Annex 1 to Module 1

Inventory

NAMAs in the refrigeration, air conditioning and foam sectors. A technical handbook.

Manual to the HFC Inventory & Projection Tool.

On behalf of

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn,
Germany

Programme Proklima

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
Phone: +49 61 96 79 - 1022
Fax: +49 61 96 79 - 80 1022

Email: proklima@giz.de
Internet: www.giz.de/proklima

Responsible
Bernhard Siegele, Proklima Programme Manager,
bernhard.siegele@giz.de

Authors
Dr. Jonathan Heubes, Irene Papst (HEAT GmbH, Glashütten)

Editors
Claudia Becker (HEAT GmbH, Glashütten)

Review
Marion Geiss, Sebastian Wienges, Markus Wypior (GIZ),
Barbara Gschrey (Öko-Recherche GmbH)

Production
Sophie Charlotte Diesing, Franziska Frölich (GIZ Proklima)

On behalf of
German Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety

Division E III 7, International Climate Finance,
International Climate Initiative

Köthener Straße 2-3
10963 Berlin, Germany
Phone: +49 (0)30 18 305 - 0
Fax: +49 (0)30 18 305 - 4375

Email: EIII7@bmu.bund.de
Internt: www.bmu.de

Photos
Titel: Marius Graf - Fotolia.com

Layout
Jeanette Geppert, Frankfurt

Place and date of publication
Eschborn, October 2013

Serial number
G-S01-2013-en-01

1. Introduction

This manual describes the calculation steps which are used in the HFC Inventory & Projection tool, to derive current emissions, demand and banks of HFCs for national inventories. The HFC Inventory & Projection tool is also called vintage bottom-up stock model; it is designed to run at the country level and to cover the 2000 to 2030 period.

In addition, a general modeling framework is introduced which describes how to quantify the mitigation potential. Therefore, three different scenarios are considered:
- a business as usual scenario (BAU)
- a direct emission reduction scenario (DER)
- a scenario which is based on DER but additionally takes into account increasing energy efficiency (DEREE)

While it is always preferable to use country-specific data, default values are suggested for many variables.

The HFC Inventory & Projection tool covers the two sectors refrigeration and air conditioning (RAC). Please note that we refer to sectors (e.g. air conditioning), subsectors (e.g. stationary air conditioning) and systems (e.g. ducted split unit) for RAC. The term system is used synonymously for appliance, equipment and unit. It is a functional unit in the different subsectors. Depending on the nature of the subsector, a unit can be as simple as a domestic refrigerator or a complete commercial refrigeration system consisting of compressors, condenser, pipe work, display cabinets.

Table 1 shows the suggested subsectors and systems for RAC.

TABLE 1
Definition of subsectors and appliance systems for refrigeration and air conditioning

Subsector	Appliance systems
Unitary air conditioning	Self-contained air conditioners Split residential air conditioners Split commercial air conditioners Duct split residential air conditioners Commercial ducted splits Rooftop ducted Multi-splits
Chillers	Air conditioning chillers Process chillers
Mobile air conditioning	Car air conditioning Large vehicle air conditioning
Domestic refrigeration	Domestic refrigeration
Commercial refrigeration	Stand-alone equipment Condensing units Centralised systems for supermarkets
Industrial refrigeration	Stand-alone equipment Condensing units Centralised systems
Transport refrigeration	Refrigerated trucks/trailers

2. Input

Central input parameters for the model are current sales figures of each system as well as stock data and ideally also historical sales figures. The sales figures refer to the number of domestically sold units. Therefore, additional data on domestic production, imports and exports must be gathered. All relevant data will be entered in an electronic data input sheet (DIS) for each country, which will later be copied into the corresponding input templates of the model. The DIS-tool can be obtained on request.

In case reliable stock data is not available, it can be estimated using current production and market data together with historical growth rates. Also, a back-calculating procedure can be used to estimate historical sales figures, which are used in turn to build up the stock (see description in HFC inventory and projection tool or use the stock projection tool alternatively). The calculation accounts for appliance systems that are disposed at the end of their life.

