CENTRE ENERGETIQUE ET PROCEDES

Global inventories of the worldwide fleets of refrigerating and air-conditioning equipment in order to determine refrigerant emissions. The 1990 to 2006 updating.

Mise à jour des banques, marchés et émissions de fluides frigorigènes dans la base de données RIEP au niveau mondial.

Extracts from the FINAL REPORT

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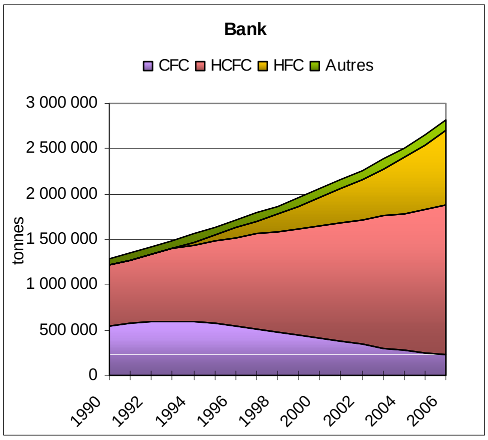

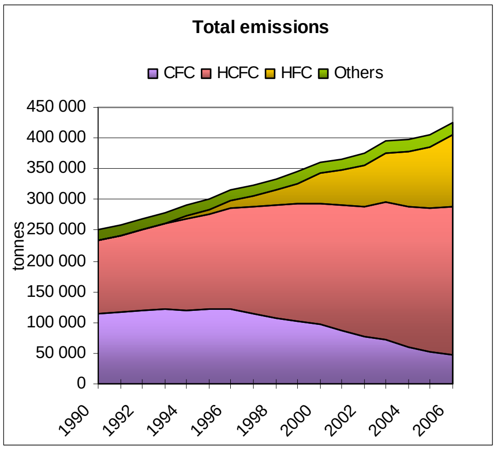

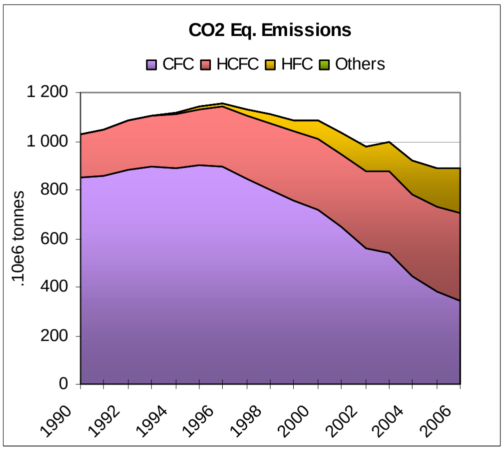

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Development Team

The RIEP database has been improved by the work of Paul MARACHLIAN and Sabine SABA.

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EXECUTIVE SUMMARY

The RIEP database is based on the Trier 2a IPCC guidelines [IPC06] and uses a bottom-up approach based on refrigeration and Air Conditioning equipment and system descriptions. This database is updated every three years thanks to the support of the French agency for the Environment and Energy Management, ADEME. RIEP is unique in terms of storing global data on all types of refrigeration equipment. Experts of the Technical Options Committee (TOC) of UNEP play an important role for the review of the different chapters. On the other hand, results are also used by those experts in the updates of the TOC and TEAP reports.

RIEP takes into account all refrigerants in use: CFCs, HCFCs, HFCs, Ammonia, Hydrocarbons and CO_2. RIEP shows the importance of the implementation of the Montreal Protocol for refrigerant changes and rapid or slow uptakes of the different substitutes to CFCs and HCFCs.

RIEP can always be improved in order to take into account specific national regulation, which accelerates the change of refrigerants or implements a more efficient recovery policy of refrigerants at end-of-life of equipment.

This 2006 report updates the refrigerant banks and emissions for each of the eight application sectors with a number of improvements both in terms of data quality and improved methods of calculation.

Data quality

The updating process is based on published data either available on web sites or available in specialized marketing studies. Global and country productions, and market data are available for domestic refrigeration, stationary air-to-air systems, chillers, and the car industry. Those numbers are also available for the past and so the installed base of all those refrigeration and AC systems can be established. One improvement made in the RIEP database is the use of lifetime curves that have replaced the average lifetime, which was implemented before. The consequence is the longer delay of CFC emissions coming from the oldest refrigeration systems using still those refrigerants.

For commercial refrigeration the same approach as used in the previous report has been developed, in order to derive the numbers of commercial outlets for all countries and regions. It has to be underlined that contradictory data on China can be found from different sources. This report states clearly that the data used in the previous report were significantly overestimated.

For the food industry, the same methodology is applied using the FAO database that is updated every year. Knowing the cooling energy needed for each quantity of meat, dairy products, beer, wine, soft drinks… it is possible to calculate the installed base of refrigeration systems installed in the food industry.

For refrigerated transports, data are available for reefer ships and refrigerated containers. Data for refrigerated trucks are available for Europe. The previous calculation method, based on food product sales, has been used again for all countries and regions.

Future improvements are indicated along the different sections.

The evaluation of refrigerant banks includes an overall uncertainty of ±18% and emissions of ±26%.

The derivation of annual refrigerant demand for each refrigerant type compared to the declaration of sales by AFEAS indicates lower differences on the derived annual markets.

Main results

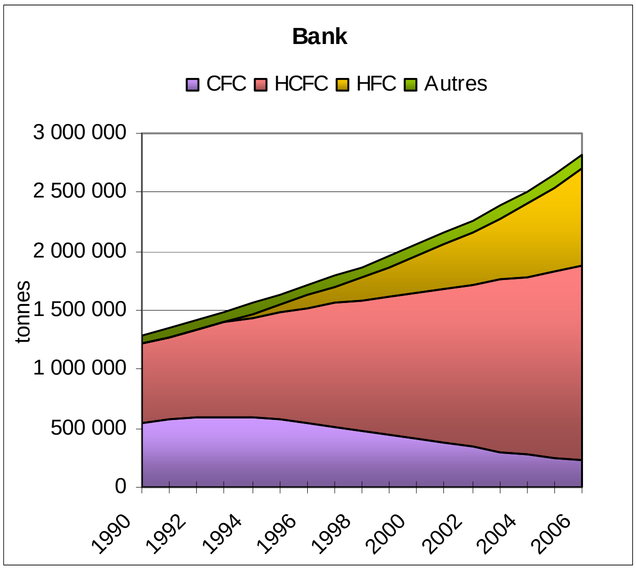
Refrigerant banks

In 2006, the sum of all banks of all refrigerant types (see Table and Figure S1) **is calculated at 2,815,000 tonnes.** The global bank is roughly equal to 4.5 times the annual demand. The refrigerant banks and the annual refrigerant demands follow the same trends:

- the size of the CFC bank is decreasing but, it still represents around 230,000 tonnes, which is about 8% of the total refrigerant bank in 2006
- HCFCs represent 1,645,000 tonnes, which equals about 58% of the total bank
- HFCs represent slightly less than 821,000 tonnes, which is around 29% of the total bank
- whereas the remaining 4% of the bank consists of ammonia and HCs.

Table and Figure S1 – Global refrigerant banks (t).

Refrigerant bank (t) in 2006		
CFC	R-11	36 611
	R-12	173 895
	R-502	17 313
HCFC	R-22	1 585 777
	R-408A	10 592
	R-401A	3 794
	R-123	45 923
HFC	R-134a	576 793
	R-404A	69 354
	R-407C	71 498
	R-410A	93 602
	R-507	8 142
	R-413A	1 979
Others	R-717	109 793
	R-600a	10 325
TOTAL	**ALL**	**2 815 391**



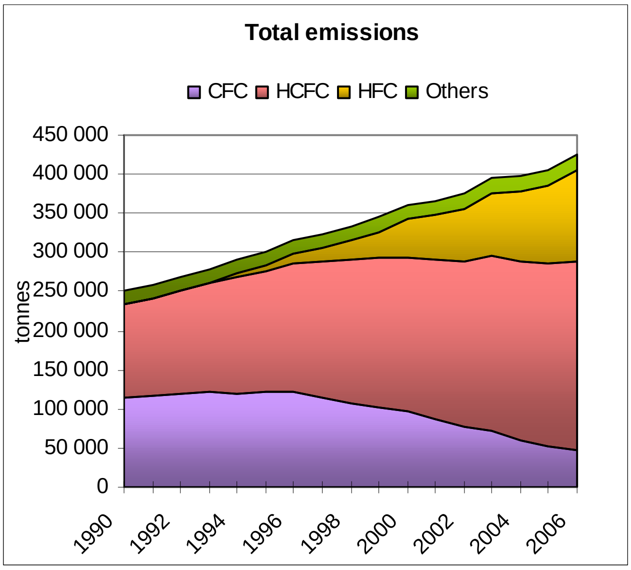
The total refrigerant bank increased by 120% for the period from 1990 to 2006.

Refrigerant emissions

Table and Figure S2 present global emissions that follow the structure of the banks. CFC emissions are decreasing, HCFC emissions are the highest due to the size of the bank, and HFC emissions are dominated by HFC-134a.

Table 2.3 – Refrigerant emissions of all refrigerant types (tonnes).

Refrigerant emissions in 2006 (t)		
CFC	R-11	6 958
	R-12	35 195
	R-502	5 430
HCFC	R-22	233 686
	R-408A	3 172
	R-401A	958
	R-123	3 983
HFC	R-134a	82 825
	R-404A	14 663
	R-407C	7 074
	R-410A	7 918
	R-507	2 271
	R-413A	616
Others	R-717	19 562
	R-600a	231
TOTAL	All	**424 542**



Emissions of all refrigerant types have increased from 250,000 tonnes in 1990 to 425,000 tonnes in 2006:

- CFC emissions reach a maximum value in 1995 at 120,000 tonnes, and decrease to 47,000 in 2006 due to their phase out,
- HCFC emissions increase from 156,000 tonnes to 242,000 tonnes, and
- HFC emissions increase from zero to around 115,000 tonnes.

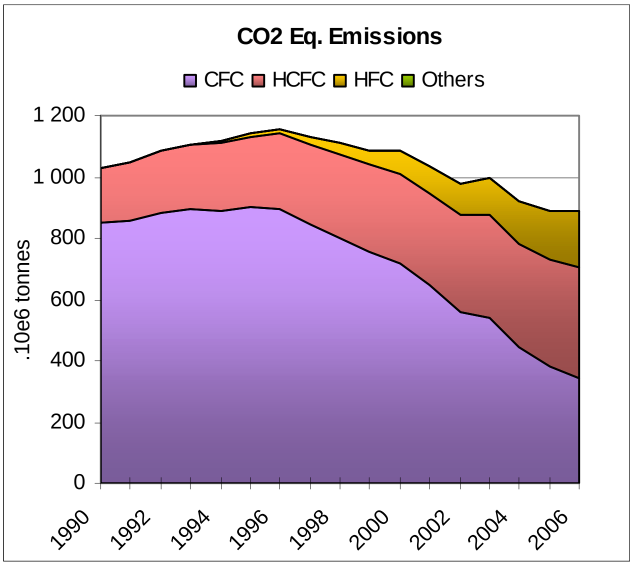
Yet, the sum of the CFC and HCFC emissions equals two third (68%) of all refrigerant emissions.

CO_2 equivalent emissions

The CO_2 equivalent emission calculations are based on GWP values published in the Second Assessment Report of the IPCC.

Table and Figure S3 – Refrigerant CO_2 equivalent emissions of all refrigerant types (tonnes).

CO_2 equiv. emissions (t) 2nd Assessment Report		
CFC	R-11	26 440 153
	R-12	285 086 629
	R-502	29 834 731
HCFC	R-22	350 532 642
	R-408A	8 402 783
	R-401A	932 246
	R-123	358 515
HFC	R-134a	107 673 924
	R-404A	47 802 130
	R-407C	10 794 708
	R-410A	13 699 040
	R-507	7 495 122
	R-413A	1 170 362
Others	R-717	0
	R-600a	4 617
TOTAL	**All**	**890 227 602**



In 2006, the main contributor to global warming is HCFC-22 (39%). In year 2003, CFC-12 represents still 32% of the total contribution of all refrigerants to global warming, whereas emissions of CFC-12 are only 8% of the total refrigerant emissions in 2006.

HFCs, accounting for 27% of the total refrigerant emissions, contribute to only 21% of the CO_2 equivalent emissions of refrigerants in year 2006 because of the relatively low GWP of HFC-134a.

Usage of the report

Results of the report will be used by experts related to UNEP or UNDP or UN for the progressive CFC and HCFC phase out along the Montreal Protocol, and by IPCC experts to follow up the uptake of HFC refrigerants.

The continuity of the work is necessary to keep the level of quality and to follow the very complex situation where refrigerants are changing depending on different regulatory frameworks in the developed and developing countries. Moreover, Europe strives for more stringent phase down even of HFCs, which creates significant uncertainties for the future choice of refrigerants within the next 15 years.

ABBREVIATIONS

AC	Air Conditioning
CDB	Country Data Base
CFC	Chlorofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
GDP	Gross Domestic Prodcut
GWP	Global Warming Potential (100 year time horizon, IPCC SAR 1996)
LFR	Leak Flow Rate
LS	Large Supermarkets
MAC	Mobile Air Conditioning
RIEP	Refrigerant Inventories and Emissions Previsions

DEFINITIONS

A5 Countries
Countries defined as developing and that consume less than 0.3 kg/capita of CFCs and halons annually. These countries are allowed postponing their phase-outs compared to the nA5 countries, i.e., they will phase-out CFCs and halons by 2010.01.01, and HCFCs by 2040.01.01.

Developed Countries
Countries that have a strict control schedule for halons (phase-out 1994.01.01), CFCs (phase-out 1996.01.01) and HCFCs (phase-out 2030.01.01).

Bottom-up method
Method of calculation of refrigerant emissions based on inventories of all emissions originating from all types of refrigerating equipment.

Top-down method
Method of calculation of refrigerant emissions based on the declarations of the refrigerant producers concerning the annual refrigerant market (refrigerant sold), which uses a global emission factor to determine annual refrigerant emissions.

Installed base
"Installed base" is the total number of pieces of equipment in a category or sub-sector independent of their vintage.

Fleet
Fleet is defined in the same way as “installed base” but is used for ships, cars, trucks, and buses.

Refrigerant bank
All refrigerant quantities stocked in refrigerating systems whatever the vintage of those systems.

Refrigerant demand
Annual refrigerant quantities consumed, which are calculated based on refrigerant inventories.

Refrigerant inventory
Annual refrigerant quantities (by type of refrigerant) derived on an application-by-application basis, which are used for charging brand new refrigerating equipment and for servicing.

Refrigerant market
The refrigerant market is equal to the refrigerant supply and again equal to the refrigerant demand, if there is no stock-piling of refrigerants by end-users, in a given year.

Refrigerant supply
Annual refrigerant quantities declared to be sold by refrigerant manufacturers and/or distributors in separate countries or globally.

Refrigerant production
The refrigerant quantities produced in a given country.

Refrigerant consumption
Based on the UNEP definitions, Consumption = Production + Imports – Exports.

tonnes (t), tons
metric tonnes (1000 kg)

ORGANIZATIONS

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie (French Agency for Environment and Energy Management)
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
CEP	Center for Energy and Processes
IPCC	Intergovernmental Panel on Climate Change
EEA	European Environmental Agency
FAO	Food and Agriculture Organization
GGEEC	Greenhouse Gases Emissions Estimating Consortium
UNEP	United Nations Environment Programme
TOC	Technical Options Committee (UNEP) under the Montreal Protocol

CONTENTS

1. Method of calculation, data and databases

1.1 Refrigerant Inventory methods and emissions calculation for the refrigeration industry

UNFCCC collects every year from signatory countries their national inventories of greenhouse gases. Three methods, Tier 1, Tier 2, and Tier 3 are proposed by the IPCC guidelines to help countries making their inventories. The refrigeration and air-conditioning industry emissions are either inventoried by sales of refrigerants or by sales of all refrigeration and air-conditioning equipment.

The six main sectors for the refrigeration and air conditioning (RAC) are:

- Domestic refrigeration
- Commercial refrigeration (centralized systems, condensing groups, and standalone equipment)
- Industrial and food processes
- Transport refrigeration
- Stationary air conditioning
- Mobile air conditioning.

This section presents the methodologies proposed by the IPCC guidelines for the estimation of GHs emissions. The RIEP model developed by the CEP is a “bottom-up” approach based on the Tier2a methodology. Some improvements have been introduced in this 2006 inventory report.

The Tier 2 IPCC method

The 1996 IPCC Guidelines provide step-by-step instructions for establishing national greenhouse gases inventories: “directions for assembling, documenting, and transmitting completed national inventory data consistently”.

Two calculation methods were developed for the estimation of emissions of fluorinated greenhouse gases and their substitutes for the refrigeration and air-conditioning sectors, the Tier 1 and Tier 2 methods. The Tier 3 method relies on actual monitoring and measurement of emissions from point sources and is not used in the refrigeration since the sources are diffuse [IPC06].

RIEP being based on the TIER 2 and its improvements, the Tier 2 methodology needs to be presented *per se*. This method calculates the actual emissions for each individual chemical in a given year on an application basis. It takes into consideration that there might be a considerable delay between the time where the fluid is produced and charged in equipment, and the time where it is released into the atmosphere.

First, it estimates the consumption of each individual chemical, at an application basis level, in order to establish the global volume from which emissions originate. An application might use several chemicals; typically in refrigeration, blends of refrigerants are used in several applications. They have to be inventoried component by component for UNFCCC reporting.

This method might be implemented in two different ways: the “bottom-up” approach (application based) or the “top-down” approach (national consumption derived).

In a “bottom-up” approach, one evaluates the consumption of a certain refrigerant based on the number of equipment in which the fluid is charged, e.g. refrigerators, stationary air-conditioning equipment, and so on. It requires the establishment of an inventory of the number of equipment charged with inventoried substances, and the knowledge of their average lifetime, their emission rates, recycling, disposal, and other parameters. Annual emissions are then estimated as functions of these parameters during the equipment lifetime.

A “top-down” approach estimates emissions for a given year on the basis of the national consumption of chemicals: it disaggregates chemical consumption data into sectors using distribution factors and then applies time-dependent emission factors. The access to such data might be very difficult due to confidentiality issues. Although in some cases producers might report to their government the quantity of a certain fluid sold into a specific sector, in other cases, when the chemical is sold by many distributors before reaching its application, it might be difficult to collect the corresponding needed data [IPC00]. In such cases, estimating of distribution factors is based on expert judgments.

In the IPCC 2006 guidelines, the mass-balance and the emission-factor approaches were introduced. The Tier 1 method addresses the total refrigeration and air-conditioning sector; the Tier 2 method requires information for each type of equipment in the six application sectors defined above.

For the mass-balance approach, emissions are calculated as follows:

$$\begin{aligned} Emissions = {} & Annual\ sales\ of\ new\ chemical - Total\ charge\ of\ new\ equipment \\ & + Original\ total\ charge\ of\ retiring\ equipment \\ & - Amount\ of\ intentional\ destruction \end{aligned} \quad (1.1)$$

The limitation on the application of Equation (1.1) to MAC systems will be explored in the next paragraphs.

Refrigerant emissions from refrigeration and air-conditioning systems occur at three main levels: emissions during the charging process, emissions from the existing bank, and emissions at the equipment disposal.

The emission-factor approach adds the emissions related to the management of containers $E_{containers,t}$ to those cited above, and equations for this approach are provided below.

The total emissions of a given refrigerant in year t $E_{total,\ t}$ are given by Equation (1.2)

$$E_{total,t} = E_{containers,t} + E_{charge,t} + E_{lifetime,t} + E_{end-of-life,t} \quad (1.2)$$

Where,

$E_{containers,t}$	Emissions related to the management of refrigerant containers
$E_{charge,t}$	Emissions occurring during the charging process of the new equipment
$E_{lifetime,t}$	Emissions occurring during the equipment lifetime
$E_{end-of-life,t}$	Emissions occurring at equipment disposal

Emissions related to the management of refrigerant containers

Emissions at the fluid manufacturing stage occur from the feedstock materials in chemical processing plants. The good design and operation of the plant lead to relatively low emissions [IPC05]. These emissions are not counted within the methods under discussion.

Once manufactured, fluids are loaded in large containers, or in individual cylinders. They are therefore delivered to product manufacturers in bulk quantities or into smaller containers. Emissions can occur at this level of fluid handling: splitting the bulk refrigerant from large containers into smaller volumes of refrigerant. Capacity heels are also considered as a main loss during the refrigerant handling. The "heels" consist of both the liquid and vapor inside the container, which cannot be extracted due to the pressure equilibrium between the vapor (the vapor heel) and the liquid phase remaining in the refrigerant volume (the liquid heel).

Emissions related to the management of containers are considered between 2 and 10% of the total refrigerant market [IPC06].

$$E_{containers,t} = RM_t * \frac{c}{100} \qquad (1.3)$$

Where,

RM_t The refrigerant market for new equipment and servicing in year t
c The emission factor of the management of refrigerant containers expressed in percentage

Emissions occurring when charging new equipment

At this stage, emissions occur when the refrigerant containers are connected to or disconnected from the equipment being charged. These emissions are usually higher for field-assembled and field-charged equipment than for the factory-produced ones. For example, these emissions include those taking place when hoses and valves are being connected or disconnected [CLO05].

All systems charged in a country in a given year t, including those that are exported are taken into account for the calculation of $E_{charge,t}$ as shown in Equation (1.4). Systems being imported are not considered [CLO05].

$$E_{charge,t} = M_t * \frac{k}{100} \qquad (1.4)$$

Where,

M_t The amount of refrigerant charged into new equipment in year t
k The emission factor occurring during assembly expressed in percentage; it ranges between 2 and 5%.

Emissions occurring during the equipment lifetime

For most applications, the largest emissions take place particularly during the in-use stage and depend on the application type. For example, domestic refrigerators show very low emission rates during their lifetime, due to their hermetically sealed technology, whereas centralized systems in the commercial refrigeration sector experience the highest annual emission rates, up to 30% of their initial charge. These emissions generally originate from leakage of fittings, joints, and seals but also from ruptures of pipes and from the refrigerant handling during servicing operations. These rates vary among applications and countries depending on the technology, operating conditions, and the servicing quality. These emissions are calculated as shown in Equation (1.5) and include those occurring during servicing.

$$E_{lifetime,t} = B_t * \frac{x}{100} \quad (1.5)$$

Where,

B_t The bank of refrigerant contained in all existing equipment in year t for all vintages

x The emission factor of annual leakage from the bank occurring in year t, given in percentage

Emissions occurring at equipment disposal

Emissions from equipment at end of life depend on country regulations affecting the recovery efficiency at disposal. Parameters used for the calculation of these emissions are shown in Equation (1.6).

$$E_{end-of-life,t} = M_{t-d} * \frac{p}{100} * (1 - \frac{\eta_{end-of-life,t}}{100}) \quad (1.6)$$

Where,

M_{t-d} The amount of refrigerant charged into new equipment in year t-d, reaching the end of life at age d

p The remaining charge in the equipment being disposed of, expressed in percentage of the initial charge

$\eta_{end-of-life,t}$ The recovery efficiency at end of life, expressed in percentage of the remaining charge in the system

At the equipment end of life, several scenarios for fluid handling exist:

- The fluid is not recovered ($\eta_{end-of-life,t}$ = 0), thus the remaining refrigerant quantity in the equipment constitutes the end of life emissions
- The fluid is recovered. After this, it can be considered as waste, and therefore is either destructed or emitted or disposed of. Alternatively, the recovered fluid can be reclaimed or recycled.

Choice of method for the refrigeration and air-conditioning sectors

Refrigeration and air-conditioning sectors are disaggregated in six sub-sectors. However, due to the diversity of equipment that can be found within the same sector, a more disaggregated level is needed in order to calculate the emission factors and the activity data, such as equipment lifetime, average charge, and refrigerant type. For example, if we consider the commercial refrigeration sector, the emission factor varies widely between the different refrigerating systems that can be found within this sector: the emission factor for standalone equipment is in the range of 1% and, as said before, for large centralized systems it can reach 30%.

The **mass-balance approach** (Equation 1.1) shows limitations especially when the recharge frequency is not on annual basis as for MAC systems: what enters for the servicing in a given year is not equivalent to what has been emitted. A delay of 5 to 8 years could be observed. In a mature market, where the average charge of the MAC system does not change and emission characteristics are also constant along time, this model could be applied since vehicle characteristics are identical, and the refrigerant stock does not change, which means that what is emitted 8 years ago is equal to what is emitted that year. This is not pretty much realistic due to the leak tightness improvements being observed on the MAC systems since the introduction of HFC-134a. Moreover, it is totally unrealistic when the market growth is significant as in Europe since 1995 and now in Asia.

Figure 1.1 shows a comparison of total emissions for MAC systems, as calculated by the emission-factor and the mass-balance approaches.

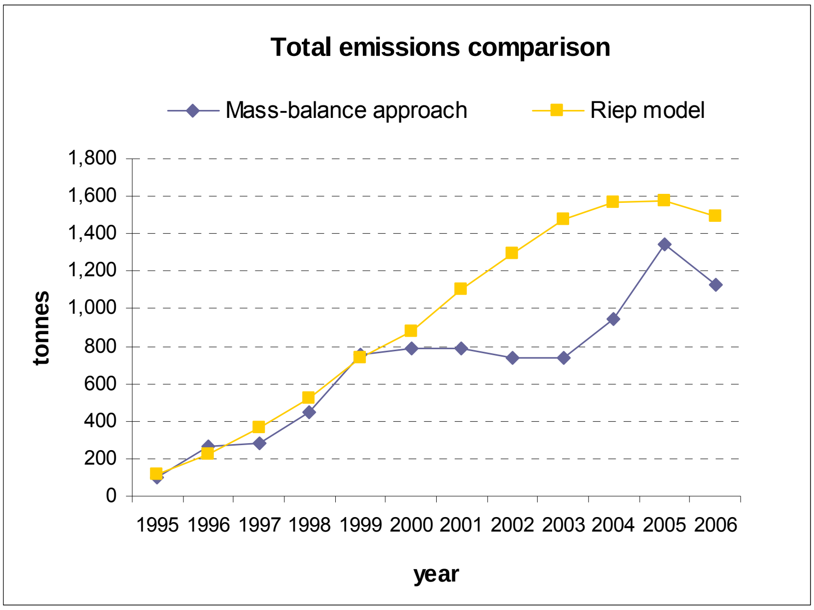


Figure 1.1 - Comparison of total emissions based on the mass-balance and the emission-factor approaches for MAC systems in France.

The mass-balance approach underestimates the emissions coming from the MAC systems as it can be seen on Figure 1. The difference between both methods is mainly due to the time lag between emissions and servicing consumption as explained previously.

The RIEP calculation method

The Center for Energy and Processes (CEP) developed a global database for the refrigeration and air-conditioning application, containing the required activity data and emission factors for the establishment of refrigerant inventories for countries and regions of the United Nations. A calculation model, called RIEP (Refrigerant Inventories and Emission Previsions), was developed based on a bottom-up approach as defined in IPCC 2000 [IPC00]. The work done by the CEP during the last eight years was taken into account for the update of the Tier 2 method as described in the IPCC 2006 guidelines [CLO05], [ASH04]. The covered sub-sectors are those listed previously, defined by the IPCC 2006 guidelines, and the disaggregation leads to the definition of 35 sub-sectors.

Improvements of the RIEP calculation method

A series of improvements of the RIEP calculation method has been done by S. Saba for her thesis work [SAB09]. Those refinements are important in order to figure out more precisely activity data such as equipment lifetime and emission factors.

Emission factors

Equations used for the emission-factor approach of the Tier 2 method are the basis of the general calculation method implemented in RIEP. Still, some particularities might appear for each sub-sector requiring specific input parameters and therefore some modifications to the main calculation algorithm. The method was adapted to the sub-sectors based on the availability of the activity data and the emission factors.

For example, for the commercial centralized systems, chillers, and industrial refrigeration, emission factors are established based on purchase invoices of refrigerants. The amount of refrigerant purchased includes the refrigerant used to replace the losses from leakages and the losses during the system servicing, and therefore both types of emissions are considered within the emission factor, which is then applied to the refrigerant bank. The same methodology is not possible for MAC or stationary air-conditioning systems. Sources of information of emission factors for this sector are scarce; some studies provide numbers on the initial leak flow rate (LFR) and others give numbers on the LFR of a fleet of vehicles from different vintages.

The calculation method implemented in RIEP considers an overall emission factor including “regular” and “irregular” emissions resulting from road accidents and accidents taking places in garages.

Regular leaks are the leaks related to joints, seals, and every location where one can find clearances between metallic parts with an elastomeric seal. Those regular leaks increase along the time due to wear and vibration, so the emission factor increases along the vehicle lifetime. Why a degradation factor has to be taken into account rather than an average value? Because the regular leaks are known from test on new systems, those values are low and do not explain the refrigerant sales dedicated to servicing in the Mobile-Air conditioning sector. Using an initial LFR increasing with time instead of an average value implies a different schedule for the maintenance operations. Taking the assumption of a degradation factor, a vehicle will undergo maintenance at the 6th year, then at the 9th, while assuming single average the vehicle will undergo maintenance every 4 years.

In summary, for MAC systems, the emissions factor is split in two factors:

- the “regular LFR” with an initial value given per vintage associated with a degradation factor, and
- the “irregular LFR” taking into account accidents.

A complementary algorithm is implemented for servicing taking into account emissions occurring during the maintenance $E_{servicing,t}$.

Change of refrigerant by retrofit

The RIEP model identifies retrofit operations for the sectors where they are occurring, and the related emissions $E_{retrofit,t}$.

Refrigeration system retrofit consists in replacing a former refrigerant (CFC or HCFC), which use is no longer possible either due to regulation or due to shortage of sales by a new one adapted to the system and in conformity with the regulation. The operation consists in recovering the "old" refrigerant from the refrigeration system, evacuating the system, and recharging the system with the new refrigerant. For the recovery operation, recovery efficiency is defined, the complementary percentage being emitted. The amount of refrigerant being replaced is calculated based on the retrofit schedule of the remaining bank of this refrigerant; for every year a percentage of this refrigerant bank being replaced.

Retirement curve instead of average lifetime

Another modification applied to the RIEP model is the use of a retirement curve to account for the equipment being disposed of instead of the mean lifetime used in the previous version. The modified equations taking into account the retirement curve are presented now. Equations related to the mean lifetime are taken from Clodic [CL005] and Ashford et al. [ASH04].

Hereafter, equations are given for mean lifetime and retirement curves:

$$B_t = \sum_{v=t-ml+1}^{t} M_v \quad (1.7)$$

$$B_t = \sum_{v=t-Ml+1}^{t} M_v * r_{v,t} \quad (1.8)$$

Where,

B_t	The bank of refrigerant at year « t » expressed in kilograms
M_v	The amount of refrigerant charged into new equipment for vintage v (per application category) expressed in kilograms and calculated by multiplying the national sales of equipment by the average charge of equipment
ml	The mean lifetime of the system
Ml	The maximum lifetime of the system when using a retirement function
$r_{,v,t}$	The remaining installed base of equipment of vintage v at year t expressed as a fraction of the initial number

Then, it can be seen that the bank calculation requires the knowledge of the mean lifetime for Equation (1.7) or the establishment of a retirement curve for Equation (1.8). The national sales of equipment as well as its average charge should also be known. The access to this activity data might be difficult especially for years before the Montreal Protocol.

For some sectors, such as the commercial refrigeration sector, emission factors are applied directly to the banks and Equation (1.5) is used to calculate emissions along the lifetime, taking indirectly into account the retirement curve for the bank calculation.

For MAC systems, the algorithm presented in Figure 1.2 is used to calculate emissions due to servicing, regular, and irregular emissions.

Emissions during lifetime are calculated as follows, according to the lifetime option:

- mean lifetime, Equations (1.9) and (1.10) are used
- when using a retirement curve, Equations (1.11) and (1.12) are chosen..:

$$E_{regular,t} = \sum_{v=t-ml+1^*}^{t} (N_v * LFR_{v,t}) \qquad (1.9)$$

** If the system is not empty*

$$E_{irregular,t} = \left(\sum_{v=t-ml+1^*}^{t} N_v \right) * EF_{irr,t} \qquad (1.10)$$

** If the system is not empty*

$$E_{regular,t} = \sum_{v=t-Ml+1^*}^{t} (N_v * r_{v,t} * LFR_{v,t}) \qquad (1.11)$$

** If the system is not empty*

$$E_{irregular,t} = \left(\sum_{v=t-Ml+1^*}^{t} (N_v * r_{v,t}) \right) * EF_{irr,t} \qquad (1.12)$$

** If the system is not empty*

Where,

N_v	The number of equipment of vintage v
LFR_v	The LFR value of vintage v at year t expressed in g/year
$EF_{irr,t}$	The emission factor for irregular emissions at year t expressed in g/year
$r_{v,t}$	The remaining installation of vintage v in year t expressed as a fraction of the initial number

Servicing emissions are calculated by Equations (1.13) and (1.14):

$$E_{servicing,t} = \left(\sum_{v=t-ml+1^*}^{t} (M_v * \frac{s_{v,t}}{100}) \right) * (1 - n_{serv,t}) \qquad (1.13)$$

** If the vintage requires servicing*

$$E_{servicing,t} = \left(\sum_{v=t-Ml+1^*}^{t} (M_v * r_{v,t} * \frac{s_{v,t}}{100}) \right) * (1 - n_{serv,t}) \qquad (1.14)$$

** If the vintage requires servicing*

Where,

$s_{v,t}$	The residual charge of vintage v in year t expressed in percentage
$\eta_{serv,t}$	The recovery efficiency at servicing expressed as a fraction of the amount contained in the equipment being recharged

The algorithm presented in Figure 1.2 describes how emissions during servicing operation are taken into account for MAC systems. This algorithm is applied to all vehicle vintages. The recharge is required when the refrigerant emitted is over a threshold corresponding to 50% of the initial charge.

For every year j, the refrigerant loss is calculated by Equations (1.9) or (1.11). The loss is compared to the threshold of residual refrigerant charge, which requires the AC system maintenance due to the lack of cooling capacity.

If the loss is larger than this quantity, and the MAC system did not reach its end-of-life, the system undergoes maintenance and the amount of refrigerant required for the servicing operation and emissions occurring during this operation are calculated for this year of recharge. After this intervention, the system is fully charged again.

However, if the loss is lower than the threshold leading to maintenance, no maintenance occurs at this year of calculation, which is then incremented. Losses calculated for the following year are then added to those previously calculated, and the threshold for maintenance is then verified. If the condition for maintenance is verified, the maintenance operation takes place as described previously; otherwise, the year of calculation is incremented again until the MAC system reaches its end-of-life. As a result of this calculation algorithm, the $s_{v,t}$ parameter used in Equation (1.13) or (1.14) is calculated dynamically each year the system undergoes maintenance. The same thing applies to the end-of-life emissions that are calculated dynamically for this sector.

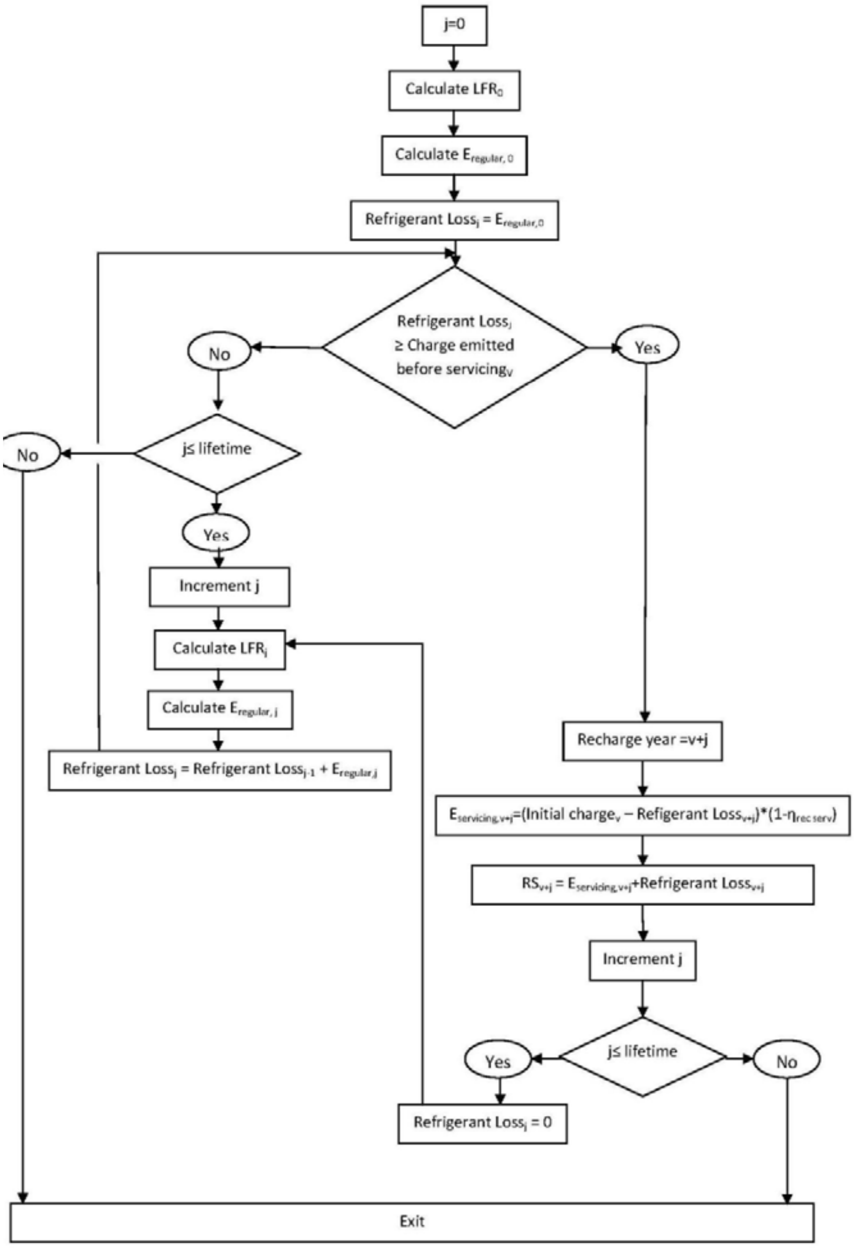


Figure 1.2 - Refrigerant servicing demand and emissions for MAC systems.

Retrofit emissions $E_{retrofit,t}$ are calculated using Equation (1.15)

$$E_{retrofit,t} = M_{refrigerant-out,t} * (1 - n_{end-of-life,t}) \qquad (1.15)$$

Where,

$M_{refrigerant-out,t}$	The refrigerant being replaced at year t
$\eta_{end-of-life,t}$	The recovery efficiency at end of life in year t expressed as a fraction of the remaining amount of refrigerant being recovered

Total emissions during the lifetime are given by Equation (1.16):

$$E_{operation,t} = E_{regular,t} + E_{irregular,t} + E_{servicing,t} + E_{retrofit,t} \quad (1.16)$$

Emissions during servicing and retrofit given by Equation (1.17) occur during the refrigerant recovery. However, when the refrigerant is being re-introduced, emissions can take place. Those emissions do not appear in equations provided by [CLO05] or the IPCC 2006 guidelines, and can be written as follows:

$$E_{charge(servicing-retrofit),t} = (RS_t + RR_t) * \frac{k}{100} \quad (1.17)$$

Where,

RS_t Refrigerant demand for servicing at year t
RR_t Refrigerant demand for retrofit at year t
k The emission factor at the charging process expressed in percentage

End-of-life emissions are calculated by Equation (1.6) when an average lifetime is used, whereas they are calculated by Equation (1.18) when using a retirement curve:

$$E_{end-of-life,t} = \sum_{v=t-Ml+1}^{t} M_v * (r_{v,t-1} - r_{v,t}) * \frac{p}{100} * (1 - \eta_{end-of-life,t}) \quad (1.18)$$

Where,

$r_{v,t-1}$ The remaining installation of vintage v at year t-1
$r_{v,t}$ The remaining installation of vintage v at year t

For MAC systems, the residual charge at end-of-life is calculated for every vintage; therefore the value of p in Equation (1.18) depends on the vintage and on the year of disposal.

1.2 Refrigerants and regulations

The use of CFCs, HCFCs or HFCs and other refrigerants is related to control schedules, which have been continuously adjusted since the Montreal Protocol has been ratified. For the developed countries (the non-Article 5(1) countries as defined in the Montreal Protocol), the phase-out of CFCs and HCFCs will be earlier than in developing countries (the Article 5(1) countries). Moreover, where it concerns non-Article 5(1) countries, the European Union has accepted a much tighter control schedule for phasing out (CFCs in the past and) HCFCs.

The rapid phase out of CFCs in Europe and also the interdiction of use of CFCs for servicing have led to a significant uptake of intermediate blends (HCFC-based blends) for the retrofit of a number of refrigerating systems using CFCs. The retrofit allows keeping the residual value of equipment until its usual end of life. It is likely that the same behavior of equipment owners will be followed for the progressive phase out of HCFCs, which will be replaced by intermediate blends of HFCs. Based on these facts, RIEP includes retrofit options where the refrigerant can be changed during the equipment lifetime.

- **Non-Article 5(1) countries**

The CFC phase-out schedule as valid for the non-Article 5(1) countries is presented in Figure 1.3. Via the EU regulation 3093/94, CFCs were phased out one year before the phase-out defined in the Montreal Protocol, i.e. on 31 December 1994.

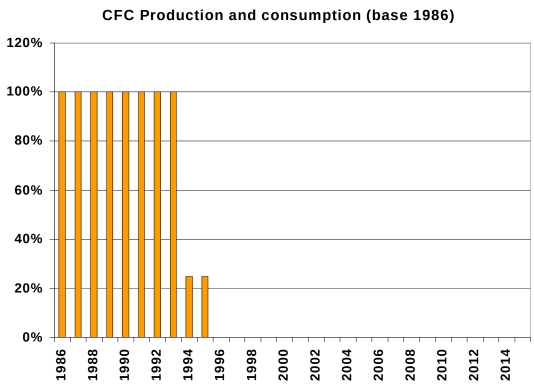


Figure 1.3 – CFCs phase out in non Article 5(1) countries.

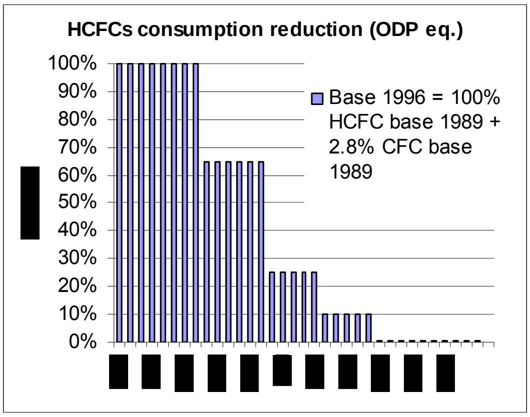


Figure 1.4 – HCFCs phase out in non Article 5(1) countries (except EU).[MOP07].

As indicated in Figure 1.4, the HCFC consumption base levels refer to the 1989 HCFC consumption plus 2.8% 1989 CFC consumption, ODP-weighted. On the basis of a certain ODP for HCFC-22 and CFCs (0.055 and 1.0 respectively), the factor of 2.8% means that if all CFCs were to be replaced by HCFC-22, about 55% of the CFC consumption in tonnes would be replaced by HCFC-22.

Figure 1.3 clearly shows that, even for non-Article 5(1) countries, brand-new equipment can be manufactured, charged with HCFC-22, and sold until 31 December 2009. Typically, the U.S. and many developed countries continue to use HCFC-22 for air-conditioning equipment.

As indicated in Figure 1.5, the EU regulation has changed the baseline level for the HCFC consumption by reducing the additional quantities of ODP weighted CFCs by nearly 30% (from 2.8 to 2.0%). Moreover, the time of the HCFC phase-out is been brought forward by about 7 years.

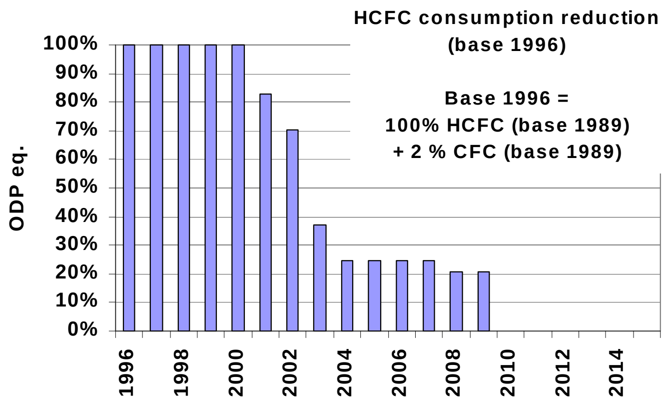


Figure 1.5 - European Union - (European regulation 2037/2000).

- **Article 5(1) Countries**

The CFC consumption and production (see Figure 1.6) for Article 5(1) countries have a delay compared to non-Article 5(1) countries of actually 14 years (1996 compared to 2010). There is an additional possibility of production and consumption of 10% compared to the 1996 level for Basic Domestic Needs of developing countries where production can take place in developed countries.

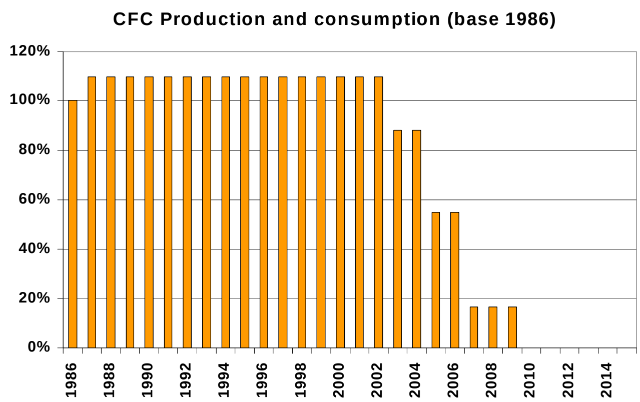


Figure 1.6 - CFC phase-out for Article 5 Countries.

For the HCFC phase-out, the Montreal Protocol schedules are slightly more complicated. Where it concerns the freeze in consumption, Article 5(1) countries have a delay of about 15 years (freeze by 2016). Where it concerns the phase-out, it is a 10-year delay period (phase-out in 2040 versus 2030) for the developing countries compared to the developed ones.

All these different constraints based on global control schedules and more stringent regional and national regulations imply different refrigerant choices in countries and country groups. The refrigerant choices need to be taken into account on an application by application basis. In this project, additional data, derived from country reports, have been used as well as data available in publications.

1.3 Refrigerant GWPs from the IPCC Second and the Third Assessment Reports

Table 1.1 lists the main refrigerant types in use: CFCs, HCFCs, HFCs, ammonia, and different blends, many of them being intermediate blends used for retrofit of CFC equipment. Table 1.1 has been updated taking into account all new blends as declared to ASHRAE 34. Among those blends, the most used of are R-401A, R-409A, and R-413A for the replacement of CFC-12, R-402A and B, and R-408A for the replacement of R-502. The use of those blends can be verified at the global level by the declarations of sales by AFEAS of HCFC-124 and HCFC-142b, which are specific components of those intermediate blends. The list is nearly exhaustive, and takes into account more than 99% of all refrigerant types in use. **The GWP values, as given in the Second Assessment Report of the IPCC (SAR),** are used for the calculations of the equivalent CO_2 emissions of refrigerants as shown in Table 1.1. The latest scientific values of refrigerant GWPs are coming from the 4^{th} Assessment Report of IPCC. As it can be verified, they are nearly all superior to the GWP values of the 2^{nd} Assessment Report. Nevertheless in the RIEP calculations, the 2^{nd} AR report values have been kept because they are those used for reporting HFC emissions to UNFCCC.

Table 1.1 - GWP and physical data of refrigerants [TOC03, IPCC06].

Refrigerant		**Physical data**				**GWP**	
Number	Chemical formula or blend composition – common name	Molecular mass	NPB (°C)	TC (°C)	Pc (MPa)	GWP 2^{nd} AR 1996	GWP AR4 2006
11	CCl_3F	137.37	23.7	198.0	4.41	3 800	4750
12	CCl_2F_2	120.91	-29.8	112.0	4.14	8 100	10890
22	$CHClF_2$	86.47	-40.8	96.1	4.99	1 500	1810
32	CH_2F_2-methylene fluoride	52.02	-51.7	78.1	5.78	650	675
115	$CClF_2CF_3$	154.47	-38.9	80.0	3.12	9 300	7370
116	CF_3CF_3-perfluoroethane	138.01	-78.1	19.9	3.04	9 200	12200
123	$CHCl_2CF_3$	152.93	27.8	183.7	3.66	90	77
124	$CHClFCF_3$	136.48	-12.0	122.3	3.62	470	609
125	CHF_2CF_3	120.02	-48.1	66.1	3.63	2 800	3500
134a	CH_2FCF_3	102.03	-26.1	101.1	4.06	1 300	1430
143a	CH_3CF_3	84.04	-47.2	72.7	3.78	3 800	4470
152a	CH_3CHF_2	66.05	-24.0	113.3	4.52	140	124
245fa	$CHF_2CH_2CF_3$	134.05	15.1	154.0	4.43	820	1030
290	$CH_3CH_2CH_3$ - propane	44.10	-42.1	96.7	4.25	20	20
401A	R-22/152a/124(53/13/34)-MP39	94.44	-32.9	107.3	4.61	973	1200
401B	R-22/152a/124(61/11/28)-MP66	92.84	-34.5	105.6	4.68	1 062	1300
402A	R-125/290/22(60/2/38)-HP80	101.55	-48.9	75.9	4.23	2 250	2800
402B	R-125/290/22(38/2/60)-HP81	94.71	-47.0	82.9	4.53	1 796	2400
403A	R-290/22/218(5/75/20)	91.99	-47.7	87.0	4.7	2530	3100
403B	R-290/22/218(5/56/39)	103.26	-49.2	79.6	4.32	3570	4500
404A	R-125/143a/134a(44/52/4)	97.60	-46.2	72.0	3.74	3 260	3900
405A	R-22/152a/142b/C318(45/7/5.5/42.5)	111.91	-32.6	106.1	4.29	4480	5300
406A	R-22/600a/142b(55/4/41)	89.86	-32.5	116.9	4.96	1560	1900
407A	R32/125/134a(20/40/40)	90.11	-45.0	81.8	4.52	1770	2100
407B	R32/125/134a(10/70/20)	102.94	-46.5	74.3	4.13	2290	2800
407C	R-32/125/134a(23/25/52)	86.20	-43.6	85.8	4.63	1 526	1800

Refrigerant		Physical data				GWP	
Number	Chemical formula or blend composition – common name	Molecular mass	NPB (°C)	TC (°C)	Pc (MPa)	GWP 2nd AR	GWP AR4
						1996	2006
407D	R-32/125/134a(15/15/70)	90.96	-39.2	91.2	4.47	1430	1600
407E	R-32/125/134a(25/15/60)	83.78	-42.7	88.3	4.7	1360	1600
408A	R-125/143a/22(7/46/47)-FX-10	87.01	-44.6	83.1	4.42	2 649	3200
409A	R-22/124/142b(60/25/15)-FX-56	97.43	-34.4	109.3	4.69	1 288	1600
410A	R-32/125(50/50)-Suva9100;AZ-20	72.58	-51.4	70.5	4.95	1 730	2100
411A	R-1270/22/152a(1.5/87.5/11)	82.36	-39.5	99.1	4.95	1330	1600
412A	R-22/218/142b(70/5/25)	92.2	-38	107.2	4.9	1850	2300
413A	R-218/134a/600a(9/88/3)	103.95	-33.4	96.6	4.07	1770	2100
414A	R-22/124/600a/142b(51/28.5/4/16.5)	96.93	-33.0	112.7	4.68	1200	1500
415A	R-22/152a(82/18)	81.91	-37.2	102.0	4.96		1500
416A	R-134a/124/600(59/39.5/1.5)	111.92	-24.0	107.0	3.98		1100
417A	R-125/134a/600(46.6/50/3.4)	106.75	-39.1	87.3	4.04		2300
418A	R-290/22/152a(1.5/96/2.5)	84.60	-41.7	96.2	4.98		1700
419A	R-125/134a/E170(77/19/4)	109.3	-42.6	79.3	4		3000
420A	R-134a/142b(80.6/19.4)	101.84	-24.9	104.8	4.11		1500
421A	R-125/134a(58/42)	111.75	-40.7	82.9	3.88		2600
422A	R-125/134a/600a(85.1/11.5/3.4)	113.60	-46.5	71.8	3.92		3100
427A	R-32/125/143a/134a(15/25/10/50)	90.44	-43.0	85.1	4.39	1827	
500	R-12/152a(73.8/26.2)	99.30	-33.6	102.1	4.17	6 014	8100
502	R-22/115(48.8/51.2)	111.63	-45.2	80.2	4.02	5 494	4700
503	R-23/13(40.1/59.9)	87.25	-87.8	18.4	4.27	11 700	15000
507A	R-125/143a(50/50)-AZ-50	98.86	-46.1	70.5	3.79	3 300	4000
1270	$CH_3CH=CH_2$ - propylene	42.08	-47.7	92.4	4.66		
600a	$CH(CH_3)2\text{-}CH_3$ - isobutane	58.12	-11.7	134.7	3.64	20	20
717	NH_3 - ammonia	17.03	-33.3	132.3	11.33	< 1	< 1
744	CO_2	44.01	-78.4	31.0	7.38		1

NBP = normal boiling point; Tc = critical temperature; Pc = critical pressure; GWP = global warming potential (for 100-yr integration).

The GWP calculation for blends is based on the GWP values of pure refrigerants, and their mass concentration in the blend. All values for blends are coming from the 2006 TOC Report [TOC06]

1.4 Consistency and improvement of data quality

The refrigerant demand calculated by RIEP for each refrigerant, including charge of new equipment and recharge of the installed base to compensate refrigerant emissions, is compared to refrigerant sales declared by refrigerant distributors.

Equation (1.19) calculates the refrigerant demand, which is then compared to the declared numbers.

$$R_t = (1 + \frac{c}{100} + \frac{k}{100}) * (RP_t + RS_t + RR_t) \quad (1.19)$$

Where,

R_t	The total refrigerant demand at year t, expressed in kilograms
RP_t	The total refrigerant demand for the new equipment being charged in the country, expressed in kilograms
RS_t	The refrigerant demand for servicing at year t, expressed in kilograms
RR_t	The refrigerant demand for retrofit at year t, expressed in kilograms
c	The emission factor of the management of refrigerant containers, expressed in percentage
k	The emission factor occurring during assembly, expressed in percentage

The refrigerant demand for new equipment is given by Equation (1.20)

$$RP_t = \sum_{i=1}^{6} (S_{prod_{i,t}} * m_{i,t}) \quad (1.20)$$

Where,

$S_{prod,i,t}$	The national production of equipment for the application i at year t
$m_{i,t}$	The average equipment charge for the application i at year t, expressed in kilograms

The refrigerant demand for servicing is given by Equation (1.21) when the emission factor is applicable to the sector bank, and by Equation (1.22) in other cases.

$$RS_t = \sum_{i=1}^{6} E_{lifetime_{i,t}} \quad (1.21)$$

Where,

$E_{lifetime\ i,t}$	The total emissions as calculated by Equation (1.22) when the emission factor is applicable to the bank of the sector i

$$RS_t = \sum_{i=1}^{6} \left[\left(\left(\sum_{v} E_{regular_{i,t\_vingtage*}} \right) + \left(1 - n_{serv_{i,t}}\right) * RemainingCharge \right) + E_{irregular_{i,t}} \right] \quad (1.22)$$

** If the vintage requires servicing*

Where,

$E_{regular\ i,t\_vintage}$	Losses of vintage v since its last recharge until year t, if the vintage requires recharging, and for application i
$\eta_{serv\ i,t}$	The recovery efficiency at servicing at year t for application i
RemaningCharge	The remaining charge in the equipment at the moment of servicing being recovered
$E_{irregular,t,i}$	The irregular emissions at year t for application i

The refrigerant demand for retrofit RR_t corresponds to the amount of refrigerant being introduced into the system during the retrofit operation.

The refrigerant demands calculated for each refrigerant and for each application, are added up to derive the national demand by refrigerant or the global demand. These demands are compared to the national declarations of refrigerant manufacturers and distributors or compared to the AFEAS sales data at the global level.
Note: It has to be mentioned that AFEAS has decided to stop its yearly publication of refrigerant sales at the end of 2009, because the production of China, India, Russia, and Brazil are not published and so a bias between the "real" sales and the AFEAS data is becoming more and more significant.

The cross-checks can be performed both on a country-by-country basis and globally. If the refrigerant inventories and the related emissions are adequately determined, the difference between the submitted figures and the calculated refrigerant sales will be small. If not, additional analyses are required.

♦ **Consistency for refrigerating equipment at the global level**

To reach high accuracy in the sizes of refrigerant inventories, the first step required is to gather reliable data for equipment numbers. Fortunately, annual statistical data are available for nearly all mass-produced equipment. Details on the availability of such numbers per application are provided in the corresponding chapters. When data is not available, correlations between sale population and wealth of countries are established to derive the missing data. Some data have been published by manufacturer associations, and some are available from marketing studies that can be purchased from specialized companies. The data on annual equipment sales allow deriving figures on production and sale at the national level for nearly all OECD countries, and also at the global level, when they are based on production data (see Figure 1.7).

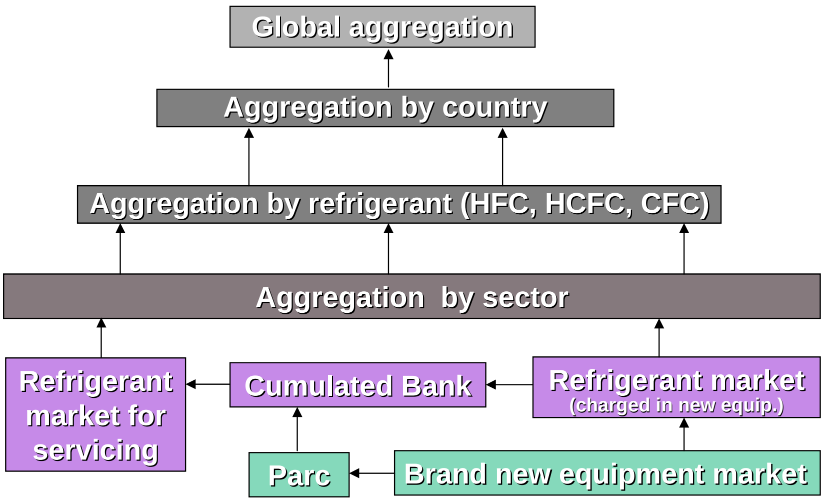


Figure 1.7 – Determination of refrigerant markets.

As shown in Figure 1.7, the derivation of the global demand of refrigerants consists in:

- establishing the annual sales of brand-new equipment and the amount of refrigerants charged in this equipment,
- the derivation of refrigerants banked in the installed bases of the six sectors, as a function of their lifetime,
- the calculation of the refrigerant market for servicing dependent on emission factors,
- then the six application sectors are aggregated

- by families of refrigerants,
- country by country,
- by country groups and globally.

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Appendix 1 to Chapter 1

1 – Geographical split

Global inventories cover six countries calculated independently and seven groups of countries:

- USA,
- China,
- Japan,
- Brazil,
- India,
- Canada,

- Latin America and the Caribbean,
- European Union 27 (EU27),
- Other Europe,
- West and Central Asia,
- South and East Asia,
- Oceania, and
- Africa.

The subdivision of the groups of countries is based on the geographical regions provided by the United Nations Statistics Division, revised on the 17th of October 2008 [UNS08]. However, the calculation assumptions (CFC and HCFC phase-out...) are not always identical over the countries within the same group. Therefore, some groups are separated in two subgroups in order to take into account the difference in the calculation assumptions.

