulating HFCs. Formerly, HFCs, having only an indirect impact on the ozone layer (Hurwitz et al., 2015), were not regulated under the Montreal Protocol. However, during the 28th meeting of the parties (MOP28) held in Kigali (Rwanda) in October 2016, 197 countries adopted an amendment to phase down HFCs. The parties committed to cut the production and consumption of HFCs by more than 80 percent over the next 30 years. Developed countries will begin reducing HFC consumption in 2019, and developing countries will follow with a freeze of HFC consumption levels between 2024 and 2028. A small group including the world's hottest countries (India, Pakistan, Iran, Saudi Arabia and Kuwait) will freeze HFC use by 2028. In this way it has been estimated that up to 0.5° Celsius warming will be avoided by the end of the century (Velders et al., 2009; 2012; 2015).

HFCs are chemicals containing only hydrogen, carbon, and fluorine. Prior to the Montreal Protocol and the phase-out of various ODS, the only HFCs produced were HFC-152a, which is a component of the refrigerant blend R-500, and HFC-23, a low temperature refrigerant which is a by-product of HCFC-22[2] production. HFC-134a entered production in 1991 and a variety of other HFCs have since been introduced and are now being used as ODS substitutes (IPCC/TEAP, 2005) among other applications. When collecting data on HFC and PFC consumption for reporting purposes, care needs to be taken to include those HFCs in blends, but, at the same time, to avoid including those components of a blend which are not required to be reported (e.g., CFCs and HCFCs).

[1] HFCs and PFCs may also be used as ODS substitutes in sterilisation equipment, for tobacco expansion applications, and as solvents in the manufacture of adhesives, coating and inks.

[2] HCFCs - hydrochlorofluorocarbons.

HFCs and PFCs have high global warming potentials (GWPs) and, in the case of PFCs, long atmospheric residence times. Table 7.1 gives an overview of the most important HFCs and PFCs (IPCC Second Assessment Report (IPCC, 1996); IPCC Third Assessment Report (IPCC, 2001); IPCC/TEAP, 2005), including their main application areas. The various HFCs and PFCs have very different potencies as greenhouse gases. PFCs have particularly high GWPs regardless of the integrated time horizon adopted because of their long atmospheric lifetimes. The consumption patterns relating to individual gases must be known, therefore, or estimated with reasonable accuracy, to achieve useful assessments for the contribution to global warming from emissions of these groups of chemicals.

As CFCs, halons, carbon tetrachloride, methyl chloroform, and, ultimately, HCFCs are being finally phased out[3], HFCs are being selectively used as replacements. PFCs are also being used, but only to a limited extent. Even though up to 75 percent of previous application of CFC may now be covered by non fluorocarbon technologies (IPCC/TEAP, 2005), HFC use is expected to continue to grow at least in the short term.

[Update/Elaboration – Table 7.1]

TABLE 7.1
MAIN APPLICATION AREAS FOR HFCS AND PFCS AS ODS SUBSTITUTES 1

Chemical [Update/Elaboration]	Refrigeration and Air Conditioning	Fire Suppression and Explosion Protection	Aerosols		Solvent Cleaning	Foam Blowing	Other Applications[2]
			Propellants	Solvents			
HFC-23	X	X					
HFC-32	X						
HFC-125	X	X					
HFC-134a	X	X	X			X	X
HFC-143a	X						
HFC-152a	X		X			X	
HFC-227ea	X	X	X			X	X
HFC-236fa	X	X					
HFC-245fa				X		X	
HFC-365mfc				X	X	X	
HFC-43-10mee				X	X		
PFC-14[3] (CF_4)		X					
PFC-116 (C_2F_6)							X
PFC-218 (C_3F_8)							
PFC-31-10 (C_4F_{10})		X					
PFC-51-14[4] (C_6F_{14})					X		

[1] Several applications use HFCs and PFCs as components of blends. The other components of these blends are sometimes ODSs and/or non-greenhouse gases. Several HFCs, PFCs and blends are sold under various trade names; only generic designations are used in this chapter.

[2] Other applications include sterilisation equipment, tobacco expansion applications, plasma etching of electronic chips (PFC-116) and as solvents in the manufacture of adhesive coatings and inks (Kroeze, 1995; U.S. EPA, 1992a). [Update/Elaboration] Note that although the use of PFCs for plasma etching is mentioned as an example in footnotes 2 and 3 to this table, the methodology for estimating emissions is described in Chapter 6 of Volume 3: Electronics Industry Emissions.

[3] PFC-14 (chemically CF_4) is used as a minor component of a proprietary blend. Its main use is for semiconductor etching.

[4] PFC-51-14 is an inert material, which has little or nil ability to dissolve soils. It can be used as a carrier for other solvents or to dissolve and deposit disk drive lubricants. PFCs are also used to test that sealed components are hermetically sealed.

[3] Refer to http://hq.unep.org/ozone/ for the phaseout schedules dictated under the Montreal Protocol.

7.1.2 General methodological issues for all ODS substitute applications

7.1.2.1 Overview of ODS substitute issues

No refinement

7.1.2.2 Choice of method

TIER 1 METHODS

No refinement

Tier 1a – Emission-factor approach at the application level

No refinement

Tier 1b – Mass-balance approach at the application level

No refinement

TIER 2 METHODS – APPLIED AT THE SUB-APPLICATION LEVEL

There are two versions of the Tier 2 method, both of which result in emission calculations for each individual chemical and distinct types of products or equipment at the sub-application level or within a sub-application. The individual chemicals and products/equipment within the sub-application form the matrix referred to earlier in this section and their analysis is comparable with methods currently applied by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) for CFCs, HCFCs and HFCs (McCulloch, Midgley and Ashford, 2001 and 2003; Ashford, Clodic, Kuijpers and McCulloch, 2004).

Both versions of the Tier 2 methodology follow two general steps:

i. Calculation or estimation of the time series of net consumption of each individual HFC and PFC chemical at a relatively detailed product and equipment level to establish the consumption basis for emission calculations. (e.g., refrigerators, other stationary refrigeration/AC equipment, appliance foams, insulated panels, pipe insulation, etc.)

ii. Estimation of emissions using the activity data and resulting bank calculations derived from step (i), and either emission factors that reflect the unique emission characteristics related to various processes, products and equipment (Tier 2a) or, relevant new and retiring equipment information at the sub-application level to support a mass balance approach. (Tier 2b).

The difference between Tier 2a and Tier 2b is the same as that for Tier 1a and Tier 1b – namely Tier 2a methods use an emission-factor approach while Tier 2b methods follow a mass-balance approach. Both, however, need to be operated at a level of disaggregation appropriate to a Tier 2 method, typically at least at the sub-application level.

