REFRIGERANT EMISSIONS and INVENTORIES PLATFORM

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Abstract

The RIEP (Refrigerant Inventory and Emissions Prevision) software has been developed by the CES to evaluate refrigerant emissions per fluid and application. Furthermore, it allows to implement forecasting scenarios. All calculations are based on RAC equipment databases created for different countries and regions.

The CES is currently working out a large online platform aiming at providing the mean for countries to establish their own refrigerant inventory and forecast scenarios using RIEP and the equipment databases that will be available for consultation, modification and improvement.

Results will be publicly released using Open Data tools for better visualization, ease of comparison between refrigerants, applications and countries.

This article provides a summary of the calculation method implemented in RIEP. The structure of the global platform is described. The interest of such approach is then discussed, especially regarding the public accessibility to a unique tool, sharing the knowledge about inventories, existing and new technologies, refrigerant use as well as emission factors

1 Calculation method for inventories and RIEP software

1.1 Calculation method used for Inventories

The Center for Energy efficiency and Systems (CES) developed a global database for the refrigeration and air-conditioning application, containing the required activity data and emission factors to establish the inventories of refrigerants for countries and regions. A calculation model called RIEP (Refrigerant Inventories and Emission Previsions), was developed at the CES based on a bottom-up approach as defined in the "Tier2" methodology of the IPCC Guidelines 2000 (UNEP, 2000). Six main application domains for the refrigeration and air-conditioning (RAC) sector are covered, based on the TOC report (UNEP, 2003) classifications : Domestic refrigeration, Commercial refrigeration, Transport refrigeration, Industrial and food processes, Stationary air conditioning, Mobile air conditioning.

Refrigerant emissions are assessed based on the fleet of equipment in which the refrigerant is charged, the lifetime, the emission rates, the recovery efficiency at servicing and disposal, and other parameters. These emissions occur at three main levels: emissions during the charging processes, emissions from the existing bank, and emissions at the equipment disposal. Emissions related to the management of refrigerant containers, introduced in the IPCC Guideline 2006 (emission-factor approach), are added to those mentioned above. Total emissions of a given refrigerant in year t $E_{total,\ t}$ are given by Equation (1) :

$$E_{total,t} = E_{containers,t} + E_{charge,t} + E_{lifetime,t} + E_{end\text{-}of\text{-}life,t} \quad (1)$$

$E_{containers,t}$ are the emissions related to the management of refrigerant containers, they are assumed to be about 3 % of the total demand of refrigerants.

$E_{charge,t}$ are the emissions occurring during the charging process of new equipment, servicing and retrofit; they are estimated to represent 5% of the average refrigerant charge of the equipment.

$E_{end\text{-}of\text{-}life,t}$ are the emissions occurring at equipment disposal; they depend on the efficiency of the refrigerant recovery sector at end-of-life.

$E_{lifetime,t}$ are the emissions occurring during the equipment in-use stage; they are constituted by fugitive emissions, emissions occurring at servicing and those taking place during retrofit operations. 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-application requiring specific input parameters and some modifications of the main calculation algorithm. The method was therefore adjusted for some sub-applications based on the availability of activity data and emission factors. For example, for centralized systems in commercial refrigeration sector, emission factors are established based on available reporting of large commercial companies. This emission factor includes the refrigerant leakage and losses due to the system servicing. Depending on the application, the fugitive emission factor is applied to the equipment newly put on the market or to the installed base of equipment; the emissions at servicing, $E_{servicing,t}$ can be included in the fugitive emissions, $E_{fugitive,t}$ or calculated using a specific model such as in mobile air conditioning and stationary air-conditioning applications (servicing is supposed to occur when the refrigerant charge of the equipment reaches a threshold level).

$$E_{lifetime,t} = E_{fugitive,t} + E_{servicing,t} + E_{retrofit,t} \quad (2)$$

The RIEP model also distinguishes the retrofit operation, and emissions $E_{retrofit,t}$ occurring during this process are calculated apart. The retrofit or drop-in operations consist in replacing one refrigerant by another one. For recovery, the operator behavior is quite similar to the one used at equipment disposal, so the same recovery efficiency is taken into account. 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 the bank of this refrigerant is to be replaced. In the current version of RIEP, this percentage is applied equally to all vintages of equipment of the corresponding installed base.
Some improvements to the RIEP calculation method were performed during the Ph.D. thesis of S. Saba (Saba S., 2009) regarding the equipment lifetime and emission factors modeling in Mobile Air-Conditioning (MAC) sector; the retirement curve of equipment has been taken into account for equipment being disposed of instead of a mean lifetime value, for each sub-application.
For mobile air-conditioning (MAC) systems, the calculation method implemented in RIEP considers two emission factors including “regular” and “irregular” emissions resulting from road accidents and accidents taking place in garages. Regular leaks are those 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 vibrations, so the emission factor increases along the vehicle lifetime. A degradation factor has to be taken into account rather than an average value because regular leaks are known from test on new systems, their values are low and do not explain the refrigerant sales dedicated to servicing of 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. As a result, the initial leak-flowrate (LFR) values considered in the RIEP database have been updated and the emission factors have been separated in two parts: the first one, relative to the initial LFR given per vintage and being worsened with time, and the second one, relative to the irregular emissions and applied to the fleet of vehicles. A specific algorithm is implemented for the servicing operation within this sub-category allowing the calculations of emissions occurring during maintenance Eservicing,t and the amount of refrigerant required during this operation.