Table A1.1 provides details about the group subdivisions and the considered calculation assumptions. Calculations are led on one database for those groups that are not subdivided, i.e. the activity data of all countries constituting the group are aggregated in one database. Regions divided in two groups (Oceania, West and Central Asia, EU27, and Other Europe) are separated each in two different databases.

Table A1.1 - Country groups description.

Group	Composition	Assumptions for phase-out of CFCs and HCFCs
Latin America and the Caribbean	Antigua, Argentina, Bahamas, Barbados, Belize, Bolivia, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Rep., Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, St Kitts and Nevis, St Vincent, Suriname, Trinidad & Tobago, Uruguay, Venezuela	Article 5
Africa	Algeria, Angola, Benin, Botswana, Burkina, Burundi, Cameroon, Cape Verde, Centrafrica, Chad, Comoros, Congo , Congo RD, Côte d'Ivoire, Djibouti, Egypt, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Guinea Eq, Kenya, Lesotho, Liberia, Libyan Arab, Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe	Article 5
West* and Central Asia	Afghanistan, Armenia, Bahrain, Georgia, Iraq, Jordan, Kuwait, Kyrgyzstan, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkmenistan, United Arab Emirates, , Yemen, Azerbaijan, Kazakhstan, Tajikistan, Uzbekistan	Article 5
	Turkey, Israel	
South and East Asia	Bangladesh, Bhutan, Brunei, Cambodia, Indonesia, Islamic Republic of Iran, People's Democratic Republic of Korea, Republic of Korea , Lao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Viet Nam	Article 5
Oceania	Australia, New Zealand	non Article 5
	Cook Islands, Fiji, Kiribati, Marshall, Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu	Article 5
EU 27	**EU 15**: Austria, Belgium, Denmark, Finland, France, Germany , Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United kingdom	non Article 5
	Other EU: Bulgaria, Cyprus, Czech republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia	transition Article 5 -> non Article 5
Other Europe	Andorra, Belarus, Iceland, Lichtenstein, Monaco, Norway, Russian Federation, Switzerland, Ukraine	non Article 5
	Albania, Bosnia and Herzegovina, Croatia, Moldova, Montenegro, Serbia , The Former Yugoslav Republic of Macedonia	Article 5

**Except Cyprus included in EU27*

[UNS08]: Composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings, United Nations Statistics Division, Revised 17 October 2008. http://unstats.un.org/unsd/methods/m49/m49regin.htm

CONTENTS

2.1 Global demand of refrigerants in year 2006

As presented in Section 1, the quality control is made by comparing the refrigerant demand calculated by RIEP and the refrigerant sales declared by manufacturers (AFEAS). This comparison is made refrigerant by refrigerant and is presented in Section 2.6.

Note: the RIEP method derives, application by application, the refrigerant needs, i.e. the refrigerants charged in new equipment and the refrigerants charged for re-filling existing equipment. These refrigerant needs are called demand.

Once the refrigerant demand has been calculated, it is cross-checked with refrigerant sales data as declared by refrigerant manufacturers and distributors. In many countries the refrigerant quantities sold are monitored; the refrigerant distributors and manufacturers publish their annual sales of CFCs, HCFCs, and sometimes HFC refrigerants. At the global level, AFEAS (Alternative Fluorocarbons Environmental Acceptability Study) publishes every year the quantities of refrigerants (by type) sold by the chemical manufacturers in developed countries. Those data have been used in the past to forecast global emissions of CFCs, HCFCs, and HFCs.

It has to be underlined once again that 2009 is the last year of published data by AFEAS and so, from now on, no public data will be available for global markets of refrigerants detailed by refrigerant types.

2.1.1 Global refrigerant demand by refrigerant types

The calculation-module linked with the RIEP database allows merging refrigerant quantities by type as well as by application; data are presented for year 2006 in Table 2.1.

This report presents one major change compared to the 2003 report, because of a previous overestimate of Chinese commercial refrigeration based on the references that were used (marketing reports). The consequence is that the CFC-12 demand is reduced by a factor 2 in 2006 compared to that calculated in the 2003 report.

Table and Figure 2.1 - Global refrigerants demand from 1990 to 2006 (in tonnes).

Refrigerant demand (t) in 2006		
CFC	R-11	6 331
	R-12	20 328
	R-502	5 579
HCFC	R-22	376 992
	R-408A	3 443
	R-401A	772
	R-123	6 295
HFC	R-134a	135 569
	R-404A	28 279
	R-407C	24 607
	R-410A	28 922
	R-507	3 986
	R-413A	143
Others	R-717	26 194
	R-600a	2 869
Total	**All**	**670 309**

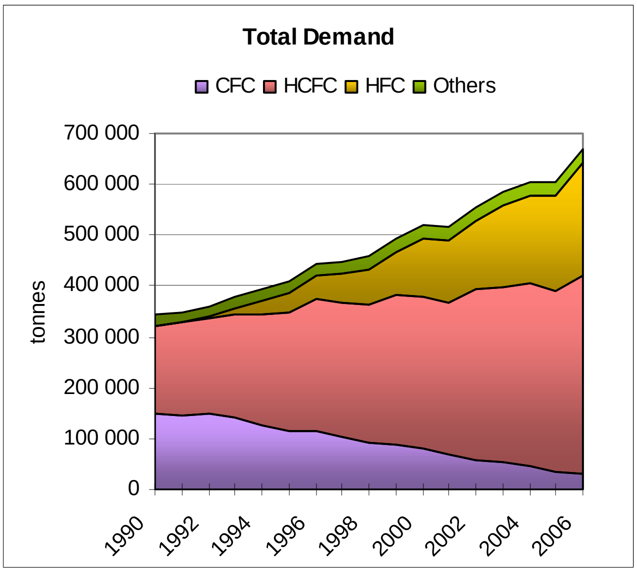


Table 2.1 and Figure 2.1 summarize the essential developments from 1990 to 2006. The total refrigerant demand for all refrigerant types has increased from 345,000 tonnes in 1990 to nearly 670,000 tonnes in 2006, which represents an increase of nearly 100%. This emphasises the impact of the economic growth of fast developing countries on the total, with a special mention to China.

Globally the annual CFC refrigerant demand has decreased from 150,000 tonnes in 1990 to 32,000 tonnes in 2006. The 2006 CFC demand represents about 5% of the total refrigerant demand.

The annual HCFC demand has increased from 174,000 to 387,000 tonnes in 2006 (around 58% of the total demand) and the HFC demand that was negligible in 1990 has raised to about 221,000 tonnes in 2006 (33% of the total demand).

The annual ammonia demand has increased from 22,000 to 26,000 tonnes in 2006, and the HC demand, which was nil in 1990, is in the range of 2,800 tonnes in the year 2006.

2.1.2 Refrigerant demand by application sector and by country

Figures 2.2 and 2.3 present the refrigerant demands, including HCs and ammonia split by application and for the main countries or country groups.

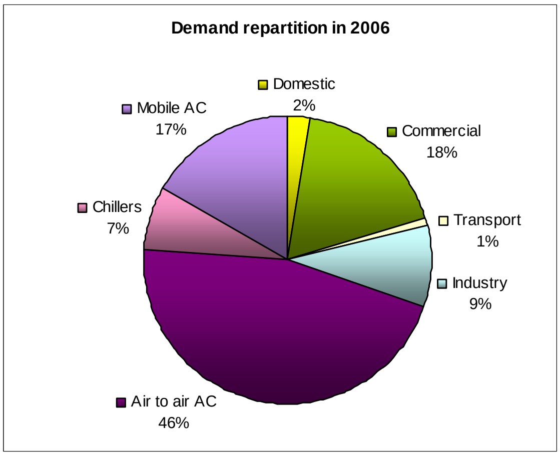


Figure 2.2 - Refrigerant demand split by application.

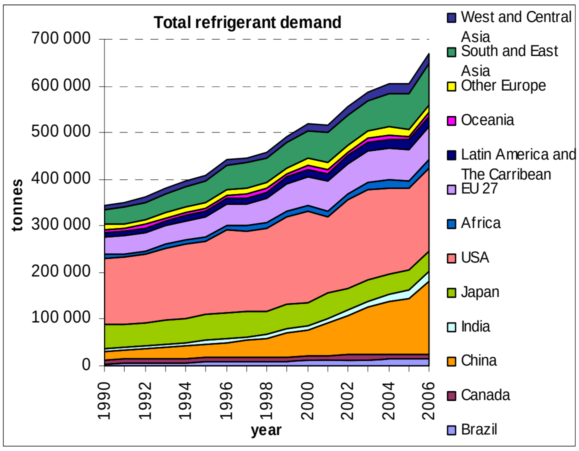


Figure 2.3 - Refrigerant demand split by country and country groups.

Figures 2.4 and 2.5 present HFC demands split by application and by countries.

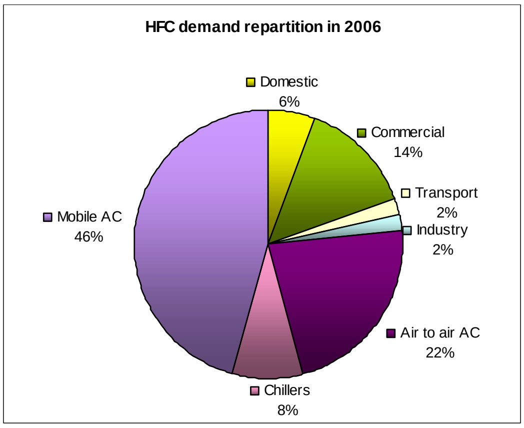


Figure 2.4 - HFC demand split by application.

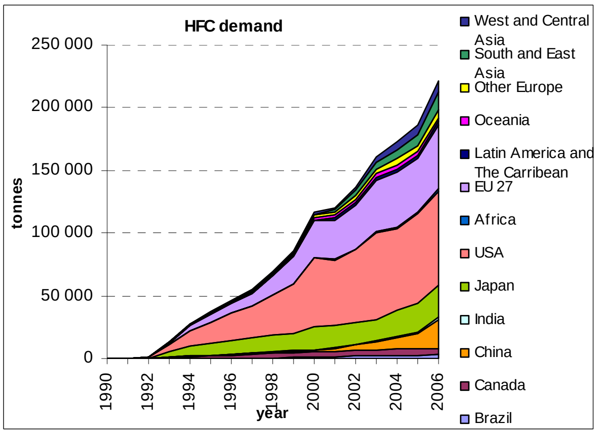


Figure 2.5 - HFC demand split by country and country groups.

Figure 2.2 indicates that when all refrigerants are accounted for, the dominant sectors are commercial refrigeration and stationary air conditioning. For HFC demand, the dominant sector is MAC with 46 % of the HFC demand.

The refrigerant demand in the U.S. is still the dominant one even if the Chinese growth is the main driver of the total refrigerant demand.

EU 25 needs for HFCs are around 40,000 t in 2003. In the U.S., because of the R-134a demand for the MAC sector, the needs are higher: 69,000 tonnes.

2.2 Refrigerant banks, by application sector and by country

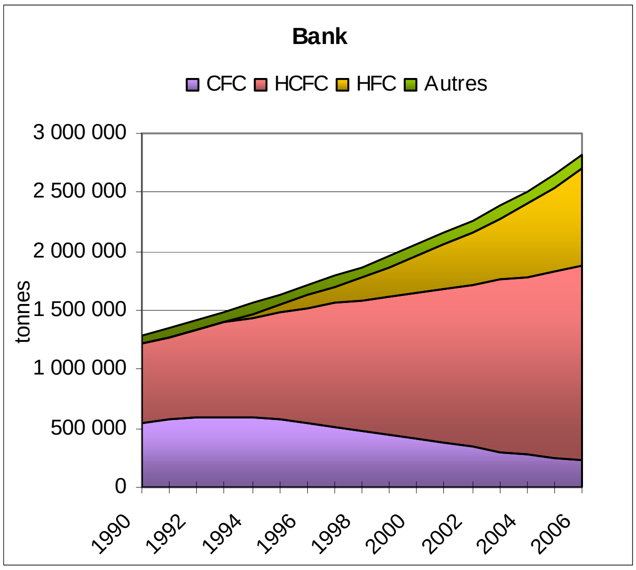
The calculation of refrigerant banks requires the determination of all installed bases and fleets of equipment for their complete lifetime. Banks of refrigerants vary substantially in sizes and in refrigerant types depending on the application sector and the country.

In 2006, the sum of all banks of all refrigerant types (see Figure 4.2) **is calculated at 2,815,000 tonnes.** The global bank is roughly equal to 4.5 times the annual demand. The refrigerant banks and the annual refrigerant demands follow the same trends:

- the size of the CFC bank is decreasing but, it still represents around 230,000 tonnes, which is about 8% of the total refrigerant bank in 2006
- HCFCs represent 1,645,000 tonnes, which equals about 58% of the total bank
- HFCs represent slightly less than 821,000 tonnes, which is around 29% of the total bank
- whereas the remaining 4% of the bank consists of ammonia and HCs.

Table 2.2 – Global refrigerant banks (t).

Refrigerant bank (t) in 2006		
CFC	R-11	36 611
	R-12	173 895
	R-502	17 313
HCFC	R-22	1 585 777
	R-408A	10 592
	R-401A	3 794
	R-123	45 923
HFC	R-134a	576 793
	R-404A	69 354
	R-407C	71 498
	R-410A	93 602
	R-507	8 142
	R-413A	1 979
Others	R-717	109 793
	R-600a	10 325
TOTAL	**ALL**	**2 815 391**



The total refrigerant bank increased by 120% for the period from 1990 to 2006.

Figures 2.6 and 2.7 present the refrigerant banks, including HCs and ammonia, split by application and for the main countries or country groups.

Comparing Figure 2.6, which represents the global refrigerant bank by sector and Figure 2.8, which represents the HFC bank also by sector, it is obvious that the very different schedule of refrigerant changes per application leads to strong differences in the domination of one sector over the others. The emphasis made on mobile air-conditioning (MAC) systems for example is related to the rapid phase out of CFC-12 in this sector as of 1992, which consequently leads to a significant market share of MAC for HFCs. In fact, taking into account all refrigerants, the dominant sectors are stationary air conditioning and then commercial refrigeration. Those two sectors represent about 70% of the total use of refrigerants.

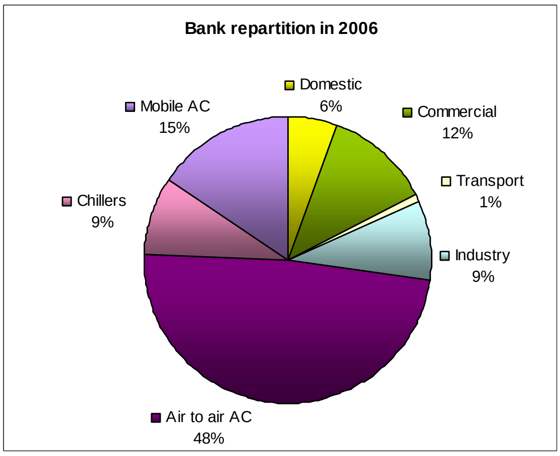


Figure 2.6 – Refrigerant bank in 2006 split by sector.

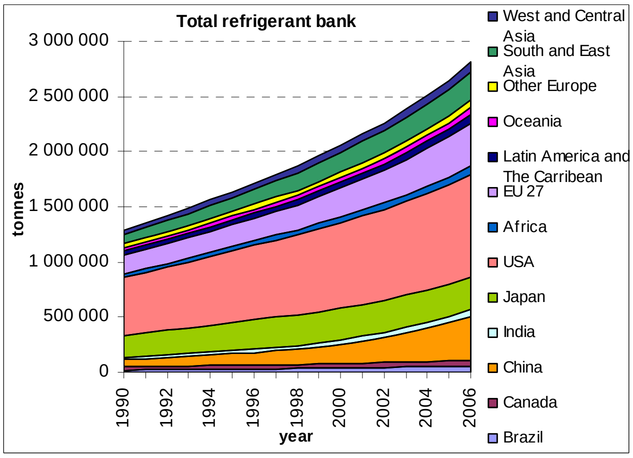


Figure 2.7 - Refrigerant bank - split by country.

Figures 2.8 and 2.9 present HFC demands split by application and countries.

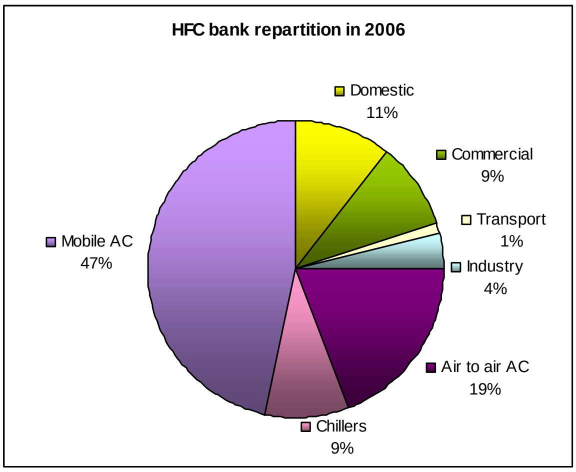


Figure 2.8 – HFC bank in 2006, split by sector.

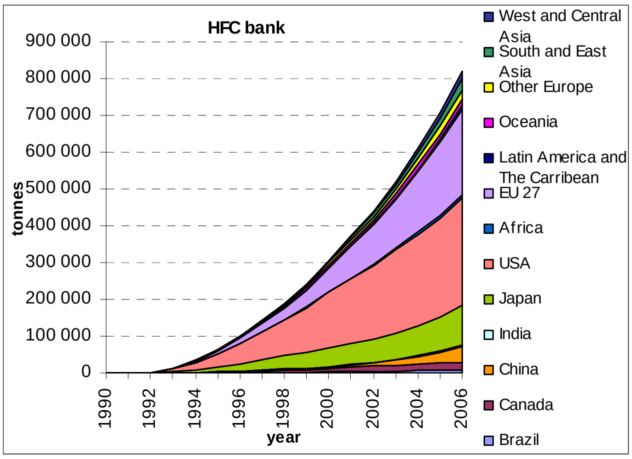


Figure 2.9 - HFC bank - split by country.

57% of the total amount of refrigerants is banked in stationary air-conditioning equipment including chillers (9%) (see Figure 2.6). This confirms the trends observed on the annual refrigerant demand.

Due to the rapid change from CFCs to HFCs, MAC systems (which contain only 15% of the total refrigerant bank) represent 47% of the total HFC refrigerant bank (see Figures 2.8 and 2.9). This important observation indicates the main future trends when the HCFC phase-out has to be accomplished. The HCFC bank is currently the largest bank and 78% (chillers included) of it is contained in stationary air-conditioning systems.

2.3 Refrigerant emissions, by application sector and by country

Based on the bottom-up approach, taking into account all refrigerant types in all refrigerating and air-conditioning systems, it is possible to derive the refrigerant emissions for all refrigerant types for the period from 1990 to 2000.

Table 2.3 – Refrigerant emissions of all refrigerant types (tonnes).

Refrigerant emissions in 2006 (t)		
CFC	R-11	6 958
	R-12	35 195
	R-502	5 430
HCFC	R-22	233 686
	R-408A	3 172
	R-401A	958
	R-123	3 983
HFC	R-134a	82 825
	R-404A	14 663
	R-407C	7 074
	R-410A	7 918
	R-507	2 271
	R-413A	616
Others	R-717	19 562
	R-600a	231
TOTAL	All	**424 542**

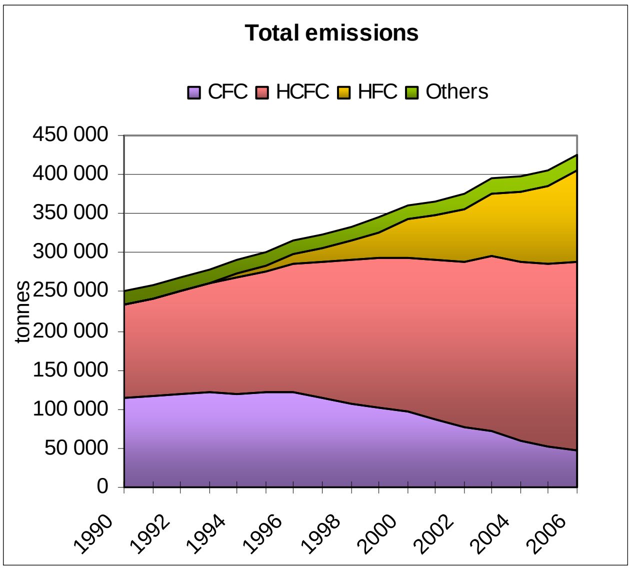


Table 2.3 presents the development of emissions of all refrigerant types from 250,000 tonnes in 1990 to 425,000 tonnes in 2006:

- CFC emissions reach a maximum value in 1995 at 120,000 tonnes, and decrease to 47,000 in 2006 due to their phase out,
- HCFC emissions increase from 156,000 tonnes to 242,000 tonnes, and
- HFC emissions increase from zero to around 115,000 tonnes.

Yet, the sum of the CFC and HCFC emissions equals two third (68%) of all refrigerant emissions.

Note: the management of refrigerant containers that are used every year both for charging new equipment and for servicing of the installed base implies the release to the atmosphere of de minimis the vapour heel that represent about 3% of the refrigerant charge, and often the liquid heel representing between 5 and 8%. For those inventories, the refrigerant heels are considered of 10% of the annual sales. Those emissions **are not taken into account** in the refrigerant emission figures related to refrigeration and air-conditioning equipment.

Table 2.4 - Emissions due to large containers heels (tonnes)

2006	Domestic	Commercial	Transport	Industry	Air-to-Air AC	Chillers	Mobile AC	TOTAL
CFC	129	817	21	484	1	784	568	2 803
HCFC	-	6 766	213	2 206	22 384	1 728	398	33 696
HFC	1 065	2 653	379	409	4 324	1 637	8 794	19 261
Others	249	71	-	2 184	-	29	-	2 534
Total	1 444	10 306	613	5 283	26 709	4 179	9 760	58 294

Figures 2.10 and 2.11 present the refrigerant emissions, including HCs and ammonia, split by application and for the main countries or country groups.

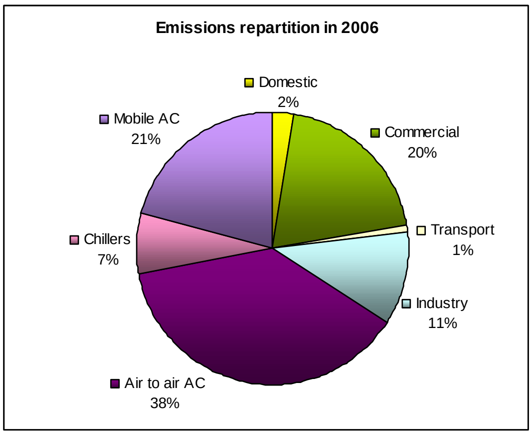


Figure 2.10 – Refrigerant emissions in 2006, split by sector.

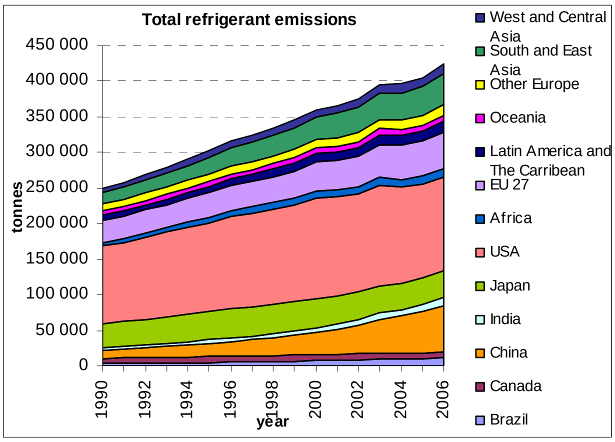


Figure 2.11 – Refrigerant emissions - split by country.

Figures 2.12 and 2.13 present HFC emissions split by application and for the main countries or country groups.

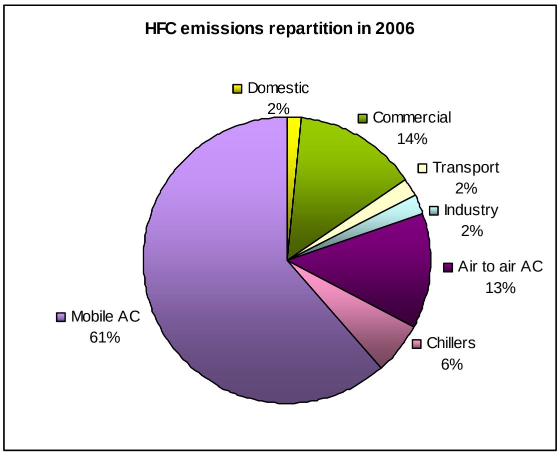


Figure 2.12 – HFC emissions in 2006, split by sector.

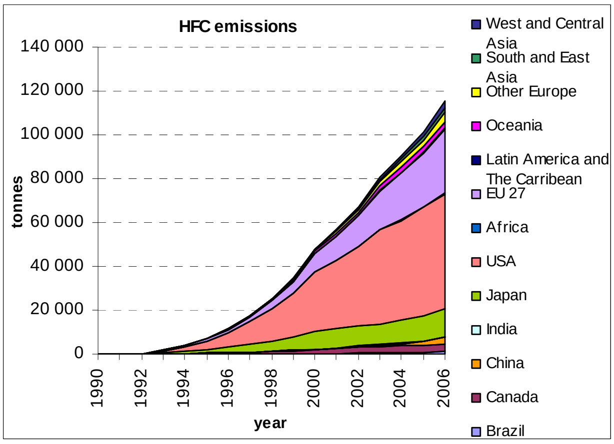


Figure 2.13 – HFC emissions - split by country.

Taking into account all refrigerant emissions (independently of the refrigerant type), 38% come from air-conditioning systems excluding chillers, 20% of emissions come from commercial refrigeration, and 21% from MAC systems. However, when only looking at HFC emissions, the MAC sector represents 61% of HFC emissions. This fact is related to the rapid shift from CFC-12 to HFC-134a, and to the relatively high emission factor, taking into account losses at servicing that apply to MAC equipment.

Commercial refrigeration is also a significant source of emissions characterized by more than 20% of the total refrigerant emissions. Emission rates are three times higher in commercial refrigeration than they are in stationary AC.

Domestic refrigeration, which actually is the sector with the largest number of equipment, is not a significant contributor to refrigerant emissions due to the small refrigerant charges and the low level of emissions.

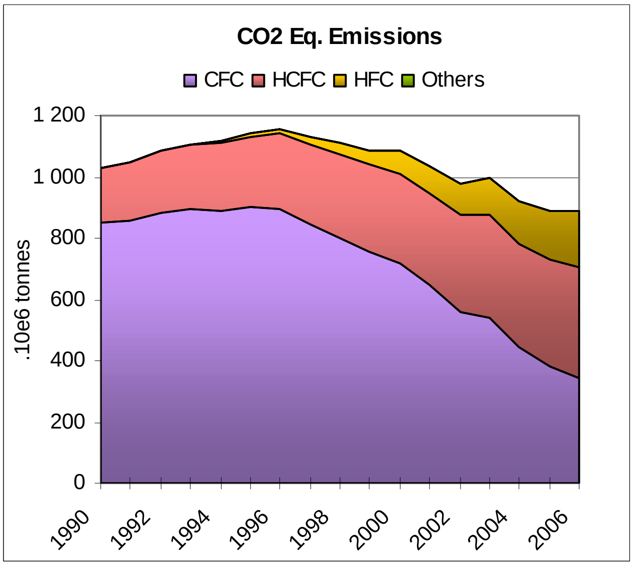
Transportation, even though characterized by a very high emission factor, is a small global contributor due to the relatively small number of equipment.

2.4 Refrigerant CO_2 equivalent emissions, by application sector and by country

The CO_2 equivalent emission calculations are based on GWP values published in the Second Assessment Report of the IPCC.

Table 2.5 – Refrigerant CO_2 equivalent emissions of all refrigerant types (tonnes).

		CO_2 equiv. emissions (t) 2nd Assessment Report
CFC	R-11	26 440 153
	R-12	285 086 629
	R-502	29 834 731
HCFC	R-22	350 532 642
	R-408A	8 402 783
	R-401A	932 246
	R-123	358 515
HFC	R-134a	107 673 924
	R-404A	47 802 130
	R-407C	10 794 708
	R-410A	13 699 040
	R-507	7 495 122
	R-413A	1 170 362
Others	R-717	0
	R-600a	4 617
TOTAL	**All**	**890 227 602**



In 2006, the main contributor to global warming is HCFC-22 (39%). CFC-12 represents still 32% of the total contribution of all refrigerants to global warming in the year 2003, whereas the emissions of CFC-12 are only 8% of the total refrigerant emissions in 2006.

HFCs, accounting for 27% of the total refrigerant emissions, contribute to only 21% of the CO_2 equivalent emissions of refrigerants in the year 2006 because of the relatively low GWP of HFC-134a.

Figures 2.14 and 2.15 present CO_2 equivalent emissions for all refrigerants split by application and for the main countries or country groups.

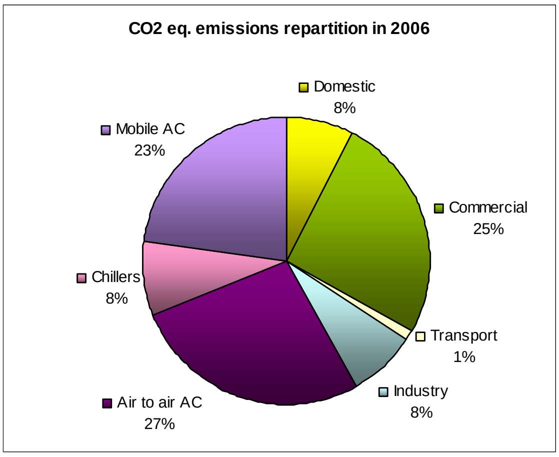


Figure 2.14 – Refrigerant CO_2 equiv. emissions in 2006, split by sector.

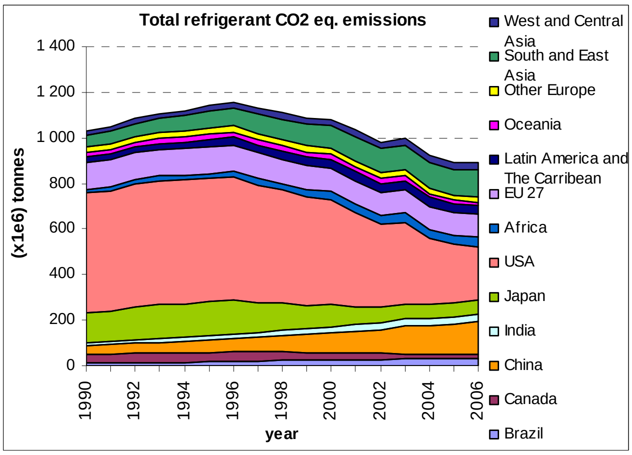


Figure 2.15 – Refrigerant CO_2 equiv. Emissions - split by country.

Figures 2.16 and 2.17 present CO_2 equivalent emissions for HFC refrigerants only, split by application and for the main countries or country groups.

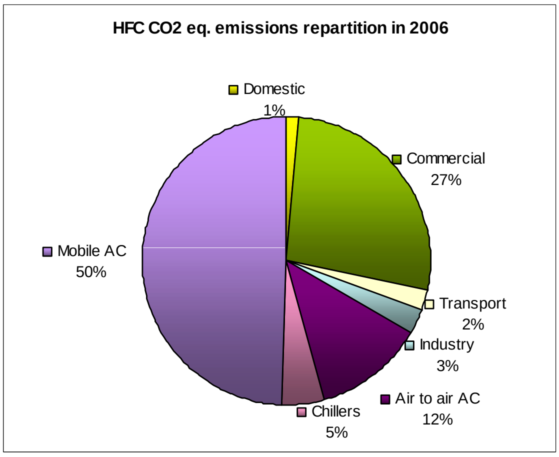


Figure 2.16 – HFC refrigerants, CO_2 equiv. emissions in 2006, split by sector.

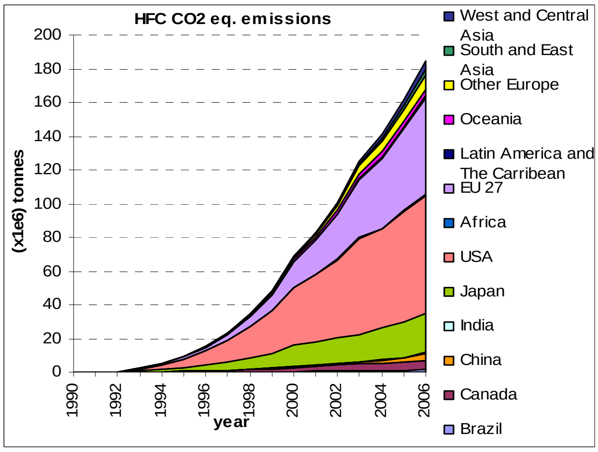


Figure 2.17 – HFC refrigerants, CO_2 equiv. emissions - split by country.

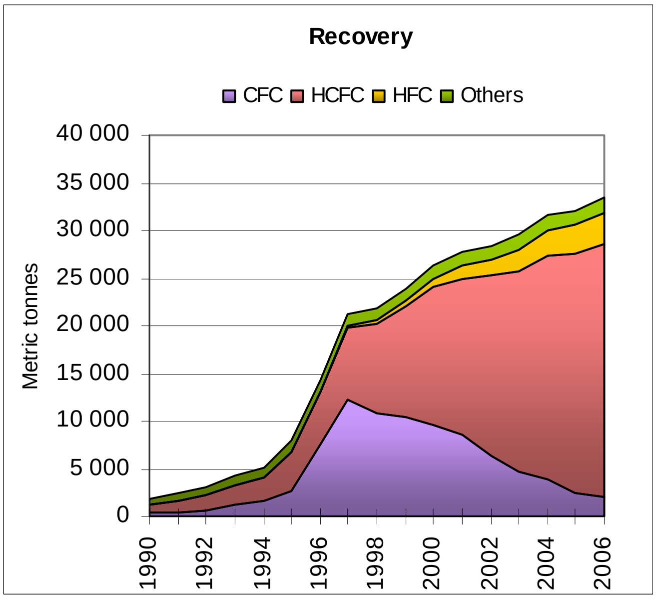
27% of the total CO_2 equivalent emissions come from commercial refrigeration equipment, taking into account all types of refrigerants.

For low temperature applications in commercial refrigeration, the (future) replacement of HCFC-22 by R-404A implies that CO_2 equivalent emissions will significantly increase in this sector. This is due to the high GWP of R-404A (2.2 times higher than the GWP of HCFC-22).

2.5 Refrigerant recovery

Table 2.6 – Recovered refrigerants (tonnes).

Refrigerant recovery (t)		
CFC	R-11	851
	R-12	1 040
	R-502	146
HCFC	R-22	25 139
	R-408A	712
	R-401A	219
	R-123	657
HFC	R-134a	2 704
	R-404A	526
	R-407C	0
	R-410A	0
	R-507	0
Others	R-717	1 625
	R-600a	0
Total	**All**	**33,619**



All quantities of recovered refrigerants calculated are directly linked to the assumptions made on an application-by-application basis and for country groups. Very few data are available on the quantity that is effectively recovered. Moreover, and in particular for CFC-12, the recovered refrigerant can be directly re-used in other equipment without being transferred back to the refrigerant reclaim sector. A high level of uncertainty exists here; if real circumstances are different from the assumptions made for calculations, part of the quantity assumed to be recovered could well be emitted.

2.6 Data quality and data consistency

In this report we have taken two complementary approaches, the first one assesses the quality of activity data and emissions factors, the second compare the consistency of refrigerant demand as derived for each type of refrigerant and for all application by RIEP compared to the refrigerant sales as declared at the global level by AFEAS.

2.6.1 Uncertainties

Depending on the application sector, uncertainties are different either because activity data include different uncertainties or because emission factors may vary significantly from one country to the other.

We have taken a simple approach that gives a quality index expressed in percentages. For activity data: the market, the refrigerant charge, and the equipment lifetime are the main elements that define the data quality. For emission factors: fugitive emissions and recovery efficiency at end of life are the two key parameters.

Uncertainties on input parameters are based on expert judgments of the different sectors.
These values are given in Table 2.7.

Table 2.7 - Uncertainties on input parameters.

Uncertainties on input	MAC	SAC	IND	TRA	COM	DOM
Equipment market (a)	2.50%	2.50%	10%	12.50%	7.50%	2.50%
Equipment lifetime (b)	7.50%	2.50%	7.50%	2.50%	7.50%	12.50%
Equipment average charge (c)	2.50%	12.50%	10%	7.50%	7.50%	2.50%
Emission rate (d)	10.00%	7.50%	10%	7.50%	10%	12.50%
Recovery efficiency (e)	10.00%	7.50%	12.50%	7.50%	12.50%	2.50%

The calculation of the lower and upper thresholds for uncertainties is based on simplified equations presented in Table 2.8. It assumes that uncertainties do not change throughout the years.

Table 2.8 - Calculation of lower and upper thresholds for banks and emissions.

Results	Minimum threshold	Maximum threshold
Bank	1- (a + b + c)	1+ (a + b + c)
EOL	1 –(a + c + e)	1 +(a + c + e)
Fugitive	1- (a + b + c + d)	1+ (a + b + c + d)
Total emissions	(Minimum EOL +Fug)/(EOL +Fug)	(Maximum EOL +Fug)/(EOL +Fug)

Based on those thresholds it is possible to evaluate the uncertainties on banks (activity data) and emissions.

Table 2.9 - Uncertainties on results.

	BANKs	EMISSIONS
MAC	12.5%	21.2%
SAC	17.5%	24.4%
IND	27.5%	37.1%
TRA	22.5%	29.7%
COM	22.5%	32.0%
DOM	17.5%	12.8%
GLOBAL	18.2%	26.6%

2.6.2 Comparison between refrigerant demands (RIEP calculations) and refrigerant markets (declared by AFEAS)

Annual refrigerant sales have been published by AFEAS since 1990. RIEP allows the calculation of the annual demand of refrigerants including the refrigerant charged into new equipment and refrigerants sold for servicing.

AFEAS publishes data only when the cumulative sales are larger than 5,000 tonnes, and therefore data are not available for some components of new HFC blends, such as HFC-125, and HFC-32. Consumptions of all non-Article 5(1) countries are traced, and also of some Article 5(1) countries: Argentina, Brazil, Mexico, and Venezuela.

The comparison of AFEAS data (declared sales) and RIEP evaluation of the refrigerant demand allows crosschecking the consistency of the calculation method at the global level.

- **CFC demand**

Before 1995 the demand is lower than the sales. After the phase-out date of the CFC production, the sales declared by AFEAS decrease rapidly to nearly a zero value in 2000, but the demand still exists during this period. This difference can be explained by a stock-piling effect (end-users buy refrigerant when allowed in order to maintain the CFC-11 chillers after the phase-out date).

The cumulative difference between AFEAS (116,000 t) data and refrigerant CFC-11 need as derived by RIEP (203,000 t) indicates that the CFC-11 has been produced by manufacturers of A5 countries not reporting to AFEAS and the cumulative demand.

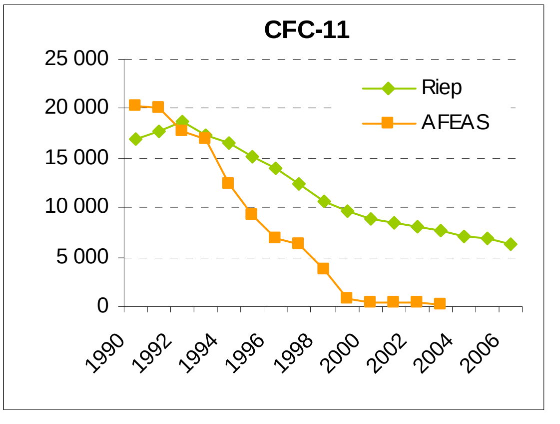


Figure 2.18 – Comparison of CFC-11 demand between AFEAS sales and RIEP calculations.

When comparing the sales as declared by AFEAS and the demand as calculated by RIEP, the stock-piling effect from 1990 to 1995 seems obvious. When making the sum of the CFC-12 sold from 1990 to 2006 and the demand as derived also for the same period, RIEP leads to 1,236,000 t and AFEAS leads to 1,069,000 t (1990 to 2003), leading to a negligible difference on those 13 years. This seems to confirm that sales and usages are disconnected when regulation forbids the sales of refrigerant and tolerates the operation of refrigerating systems after the end of refrigerant commercialization.

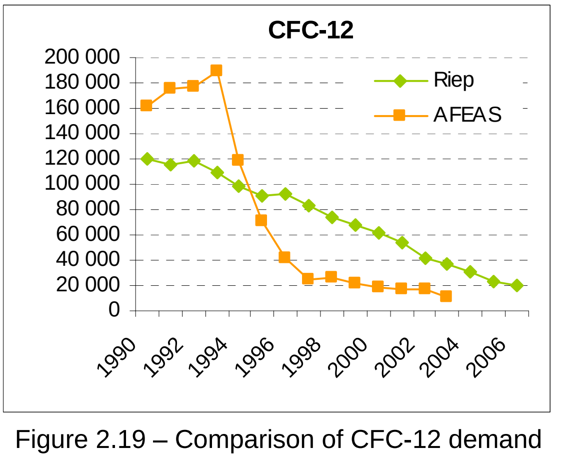


Figure 2.19 – Comparison of CFC-12 demand between AFEAS sales and RIEP.

CFC-115 is one of the two components of R-502.

The cumulated demand between 1990 and 2006 is 82,000 t, compared to the cumulated demand of 75,000 t.

Considering a stock-piling effect beginning in 1989, the difference of cumulated demand and demand is very low.

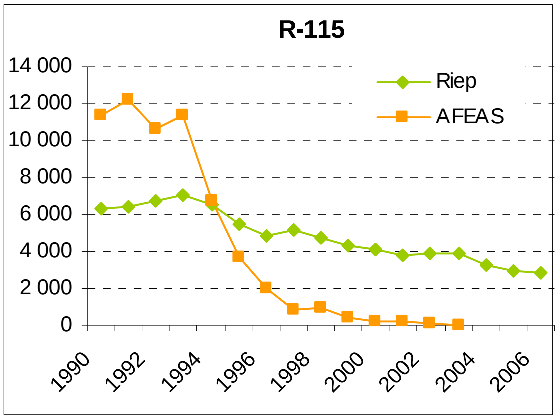


Figure 2.20 — Comparison of CFC-115 demand between AFEAS data and RIEP calculations.

♦ HCFC demand

The comparison between the HCFC-22 demand and the HCFC-22 sales by manufacturers reporting to AFEAS shows clearly the impact of HCFC-22 production in developing countries. It is certainly a reason why AFEAS has stopped at the end of 2009 to make this reporting for HCFC-22. It appears that more of it is produced out of AFEAS manufacturers.

The cumulative production as reported by AFEAS from 1990 to 2006 is of 3,245,000 tonnes, and the cumulative needs calculated by RIEP are of 4,600,000 tonnes.

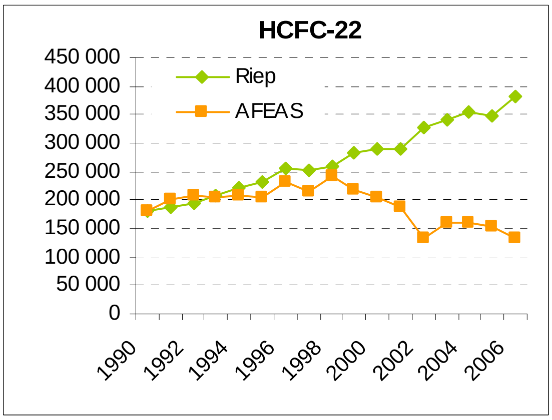


Figure 2.21 — Comparison of HCFC-22 demand between AFEAS data and RIEP calculations.

♦ HFC demand

The HFC-134a demand calculated by RIEP is very closed to the declarations of sales.

The growth rate is similar and the cumulated values from 1990 to 2006 are quite the same: 1,181,000 tonnes for the total sales (RIEP) and 991,000 tonnes for the cumulated demand (AFEAS), which is still a difference of about 15%. One of the main issues is to verify if the emission rates of MAC systems have been effectively decreasing as modelled in RIEP since 2000.

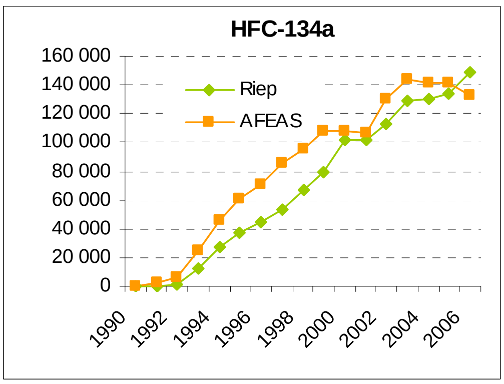


Figure 2.23 – Comparison of HFC-134a demand between AFEAS data and RIEP calculations.

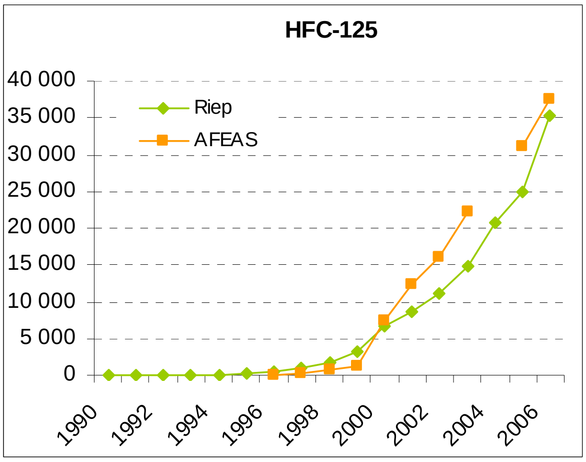


Figure 2.24 – Comparison of HFC-125 demand between AFEAS data and RIEP calculations.

HFC-125 is used in refrigerant blends such as R-404A, R-507, R-410A, and R-407C.

The trend is the same between sales as reported by AFEAS and the demand as calculated by RIEP. It can be noticed that even if AFEAS data were missing in 2003, the RIEP derivation leads to similar evaluation of HFC-125 needs in 2006. These results confirm that the assumptions for refrigerant changes are good and that HFC-125 is manufactured only AFEAS manufacturers.

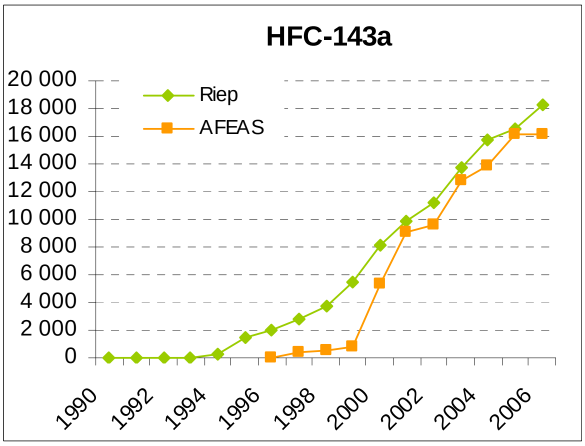


Figure 2.24 – Comparison of HFC-143a demand between AFEAS data and RIEP calculations.

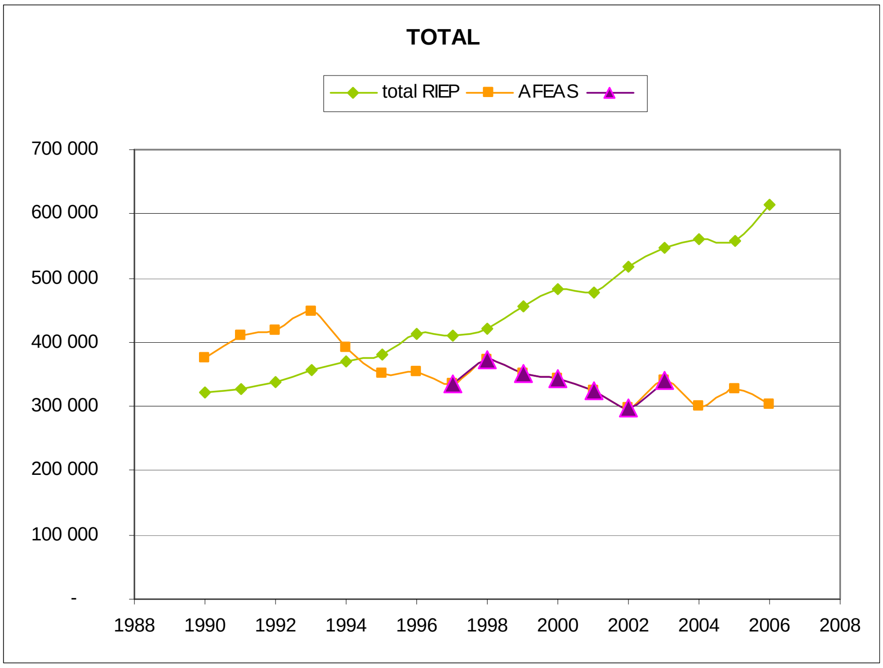
HFC-143a is used in refrigerant blends (R-404A, and R-507) for low-temperature applications, in commercial refrigeration, and mainly in Europe.

The trend is the same between sales, as reported by AFEAS, and the demand as calculated by RIEP. So lessons from the comparison are identical to those drawn for HFC-125.

♦ Total demand

The trend as shown by RIEP indicates the dominance of HCFC-22 sales, which makes the difference between AFEAS data and RIEP calculations since 1998. As shown in the previous charts analyzing sales and demand refrigerant by refrigerant, the only significant difference between AFEAS data and RIEP calculation is related to HCFC-22.

Figure 2.25 – Comparison between AFEAS sale data and RIEP calculated refrigerant needs.



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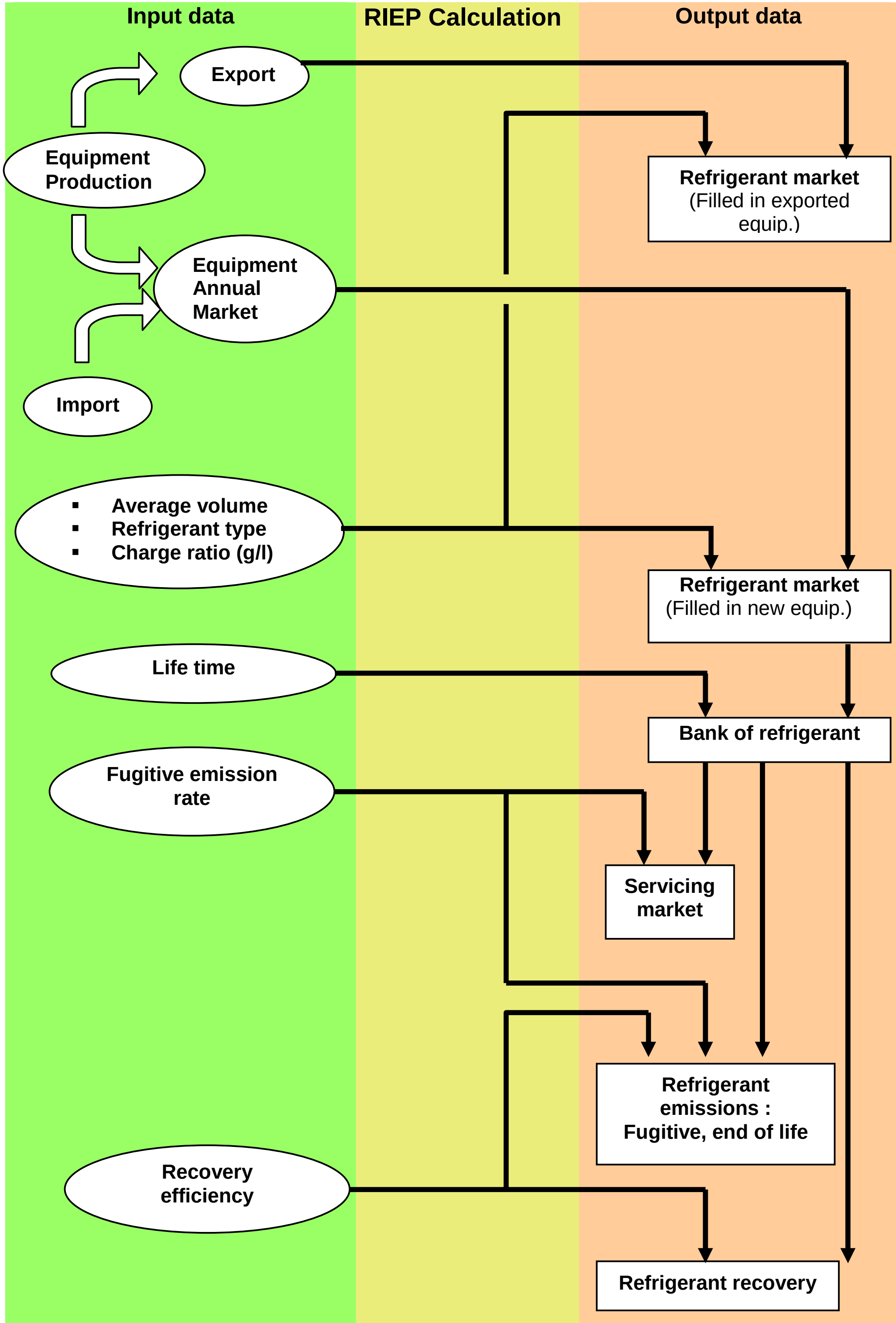

Figure 3.1 – Calculation steps for refrigerant emissions from domestic refrigerators [PAL03b].

3. DOMESTIC REFRIGERATION

The inventory methodology for domestic refrigeration remains identical to the one in the previous report [CLO06], except the mean lifetime of equipment that is replaced by a survival curve (see chapter 1). The main steps are reminded in Figure 3.1.

3.1 Data and assumptions

The data that have been collected and updated are as follows:

- appliance markets,
- appliance production,
- typical refrigerator volumes,
- ratio of the refrigerant charge to the refrigerator volume (depending mainly on the appliance technology),
- refrigerant choice.

The introduction of a survival curve instead of a mean lifetime in the calculation method implies that all data have to be available in the data base from the '70s.

3.1.1 Domestic refrigeration market and production

"Appliance magazine" is one of the major sources being used at the CEP for the global equipment sales of refrigerators ([APP03], [APP08], and [CLO08]). Other sources like Gifam for France have also been used. For domestic refrigeration, if the year of the inventory is 1990, considering an average lifetime of 15 years in the U.S. for example, sales should be known from the year 1975 (=1990-15). Figure 3.2 shows a sample of available data at the global level, limited in the past to the year 1980 for a country like Australia, and to the year 1989 for the U.S.

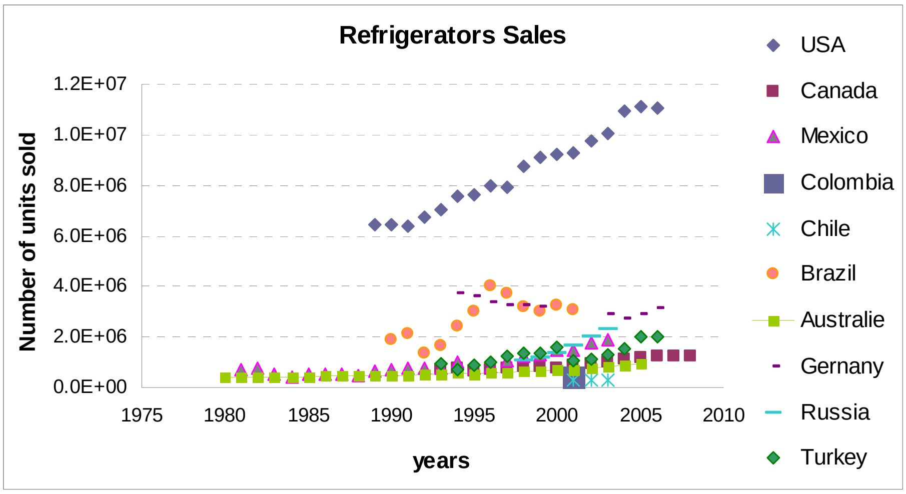

Figure 3.2 - Sample on refrigerators sales.

As shown in Figure 3.2, data can be missing: the historical ones (usually before the '90s), between two years or two periods given by a reference source, or for small countries. These data, for the refrigerator market or production, are calculated using an economic correlation taking into account the country GDP/Capita data, the population, and the appliance market. Between a high limit of the GDP/Capita value (where market saturation is verified) and a low limit of this value (where the market is limited to the upper social classes), it can be assumed that the population/market ratio is proportional to the GDP/Capita value within a geographical zone and along the years for each country.

Table 3.1 provides the equipment sales for 2006 in China, U.S., India, Japan, Brazil, Russia, Korea, and EU27, accounting for 76% of the total demand of refrigerators for this year. This scheme has not changed much since the '90s; therefore, the data quality of the market of refrigerators for these countries is essential for the global inventory quality.

Table 3.1 – Share of refrigerators sales in 2006.

Country/region	*Demand(1,000 units)*	*Share (%)*
World total*	**79 287**	100
China*	12 180	15.4
United states*	11 077	14.0
India*	4 569	5.8
Japan*	4 252	5.4
Brazil*	3 798	4.8
Russia*	3 242	4.1
Korea*	2 763	3.5
EU 15**	15 649	19.7
EU New**	3 016	3.8
Total	60,575	76.4

* JARN, November 2008, n° 478
*** Includes estimated values by the curve of refrigerator sales per capita as a function of GDP/capita for some countries*

The overall market data as well as the production data are determined by bringing the countries together in certain geographical regions and by subsequently combining the regions. The consistency of data can be checked at the global level, i.e., by verifying that the market of a given year is not very different from the production of that same year. Figure 3.2 shows the development of the overall market and the production from 1990 through 2006, and indicates the need of regular updates. From 1990 to 2006, the annual production has increased from 51 to 116 millions units.

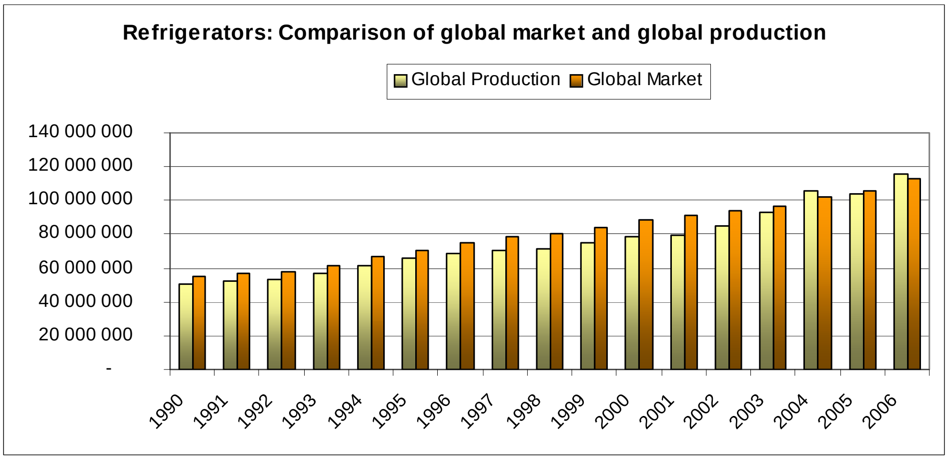

Figure 3.3 – Global market and production of refrigerators.

As shown in Figure 3.3, differences between the global refrigerator market and the refrigerator production of a specific year are very small, which is an indicator of the level of consistency.

Calculations indicate that each geographical zone is for a large part self-supporting. It means that appliances are mainly bought in the region where they are produced. However, some transfer exists between close regions; especially between Eastern Europe and Western Europe, and between Mexico and South America.