If the requisite data are available, a Tier 2 method is preferred for estimating emissions from ODS substitutes, particularly where the sub-applications within an overall application area are relatively heterogeneous. Some countries may already have the relevant information available to apply a Tier 2 methodology. Other countries might not have access to data for Tier 2 at present, but they are encouraged to establish routines to collect either country-specific or globally or regionally-derived activity data by chemical and sub-application within an application area (e.g., different types of refrigeration and air conditioning sub-applications). Tier 1, in contrast, requires data collection at a more aggregated application level (e.g., refrigeration and air conditioning in its totality).

As a first step in using the Tier 2 method, countries may wish to make first order approximation of the information needed for step (i). This will give direction to more focused data collection efforts in certain application areas or sub-categories. Table 7.3 gives examples of HFC/PFC consumption distribution at the application level in 2002 among various application areas in selected countries.

[Update/Elaboration]

Table 7.3a gives the consumption distribution in 2015 for the Article 5 (developing countries) and Non-Article 5 Parties (developed countries) to the Montreal Protocol. The distribution is based on estimated consumption for HFCs in CO_2-equivalents (UNEP-TEAP 2016). The most important application area was by large Refrigeration and Air Conditioning. Table7.3b gives the consumption of HFCs for Refrigeration and Air Conditioning in 2015 for Article 5 Parties, by substance and sub-application. Table 7.3c shows the share of total consumption used for manufacturing (filling of new equipment) and servicing (refilling of operating equipment).

TABLE 7.3
EXAMPLE DISTRIBUTION OF HFC/PFC USE BY APPLICATION AREA (2002)[A]

Country	Refrigeration Air Conditioning	Foam Blowing	Solvent[b]	Fire Protection[b]	Aerosol Propellant[b]	Other Applications[b]
Austria	18%	81%	0%	1%	0%	0%
Denmark	81%	18%	0%	0%	1%	0%
Norway	72%	11%	0%	16%	1%	0%
Sweden	48%	42%	0%	4%	6%	0%
United Kingdom	31%	22%	0%	9%	38%	0%

[a] UNFCCC Reported Data for 2002 as re-submitted in 2004

[b] A zero declaration may not always reflect non-use but could reflect reporting under other categories.

TABLE 7.3A
DISTRIBUTION OF HFC USE BY APPLICATION AREA FOR 2015[A]

COUNTRY	RAC	FOAMS	MDIS	TECH AEROSOLS	FIRE PROTECTION AND OTHERS
Article 5 Parties[b]	91 %	2 %	1 %	1 %	5 %
Non-Article 5 Parties[c]	76 %	12 %	3 %	5 %	3 %

[a] TEAP September 2016 Report Volume II

[b] Developing countries. See list of Article 5 Parties to the Montreal protocol at the Unep Ozone Secreteriat web page

[c] Developed countries. See list of Non-Article 5 Parties to the Montreal protocol at the Unep Ozone Secreteriat web page

TABLE 7.3B
HFC CONSUMPTION FOR REFRIGERATION AND AIR CONDITIONING IN ARTICLE 5 PARTIES[A]. PER CENT OF TOTAL BY SUBSTANCE AND SUB-APPLICATION AREA FOR 2015[B]

	Total	HFC-134a	R-410A	R-407C	R-404A	R-507
TOTAL	100	27	39	20	7	7
Stationary Air Conditioning	60	1	39	20	-	-
Mobile Air Conditioning	19	19	-	-	-	-
Commercial Refrigeration	13	2	-	-	6	6
Domestic Refrigeration	5	5	-	-	-	-
Industrial Refrigeration	2	<1	-	-	1	1
Transport Refrigeration	1	<1	-	-	<1	<1

[a] UNEP/OzL.Pro/ExCom/78/4

[b] Developing countries. See list of Article 5 Parties to the Montreal protocol at the Unep Ozone Secreteriat web page

TABLE 7.3C
HFC CONSUMPTION FOR REFRIGERATION AND AIR CONDITIONING IN ARTICLE 5 PARTIES[B]. PER CENT OF TOTAL BY MANUFACTURING AND SERVICING FOR 2015[A]

Manufacturing	Servicing
68	32

[a] UNEP/OzL.Pro/ExCom/78/4

[b] Developing countries. See list of Article 5 Parties to the Montreal protocol at the Unep Ozone Secreteriat web page

G*ood practice guidance* in this section deals with variations of the Tier 2 method. Tier 1 methods, covered previously, are generally seen as default methods where the application is not a *key category* and data availability is limited. (Exceptionally, for Fire Protection, Tier 1a method with country-specific activity data and emission factor will be used in the case it is identified as *key category*.) Each sub-section of Sections 7.2 to 7.7 discusses how to apply these methods to specific ODS applications, reviews existing data sources, and identifies gaps therein.

Tier 2a – Emission-factor approach

No refinement

Tier 2b – Mass-balance approach

No refinement

7.1.2.3 CHOICE OF EMISSION FACTORS

No refinement

7.1.2.4 CHOICE OF ACTIVITY DATA

No refinement

7.1.2.5 COMPLETENESS

No refinement

7.1.2.6 DEVELOPING A CONSISTENT TIME SERIES

No refinement

7.1.3 Uncertainty assessment

No refinement

7.1.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation for all ODS substitutes applications

No refinement

7.2 SOLVENTS (NON-AEROSOL)

No refinement

7.3 AEROSOLS (PROPELLANTS AND SOLVENTS)

No Refinement

7.4 FOAM BLOWING AGENTS

No refinement

7.5 REFRIGERATION AND AIR CONDITIONING

7.5.1 Chemicals covered in this application area

No refinement

7.5.2 Methodological issues

7.5.2.1 CHOICE OF METHOD

TIER 1

Tier 1 a/b

No refinement

TIER 2

Overview

No refinement

Tier 2b - Mass-balance approach

No refinement

Tier 2a – Emission-factor approach

No refinement

Refrigerant management of containers

No refinement

Refrigerant charge emissions of new equipment

No refinement

Emissions during lifetime (operation and servicing)

No refinement

Emissions at end-of-life

No refinement

[Elaboration – Box 7.2a, Box 7.2b and Box7.2c]

BOX 7.2A

COOK BOOK FOR INVENTORY COMPILERS FIRST BUILDING A RAC INVENTORY – A STEP BY STEP GUIDANCE ON THE TIER 2 EF APPROACH

Step 1. Understand the emission source and the basics of the emission estimates

In order to make good decisions when first setting up an inventory for ODS-substitutes, it is important to have a broad understanding of where these substances are used, why they are emitted and how this can be estimated.