To project the future stock, it is sufficient to have stock data from one single year, e.g. 2000, as the development of the stock can be estimated by:

$$n_{stock,y} = n_{stock,y-1} + n_{sales,y-1} - \frac{n_{stock,y-1}}{LT}$$

Where:

$n_{stock,y}$ = number of units in the stock in the year y
$n_{sales,y-1}$ = number of sold units in the year y^{-1}
y = year
LT = Average lifetime of the appliance

The last term of the equation describes the number of units that are decommissioned. This number is estimated by dividing the current stock by the lifetime of the appliance. We acknowledge that the stock might be underestimated using this approach; the magnitude also depends on the expected future growth rates which determine the future sales figures.

A reduction in the formula is given for units using chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC). In the model we assume that units using CFCs are not sold anymore as of 2000 and we assume that there are no units using HCFCs in the sales figures as of 2020. Thus, the stock of CFC and HCFC units slowly decreases due to ongoing decommissioning of the units.

An important parameter for the calculation of emissions, demand and banks for the different subsectors is the refrigerant distribution of the sales figures and the stock. The refrigerant distribution is defined as the share of a specific refrigerant in the various systems. Comprehensive F-gas inventories take into account the refrigerant per system type and accordingly allow the calculation of the refrigerant distribution.

Additionally, the following technical input parameters are needed for each appliance system:

Initial charge (kg) and the dominant refrigerant that is used in the systems

- Manufacture emission factor (%)
- In-use emission factor (%)
- Disposal emission factor (%)
- Product lifetime
- Average cooling capacity (kW)
- Average coefficient of performance (COP)
- Cost per unit (cf. module 4)
- Expected future annual growth rates
- Runtime ratios of the systems (similar to average annual runtime hours)
- Emission factor for electricity and motor gasoline, respectively (t CO_2/MWh)

The model uses default values for the technical parameters, some of which are taken from the IPCC Guidelines for National Greenhouse Gas Inventories (2006) and a study from Schwarz et al. (2011). However, country-specific parameters should be used whenever possible. Since these parameters may change over time, the model reveals the flexibility to account for non-static parameters.

The annual growth rate can be estimated from historical sales data, using the following estimation:

$$Growth_{j,y} = \left(\left(\frac{n_{sales,j,y}}{n_{sales,j,y-1}}\right) - 1\right) \cdot 100$$

Where:

$Growth_{j,y}$ = Growth rate of the type of appliance j in the year y
$n_{sales\ j,y}$ = number of sold appliances j in the year y
y = year

The growth rates should be averaged over several years to get a more robust estimate. However, growth rates can also be taken from market studies, expert judgment, gross domestic product growth estimates or aggregated national refrigerant demand data.

3. Appliance system calculations

3.1 Business as usual (BAU)

The calculation of emissions, demand and banks are performed for each type of appliance. Furthermore, the demand is calculated for each individual refrigerant separately per system type.

Based on total sales figures and stock figures, the appliances and stock numbers filled with specific refrigerants are derived by multiplying the absolute sales and stock figures with the refrigerant distribution:

$$n_{sales,j,ref,y} = n_{sales,j,y} \cdot RD_{ref,j}$$

Where:

$n_{sales,j,ref,y}$ = number of sold units j in the year y, filled with the refrigerant ref
j = specific system
ref = specific refrigerant
y = year
$n_{sales,j,y}$ = total sales figure of system j in the year y
$RD_{ref,j}$ = refrigerant distribution (%) of refrigerant ref for the system j

The refrigerant distribution of the sales figures are defined for the years 2000, 2010 and 2020/2030 and linearly interpolated to get the complete time series. The value of the year 2020 is assumed to remain constant until 2030. The refrigerant distributions are either derived from the inventory or they have to be taken from literature.