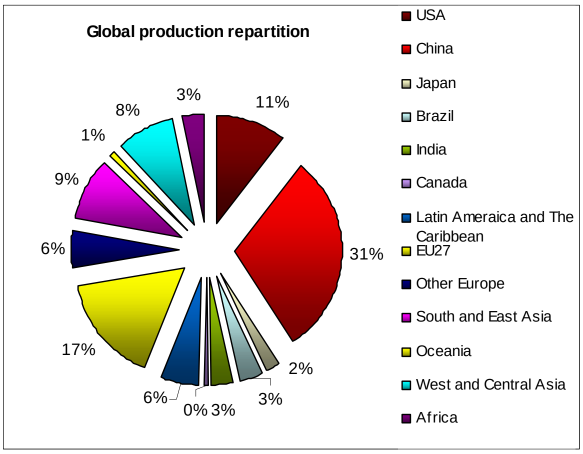

Figure 3.4 – Production share in 2006.

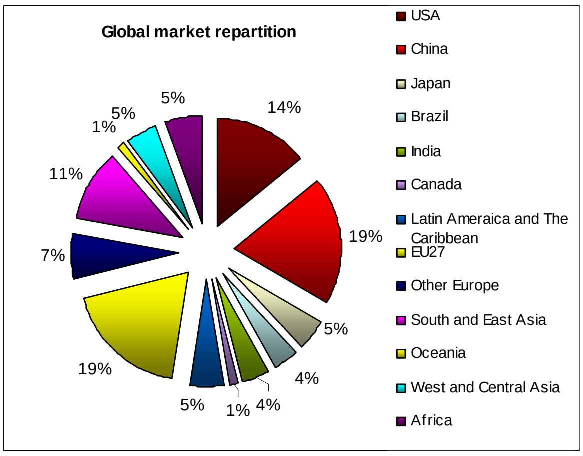

Figure 3.5 – Market share in 2006.

The 2006 production and market shares are presented in Figures 3.4 and 3.5, which show the importance of the Asian market and their production share. This is due in particular to the fast growth of China and India, and the presence of Japan and North Korea. This region is analyzed with a special attention because of this fast market transformation; moreover this growth is coupled with refrigerant change, especially in China and India. Indeed, China started phasing out CFC-12 and replacing it by HFC-134a as of 2002. The European manufacturers acting in China brought as well HC-600a as an alternative to HFC-134a.

3.1.2 Refrigerator characteristics

- **Average volume and Refrigerant charge**

The Center for Energy and Processes has carried out studies [PAL04, PAL03a] to determine the ratio between the refrigerant charge and the useful volume of refrigerators and freezers. The ratio (in g/L) is dependent on the refrigerant in use and is specific for CFC-12, HFC-134a, and HC-600a.

Figure 3.6 shows the different volumes used in calculations and Figure 3.7 ratios defined for each region. Updating data have been taken into account: only for the U.S. and Canada, CFC-12 ratio for freezers and HFC-134a ratio for refrigerators have been significantly modified [INE09].

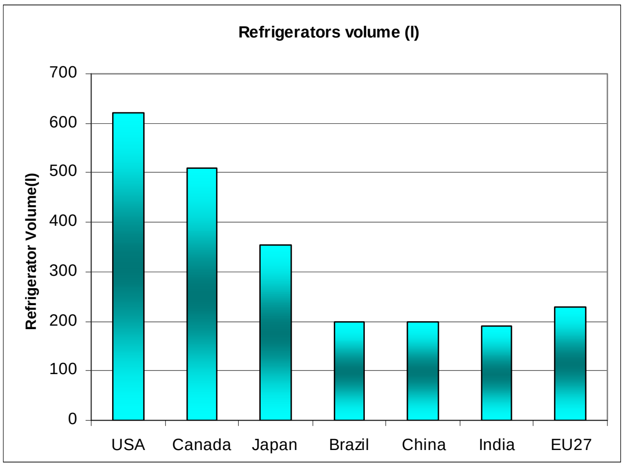

Figure 3.6 – Refrigerator volumes depending on the region.

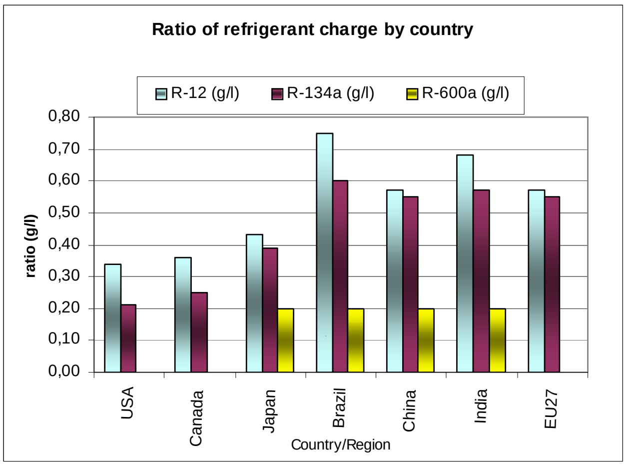

Figure 3.7 – Ratios of refrigerant charge by country for refrigerators, updating in 2006.

♦ Lifetime

The lifetime is a key parameter for the bank size and it varies widely according to the people wealth, and so the lifetime is significantly longer in developed countries than in developing countries. Table 3.2 presents the mean lifetime by country. As explained in Section 1, a survival curve is associated to it.

Table 3.2 - Mean lifetime (refrigerators and freezers).

	USA	***Canada***	***Brazil***	***China***	***India***	***Japan***	***EU27***
Lifetime (years)	15	15	16	20	20	15	15

♦ Refrigerant type

The choice of refrigerant depends on the Montreal Protocol schedule for the phase-out of CFCs. In developed countries, HFC-134a has replaced CFC-12 as of 1994 in Europe and since 1995 for all developed countries. In Japan, HC-600a has been introduced since 2003 and is replacing progressively HFC-134a. In 2006, about 90% of the market of new refrigerators are running with HC-600a in Europe and 20% in Japan.

The shift from CFC-12 to HFC-134a in Article 5 countries has begun progressively from 1999 to 2005. In comparison to the previous study [CLO06], some corrections have been made:

- In Brazil, the legislation banning CFC in new equipments since 2001 has been taken into account [RES00]
- HC-600a is not used in Central and South America [UNE06]
- In India, CFC-12 phase out was done in 2005, HC-600a has been slowly introduced as of 1995 to represent a share of 35% in 2006.

Available information on refrigerants in use and the shares of each refrigerant are set up on the basis of geographical regions.

♦ **Fugitive emissions**

Fugitive emissions are well known for the developed countries (data coming from after sale services). The number of refrigerators where the refrigerating circuit has broken is very small, typically in the range of 1/10 000. For developing and also less developed countries, these emissions seem to be largely overestimated by many country reports. In this study, more reasonable values, such as 5 to 10 times the ratio of developed countries, are used in calculations for establishing emissions.

The same pattern is used for emission ratios related to the servicing that are based on servicing data and country reports. The level of emissions is considerably different and very much depends on the qualification of operators.

Table 3.3 presents emission rate by country. It is considered as an average constant rate by year.

Table 3.3 - Average emission rate by year (refrigerators and freezers).

	USA	***Canada***	***Brazil***	***China***	***India***	***Japan***	***EU27***
% of nominal charge by year	0.01	0.01	0.5	2	5	0.01	0.01

♦ **Refrigerant recovery**

Refrigerant recovery at end of life is the main issue for refrigerator emissions, and depends on regulations. The parameter of recovery efficiency is most often zero, except in Europe, the U.S., and in Japan. More precise data are expected from the U.S. EPA about refrigerant quantities recovered in the U.S.

3.2 Results of calculations: refrigerant demand, banks, and emissions

3.2.1 Refrigerant banks

Compared to 2003 Inventories [CLO06], the evolutions in the calculation method impact part of the results. For instance:

- New estimates for equipment markets between the years 1970 and 1990 imply changes on the bank results for the year 1990 within a range of ±5 to ±20%
- The use of a survival curve instead of the average lifetime implies changes in the bank values for the year 1990 from ± 0.5% to about ±10%.

Globally the CFC bank has culminated at about 110,000 tonnes in 1994 and has begun to decrease slowly. Since 2004, the rate of the decrease is even higher (8 to 10% per annum) due to the phasing out of CFC use in new equipments between 2001 (Brazil [RES00]) and 2005 for A5 countries (see Figure 3.8).

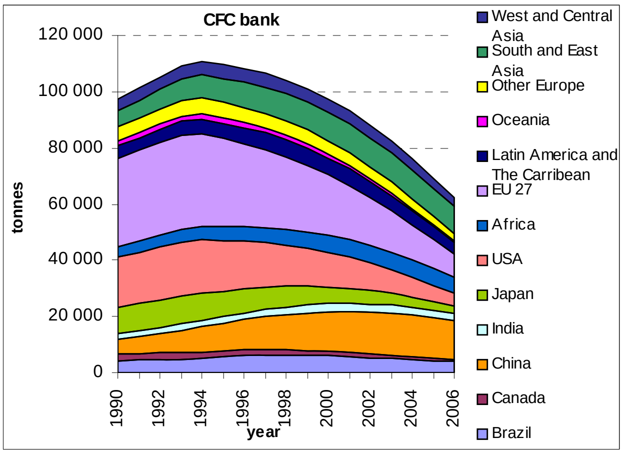

Figure 3.8 - Global bank of CFC-12.

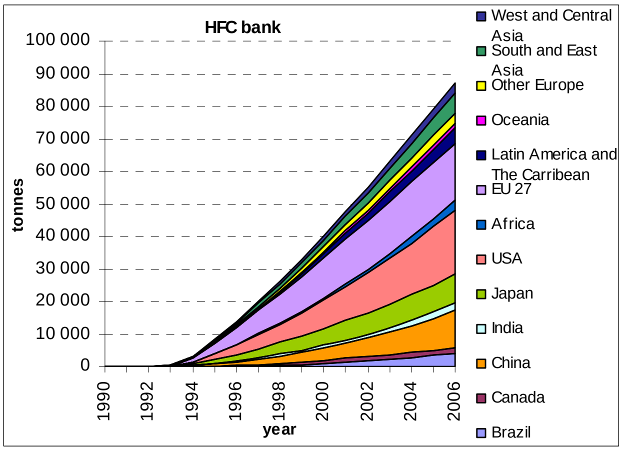

Figure 3.9 - Global bank of HFC-134a.

Figure 3.9 shows the raise of the HFC-134a bank in refrigerators from nil in 1992 to about 87,000 tonnes in 2006.

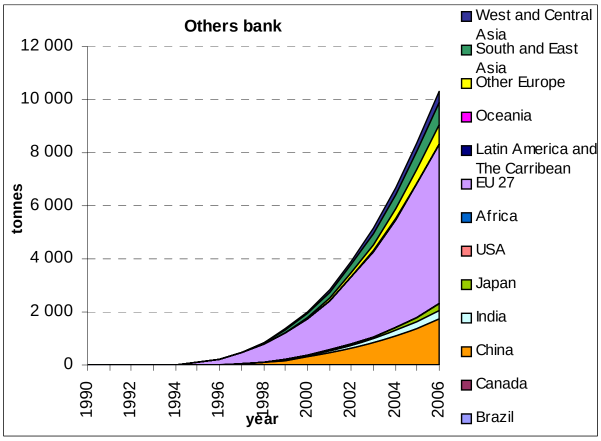

Figure 3.10 - Global bank of HC-600a.

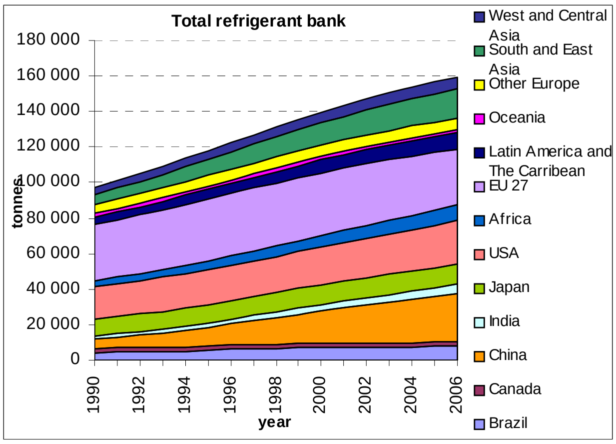

Figure 3.11 –Total bank.

The increase in HC-600a use (see Figure 3.10) is very steep due to the rapid change in EU from HFC-134a to HCs as of 1994. Until now, HC-600a has never been used in North America nor in South America and the shift is low in other regions. Some manufacturers are beginning to shift from HFC-134a to HC-600a in Japan and Korea, and more recently in China (Figure 3.10). For the future, the development of HC-600a use outside Europe will be followed carefully.

In 2006, the CFC-12 bank represents still 39% of the global bank of refrigerants used in domestic refrigeration (see Figure 3.11).

3.2.2 Refrigerant emissions

Refrigerant emissions due to domestic refrigeration are estimated to more than 10,000 t in 2006. In this sector, emissions are essentially coming from the equipment end-of-life, which explains the importance of CFC emissions (see Figures 3.12 and 3.13). HFC refrigerators have started to be marketed only in 1994.

Compared to the previous report [CLO06], the introduction of a survival curve based on a mean lifetime of approximately 15 to 20 years (depending on the countries) affects the trends of emissions, which clearly appears on Figure 3.13. In Europe for instance, the first end-of-life HFC-134a equipment occurs in 2004 instead of 2009, if a mean lifetime had been used. On Figure 3.12, the rise of emissions between 2004 and 2006 corresponds to the impact of the start of end-of-life emissions in developed countries.

If emissions are compared to the bank, the significant share of Asia comes from higher emission rates, which are estimated at 2% for China [AFE03]. HFC-134a emissions in China, represented on Figure 3.13, are not end-of-life emissions: they are fugitive ones, due to higher rates of failures, and lower qualification of technicians for repair. For the future, it will be necessary to verify that emission rates of developing countries remain at such high values.

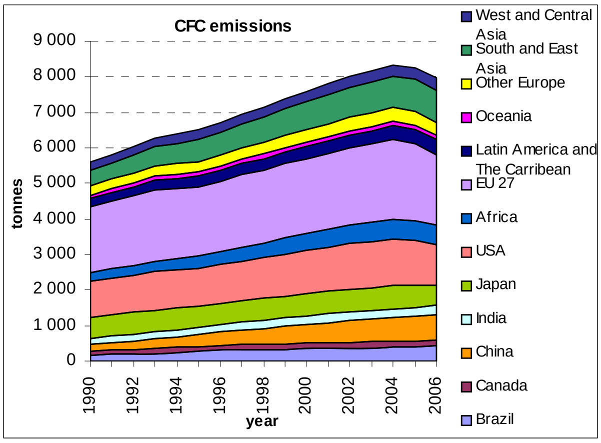

Figure 3.12 – CFC-12 emissions.

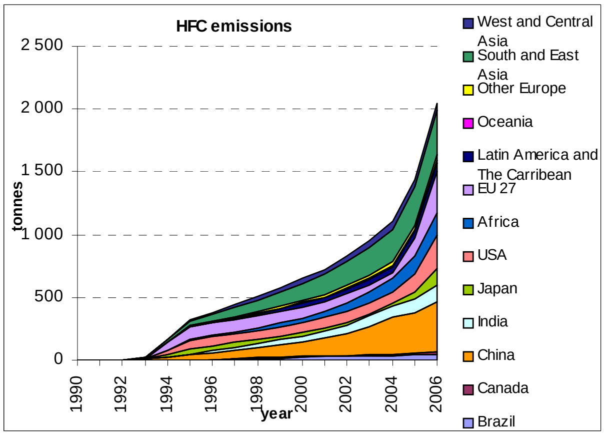

Figure 3.13 – HFC-134a emissions.

HC emissions are low (see Figure 3.13) and are only due to failures and to refrigerant handling.

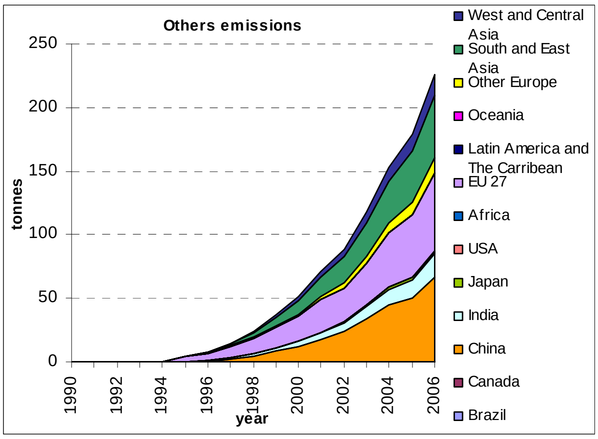

Figure 3.14 – HC-600a emissions.

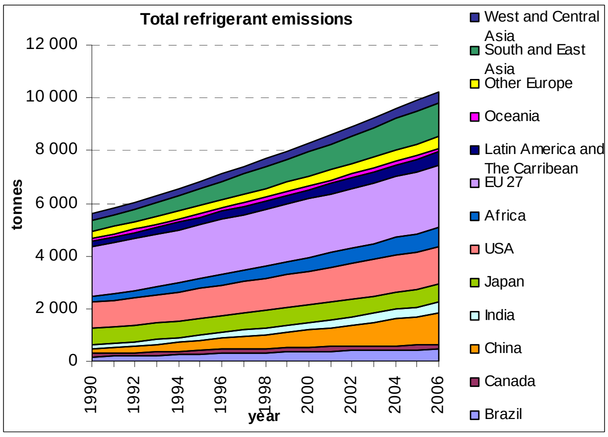

Figure 3.15 – Total emissions.

3.2.3 Refrigerant emissions in equivalent CO_2 tonnes

For domestic refrigeration, CFC emissions are estimated around 65 millions of tonnes equivalent CO_2 in 2006. The very high emissions of CFCs expressed in CO_2 equivalent are due to the high GWP of CFC-12 in the 2nd AR (8,100 kg $_{CO2}$/kg $_{CFC-12}$) as shown on Figure 3.16. The analysis of Figures 3.16 and 3.17 indicates that there is more than a factor 20 between CO_2 equivalent emissions of CFCs and the ones of HFCs for the domestic refrigeration sector.

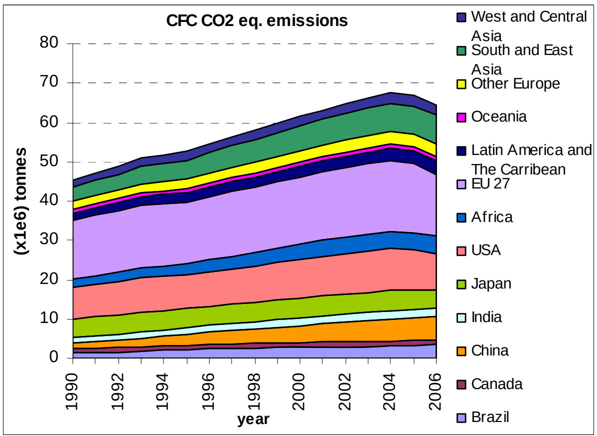

Figure 3.16 – Eq. CO_2 CFC-12 emissions (10^6tonnes).

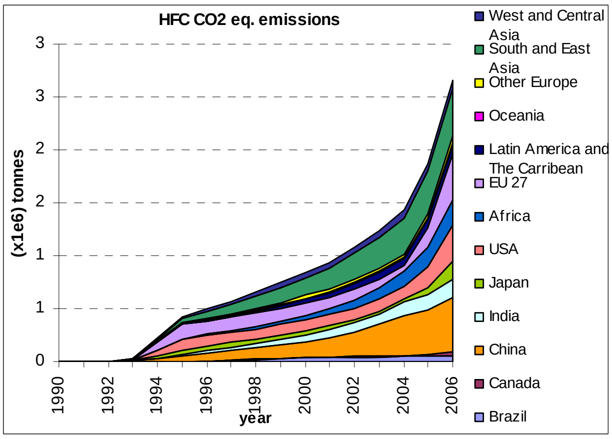

Figure 3.17– Eq. CO_2 HFC-134a emissions (10^6 tonnes).

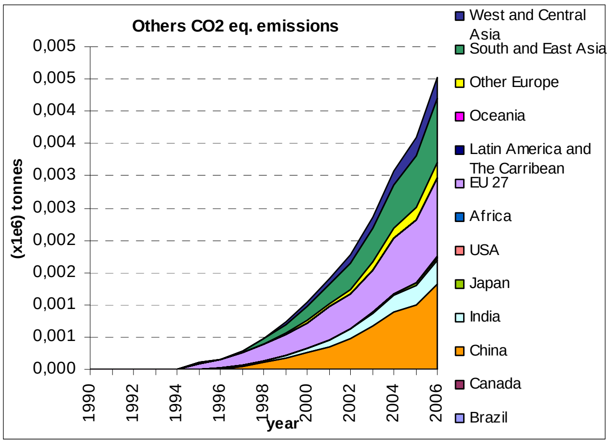

Figure 3.18 – Eq. CO_2 HC-600a emissions (10^6tonnes).

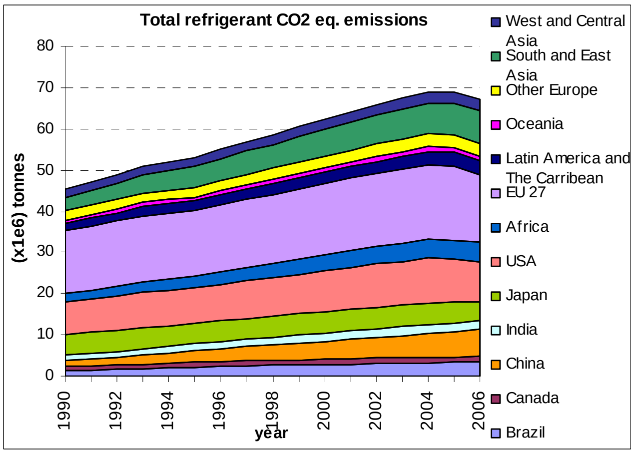

Figure 3.19 – Total eq. CO_2 emissions of refrigerants (10^6 tonnes).

3.2.4 Refrigerant recovery

The recovered quantity of CFC-12 is small (Figure 3.20) referred to the potential recoverable refrigerant due to the very high cost of the recovery process for domestic refrigerators. As shown in Figures 3.20 and 3.21, the recovery occurs only when a regulation is enforced.

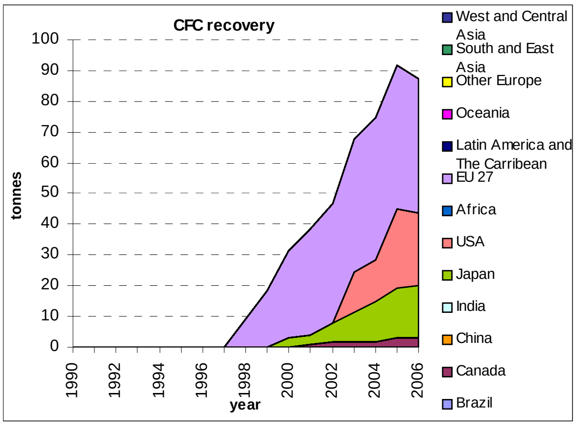

Figure 3.20 – CFC-12 recovery.

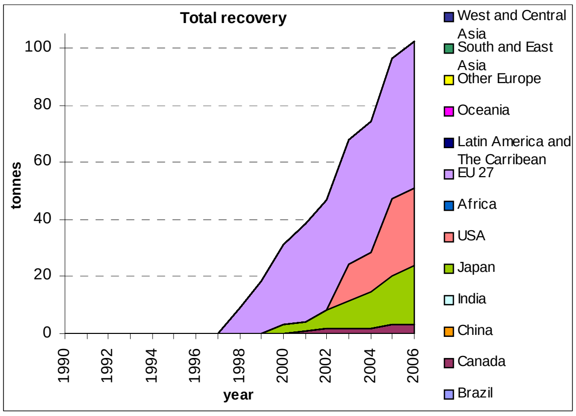

Figure 3.21 – Total recovery.

3.3 Conclusions

Data for the market of domestic refrigerators are well documented by marketing studies and manufacturer associations, and, to a lesser extent, production of refrigerators. Refrigerator volumes and charge ratios, depending on the refrigerant, are also well known. The main uncertainty is related to the lifetime, which is the main factor of influence for emissions because the bulk of refrigerant emissions occur at end of life. The introduction of a survival curve takes into account the impact of this parameter in a more realistic way.

Glossary

GIFAM (Groupement Interprofessionnel des Fabricants d'Appareils d'Equipement Ménager)

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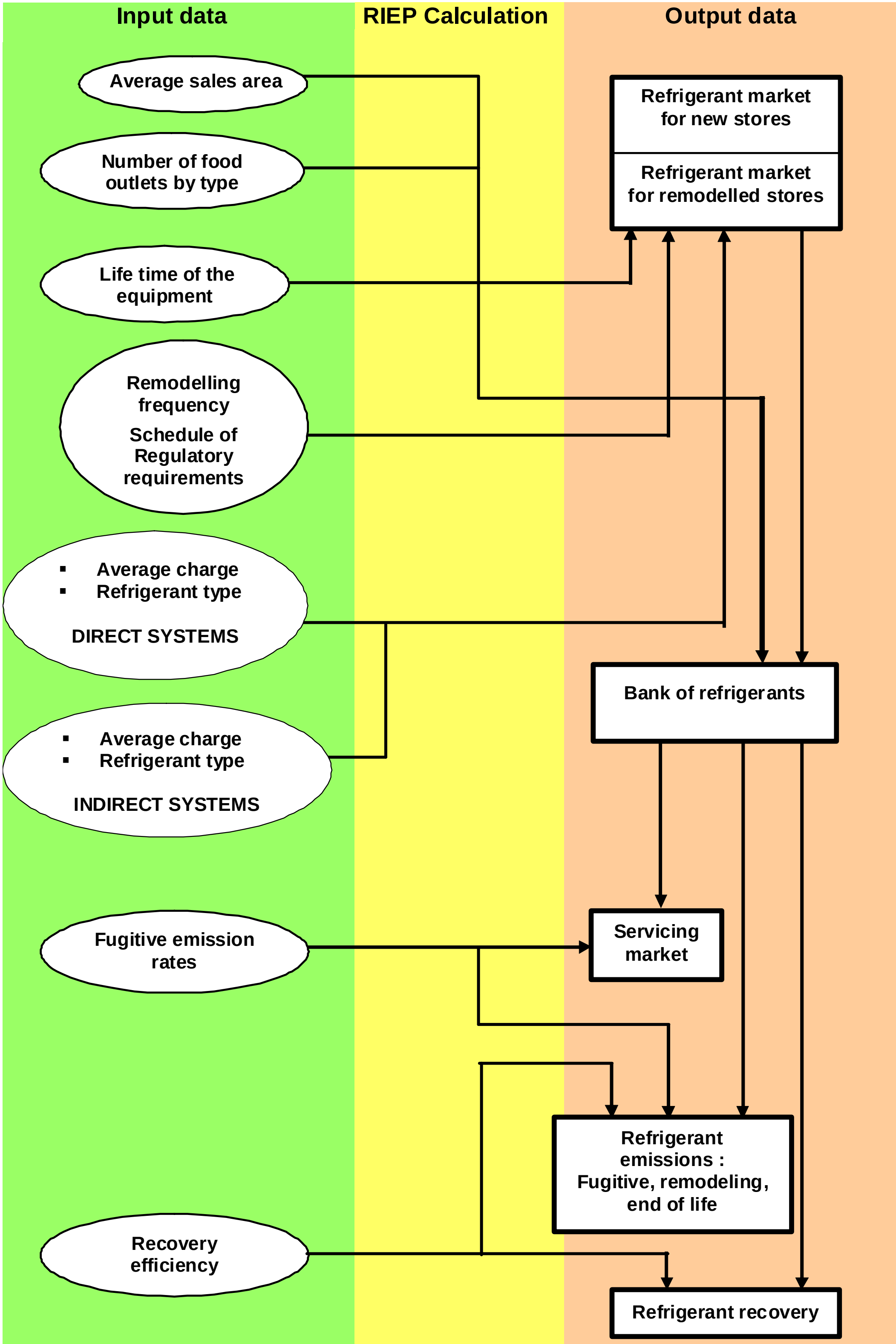

Figure 4.1 - Calculation steps for refrigerant emissions in commercial refrigeration.

Introduction

In the commercial refrigeration sector, four sub-sectors are characterized by specific refrigeration equipment:

- large supermarkets (called sometimes hypermarkets),
- supermarkets,
- convenience stores and food specialists equipped with condensing units,
- Stand alone equipment as vending machines, ice machines, ice cream freezers, small display cases and are found in all types of commercial outlets.

Large supermarkets (LS) and supermarkets have a machinery room where is located a centralized refrigeration system. Large supermarkets are defined by sales areas that are larger than 2,500 m^2 and supermarkets by sales areas ranging between 400 and 2,500 m^2.

Centralized systems consist in racks of compressors connected by long lines with the display-cases in the sales area. This concept called direct expansion requires large quantities of refrigerant varying from some hundreds kilograms to more than 1.5 tonne. The refrigerating capacities are generated by independent racks of compressors at two main levels of evaporating temperatures -40 / -35°C for frozen food (and ice-creams) and -15 / -10°C for fresh food (dairy and meat).

In order to limit the refrigerant charge and so refrigerant emissions, indirect systems using a secondary heat transfer fluid such as MPG (Mono-Propylene-Glycol) is used to transfer the heat from the display cases to the machinery room; indirect systems can limit the refrigerant charge by a factor 2 and even a factor 4. The introduction of indirect systems is taken into account in the supermarket and LS sub-sectors.

Except in the U.S. [SAB08], where detailed statistics have been used, the twelve types of stores in the convenience store and food specialist sub-sector have been grouped in three categories:

- Mini-markets that also include freezer centers and highway stations
- Traditional Outlets that include convenience stores, groceries, and all food-specialists (groceries, bakeries, butcheries, fishmongers, greengroceries, dairy product shops, bars-hotels-restaurants, service stations).
- Vending machines and fountains.

4.1 Calculation method

The main principles of the calculation method of this sector have not evolved since the previous report [CLO06] and are represented in Figure 4.1.

Modifications are related to the integration in RIEP of LS and supermarket **remodeling**, which are done on a regular basis for changing display cases and the structure of the sales area. The regulation requires the phase out of the current refrigerant (HCFC-22), so the refrigerant will be replaced when the remodeling is made. Remodeling and retrofit require distinguishing between the refrigerant lifetime, the refrigerating system lifetime and the store lifetime.

The calculation method considers two types of remodeling:

- The refrigerant is changed during the remodeling due to the regulation that requires the phase out of CFCs or HCFCs. So the refrigeration system is retrofitted i.e. small changes are made in order to use a new refrigerant, typically an HFC or an HFC-blend.

- The additional refrigerant needs are covered by the refrigerant in use and so the remodeling is considered as servicing.

The lifetime of centralized refrigeration systems is considered of 30 years, but French Inventories [BAR07] showed the necessity to take into account refrigeration system renewal. In this report refrigeration equipment renewal corresponds to 15 years in developed countries and 20 years for other countries. At the end of the store lifetime as wall at the end of the refrigeration system lifetime, the refrigeration system is disposed of, the refrigerant is recovered (the recovery efficiency depends on the region), and end-of-life emissions occur.

As for other sectors, a survival curve has been introduced instead of a mean lifetime. This method requires deriving the number of installed stores for each vintage as of 1960 (or from the installation of the first supermarkets or large supermarkets). The choice of refrigerants used during the same period has to be established and so are derived the banks of refrigerants in the commercial sector.

Data sources

In the previous report [CLO06], a large coherence analysis of the different reference sources had been carried out. The first step of the analysis of commercial refrigeration data had been to compare data from the two Euromonitor surveys ("RTI 2001" [EUR01] and "IMIS 2003" [EUR03]) due to a lack of consistency between those surveys. Contacts have been taken with embassies and literature search has been made in order to represent the structure of the country retailing sector.

Data on commercial outlets have been established with economic services of the main countries or by using available data and statistics, the main interesting sources being:

- National Bureau of Statistics or Ministry
- Data from Economic department of the Embassy of France in other countries
- Other regional surveys or audits carried out by independent consultants to help foreign investors.

Except for Europe [Eur08], very different data were found for China where recent studies showed a large gap with the old ones ([HU04], [HU05], [NIE08]). In China, the reference source was chosen by comparing the number of supermarkets per urban inhabitants in 2006 with the European value. Table 4.1 presents the main reference sources used in this report to obtain data for the number and types of food outlets. Some references may give data only for one year, which is used to estimate data for the other years. Data concerning sales areas are scarce and, when the quoted reference in Table 4.1 does not mention information about them, old values are used ([EUR01]).

Table 4.1 – Main reference sources for installed base of outlets.

Country	***Main reference source used***	***REF***
China	Institute of Agricultural Economics (CAAS)	[HU04], [HU05]
India	AC Nielsen	[NIE08]
USA	US Census Bureau	[USB08]
Brazil	ABRASE	[ABR06]
Japan	Ministry of Economy, Trade and Industry (METI)	[GAI06]
EU27	Euro Store Book	[EUR08]

Derivation

When no source is available or several sources are not consistent, an approach based on the economy indicators, regional analogies, and social habits has been used. The evolution of the number of food outlets has been estimated using the following parameters:

- the introduction date of the first supermarkets and large supermarkets, when it is known
- the GDP evolution,
- the population evolution,
- the assumption of a significant growth of the supermarkets or LSs outlets after their introduction (an exponential law usually),
- Information about economic crisis or expansion periods.

For this report the numbers of outlets in all regions – except EU27 - were estimated using this approach, considering a reference country and using population and GDP/capita ratios.

4.2.1 Supermarkets (and large supermarkets) characteristics

4.2.1.1 Number of food retail outlets and sales area

As described above, the installed bases of supermarkets and large supermarkets by country or region have been obtained by using available consistent statistical data or evaluation based on GDP and population ratios. They are presented in Table 4.2.

Table 4.2 – Number of supermarkets and large supermarkets outlets in 2006

Number of supermarkets	*2006*
China	77 692
Japan	17 686
USA	24 815*
Brazil	40 410
India	4 640
Canada	2 014*
EU27	73 724
South&East Asia	1 800
Central Asia	4 859
Latin America	5 235
Oceania	1 492*
Other EU	13 763
Africa	1 659
World Estimate	**269 789**

*** Large supermarkets included**

Number of large supermarkets	*2006*
China	1512
Japan	1685
Brazil	257
India	6
EU27	6849
South&East Asia	6
Central Asia	314
Latin America	19
Other EU	580
Africa	3
World Estimate	**11 231**

Some data of the previous report [CLO06] have been significantly corrected as mentioned in Section 4.2:

- Supermarket number in China and India
- Supermarket sales areas in Japan

- All assumptions made for each region have been re-estimated, based on a reference country and changes in GDP/capita and population ratios.

4.2.1.2 Refrigerant charge, emission rates and recovery efficiency

- The average refrigerant charge is referred to the sales area as in the previous report [CLO06]. Ratio values have been updated for developed countries, to take into account the growing share of indirect systems (see Table 4.3).

Table 4.3 – Average **refrigerant charge per m^2 of sales area** in 2006 (indirect systems included).

	Large supermarkets	*Supermarkets*
USA, Canada	0.37	0.37
Japan	0.26	0.29
China	0.27	0.20
Brazil	0.27	0.25
EU15	0.26	0.29
Other EU	0.27	0.29
India: A5 model	0.27	0.20

- Annual evolution is considered for emission rates. Table 4.4 presents values for 2006 that show 5% decrease in reference to 2003. In most of A5 countries, hypermarkets begin to be introduced, characterized by emission rates close to those of developed countries.

Table 4.4 – Emission rates in 2006.

	Large supermarkets	*Supermarkets*
USA, Canada	30%	30%
Japan	28%	18%
China	35%	40%
Brazil	35%	35%
EU15	30%	22%
Other EU	30%	22%
India: A5 model	35%	40%

In all cases, annual servicing is taken into account whatever the emitted refrigerant charge. Emission rates tend to decrease in developed countries, especially in Europe because of the regulation. The interdiction of use of HCFCs in new equipment as of January 1st 2000 [EU00] has led to numerous retrofits and the installation of new refrigeration systems with lower emission rates.

- Recovery efficiency

Table 4.5 gives assumptions about recovery efficiency at end of life of equipments. The same values are considered for retrofits and renewal of equipment.

Table 4.5 – Recovery efficiency at end of life in 2006.

	Large supermarkets	*Supermarkets*
USA, Canada	70%	70%
Japan	80%	80%
China	20%	20%
Brazil	30%	30%
EU15	80%	80%
Other EU	75%	75%
India: A5 model	20%	20%

Most of Article 5 countries have very low recovery efficiency. Nevertheless, some countries, such as Brazil, begin to have a refrigerant policy and tend to improve their recovery efficiency since a few years.

4.2.1.3 Type of refrigerants

The main change in the type of refrigerant in use is related to European countries. European regulation [EU00] has forbidden the use of HCFCs in new equipment and the use of HCFCs for servicing with virgin HCFCs is forbidden as of January 1st 2010. This regulation has led to a significant retrofit activity in European large supermarkets and supermarkets. Moreover, in RIEP calculations it is taken into account that for each remodeling, the refrigerants are changed going from HCFCs to HFCs. A delay between the 15 "old" European countries and the 12 "new" European countries is taken into account.

In other regions, new information allowed to correct some assumptions. For instance, in Brazil, regulation [RES00] has forbidden the use of CFCs in new equipment as of 2001.

Moreover, the phase down of HCFCs in other developed countries is significantly slower compared to Europe.

- In developed countries CFCs have progressively disappeared and have been replaced first by HCFCs, mainly HCFC-22. Around 2000, HFCs began to appear in new refrigeration systems. Some exceptions have to be underlined: in Japan R-507 is more used than in other countries, and R-407C has a significant share for medium-temperature applications.

- In Article 5 countries, new refrigeration systems use both CFCs and HCFCs, but CFCs are decreasing. It is considered that in developing countries, new refrigerating equipment used no longer CFCs as of 2005. Changes of refrigerant during retrofits are not occurring yet, due to the availability of HCFC-22.

Figures 4.3 to 4.6 present examples of assumptions used in RIEP for the refrigerant choice for new refrigeration systems in supermarkets in the U.S., Japan, EU15, and China.

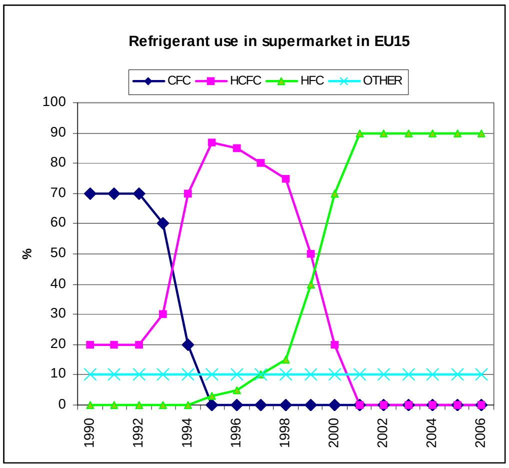

Figure 4.3 – Refrigerant distribution in supermarket in EU15.

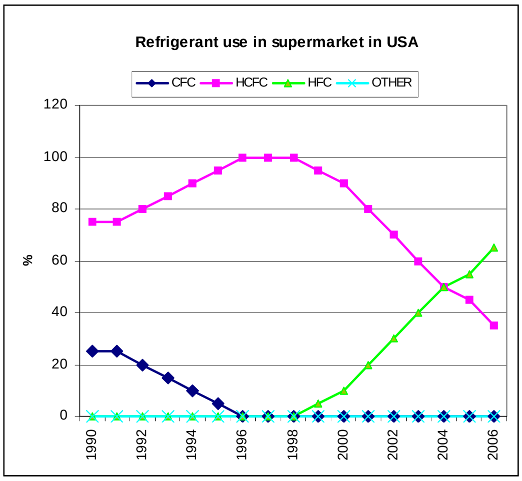

Figure 4.4 – Refrigerant distribution in supermarket in USA.

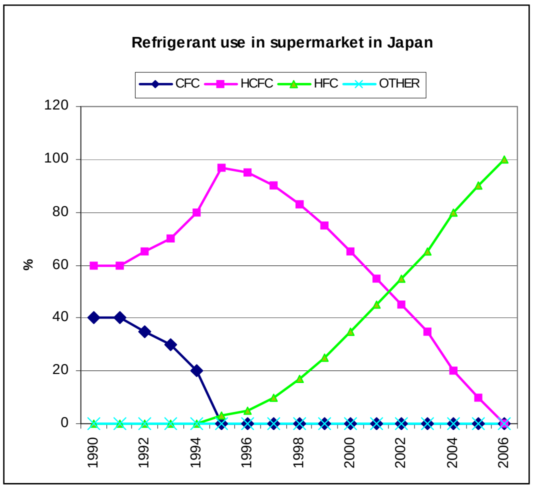

Figure 4.5 – Refrigerant distribution in supermarket in Japan.

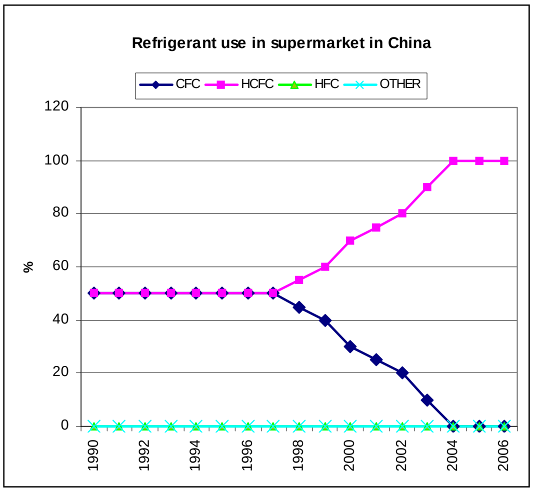

Figure 4.6 – Refrigerant distribution in supermarket in China.

Retrofit tables are necessary to take into account the change of refrigerant during remodeling and when the regulation comes into force for CFC and HCFC phase out and phase down for Europe.

4.2.2 Convenience stores, food specialists, and vending machines

This sub-sector covers refrigerating equipment of mini-markets, freezer centers, highway stations, and all the types of convenience stores or food specialists (groceries, bakeries, butcheries, fishmongers, greengroceries, dairy product shops, bars-hotels-restaurants, service stations) as well as vending machines. This sector has been restructured and stores are decomposed in three categories: mini-markets, traditional outlets, and vending machines. Equivalent refrigerant charges have been estimated. Nevertheless, two structures of refrigerating equipment are always identified: the stand-alone equipment and condensing units [PAL03].

4.2.2.1 Number of retail outlets

Similarly to large supermarkets and supermarkets, the convenience stores and food specialists' data have been studied, comparing several reference sources. However, detailed data are scarce and the share of refrigerated food outlets among food specialists is difficult to estimate in A5 countries. Table 4.6 presents estimated numbers of food retail outlets, using reference sources mentioned in Table 4.1 or [EUR01] when no data are available. Values are to be confirmed.

Table 4.6 – Evaluation of the number of food specialist outlets in 2006.

2006	*Type 1: Minimarkets*	*Type 2: Traditional outlets*	*Type 3: vending machines*
China	81 839	1 573 528	46 356
Japan	137 731	585 508	2 734 971
USA	39 890	667 227	9 068 015
Brazil	40 833	371 261	79 705
India	900 622	1 173 503	8 719
Canada	3 509	57 651	773 264
EU27	116 299	1 739 093	106 223
South&East Asia	900 622	1 173 503	9 082
Central Asia	267 077	401 755	2 879
Latin America	882 295	383 408	28 593
Oceania	10 676	50 375	672 143
Other EU	74 611	828 738	101 702
Africa	606 464	829 247	9 087
WORLD	**4 062 467**	**9 834 798**	**13 640 000**

4.2.2.2 Refrigerant charge, emission rates and recovery efficiency

Typical equipment, as defined by region in [PAL03], has been used. The twelve categories of stores defined in food specialists and convenience stores have been gathered in three groups, so equivalent charge has been estimated by country, taking into account the number of retails by category in 2000. The equivalent refrigerant charges are presented in Table 4.7.

Table 4.7 – Equivalent refrigerant charges.

Mean charge (kg) Hermetic groups	*USA & Canada*	*China*	*India*	*Brazil*	*Japan*	*EU15*
Type1: Mini-markets and convenience stores	2.86	1	1	1	1	2.8
Type 2: General feedings and traditional food outlets	4.0	1.3	1.4	1.3	1.3	1.4
Type 3: Vending machines	0.3	0.3	0.3	0.3	0.3	0.3

Mean charge (kg) Condensing units	*USA & Canada*	*China*	*India*	*Brazil*	*Japan*	*EU15*

Type1: Mini-markets and convenience stores	98 (minimarkets)	20	19	20	150	129
Type 2: General feedings and traditional food outlets	10.7	6.0	4.3	4.5	4.0	3.5

Emission rates and lifetime are the same as in the Palandre et al. report [PAL03]. It has to be underlined that emissions from stand-alone equipment and condensing units are significantly lower compared to centralized systems, as shown in Table 4.8.

Table 4.8 – Lifetime and emission rates in the convenience stores and food specialists' outlets.

2006	***Lifetime (years)***	***Emissions rate (%)***	***Recovery rate (%)***
Condensing units	15	15	Between 5 and 50%, depending on countries
Hermetic systems	15	1	0

4.2.2.3 Type of refrigerants

Refrigerants used in new refrigerating equipment depend on the technologies and follow different trends in Europe, other developed countries, and Article 5 countries, as shown in Figures 4.7 to 4.12.

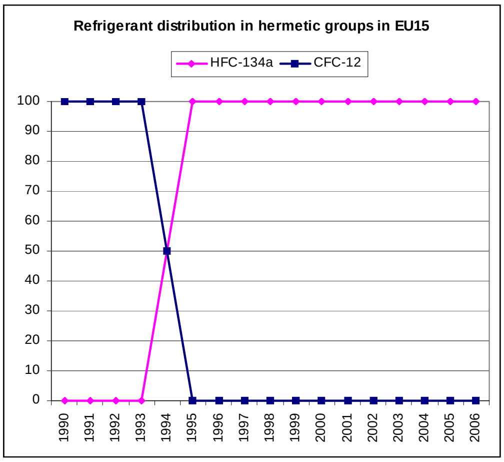

Figure 4.7 – Refrigerant distribution in hermetic groups in EU15.

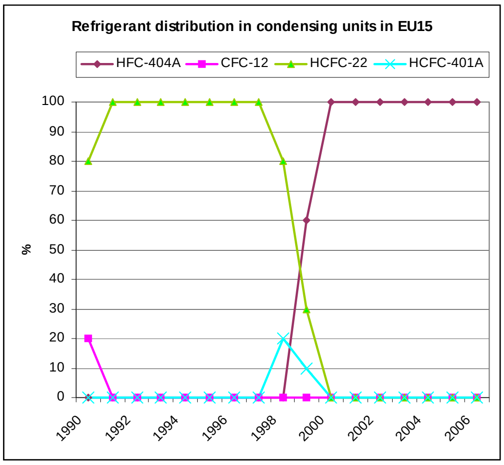

Figure 4.8 – Refrigerant distribution in condensing units in EU15.

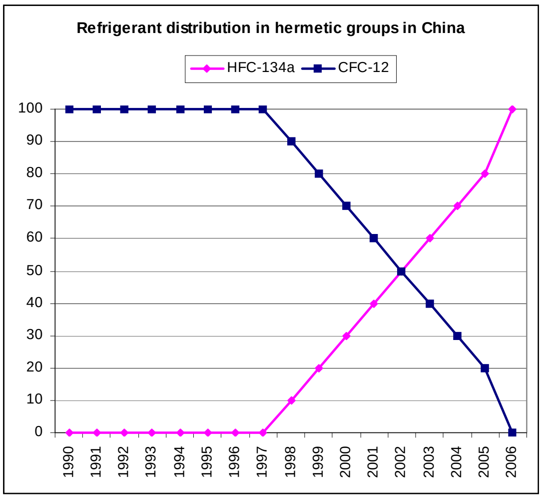

Figure 4.9 – Refrigerant distribution in hermetic groups in China.

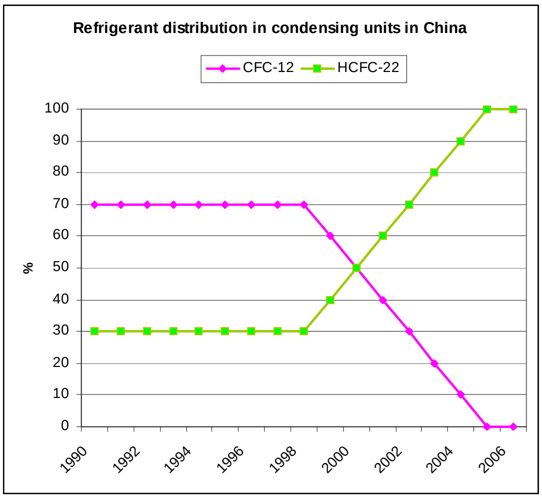

Figure 4.10 – Refrigerant distribution in condensing units in China.

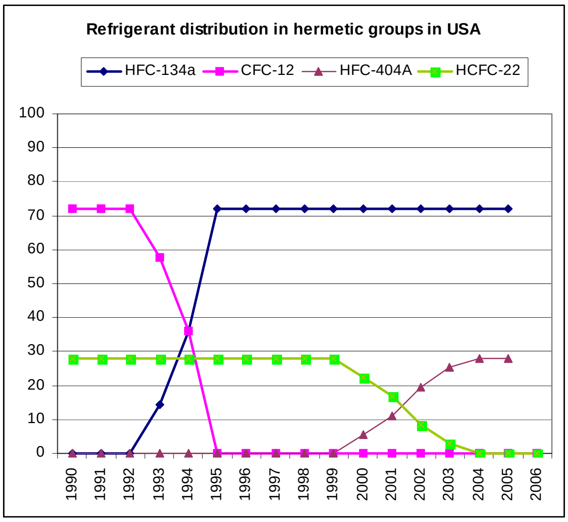

Figure 4.11 – Refrigerant distribution in hermetic groups in USA.

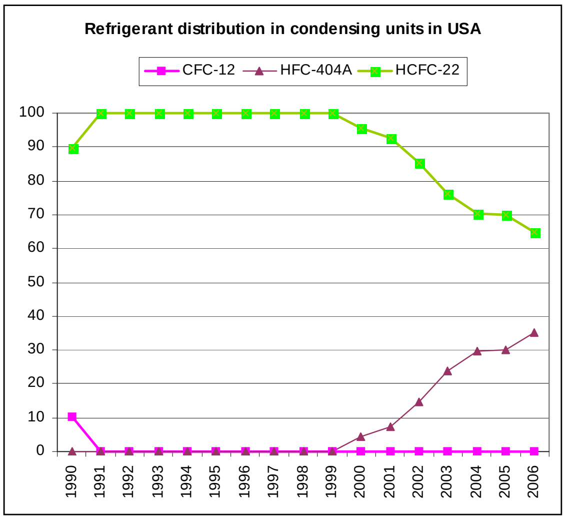

Figure 4.12 – Refrigerant distribution in condensing units in USA.

4.3 Results of calculations

It is necessary to underline that data have been structured in order to reach consistency between GDP growth, number of outlets, and size of sales area.

4.3.1 Refrigerant bank

In this report, **the global bank of commercial refrigeration is estimated at 336,000 tonnes**, which constitutes a reduction of about 40% compared to the previous report [CLO06]; the update has shown that data concerning supermarket number in China have been strongly modified. According to AC Nielsen reports [NIE08], supermarket numbers in China have been significantly overestimated as well as the number of outlets using refrigeration equipment in Article 5 countries. Therefore, the refrigerant banks are lower than previously estimated, especially the CFC one. This important correction reduces of about 50% **the CFC bank in 1994, which is now evaluated at 94,000 tonnes.** The CFC phase out in developed countries in 2000 and, in developing countries in 2005, has led to a global CFC bank estimated at about 52,000 tonnes in 2006. In 2006, the CFC bank is still significant in Article 5 countries, with about 13,000 tonnes in China and 10,000 tonnes in India (Figure 4.13).

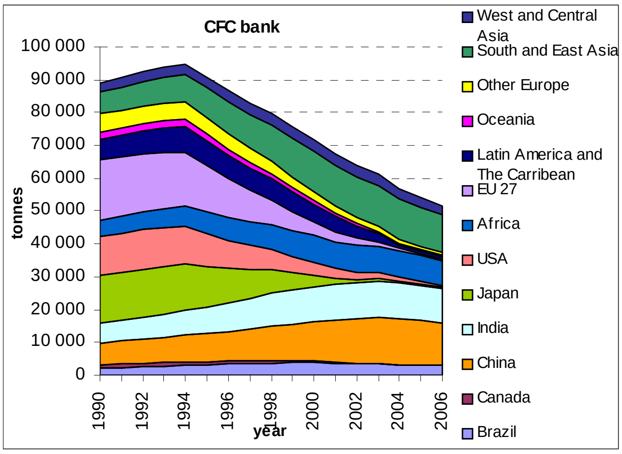

Figure 4.13 – CFC bank.

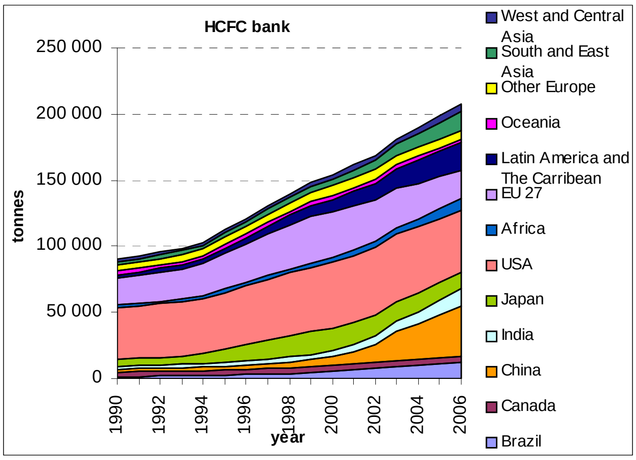

Figure 4.14 – HCFC bank.

The impact of the corrected data on the HCFC bank is less significant because of the evolution of refrigerant use assumptions. **HCFC has risen from 103,000 tonnes in 1994 up to 207,000 tonnes in 2006.** The dominant bank is the HCFC-22 one, which is reaching more than 190,000 tonnes in 2006 (Figure 4.14), growing again about 6% per year during the three last years, dominated by the U.S. bank (23%) and the China one (18%).

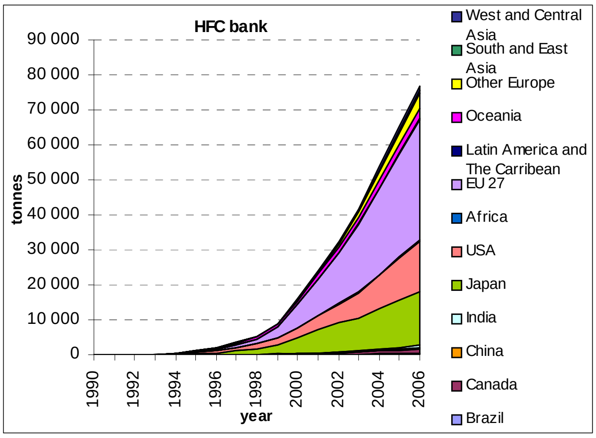

Figure 4.15 – HFC bank.

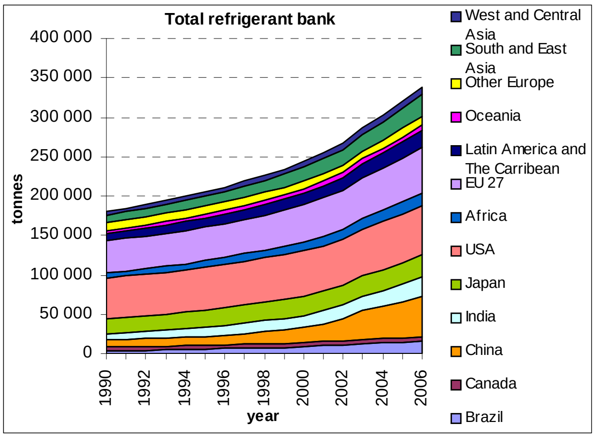

Figure 4.16 Total bank.

The HFC bank (Figure 4.15) is increasing steeply and is dominated by EU27 due to the European regulation, around 75,000 tonnes in 2006.

Figure 4.16 shows that the dominant refrigerant banks in commercial refrigeration are in the U.S. (18%), in EU27 (17%), and in China since 2003 (15%).

4.3.2 Emissions

Emission rates vary along the equipment lifetime and have been updated to take into account improvements in servicing, especially in large supermarkets and supermarkets in Article 5 countries. However, the emissions being directly related to the bank, global emissions are continuously growing and are evaluated at 84,000 tonnes of refrigerants in 2006.

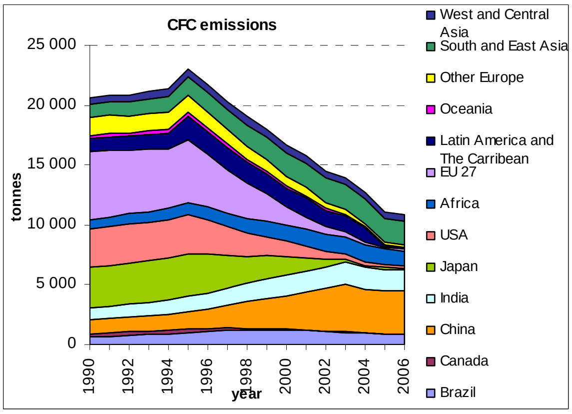

Figure 4.17 – CFC emissions.

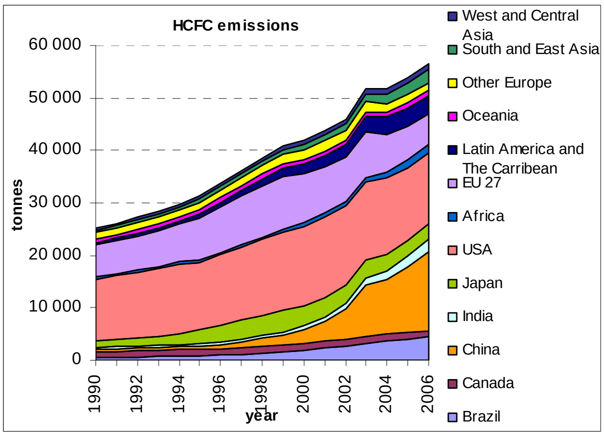

Figure 4.18 – HCFC emissions.

Figure 4.20 confirms that the dominant emissions are those of HCFCs (68%) worldwide and CFCs have a significant share in developing countries. HFC emissions are growing steeply but are still relatively low (15,500 tonnes in 2006) compared to HCFC emissions.

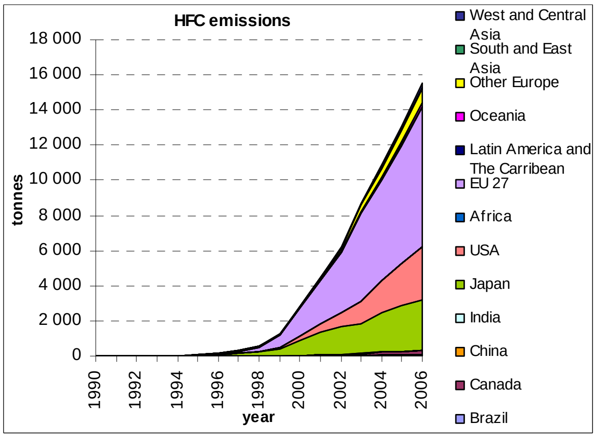

Figure 4.19 – HFC emissions.

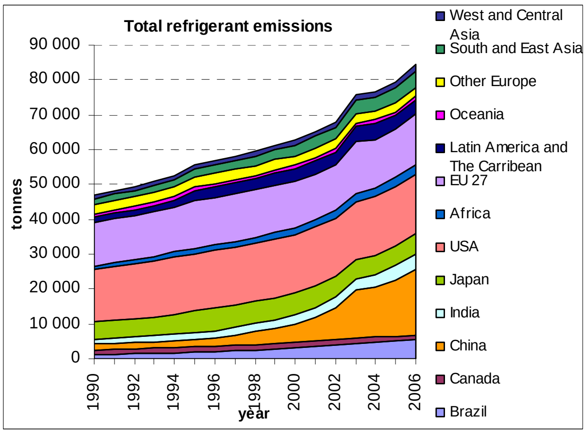

Figure 4.20 - Global emissions.