The "Fact Sheets on HFCs" provided at the UNEP Ozone Secretariat web site (http://ozone.unep.org) gives "easy to understand" information on substances, equipment and technologies. The IPCC 2006 Guidelines focuses mostly on methodology, but there is some information on application areas and the various ODS-substitutes in section 7.1.1 and 7.5.1.

Box 7.2 provides an overview of the basic elements of the ODS-substitutes inventory. For more information on methodology specific for Refrigerating and Air Conditioning equipment, see the IPCC 2006 Guidelines section 7.5.2.1. Section 7.1.2 provides general information for all application areas.

Step 2. Identify reporting requirements and other end uses of the inventory data

What is the aim of developing the RAC inventory? Countries under the UNFCCC have different reporting requirements, and you need to identify yours. Are there other needs or uses of the inventory data that you want to keep in mind while deciding how to build the inventory?

Regardless of reporting requirements, a solid foundation for an emission inventory is to estimate annual consumption and emissions figures at three points in the lifetime of the equipment containing ODS-substitutes:

Manufacturing/Assembly: The amount of gas used for filling of new equipment and the emissions related to this activity.

Bank: The amount of gas stored in various kinds of operating equipment and the emissions generated in this phase of the life cycle.

Retired equipment: The amount of chemical stored in retired equipment and the emissions generated at system end-of-life.

These should be available for each kind of ODS-substitute, and for each relevant sub-application category.

Step 3. Decide on the level of ambition and plan for gradual improvements

Building a Tier 2 RAC inventory may initially be demanding. After identifying the reporting requirements, you should decide on how much information and time you need to achieve the desired aim. Set up a plan to estimate the most important emission sources and plan for gradual improvements over time.

Step 4. Identify where to focus your resources

Setting up a RAC inventory is much about understanding where the most important uses of refrigerants are taking place; present and historical.

To get an idea of what the most important uses and gas types are at an aggregated global level, look at table 7.3 in IPCC 2006 Guidelines, and tables 7.3a-c in this update.

E.g. the largest RAC sources for all Article 5 countries combined are: MAC (HFC 134a), Commercial refrigeration (R-404A, R-507A) and Stationary air conditioning (R-407C, R-410A). As RAC equipment leaks until empty or retirement, it is important to keep track of the accumulated amount of chemicals stored in equipment in the country in a given year.

Step 5. Map the data sources

Annual figures on production, import, export and domestic sales of ODS-substitutes and equipment containing ODS-substitutes, are examples of important data that may be used for compiling this inventory. Number of equipment units and growth rates in sales are also often collected.

Box 7.4 in this update provides a short description of common data sources. These are also listed in table 7.10 in GL 2006. See section 7.1.2.4 and 7.5.2.3 in 2006 for more on this issue.

Keep in mind that you will need data for both future annual updates and estimation of emissions for historical years. Also, consider the accessibility of data, as e.g. sometime data needed may be confidential. General guidance on data collections is given in Volume 1 of the IPCC 2006 Guidelines.

Step 6. Choose methodology and calculation model that fits the available data

The input data determines the methodology and what calculation model or tool you should use. You might want to use different models for different equipment categories (sub-applications).

Excel worksheets are available at the IPCC web site (https://www.ipcc-nggip.iges.or.jp/). Look for "Calculation Example for 2F1" in the online version of the IPCC 2006 Guidelines, Volume 3. It is based on the Tier 1a approach, but could be used to develop Tier 2a calculations by sub-application.

Step 7. Identify the relevant emission factors

Inventory compilers are encouraged to develop country-specific emission factors if sufficient information is available. Country-specific emission factors can be derived from peer reviewed studies, but also from technical reports on measurements of equipment leakages. When developing country-specific emission factors inventory compilers should take into account changes over time in equipment technical development and, when relevant, national practices and introduction of relevant regulation. It is common that leakage rates are higher in the beginning of the time series then in later years due to the technical development of the equipment. However, this is not true for second hand markets. Inventory compilers should, when relevant, check to what extent the new installed/imported equipment are from second hand markets.

As studies on leakage measurements are sparse in most countries, inventory compilers can use studies from other countries with similar circumstances.

When national data is unavailable, inventory compilers should make use of the default ranges presented in Table 7.9 in section 7.5.2.2 in the IPCC 2006 Guidelines. The lower end of the lifetime and emission factor ranges is intended to indicate the status within developed countries, while the upper end of each range is intended to indicate the status within developing countries.

The ranges in Table 7.9 can be used to develop gradual changes over time in emission factors.

Step 8. Collect data and run the calculations

General guidance on data collections is given in Volume 1 of the IPCC 2006 Guidelines. Section 7.5.2.4 in the IPCC 2006 Guidelines gives an example of calculating emissions from mobile air conditioning.

Step 9. Verify the estimates

Verify your model calculations by ensuring that all quantities of refrigerant input, not destroyed, are released as emissions over an extended time series. Read section 7.5.4.1 in the IPCC 2006 Guidelines for more on QA/QC procedures.

Step 10. Document and plan for future activities to improve estimates

Like for all parts of the inventory, it is important that the assumptions applied in the calculation process is well documented.

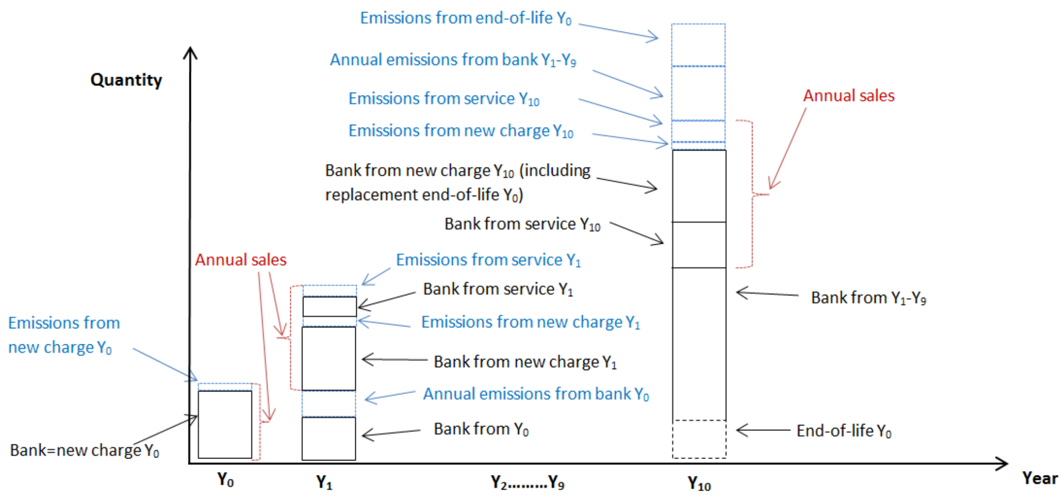
Plan ahead and find resources for gradual improvement of the ODS-substitutes inventory.