Bank

The bank is defined as the amount of substances which is stored (in appliances) in the country. This amount is estimated via the stock of the appliance systems and calculated on an annual basis:

$$B_j = \sum n_{stock,i,j} \cdot IC_j$$

Where:

B_j = bank of refrigerants stored in the appliances systems j
$n_{stock,j,i}$ = number of appliance systems j in the stock, filled with the refrigerant i
IC_j = initial charge of the appliance system j

Manufacture emissions

The manufacture emissions are calculated on an annual basis, expressed as metric tonnes:

$$E_{manuf,j} = \sum n_{prod,i,j} \cdot IC_j \cdot EF_{manuf,j}$$

Where:

$E_{manuf,j}$ = manufacture emissions of the produced/installed units j
$n_{prod,i,j}$ = number of domestically produced units j, filled with the refrigerant i
IC_j = initial charge of the unit j
$EF_{manuf,j}$ = manufacture emission factor of the unit j

To derive the amount of CO_2eq, the upper equation extends to:

$$E_{CO2,manuf,j} = \sum n_{prod,i,j} \cdot IC_j \cdot EF_{manuf,j} \cdot GWP_i$$

where GWPi is the global warming potential of the refrigerant i.

Please note that the sum operator refers to i in the above mentioned and all following formulas.

In-use emissions

Annual in-use emissions are estimated by:

$$E_{CO2,in-use,j,y} = \sum B_{j,i} \cdot GWP_i \cdot EF_{in-use,j}$$

Where:

$E_{CO2,in-use,j,y}$ = in-use emissions (CO_2eq) of the stock appliances j in the year y
$B_{j,i}$ = bank of refrigerant i stored in the appliances systems j
GWP_i = global warming potential of the refrigerant i
$EF_{in-use,j}$ = in-use emission factor of appliance system j

Disposal emissions

Disposal emissions are estimated considering the amount of refrigerant that is stored in the products at their end of life, when they are decommissioned:

$$E_{CO2,disp,j,y} = \sum \frac{n_{stock,i,j,y-1}}{LT_j} \cdot IC_j \cdot GWP_i \cdot EF_{disp,j}$$

Where:
$E_{CO2,disp,j,y}$ = disposal emissions (CO_2eq) of units j at end of life in the year y
$n_{stock,i,j,y-1}$ = number of stock units j, filled with the refrigerant i in the year y^{-1}
IC_j = initial charge of the unit j
LT_j = lifetime of the unit j
GWP_i = global warming potential of the refrigerant i
$EF_{disp,j}$ = disposal emission factor of unit j

This formula assumes that no reclaim takes place. While this assumption is valid in the majority of Non-Annex I countries, it might not be applicable in Annex I countries. Additionally, the model assumes that the appliance systems are fully charged when decommissioned. This assumption is based on the regular service routines that take place during lifetime for most of the systems. During servicing, the units are topped-up to maintain the initial charge amount.

Direct emissions

Direct emissions are also calculated on an annual basis, as the sum of manufacture emissions, in-use emissions and disposal emissions:

$$E_{CO2,dir,j} = E_{CO2,manuf,j} + E_{CO2,in-use,j} + E_{CO2,disp,j}$$

Where:
$E_{CO2,dir,j}$ = direct emissions (CO_2eq) of units j
$E_{CO2,manuf,j}$ = manufacture emissions (CO_2eq) of the produced units j
$E_{CO2,in-use,j}$ = in-use emissions (CO_2eq) of the stock units j
$E_{CO2,disp,j}$ = disposal emissions (CO_2eq) of scrapped units j

Indirect emissions

The indirect emissions stem from the energy consumption of the units in use (stock). The annual indirect emissions are given by:

$$E_{CO2,ind,j} = n_{stock,j} \cdot \frac{CP_j}{COP_j} \cdot RT_j \cdot EF_{electr}$$

Where:
$E_{CO2,ind,j}$ = indirect emissions (CO_2eq) of units j
$n_{stock,j}$ = stock of units j
CP_j = cooling capacity of the unit j
COP_j = coefficient of performance of the unit j
RT_j = average annual runtime hours of the units j
EF_{electr} = emission factor of electricity