Taking into account all types of equipment the average emission rate is about 25% in 2006.

4.3.3 CO_2 equivalent emissions

Due to the aforementioned corrections in data sources, CFC CO_2 equivalent emissions are reduced compared to the previous report. However, due to the very high GWP of CFC-12 and CFC-115, the major contribution to global warming remains that of CFCs with 175 million of tonnes in 1995 and 89 million, equivalent to CO_2 equivalent emissions of HCFCs, in 2006 (see Figures 4.21 and 4.22).

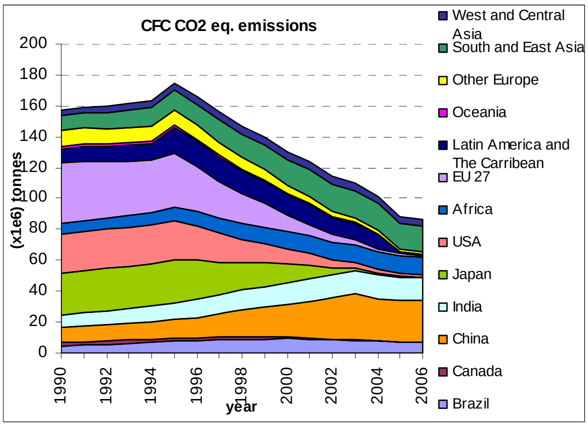

Figure 4.21 – CFC CO_2 eq. emissions.

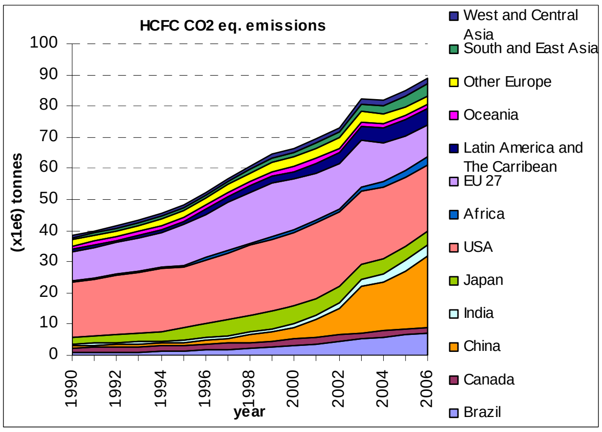

Figure 4.22 – HCFC CO_2 eq. emissions.

The relatively low emissions of HFCs (Figure 4.19) of 15,000 tonnes lead to significant CO_2 equivalent emissions, around 50 million of tonnes (Figure 4.18), due to the high GWP of R-404A.

Figure 4.24 indicates that CO_2 equivalent emissions are dominated by China (22%) at almost 50 million of tonnes due to the very high impact of CFC emissions, but are followed by EU27 (16%), because of the impact of increasing HFC-404A emissions, and the U.S. (15%).

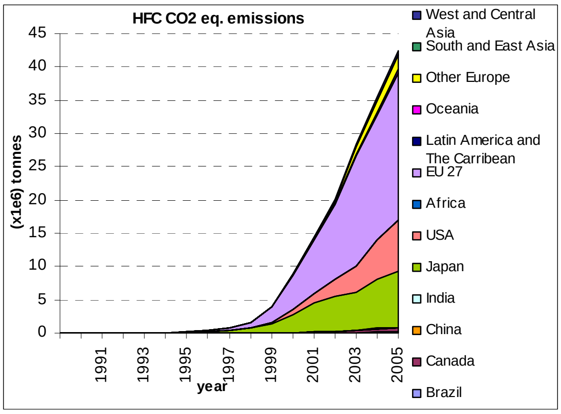

Figure 4.23 – HFC CO_2 eq. emissions.

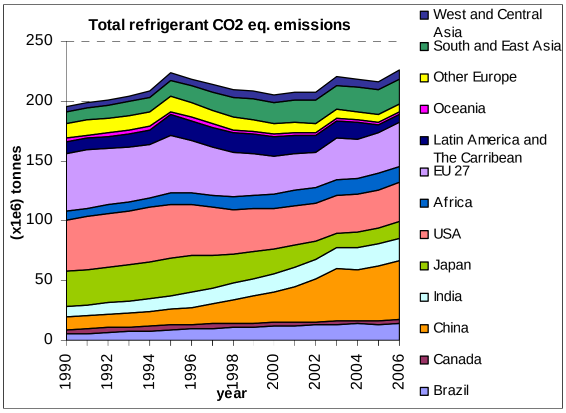

Figure 4.24 – Global CO_2 eq. emissions.

4.3.4 Recovery

Few improvements are observed in the recovery sector except in Europe, due to the regulation.

As indicated in other sections, data on recovery are scarce, and the calculation results need to be verified, but a significant uncertainty will remain on those data.

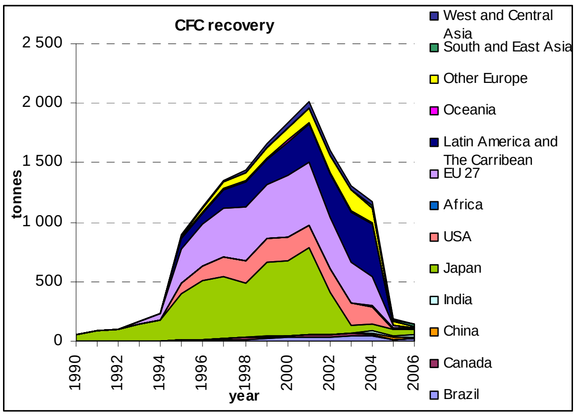

Figure 4.25 – CFC recovery.

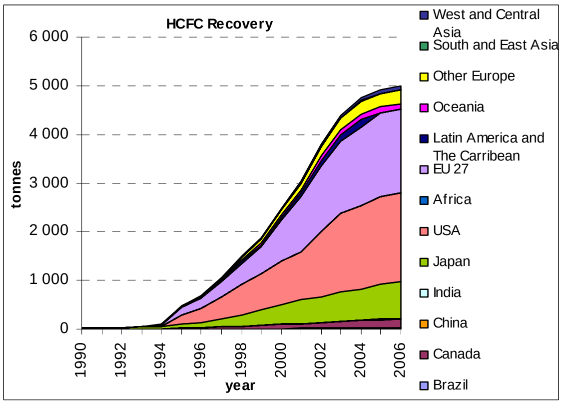

Figure 4.26 – HCFC recovery.

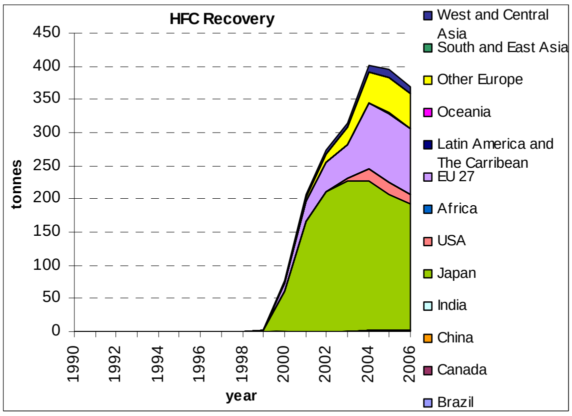

Figure 4.27 – HFC recovery.

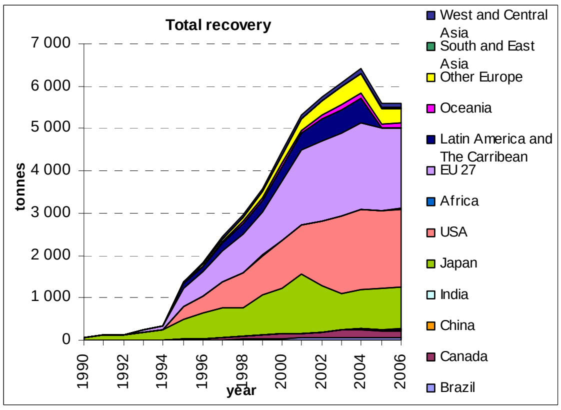

Figure 4.28 – Global refrigerant recovery.

The recovery potential of CFCs, such as indicated in Figure 4.25, is plausible if the availability of CFCs is low in the reference countries. On the contrary, the large potential of HCFC recovery is certainly not well used due to the low cost of HCFC-22.

Figure 4.28 indicates that a large potential exists for recovery in many countries, which is not currently used, and so large improvements are possible if regulations and economical incentives are implemented.

4.4 Conclusions

The commercial refrigeration sector is the most difficult sector in terms of activity data gathering due to the wide variety of commercial outlets as well as types of equipment. A continuous work on surveys and consistency analyses has led to significant improvements in the present report, in terms of number of supermarkets as well as numbers of small commercial outlets.

It has to be underlined that inputs necessary to calculations are difficult to obtain, especially the average area of new stores such as large supermarkets and supermarkets, the number of new small stores, and the share of small refrigerated stores in Article 5 countries. When the area of stores is available, most of the time the value indicates the mean area of stores considered in the installed base.

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CONTENTS

Introduction

The refrigerated transport sector is subdivided in three sub-sectors:
- road refrigerated transport,
- containers, and
- reefers.

The road refrigerated transport sector is analyzed on a country-by-country basis, **whereas reefers and containers are analyzed globally**. For the latter two sub-sectors, refrigeration equipment is serviced and maintained in a limited number of harbors. For all sub-sectors fugitive emissions are high compared to other sectors due to the operating conditions.

5.1 Reefer ships and refrigerated containers

For sea transportation, refrigerated containers and reefer ships with refrigerated holds are addressed separately. Reefer ships are now mainly used for the transportation of fruits. Some reefer ships are also used for the transportation of frozen fish but the competition with refrigerated containers has led to shrink the global fleet of reefer ships, especially for frozen food.

The methodology for ships and containers is simpler than for many other sectors because:
- the inventory is determined on a global basis and not on a country-by-country basis,
- numbers of refrigerated containers and reefers can be found in publications, even when there may be some discrepancies, especially for reefers.

The annual refrigerant demand for brand-new equipment and the refrigerant demand for servicing are determined based on the total numbers of ships and containers. Emission factors are also known.

5.1.1 Global fleet of reefers

The global reefer ship fleet has continuously decreased from 1994 and in 2006 the reefer ships in 2006 is of 1250 according to [UNE06], which slightly overestimates data used in the previous inventories [CLO06] with about 1190 ships in 2003. According to [SHI07], new orders for reefers are respectively of six, three and two vessels for 2004, 2005, and 2006. Historical market data have been reconstituted to obtain a fleet of 1245 reefers in 2006 (see Table 5.1).

Table 5.1 - Estimate of the global fleet and new market of reefer ships ([UNE06], [SHI07]).

	1990	***1995***	***2000***	***2003***	***2006***
Global fleet	1 385	1 465	1 455	1365	1245
Market	60	40	30	10	3

The current fleet is now rather young, about 50% of the reefer ships are under 15 years old and very specialized in the transportation of fruits and especially tropical fruits. In the next few years, about 60 ships over 20 years old will be dismantled.

♦ Type of refrigerants

The trends are not changing for the refrigerant choice, with mainly R-410A, R-404A, R-407C, and a few ammonia systems. Indirect system is the preferred option that limits the refrigerant charge and leaks. Indirect systems represent approximately 50 % of the new reefer ships and are used for both medium and low-temperature applications. R-410A is mainly used for low-temperature applications.

♦ Characteristics

According to [UNE06], emission rates for old systems are estimated about 20% whereas new ones have emission rates between 5 and 10% due to indirect systems and improvement in leakage prevention with the use of leak detectors. Therefore, assumptions from 2003 to 2006 take into account this emission rate decrease and historical rates have been corrected from 40 to 30%, as shown in Figure 5.1.

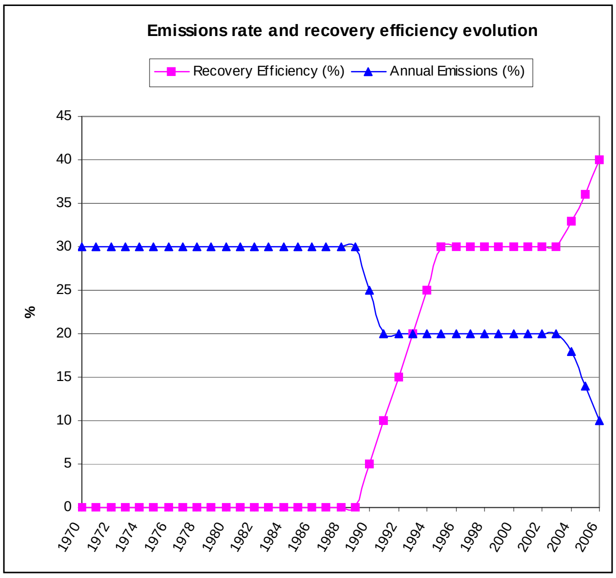


Figure 5.1 - Evolution of emission rates and recovery efficiency.

Table 5.2 - Reefer characteristics in 2006.

Lifetime (years)	Annual emissions (%)	Recovery efficiency (%)	% of charge emitted before servicing	Refrigerant charge for new equipment (kg)
30	10	40	35	1 000

70% of the refrigerating systems installed on current refrigerated ships are direct systems. The refrigerant charge varies between 3 and 5 tonnes. The refrigerant charge of indirect refrigerating systems is much lower, between 500 kg and 1000 kg [UNE06].

5.1.2 Containers

The use of refrigerated containers is expanding steadily as indicated in Table 5.3 and Figure 5.2 because of the growth in the transport of perishable food, and the flexibility of autonomous refrigerated containers, which can be transported on usual container ships. 40-feet type containers with large height form the dominant group (compared to the 20-feet capacity ones). According to [UNE06], the refrigerated containers fleet can be estimated to 1,270,000 TEU (Twenty feet Equivalent Unit) in 2005, which is in line with Table 5.3 data.

Table 5.3 - Evolution of the global fleet of refrigerated containers (TEU) [CH09].

Year	Annual production	Added to fleet	Replaced in fleet	Fleet size at the end of the year
1990	43 000	35 000	8 000	294 000
1991	29 500	23 000	6 500	317 000
1992	51 500	46 000	5 500	363 000
1993	53 500	48 000	5 500	411 000
1994	63 500	55 000	8 500	466 000
1995	80 000	60 000	20 000	526 000
1996	78 500	52 000	26 500	578 000
1997	90 500	68 000	22 500	646 000
1998	93 500	67 000	26 500	713 000
1999	89 500	65 000	24 500	778 000
2000	100 000	70 000	30 500	848 000
2001	96 000	67 000	29 000	915 000
2002	113 800	71 000	42 800	986 000
2003	133 700	57 000	76 700	1 043 000
2004	142 700	78 500	64 200	1 121 500
2005	152 306*			
2006	162 558*			

* Estimates based on 2004/2005 growth of the production.

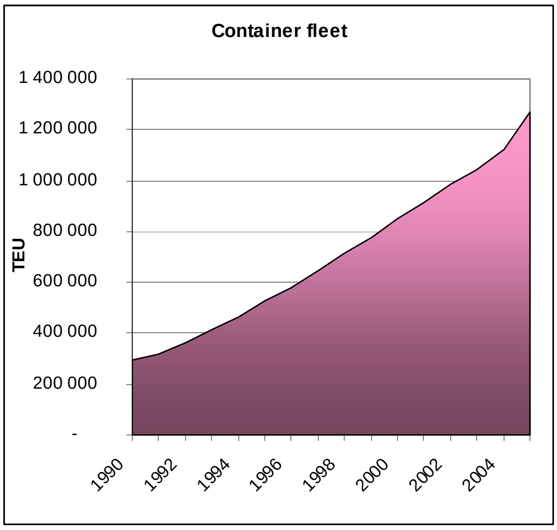


Figure 5.2 – Evolution of the fleet of refrigerated containers.

Note: TEU is equivalent to 20-ft container meaning that a 40-ft container is counted as 2 TEU.

For the production of refrigerated containers, Figure 5.3 shows the strong raise of China, which, because of its low cost production, has put out of the market South Korea, Mexico, Taiwan, and even Japan and the U.S. So the only remaining significant competitor to China for the production of refrigerated containers is Europe.

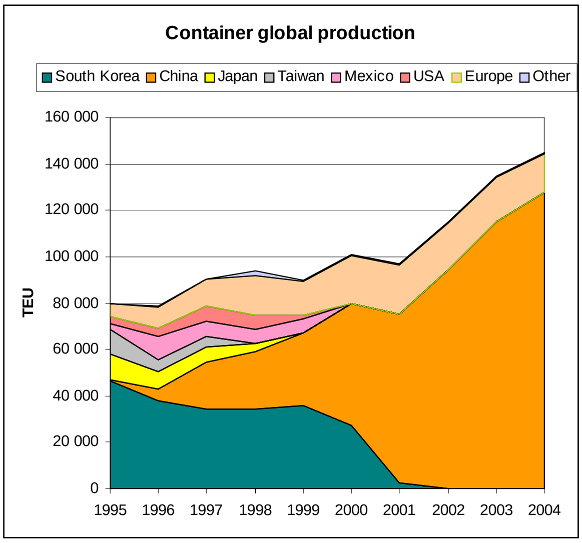


Figure 5.3 - Repartition of the production of refrigerated containers.

- **Type of refrigerants**

In 2006, 100% of the new refrigerated containers use HFC-134a. It is assumed that CFC-12 was no more used in new equipment as of 1997 and HCFC-22 as of 2004.

The average lifetime of containers is about 14 years and the number of retrofits has been limited, which explains that a large number of CFC-12 containers remain in the global fleet.

- **Refrigerant charge, emissions, and recovery efficiency**

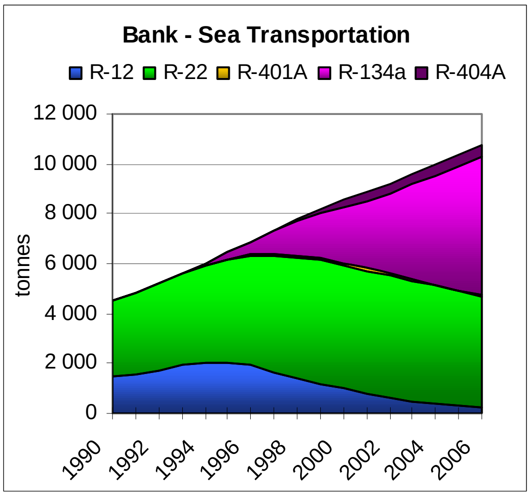
The annual emission rate is less than the one valid for reefers. Typical refrigerant servicing is done once a year. Except a small improvement of the recovery efficiency, container characteristics have not evolved since 2003 and are presented in Table 5.4.

Table 5.4 - Container characteristics in 2006.

Lifetime (years)	*Annual Emissions (%)*	*Recovery Efficiency (%)*	*% of Charge Emitted before Servicing*	*Refrigerant Charge (kg)*
14	20	40	20	4.6

5.1.3 Results of calculation – Global sea transportation

- **Refrigerant bank**



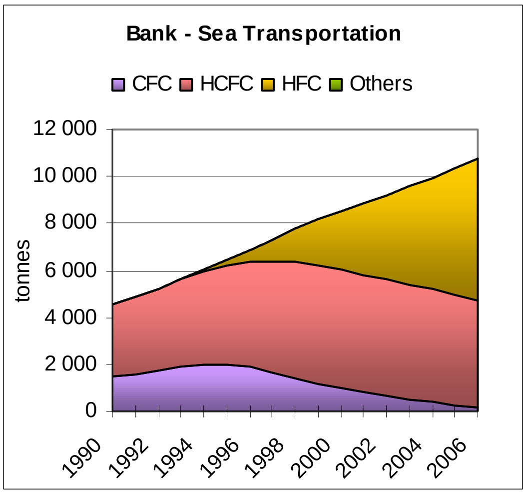


Figure 5.4 – Refrigerant bank.

Globally the bank has increased significantly, by more than a factor 2 in the last 15 years, which is directly related to the steep increase in the number of refrigerated containers. The CFC-12 bank is nearly at the end because of the relatively short lifetime of containers. The overall refrigerant bank of sea transportation is composed of 42% of HCFC-22, and 56% of HFC-134a.

❖ Refrigerant emissions

In the marine sector, the level of emissions is quite high, about 26% in annual average value, and it is not seen as a significant issue by operators. The only measure that has been really implemented is the refrigerant recovery before recharge. On the long term, the change from direct to indirect system for reefer ships would lead to improved containment and will decrease the emitted quantities. For refrigerated containers, no new solution appears yet, and thus the level of refrigerant emissions will remain high. It has to be underlined that CO_2 refrigerated containers are under development at the demand of the shipping company Maersk but in 2010 it is still at the prototype level.

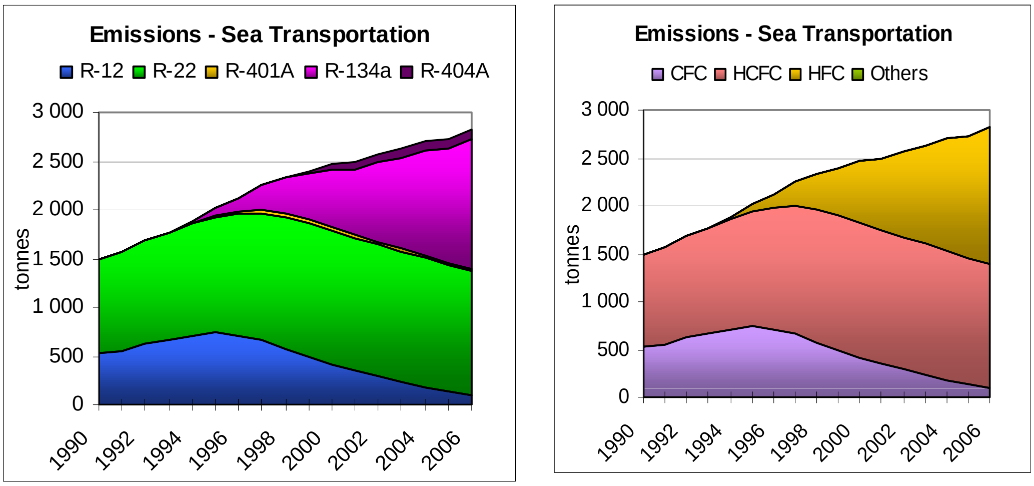


Figure 5.5 – Refrigerant emissions from reefer ships and containers.

Compared to the previous inventory report, global emissions are lower, due to corrections concerning historical data, related mainly to emissions rates before 1990 [UNE06].

CO_2 equivalent emissions of refrigerants

As indicated in Figure 5.6, the CFC-12 phase out has a significant impact on equivalent CO_2 emissions of the refrigerated merchant fleet, which has peaked at 7,7 million tonnes eq. CO_2 in 1997, and is about 4,7 millions of tones in 2006.

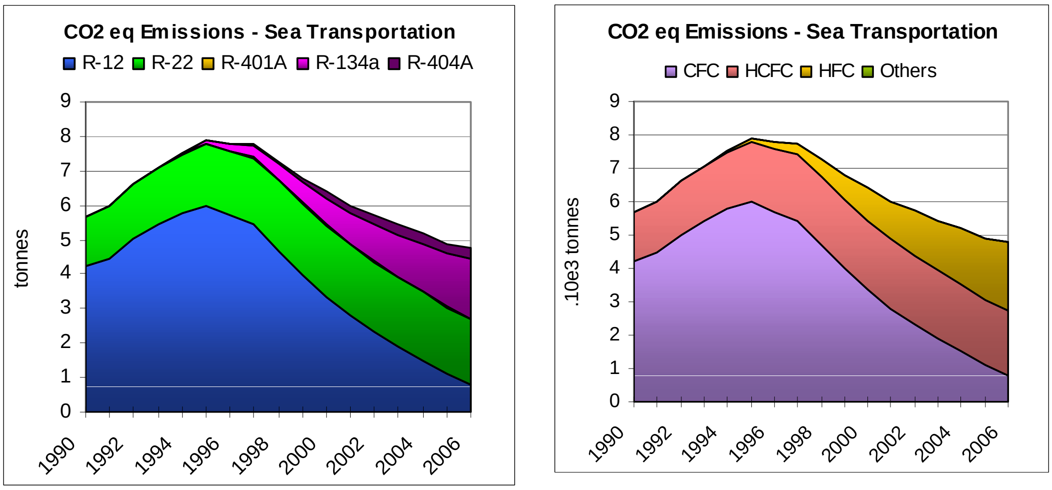


Figure 5.6 – CO_2 equivalent emissions.

Refrigerant recovery

The CFC-12 recovery was a winning strategy for the continuous operation of the CFC-12 refrigerated container fleet. In the future, efficient recovery of HFCs will have to be verified.

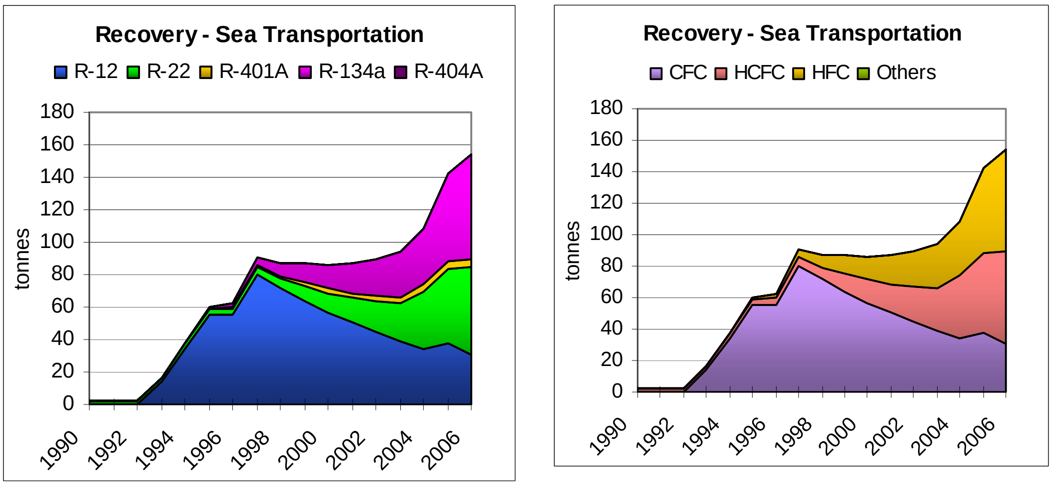


Figure 5.7 – Refrigerant recovery.

5.2 Road refrigerated transport

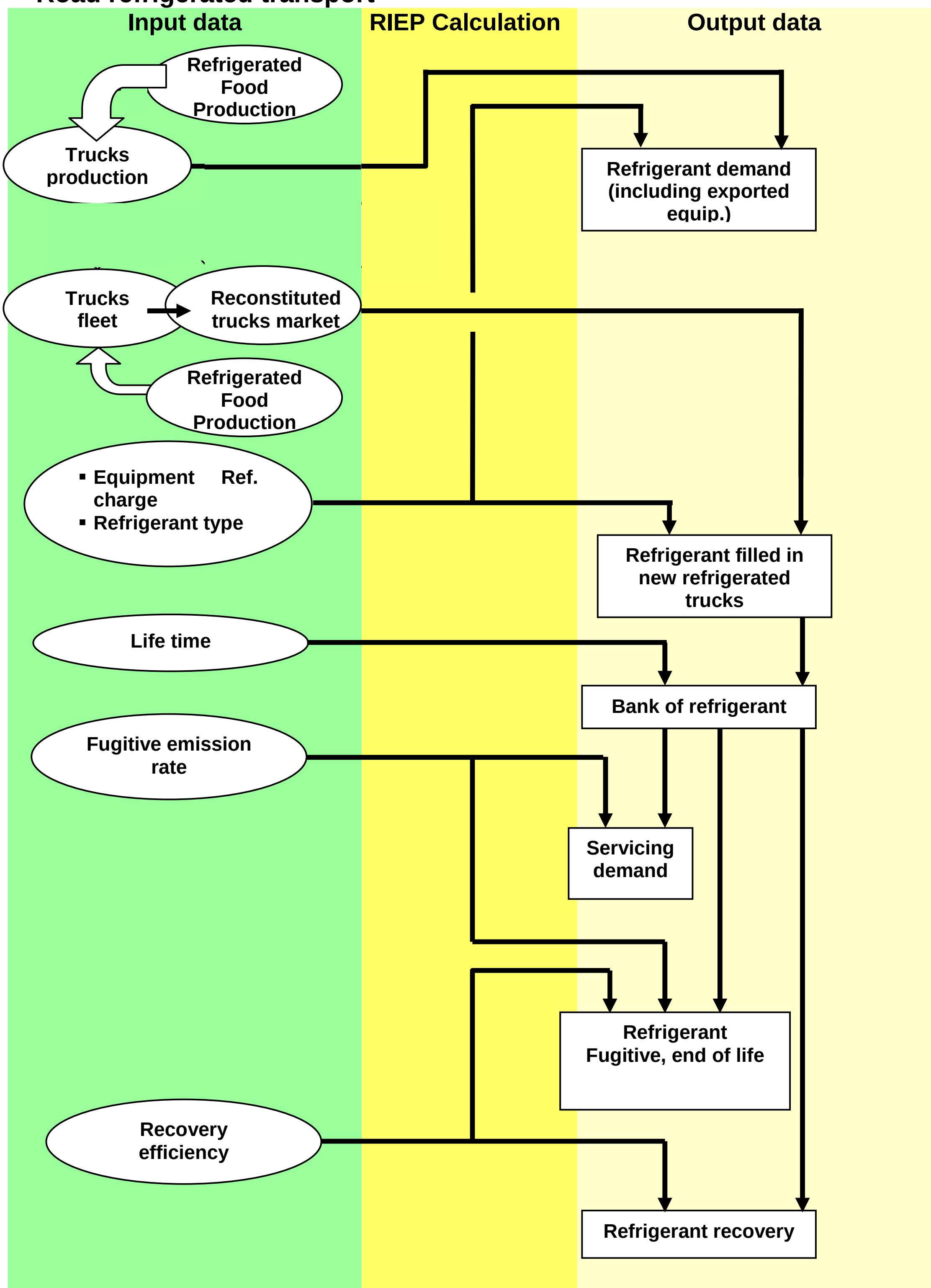


Figure 5.8 - Calculation steps for refrigerant emissions from refrigerated trucks.

5.2.1 Method of calculation

In the previous report, the method of calculation has changed. The ratio between the number of refrigerated trucks and usual trucks was no longer used, and was replaced by the ratio between the **production** of trucks and the food tonnage of refrigerated and frozen food. In this report, the new method has been kept, however ratios have been corrected to be more realistic and represent the needed **fleet** of refrigerated trucks to transport the tonnage of refrigerated and frozen food.

The FAO database, which is updated annually, allows analyzing the evolution of refrigerated food tonnage. The food products taken into account are meat, fish, dairy products, and frozen food. Wines, soft drinks, and beers are not taken into account for transportation because those products are not transported under controlled temperatures. The data provided by FAO for each country allows defining a ratio, which is the relation between the refrigerated truck fleet and the annual production of refrigerated food. This ratio is established for France where reliable data are available for refrigerated trucks, and then applied to countries where no data are available (for trucks).

Figure 5.8 shows the different steps that enable the calculation of:

- The annual refrigerant demand for the charge of new refrigeration equipment and for servicing
- The bank of refrigerants in all refrigerated trucks
- The refrigerant emissions, and
- The recovered refrigerants.

Two categories of refrigerated trucks exist. They are characterized by specific compressor technologies and have different capacity levels.

Belt-driven system: for low and medium capacity trucks; the compressor is driven by the traction engine via a pulley-belt assembly and so cooling capacity is provided only when the vehicle engine is operating.
Independent engine: the mechanical power is produced independently of the vehicle engine (by a small fuel engine). Large refrigerated trucks are equipped with this system, because of the possibility to operate the system fully independently.

In developed countries, the lifetime of refrigerated trucks is about 9 years, and this is determined by regulations. In other countries, the lifetime of these vehicles is longer but it has still been assumed that the lifetime of this equipment is 9 years before a refurbishing takes place (e.g., replacement of the compressor).

5.2.2 Fleets of refrigerated trucks

The fleet of refrigerated trucks is evaluated year by year according to the production of refrigerated food.

In the previous report, ratios compared the production of new refrigerated trucks with the production of refrigerated food. In this report, ratios have been corrected to define the global fleet of refrigerated trucks. Based on French values [BAR06], they are of 1,057 belt-driven, and 1,356 independent engine vehicles per million of tonnes of food products. These ratios allow obtaining a European fleet value matching the one given by publications [GUI03] (the fleet of refrigerated trucks is estimated to 450,000 units in 2003).

Available data about refrigerated trucks in India have led to adjust these ratios for A5 countries: they are assumed to be 352 belt-driven and 452 independent engine vehicles per million of tonnes of food products.

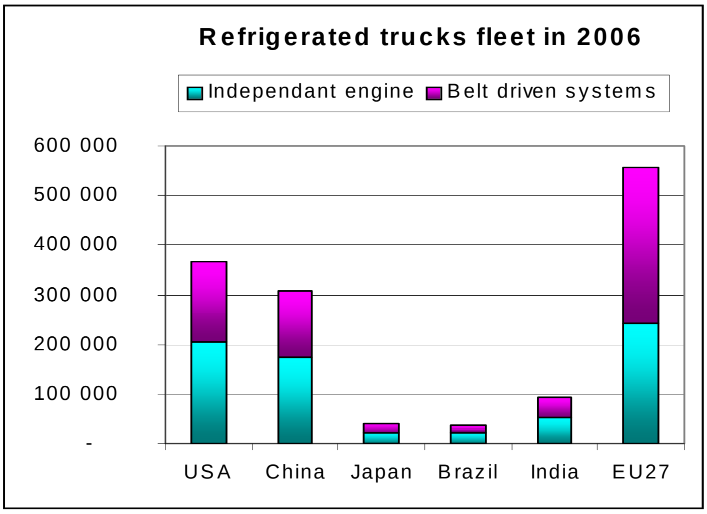


Figure 5.9 - Evaluation of the country fleets of refrigerated trucks in 2006.

The global fleet in 2006 is evaluated to 2 million of vehicles with 1.1 million belt-driven and 0.9 million independent engine vehicles. Figure 5.9 indicates the repartition of refrigerated trucks for the main countries.

5.2.3 Refrigerant charge, emissions, and recovery efficiency

Table 5.7 – Refrigerated system characteristics in 2006.

System type	***Life (years)***	***Annual Emissions (%)*** ***Dev. countries / A5 countries***	***Recovery Efficiency (%)*** ***Dev. countries / A5 countries***	***% of Charge Emitted before Servicing***	***Average Charge (kg)***
Belt-driven	9	22/ 30	15 /75	30	2
Independent engine	9	15/ 15	15/ 75	30	7.2

The compressor of the belt-driven system is located in the vehicle engine compartment and the circuit is long and complex. Those vehicles are used for short transportation (< 1 day), and the refrigerating capacity is only available when the engine is running. Due to the complexity of the circuit, the emission factor is two times higher than independent engine systems, which systems are much more compact. Nevertheless, due to the much higher refrigerant charge of the independent engine systems, their emissions are 50% higher than those of belt-driven systems.

5.2.4 Type of refrigerants

The global demand of truck refrigerating systems is dominated by two global companies. The refrigerant selection is well known and the shift from CFCs to HCFCs and/or HFCs has been well documented.

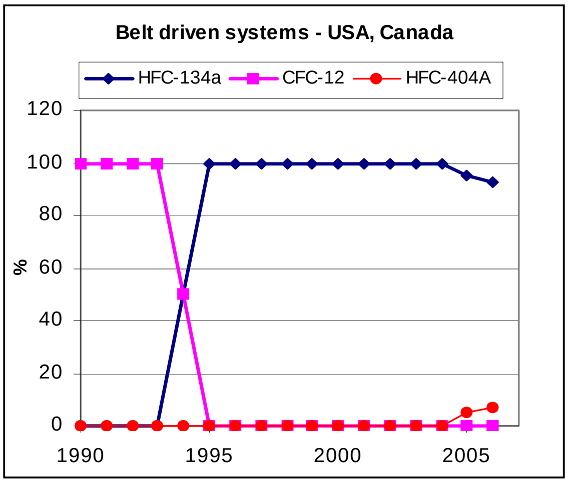


Figure 5.10 – Fluid distribution for belt-driven systems in USA and Canada.

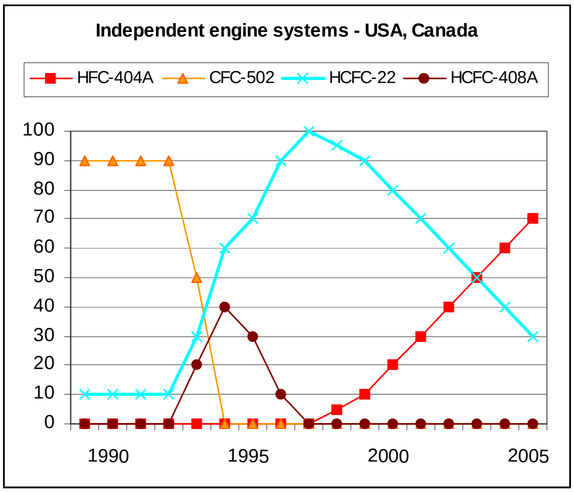


Figure 5.11 – Fluid distribution for independent engine systems in USA and Canada.

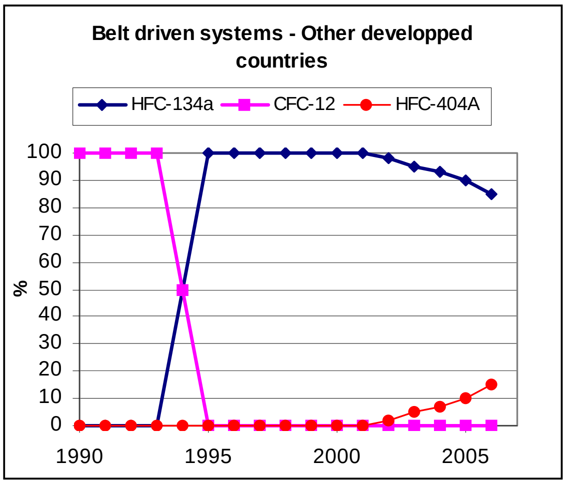


Figure 5.12 – Fluid distribution for belt driven systems in other developed countries.

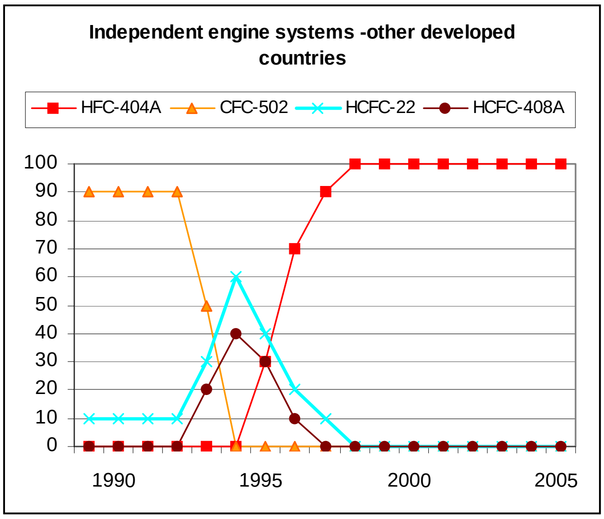


Figure 5.13 – Fluid distribution for independent engine systems in other developed countries.

For belt-driven systems in developed countries, the first refrigerant choices were similar to the mobile air conditioning systems. The shift from CFC-12 to HFC-134a has been done as of 1994 and R-134a was the unique refrigerant in use in belt-driven system (see Figure 5.12). Since then, R-404A was introduced and its market share is constantly increasing.

Even if the level of temperatures of refrigerated products can be different, the independent engine systems are in principle designed for low-temperature conservation (-18°C), and so low-temperature refrigerants or blends are normally selected. For new equipment, the choice of R-404A has been maintained until now.

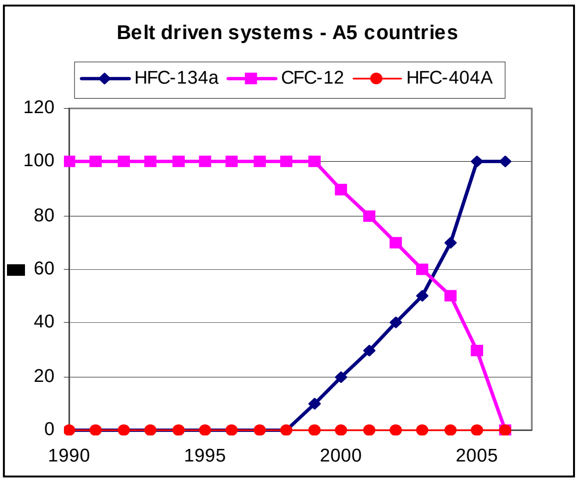


Figure 5.14 – Fluid distribution for belt-driven systems in A5 countries.

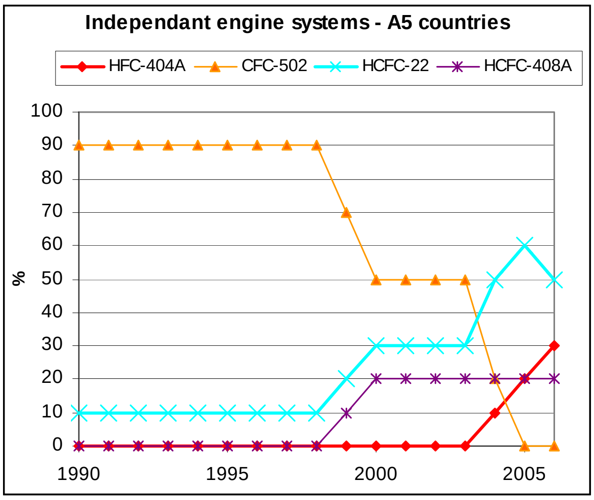


Figure 5.15 – Fluid distribution for independent engine systems in A5 countries.

The choices for belt-driven systems in A5 countries are similar to those made in the developed countries. However, the use of CFC-12 has lasted longer but, due to the availability of compressors dedicated to HFC-134a, it is considered that the share of HFC-134a in brand new systems becomes dominant in 2003 (see Figure 5.14).

For independent engine systems, the shift from R-502 has progressed and can be assumed to be significant as of 2000 (see Figure 5.15).

More generally, the lifetime of trucks in developing countries is not well known. It is certainly longer than what is typical for the developed countries. Also a number of old trucks (that cannot be used any longer in developed countries) are sold to the developing countries, which complicates the estimates of the real numbers for the fleet of trucks and also for the type of refrigerants.

5.3 Results of calculations: refrigerant banks and emissions for refrigerated trucks

5.3.1 Refrigerant bank

Globally, the total refrigerant bank has grown as the fleet of refrigerated trucks, i.e. 40% from 1990 to 2006. Due to the relative short lifetime of the equipment (see Figure 5.16) the CFC bank is decreasing rapidly. The HCFC bank has grown substantially between 1993 and 2000 (see Figure 5.17) and its level was nearly constant until 2004. However, when taking into account the growth of China, the HCFC bank has started to increase again and reached 2 800 tonnes in 2006.

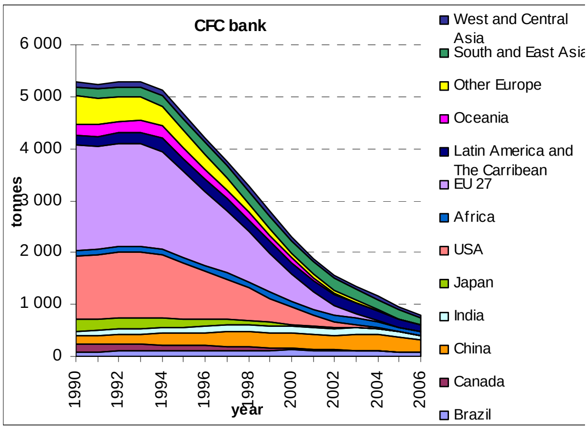


Figure 5.16 - CFC bank.

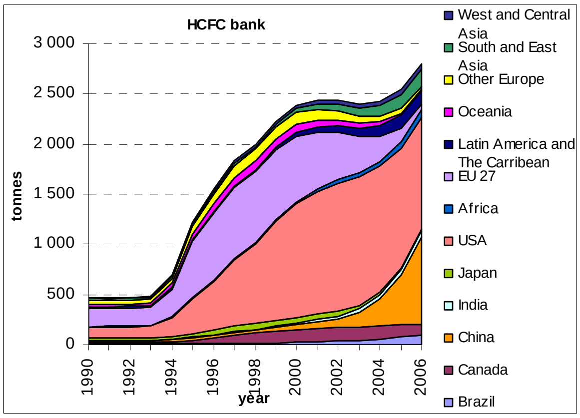


Figure 5.17 - HCFC bank.

The increase of the HFC bank has been fast from nil to nearly 4 500 t in 2006 (see Figure 5.18) and this bank represents 55% of the global bank at this date.

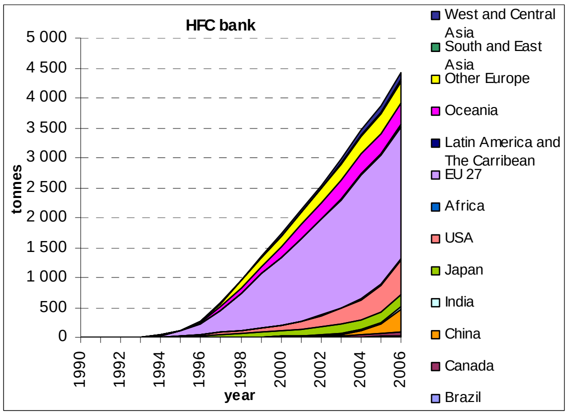


Figure 5.18 - HFC bank.

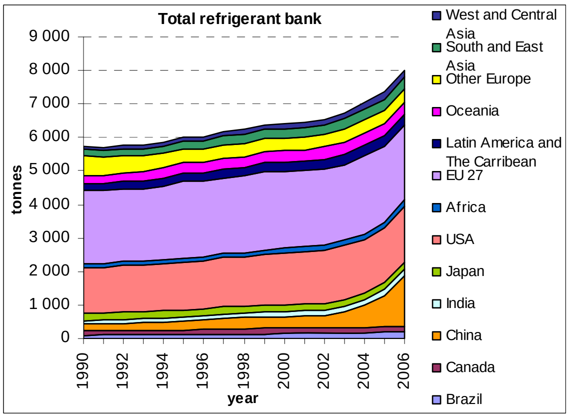


Figure 5.19 - Refrigerant bank by country.

The global refrigerant bank in refrigerated trucks is about 8,000 t, EU27 representing 28% of this bank. The share of the belt driven systems is estimated to only 18%, i.e. 1 500 tonnes.

5.3.2 Refrigerant emissions

Emissions follow the bank. In this sector the level of emissions is high, even if some new features are introduced in the market such as hermetic compressors replacing open-type compressors in independent engine systems.

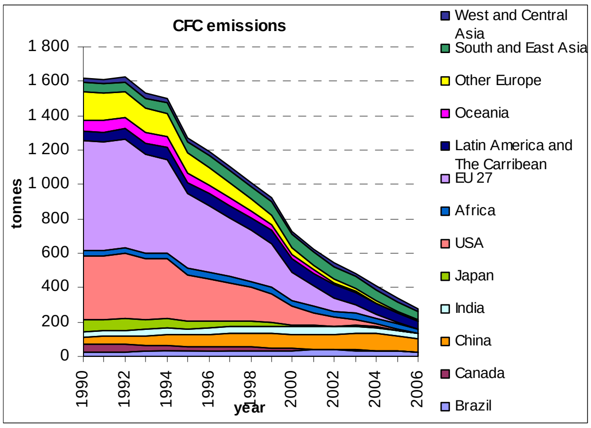


Figure 5.20 - CFC emissions.

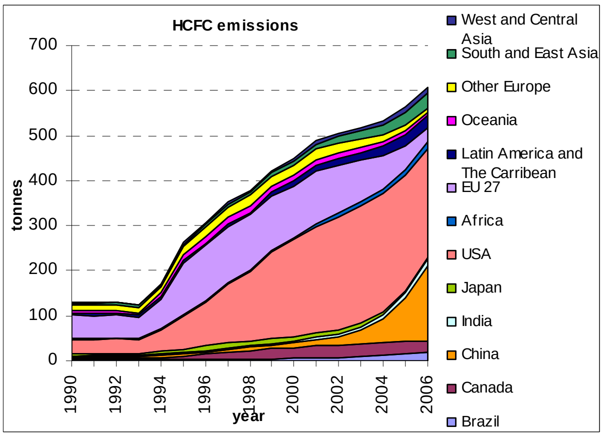


Figure 5.21 - HCFC emissions.

The global level of emissions of refrigerated trucks is about 1,600 tonnes/yr. CFC emissions have rapidly decreased from 1,600 to about 300 tonnes in 2006 (see Figure 5.20). HCFC emissions were about 600 tonnes in 2006: they were steady from 2001 to 2004, but then they started to increase again (see Figure 5.22) because of the recent growth of China in this sector. HFC emissions have increased steeply and are near 1,000 tonnes/yr in 2006 (see Figure 5.23).

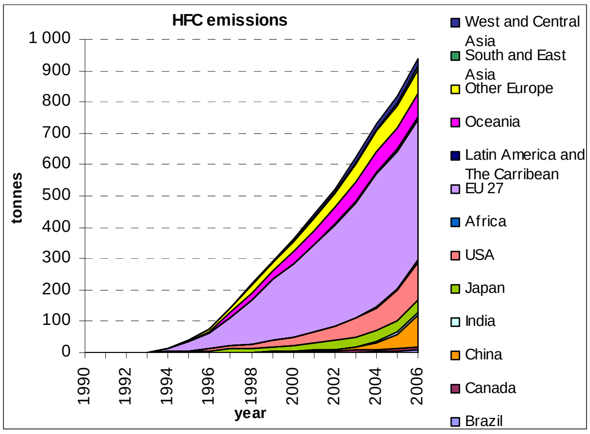


Figure 5.22 - HFC emissions.

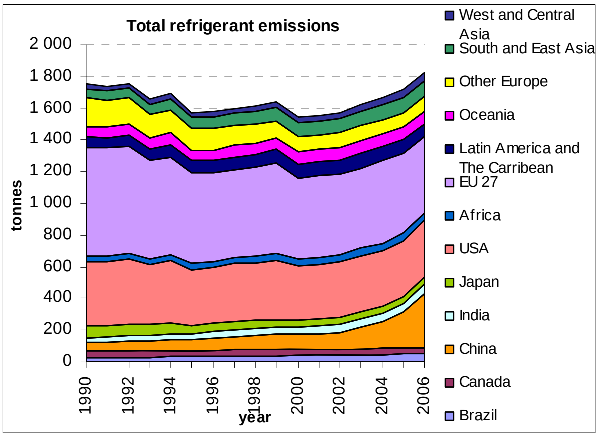


Figure 5.23 – Global refrigerant emissions.

5.3.3 Refrigerant CO_2 equivalent emissions

The total emissions in CO_2 equivalent of refrigerated trucks represent about 5.2 million of tonnes. They are dominated by HFCs emissions, reaching 2.5 million of tonnes in 2006. Even if the emissions of CFCs have significantly decreased, they still represent 33% in CO_2 equivalent (see Figure 5.24).

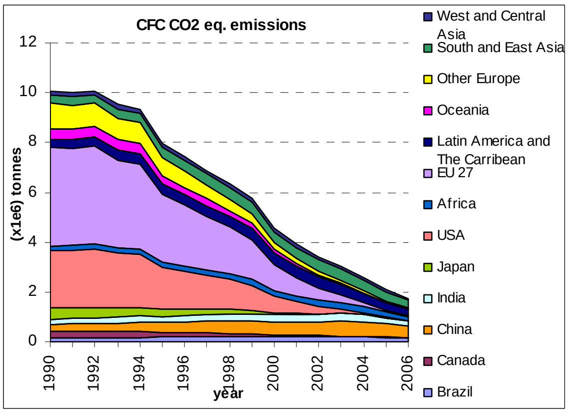


Figure 5.24 - CFC - CO_2 equivalent emissions.

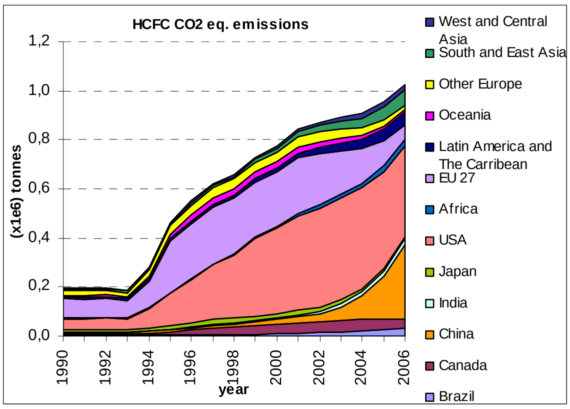


Figure 5.25 - HCFC - CO_2 equivalent emissions.

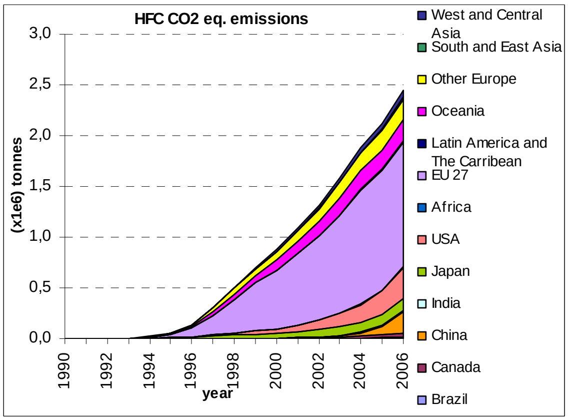


Figure 5.26 - HFC - CO_2 equivalent emissions.

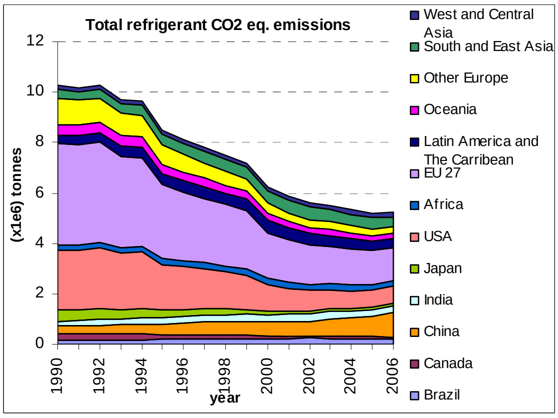


Figure 5.27 – Global CO_2 equivalent emissions.

5.3.4 Refrigerant recovery

As shown in Figure 5.29, recovery is mainly done in A5 countries. Recovery in the sector of road refrigerating transport is evaluated around 460 tonnes, in 2006. In 2000, because of retrofit of CFC systems, the recovered CFC quantities are evaluated at 300 tonnes.

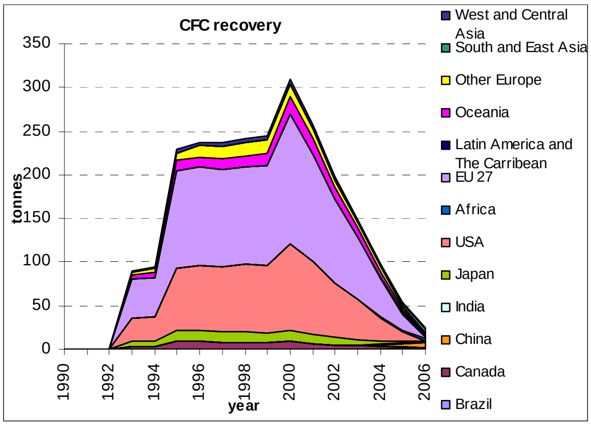


Figure 5.28 - CFC recovery.

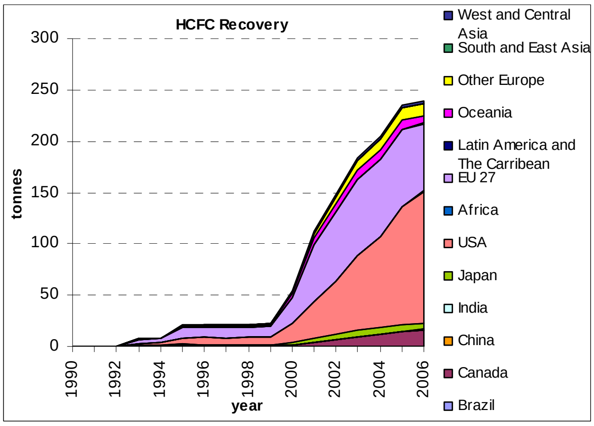


Figure 5.29 - HCFC recovery.

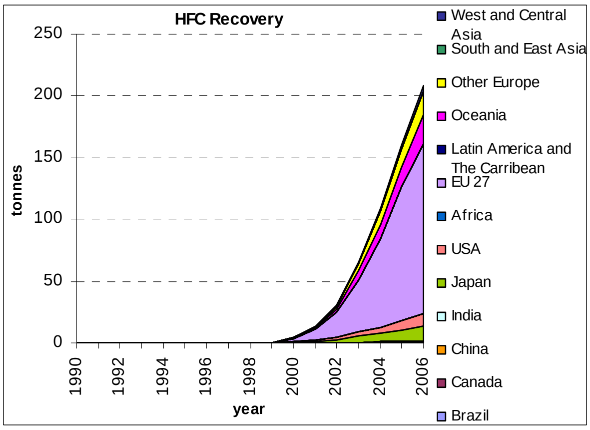


Figure 5.30 - HFC recovery.

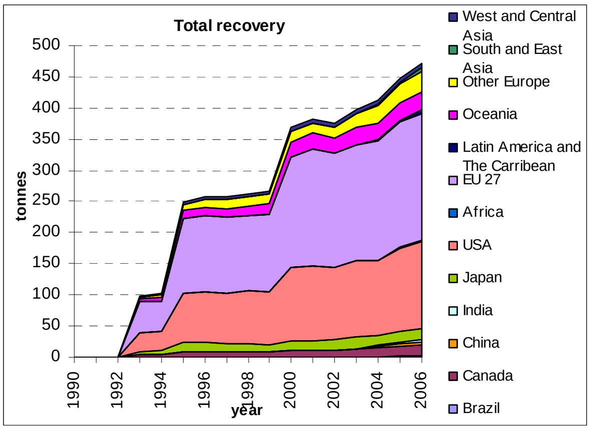


Figure 5.31 – Global refrigerant recovery.

5.4 Data consistency and further improvements

Compared to the previous report [CLO06] statistical data are available for reefer ships and containers, and their quality is similar. So the fleet of refrigerated containers and reefers is known as well as refrigerants in use.

The calculation of the number of refrigerated trucks is similar to the one the 2003 report. Those numbers are calculated based on the ratio of refrigerated and frozen food and the number of refrigerated trucks. So the FAO database which is updated each year is used to derive the number of refrigerated trucks. In this report, new ratios have been established between food production and the refrigerated truck fleet. The European fleet had been well derived from field data. Complementary studies and researches will be necessary in the future to verify the estimated fleet by country and conclude if it is necessary to take into account an evolution of the ratios along time. The share between belt-driven and independent engine systems of refrigerated trucks is also to be confirmed.

Moreover the change in technology and refrigerant has to be carefully monitored to properly evaluate the emissions of refrigerants and their impact on the environment.