BOX 7.2B

OVERVIEW OF THE BASIC ELEMENTS OF THE ODS-SUBSTITUTES EMISSION INVENTORY

The emission inventory is a product of several components, reaching back to the introduction of the ODS-substitutes. In order to develop a consistent time series, inventory compilers should estimate the yearly fluxes of substances (see figure below).

FIGURE. SCHEMATIC EXAMPLE OF THE YEARLY INVENTORY DEVELOPMENT



1. The starting point: Bank of ODS-substitutes in operating equipment

The starting point for the annual estimates is always a snapshot of the bank of ODS-substitutes at the end of the previous year. For each of the relevant RAC sub-applications (see table 7.9), you need to have an estimate of the types and amounts of ODS-substitute it contains. Note that in a given year, RAC equipment in a sub-application may contain several different types of chemicals. If this is the case, you need to estimate the share of ODS substitutes in relation to other chemicals (e.g. HCFC, HFOs, etc.).

In the future, this kind of snapshot of the equipment population (bank) will be one of the outputs from the calculation model you run every year. The first year of making the inventory however, you will have to start from scratch and spend time putting together information on what the bank looks like in your country. How to do this is described in box 7.4.

2. Annual addition of new substances

For each of the RAC sub-applications, you then need to add the amount of ODS-substitutes being put on the market the year you are making an inventory for.

A common approach for estimating the additions to the bank a certain year is to use figures on domestic sales of ODS-substitutes. The sum of production and imports, minus exports, is normally the basis for estimating domestic sales. For instance, if your country is neither producing the ODS-substitutes, nor cars, the annual addition to the bank of HFC-134a in mobile air conditioning will consist of the imports of HFC-134a in bulk and small containers for refilling of air conditioning in cars that are in use, plus the amount contained in imported cars.

It is necessary to keep track of both the sales of chemicals in bulk and in equipment. These figures are both needed for keeping track of the structure of the bank and estimating emissions.

Bulk data: Only a few countries produce ODS-substitutes, hence most compilers solely need to focus on the imported amounts. Ideally, you want to know the amount of each kind of ODS-substitute imported to your country, and what it will be used for; whether it will be used for manufacturing/assembly (filling of new equipment) or for servicing of equipment in use (refilling), and the kind of sub-application it is used for.

Se box 7.4 for tips on where to find this kind of data.

Data on equipment: Commonly, you will have to obtain figures on the number of equipment units, and combine it with information on type and content of ODS-substitute.

Se box 7.4 for tips on where to find this kind of data.

3. Removal of substances exported, emitted, retired or destructed

From the annual bank you should subtract the amounts of ODS-substitutes exported in bulk or in products, emitted at new charge of equipment, due to annual leakage, during service or at end-of-life treatment, or leaving the bank due to incineration/destruction. Any amount of chemicals recovered and recycled should not be deducted from the bank.

Export: Exports of chemicals in bulk may occur, but is normally not significant for other than the producing countries. For countries producing RAC equipment, export of chemicals in products may be significant and the amounts of ODS-substitutes should be deducted from the annual sales.

Emissions: Emissions from new charge of equipment includes leaks at manufacturing and at assembly. Annual operation emissions include annual leakage from the bank and emissions at intermittent services (not relevant for all sub-applications). Where no measures for chemical reclaim and recovery are in place, emissions from end-of-life treatment equal remaining amounts in retired RAC equipment. In cases where destruction of chemicals occurs, there may be emissions released during the incineration process.

Retired equipment: In order to know when a RAC equipment is retired, you need to tag them with age groups. For instance, you want an estimate of the amount of HFC-134a contained in mobile air conditioning at the end of last year. You also want to have an estimate of the age of the car or air conditioning unit, in order to apply assumptions on when the car is retired at a later stage.

In your model, you have information on the number of years a certain group of equipment has been in the bank. When this group of equipment reaches its assumed end of life, the amount of substances contained in that group of equipment should be removed from the bank. The amount of chemicals in retired equipment is either released as emissions or recovered. The amount of remaining chemicals depends on your assumptions on initial charge, annual leakage and the frequency of services. For RAC equipment where no service is expected, remaining amount at end-of-life equals initial charge minus operation emission factors times equipment lifetime.

Destruction: Currently quite small on a global scale, but may be relevant in countries with measures in place. In some countries, reclaimed ODS-substitutes may be exported to other countries for destruction.

4. The result: New bank of ODS-substitutes in operating equipment

The result is the new bank at the end of the current year. This is the starting point for next year’s emission estimates.

BOX 7.2C
HOW TO BUILD THE BANK OF ODS-SUBSTITUTES

How to map the contents and structure of the bank:

There are two common ways of "knowing" what the bank currently looks like:

- **Building it through annual data on fluxes, starting at year 0.**

If data on domestic sales for all years since the ODS-substitutes were first introduced is available, this can be used to move forward from zero to the current bank. Adding the sales and subtracting the emissions every year (see box 7.2).

- **Counting the number of equipment units currently in place.**

Most countries setting up an inventory for the first time do not have information on the flux of ODS-substitutes for all years back to when it first started. An alternative way of estimating the contents and structure of the bank, is to start by estimating the number of equipment units in the country. This number can then be combined with information on the types of ODS-substitutes normally used and average amount in each unit.

For instance, the number of some kind of equipment, like cars, might be available from national statistics or from a national register used for taxation. Industrial organizations often have statistics on mass produced types of equipment, like numbers of household refrigerators, small air conditioning units, heat pumps and cars. If not, they might help you getting an idea on the size of markets, and hence the consumption figures.

It is often challenging to get information on the number of large refrigeration and air conditioning systems. You might need to estimate this going via information on the number of, for instance, large office buildings, hospitals, universities etc. in your country. Then you need to combine this with information on the typical number and types of air conditioning units per building. Again, industrial associations can often be helpful in getting this sort of information.

How to get all the needed information back to year 0:

To fulfil the UNFCCC reporting requirements, most countries need time series back to "year 0" when the ODS-substitutes were first introduced in the relevant country. If the current bank was built on the basis of annual data on fluxes, as described above, then all needed information is already there.