For mobile air conditioning, EF_{electr} is replaced by $EF_{motogas}$

Demand

The demand is generally defined as first fill of newly produced or installed units plus refill of existing units (stock). This can be expressed as:

$$D_{CO2,j} = \sum n_{prod,i,j} \cdot IC_j \cdot \left(1 + EF_{manuf,j}\right) \cdot GWP_i + E_{CO2,in-use,j}$$

Where:
$D_{CO2,j}$ = demand of refrigerants (CO_2eq) for the units j
$n_{prod,i,j}$ = number of domestically produced units j filled with the refrigerant i
IC_j = initial charge of the unit j
$EF_{manuf,j}$ = manufacture emission factor of the system j
GWP_i = global warming potential of the refrigerant i
$E_{CO2,in-use,j}$ = in-use emissions (CO_2eq) of the stock units j

Please note that the refill is given by $E_{CO2,\ in-use,j}$. That is, the model assumes the amount of leaked gas during use to be equal to the refilled amount. The first fill includes initial charge of the systems plus the component that is lost during the first filling or installation process (manufacture emission).

To derive total demand, bank and emissions of a country, the appliance and subsector results have to be added up.

3.2 Alternative technology

In both the DER-scenario and the DEREE-scenario, new technology is introduced. The DER scenario accounts for direct emissions reductions only whereas the DEREE scenario additionally accounts for improvements of energy efficiency. Thus, the latter scenario not only takes into account reductions of direct but also of indirect emissions. We differentiate between the two scenarios because in general the design of any technical option is adjusted up or down, in order to achieve the same average, annual efficiency as the baseline, i.e. business-as-usual, technology. Thus, the introduction of alternative technology does not per se imply improved energy efficiency, unless it is explicitly aimed for.

Demand, banks and emissions under the DER and DEREE scenarios are calculated using the same formulas as in the business as usual scenario above. However, certain parameters will change:

- Refrigerant type: Different refrigerants have different GWP. A lower GWP reduces direct emissions.
- Initial charge: A lower charge reduces direct emissions.
- Emission factors: A lower emission factor reduces direct emissions.
- Coefficient of performance: A higher COP reduces indirect emissions.

Additionally, the penetration rate of appliance system with alternative technology is introduced as parameter. The penetration rate influences the sales figures and consequently the stock.

We define a maximum of five realistic technical options for each system (see Module 3). At least one of the above mentioned parameters will change, but not necessarily all of them. The degree to which each technical option will penetrate the market is given by a cost-optimisation procedure. The key parameter to be considered in the cost-optimisation procedure is the cost per reduced tonne of CO_2 emissions. From an economic viewpoint, as in the cost-optimisation procedure, priority is given to those technical options with the lowest cost per reduced tonne of CO_2 emissions.

We define a weighting vector X, which describes the penetration rates of the five different technical options in each subsector. Each of the new technical options exhibits individual initial charge, emission factors and energy consumption as determined by the COP. Therefore the overall initial charge, emission factors and energy consumption is given by the product of the individual parameters and the weighting vector X. For the initial charge, this is expressed as:

$$IC_{DER,j} = IC_{TO} \cdot X$$

Where:

$IC_{DER,j}$ = initial charge of the average appliance system j (with alternative technology) under the scenario DER

IC_{TO} = vector with the initial charges of the five different alternative technical options

X = weighting vector, given by the adjusted penetration rates of the alternative technologies

The same calculation method applies analogous for the emission factors and the energy consumption.

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IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3. Japan: IGES.

Schwarz, W., Gschrey, B., Leisewitz A., et al. (2011). Preparatory study for a review of Regulation (EC) No 842 / 2006 on certain fluorinated greenhouse gases.

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Registered offices
Bonn and Eschborn,
Germany

Programme Proklima

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
Phone: +49 61 96 79 - 1022
Fax: +49 61 96 79 - 80 1022
Email: proklima@giz.de
Internet: www.giz.de/proklima