5.5 References

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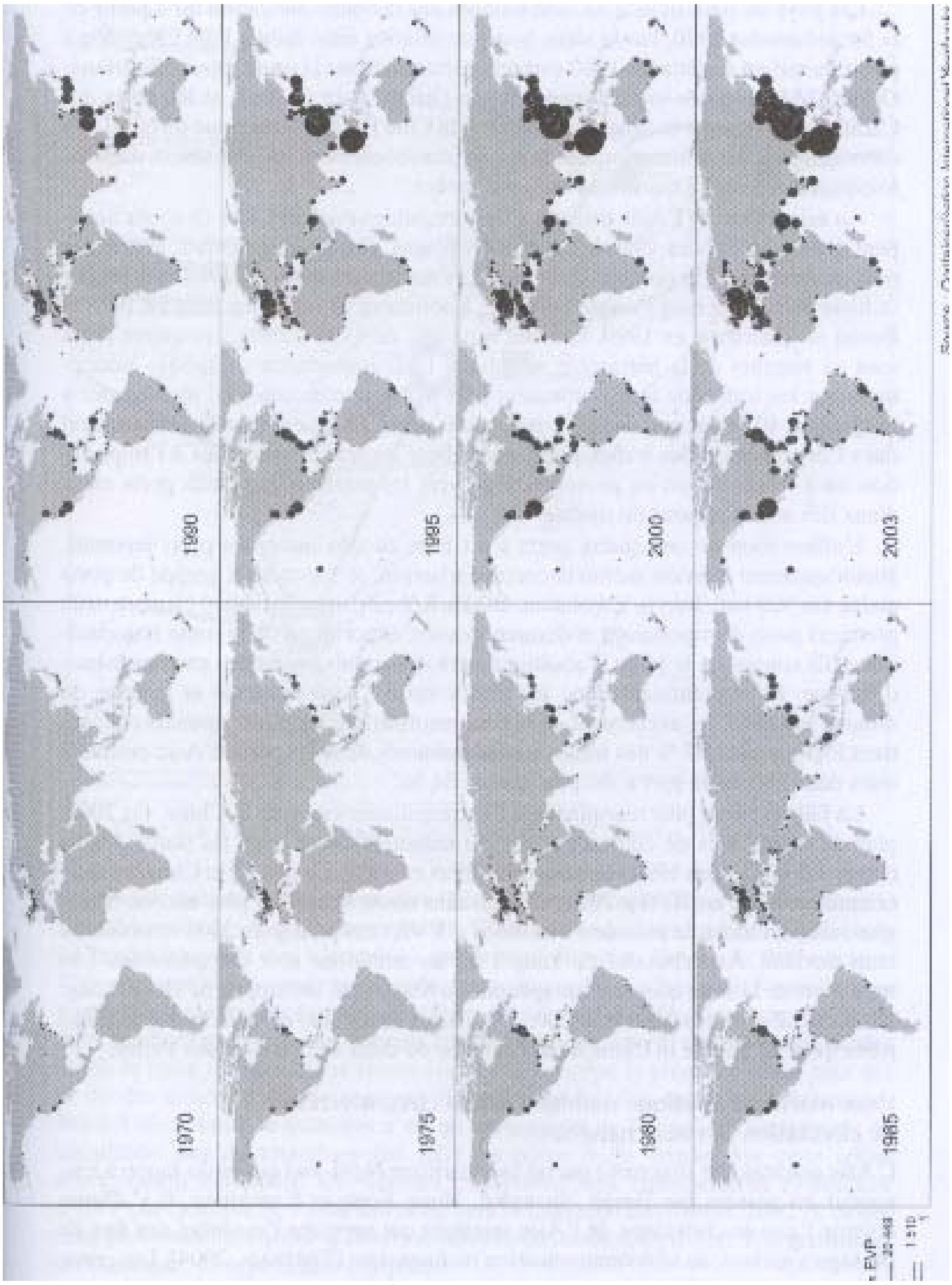
[SHI07] Shipping and Shipbuilding Markets 2007, BRS (Barry Rogliano Salles).

[UNE06] UNEP. 2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee. 2006 Assessment.

Appendix 5.1 - Containers world diffusion



Reference source : page 211, L. Carroué (sous la direction de), *La mondialisation*, édition CNRS-SEDES, 2006, 311 pages.

CONTENTS

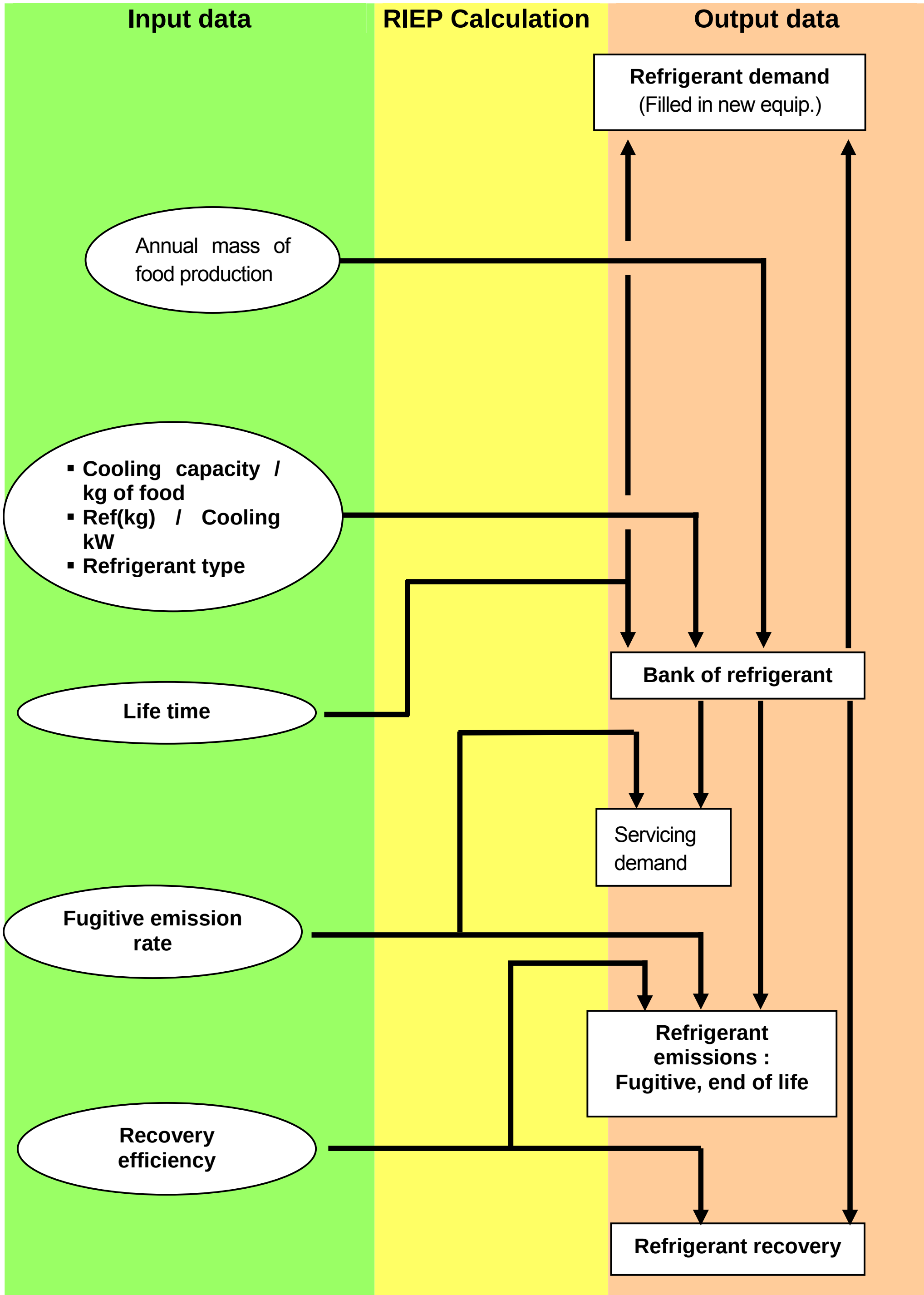


Figure 6.1 – Calculation steps for emission forecasts in the food industry.

6.1 Food industry and cold storage

Cooling and freezing processes in the food industry are applied to meat, dairy products, wines, beers, soft drinks, for some fresh fruits and vegetables and for bakeries, pastries, and chocolate. Flake ice is used for conservation of fresh fish.

6.1.1 Global calculation method

The calculation method (see Figure 6.1) for refrigerant inventory is based on:

- The ratios between cooling capacities and refrigerant charges depending on the level of temperature and the refrigerant
- The necessary cooling capacity determined by the cooling energy required by each specific food processing for each type of product
- The production and consumption data for each type of food product and each country or region.

Annual refrigerated food products are taken from the FAO database [FAO09]. Indeed, FAO updates its database every year for food products produced and sold in each country.

Food sectors taken into account are those of major importance: meat, dairy products, wines, beers, soft drinks, fishes, frozen food and chocolate. Chocolate inventories are based on production data of cocoa beans given in the FAO database. Production data of soft drinks are not available. So in a first estimate, it is assumed that the soft drink production is roughly the same as beer and wine ones, which are well described in the FAO database.

Cold storage is taken into account:

- at the process facilities using a ratio between the cooling process and the properties of the product; it is therefore integrated in the cooling capacity dedicated to products,
- for general cold storage purposes, where needs are calculated separately.

Conservation of vegetables and fruits is taken into account by the cold storage and warehouse calculations. This choice has been made due to the very large difference that exists between crops and refrigerated vegetables and fruits. The calculation of the storage volume avoids large overestimates.

The different food products are cooled or frozen at the production sites, transported in refrigerated transport means, and then possibly stored in general warehouses. So, the food production data is used to establish the refrigerating equipment installed in the food industries.

Since a few years, frozen foods are not included in the FAO database any longer. In these inventories, frozen food production has been estimated by working out a ratio between past known frozen consumptions (old FAO data) and domestic freezers numbers by country. This estimate has to be confirmed.

The calculation steps for activity data are as follows.

- Analysis of the usual process design of a slaughterhouse, dairy, brewery, etc… to determine the installed refrigerating capacity (see appendix 6.1)
- Definition of typical ratios of refrigerant charge referenced to the refrigerating capacity and the temperature level.
- Definition of the type of refrigerants selected which selection depends on the temperature level and on the country type.

- Calculation of the refrigerant bank.
- Calculation of the refrigerant demand for new equipment (based on the equipment lifetime and the bank).
-

And emission factors are defined by regions and refrigerant types.

6.1.2 Calculation of the cooling capacity and the refrigerant charge

Calculations are performed for the eight following sub-sectors:
- meat industry
- dairy industry
- wine and beers
- flake ice for fresh fish
- frozen food
- warehouses
- chocolate industry
- soft drinks.

Annex 6.1 presents detailed calculations for each sub-sector where the ratio between the cooling capacity and the annual production of a given product (kW/kg) is defined.

Figure 6.2 summarizes the methodology and describes the relation between the annual production of refrigerated and frozen food, and the refrigerant bank for all sub-sectors.

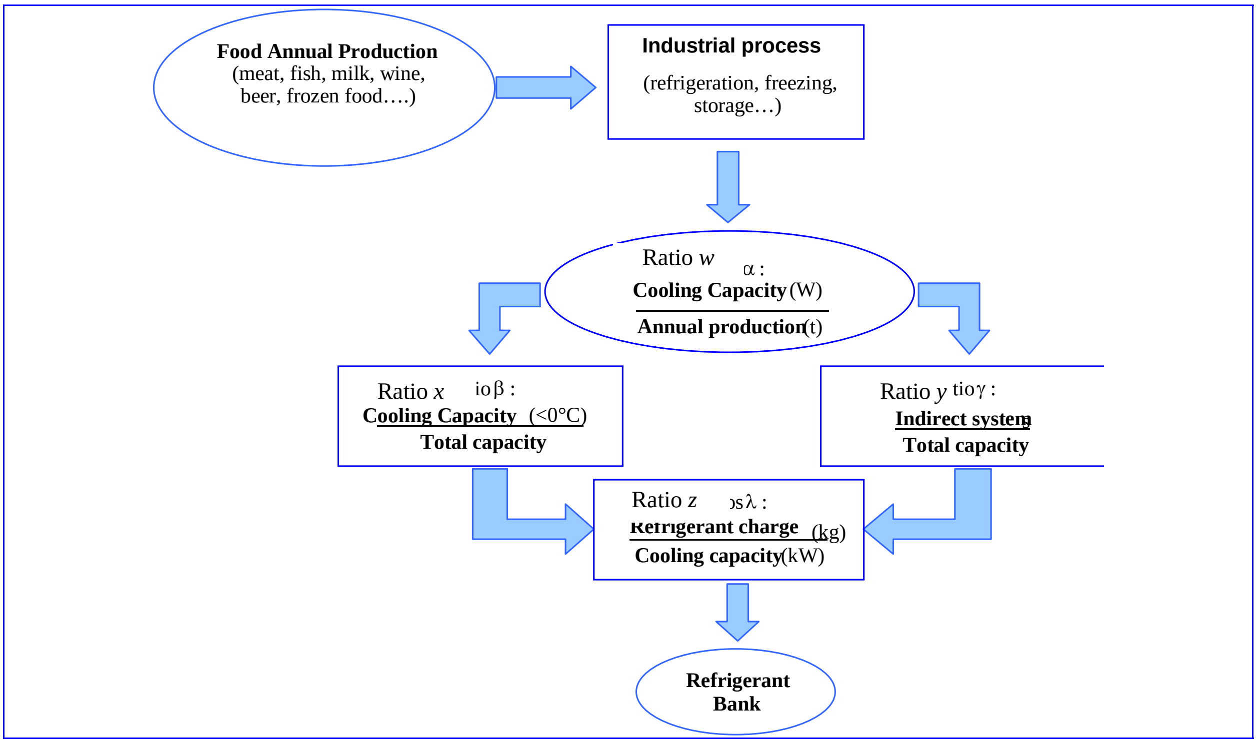


Figure 6.2 - Methodology for each type of refrigerated/frozen food industry.

The detailed studies of processes applied in each sub-sector (see Appendix 6.1) determine the ratio between the total cooling capacity and the annual mass production of each sub-sector:

***w* = Cooling Capacity** (W) **/ Annual production** (t) (6.1)

Taking into account the distribution of cooling capacities for low and medium temperatures, which are dependent on the product, for each sub-sector the ratio *x* is defined:

***x* = Low Temp. Cooling Capacity** (<0°C) **/ Total cooling capacity** (6.2)

Depending on the sub-sector and the technology, the refrigerating system could be of 3 possible designs with different refrigerant charge to refrigerating capacity ratios:

- direct expansion system where the evaporation is controlled by thermo-expansion valves –(TXV).
- Flooded evaporation with evaporators fed by pump with large low pressure receiver containing large refrigerant quantities
- Indirect systems with CO_2 at the low temperature and usually ammonia at the medium temperature.

An average value between direct expansion and flooded evaporation is taken for each sector, complementary to this ratio, *y* is defined as the ratio of the cooling capacity of indirect systems and the total cooling capacity (direct + indirect):

***y* = Cooling Capacity of indirect systems / Total capacity** (6.3)

The ratio *z* refers the refrigerant charge to the cooling capacity while considering the temperature level, and the technology.

***z* = Refrigerant charge** (kg) **/ Cooling capacity** (kW) (6.4)

♦ **The cooling capacity per mass of product and by level of temperature**

Values of the ratios defined in Equations (6.1) and (6.2) are presented in Table 6.1 (see also Annex 6.1 for a justification). For chocolate and soft drinks, ratios have been established in the French inventories [BAR07].

Table 6.1 – Ratios *w* and *x* for the different sub-sectors.

	W Cooling Capacity / unit	*x* Low Temp. Cooling Capacity / Total cooling capacity
Meat industry	43.5 W/t	0.2
Dairy industry	12.7 W/t	0.2
Wine and beers	17.3 W/t	0
Flake ice for fresh fish	43.5 W/t	1
Frozen food	35.8 W/t	1
Warehouses	11.6 W/m^3	0.5
Chocolate industry	3.7 W/t	0
Soft drinks	9.5 W/m^3	0

The freezing capacity for meat is included in the calculations for the amount of frozen products globally. The cooling capacity in the meat industry is only defined for the production of fresh meat.

- **The cooling capacity of indirect systems**

Values of the *y* ratio as defined in Equation (6.3) are given in Table 6.2 for each sub-sector, for the year 2006, for the main countries: U.S.A., Japan, EU15, and China, as an example of A5 countries. This ratio is country and year dependent.

Table 6.2 – Ratio of indirect systems in new equipment in 2006.

	***y* = Cooling Capacity of indirect systems / Total capacity**			
	U.S.A. & Canada	Japan	EU15	China
Meat industry	0.15	0.2	0.08	0.10
Dairy industry	0.3	0.3	0.8	0.25
Wine and beers	0.15	0.2	0.45	0.10
Flake ice for fresh fish	0	0	0.08	0
Frozen food	0.25	0.40	0.08	0.20
Warehouses	0.15	0.2	0.25	0.1
Chocolate industry	0.01	0.01	0.01	0.01
Soft drinks	1	1	1	1

The share of indirect systems in developed countries has been increasing since 1994, after the CFC phase-out (Europe).

- **The refrigerant charge**

Values of the *z* ratio as defined in Equation (6.4) are given in Table 6.3. This ratio is given for medium and low temperatures, for direct and indirect systems.

Table 6.3 – Refrigerant charge referred to the cooling capacity.

System	***z* = Refrigerant charge (kg) / Cooling capacity (kW)**
Med Temp. Direct system	5.5
Low Temp. Direct system	8.8
Med Temp. Indirect system	1
Low Temp. Indirect system	1.5

6.1.3 Type of refrigerants

For each country and each sub-sector, refrigerant repartition in production has to be described. Figure 6.3 summarizes the trends of the use of refrigerants at the global level. R-717 (ammonia) is widely used in industrial refrigeration. Regional variations exist and are taken into account for the calculations.

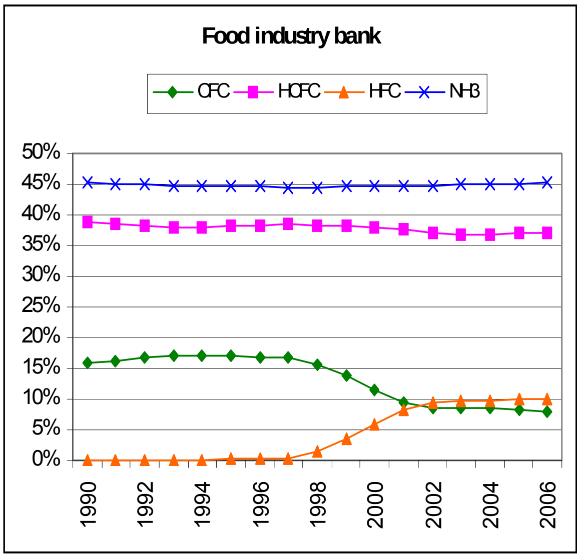


Figure 6.3 – Evolution of refrigerant bank in food industry.

6.1.4 Other characteristics

For all countries, a mean lifetime of 30 years and an emission factor of 30% are assumed. Emission rates and recovery efficiencies are given in Table 6.8.

Table 6.8 – Emissions factors and recovery efficiencies by country in 2006.

Country	***Emission rate in 2006***	***Recovery efficiency in 2006***
USA	8%	72%
Japan	7%	75%
EU15	8%	80%
A5 countries	20%	30%

According to [UNE06], recent European studies show improvements in emission rate levels. They are taken into account in values presented in Table 6.8 for new equipment in developed countries, during the period 2003 to 2006. In 2003, the mean level of emissions in industrial sector was of 10%.

6.1.5 Milk tanks

Milk tanks are installed in farms and represent a sub-sector included in the dairy sector. The calculations are specific, based on the milking number which defines the storage volume of the milk tank. Based on the storage volume, it is possible to define the refrigerating capacity and the refrigerant charge; the method and additional data are presented in Appendix A6.1.2.2.

- **Average refrigerant charge**

The average charge of refrigerant is 2.09 kg/m^3 of storage.

- **Characteristics**

A number of milk tanks are exported from the developed to the developing countries where the lifetime is usually much longer. This issue is indirectly taken into account via the choice of refrigerant as given in Table 6.9.

Table 6.9 – Characteristics of milk tanks.

Life (years)	Annual Emissions (%)	Recovery Efficiency (%)	% of Charge Emitted before Servicing
15	5	50	30

- **Refrigerant type**

HCFC-22 has been mainly used, with CFC-12 (20%), in milk tanks. It has been replaced by R-404A in developed countries as of 2001. Starting in 2002, CFC-12 has not been used any longer in milk tanks in A5 countries, where only HCFC-22 is used from now on.

6.1.6 Production data for food products for the year 1990 and the year 2006

Table 6.10 presents the productions for meat, milk, wines, and beers, frozen food, for ice for fresh fish conservation, and it also presents the volumes of warehouses. Data are available from 1960, but for simplicity reasons only data for the years 1990 and 2006 are presented.

Table 6.10 – Data for food products and warehouse volumes, by region.

Productions	U.S.A.	China	Japan	Brazil	India	EU27
Meat (t) in 1990	28 289 327	30 421 460	3 503 087	7 709 088	3 929 481	42 604 396
In 2006	41 066 510	72 710 169	3 120 906	17 776 208	6 329 516	42 525 045
Milk (t) in 1990	70 738 800	7 260 643	8 347 843	15 211 430	54 715 550	178 044 190
In 2006	87 793 189	36 849 253	8 339 272	26 447 364	104 050 050	163 938 806
Breweries (l) in 1990	25 546 500	7 794 902	6 621 883	4 695 732	191 814	58 538 514
In 2006	25 432 200	37 291 519	3 892 000	9 564 200	293 726	56 652 838
Ice (t) in 1990	5 780 944	7 794 902	9 814 535	619 805	2 862 586	9 506 932
In 2006	5 280 134	37 291 519	4 475 151	780 092	3 844 838	5 657 887
Warehouses (m^3) in 1990	44 175 804	3 536 531	32 137 327	4 699 697	984 992	59 444 614
In 2006	68 616 038	5 976 594	45 722 527	7 811 055	1 814 377	80 237 892
Frozen prod. (t) in 1990	13 784 780	1 417 509	467 840	424 047	492 984	5 498 863
In 2006	17 287 980	3 444 963	1 028 468	754 085	2 313 867	10 089 062
Chocolate (t) in 1990	1 918 116	1 417 509	345 141	175 737	17 568	2 747 703
In 2006	2 297 070	3 444 963	593 247	246 645	47 968	3 291 807

The low level of beef consumption in India as well as the social and food habits form explain why the meat production in India is relatively low compared to other countries.

On the other hand, the high development of the milk industry in Europe leads to a significant share in the global milk production.

Table 6.10 shows how frozen food is closely related to high GDP countries.

In calculations, flake ice production is directly linked to the daily catch of sea and river fish. The very high level of ice production in China is associated with the high catch of river fish in this country and represents 37 Mt of total fish catches in China.

6.2 Industrial processes (other than food industry)

♦ Data sources and detailed calculations

Refrigerating needs in industrial processes other than food processing are multiple. They cover a broad range of temperatures. Two types or categories of refrigerating equipment have been defined and analyzed in [PAL03]. They had not been updated, data were not available. So, trends have been prolonged and have to be confirmed.

1. Chillers operating at a temperature above 0°C.: they are found in all kind of industries and for example, they are the only refrigerating systems for the micro-processor industry
2. Refrigerating systems particularly designed for low-temperature applications.

In order to avoid double counting, chillers are not taken into account in this section because the chiller production and demand is published for all types of chillers for comfort cooling on one side and for industrial processes on the other side (see Section 7.2). For large centrifugal chillers, chiller manufacturers know that 2/3 is used for comfort cooling and 1/3 for industrial processes. For small and medium size chillers this share is of 50% for each type of applications. In this report chillers are only covered in the section 7 because there no consequence on refrigerant bank and emissions wither chillers are split in two sections or addressed in a signle one.

In section 6.2 only the low-temperature refrigerating systems installed in the chemical industry are considered, because:

- This sub-sector is the more significant (except food) for low-temperature applications,
- Data for study are available.

Improvements are still possible by adding the low-temperature cooling needs of the pharmaceutical industry to the needs considered in this study.

A thorough analysis of the installed base of a chemical company (under confidentiality agreement) has enabled the development of the typical scheme of an industrial production site. Taking this study as a basis, the low-temperature cooling capacity has been projected to all other chemical manufacturers, in order to have a first estimate. The characteristics are presented in Table 6.11.

Table 6.11 - Refrigerant charge and cooling capacity for a chemical plant.

	Medium temperature	**Low temperature**
Cooling capacity	55%	45%
Ratio (kg/kW)	1	1.6
Refrigerant charge	40%	60%
Average charge / plant	7 t	10,5 t

Even if many installations may have a lifetime of more than 30 years -taking into account the big overhauls- the lifetime of equipment is considered to be 15 years, i.e., the time before a significant remodeling takes place.

Table 6.12 – Other characteristics of typical refrigerating systems installed in chemical plants.

Life (years) Before remodeling	**Annual Emissions (%)**	**Recovery Efficiency (%)**	**% of Charge Emitted before Servicing**
15	10	50	30

Based on available information collected from the websites of the main chemical companies, operating globally, it has been possible to describe the chemical industrial plants to countries as indicated in Table 6.13. Due to the fact that data on the effective refrigerant charge in all these different plants are not available, the refrigerant charges averaged from about one hundred sites have been projected to all the sites given in Table 6.11, as a first estimate.

Table 6.13 – Division of chemical plants of 8 major companies over countries.

		Companies							
	total	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Africa	**5**			4				1	
Algeria	**1**			1					
Argentina	**15**		3	4			4		4
Australia	**22**	4	5	9			1	3	
Austria	**22**		2	12			7	1	
Balkans	**19**			8			11		
Bangladesh	**2**			2					
Belgium	**59**		1	17	2	2	30	2	5
Brazil	**55**	8	5	17	2		13	10	
Canada	**32**		11	1		1	3	15	1
CEIT	**15**			7			5	3	
Central America	**18**			16		1	1		
Central Asia	**3**			3					
Chile	**7**			4			1	1	1
China	**68**	9	5	18			10	20	6
Colombia	**6**		1	3				1	1
Czech Republic	**5**			2			3		
Denmark	**10**			7			2	1	
Egypt	**4**			3				1	
Finland	**9**			5			4		
France	**151**		5	22	1	2	53	8	60
Germany	**185**		11	98	8	1	49	13	5
Greece	**5**			3			2		
Honk Kong	**0**								
Hungary	**8**			2			5	1	
India	**33**		5	19	2		3	2	2
Indonesia	**18**		6	6	1			5	
Iran	**1**			1					
Ireland	**6**		1	3		1			1
Israel	**2**			1					1
Italy	**91**		5	32	10	2	25	5	12
Japan	**63**	1	7	19	1		4	25	6
Kuwait	**0**								
Libya	**0**								
Malaysia	**19**	3	4	11				1	
Mexico	**34**		5	12			5	11	1
Middle East	**12**			11					1
Morocco	**2**			1					1
Myanmar	**1**			1					
Netherlands	**50**		8	17	1	2	8	6	8
New Zealand	**7**	1	3	2			1	0	
Nigeria	**5**						5	0	
Norway	**8**			2			5	1	
Oceania	**0**								
Pakistan	**8**		4	4					
Peru	**1**			1					
Philippines	**7**		2	5					
Poland	**13**			4			5	3	1
Portugal	**17**			7			10		
Roumania	**7**			2			5		
Russia	**14**			3			1	10	
Saudi Arabia	**6**		1	5					
Singapore	**11**	1	1	3			1	4	1
South & East Asia	**2**					1			1
South Africa	**8**		2	4	2				
South America	**5**			5					
South Korea	**28**	4	5	9			7	3	
Spain	**67**		4	21			30	4	8
Sweden	**13**		2	3			5	3	
Switzerland	**17**			9	1		3	2	2
Taïwan	**9**	2	1	3				3	
Thailand	**29**	4	6	5	1		11	1	1
Turkey	**11**			5			3	3	
Ukrania	**1**						1		
United Arab Emirates	**2**			2					
United Kingdom	**92**	15	19	22	12	1	7	10	6
United States of America	**308**		44	58	5	37	33	95	36
Venezuela	**6**		2	2				1	1

Figures 6.4 to 6.6 show the evolution of refrigerants in use for the new refrigerating systems installed in the chemical industry.

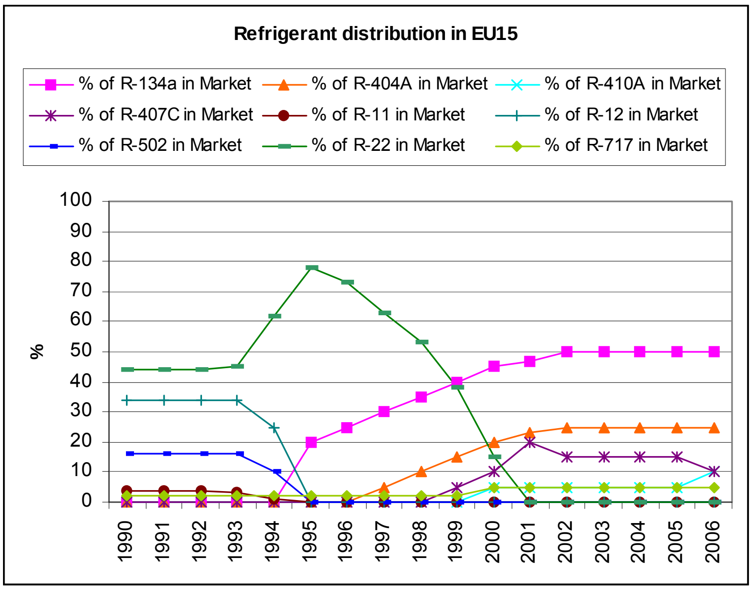


Figure 6.4 - Refrigerant distribution for new equipment (%) in Europe.

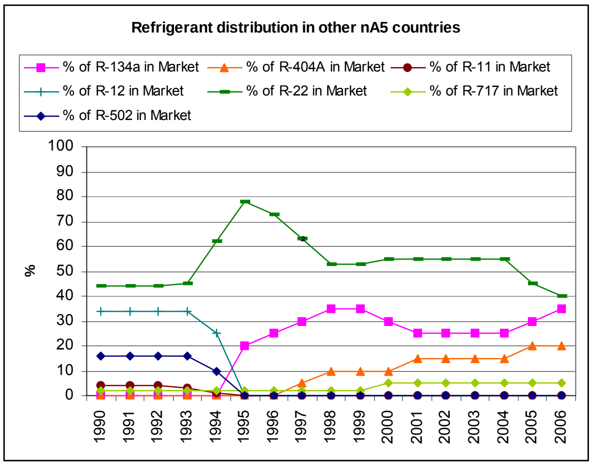


Figure 6.5 - Refrigerant distribution for new equipment (%) in other developed countries.

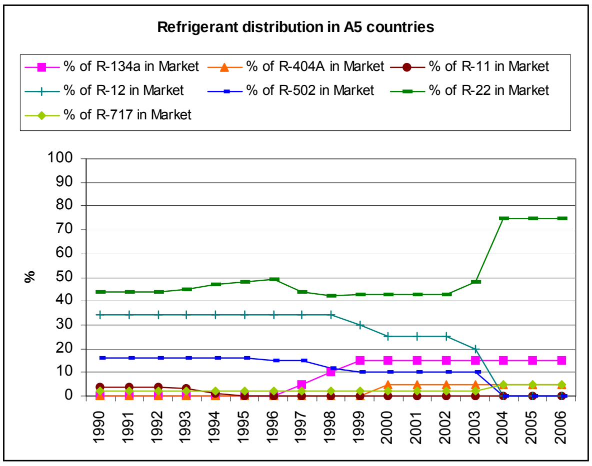


Figure 6.6 - Refrigerant distribution for new equipment (%) in A5 countries.

6.3 Results of calculations: refrigerant banks, emissions, and recovery

For the sake of simplicity in this report, all industrial sectors have been merged to present the calculation results. However, globally the food industry represents more than 90% of the refrigerant banks and the related emissions.

6.3.1 Refrigerant banks

As shown in Figure 6.7, the impact of the EU regulation [EU00] on the interdiction of use of any CFCs for the servicing as of 2001 has led to rapid change of the bank of CFCs due to a rapid retrofit policy. The impact of the same regulation forbidding the use of HCFCs in new installations as of January 1st, 2000 has also an impact but with a lower extend as shown in Figure 6.8.

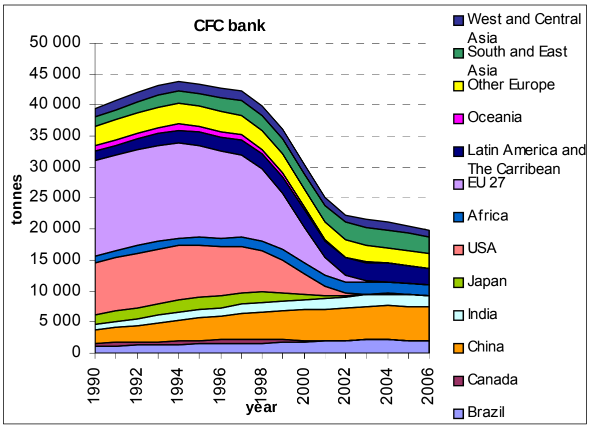


Figure 6.7 - CFC bank.

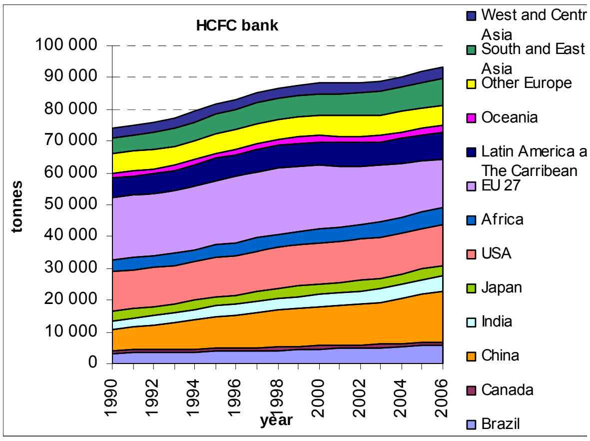


Figure 6.8 - HCFC bank.

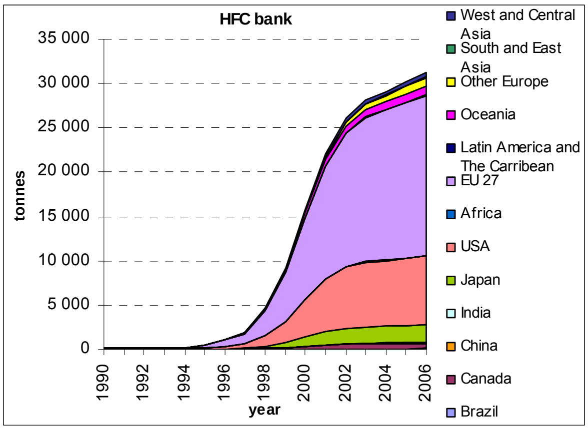


Figure 6.9 - HFC bank.

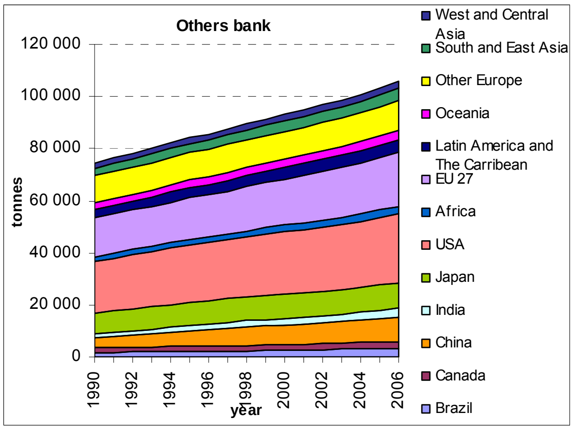


Figure 6.10 - R-717 bank.

A consequence of the EU regulation is also shown in Figure 6.9 where the rapid growth of the HFC bank in Europe is the dominant trend. Nevertheless, both the HCFC and ammonia banks, respectively of about 94,000 tonnes and 106,000 tonnes (see Figures 6.10 and 6.8) are the dominant banks of the sector.

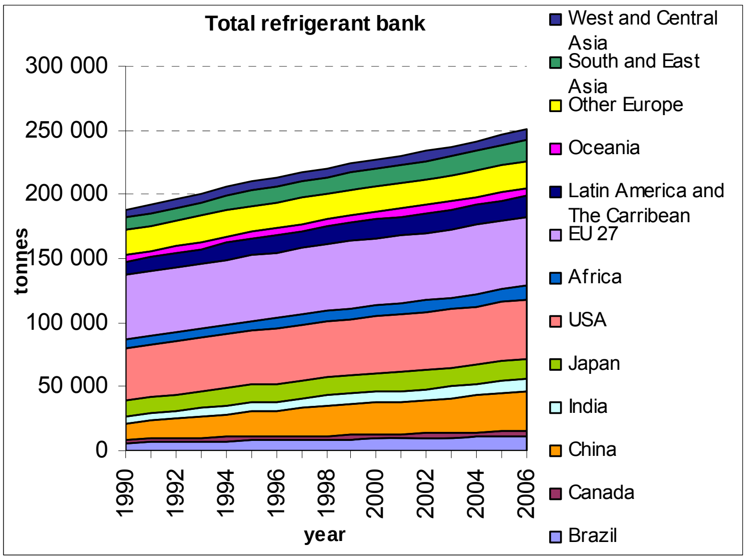


Figure 6.11 – Global refrigerant bank in industrial refrigeration.

Figure 6.11 underlines that the strong European food industry implies a large number of refrigerating systems with a global EU27 bank of about 54,000 tonnes of refrigerants (21%).

In 2006, the U.S. share is about 19% with 47,000 tonnes of refrigerants and the China one is of 12% with 31,000 tonnes.

6.3.2 Refrigerant emissions

Refrigerant emissions follow the evolution of the bank. However, improvement in emission rates [UNE06] and the CFC bank decrease lead to a stability of the global emissions at the level of 37,000 tonnes per year (see figure 6.16). HFC emissions are rising at 2800 tonnes in 2003 (see Figure 6.14) but are slowly decreasing from 2003 to 2006.

Ammonia emissions are steady at about 9400 tonnes (see Figure 6.15) in 2006. CFC emissions are decreasing rapidly and are about 5500 tonnes in 2006 (see Figure 6.12).

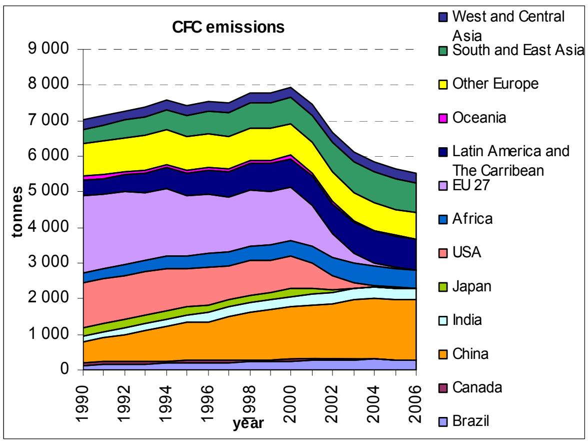


Figure 6.12 - CFC emissions.

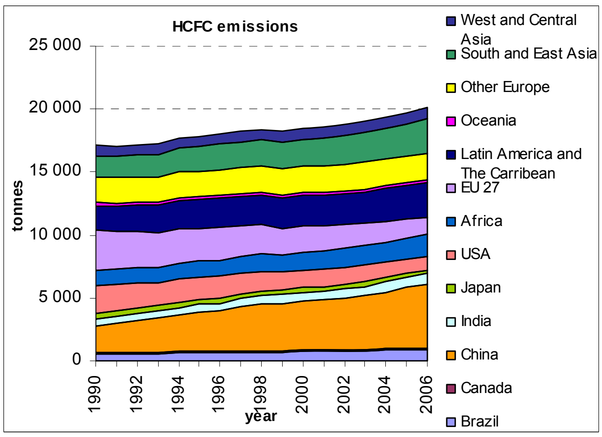


Figure 6.13 - HCFC emissions.

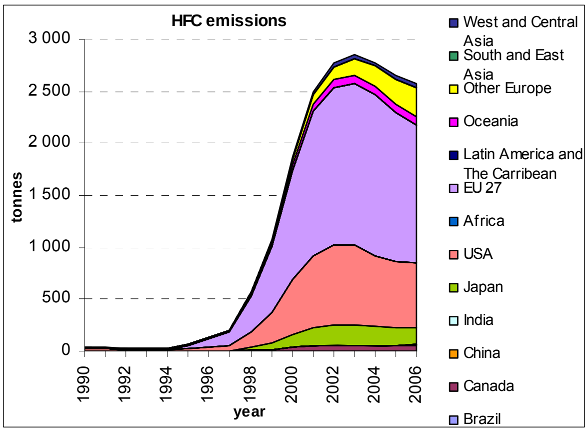


Figure 6.14 - HFC emissions.

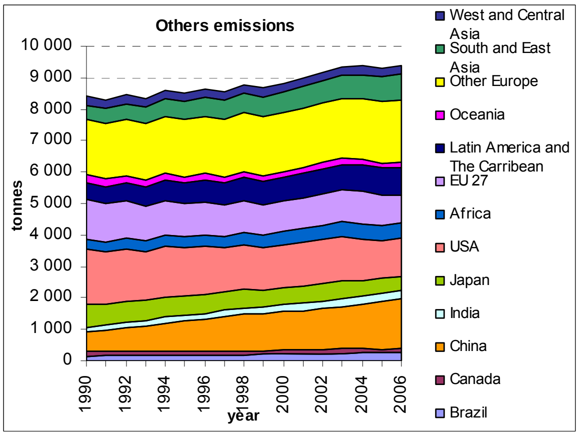


Figure 6.15 - R-717 emissions.

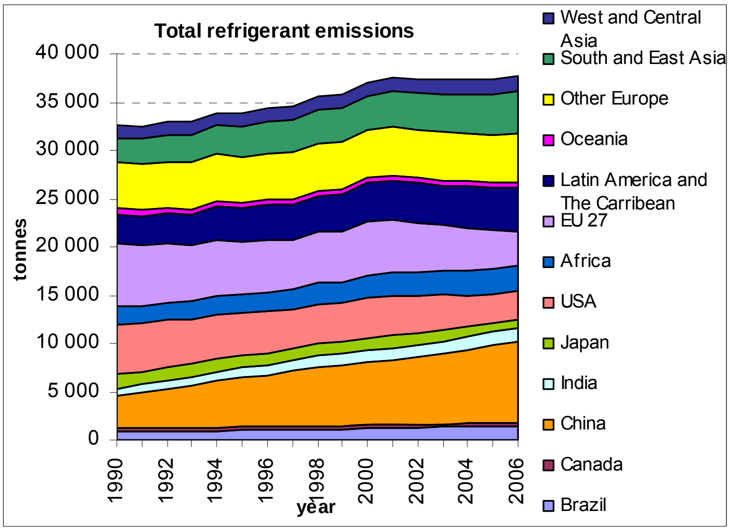


Figure 6.16 – Global refrigerant emissions in industrial refrigeration.

6.3.3 CO_2 equivalent emissions

As shown in Figures 6.17 and 6.18, even if CFC emissions have lowered significantly, their CO_2 equivalent is of 34 million tonnes eq. CO_2 in 2006 whereas it is of 30 million of tonnes for HCFCs, due to the different GWP value of CFC-12 compared to HCFC-22.

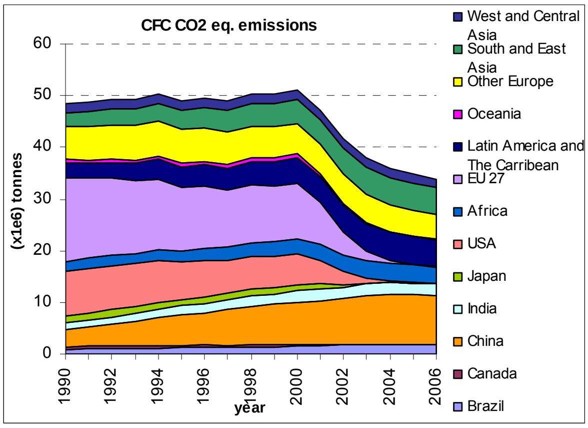


Figure 6.17 - CFC - CO_2 equivalent emissions.

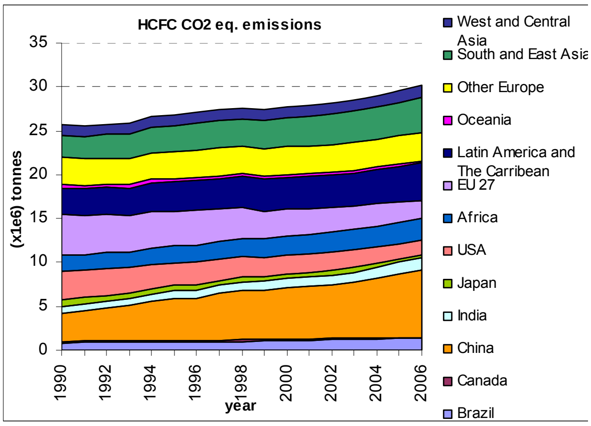


Figure 6.18 - HCFC - CO_2 equivalent emissions.

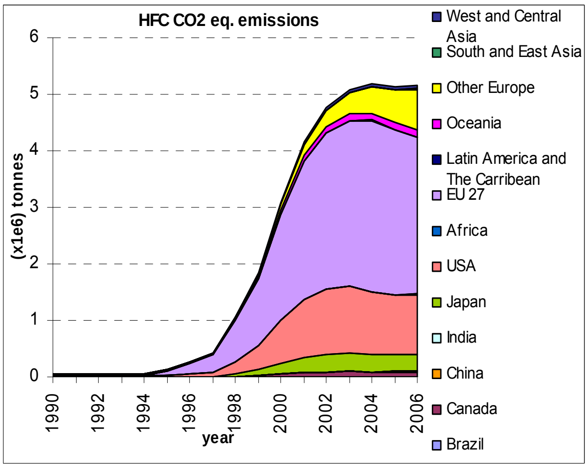


Figure 6.19 - HFC - CO_2 equivalent emissions.

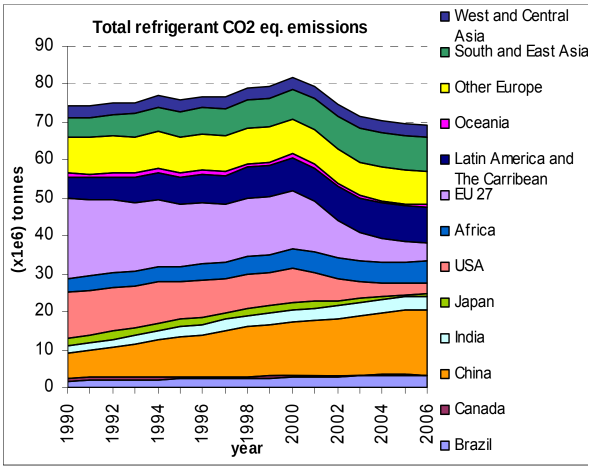


Figure 6.20 – Global refrigerant CO_2 equivalent emissions in industrial refrigeration.

Figure 6.19 shows that because of the high GWP of R-404A, the equivalent CO_2 emissions of HFCs are of 5.1 million tonnes eq. CO_2 in 2006 for "only" 2500 tonnes of refrigerant emissions.

Globally, refrigerant emissions of developing countries in CO_2 equivalent are dominant due to the use of CFCs (see Figure 6.20). China represents 25% of the total CO_2 equivalent emissions due to the industrial refrigeration sector.

6.3.4 Refrigerant recovery

Usually, due to the large amount of refrigerant charged in industrial installations, recovery is much more common than in many other sectors, even before the entry into force of any regulation. This sector is therefore known as “efficient” in terms of refrigerant recovery.

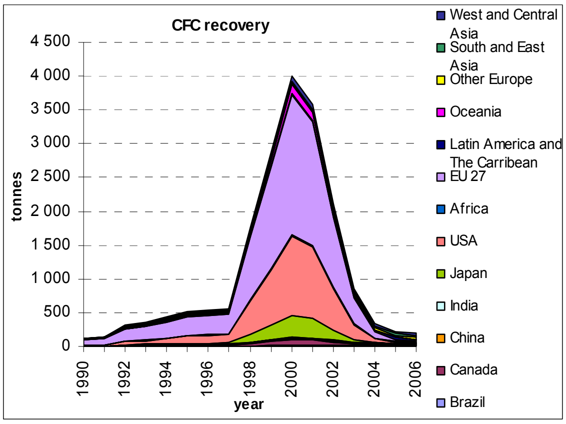


Figure 6.21 - CFC recovery.

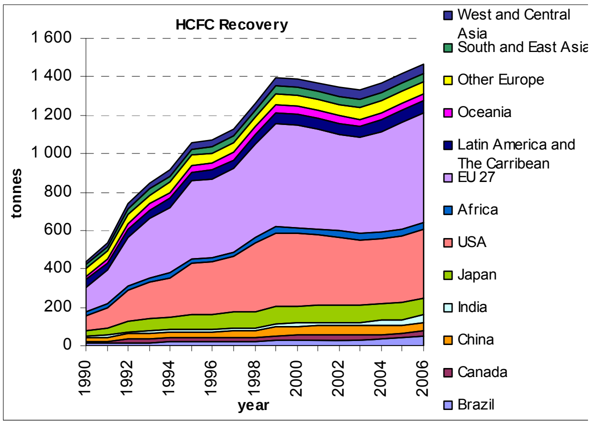


Figure 6.22 - HCFC recovery.

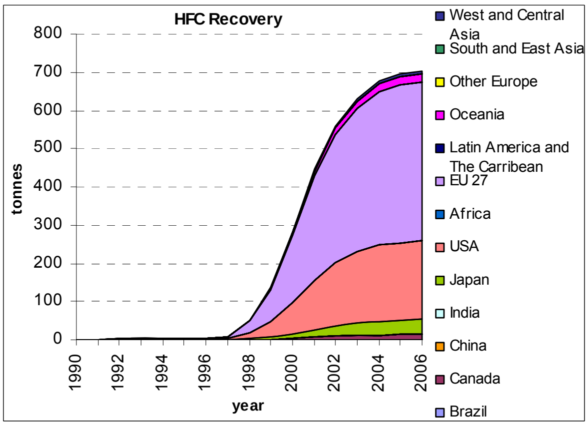


Figure 6.23 - HFC recovery.

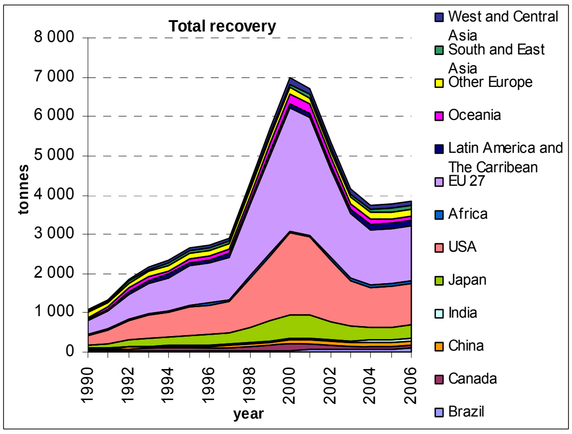


Figure 6.24 – Global refrigerants recovery.

6.4 Data consistency and further improvements

For the food industry, the chosen approach based on the use of the FAO database allows giving the global picture with an annual update, which is a very significant advantage. The introduction of the retrofit option in RIEP has been taken into account and so the impact of the European regulation forbidding the use of CFCs for servicing of existing equipment has been acknowledged. Intermediate blends such as R-401A, R-409A, R-402B, R-408A, have been traced and explain the rapid decrease of the CFC bank in Europe.

In these 2006 inventories, the refrigerating equipment used in the chocolate manufacturing as well as those used for the soft drink production have been introduced. However, neither the production of soft drinks nor the frozen food data have been included in the FAO database since two years. It would be useful to collect more data to verify production estimates of these sub sectors.

Complementary analyses will be needed to follow the sharing between direct and indirect systems in the food industry. Some global companies have made the decision not to use HFCs in their processes any longer and even if this policy is for the choice of new equipment, the impact will be significant on the medium term in developed countries.

Progresses in terms of activity data are still necessary in industrial processes using refrigerating systems at low temperature: the pharmaceutical industry and production of industrial gases need to be introduced.

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Appendix 6.1 - Method of calculations of the refrigerating capacity of the food industry

A6.1 Global cooling capacity for all meats

The refrigerant inventory for the meat sub-sector has been determined using meat production figures. The FAO database gives a very detailed description of the meat demand and production for all countries since 1961.

Cooling process for meat
The vast majority of four-footed animals are slaughtered in commercial slaughterhouses under supervision. The small portion still slaughtered on the farm has not been taken into account.

After killing, bleeding, skinning, and evisceration, meats (M1) are cooled, then either cut and packaged for frozen meat (M2) or stored in one piece if for fresh meat (M3) (see Figure A6.1).

The quantities M1, M3, and M4 are known from the FAO database. For frozen meat, the quantities are directly included in the frozen food demand, which has been analyzed as one specific entity (see Section 6.6).

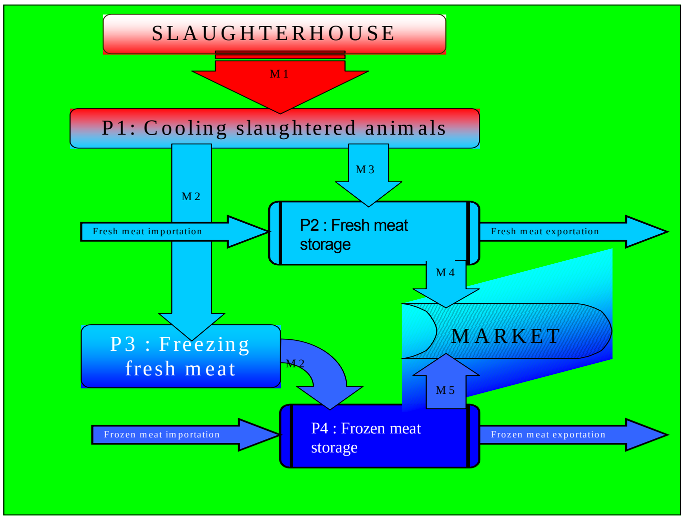

Figure A6.1- Cooling and freezing for production and storage.

Based on the different meat masses, the following refrigerating capacities are defined:
- P1 and P2 are the cooling capacities for fresh meat chilling and storage, respectively
- P3 and P4 are the cooling capacities for meat freezing and frozen meat storage, respectively.

A6.1.1 Cooling model for beef

The cooling capacity for meat is based on the maximum needed capacity at peak load, which in fact is the design criterion of refrigerating equipment. Peak load occurs at the beginning of meat chilling, just after the slaughter when carcasses have their highest temperature.

Figure A6.2 shows the exponential curve of beef carcass temperature drop. The chill rate is $\Delta\theta$ / Δt, but the peak load corresponds to the maximum slope α ($\Delta\theta$ / Δt), which is required for sanitary issues.

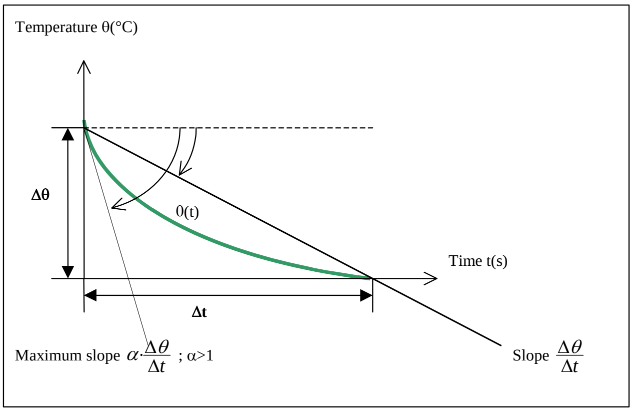

Figure A6.2 - Cooling model of beef.

From Figure A6.2 the maximum product cooling capacity P_{meat} can be calculated, i.e., by using Equation (A6.1).

$$P_{meat} = \frac{\alpha \cdot M \cdot c \cdot \Delta\theta}{\Delta t} \qquad \text{(A6.1)}$$

where:

P_{meat} meat maximum cooling capacity (kW)
α coefficient for the determination of the maximum chill rate (see Figure A6.2),
c average heat capacity (kJ/kg.K)
$\Delta\theta$ / Δt temperature difference for a given time difference (K/s).

The water evaporated from the beef carcass condenses and freezes on the evaporator coils requiring additional capacity due to frost formation. The rate of water evaporation is proportional to the rate of meat being cooled; and the corresponding cooling capacity can be calculated by Equation (A6.2):

$$P_{frost} = \beta \cdot \frac{\alpha \cdot M}{\Delta t} \cdot H_{sol} \qquad \text{(A6.2)}$$

where :

$\frac{\alpha \cdot M}{\Delta t}$ maximum rate of chilled meat
H_{sol} = ice heat of solidification = 335 kJ/kg
β<1, part of water lost from the chilled meat

Miscellaneous loads such as conveyors, air infiltration, personnel, fan motors, lights, and equipment heat losses need to be taken into account. The latter loads are proportional to the maximum cooling capacity M.

$$P_{misc} = \gamma \cdot M \qquad \text{(A6.3)}$$

where:

γ(W/kg) is the factor for maximum miscellaneous losses.
The total cooling capacity is :

$$P_{tot} = P_{meat} + P_{frost} + P_{misc}$$

$$\Rightarrow P_{tot} = \frac{\alpha \cdot M \cdot c \cdot \Delta\theta}{\Delta t} + \beta \cdot \frac{\alpha \cdot M}{\Delta t} \cdot H_{fusion} + \gamma \cdot M$$

Thus the cooling capacity per unit of mass is:

$$p = \frac{P_{tot}}{M} = \frac{\alpha \cdot c \cdot \Delta\theta}{\Delta t} + \beta \cdot \frac{\alpha}{\Delta t} \cdot H_{fusion} + \gamma \qquad \text{(A6.4)}$$

where
p specific cooling capacity (W/kg).

♦ **Coefficient values for chill and holding coolers**

Chilling of the beef carcass is performed in two different coolers. First the rapid cooling is performed in the chill cooler and then cooling takes place at reduced rate in the holding cooler. The carcass density is significantly lower in the holding cooler (45 kg/m^3) than in the chill cooler (60 kg/m^3). So, if referred to the mass of a chilled carcass, the ratios of miscellaneous heat losses are different. Taking into account that for large storage the volumetric G factor amounts to 30 W/m^3, this leads to

γ_1 = 0.5 W/kg for chill cooler, and

γ_2 = 0.677 W/kg for holding cooler.

♦ **Coefficient for chill cooler**

Dressed beefs are split into half carcasses (the average half carcass mass is around 150 kg) and the average specific heat c is around 3.14 kJ/kg.K [ASH98].

α is determined according to the curve of average carcass temperature of meat cooling versus time (Figure 6.3),

Δt = 20 h and $\Delta\theta$ = 28°C, the first 4 hours (= 0.2 Δt) the temperature decreases by 11.2 K (= 0.4$\Delta\theta$) therefore α = 2.

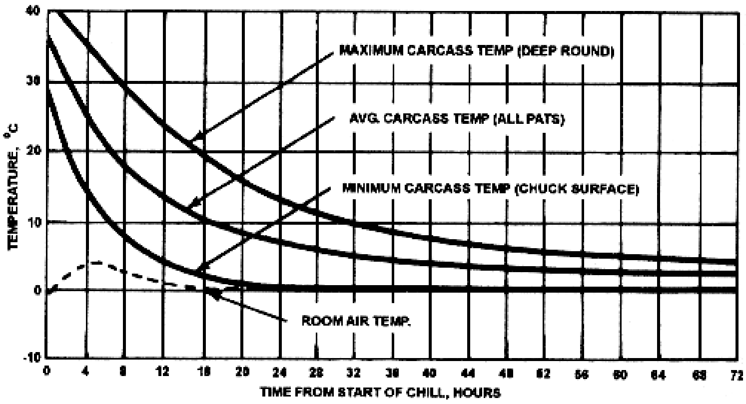

Figure A6.3 - Beef chilling curves [ASH98].