If not, a common way of handling this is to interpolate (fill in the holes in the time series) between the year of introduction and the current situation (bank), either linearly or by some proxy data, like growth in sales of equipment.

First, information or assumptions on the year each relevant kind of ODS-substitute was first used in each relevant type of equipment (sub-application). For instance, the year HFC-134a was first used in mobile air conditioning in your country.

Then, the way to fill in the years between needs to be decided. If you have no information on the development of the bank, a simple linear interpolation should be used. Other ways, if some kind of information on the development is available, like the annual growth in sales of cars with air conditioning, this data can be used to model the bank year by year. See the excel workbook "Calculation Example for 2F1" provided in the IPCC 2006 Guidelines for example on how to backtrack both bank and emissions by this simplified approach.

See box 7.3a for tips on where to find data.

7.5.2.2 CHOICE OF EMISSION FACTORS

Tier 1a/b method

As explained within Section 7.5.2.1, Choice of Method, a composite emission factor is required to complete a Tier 1 method. Since the sub-applications within the refrigeration and air conditioning application are relatively heterogeneous, the validity of any single composite emission factor must be in doubt unless it takes into consideration the particular mix of sub-applications in the country. It is therefore *good practice* to develop composite emission factors on the basis of research within the country. The over-arching default emissions factor of 15 percent of the bank annually is used in the example of spreadsheet calculation contained in the *2006 Guidelines* CDROM attached to these *Guidelines*.

Tier 2a method

[Update/Elaboration]

Good practice for choosing emission factors is to use country-specific data, based on information provided by equipment manufacturers, service providers, disposal companies, and independent studies. When national data are unavailable, inventory compilers should use the default emission factors shown in Table 7.9, Estimates for Charge, Lifetime and Emission Factors, which summarises best estimates of equipment charge, lifetime, and emission factors. These default values are taken from the IPCC 2006 Guidelines and can still be considered to reflect the current state of knowledge about the industry, and are provided as ranges rather than point estimates. The lower end of the lifetime and emission factor ranges is intended to indicate the status within developed countries, while the upper end of each range is intended to indicate the status within developing countries. Emission factors in the low end of the ranges should especially apply for those countries that have a legislation or system in place that ensure a high level of maintenance to keep leakage rates low. Studies of leakage rates in Japan for 2009 [reference to literature] and Germany for 2011-2015 (Umweltbundesamt, 2015) showed that the average leakage factors in these countries were close to the lower range for most sub-application categories within the application area of Refrigeration and Air Conditioning. For the sub-application areas Medium and Large Commercial Refrigeration and Industrial Refrigeration, the German study provided leakage rates below the ranges given in table 7.9. These factors are given in table 7.9a. Countries with similar regulations or incentives in place can consider using these factors for relevant years.

Since the 2006 IPCC Guidelines, no new studies were found for confirming the applicability of the upper end of each range for developing countries, but for some equipment types (e.g. refrigeration in supermarkets) there are indications of reoccurring refilling of equipment several times a year. This would mean that a leakage factor of [about hundred] per cent could be applicable. [PLACEHOLDER. Possible inclusion of information on regional/updated default EFs for developed countries based on information from the CAs from Montreal protocol TEAP].

It is *good practise* to consider changes in emission factors over years due to improved technical development of equipment leading to reduced leakage rates. Changes in emission factors over time could also be relevant for countries that have introduced mandatory periodical inspection and repair regulations/schemes or similar incentives.

For road vehicle air conditioning, emissions can occur during different stages: regular leaks (e.g. from seals), irregular leaks (e.g. due to accidents) and at service (maintenance and refilling). The 2006 IPCC Guidelines default ranges in Table 7.9 encompass emissions from all stages. Several newer studies (Table 7.9b) indicate that annual leakage rates for modern passenger cars may be lower than the default emission factor lower range. However, in most cases the presented leakage rates include only regular leaks, or regular and irregular leaks. It is *good practice* to include emissions from all three stages when choosing emission factors. As the practice for mobile A/C services may vary considerably between countries and over time inventory compilers should investigate the national circumstances when developing country-specific emission factors. In some countries A/C RRR service units (recover/recycle/recharge) are used to significantly reduce the leakage at the service stage.

There are few studies on remaining charge of refrigerants at end-of-life (p) and recovery efficiency (n_{rec}) in MAC (see Table 7.9c). For remaining charge, Kim&Kim (2014) provided an estimated of 55.6±1.1% (modelled rates, based only on regular emissions), Wimberger (2010) of 27% (based in recovered amounts from scrapped cars) and Schwarz (2012) of 34% (based on interviews with German dismantling plants). In Schwarz (2012), recovery efficiency (n_{rec}) was estimated at 38%.

Emissions at end-of-life may depend on national practices and possible regulation. Some countries have started mandatory recovery of refrigerants at the end-of-life, in which case the recovery efficiency could be higher than suggested ranges in Table 7.9. Inventory compiler should therefore investigate the national conditions when developing country-specific factors for recovery efficiency (n_{rec}).

Certain import and export of used vehicles and end-of-life vehicles between countries occurs (mostly between developed countries to developing countries). It is important for inventory compilers to take into account such flows of MAC equipment when estimating emissions from MAC as it may affect the composition of vehicle stock at various emission stages (operation and end-of-life).

Inventory compilers should choose from the range according to country-specific conditions, and document the reasons for their choices. If data collected from the field cannot be broken down into the sub-applications as in Table 7.9, it is *good practice* to use expert judgement to estimate the relative share of each type of equipment, and calculate composite emission factors weighted according to that relative share, as proposed for Tier 1a/b, or use the emission factor appropriate to the most common type(s) of equipment.

[Update/Elaboration – Table 7.9]

TABLE 7.9
ESTIMATES[1] FOR CHARGE, LIFETIME AND EMISSION FACTORS FOR REFRIGERATION AND AIR-CONDITIONING SYSTEMS

Sub-application	Charge (kg)	Lifetimes (years)[2]	Emission Factors (% of initial charge/year)[3]		End-of-Life Emission (%)	
Factor in Equation	**(M)**	**(d)**	**(k)**	**(x)**	**($\eta_{rec,d}$)**	**(p)**
			Initial Emission	**Operation Emission**	**Recovery Efficiency[4]**	**Initial Charge Remaining**
Domestic Refrigeration	$0.05 \le M \le 0.5$	$12 \le d \le 20$	$0.2 \le k \le 1$	$0.1 \le x \le 0.5$	$0 < \eta_{rec,d} < 70$	$0 < p < 80$
Stand-alone Commercial Applications	$0.2 \le M \le 6$	$10 \le d \le 15$	$0.5 \le k \le 3$	$1 \le x \le 15$	$0 < \eta_{rec,d} < 70$	$0 < p < 80$
Medium & Large Commercial Refrigeration	$50 \le M \le 2000$	$7 \le d \le 15$	$0.5 \le k \le 3$	$10 \le x \le 35$	$0 < \eta_{rec,d} < 70$	$50 < p < 100$
Transport Refrigeration	$3 \le M \le 8$	$6 \le d \le 9$	$0.2 \le k \le 1$	$15 \le x \le 50$	$0 < \eta_{rec,d} < 70$	$0 < p < 50$
Industrial Refrigeration including Food Processing and Cold Storage	$10 \le M \le 10,000$	$15 \le d \le 30$	$0.5 \le k \le 3$	$7 \le x \le 25$	$0 < \eta_{rec,d} < 90$	$50 < p < 100$
Chillers	$10 \le M \le 2000$	$15 \le d \le 30$	$0.2 \le k \le 1$	$2 \le x \le 15$	$0 < \eta_{rec,d} < 95$	$80 < p < 100$
Residential and Commercial A/C, including Heat Pumps	$0.5 \le M \le 100$	$10 \le d \le 20$	$0.2 \le k \le 1$	$1 \le x \le 10$	$0 < \eta_{rec,d} < 80$	$0 < p < 80$
Mobile A/C	$4 \le M \le 18$ (busses) $0.5 \le M \le 1.5$ (other MAC)	$9 \le d \le 16$	$0.2 \le k \le 0.5$	$10 \le x \le 20$	$0 < \eta_{rec,d} < 50$	$0 < p < 50$

[1] Based on information contained in UNEP RTOC Reports (UNEP-RTOC, 1999; UNEP-RTOC, 2003), Umweltbundesamt (2015), "Japanese study"

[2, 3] Lower value for developed countries and higher value for developing countries

[4] The lower threshold (0%) highlights that there is no recovery in some countries.

TABLE 7.9A
GERMAN STUDY 2015: EMISSION FACTORS FOR REFRIGERATION AND AIR-CONDITIONING SYSTEMS

Sub-application	Emission Factors (% of initial charge/year)
Factor in Equation	**(x)**
	Operation Emission
Medium & Large Commercial Refrigeration (centralized)	7.64 – 10.02
Small Commercial Refri-geration (condensing units)	3.09 -5.18
Industrial Refrigeration including Food Processing and Cold Storage	4.71
AC Chiller	3.39
AC Multisplit/VRF	3.80

Source: Gschrey, et al. (2015)

TABLE 7.9B
EMISSION FACTORS FOR MOBILE AIR CONDITIONING

Sub-application	Emission Factors (% of initial charge/year)
Factor in Equation	**(x)**
	Operation Emission
Passenger cars A/C[a]	5.1 ± 0.4 (regular leaks)
Passenger cars A/C[b]	5.3-10.6 (regular leaks) 2.2 (irregular leaks)
Passenger cars A/C[c]	5.2 (regular and irregular leaks)
Passenger cars A/C[d]	6-8.8 (regular, irregular and service leaks).
Passenger cars A/C[e]	0.5-5.7 (regular leaks. Manufacturer data. Car model year 2017. Mainly passenger cars and SUVs.)
Medium- and heavy-duty on- and off-road vehicle/ equipment[f]	103 g/yr for vehicle/equipment from 2006 and 306 g/yr for older systems (257 g/ yr combined average). (regular leaks)
Trucks over 16 t GVW[g]	8.3 ± 0.8 (87.8 ± 8.9 g/yr) (regular leaks).
Large buses[f]	1340 g/yr (regular, irregular and service leaks).
Buses and coaches[g]	Buses: 13.7 (920 g/yr) (regular and irregular leaks – up to 5 years old) Coaches: 13.3 (1.250 g/yr) (regular and irregular leaks – up to 5 year-old)

[a] S. Kim, E.-K. Kim, J. (2014)
[b] Schwarz, W. and Harnisch, J. (2003)
[c] Japan Automobile Manufacturers Association (2008)
[d] Papasavva, et al. (2009)
[e] Minnesota Pollution Control Agency (2017)
[f] Baker and Burnette (2010)
[g] Schwarz (2007)

TABLE 7.9C
END-OF-LIFE EMISSION FACTORS FOR MOBILE AIR CONDITIONING

Sub-application	End-of-Life Emission (%)	
Factor in Equation	**($\eta_{rec,d}$)**	**(p)**
	Recovery Efficiency	**Initial Charge Remaining**
Passenger cars [a]		55.6 ± 1.1
Road vehicles [b]		27
Passenger cars [c]	38	34

[a] S. Kim, E.-K. Kim, J. (2014)
[b] Wimberger (2010)
[c] Schwarz (2012)

7.5.2.3 CHOICE OF ACTIVITY DATA

Tier 1a/b method

No refinement

Tier 2 methods

No refinement

Other shared issues

No refinement

BOX 7.3
ACCOUNTING FOR IMPORTS AND EXPORTS OF REFRIGERANT AND EQUIPMENT

No refinement

[Elaboration – Box 7.3A, see below]

BOX 7.3A
COMMON DATA SOURCES FOR THE ODS-SUBSTITUTES INVENTORY

This box provides a short description of common data sources for the ODS-substitutes inventory, complementing table 7.10 in the IPCC 2006 Guidelines. Examples of data are production, imports, exports and destruction of ODS-substitutes and equipment containing ODS-substitutes. Number of equipment units and growth rates in sales are also data commonly collected.

Governmental reports

Most countries have collected data for Refrigerant Management Plans (RMPs) or HCFC Phase-out Management Plans (HPMPs) through ODS-alternatives surveys, or they have started looking into the consumption due to the inclusion of HFCs in the Montreal protocol.

The consumption data generally contain information on:

- past consumption of CFCs, current and past consumption of HCFCs and possibly also HFCs. Data on ODS are often given in ODP tonnes, which can be converted into metric tonnes using the substance specific ODP values;

- sector specific consumption of HCFCs and possibly also HFCs (e.g. amounts used in air conditioning, refrigeration, fire extinguishers, aerosols etc.);

- breakdown of HCFCs according to their use per sector such as manufacturing/assembly (initial charge) or servicing (refill);

Montreal protocol

Countries that have ratified the Kigali amendment to the Montreal Protocol will have to report consumption data on HFCs annually. This might provide valuable data for the ODS-substitutes inventories.