β = 0.03 represents typically 3% of the chilled mass [ASH98]; γ = 0.5 W/kg (see above).

In summary, for Δt = 20 h = 72,000 seconds and $\Delta\theta$ = 28°C , α = 2, β = 0.03, γ = 0.5.

And p_1 = 3.2214 W/kg (**ratio 1**)

♦ **Holding cooler coefficient**

Equation (1) is applicable here. The temperature drop is lower for a longer time, and the water evaporation speed is low, leading to the following coefficient.
(α = 1.2, β = 0.0035 = 0.35%, γ = 0.667 W/kg, $\Delta\theta$ / Δt = 4.17 K/24h)

p_2 = 0.866 W/kg (**ratio 2**)

A6.1.2 Cooling capacity for ancillaries

Besides cooling, freezing, and storing, many other operations are needed in meat processes, like cutting, packing, examining, expedition…. The cooling needs here are proportional to the size of the slaughterhouse and so also proportional to the annual capacity of meat being processed.

Based on a detailed case study of a large French slaughterhouse [CLO96], the typical ancillary cooling capacities are presented in Table A6.1.

Table A6.1 – Ancillary cooling capacities.

Designation	**Nb**	**Unit Capacity (kW)**
Offal process room		16
Offal refrigeration	2	27
White offal storage		26.5
Wastes	3	16.5
Blood tank		16
Hides	3	13.5
Exam		7
Pre-check room		10.5
Check room		10.5
Input room		7
Food for animals		4
Complement storage	2	22
Large part cutting	3	13
Expeditions	3	16.5
Storage before cuts	2	16.5
Offal process room (2)		13
Cutting room 1		46.5
Cutting room 2		13
Offal storage room		13
Offal packing room		16.5
Packaging		14
Vacuum storage		14
Packaging consignment		12.5
Consignment	3	12.5
Passageways	3	4
Total		599 kW

30,000 tons are processed in this slaughterhouse annually. From this case study the ancillary ratio is fixed.

$$p_3 = \frac{599}{30000} = 0.02 \; kW/at^{*} \qquad \textbf{(ratio 3)}$$

** at: is the meat annual production in tons*

p_3 is calculated and it is based on the total quantity of processed meat, not taking into account the characteristics of the different cooling rooms; this ratio is therefore used for the annual meat production.

A6.1.3 Generalization to all types of meat

Meat cooling, whatever the type of meat, is very similar due to the sanitary specifications. The carcass shall be cooled down as quickly as possible, the limit being linked to the meat hardness.

Due to physiological changes after slaughtering, heat is generated inside the body and tends to increase its temperature to around 41°C when the carcass enters the chilling cooler.

HACCP (Hazard Analysis and Critical Control Point) [ASH98] recommends that red meat carcasses be chilled to 5°C within 24 hrs, and that this temperature be maintained during storage, shipping, and product display.

Heat capacities of meats vary with the percentage of fat and moisture, but an average heat capacity of 3.1 kJ/(kg.K) is used for calculations of all meats [ASH98].

Meats are divided into three groups according to the carcass size that influences the cooling time:

- first group with an average mass per carcass of 150 kg, e.g. beef, veal, horse
- second group with an average mass per carcass of 60 kg, e.g. pig, mutton, lamb, goat …
- third group with an average mass per poultry of 4 kg, e.g. turkey, chicken, duck, goose….

The beef cooling model is used as a general model and the different coefficients for each group are given in Table A6.2.

Table A6.2 - Physical properties and ratios for cooling capacity calculations.

	Group I	**Group II**	**Group III**
Parameters/ratios	Beef, veal, horse meat	Goat, Mutton, lamb, Pig	Chicken, duck, goose, birds, rabbit, turkey
α	2	1.5**	1.2**
C (J/(kg.K))	3,140	3,140	3,140
$\Delta\theta$ (K)	30	30	30
Δt (h)	20	12**	6**
β	0.03	0.03	0.03
.γ(W/kg)	0.5	0.5**	0.5**
Fresh meat cooling ratio (W/kg)	3.326	4.05	5.733
Fresh meat storage ratio (W/kg)	0.866	0.866**	0.866**
Ancillary cooling capacity kW/at*	0.02	0.02**	0.02**

*at = annual ton **Estimation

A6.1.4 Calculation of the national installed cooling capacity for meat

The FAO website presents statistics on the annual meat production, imports, and exports. Production figures relate to animals slaughtered within national boundaries regardless of their origin. These figures are used as inputs in the country database for all countries, years, and types of meats. The format is a uniform table of countries by year and it is adopted for all types of meat. Table A6.3 shows other constants needed to estimate the installed cooling capacity.

Table A6.3 –Working time assumptions

	Constants
Slaughterhouse coefficient of use	0.8
Warehouse coefficient of use	0.6
Residence time in the warehouse (days)	2
Working days per year (slaughterhouse)	300
Working days per year (warehouse)	360

The national installed cooling capacity is calculated based on the national demand of all countries and for all types of meat.

The installed cooling capacity takes into account three terms:

- meat cooling
- meat storage, and
- ancillary cooling capacities.

♦ **National fresh meat cooling capacity**

The national installed cooling capacity for fresh meat cooling is calculated by the following equation:

$$P_1 = \frac{M_p \cdot p_1}{\tau.\lambda}$$

Where:

P_1 national installed cooling capacity for fresh meat (kW)

M_p annual meat production obtained from the FAO database per country (annual tons)

p_1 ratio of fresh meat cooling (W/kg) (see Table 6.2)

τ working days per year (slaughterhouse) (see Table 6.3)

λ coefficient of use of the slaughterhouse (see Table 6.3).

♦ **National cooling capacity for fresh meat storage**

The national installed cooling capacity for fresh meat storage is calculated by the following equation:

$$P_2 = \frac{M_p . p_2 . \sigma'}{\tau' . \lambda'}$$

Where:

P_2 national installed cooling capacity for fresh meat storage (kW)

M_p annual meat production obtained from the FAO database per country (annual tons)

p_2 ratio of fresh meat storage (W/kg) (see Table 6.2)

σ' storage residence time (day)

τ' working days per year of the warehouse (see Table 6.3)

λ' coefficient of use of the warehouse (see Table 6.3).

♦ **National installed cooling capacity for ancillaries**

The national installed cooling capacity for ancillaries is calculated by the following equation:

$$P_3 = \frac{M_p \cdot p_3 \cdot}{\lambda}$$

Where:

P_3 national installed cooling capacity for fresh meat storage (kW)

M_p annual meat production obtained from FAO database per country (annual tons)

p_3 capacity ratio of ancillaries (kW/annual tons) (see Table 6.2)

λ coefficient of use of the factory (see Table 6.3)

♦ **Verification with the French Inventory report [PAL02]**

After aggregation of all installed parcs for all groups of meat, the total installed parc for France is listed in Table A6.4

Table A6.4 - France refrigerating parc for meat industry.

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Total installed cooling capacity (MW)	341.84	351.69	355.14	367.39	378.44	389.98	393.25	398.32	392.94	384.99

In Inventory Reports for France issued previously, another method was used to determine the installed cooling capacity.

If the energy consumption in refrigeration for the meat industry is known (i.e., 1228 GWh per year), assuming a COP of 2, a factory working time of 300 days per year and 16 hours per day, the calculated installed capacity is 512 MW for the year 1998. Referred to the installed cooling capacity listed in Table 6.4, the error is 22.15%.

A6.2 Global cooling capacity for dairy industry

A6.2.1 Calculation of installed cooling capacity

The refrigerant inventory for the dairy sub-sector is determined using the dairy production and sales. The FAO database gives a very detailed description of the dairy demand and production for all countries starting in 1961.

Frozen dairy products are not considered in this section, they are aggregated in the frozen product sector.

Figure A6.4 gives the link between different figures available in the FAO Database for dairy processes.

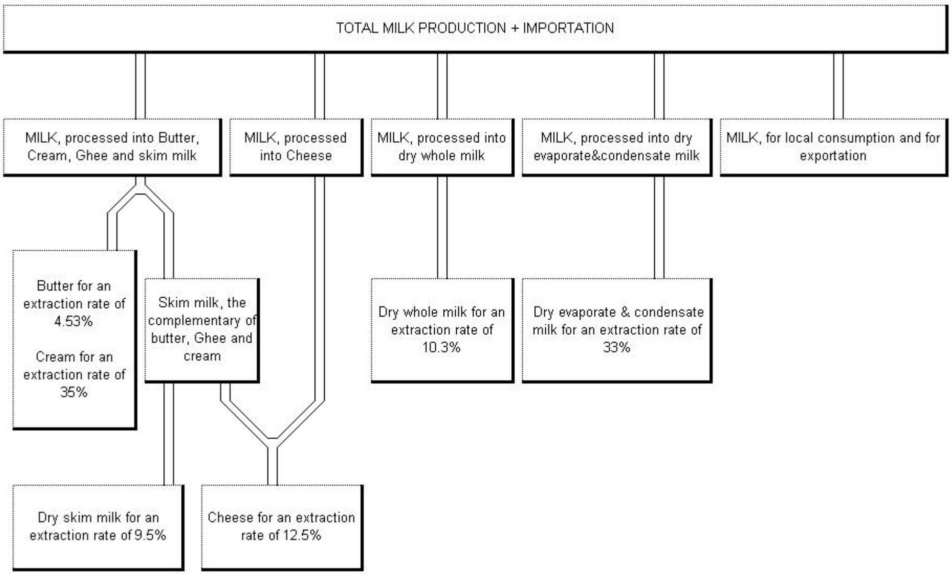

Figure A6.4 - The FAO link between different dairy processes.

Milk undergoes the cooling in the farm, is transported by insulated trucks, and is treated in the factory where it will be processed into different dairy products.
The major refrigerated processes for milk are:

- farm refrigeration (milk tank)
- bacteria treatment (pasteurization, UHT…)
- fermentation (depending on dairy product).

A6.2.2 Milk tank installed cooling capacity

For the milk cooling at the farm, the following rules for cooling are applied:

- cooling from 35 to 5°C in 2 hours
- no frosted milk in the tank, even partial
- allowable temperature increase equal to 5 K if a second milking is added to the milk tank.

To avoid every risk of the milk temperature decreasing below the frosting point, 4°C is the lowest controlled temperature for direct expansion milk tanks (which are the most widespread). Some milk tanks use ice accumulation technology to maintain a lower temperature, between 0 and

+1°C. The above mentioned two types of milk tanks show similar performances. For both types, the law for cooling can be considered as linear.
At 4°C, the milk cannot be conserved in milk tanks at the farm longer than two days, because of bacteria proliferation.

The cooling model for a milk tank is similar to the cooling model for meat:

$$p_{milk} = \frac{\alpha \cdot c \cdot \Delta\theta}{\Delta t} + \gamma \qquad \text{(A6.5)}$$

with :

$\Delta\theta$ = 30°C pour Δt = 2 h = 7200 sec

α = 1 (temperature curve is linear cause of cooling time is short in respect of temperature drop)

c = 4 kJ/(kg.K) [ASH98].

Calculation of miscellaneous heat losses

γ has been evaluated taking into account the insulation of typical milk tanks. Calculations show that γ = 0.033 W/kg, which is negligible and it is therefore not taken into account in the formula.
Based on those assumptions, the milk capacity ratio p_{milk} can be derived as follows:

p_{milk} = 16,7 W/kg (**ratio 4**)

Milk capacity ratio verification

For France, the average milk tank volume installed amounts to 3000 L. Data sheets of a standard milk tank are obtained from literature [INTVMZ]. This reference gives the nominal volume of a typical direct expansion milk tank and its installed compressor power (2500 L; 15.47 kW). Assuming a COP of 2.5, the cooling capacity amounts to 38.67 kW. The milk capacity ratio calculated with the data mentioned leads to 15.47 W/kg. The difference with the milk capacity ratio calculated using Equation (6.5) is about 8%, which is acceptable.

The milk capacity ratio will therefore be calculated using a ratio of 4.

Installed cooling capacity for Average National Daily Milk Production (ANDMP)

To establish the world installed cooling capacity for milk tanks, it is necessary to determine the Average National Daily Milk Production. Knowing the annual milk production from the FAO, (i) with a maximum residence time of two days, (ii) in which a maximum of four milkings are considered (two milkings a day), and (iii) a maximum filling ratio of 0.7 of the milk tank, (which is an average value taking into account the annual variation from 0.6 to 0.8), the Average National Daily Milk Production for a given country is calculated as follows:

$$M_{ANDMP} = \frac{M_p.\sigma}{n.\tau.\rho}$$

where:

M_{ANDMP} average national daily milk production (ANDMP) (kg)
M_p annual milk production obtained from FAO database (annual kg)
σ maximum residence time (days)
n number of milkings in a milk tank
τ number of days per year
ρ filling ratio

Parameters	
Days per year	360
Max residence time (day)	2
Cooling ratio W/kg	16.7
Number of milkings	4
Filling ratio	0.7

Table 6.5 – ANDMP parameters

The national installed cooling capacity for milk tanks is then:

$$P_{milk} = M_{ANDMP} \cdot p_{milk}$$

A6.2.3 Milk bacterial process and cooling

For pathogenic bacteria elimination, several milk processes are applied: pasteurization, UHT…. This process consists of:
- heating the milk;
- maintaining it at high temperature during the necessary time for complete pathogenic bacteria elimination,
- cooling it to 4°C.

Refrigeration is only related to the milk cooling from 35°C to 4°C, since the milk cooling from temperatures higher than 35°C is done either by cold water or, better, by regeneration in a milk / milk heat exchanger.

Several cooling techniques are used, chilled water being the most widespread for large milk facilities.

Pasteurization and cooling take place in the same heat exchanger, which includes three zones:
- a heating zone for the pasteurization,
- a central zone where the homogenized cold milk is heated by the counter current of pasteurized hot milk (regeneration process),
- a cooling zone where the milk is cooled by chilled water.

To determine the cooling capacity for the national pasteurization, the following formula is used:

$$P_{past} = \eta \times \left(\frac{M_p}{\tau'}\right) \times Cp \times \Delta\theta$$

$$P_2 = \frac{\eta}{\lambda} \times \left(\frac{M_p}{\tau'}\right) \times Cp \times \Delta\theta = \frac{M_p \times p_{past}}{\lambda} \quad (6.6)$$

Where
P_{past} national cooling capacity for pasteurization (kW)
η heat loss factor
λ coefficient of use
M_p milk annual production obtained from FAO database (annual tons)
τ' factory working time in seconds
Cp heat capacity of milk
$\Delta\theta$ temperature drop (°C)

$\frac{M_p}{\tau'}$ average mass flow rate of the factories

Table A6.6 - Cooling parameters after pasteurization.

Factory working days per year (days)	300
Factory working hours per year (hours)	16
Temperature drop (°C)	31
Cp (kJ/kg.K)	4
Heat loss factor η (Indirect systems + Other installations)	1.4
Coefficient of use λ (real mass flow rate / dimensional mass flow rate)	0.8

$\Rightarrow p_{past}$= 0.01256 W/annual kg.

A6.2.4 Fermentation and cooling

Some dairy products need to be stored in refrigerated rooms for fermentation, but the residence time differs from one product to another and from one country to another. Table A6.7 lists chosen parameters for the calculation of cooling in fermentation rooms.

The national cooling capacity for fermentation rooms is calculated as follows:

$$P_{ferm} = \frac{M_p \cdot p_{ferm} \cdot \sigma}{\tau \cdot \phi}$$

where

P_{ferm} national installed capacity for fermentation rooms (kW)

M_p annual dairy product obtained from FAO database (annual tons)

p_{ferm} volumetric cooling ratio for fermentation (W/m^3)

ϕ minimum storage ratio of products in 1 m^3 of warehouse (kg/m^3)

σ staying delay in factory warehouse (day)

τ working days per year of factory warehouse.

Table A6.7 – Fermentation and storage parameters

	Butter and Ghee	Cheese	Cream
Temperature (°C)	5	5	5
Cooling ratio (W/m^3)	30	30	30
Storing ratio (kg/m^3)	300	500	300
Residence time (days)	5	30	5

A6.3 Global cooling capacity for wine and beers

The FAO database includes global wine and beer production figures. In order to derive the installed cooling capacities from the wine and beer production figures, two cooling models have been developed.

A6.3.1 Wine cooling model

The wine cooling model is based on a detailed case study of a winery where the cooling capacities and production are known. From [CLO96], Table A6.8 has been established using the annual production figure of 75,000 hL.

Table A6.8 - Cooling data of the typical case.

Cooling stage	Cooling capacity (kW)	Product capacity (hL)	Ratio: cooling capacity/product capacity (W/kg)	Ratio: annual production/product capacity	Ratio: cooling capacity/annual production (W/annual kg)
Wine-making process	70	25000	0.028	3	0.0093
Tartaric stabilization ultra-cooling	50	25000	0.020	3	0.0067
Storage	175	75000	0.0233	1	0.0233

From Table A6.8 the total cooling ratio of wine can be derived as 0.03933 W/annual kg.

The average time for wine-making process is one week for red wine and 15 days for white wine. The average time for tartaric stabilization is 15 days [CLO96]. For the case under study, the storage is air-conditioned because during summer the ambient temperature is very high and the storage temperature must be kept under 21°C. This case is not applicable to all wineries, therefore the storage cooling ratio has been multiplied by a factor α less than 1, α = 0.4 (40% of wineries use air conditioning in their wine storage).

P_{wine} = 0.03 W/annual kg (**ratio 5**)

A6.3.2 Beer cooling model

Wort cooling

The following formula is used for the national wort cooling capacity: $P_{wort} = \frac{\eta}{\lambda} \times (\frac{M_p}{\tau'}) \times Cp \times \Delta\theta$

Where

P_{wort} national wort cooling installed capacity (kW)

η loss multiplier factor (η = 1.4)

λ coefficient of use (real flow rate/ dimensioned flow rate, λ = 0.8)

M_p beer annual production obtained from FAO database (annual tons)

τ' factory working time in seconds (the factory works 300 days/yr and 16 hrs/day)

Cp wort heat capacity (Cp = 4 kJ/(kg.K) [ASH98])

$\Delta\theta$ temperature drop (°C) ($\Delta\theta$ = 31°C [ASH98])

$\frac{M_p}{\tau'}$ average wort mass flow rate.

$p_{wort} = 0.01256$ W/annual kg (**ratio 6**)

Fermentation
Beer ratio fermentation amounts to 0.0033 W/annual kg, which has been taken from [ASH98].

p_{ferm} = 0.033 W/annual kg (**ratio 7**)

A6.4 Global cooling capacity for flake ice for fresh fish conservation

The cooling capacities applied and the refrigerant types used on board of fishery vessels are taken into account with regards to the refrigerated vessel fleet. But, once the fish is delivered for sale, fresh fish conservation is essentially performed on flake ice.

The ratio of ice used for fish conservation, IFR, is:

IFR = mass of ice / mass of fish = 0.5 (0.25 for cooling and 0.25 for lost [RGF02]).

The National Fresh Fish Annual Production (NFFAP) data are coming from the FAO database.

The capacity ratio for producing flake ice is:
Ice Cooling Capacity Ratio, ICCR = 6.95 W/kg [ASH98].

Average number of catches (catching days) per year: 300 catches per year.

The national installed cooling capacity for production of flake ice for fish conservation is calculated as follows:

$$P_{fish} = \frac{NFFAP}{\tau'} xICCRxIFR \text{ (W)}$$

where
τ' is the number of catching days per year (300)
NFFAP (kg/yr)
ICCR (W/kg).

A6.5 Global cooling capacity for frozen food

A6.5.1 Frozen food production

Annual frozen food production is not yet available from the FAO Database, but export and import data are available, and they allow to establish the world frozen food production using the Kaminsky ratios [KAM95] for annual consumption of frozen food per capita as presented in Table A6.9, and using the equation:

Production = Consumption + Export – Import

Table A6.9 – Annual consumption of frozen food per inhabitant [KAM 95].

Countries	**USA, Denmark**	**UK, France, Sweden**	**Germany, Switzerland**	**Norway, Austria, Belgium, Finland, Spain, Australia, Japan, The Netherlands**	**Italy, Hungary, Poland, ex-URSS and others**
Annual consumption/ habitant (kg)	> 40	30 – 40	20 – 30	10 – 20	< 10

For each group presented in Table A6.9, linear interpolation with the mean GDP of the corresponding country allows the determination of the annual consumption per capita.

In the FAO database, import and export figures are available for: Ice cream, frozen potato, frozen sweet corn, frozen cephalopods, frozen crustaceans, demersal frozen fillets, demersal frozen whole, chilled frozen fish fillet, fish frozen whole fillet, frozen fish shellfish, freshwater frozen whole, freshwater frozen fillets, marine nes frozen fillet, marine nes frozen whole, frozen mollusc, pelagic frozen fillets, pelagic frozen whole.

Based on previous calculations, the world frozen food production as determined is presented in Table A6.10.

Table A6.10 - World frozen food production.

Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Production (10^6 t)	26.51	27.28	27.38	27.34	27.56	27.04	27.42	28.35	28.13	29.71	29.36
Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	
Production (10^6 t)	32.14	32.78	32.90	35.93	37.37	36.27	38.38	39.80	38.40	38.54	

[KAM95] estimates the world frozen food production by the beginning of 1990 at a level of 30 million tons. The calculated value for this year is 7% higher (Table 6.10).

A6.5.2 Frozen food cooling model

Based on data from a manufacturer of a blast freezer [SBL], it can be given that the freezing ratio per kg of frozen food per hour is of 121.472 W/(kg h). This value has been used for all types of food.

The frozen food production is considered as continuous production during 16 hours per day and 300 days per year. The factory use coefficient equals 0.8. The national installed capacity for frozen food is calculated according to Figure A6.5.

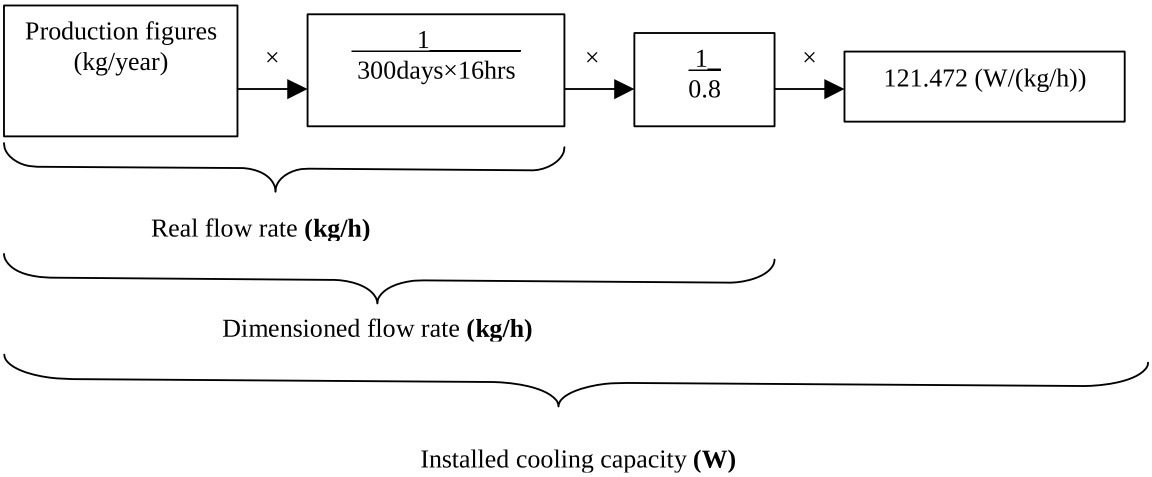

Figure A6.5 – Flow sheet for national installed capacity for frozen food.

The national installed capacity ratio p_{frozen_food} is

$$p_{frozen\_food} = 0.0316 \text{ W/annual kg}$$

For the factory storage, the same parameters are used.

A6.6 Installed cooling capacity for cold storage

In this section, cold storage means all cold storage except the storage in food processing facilities. The refrigerated volumes correspond to low and medium-temperature storage, specialized and multi-purpose cold stores and fruit packing stations. The cold storage volume estimates by country are based on ratios that have been elaborated on for different developed countries [KAM95, GLO92-93]. Based upon these ratios additional calculations have been performed in order to refer the cold storage volume to the GDP. Figure A6.6 indicates the evolution of the cold storage referred to the GDP as a function of time (from 1930 to 2000).

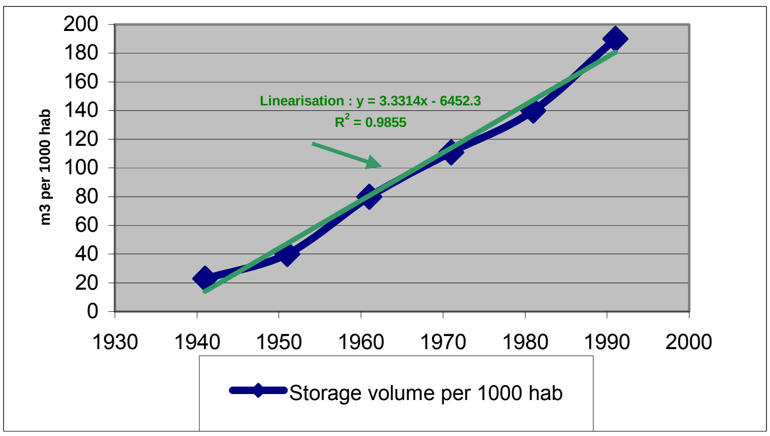

Figure A6.6 – The U.S. typical storage volume example [KAM95].

A saturated linear extrapolation with the US storage volume per capita and the mean GDP allows the establishment of the storage volume per capita for each country (Figure A6.7). The extrapolation with the U.S. storage increased volume per year and the GDP standard deviation makes it possible to establish the storage-increased volume for each country. Extrapolations have been done for year 1961 and have been projected to the year 1999 using the storage-increased volume per year and the population figures.

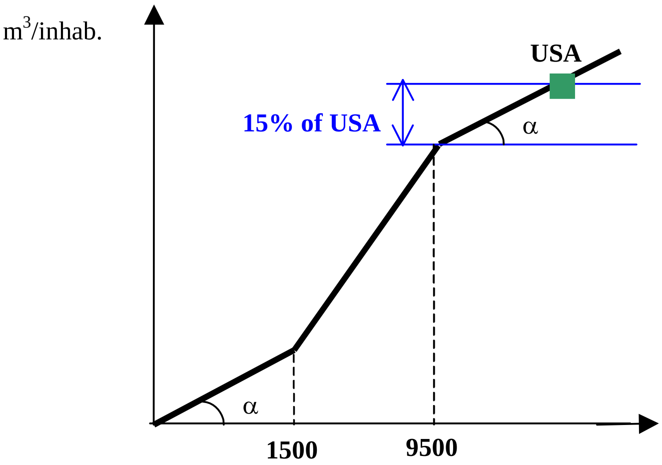

Figure A6.7 – Saturated linear extrapolation based on the U.S. typical example.

Low-temperature cooling capacity over total cooling capacity is calculated taking into account the frozen food consumption per inhabitant.

Medium and low-temperature cooling capacities referred to the cold storage volume are known from the report [ADE00].

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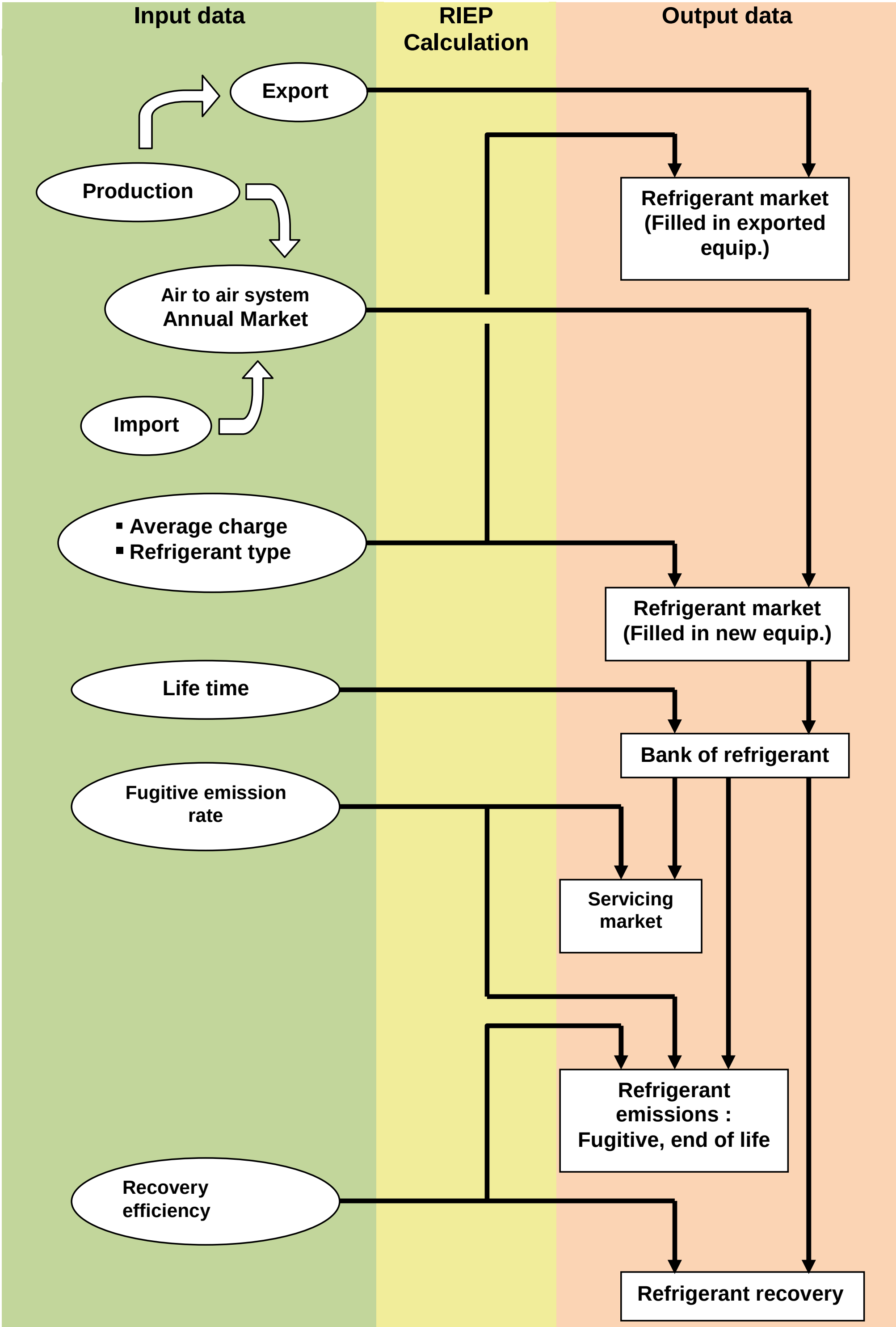

Figure 7.1 – Calculation steps for refrigerant emissions from air to air systems.

Introduction and calculation method

The calculation method is presented in Figure 7.1.

- Based on the data from the reference sources, the annual equipment production and market are calculated.
- Taking into account the average charge and the type of refrigerant selected for each category of the air-to-air AC systems, the annual refrigerant quantity charged in new equipment is calculated. This applies also to the total refrigerant charge of the exported equipment.
- Based on the annual equipment sales and the equipment lifetime data, the country refrigerant bank can be determined.
- Using the fugitive emission rate of each category, the annual refrigerant servicing market of a country is determined.
- Refrigerant emissions (fugitive and at end of life) can be derived from the refrigerant bank while using data on the equipment lifetime.

Calculation is performed by sub-sector of equipment and by country.

7.1 Data sources

7.1.1 Markets

Stationary air-to-air AC system sector are split into 8 different sub-sectors according to the technology and the refrigeration capacity. Those 8 categories are presented in Table 7.1 and are consistent with the BSRIA reports, which are the essential source of information for equipment sales numbers ([BSR02-1], [BSR05] and [BSR08]).

Table 7.1 – Stationary AC system Categories o

Categories	End-Use
Portable	Residential
Split < 5 kW	Residential
Split > 5 kW	Residential
Window	Residential
Indoor Packaged	Commercial
Roof Top	Commercial
Ducted Split < 17.5 kW	Commercial
Ducted Split >17.5 kW	Commercial

These reports provide numbers on equipment sales from 1995 to 2006. The historical values before 1995 for equipment sales are estimated from the GDP evolution. Table 7.2 shows the global market of all air-to-air systems for the five main countries and EU15.

Table 7.2 – Air-to-air system market in 2006 [BSR08].

	USA	China	Brazil	India	EU15	Japan	Total World
MARKET 2006	19,216,200	22,359,600	1,625,845	1,594,430	5,592,600	9,368,100	77,000,000

As shown in Table 7.2, the tremendous growth of the AC market positions China to become the number one market before the U.S. Three years ago, China was just above the Japanese market. The Chinese market doubled between the years 2000 and 2006.

The installed base of equipment can then be calculated from the mean lifetimes given in Table 7.3.

Table 7.3 - Equipment nominal charges and lifetimes.

Categories	Charge (kg)	Lifetime (years)
Portable	0.5	10
Split < 5 kW	1	15
Split > 5 kW	7.5	15
Indoor Packaged	5.5	15
Window	0.7	12
Roof Top	21 (EU27) – 5 (others)	20
Ducted Split < 17.5 kW	3.5	15
Ducted Split >17.5 kW	9	15

Results are compared to the numbers obtained from the different TOC reports in Table 7.4.

Table 7.4 - Comparison of installed base obtained from BSRIA/derivation for historical missing data and the TOC numbers.

Year	Installed base based on GDP evolution	TOC numbers
1996	325,655,325	239,000,000 (1998 Assessment)
2001	446,359,918	368,000,000 (2002 Assessment)
2004	541,670,076	478,000,000 (2006 Assessment)

The source for statistics on equipment sales used by the TOC is JARN and ARI. When tracking the source of numbers used by the TOC, i.e. the JARN magazine numbers (available since 1994), the difference on the equipment sales varies from 0 to 9% per year. However, when comparing both installed bases (TOC and RIEP), differences of 30%, 18%, and 12% are observed respectively for the years 1996, 2000, and 2004. The 30% could result from the derivation of the historical sales numbers but also from the mean lifetime considered in both sources. A mean lifetime of 11 years applied to JARN and BSRIA equipment sales numbers allows matching the numbers given by the different TOC reports. However, the mean lifetime considered for RIEP is higher and is around 14 years all sectors included, which mainly explains the difference between the two results for the installed base.

As indicated in the RIEP database the eight different categories are calculated separately, and the same global methodology is applied to all categories. Differences related to refrigerant charge and refrigerant choices are given in detail in the following sections.

7.1.2 Type of refrigerants

This section provides assumptions regarding the refrigerant distribution for the new equipment sold and produced for each category. Refrigerant use evolution is established taking into account technology, regulations, and national preferences. In most categories of equipment, six models are proposed, relative to the countries: U.S., Japan, China, Europe (EU15), other Europe, and other A5. Assumptions concerning refrigerant distribution by country are presented for three types of equipment: portable, ducted splits (> 17,5 kW), and rooftops, from figure 7.2 and to 7.13. Other categories are detailed in Appendix 7.1.

Portable

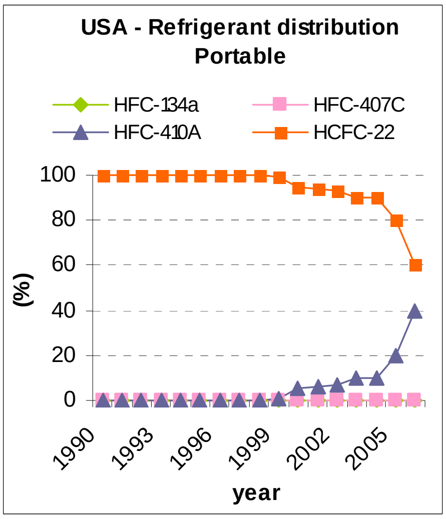

Figure 7.2 - Refrigerant distribution for new portables in the U.S.

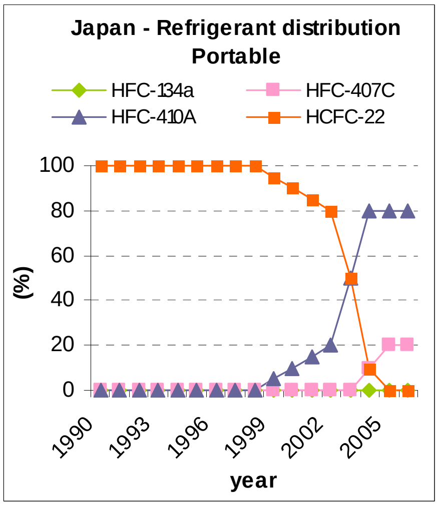

Figure 7.3 - Refrigerant distribution for new portables in Japan.

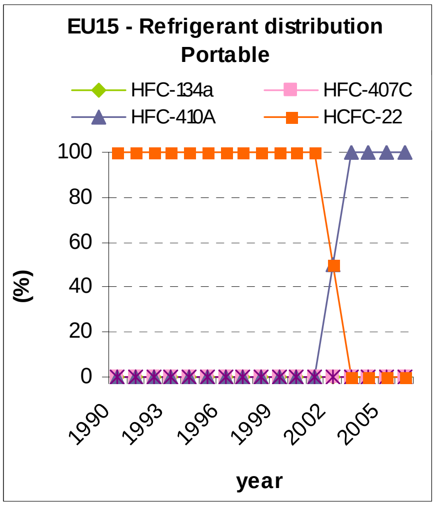

Figure 7.4 - Refrigerant distribution for new portables in EU15.

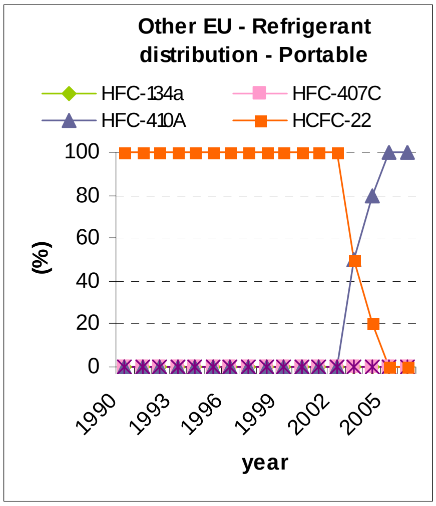

Figure 7.5 - Refrigerant distribution for new portables in Other EU.

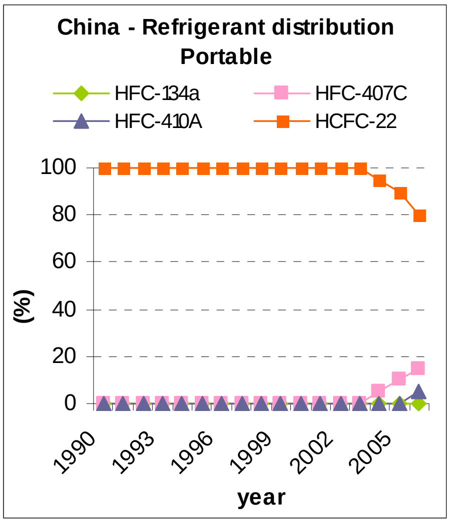

Figure 7.8 - Refrigerant distribution for new portables in China.

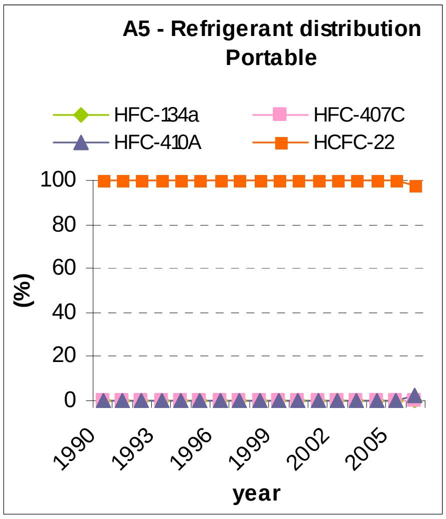

Figure 7.9 - Refrigerant distribution for new portables in A5 countries.

For air-to-air AC systems, six country types of evolutions are taken into account, as presented from Figures 7.2 to 7.9 for portable systems. For each type of equipment, for other countries and zones, evolution in refrigerant use is established, referencing to one of these country models (see Table 7.5).

Table 7.5 – Country model for zones for refrigerant use in air-to-air systems.

Country or zone	Reference model
Brazil	A5
Canada	USA
Other Europe	EU15 (with delay)
Latin America	A5
South & East Asia	A5
Central Asia	A5
Turkey Israel	EU15
Africa	A5
Australia and New Zealand	USA
Other Oceania	A5

Main trends can be summarized as follows.

- In Europe in the years 2000, HCFC-22 systems have been quickly replaced by either R-407C or R-410A, depending on the required cooling capacity: R-410A for split systems up to 5 kW cooling capacities, and R-407C for higher capacity systems. As of 2006, the use of R-410A started to be more significant, even for capacities where R-407C is being used in Europe.
- In the U.S, the shift from HCFC-22 to HFC refrigerants is slower than in Europe. R-410A is used to replace HCFC-22 in new equipment. Its share on the new market increased from 2004 for indoor packaged, portable, window, and split < 5 kW. R-407C is not used in the U.S.
- In Japan, HCFC-22 tends to be almost not used in 2006. The shift from HCFC-22 to HFCs took place faster than in the U.S. Either R-407C or R-410A may be found in new equipment, depending on the cooling capacity of systems.

- In A5 countries, HCFC-22 is still mainly used. In 2006, HFCs are not yet introduced, except in China and some countries of South and East Asia, due to exportations.

Ducted Split > 17.5 kW

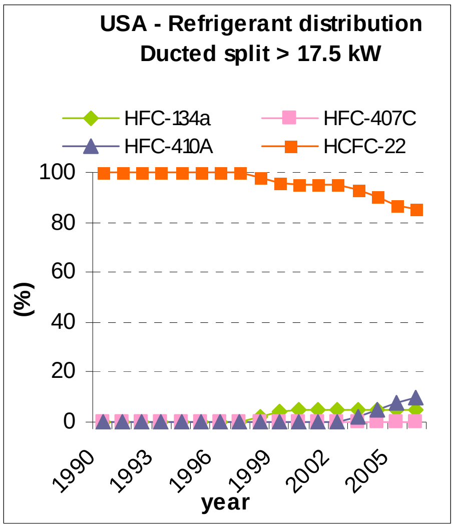

Figure 7.10 - Refrigerant distribution for new ducted splits > 17.5 kW in the U.S.

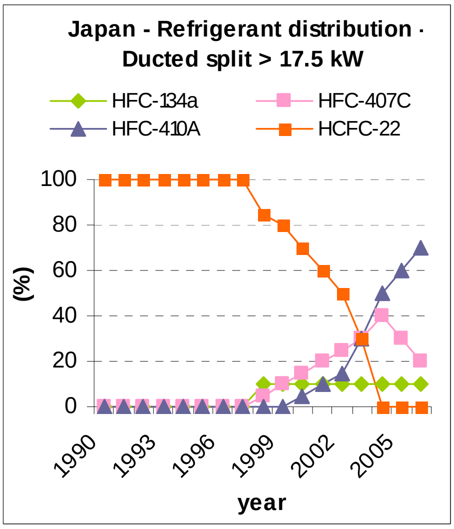

Figure 7.11 - Refrigerant distribution for new ducted splits > 17.5 kW in Japan.

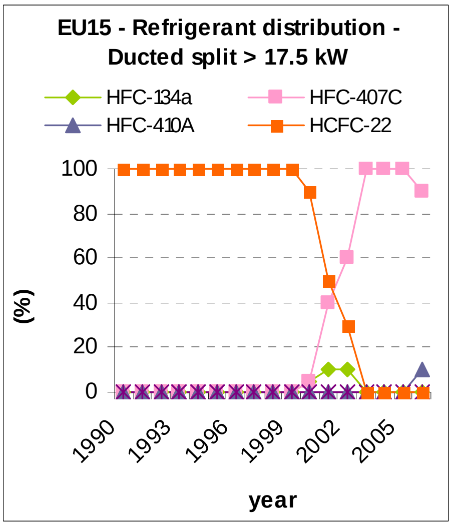

Figure 7.12 - Refrigerant distribution for new ducted splits > 17.5 kW in the EU15.

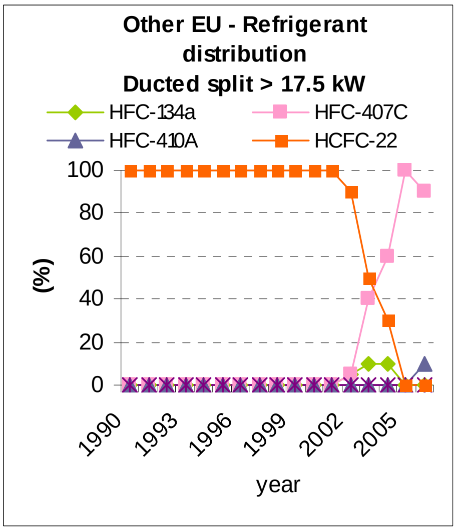

Figure 7.13 - Refrigerant distribution for new ducted splits > 17.5 kW in the Other EU.

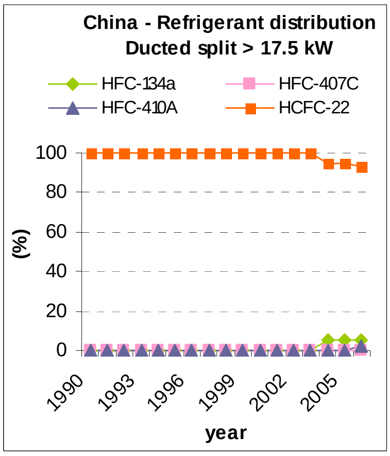

Figure 7.14 - Refrigerant distribution for new ducted splits > 17.5 kW in China.

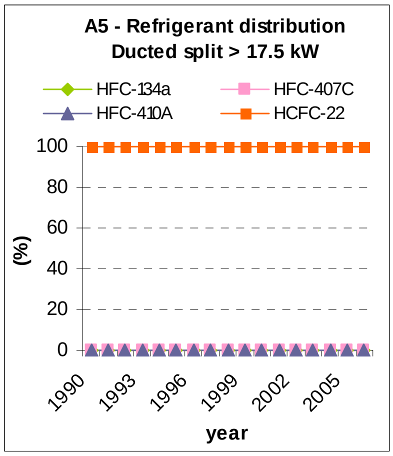

Figure 7.15 - Refrigerant distribution for new ducted splits > 17.5 kW in A5 countries.

Rooftops

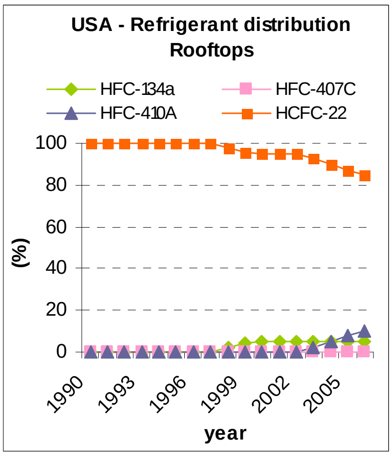

Figure 7.16 - Refrigerant distribution for new rooftops in the U.S.

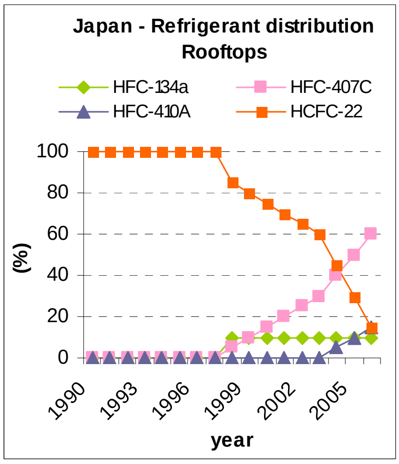

Figure 7.17 - Refrigerant distribution for new rooftops in Japan.

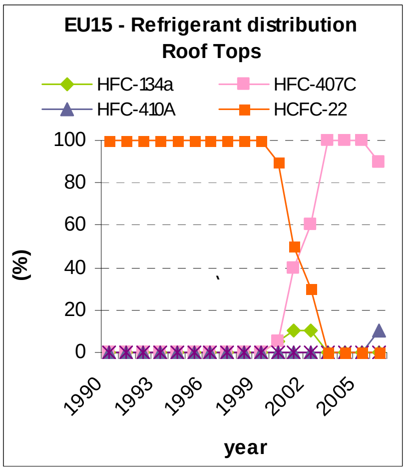

Figure 7.18 - Refrigerant distribution for new rooftops in EU15.

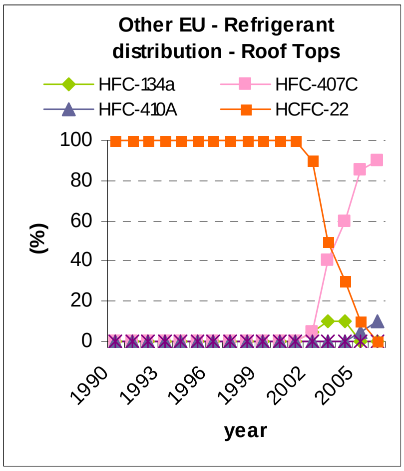

Figure 7.19 - Refrigerant distribution for new rooftops in the Other EU.

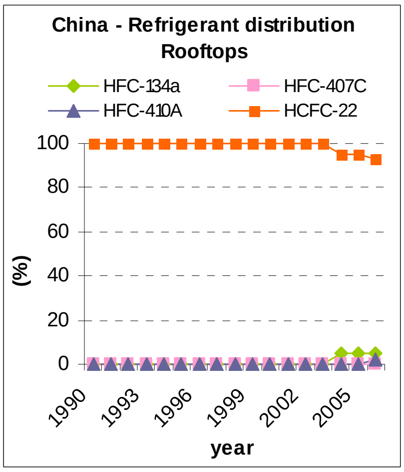

Figure 7.20 - Refrigerant distribution for new rooftops in China.

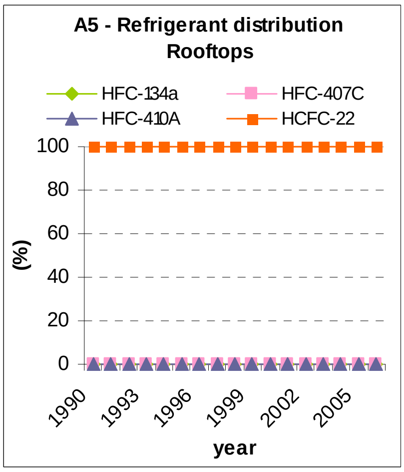

Figure 7.21 - Refrigerant distribution for new rooftops in A5 countries.

For roof tops, the EU regulation and the fact that Japanese companies anticipated stringent new regulations caused a quicker change from HCFC-22 to HFCs compared to the U.S. Depending on the equipment type, either the blend R-407C or the pure refrigerant HFC-134a was selected.

7.1.3 Assumptions on annual emission rates and recovery efficiencies

Assumptions on the annual emission rates and recovery efficiencies are presented in Table 7.6 and 7.7. **Values for the annual emission rates in the 90's have been modified compared to the previous inventories to account for the improvements brought to the equipment.** In the previous version of global inventories [Clo06], emission rates were considered constant throughout the years, while in this update, a decrease in the emission rates is considered for some categories as shown in the following tables.

Table 7.6- Assumptions on annual emission rates.

Annual Emissions (%)	Portable			Split <5kW			Split >5kW			Indoor packaged		
	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006
OtherEU	2	2	2	10	5	5	15	10	10	10	7	5
China	5	3	2	10	7	5	15	11	10	10	9	6
Japan	2	2	2	5	5	5	10	10	10	5	5	5
USA	5	2	2	10	6	5	15	10	10	10	7	5
EU15	2	2	2	10	5	5	14	10	10	8	6	5
Other A5	5	3	2	10	7	5	15	11	10	10	9	6

Annual Emissions (%)	Window			Roof Top			Ducted Split < 17.5 kW			Ducted Split > 17.5 kW		
	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006
OtherEU	2	2	2	10	5	5	10	7	5	10	7	5
China	5	3	2	10	9	6	10	9	6	10	9	7
Japan	2	2	2	5	5	5	5	5	5	5	5	5
USA	5	2	2	10	7	5	10	7	5	10	6	5
EU15	2	2	2	9	5	5	8	6	5	10	6	5
Other A5	5	3	2	10	9	6	10	9	6	10	9	7

Table 7.7- Assumptions on recovery efficiency levels at end-of-life.

Recovery Efficiency at end of life (%)	Portable			Split <5kW			Split >5kW			Indoor packaged		
	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006
OtherEU	0	0	0	0	0	0	0	5	5	0	5	5
China	0	0	0	0	0	0	0	5	5	0	5	5
Japan	0	0	8	0	0	8	2	50	55	2	50	65
USA	0	0	0	0	0	0	0	12	30	0	30	50
EU15	0	0	0	0	0	0	0	40	55	0	30	60
Other A5	0	0	0	0	0	0	0	5	5	0	5	5

Recovery Efficiency at end of life (%)	Window			Roof Top			Ducted Split < 17.5 kW			Ducted Split > 17.5 kW		
	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006
OtherEU	0	0	0	0	5	30	0	5	5	0	5	10
China	0	0	0	0	5	30	0	5	5	0	5	10
Japan	0	0	8	0	70	87	2	50	65	0	70	87
USA	0	0	0	0	60	75	0	30	50	0	60	75
EU15	0	0	0	0	70	80	0	30	60	0	70	80
Other A5	0	0	0	0	5	30	0	5	5	0	5	10

7.2 Results of calculations: refrigerant bank, emissions and recovery

7.2.1 Refrigerant bank

For stationary air conditioning, the most significant bank is clearly the HCFC bank that culminates at about 1.2 million tonnes in 2006. This is a dominant bank representing more than 70% of the total quantity of HCFCs in use in refrigeration and air conditioning. Except for Europe and Japan, HCFC banks are growing in countries continuing to use this refrigerant for air-conditioning systems, especially in China.

2006 can be considered as the first year of the CFC phase out for air-to-air AC systems. The CFC bank decrease was mainly due to Europe and has begun in 1994. Moreover, the EC 2037/2000 regulation has led to the progressive phase-out of HCFC in new equipment of air-conditioning systems between 2000 and 2004 (see Figure 7.22).

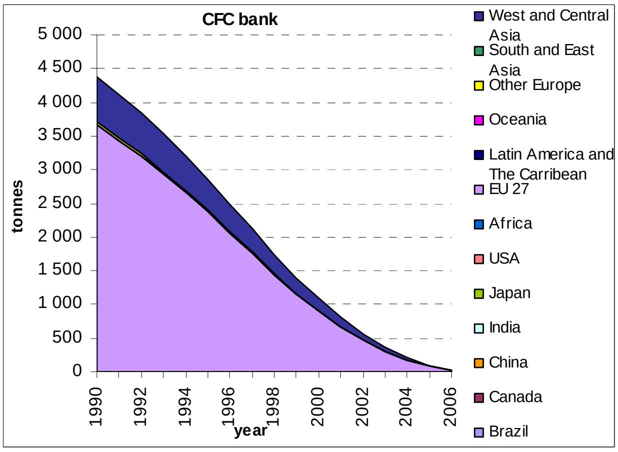

Figure 7.22 – CFC bank in stationary air conditioning.

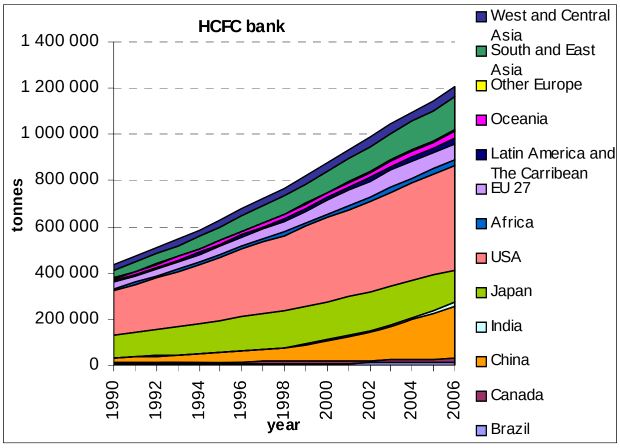

Figure 7.23 – HCFC bank in stationary air conditioning.

The HFC bank is rising steadily due to the ban of CFCs and HCFCs (see Figure 7.22). Europe, Japan, and also the U.S. are the key regions for the build-up of the HFC bank.

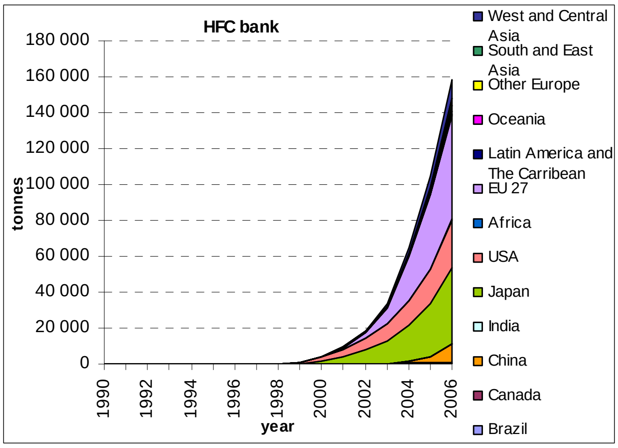

Figure 7.24 – HFC bank in stationary air conditioning.

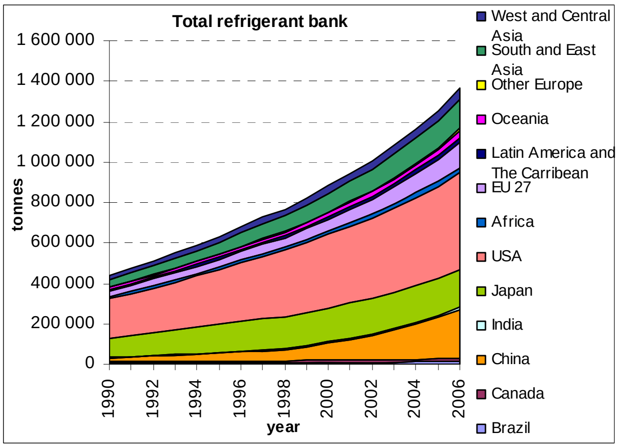

Figure 7.25 - Total refrigerant bank in stationary air conditioning.

Figure 7.25 confirms the domination of the U.S. in terms of number of installed equipment of air-conditioning systems: the global bank is dominated by the U.S. one, which is estimated to 480,000 tonnes in 2006, including 94% of HCFCs.

7.2.2 Emissions

Emissions are in line with the bank and totalize 160,000 tonnes in 2006. The dominant emissions are HCFC ones: they are evaluated at approximately 145,000 tonnes in 2006 (see Figures 7.26 and 7.29), the U.S. contributing for 29%, followed by China, 18%.

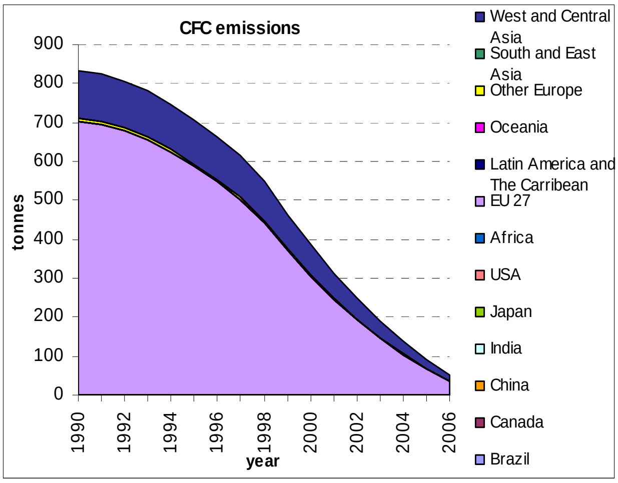

Figure 7.26 – CFC emissions in stationary air conditioning.