Surveys

There is often a limited number of companies producing, importing and exporting refrigerants (ODS-substitutes) in bulk, hence a way to obtain high quality data is to ask the importers for information. They should provide information on the amount of gas imported a certain year and what equipment type it will be used in.

The number of companies importing equipment containing ODS-substitutes is normally higher, and surveying this might be resource intensive.

Surveys can also be a way to obtain information on ODS substitutes from end-users. Generally, this requires good knowledge of the market but it could also be a way to discover areas and applications previously unknown to the inventory compilers.

National Customs Registers

National Customs Registers contain information on imports and exports of chemicals and equipment potentially containing ODS-substitutes. If the ODS-substitutes are subject to tax, such a register might provide the amounts of refrigerant contained in the products. If not, you will probably need to apply assumptions on types of ODS-substitute and average charge sizes on number of equipment units.

Other national registers

Many countries have national registers of cars uses for taxation purposes. This data source might provide figures on the number of cars, and possibly other information like age and size.

National Product Register/European Chemical Agency: In some countries, a national Products Register is used to store information on chemical products (ODS-substitutes) that are manufactured in or transferred or imported into the country and information on the ways in which these are being used.

Industrial organizations

Industrial organizations or trade associations often have statistics on mass produced types of equipment, like numbers of household refrigerators, small air conditioning units, heat pumps and cars.

If not, they might help with assumptions on the size of markets, and hence the consumption figures. It is often challenging to get information on the number of large refrigeration and air conditioning systems. Industrial organizations might provide useful information like annual growth in sales of equipment and average charge size of various types of equipment.

National statistics

Many countries have national offices publishing annual statistics with useful information, like the stock of vehicles and buildings (number or area by type of building), or production of commodities.

7.5.2.4 APPLYING TIER 2 METHODS – THE EXAMPLE OF MOBILE AIR CONDITIONING (MAC)

The Box 7.4 below sets out the step-by-step approach required to assess the emissions from the mobile air conditioning sub-application of a hypothetical country's inventory. The method adopted is primarily a Tier 2a approach, although there are also elements which would be equally applicable to Tier 2b. This example, therefore, highlights the reality that pure approaches and methods are rare in practice. There will often be a mix of emission-factor approach and mass–balance approach as well as a mix of country-specific data and globally or regionally derived data. As pointed out in Section 7.1.2.1, one method, approach or dataset will often be used to cross-check another. This example also demonstrates that a detailed implementation of the Tier 2a method requires a significant amount information gathering about a sub-application. Once established, it is less burdensome to implement the approach in subsequent years. Also note that assumptions made are for example only; inventory compilers should collect country-specific information rather than using the assumptions shown.

[Update- Box 7.4]

BOX 7.4
EXAMPLE OF THE APPLICATION OF A TIER 2A CALCULATION FOR MOBILE AIR CONDITIONING

Introduction

National inventories and other studies to date show that emissions of HFC-134a from mobile air conditioners (MACs) contribute significantly to the Refrigeration and Air Conditioning (RAC) Application emissions and the ODS Substitutes Category emissions. For many countries, emissions from MACs will comprise 50 percent or more of the RAC emissions and possibly more than 50 percent of the total ODS Substitutes Category emissions. This is due to many factors, including:

- The phaseout of ODSs to HFCs in MACs occurred earlier and more quickly than other Sub-Applications, such as residential (stationary) air conditioning and commercial refrigeration (supermarkets), which still rely substantially on ODSs.
- MACs are subject to extremes in terms of physical shock and vibration and hence emissions tend to be large.
- The lifetime of MACs tends to be shorter than many other RAC Sub-Applications, so that end-of-life emissions are seen earlier and equipment stocks relying on ODSs are replaced sooner with HFCs.
- Due to the small charge of refrigerant involved, recovery from MACs is often seen as uneconomical and hence is not often practiced during service and disposal.

In addition, data on vehicle purchases and registrations in a country are often known to a higher degree of quality or are easily obtained. Hence, it is *good practice* to estimate emissions from this Sub-Application. The following text describes how the general equations for the RAC Application can be applied to the MAC Sub-Application.

Data Gathering and Assumptions

An accurate estimate of MAC emissions may be obtained by collecting some data at the Sub-Application level and applying a few basic assumptions to simplify the data and calculations required, as follows:

Refrigerant Type. It will be important to separate each data point by refrigerant, so that emissions of each refrigerant are calculated separately. For MACs, this may be simplified by the fact that all MACs produced since the mid- to late-1990s use HFC-134a as the refrigerant. However, CFC-12 was used in the past and still exists in some operating systems. Furthermore, for the future other refrigerants such as HFC-152a and R-744 (carbon dioxide) are being considered.

Refrigerant Sold in Containers (*RM_t*). For MACs, refrigerant generally comes in three basic types of containers – 'bulk containers' sent to vehicle manufacturers to fill new MACs, 'small cans' containing about 300-500 grams of refrigerant generally used by individuals servicing their own equipment, and 'cylinders' containing about 10-15 kilograms of refrigerant used by shops that service many vehicles. If one assumes no losses from bulk containers (see below), then in order to calculate $E_{containers}$, one needs to know the total refrigerant sold in small cans (RM_{sc}) and cylinders (RM_{cy}). It will be important to distinguish the refrigerant sold into different Sub-Applications (e.g., HFC-134a is also used in the chillers and domestic refrigeration Sub-Applications) so that only the refrigerant sold for MACs is used in the calculations. This data may be obtained from small can packagers and refrigerant producers/distributors.

Container Heels (*c*). For this example, we assume the heels from service containers are not recovered (e.g., the cylinders are discarded, not reused) and are c_{sc} = 20% for the small can and c_{cy} = 2% for the cylinder. Because bulk refrigerant containers generally go back to the refrigerant producer and are refilled, we can assume there are no heels that would be emitted and hence c_{bulk} = 0%.

MACs Produced Each Year (*N_t*). If the number of MACs placed in service each year is not known, an estimate can be made by multiplying the number of cars placed in service each year by an estimate of the percentage that were sold with MACs. These data may be available from automobile manufacturers, MAC producers/suppliers, or government agencies involved in transportation, infrastructure and highway safety. If more than one type of refrigerant is used, it is important to separate each Nt into the different refrigerants, e.g., $N_{1994} = N_{1994,CFC-12} + N_{1994,HFC-134a}$.

Nominal Charge of Each MAC (*m_t*). This factor would likely vary by the type of vehicle; for instance small passenger cars will likely have lower refrigerant charges than buses or larger cars, especially those with multiple evaporators. Likewise, this could vary over time, for instance decreasing as manufacturers make smaller systems for the same vehicle size, or increasing as larger cars and more multiple-evaporator units enter the market. For this example, we assume a constant over time at an average m = 0.7 kg, which is typical of small to medium-sized passenger cars.

Refrigerant Charged into New Equipment (*M_t*). This is easily calculated as $M_t = N_t \bullet m_t = 0.7 \bullet N_t$.

Assembly Losses (*k*). This is used to calculate the Charge Emissions, also referred to as 'First-Fill Emissions.' The loss rate is often small, on the order of k = 0.5% or smaller. For simplicity, we assume k = 0 in this example.

Lifetime (*d*). The presumed lifetime of a MAC. This variable can be based on national data and can be different for different types of MACs (passenger cars, buses, etc.) For this example, we assume the lifetime of all MACs is d = 12 years.

Bank in Existing Equipment (*B*). The bank will be the amount of refrigerant in MACs put into service, minus the amount of refrigerant in MACs disposed, plus the amount of refrigerant used to service MACs, minus the amount that has leaked. In actuality, a given MAC will probably leak over several years before being serviced. Rather than attempting to account for this, for this example we apply Equation 7.13 which assumes all MACs are serviced each year such that the estimated charge of each MAC is the same as the nominal charge. The annual emission rate is averaged to account for this assumption. This will only produce small errors unless the year-to-year sales of MACs fluctuate widely. Hence the bank in any given year is the sum of the Refrigerant Charged into New Equipment each year from the current year back to the assumed average lifetime of the equipment. Thus,

$$B_t = \sum_{i=1}^{d} M_{t-i+1}$$

For example, using d = 12 years, the bank in 2006 would be $B_{2006} = M_{2006} + M_{2005} + M_{2004} + \ldots + M_{1997} + M_{1996} + M_{1995}$.

Annual Emission Rate (*x*). This factor accounts for both leaks from equipment as well as any emissions during service. Both of these items can be different for different types of MACs and can also vary by when the MAC was produced (i.e., older MACs may leak more than newer MACs). If annual servicing does not occur, the amount emitted at any servicing event needs to be average over the number of years between servicing event to obtain the annual rate. This amount is likely to vary considerably depending on national conditions and what type(s) of service is (are) performed. Whether recovery of the given charge before service is performed must be considered, and may be deduced in part by examining the amount of refrigerant sold in small cans versus cylinders. For this example, we assume that 15% of the nominal charge is leaked each year and 5% on average is emitted during servicing. Hence, x = 20%.

Residual Charge in MACs Disposed (*p*). Assuming that the MAC is serviced the year before it is disposed, and that the annual emission rate is estimated, this is easily calculated as p = 1 – x. In our example, p = 1 – 15% = 0.85.

Recovery Efficiency (*nrec*). If no regulations or incentives exist to require recovery of refrigerant from MACs disposed, then likely very little will occur. So, for this example, we assume that nrec = 0.

<u>Calculation of Different Types of Emissions</u>

Now that these data have been gathered and assumptions have been made, calculating the emissions may be performed. An example for year t = 2006 follows:

Container Emissions (Equation 7.11).

$$E_{containers,2006} = RM_{cy,2006} \bullet c_{cy} + RM_{sc,2006} \bullet c_{sc} = 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006}$$

Charging Emissions (Equation 7.11).

$$E_{charge,2006} = M_{2006} \bullet k = 0$$

Lifetime (Operating and Servicing) Emissions (Equation 7.13).

$$\begin{aligned} E_{operation,2006} &= B_{2006} \bullet x = 0.20 \bullet B_{2006} = 0.20 \bullet \sum_{i=1}^{d} M_{t-i+1} \\ &= 0.20 \bullet (M_{2006} + M_{2005} + M_{2004} + \cdots + M_{1997} + M_{1996} + M_{1995}) \\ &= 0.20 \bullet m \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \\ &= 0.20 \bullet 0.7 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \\ &= 0.14 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) \end{aligned}$$

End-of-Life Emissions (Equation 7.14).

$$\begin{aligned} E_{end-of-life,2006} &= M_{2006-d} \bullet p \bullet (1 - n_{rec}) = M_{2006-12} \bullet 0.85 \bullet (1-0) \\ &= 0.85 \bullet M_{1994} = 0.85 \bullet 0.7 \bullet N_{1994} = 0.595 \bullet N_{1994} \end{aligned}$$

<u>Calculation of Total Emissions</u>

Total MAC Emissions (Equation 7.8).

$$\begin{aligned} E_{total,2006} &= E_{containers,2006} + E_{charge,2006} + E_{lifetime,2006} + E_{servicing,2006} + E_{end-of-life,2006} \\ &= 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006} + 0 \\ &\quad + 0.14 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) + 0.595 \bullet N_{1994} \\ &= 0.02 \bullet RM_{cy,2006} + 0.2 \bullet RM_{sc,2006} \\ &\quad + 0.14 \bullet (N_{2006} + N_{2005} + N_{2004} + \cdots + N_{1997} + N_{1996} + N_{1995}) + 0.595 \bullet N_{1994} \end{aligned}$$

The only unknowns are:

- RM_{sc} – refrigerant (in kilograms) sold in small cans to service MACs, which may be obtained from small can packagers;
- RM_{cy} – refrigerant (in kilograms) sold in cylinders to service MACs, which may be obtained from refrigerant producers/distributors; and,
- N_t – the number of MACs put in service each year, which may be available from automobile manufacturers, MAC producers/suppliers, or government agencies involved in transportation, infrastructure and highway safety.

If the emissions from refrigerant containers and from end-of-life are not included, for example if it is believed that service cylinders are completely evacuated and minimal MACs reach their end-of-life in the given year, this equation becomes simply an activity (the number of MACs) multiplied by an emission factor (annual emission rate times average charge size, in this case 0.14 kg per MAC). This calculation yields the total emissions in kilograms of refrigerant. Keeping each refrigerant separate and multiplying each sum by the refrigerant's GWP will yield kilograms of CO_2 equivalent emissions. Dividing by 1 billion (10^9) will yield emissions in teragrams of CO_2 equivalent ($TgCO_2eq$).

7.5.2.5 COMPLETENESS

No refinement

7.5.2.6 DEVELOPING A CONSISTENT TIME SERIES

No refinement

7.5.3 Uncertainty assessment

No refinement

7.5.4 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

No refinement

7.6 FIRE PROTECTION

No refinement

7.7 OTHER APPLICATIONS

No refinement

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