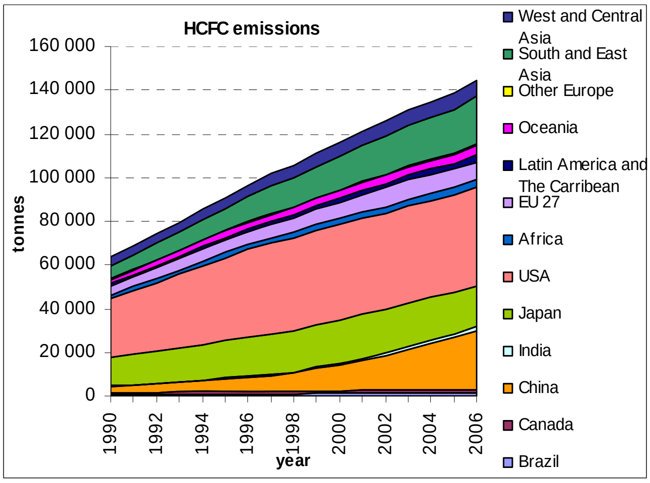

Figure 7.27 – HCFC emissions in stationary air conditioning.

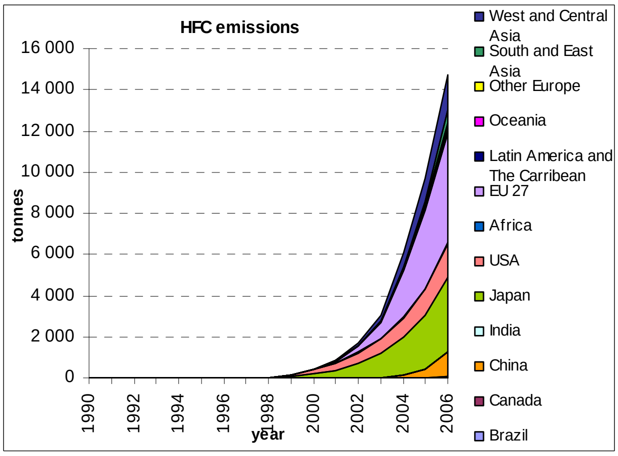

Figure 7.28 – HFC emissions in stationary air conditioning.

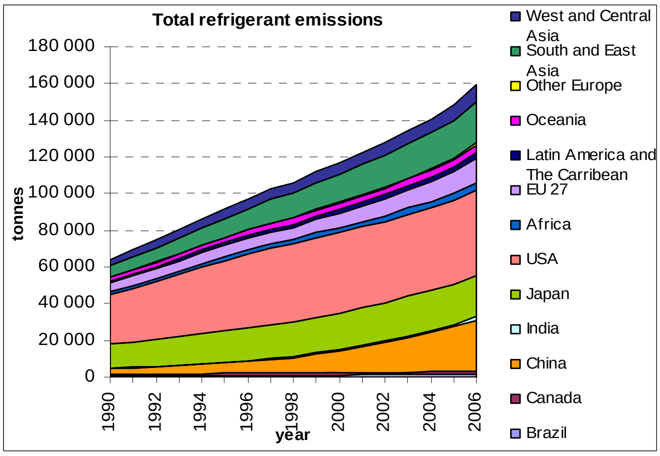

Figure 7.29 - Total emissions in stationary air conditioning.

HFC emissions are only about 15,000 tonnes in 2006 but have been growing at a rate of about 50% per year for the past two years.

7.2.3 Refrigerant CO_2 equivalent emissions

Total CO_2 equivalent emissions are increasing of about 5% per year, and 8% from 2005 to 2006. Stationary air-conditioning systems contribute to 240 millions of tonnes equivalent CO_2 in 2006, with 29% due to the U.S. and 18% to China (see Figure 7.33).

As shown in Figures 7.31 and 7.33, HCFC emissions in terms of CO_2, still contribute to 90% of the total of stationary air-conditioning emissions in 2006.

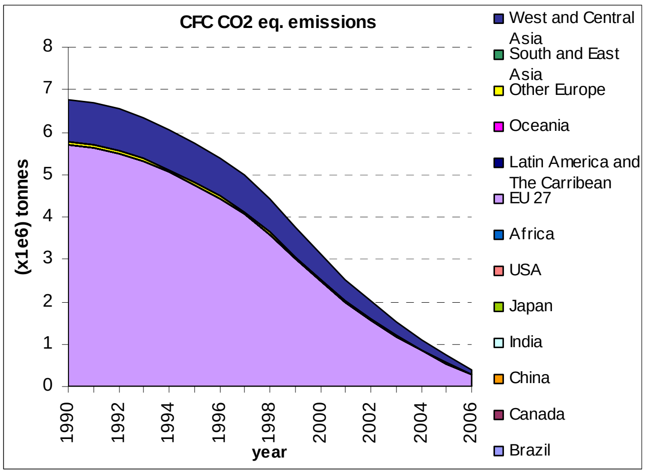

Figure 7.30 – CFC CO_2 equivalent emissions in stationary air conditioning.

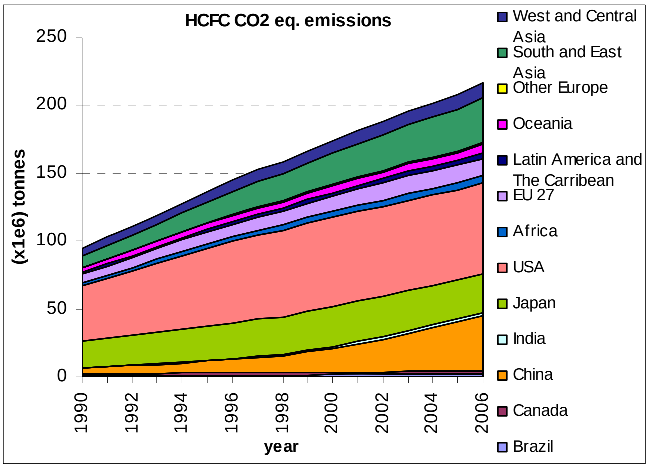

Figure 7.31 - HCFC CO_2 equivalent emissions in stationary air conditioning.

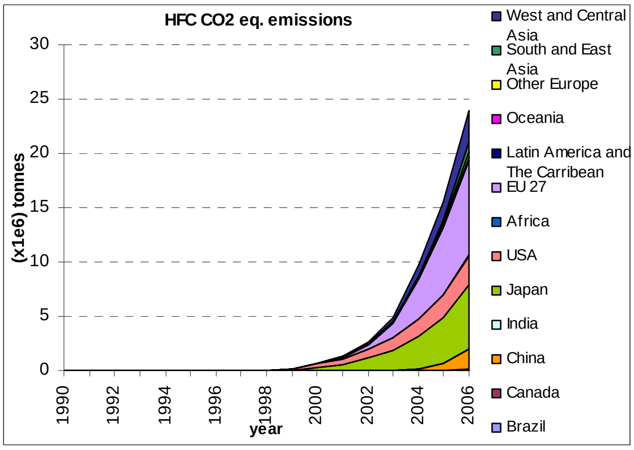

Figure 7.32 – HFC CO_2 equivalent emissions in stationary air conditioning.

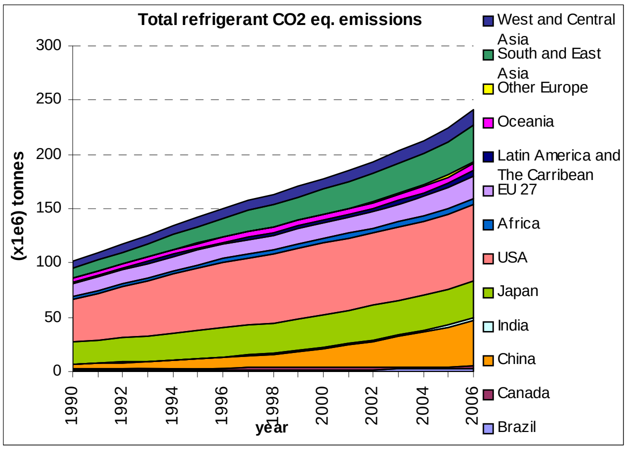

Figure 7.33 - Total CO_2 equivalent emissions in stationary air conditioning.

7.2.4 Refrigerant recovery

The evaluation of the recovery efficiency of HCFCs is arguable and needs to be verified, especially in the U.S. where it is evaluated at more than 11,000 tonnes in 2006 (see Figure 7.35).

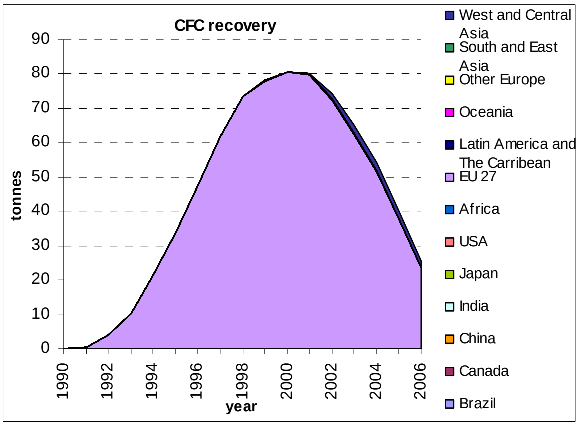

Figure 7.34 – CFC recovery.

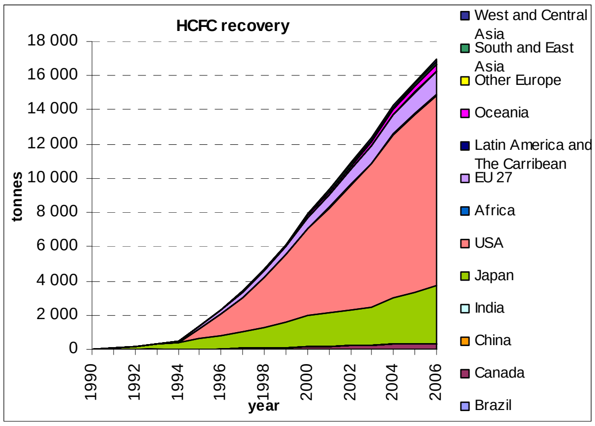

Figure 7.35 – HCFC recovery.

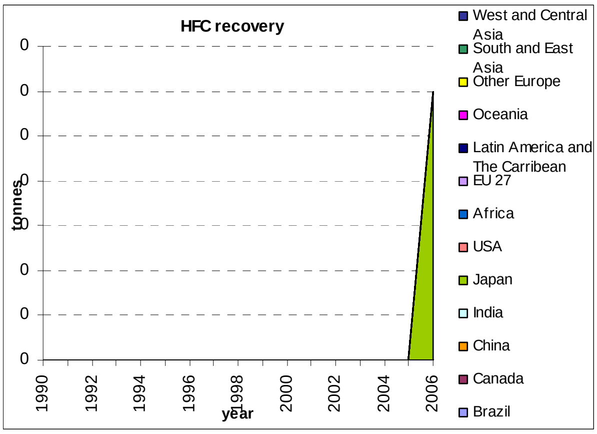

Figure 7.36 – HFC recovery.

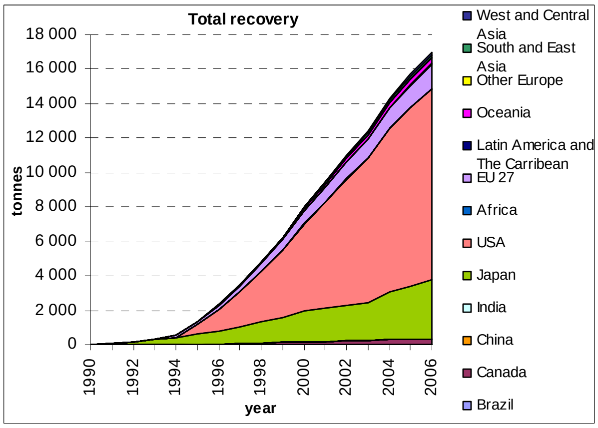

Figure 7.37 - Total refrigerant recovery in stationary air conditioning.

Assumptions regarding recovery efficiency have been corrected in order to take into account an improvement in the end of life policies. Therefore, considering lifetimes of equipment and late introduction of HFCs in the air-to-air sector, HFC recovery is still nil in 2006.

7.3 Data consistency and further improvements

The quality of data used for air-to-air AC systems are good, based on detailed marketing studies [BSR02, BSR05, BSR08]. Moreover, technical analyses coming from TOC ([TOC03], [TOC06], and [TEA04]) give also a good level background for the description of technologies, the refrigerant charge, emission rates, and lifetimes.

One of the main uncertainties remains related to the phase-out schedule of HCFC-22 and the derivation of historical data, especially concerning production and emission rates.

Assumptions on recovery need to be verified in a number of countries. If the recovery process at the equipment end of life is less efficient than calculated, emission levels will be higher.

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Appendix 7.1 of section 7

Refrigerant use evolution for different equipment types of air-to-air AC systems

Ducted Split < 17.5 kW

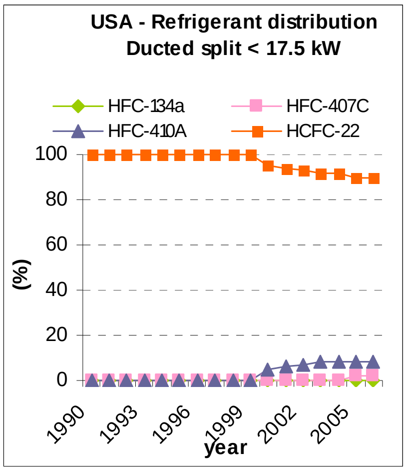

Figure 7.1.1 - Refrigerant distribution for new ducted splits < 17.5 kW in the U.S.

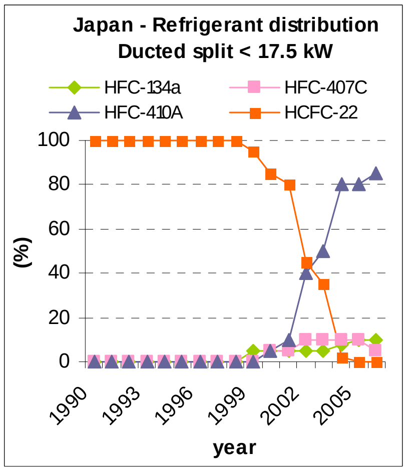

Figure 7.1.2 - Refrigerant distribution for new ducted splits <17.5 kW in Japan.

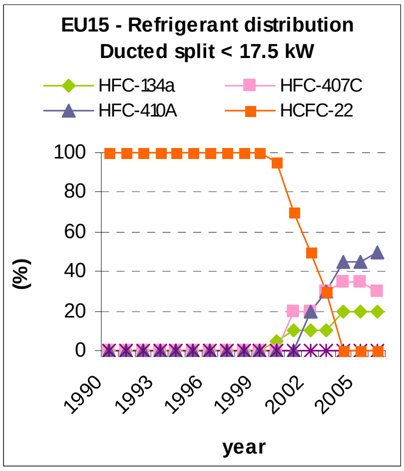

Figure 7.1.3 - Refrigerant distribution for new ducted splits <17.5 kW in EU15.

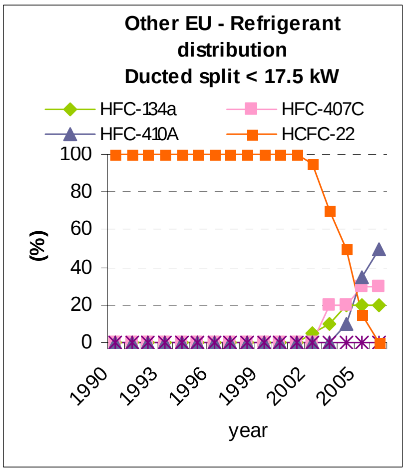

Figure 7.1.4- Refrigerant distribution for new ducted splits <17.5 kW in Other EU.

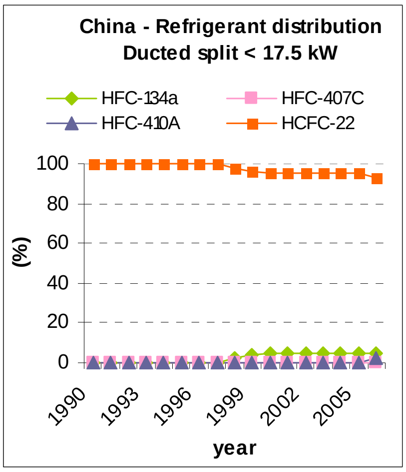

Figure 7.1.5 - Refrigerant distribution for new ducted splits <17.5 kW in China.

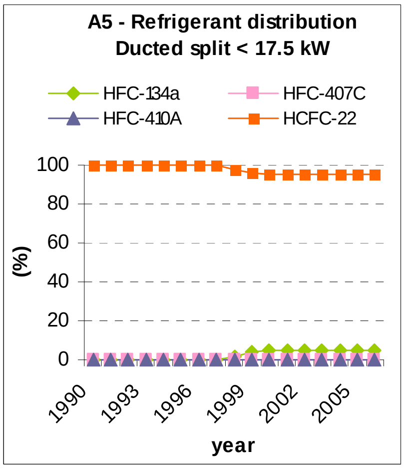

Figure 7.1.6 - Refrigerant distribution for new ducted splits <17.5 kW in A5 countries.

Indoor packaged

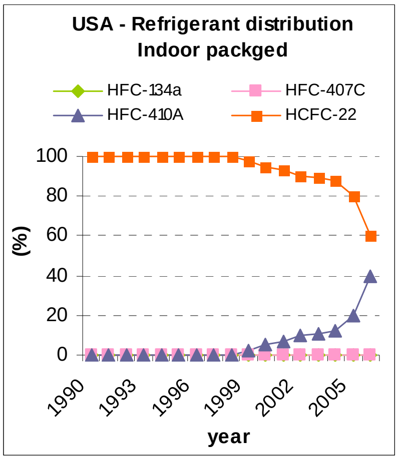

Figure 7.1.7 - Refrigerant distribution for new indoor packaged in the U.S.

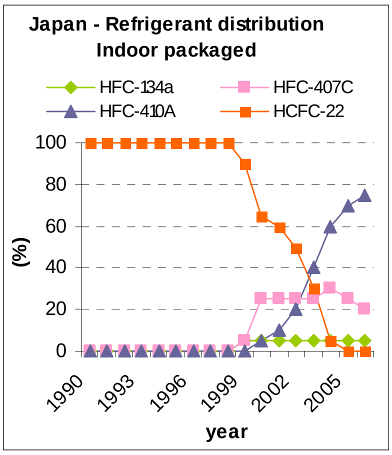

Figure 7.1.8 - Refrigerant distribution for new indoor packaged in Japan.

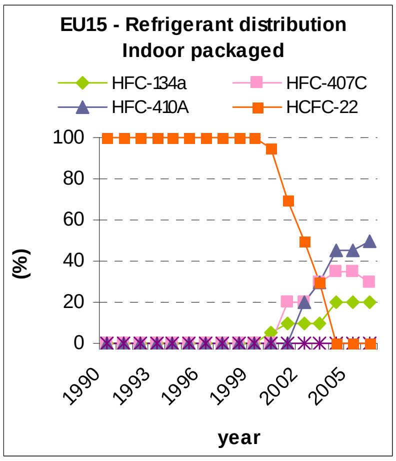

Figure 7.1.9 - Refrigerant distribution for new indoor packaged in EU15.

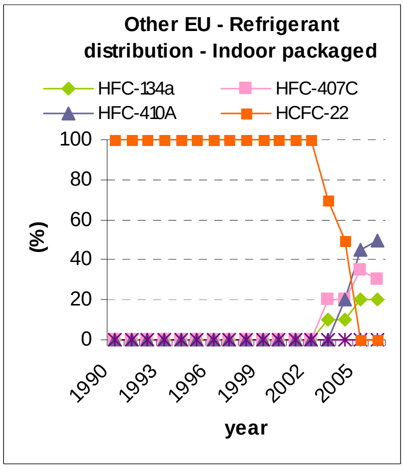

Figure 7.1.10 - Refrigerant distribution for new indoor packaged in Other EU.

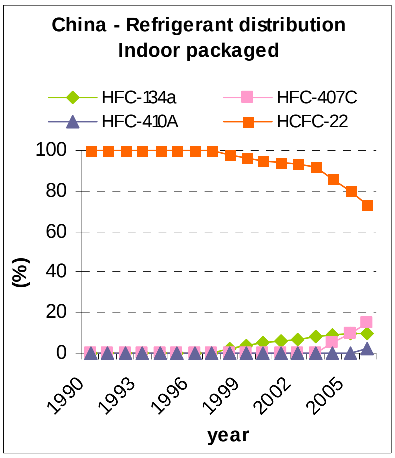

Figure 7.1.11 - Refrigerant distribution for new indoor packaged in China.

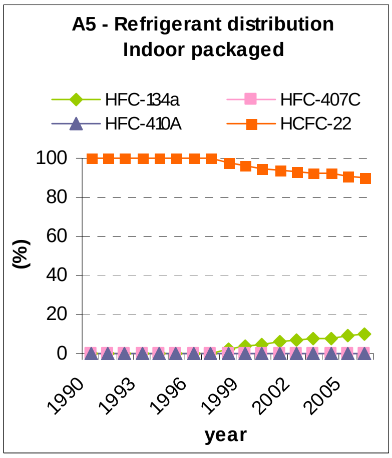

Figure 7.1.12 - Refrigerant distribution for new indoor packaged in A5 countries.

Split < 5 kW

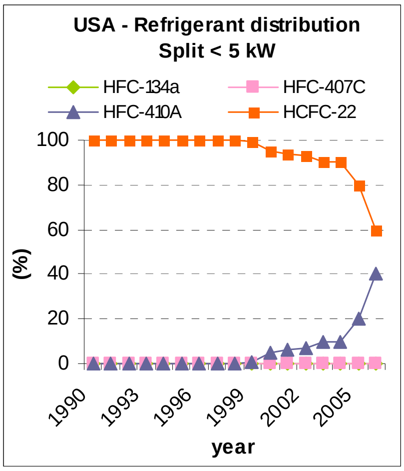

Figure 7.1.19 - Refrigerant distribution for new Splits < 5 kW in the U.S.

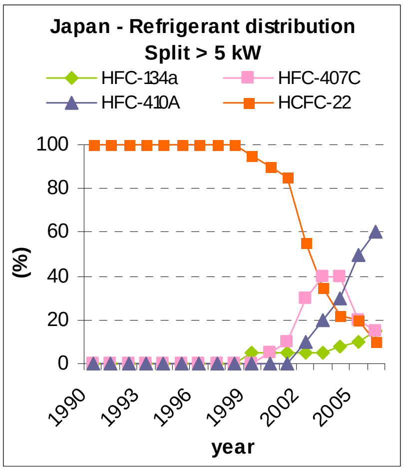

Figure 7.1.20 - Refrigerant distribution for new Splits < 5 kW in Japan.

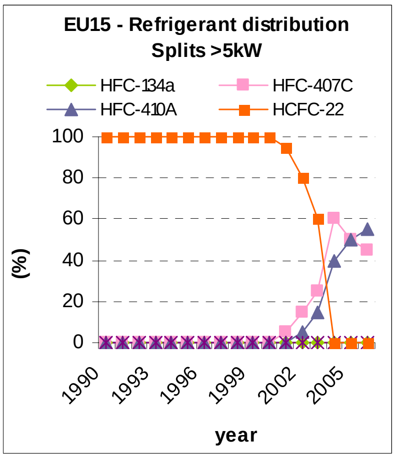

Figure 7.1.21 - Refrigerant distribution for new Splits < 5 kW in EU15.

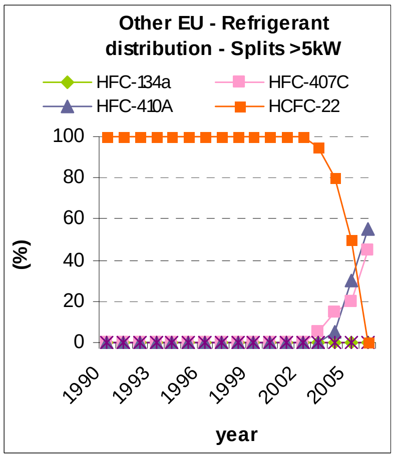

Figure 7.1.22 - Refrigerant distribution for new Splits < 5 kW in Other EU.

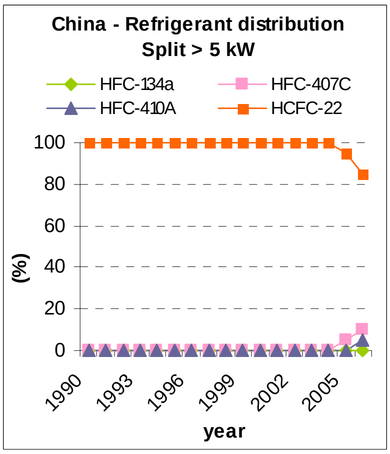

Figure 7.1.23 - Refrigerant distribution for new Splits < 5 kW in China.

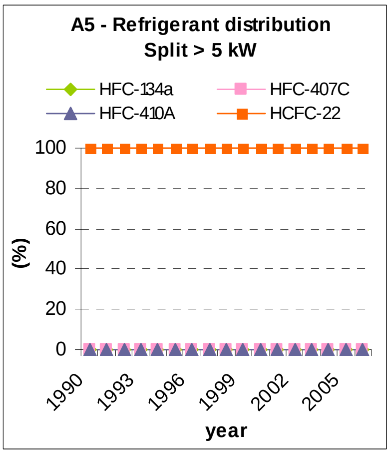

Figure 7.1.24 - Refrigerant distribution for new Splits < 5 kW in A5 countries.

Split > 5 kW

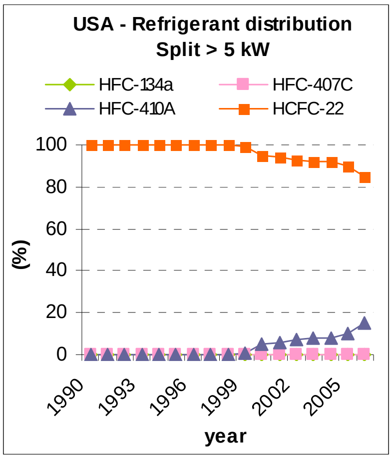

Figure 7.1.25 - Refrigerant distribution for new Splits > 5 kW in the U.S.

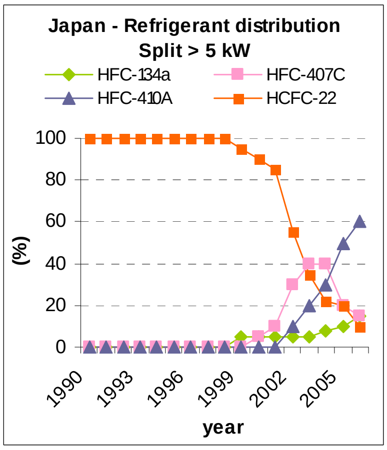

Figure 7.1.26 - Refrigerant distribution for new Splits > 5 kW in Japan.

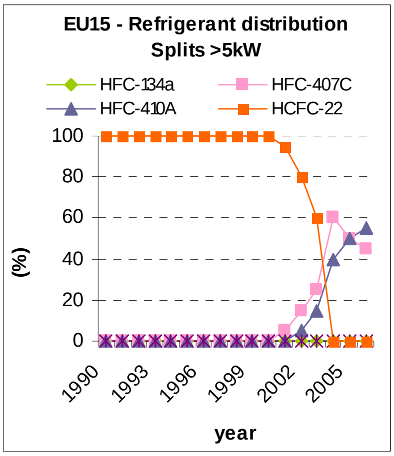

Figure 7.1.27 - Refrigerant distribution for new Splits > 5 kW in EU15.

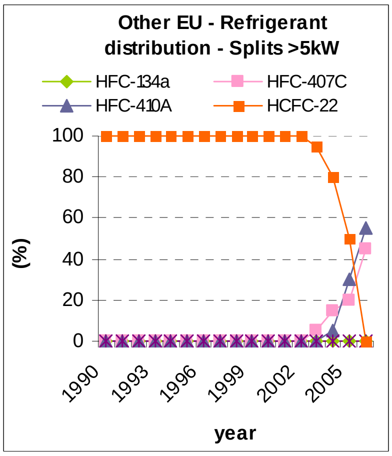

Figure 7.1.28 - Refrigerant distribution for new Splits > 5 kW in Other EU.

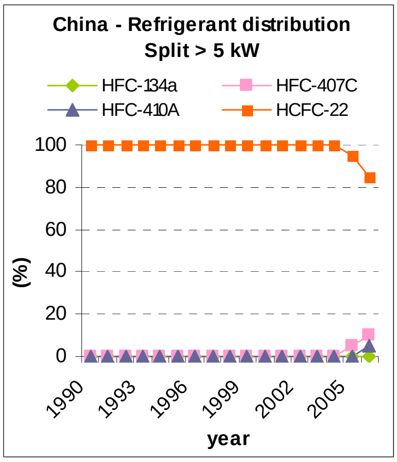

Figure 7.1.29 - Refrigerant distribution for new Splits > 5 kW in China.

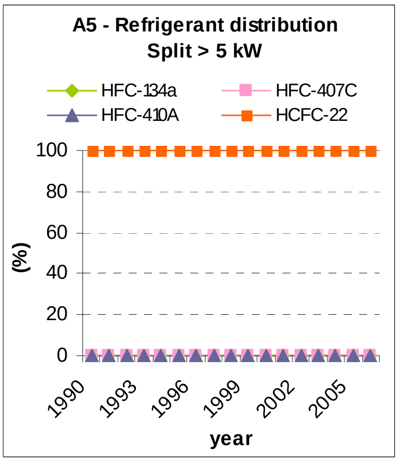

Figure 7.1.30 - Refrigerant distribution for new Splits > 5 kW in A5 countries.

Window

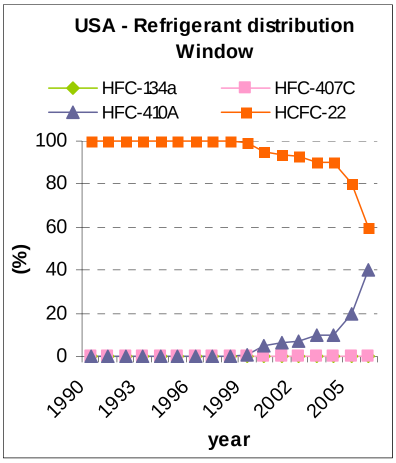

Figure 7.1.31 - Refrigerant distribution for new windows in the U.S.

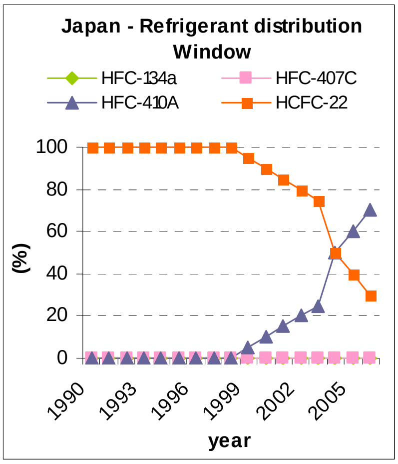

Figure 7.1.32 - Refrigerant distribution for new windows in Japan.

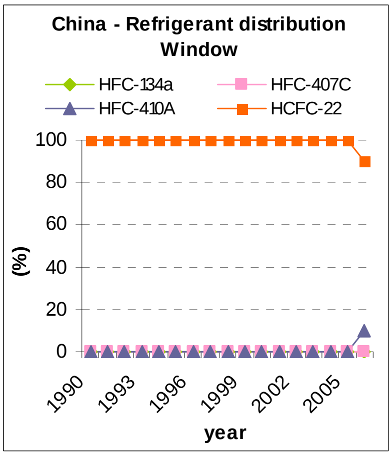

Figure 7.1.33 - Refrigerant distribution for new windows in China.

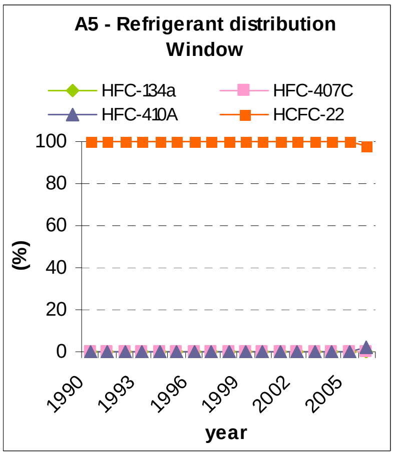

Figure 7.1.34 - Refrigerant distribution for new windows in A5 countries.

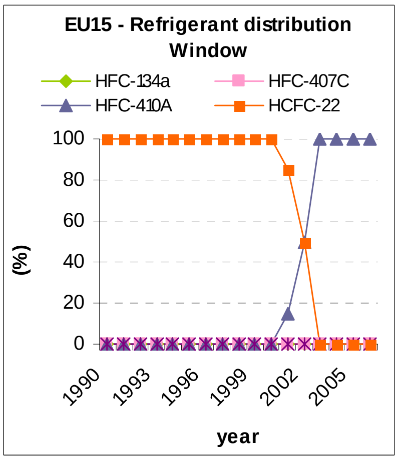

Figure 7.1.35 - Refrigerant distribution for new windows in EU15.

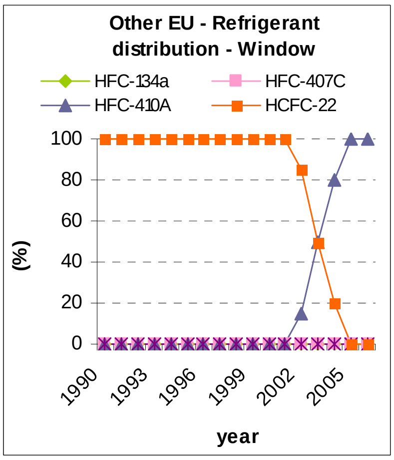

Figure 7.1.36 - Refrigerant distribution for new windows in Other EU.

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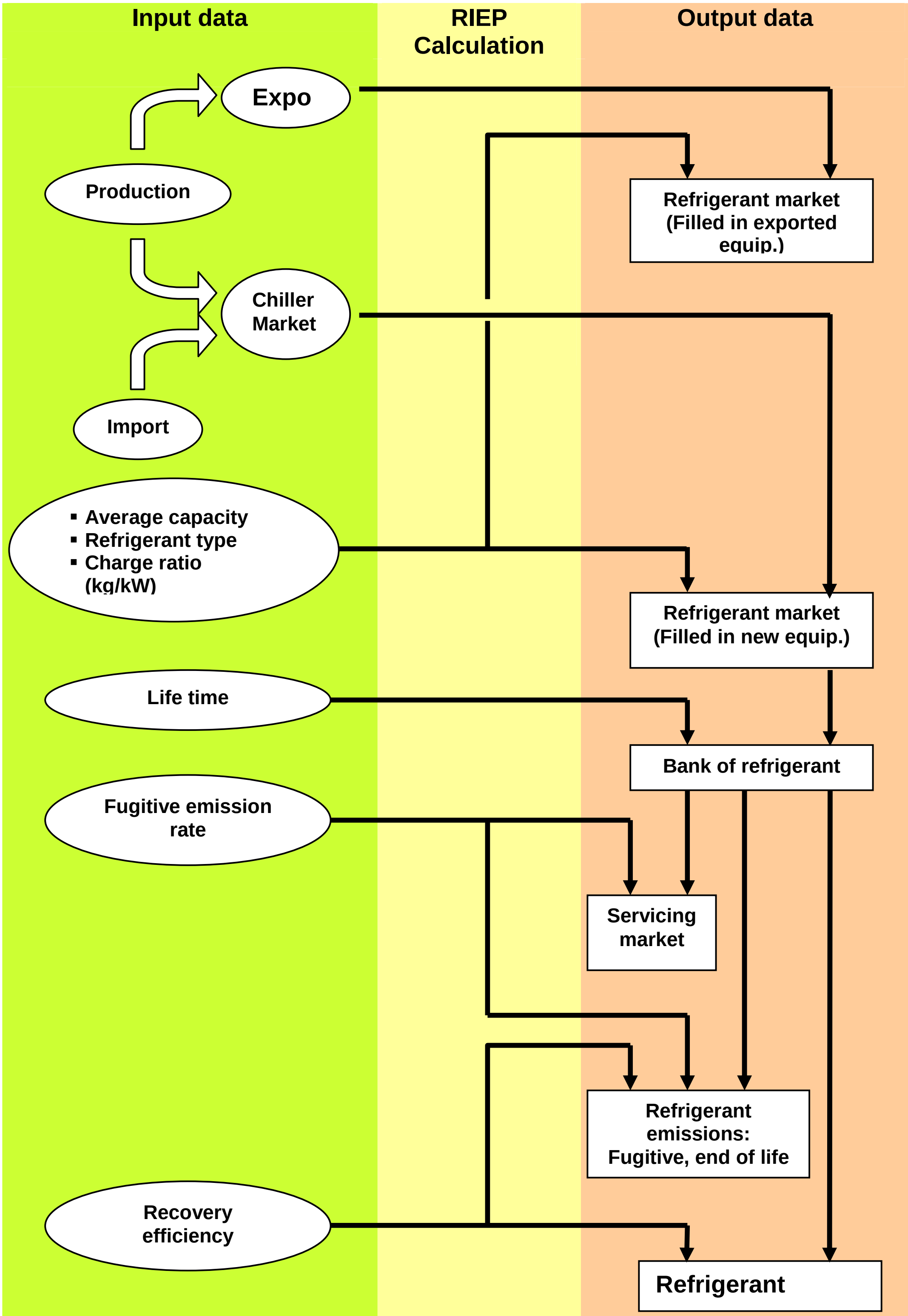

Figure 8.1 – Calculation steps for refrigerant emissions from chillers.

Introduction

Chillers are used for climate comfort and in industrial processes. Chiller manufacturers consider that about 2/3 of the large chillers manufactured have been installed for climate comfort. For medium size reciprocating chillers, it is possible that the ratio of use between climate comfort and industrial processes is slightly different; it could be typically 50/50 in European countries.

8.1 Data sources and calculation method

The calculation method is similar to the one used for air-to-air AC systems and the method is presented in Figure 8.1. One additional parameter, the refrigerant charge ratio, is used here in the calculation process. The refrigerant charge ratio depends on the type of chiller, whether volumetric (reciprocating, screw, and scroll) or centrifugal.

8.1.1 Market and production

The global statistics for equipment shipments are available from BSRIA ([BSR05], [BSR08]) since the year 1995 and are distinguished by chillers categories: "Centrifugal" chillers and "Reciprocating, screw and scroll" chillers.

Figure 8.2 and Figure 8.3 show the distribution of the sales of chillers in the world.

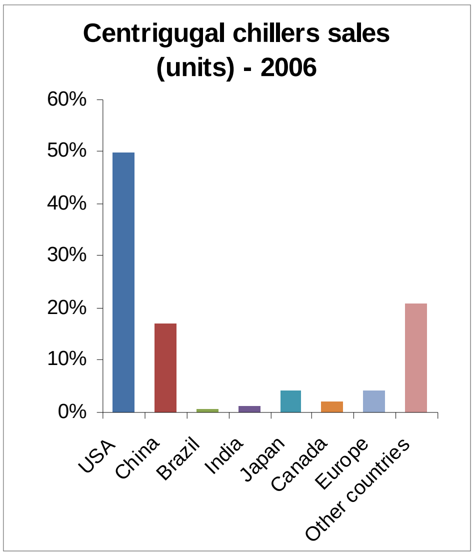

Figure 8.2 - Global distribution of centrifugal chillers sales for the year 2006.

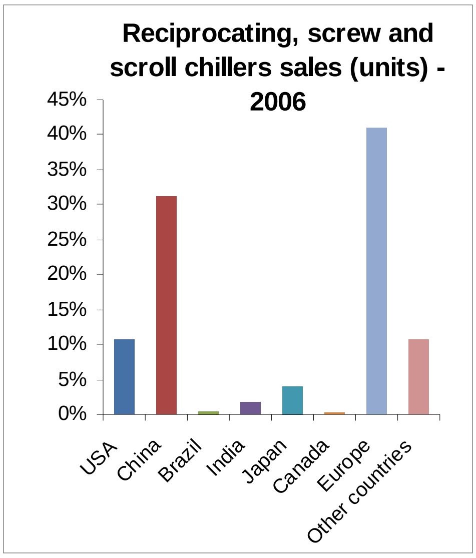

Figure 8.3 - Global distribution of reciprocating, screw and scroll chillers sales for the year 2006.

In 2006, the U.S. exhibits the highest share (50%) in terms of domestic shipments of centrifugal chillers followed by China accounting for 17%. The share of the positive displacement chillers in the U.S. is only around 10% of the global sales in the year 2006, while the European countries account for almost 40% followed by China with 30% of the total sales. Markets are given in Table 8.1 for both categories, for the main countries, in 2006.

Table 8.1 - Chiller market in 2006 [BSR08].

Chillers markets	***Brazil***	***USA***	***Japan***	***China***	***India***	***Canada***	***EU 27***
Centrifugal	85	6 139	536	2 093	150	259	444
Other Chillers	1 103	26 138	9 248	75 600	4 240	564	91 053

The historical years are derived from the GDP/capita and the market ratios evolutions.

The population of centrifugal chillers in the U.S. announced in the [TOC06] is of the range of 90,000 chillers (the year is not given). The source of this number is the ARI and the JARN magazine [JAR05] telling that « The U.S. has no rivals in the use of centrifugal chillers. Out of about 120,000 units installed in the world, 90,000 units are in the U.S., with 13,700 units in Japan and the other units in Europe and East Asia". The population of centrifugal chillers obtained from the BSRIA numbers and the derivation of the historical values based on both GDP/capita and market ratios is in the range of 58,000 chillers in 2001 and 68,000 in 2006. The discrepancy is coming from the fact that ARI statistics include in the large chiller category both centrifugal and large screw chillers. RIEP calculations are based on BSRIA data.

8.1.2 Type of refrigerants

Refrigerants used in centrifugal chillers (CFC-11, CFC-12, HCFC-123, and HFC-134a) are significantly different from the ones used in volumetric chillers (HCFC-22, HFC-134a, R-407C, and ammonia). Furthermore, the use of refrigerant in chillers is significantly different between the U.S., Japan, and Europe. In the '90s, CFC-12 was dominant in Europe while CFC-11 was dominant in the U.S. and Japan. HFC-134a is the major replacement refrigerant in Europe, while HCFC-123 is used in competition to HFC-134a in the U.S. and in Japan. In developing countries, the selection of refrigerants is very much dependent on imports and on company strategies. In many countries, CFC-11 and CFC-12 were the dominant refrigerants.

♦ **Centrifugal chillers**

In the U.S., in Japan, and other Asian countries, the dominant technology has always been low-pressure chillers using CFC-11.

On the contrary, in Europe the CFC-12 centrifugal chiller technology was dominant. The refrigerant that has now replaced CFC-12 in Europe is HFC-134a. HFC-134a has also replaced CFC-12 in the U.S. and Japan.

HCFC-123 has been used as a replacement for CFC-11 in the U.S., and also, but to a lesser extent, in Japan. HCFC-123 has hardly been chosen for any applications in Europe. Figures 8.4 to 8.7 summarize the refrigerant shares in centrifugal chiller applications in Europe, the U.S., Japan, and A5 countries.

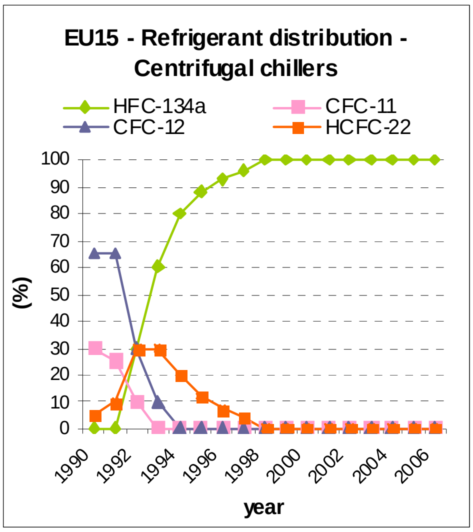

Figure 8.4 - In Europe (%).

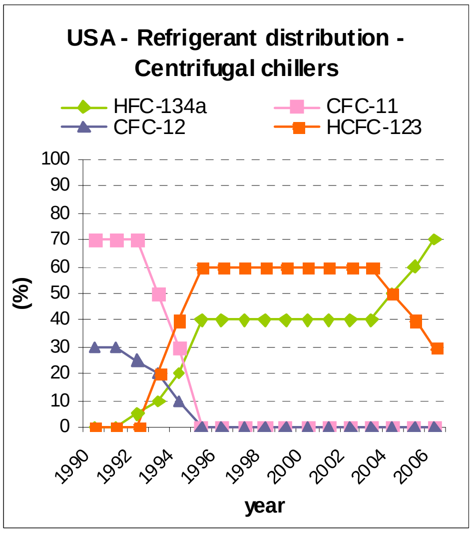

Figure 8.5 – In the U.S. (%).

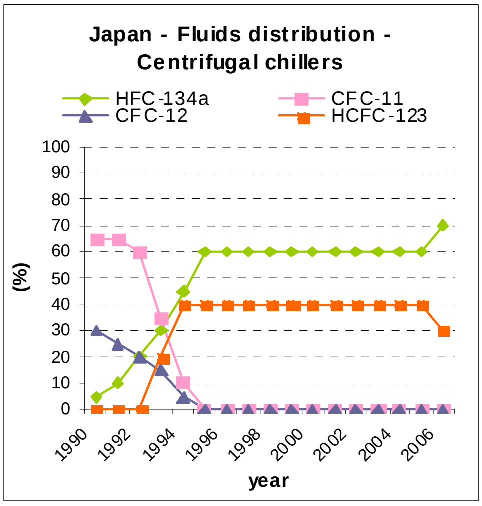

Figure 8.6 - In Japan (%).

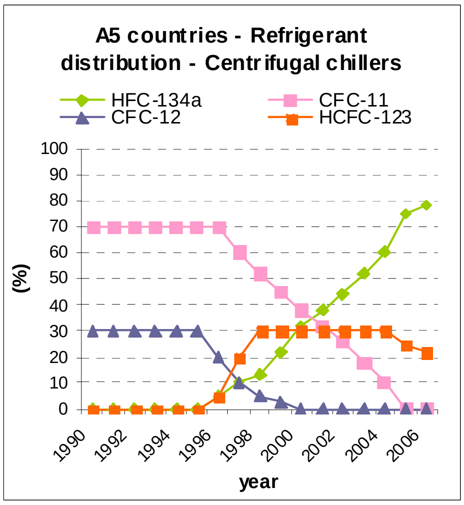

Figure 8.7 – In A5 countries (%).

The remaining hundred chillers in Japan have been considered as completely retrofitted or disposed of as of 2001. It is not the case of USA where a great part of CFC-11 chillers have been retrofitted between 1995 and 2000 (about 2/3 of the bank). However, since 2001, it is considered that 5 % of the remaining installed base is retrofitted (or replaced) each year.

In A5 countries, one can observe different trends; these are very much dependent on company strategies and certainly also on imports. In China and Korea, the refrigerant selection is and has been significantly influenced by the preferences of U.S. and Japanese companies; therefore CFC-11 has also had a significant market share in China and Korea. In many other countries, CFC-12 was (and sometimes still is) the dominant technology. For the replacement of CFCs, HCFC-123 and HFC-134a have been selected; furthermore, where it concerns imports of centrifugal chillers, HCFC-123 and HFC-134a technologies are introduced.

- **Volumetric chillers**

Volumetric chillers form a category of chillers that covers a very wide range of refrigerating capacities. Europe is characterized by a very large number of small and medium size cooling capacities (from 50 to 300 kW). In the U.S., centrifugal chillers form the dominant technology, and the average refrigerating capacity of volumetric chillers is also higher compared to Europe.

Taking the above characteristics into account and also paying attention to the earlier HCFC-22 phase-out in Europe, different trends can be observed. In the European Union, the shift from HCFC-22 to R-407C and HFC-134a is more rapid; the market share of ammonia equipment is very small. In Japan, similar trends can be observed. In the U.S., the share of HCFC-22 in the market is still very important and the preferred choice for HCFC-22 replacement is HFC-134a or R-410A rather than R-407C.

Figures 8.8 to 8.11 present the shares of the different refrigerants for the U.S., Europe, Japan, and A5 countries.

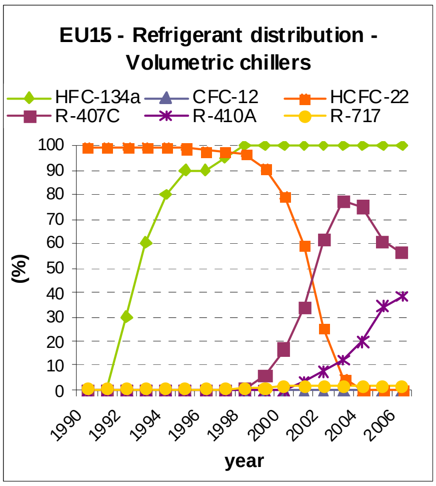

Figure 8.8 - In Europe (%).

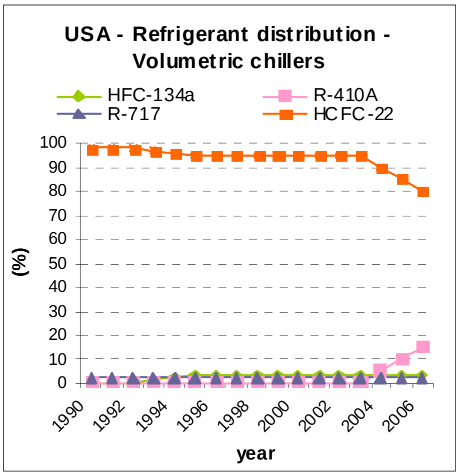

Figure 8.9 – In the U.S. (%).

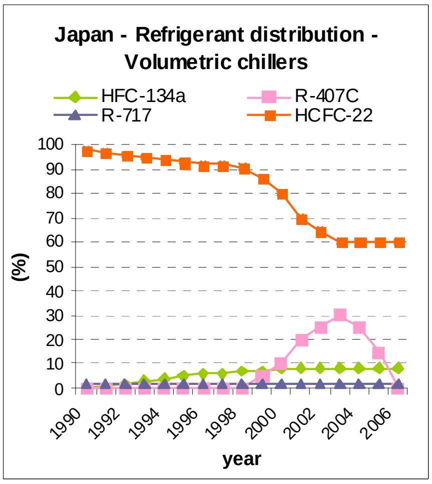

Figure 8.10 - In Japan (%).

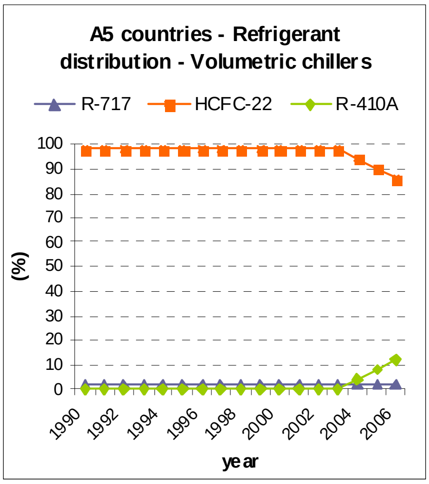

Figure 8.11 – In A5 countries (%).

8.1.3 Refrigerant charge

The average refrigerant charge is computed based on the average cooling capacities and estimated ratios of the charge/cooling capacity given in kg/kW.

For centrifugal chillers, the countries all over the world are divided in two main groups following either the U.S. model or the European model [PAL03]. The U.S. model is characterized by an average cooling capacity of 3,000 kW for centrifugal chillers [PAL03]. The European model has lower values considered to 2,000 kW for centrifugal chillers [PAL03]. Japan and Canada are assumed to follow the U.S. model.

Concerning the volumetric chillers, the U.S. model has a cooling capacity of 350 kW [SAB09] while the European model was considered to 50 kW in the global inventories 2003 [PAL03], and is updated based on BSRIA volumetric chillers sales detailed by cooling capacities. The value for India is also updated based on BSRIA numbers. The charge/cooling capacity ratios are taken from [PAL03] and are also presented in Table 8.2.

Table 8.2 - Cooling capacities and average charge/cooling capacity ratios for chillers.

Volumetric		***Centrifugal***	
kg/kW	kW	kg/kW	kW
0.5	120	0.5	2000
0.5	100	0.5	2000
0.5	365	0.5	2000
0.3	100	0.25	3000
0.3	100	0.25	3000
0.35	335	0.3	3000
0.3	89	0.3	2000

8.1.4 Emissions and recovery efficiency

Values of emission factors are based on the TEAP report 2004 [TEA04]. In the absence of a precise source for a given country, specific models are used. The countries all over the world are divided in two main groups following either the U.S. model or the European model. The evolution of the emission rate and recovery efficiency values along the time is taken into account in RIEP calculation. Table 8.3 and Table 8.4 show values considered for the year 2006.

Table 8.3 - Centrifugal chillers – Annual emission rates and recovery efficiency in 2006.

	Emission rate (%)				***Recovery efficiency (%)***
	CFC-11	CFC-12	HCFC-123	HFC-134a	
U.S.	10	10	3	5	80
EU15	8	8	5	5	80
A5-countries	10	10	5	5	5

Table 8.3 takes into account the improved containment associated with chillers put on the market after 1995. HCFC-123 centrifugal chillers show very low emissions even lower than the 3% in Table 8.3 but ruptures of safety valves have to be taken into account, with a possible loss of the entire refrigerant charge and so, 3% seem a reasonable average value.

For HFC-134a centrifugal chillers, a number of progresses have also been made, but due to the higher pressure the average leak flow rate is set higher at 5%.

For all chillers still using CFC-11 and CFC-12, even if containment is effective in order to keep the old chillers running, the average emissions are higher and losses during servicing are still high in many countries.

For volumetric chillers, the emission rate varies significantly depending on the cooling capacity and the technology. In the 1990's an average emission rate of 15% was considered. For new chillers installed progressively since 1995, a decrease of the emission rate has been taken into account until the range from 5 to 8%, depending on the country (see Table 8.4).

Table 8.4 - Volumetric chillers – Annual emission rates and recovery efficiency in 2006.

	Average emission rate (%)	*Recovery efficiency (%)*
U.S.	5	50
China	8	5
Brazil	8	5
Canada	5	50
Japan	5	50
India	8	5
EU-15	6	55

In Table 8.5 the other input data for volumetric and centrifugal chillers are reminded.

Table 8.5 – Characteristics of volumetric chillers.

Chiller type	*Lifetime (years)*	*Recovery efficiency (%)*	*% of charge emitted before servicing*
Volumetric	15	60	20
Centrifugal	30	80	20

8.2 Results of calculations: refrigerant bank, emissions, and recovery

When comparing the previous study [CLO06] and the current one, some elements have been changed: the average refrigerating capacity of CFC centrifugal chillers in the U.S. has been increased of 1/3 in this update. Better data were available for the 2006 update South & East Asia.

8.2.1 Refrigerant bank

The CFC bank is decreasing but is still significant in 2006, about 52,000 tonnes. It is dominated by South and East Asia (40%), China (24%), and the U.S.(21%) (see Figure 8.12).

In 2006, the most significant bank is the HCFC bank that culminates at about 120,000 tonnes. This is a dominant bank representing 48% of the total quantity of refrigerants in use in chillers (see Figure 8.13). This trend was already observed in the previous inventories. It is confirmed because developing countries, especially India, China, and Brazil that are still using HCFC-22 in a large share of their equipments.

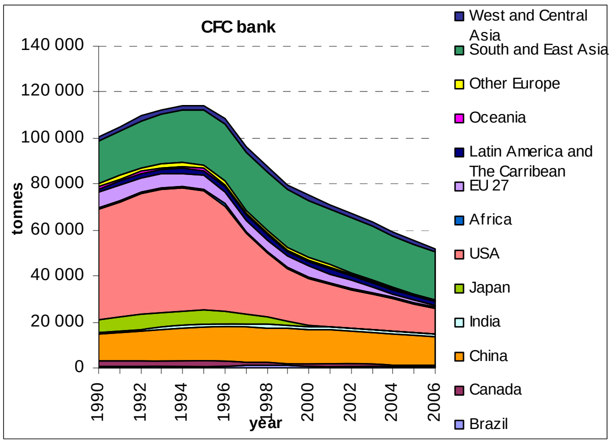

Figure 8.12 – CFC bank.

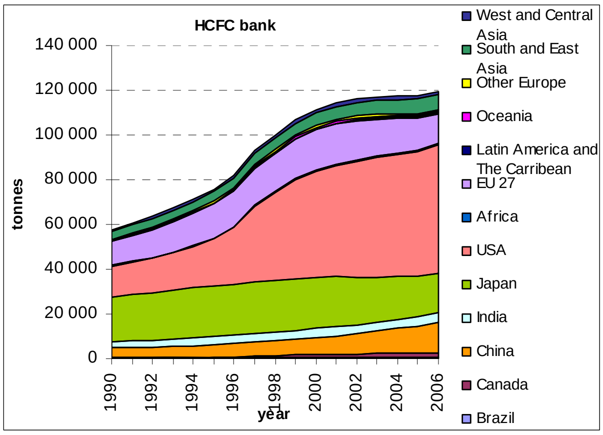

Figure 8.13 – HCFC bank.

The HFC bank is rising steadily (see Figure 7.9) due to the ban of CFCs and HCFCs in Europe. It is estimated to about 75,000 tonnes in 2006. Japan, EU27 but also the U.S. are the key regions for the build up of the HFC bank.

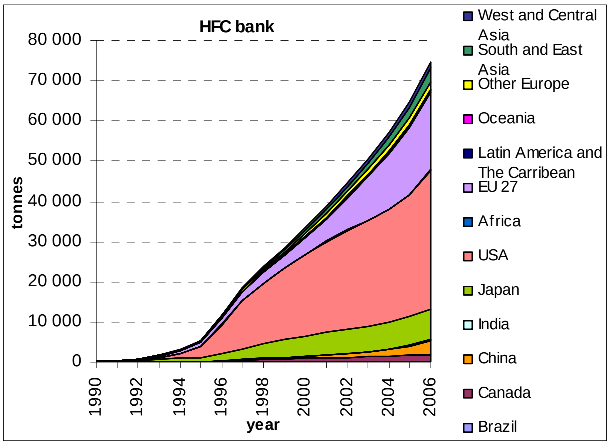

Figure 8.14 – HFC bank.

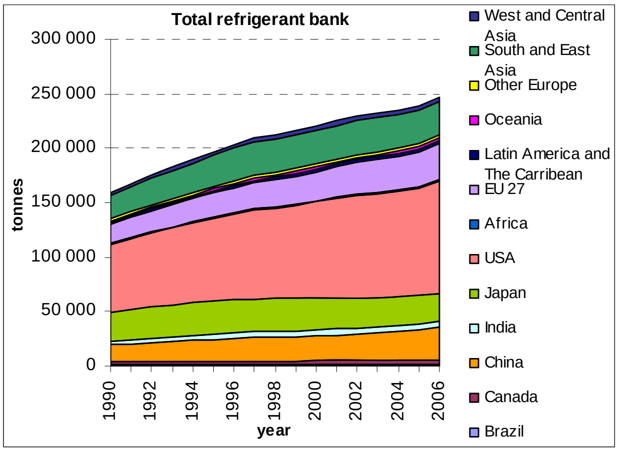

Figure 8.15 – Global refrigerant bank in chillers.

Figure 8.15 confirms the domination of the U.S. in terms of number of chillers with a total bank of 103,000 tonnes in 2006. The ammonia bank is not presented because it represents only 1,500 tonnes in 2006, mainly in the U.S., Japan, U.S., and EU27.

8.2.2 Refrigerant emissions

Emissions are in line with the bank. CFC emissions are decreasing from 20,000 tonnes in 1996 to about 10,000 tonnes in 2006 (see Figure 8.16).

HCFC emissions are dominant. They are evaluated at about 14, 000 tonnes in 2006 (see Figure 8.17), the U.S. contributing for 39% of them.

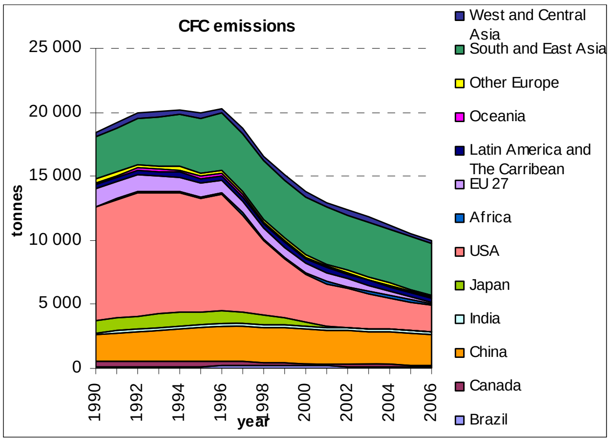

Figure 8.16 – CFC emissions.

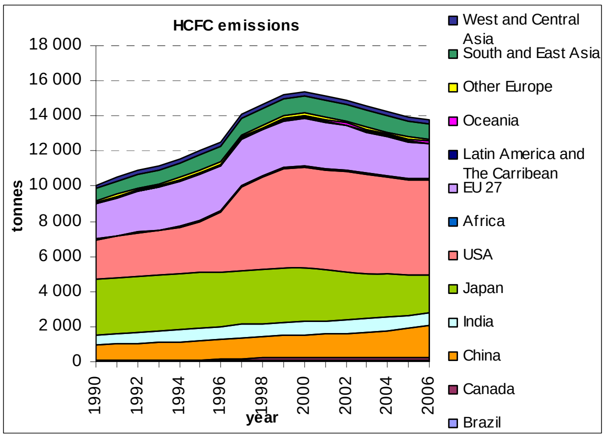

Figure 8.17 – HCFC emissions.

Currently the HFC emissions are "only" of 7 000 tonnes (see Figure 8.18).

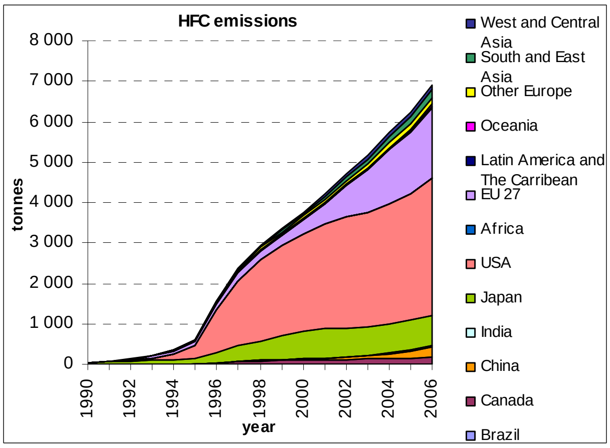

Figure 8.18 – HFC emissions.

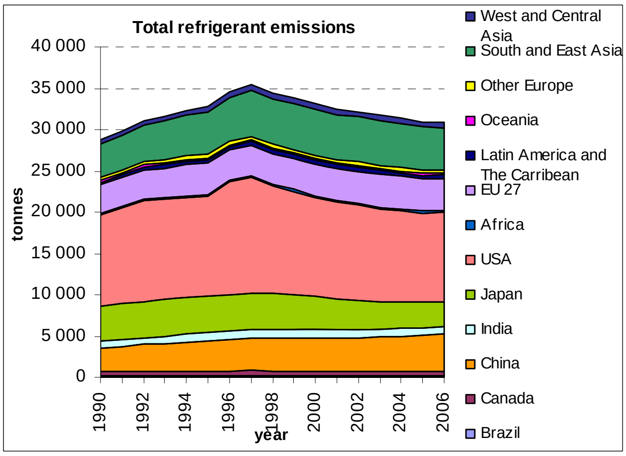

Figure 8.19 - Global refrigerant emissions.

Figure 8.19 is on line showing that emissions are dominated by CFCs.

8.2.3 Refrigerant CO_2 equivalent emissions

In terms of CO_2 equivalent, CFC emissions are mainly responsible for CO_2 equivalent emissions of the chiller sector, because of the high GWP of CFCs (see Figure 8.20). In 2006, in this sector CFCs and HCFCs still represent around 66 million of tonnes equivalent CO_2, which are not taken into account by the Kyoto Protocol. As shown in Figure 8.23, the only emissions taken into account in terms of CO_2 are those of HFCs, which are of about 9 million of tonnes.

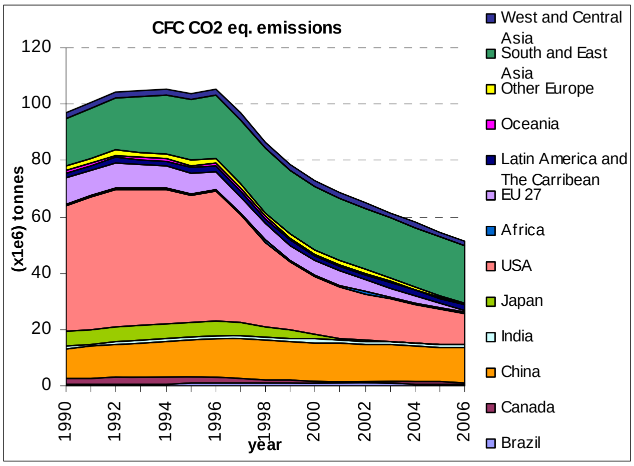

Figure 8.20 – CFC CO_2 equivalent emissions.

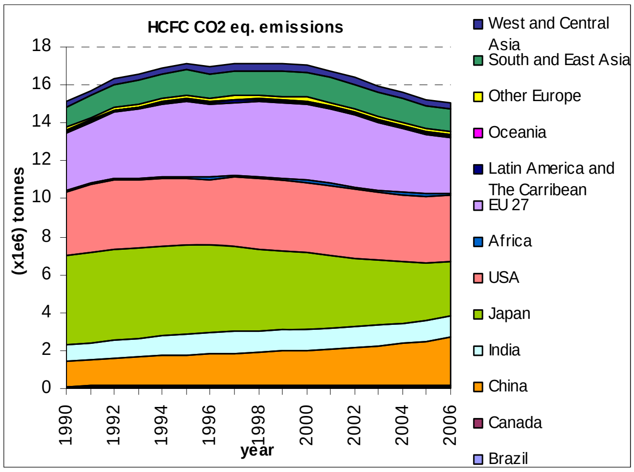

Figure 8.21 - H CFC CO_2 equivalent emissions.

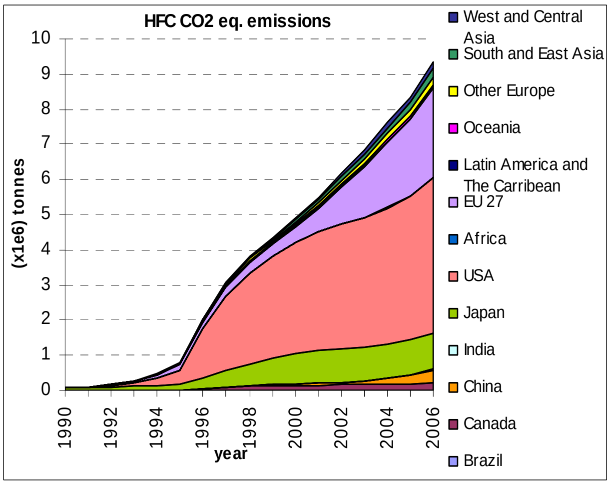

Figure 8.22 – HFC CO_2 equivalent emissions.

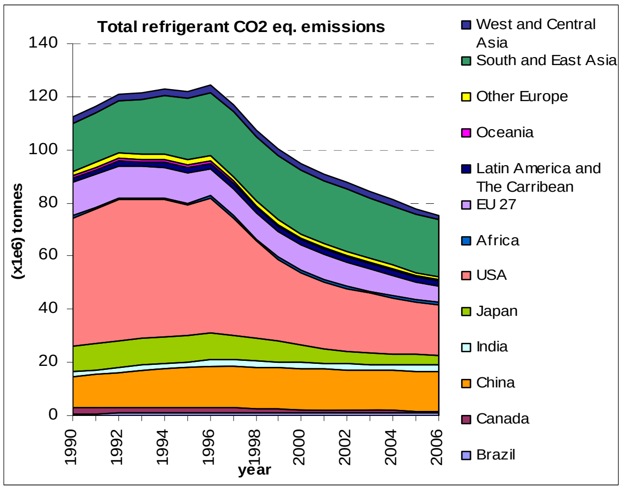

Figure 8.23 – Global refrigerant CO_2 equivalent emissions.

8.2.4 Refrigerant recovery

Figure 8.24 shows the typical heap due to the phase out and the recovery for destruction, which has occurred in the U.S., Japan, and at a lesser extent in Europe. Assumptions regarding CFC-11 retrofit in the U.S. have been modified in these inventories, compared to the previous report, and are to be confirmed.

The evaluation of the recovery efficiency of HCFC is arguable and needs to be verified, especially in the U.S. where it is evaluated at about 1,200 tonnes in 2006 (see Figure 8.25).

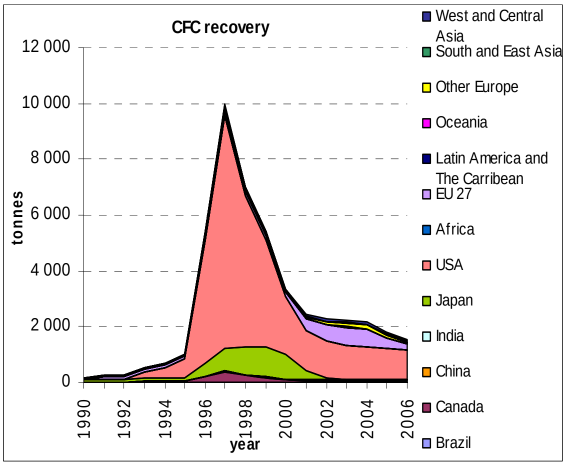

Figure 8.24 – CFC recovery.

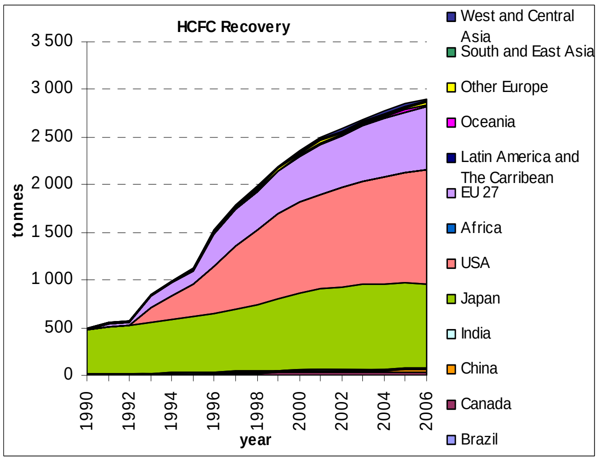

Figure 8.25 – HCFC recovery.

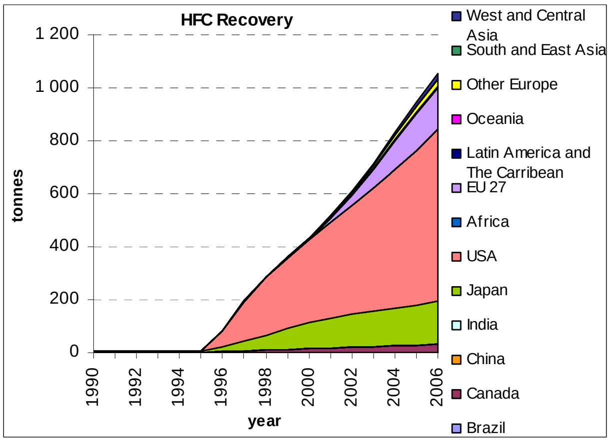

Figure 8.26 – HFC recovery.

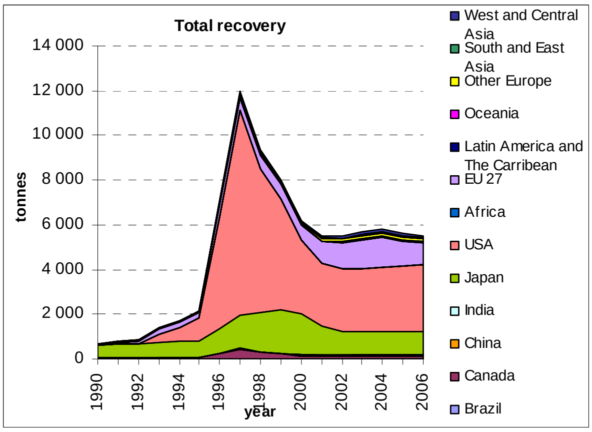

Figure 8.27 – Global repartition of the refrigerant recovery.

8.3 Data consistency and further improvements

The quality of data used for chillers are good based on detailed marketing studies [BSR02, BSR05, BSR08]. However, historical data and some region market estimates, in particular the South and East Asia one, have to be confirmed. The knowledge of the number of installed chillers by refrigerant for some countries would be very useful to confirm evolutions.

Technical analysis coming from TOC ([TOC03], [TOC06] and [TEA04]) gives also a high level background for the description of technologies, the refrigerant charge, emission rates, and lifetimes.

One main uncertainty is always related to the schedule of HCFC-22 phase out.

The assumptions on recovery need to be verified in a number of countries. If the recovery process at the equipment end of life is less efficient than calculated, emission levels will be higher.

Even if UNEP has carried out a number of country studies, some uncertainties remain on the number of CFC chillers still in use out of the U.S. It has also to be noticed that the picture of chillers becomes more complex due to the larger number of small and medium size chillers using reciprocating, scroll or screw technology. Hopefully the regular survey of BSRIA helps a lot in this matter.

The improvements will certainly be made in the domain of leak flow rates and also in following very precisely the refrigerant choice in developing countries.

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[SAB09] SABA, Sabine, SLIM, Rayan, PALANDRE, Lionel and CLODIC, Denis. Inventory of Direct and Indirect GHG Emissions from Stationary Air Conditioning and Refrigeration Sources, with Special Emphasis on Retail Food Refrigeration and Unitary Air Conditioning. Final report for CARB, mars 2009.

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CONTENTS

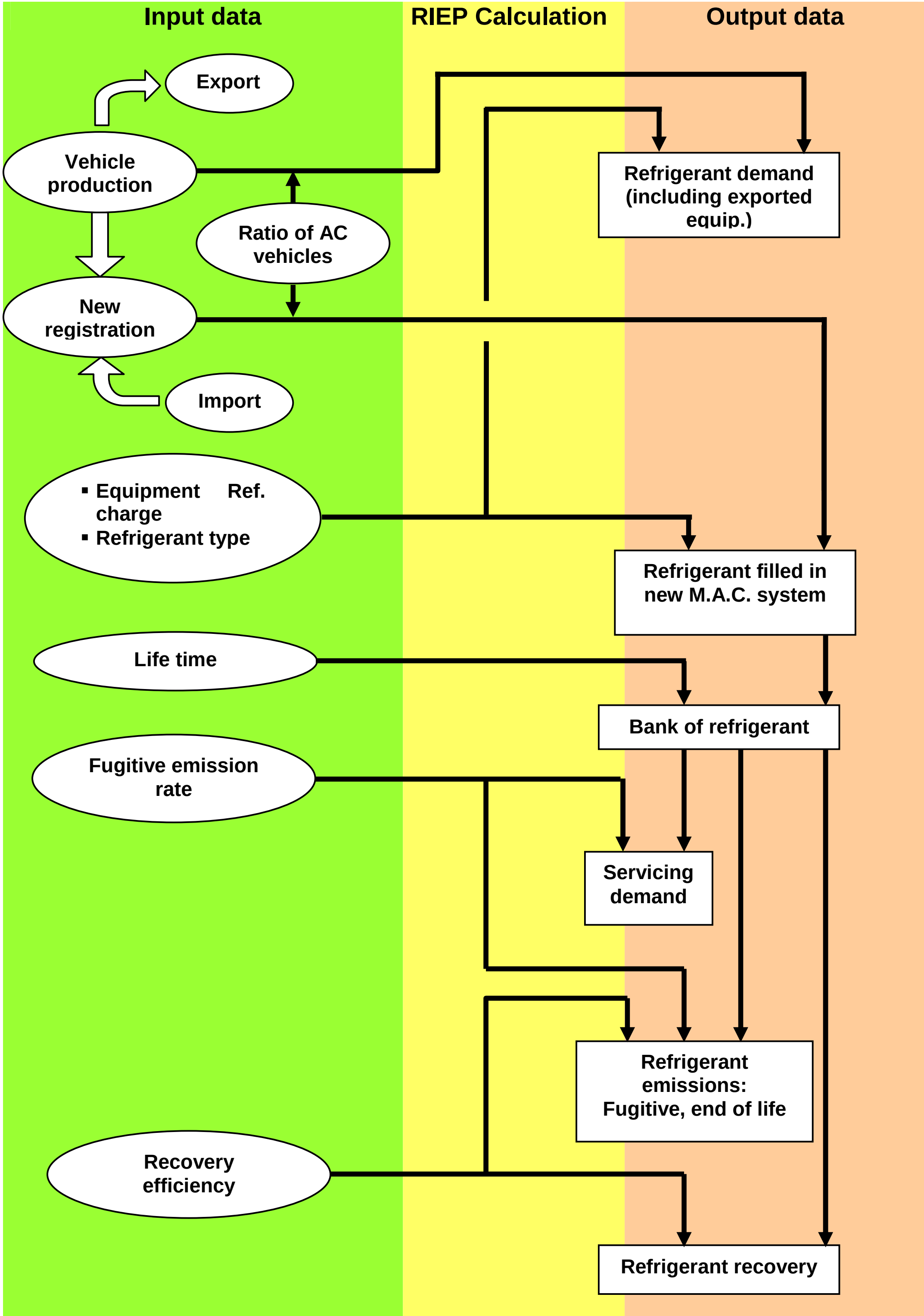

Figure 9.1 – Calculation steps in the determination of refrigerant emissions from MAC systems.

Introduction

The mobile air-conditioning (MAC) system sector includes four sub-sectors that occupy separate parts in the database:

- cars and light commercial vehicles (LCVs),
- trucks or industrial vehicles,
- buses
- trains, a sector that has not been updated in this report

However, these sectors are merged for the presentation of the result calculations in Section 9.3.

9.1 Detailed calculation method and data sources

9.1.1 - Evolution of the calculation method [SAB09]

The calculation steps are identical for the four sub-sectors, as indicated in Figure 9.1.

- The number of vehicles produced and the registration of new vehicles are derived from reference sources allowing study of separate data for imports and exports of vehicles.
- A ratio between the number of vehicles equipped with an air-conditioning system and the total number of vehicles is used annually as presented below.
- Taking into account the decrease of the refrigerant charge in the last years and the refrigerant type, the annual refrigerant demand for new vehicles, both sold in and exported from a country, can be calculated.
- Once the average lifetime of cars and their AC systems is known, the bank of refrigerants can be determined (merging all charges used in the total fleet of vehicles).
- Based on emission rates, recovery efficiencies at servicing, and the derivation of the refrigerant bank, the annual servicing demand is calculated, and subsequently the total refrigerant emissions, including fugitive and end-of-life emissions.
- Refrigerant recovery quantities are known via the recovery efficiency at end of life parameter.

Emission rates

Emissions from MAC systems are classified into two categories: regular and irregular [SAB09].

Regular emissions are those occurring during the in-use phase of the product lifetime based on the characteristics of joints and elastomeric parts. They are considered as fatal emissions related to permeation of refrigerant through the flexible hoses, and also micro-flows through clearance of mechanical parts. They are not related to ill-mounted joints or poorly brazed joints. The manufacturing process has been well done. Regular leaks are related to joints, stems, and open shaft seals. They are more important in mobile systems where flexible lines are necessary when the circuit connects components fixed on walls and others to the engine.

Regular leaks can increase during the equipment lifetime, due to wear and vibrations. The limit is difficult to establish between fatal loss of leak tightness and poorly designed components. Still, their existence is not related to refrigeration system failures.

On the contrary, irregular emissions are those resulting from component failures or accidents. For MAC systems, irregular emissions are coming from road accidents, or shocks on the front end that might lead to the complete loss of the refrigerant charge within few seconds [SOU08] or to perforations in the MAC system that might also be the result of simple stone impacts.

Recent studies [CLO05a, CLO05b, CLO07, TRE08] have allowed determining initial leak flow rates from new vehicles (expressed in g per year). Emission rates of MAC systems had been reviewed to take into account available experimental results.
Two values are introduced into the RIEP model:

1- Regular emissions defined by an initial leak flow rate being worsened with the vehicle age
2- Irregular emissions resulting mainly from accidents as explained previously.

The leak flow rates defined in RIEP are expressed in g/yr (not in % of the initial average charge) because measurements performed on vehicles have shown that no relationship exists between the leak flow rate level and the nominal vehicle refrigerant charge.

These values are specific to vintages to which a degradation rate is then applied, in order to take into account the degradation of the MAC system leak tightness along its lifetime. The referenced studies have shown that emission rates of used vehicles are higher than those of brand new ones, and that MAC circuits are not as leak tight once they have been dismounted either in part or completely. The following linear degradation model is used [SAB09].

$$LFR_{v,j} = (1 + x * j) * LFR_{v,0} \qquad (9.1)$$

Where:

v	The vintage being calculated
j	The vehicle age expressed in years and initialized to 0
x	The LFR increase expressed in percentage
$LFR_{v,0}$	The initial LFR of vintage “v”.

For a linear LFR increase, the LFR evolution of vintage v is calculated as shown in Equation (9.1). In order to understand the impact of the x value in Equation (9.1), consider x equal to 100%. This means that if the initial LFR is equal to 20 g/yr, the LFR at year 2 will be 40 g/yr, at year 3 it will be 60 g/yr, and at year 4 it will be 80 g/yr, and the cumulative emitted charge from the first year until the fourth will be the sum of all the LFRs, i.e. 200 g/yr. The method considers that no repair of the leak source is done during the MAC system servicing operation, i.e. for the example provided above, even if the MAC system requires servicing at year five, the LFR at this year will be 100 g/yr, and the year after 120 g/yr leading to a cumulative emitted charge of 220 g/yr within the following two years. This assumption represents the worst case scenario, where the MAC system servicing did not fix the leak.

The resulting emission rate is then equal to the sum of the LFR and of the irregular emissions.

In previous inventories, a degradation rate was applied to an overall emission rate (i.e. the initial LFR to which the irregular emission rate is added) calculated in order to take into account its evolution during the vehicle lifetime. One major modification was brought to this method [SAB09]; the separation of the annual leak flow rate in two parts, the first one includes regular emissions while the second one includes irregular emissions and the degradation is only applicable to regular emissions.

S. Saba [SAB09] implemented a double top-down /bottom-up approach to establish a coherent emission factor for MAC systems and degradation curves of the initial LFR as a function of the vehicle age. This method is based on a follow-up of the HFC-134a and is summarized below.

1- Inventories of applications using HFC-134a
The use of HFC-134a is dominant in domestic refrigeration, chillers, standalone commercial equipment, and MAC systems. The bottom-up approach allows estimating the HFC-134a demand (new equipment charge plus servicing of the installed bases) for the first three applications with relatively low uncertainties.

2- The bottom-up approach allows the estimation of the refrigerant demand for new MAC systems based on the annual sales of cars equipped with AC systems and the knowledge of the evolution of the average refrigerant charge with the car vintage. The recent measurements made on MAC systems show that efforts have been made by component suppliers for improving leak tightness. Initial LFRs are provided for recent years and then estimated for previous years.

3- The mixed bottom-up / top-down approach allows the inference of HFC-134a sales for MAC systems, and the separation between the volume that is sold for the charge of the annual new fleet and the part used for servicing the installed base. The servicing demand covering the irregular emissions is also deduced. The resulting HFC-134a demand is studied in order to estimate an averaged LFR of a vehicle. These high emission rates are then confirmed by those obtained from laboratory tests, and degradation curves are established based on these laboratory measurements and using an inverse model.

The resulting linear degradation obtained is 20%.

❖ **percentage of charge emitted before servicing**

The algorithm for estimating servicing demand for MAC systems was presented in Section 1. One of the required parameters is the “percentage of charge emitted before servicing”. This parameter defines the threshold of charge below which vehicle shall undergo maintenance. The combination of this parameter, expressed in percentage, the average charge, and emission rates define the years at which the vehicle needs maintenance. This combination resulted usually in highly oscillating refrigerant demand for servicing with years. In order to reduce such peaks observed in the servicing demand when using the previous RIEP calculation method, another modification was introduced to the RIEP model [SAB09]. A distribution of the parameter “percentage of charge emitted before servicing” is considered instead of the mean value discussed previously. Although, nowadays, the lack of information forbids developing a precise distribution of this parameter, the consideration of a normal distribution around the mean value of 50% or a uniform distribution within the interval 35%-75% can be considered as plausible. Vincent and al. [VIN04] obtained for the Californian vehicles fleet a fraction of charge missing before servicing of 0.52 ±0.35. In the following calculations, we considered a mean value of 50% and a standard deviation of 10% for the normal distribution.

9.1.2 – Data sources

A comparative analysis of sources presented in Table 9.1 and of those issued of governmental statistics has been performed in order to obtain values by year since 1970, for each sector market and production. Most often, data by Wards Auto [WAR09] have been used. When they were not available, historical data have been reconstituted using GDP/capita, population or evolution ratios. Figure 9.2 shows that the consistency between market and production is well verified, at the global level.

Table 9.1 - Reference sources.

Title	***Publisher***
Wards Auto	http://www.wardsauto.com/
ACEA : European Automobile Manufacturers Association	http://www.acea.be/
ANFAVEA: Associaçao Nacional dos Fabricantes de Veiculos Automotores	http://www.anfavea.com.br/tabelas.html
CCFA : Comité des Constructeurs Français d'Automobile	http://www.ccfa.fr/
VDA: Verband Der Automobilindustrie	http://www.vda.de/
OICA : Organisation Internationale des Constructeurs d'Automobiles	http://www.oica.net/

Note: national statistics have also been used for a lot of countries but are not listed here because of their large number.

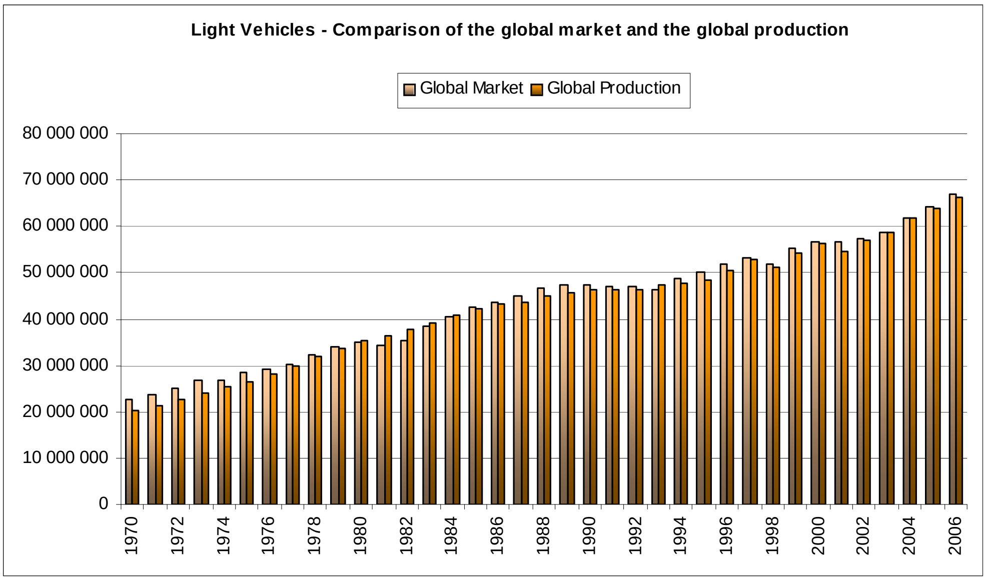

Figure 9.2 – Global market and production: reconstituted data since 1970.

Tables 9.2 to 9.4 give an overview of the automotive industry world-wide in 2006. Detailed data are given for productions and new registrations for the main countries and Europe.

Table 9.2 – New registrations and produced vehicles: cars and light commercial vehicles in 2006.

Cars and VUL	***USA***	***Canada***	***China***	***India***	***Japan***	***Brazil***	***EU27***
Market in 2006	15 166 088	1 614 643	6 730 694	1 455 427	5 564 384	1 844 222	17 495 458
Production in 2006	10 813 135	2 496 659	6 683 462	1 639 980	11 146 154	2 277 869	17 997 174

Table 9.3 – New registrations and produced vehicles: industrial vehicles in 2006.

Industrial Vehicles	***USA***	***Canada***	***China***	***India***	***Japan***	***Brazil***	***EU27***
Market in 2006	536 411	43 884	602 635	256 093	209 283*	76 258	415 035
Production in 2006	429 972	73 999	719 212	276 715	699 410*	106 001	556 548

*these values may seem quite high but they are confirmed by national source, JAMA.

Table 9.4 – New registrations and produced vehicles: buses in 2006.

Buses	***USA***	***Canada***	***China***	***India***	***Japan***	***Brazil***	***EU27***
Market in 2006	36 297	9 616	95 555	40 606	17 600	19 768	35 530
Production in 2006	31 846	2 362	195 333	30 300	88 637	33 809	37 803

In 2006, the global automotive production equals a little more than 66 million vehicles. The total number of new registrations for the same year amounted to almost 67 million vehicles. Results are less precise on buses and industrial vehicles for which differences between markets and productions are about 21% and 28%, respectively, in 2006. The influence on results is small because the global refrigerant bank for the MAC sector in light vehicles is really dominant, about 93% of the total MAC sector bank in 2006.

There are several reasons for the differences between production numbers and new registrations observed. Depending on the reference source, passenger cars and part of light commercial vehicles could be merged or LCVs and Industrial vehicles. Secondly, differences exist between the national production and the domestic production because of relocation. In this case there is a risk of double counting, and this double counting may overestimate the global production. The delay between the production date of and the date of sales needs to be taken into account as well. Usually, the storage time after production is short but it can generate a gap between production and registration numbers.

9.2 Characteristics of the Mobile Air-Conditioning systems

Because of the specific properties of their AC systems, cars, trucks, and buses have been investigated separately in this study. For each category, the AC penetration rate on the demand is different. The technical characteristics of the AC system are not the same where it concerns refrigerant charges, emission rates, and lifetimes.

9.2.1 – Penetration curve

80% of the market of air-conditioned cars is known (United-States, Europe, and Japan). The ratio between the number of air-conditioned cars and the total market is calculated using a penetration curve as shown on Figure 9.3. This kind of curve is not always available for all countries and all categories of equipment. Curves on Figure 9.3 give trends by region and some publications such as Hu and al. [Hu03] for China or Kanvar and Vikas [KAN04] for India allow adjusting the trend with precise data for a few years.

The curve includes there different periods of time via which the market development of AC equipped vehicles can be described.

1. The first period corresponds to the introduction of air-conditioning systems on the automotive market. The growth rate is linear. Only luxury cars are air-conditioned at this period of time.
2. The second period corresponds to the exponential increase of the number of AC systems on the vehicle market.
3. The third period ends asymptotically, somewhere lower than 100%.

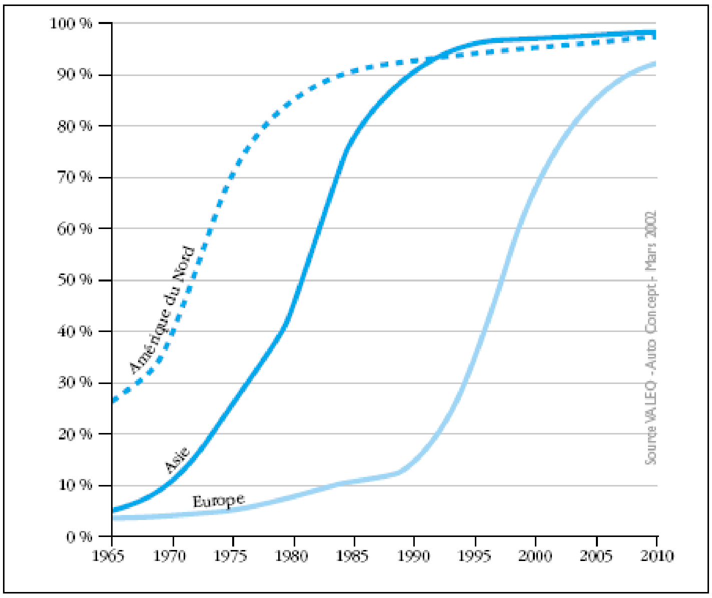

Figure 9.3 - Typical penetration curves on MAC systems [BAR03].

The shape of the curve is defined by five parameters:

- the AC rate value in 1980
- the linear growth rate
- the year of the beginning of the exponential increase
- the time of the exponential increase
- the asymptotic value.

9.2.2 Lifetime

The time during which the MAC system is assumed to be operating, is supposed to be lower than the vehicle lifetime, which varies between 10 and 16 years. Table 9.5 provides values of lifetimes for both the equipment and the vehicle.

Table 9.5 – Average lifetime of vehicle and MAC systems.

Lifetime (years)	*EU15*	*USA & Canada*	*Japan*	*China*	*India*	*Brazil*
Vehicle	12	16	10	12	12	16
MAC system	9	15	7	9	9	15

9.2.3 Average charge

Confidential data on the average charges per model of vehicles are provided by MAC system suppliers to the CEP. The average charge is then estimated taking into account best motorcars sales, when these data are available, such as in Europe [CCF09]. In some cases, publications indicate detailed data concerning the evolution of refrigerant charge, most often since 1995, in China [Hu03], in Japan [IKE05] or in India [KAN04]. For countries where data are not available, similarities between countries are identified (manufacturers, technologies), and the known values of the average charges are applied on the remaining countries.

Some particularities may be underlined: the preference of Japanese customers for compact cars imply the lowest average charge worldwide [IKE05], while the large share of sport utility vehicles (SUVs) and light trucks in the U.S. induces a higher average charge. However, in the U.S., recent trend for new vehicle refrigerant charge quantity shows lower values, as it can be seen in Table 9.6. One of the reasons for that is the change from orifice tube to TXV (Thermostatic eXpansion Valves) as well as the generalization of micro-channel heat exchangers for condensers and now also for evaporators. This reduction is also related to design changes (smaller internal volume condenser and evaporator, smaller diameter liquid line…). These changes led to a decrease in the refrigerant charge of about 30% [VAL09].

Table 9.6 provides values considered for the average refrigerant charge of MAC systems for years 1990, 2000, and 2006.

Table 9.6 - Average refrigerant charge of MAC systems.

Refrigerant charge (g)	*EU15*	*Japan*	*USA*	*Canada*	*China*	*India*	*Brazil*
1990	900	740	1 050	825	1 100	1 100	1 100
2000	770	540	880	750	900	900	900
2006	590	425	650	610	670	670	670

9.2.4 Emission rates

A significant change has been introduced in the emission rate calculation method. As explained in Section 9.1, in the previous report [Clo06] the fugitive emission rate, expressed in g/yr, was including leaks occurring during the vehicle lifetime, as well as failures and accidents. From now on, the fugitive emission rate is decomposed in two parts: regular and irregular emissions. The regular emission rate changes with time according to LFR degradation. According to Saba [SAB09], the degradation rate is considered to be 20% per year of the initial value, i.e. for a country having 60 g/yr the first year, the second one its emission rate will be 72 g/yr, the third one 84 g/yr, and so on. The U.S. having larger MAC systems, therefore longer circuits and more connections, are assumed to have higher initial LFR than the European or the Japanese models for the historical years. The irregular part is supposed constant per year: 15 g/yr for Europe and Japan, and 20 g/yr for other countries.

Table 9.7 summarizes values of LFR in 2006, based on recent experimental studies [TRE08, CLO07, JAM04].

Table 9.7 – Initial Leak flow rates of MAC systems.

LFR (g/yr)	*EU15*	*USA & Canada*	*Japan*	*China*	*India*	*Brazil*
1995	60	70	30	70	70	70
2006	10	10	10	10	10	10

9.2.5 Recovery efficiency

Surveys performed with the major stakeholders of MAC servicing indicate quality improvement in servicing operations better than what could be expected, and recovery rates can reach 95 % in some European countries. Recovery rates have been raised, especially for the period from 1998 to 2006 for most countries, as it can be seen in Table 9.8.

Table 9.8 – Recovery efficiency at servicing.

Recovery efficiency %	*EU15*	*USA*	*Canada*	*Japan*	*China*	*India*	*Brazil*
1995	50	30	30	10	0	0	0
2006	95	70	75	98	50	50	50

The U.S.A is still a specific country because of disposable cans, also used in A5 countries. An uncertainty exists on illegal use in some countries such as Canada, Australia, and New Zealand.

At end of life, recovery is usually nil. Most countries do not recover refrigerant at equipment end of life. In Europe, some recovery networks begin to be set up, but results are not significant yet. Only Japan has implemented an efficient system, as of 2001, which results in a recovery rate at equipment end of life of 29% in 2003 [JAM04] and 36% in 2005 [IKE05].

9.2.6 Refrigerants

The only refrigerant in use for new MAC systems is HFC-134a. Recent information stated that the use of CFC-12 for new equipment was stopped as of 2005 in most of A5 countries. For MAC systems, the end of CFC-12 charge in new equipment took place as of 2002 in China and in India, and as of 2001 in Brazil.

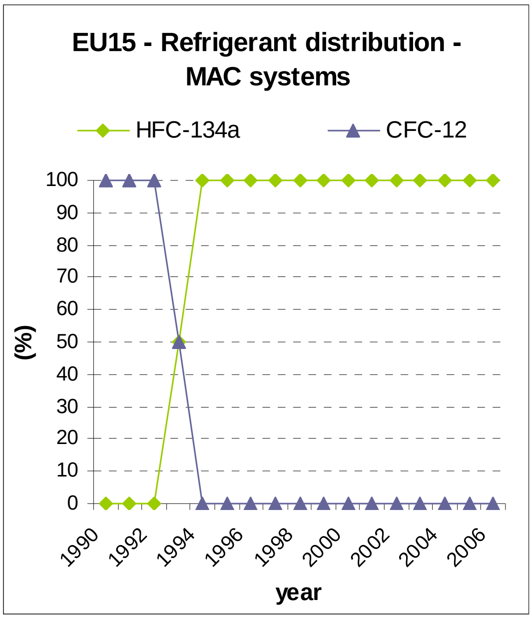

Figure 9.4 - Refrigerant distribution – EU15 countries – MAC systems.

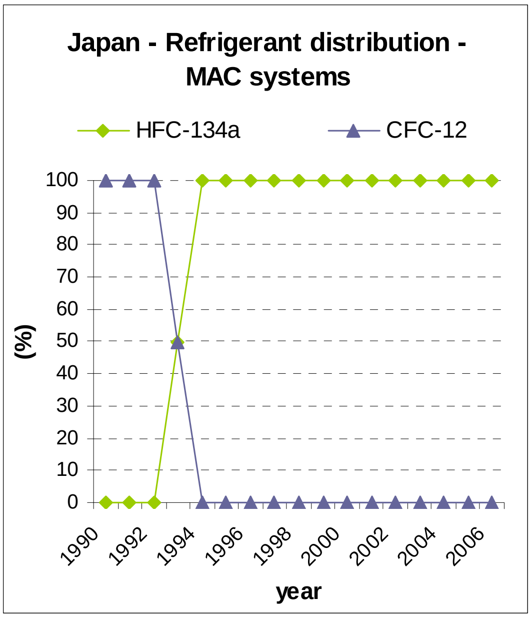

Figure 9.5 - Refrigerant distribution – Japan – MAC systems.

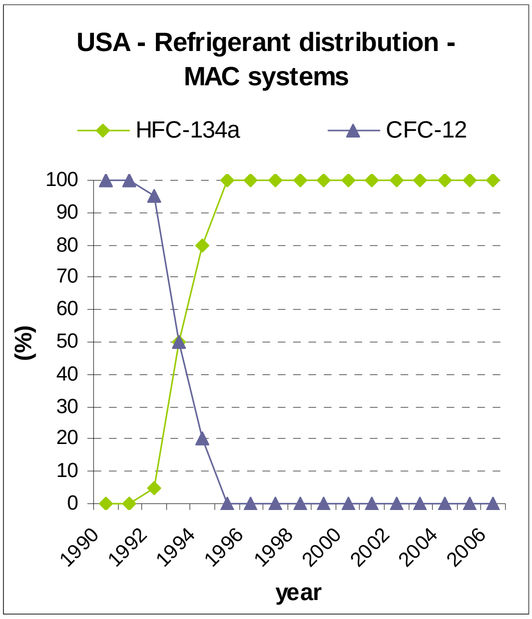

Figure 9.6 - Refrigerant distribution – USA – MAC systems.

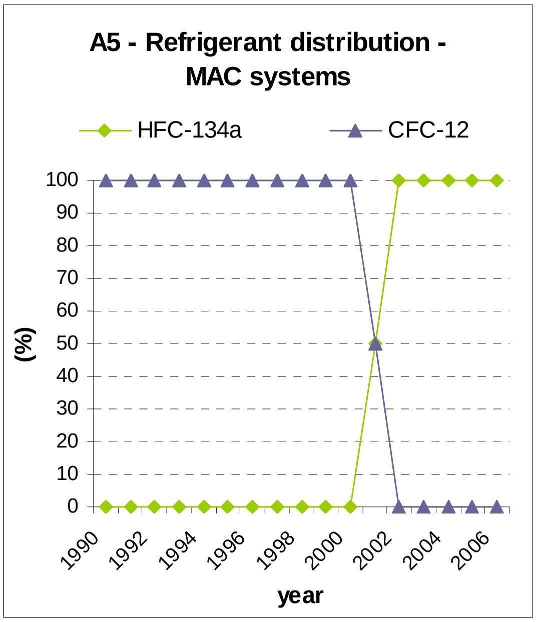

Figure 9.7 - Refrigerant distribution – A5 countries – MAC systems.

Retrofit operations have been taken into account for developed countries, especially in the U.S. where a lot of conversions occurred from CFC-12 to R-413A since 1998 but also to HFC-134a, in a large way, since 2000 to 2002 [MAL09].

9.3 Mobile air conditioning for trucks

The same methodology is used for this category of systems.

The increase of truck cabins equipped with air-conditioning systems is represented by the same curve as given in Figure 9.3. However, a time lag of 5 years is assumed compared to cars e.g., if the car demand started to be equipped with AC systems in 1980, the truck demand is assumed to be equipped with AC as of 1985.

♦ Average charge

The AC system installed for truck cabins is the same as the one used in cars. The decrease in the refrigerant charge with time, which is also related to the shift from CFC-12 to HFC-134a as of the year 1992, is taken into account. In 2006, it is reduced to a mean value of 0.95 kg.

♦ Other characteristics

Except for the refrigerant charge, the assumptions are identical to those valid for AC equipped cars. From now on, the emission rate is expressed in g/yr and decomposed in regular and irregular emission rates. LFRs and recovery efficiencies are of the same order as those presented in Tables 9.7 and 9.8.

♦ **Refrigerant type**

The shift from CFC-12 to HFC-134a has started in developed countries in 1992, in the same way and the same year as for AC equipped cars. Changes in refrigerant uses in industrial vehicles are similar to those of mobile air conditioning.

9.4 Mobile air conditioning for buses

The methodology to determine the refrigerant bank and emissions for buses is the same as the one applied to trucks and cars. However, the time lag assumed for the beginning of installing AC equipment in buses is 10 years compared to the start of installing AC equipment in cars. The asymptote (see Figure 9.3) is fixed at 75% of the asymptotic value assumed for passenger cars. This maximum rate of 75% for AC equipped buses is chosen because it is likely that part of the fleet will never be AC equipped.

♦ **Average charge**

The average refrigerant charge in AC systems of buses is 15 kg.

♦ **Other characteristics**

Lifetime is assumed to be 15 years in developed countries, and 20 years in A5 countries.

The emission rate is expressed as a percentage of the nominal refrigerant charge. Emission and recovery rates have been updated. In 2006 they vary as follows:

- emission rates are estimated about 15% in developed countries and 20% in A5 countries;
- recovery efficiencies at servicing are estimated between 0 and 15% for A5 countries, 50% for the U.S., and 90% for other developed countries.

♦ **Refrigerant type**

In 1990, the dominant refrigerant applied in bus AC was HCFC-22 in developed countries. Before this date, CFC-12 was also used; therefore it is assumed that there will be a 50% share of CFC-12 and a 50% share of HCFC-22 in A5 countries.

Due to the HCFC phase-out schedule and the present dominance of HFC-134a in car AC systems, it is assumed that HFC-134a has been and will be used in new bus AC systems starting 1999. It is the only refrigerant used in new buses in Europe as of 2001.

Particularly for the U.S., the dominance of HCFC-22 (70%) in bus AC systems needs to be verified.

9.5 Results of calculations: refrigerant banks, demands, emissions and recovery

9.5.1 Refrigerant bank

In the 1990's, mobile air conditioning was largely introduced in the U.S (also in Japan and Canada, but the fleet are much less important) whereas it was only the beginning in other countries such as in Europe. That explains the dominance of the U.S. CFC bank on Figure 9.8.

Compared to previous inventories, the introduction of a survival curve led to maintain longer the CFC bank. The bank has decreased from about 230,000 tonnes in 1992 to about 41,000 tonnes in 2006, steadily, as shown in Figure 9.8, due to the relative short lifetime of vehicles.

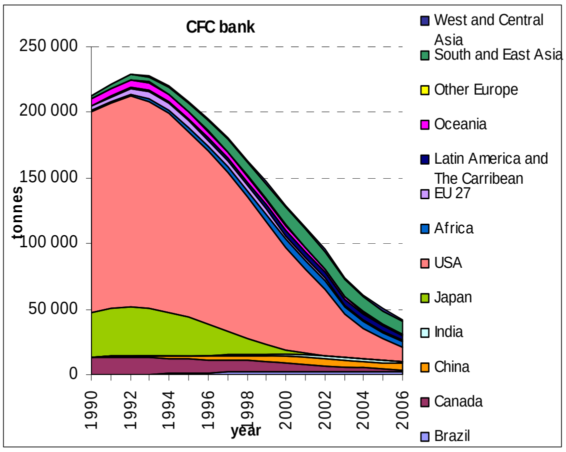

Figure 9.8 – CFC refrigerant bank.

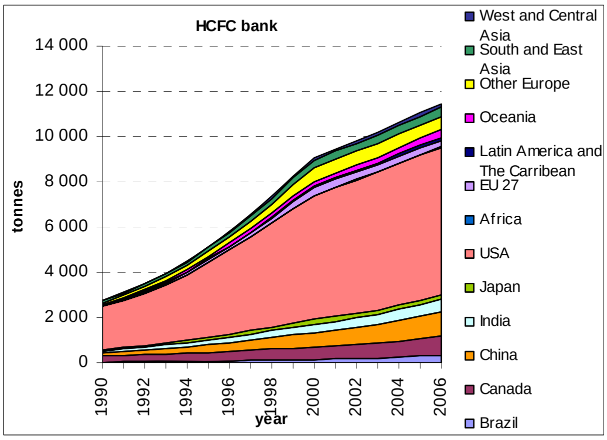

Figure 9.9 - HCFC refrigerant bank.

The HCFC bank only concerns buses and trains. It is increasing to reach about 11,400 tonnes in 2006, with the U.S. share of 57%.

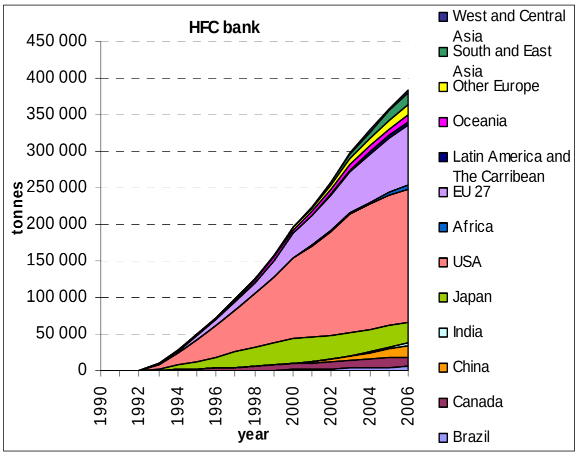

Figure 9.10 – HFC refrigerant demand.

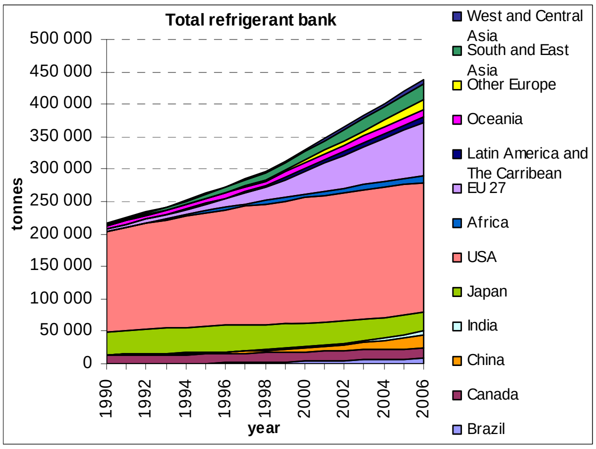

Figure 9.11 – Global refrigerant bank in MAC systems.

Concomitantly, the HFC bank has been rapidly built up; up to 385,000 tonnes in 2006 showing also the increase in the fleet of air-conditioned cars out of the U.S (see Figure 9.10). In EU27, the growth of the HFC-134a bank for MAC is again between 11% and 15% per year, over the three past years.

Figure 9.11 shows that the dominant bank is the U.S. one (46%), with nearly 200,000 tonnes in 2006.

9.5.2 Refrigerant emissions

Emissions are consistent with the banks and are steeply decreasing for CFCs (see Figure 9.12) and increasing for HFCs (see Figure 9.14). Compared to the previous inventories, trends on the 1990 to 2003 period remain similar, but levels are significantly lower (30 to 40%), due to the revision and correction of emissions rates on historical years [SAB09].

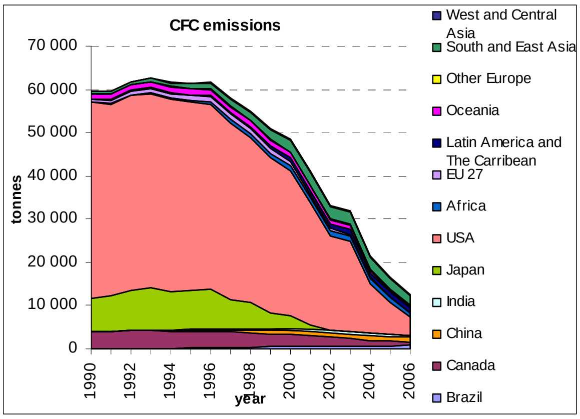

Figure 9.12 – CFC refrigerant emissions.

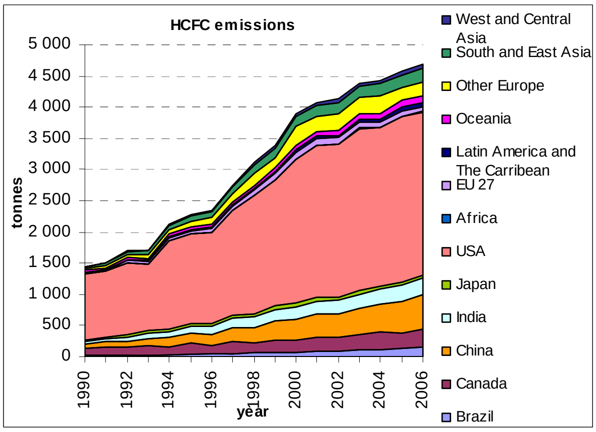

Figure 9.13 - HCFC refrigerant emissions.

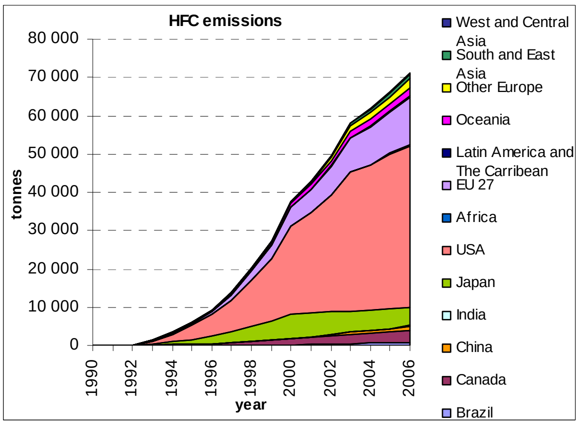

Figure 9.14 – HFC refrigerant emissions.

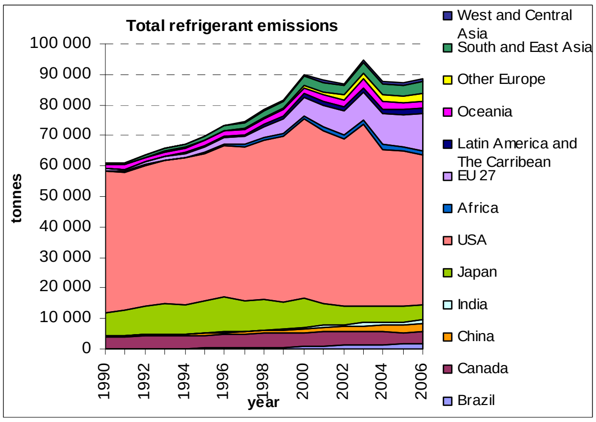

Figure 9.15 - Global refrigerant emissions in MAC systems.

9.5.3 CO_2 equivalent emissions of refrigerants

Although the global CO_2 eq. emissions level has really decreased starting in 1995, where it reached about 500 million tonnes, the MAC system sector is still responsible for 200 million tonnes in 2006.

Even if the CFC emissions represent only 14% of the total emissions in 2006, in terms of CO_2 equivalent, CFCs still represent 50% of the total with about 100 million tonnes (see Figure 9.16), whereas HFC emissions represent 93 million tonnes (see Figure 9.18).

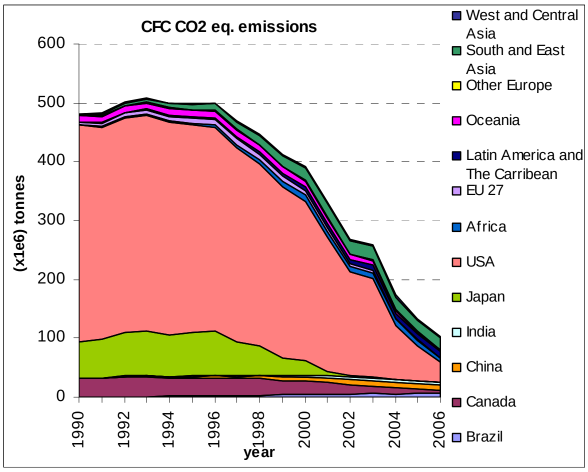

Figure 9.16 – CFC refrigerant CO_2 eq. emissions.

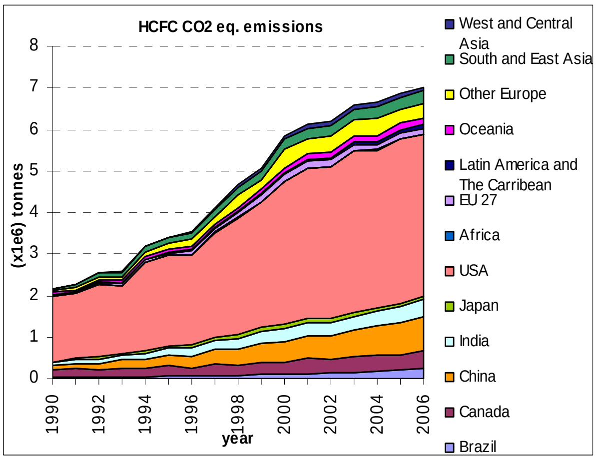

Figure 9.17 - HCFC refrigerant CO_2 eq. emissions.

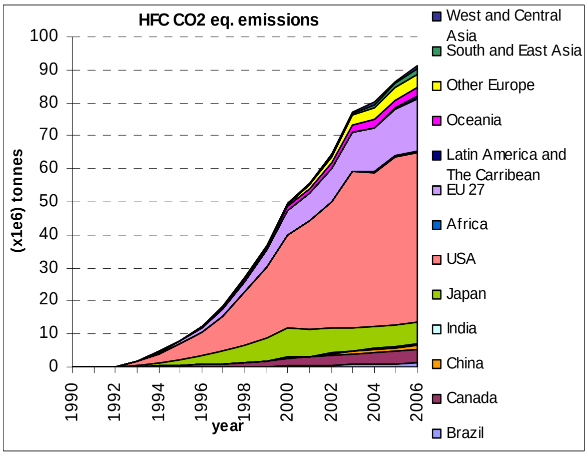

Figure 9.18 – HFC refrigerant CO_2 eq. emissions.

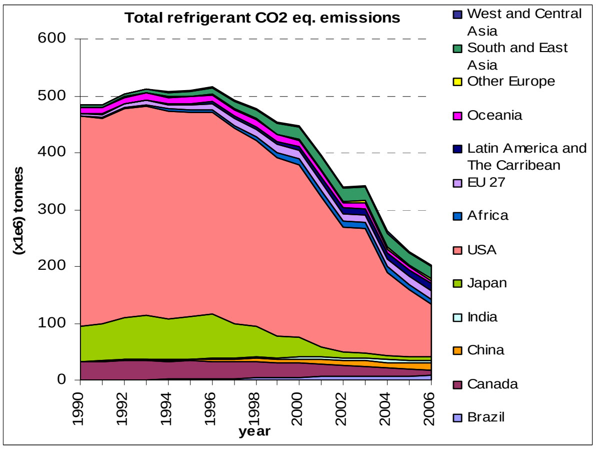

Figure 9.19 - Global refrigerant CO_2 eq. emissions in MAC systems.

Given the significant penetration rate of the MAC systems (using CFCs) in the U.S. in the 1990s, this country share in the global CO_2 equivalent emissions was significantly dominant. The decrease of the CFC-12 vehicle fleet led to reduce this share, which was still dominant in 2006 (45%), but is now mainly due to HFC-134a emissions, this refrigerant constituting 90% of the US fleet.

9.5.4 Refrigerant recovery

As in other sectors, the refrigerant recovery only takes into account the recovered quantities of refrigerant at the end of life of vehicles. Even if recovery at end of life is mandatory in the EU, the regulation is not well applied and the recovered quantities are small. In the U.S., the CFC-12 recovery at end of life seems not to be well applied.

The only significant quantities are recovered in Japan, concern mainly HFC-134a and are estimated to about 800 tonnes by calculation.

9.5 Data consistency and further improvements

The quality of annual data for the total number of vehicles in all categories is good, except in the train sector. Concerning the classification of commercial vehicles, some confusion may occur. However, market data have been studied thoroughly and several reference sources compared. For the future, one of the issues to be dealt with will be to assess the penetration of AC systems in trucks and buses in developing countries. The assumptions made in this report can be considered as the high threshold of the AC penetration in trucks and buses.

The separation between the regular and irregular leaks led to the consideration of new initial emission rates based on the scarce available literature and on laboratory tests and field measurements. A degradation of the leak flow rate is considered according to vehicle aging. Although newly introduced MAC systems present lower LFRs (10 g/yr), one open question concerns the evolution of such LFRs with the vehicle age.

One of the open questions for the future is to verify that the leak flow rates, which are low for brand new MAC systems, will be still low after the aging process of 6, 9, and 12 years.

Survey on refrigerant sales for servicing would be a key for the future assessment of real life emissions of MAC systems, especially in the U.S.

Another open question for the future is the assessment of how effective is the recovery of HFC-134a at the end of life of vehicles. Japan has enforced a new regulation starting in 2004 that seems effective. End-of-life vehicle Directive in Europe makes mandatory refrigerant recovery at end of life of MAC systems. Until now, it seems not to be effective.

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