1.2 The RIEP (Refrigerant Inventory and Emissions Prevision) software

The RIEP software has been developed by the CES to calculate direct refrigerant emissions coming from the Refrigeration and Air Conditioning applications. It was created in 1998 and has been continuously improved. It is used by the CES for carrying out, each year, the French Inventory of refrigerant emissions (Barrault and Al, 2012). RIEP consists of a user interface, used for launching calculations, which is linked to Access databases. These databases are related to a country or a group of countries. They contain all parameters needed for the calculation of emissions for each of the 44 sub-applications taken into account: characteristics regarding lifetime, refrigerant charge or cooling capacity of the equipment, emission rates, and refrigerants in use on new market or for retrofit of equipment, as well as market, production or fleet data for equipment, depending on the application. All refrigerant types are taken into account: CFCs, HCFCs, HFCs, HCs, ammonia, and CO_2. Calculations may thus be performed refrigerant by refrigerant, for all types of refrigerating systems, considering specific emission and recovery factor for each sub-sector. All assumptions have to be made over a period at least equal to the mean lifetime of the equipment. Results of calculations are detailed as follows: total emissions in tons or in CO_2 equivalent tons, emissions at the manufacturing process, fugitive emissions, emissions during servicing and at end of life, etc. In addition, refrigerant banks, consumptions for new equipment and for servicing and recovered quantities at decommissioning are estimated. Results are then exported from the database to the Excel spreadsheet for an easy handling of tables and graphs.

2 Objectives

The CES achieved many studies related to inventories and forecast, at a global (Clodic & al., 2009) and at European level (Clodic & al. 2011), among others. Refrigerant inventory and forecast studies require the knowledge and expertise

on refrigerants, technologies of equipment, regulations (their implementation, their potential changes), tests on new equipment (which indicate their emission rate levels), consumption of refrigerant for servicing of large installations (which indicates fugitive emissions level), reported data, practices by country (in terms of servicing, recovery installations), under-development technologies and refrigerants (for forecast), etc.. Most of data have to be regularly updated. Some information is difficult to find and therefore expert judgment is required for the derivation of missing data. For inventories makers, it could be very useful to access to a whole structure including such various data and information. It is one of the purpose of the Open RIEP platform that is currently under development by the CES.
Furthermore, the global actual trends towards Open Data stress out the importance and need to make available certain data for public use. Open Data is the concept by which certain data is publicly available to everyone for use and share. Data must be available in a convenient modifiable form and "shall be available as a whole and at no more than a reasonable reproduction cost, preferably downloading via the Internet without charge"; data can be reusable by other party and must be interoperable. Many governments and organizations have created their own websites for data providing. For instance, the CCNUCC website
(http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories _submissions/items/6598.php)
contains a lot of information related to all the reported greenhouse-gas emissions; it is possible to access some data about HFCs in the Common Reporting Format even if they are difficult to identify and not detailed. The UNEP website also mentions reported data about HCFCs; some information may be found by application for some countries. Thereby, some specific information and data regarding refrigerants may be found on official organization websites, but also in journals, on websites of environmental organizations and equipment or refrigerant producers, in newsletters, etc.
Knowledge on RAC systems and refrigerant use, consumption, and emissions are of interest for:
- Policy makers who will be able to propose emission reduction scenarios as a support for developing and implementing new regulations.
- Companies that will be interested in a global database on technologies and refrigerants used in different countries, as well as a guidance for the choice of new systems/refrigerants taking into account actual and future regulations.
- Technical experts who will be able to access, review and modify the public databases on technologies/refrigerants.
- Technical persons who will be able to access data from the databases and information about regulations and best practices.
- Refrigerant producers for the forecast of refrigerant consumptions.
Therefore, it is a must to have a complete, dynamic, regularly updated platform that would focus on refrigerants and RAC equipment and allow the access, visualization and comparison of data regarding refrigerant uses and emissions. This platform is intended to:
- Exchange information and data for the share and improvement of knowledge related to equipment technologies and inventories within refrigeration and air-conditioning applications.
- Provide online databases on available RAC technologies and refrigerants in use.
- Provide information on newly developed technologies and refrigerants as well as their potential use in different countries and regions in the world.
- Provide an online tool and model databases that can be accessed and modified by registered members, for the determination of national inventories and the visualization of specific public results in a standardized form allowing their comparison among countries.

Figure 1 - Open RIEP Platform basis

3 First structure of the OpenRIEP platform

The aim of the OpenRIEP platform is to allow to perform inventory and forecast calculations as well as to share knowledge and data regarding refrigerant and RAC equipment. At the moment, the structure of the OpenRIEP Platform is constituted by five main sections, as shown on figure 1.
The Open RIEP platform is located at this address: **www.openriep.com**.

3.1 The Refrigerant Database

On one hand, the Refrigerant Database will describe the existing refrigerants, their properties, their adequacy with some applications, their advantages and disadvantages regarding environment, technical use, energy consumption, servicing, under-review regulations, depending on the application and on the country. The alternative possibilities to HFCs and HCFCs will be suggested.
On the other hand, a large part of this section will be associated to the newly developed and under-development refrigerants. Links forward publications and test programs will be proposed. In particular, some of the CES publications and works related to refrigerants will be accessible.

3.2 The Technology database

The Technology database will provide information on available RAC technologies in use. In this section too, existing equipment will be distinguished from new technologies. Newly developed and under development technologies will be highlighted as well as their potential use in different countries and regions in the world. A help sub-section could be created to choose the best equipment from CO_2-emission point of view, depending on the user constraints. Links forward producers of equipment or technical reviews could be considered.
Some websites, such as the UNEP one (http://ozone.unep.org/teap/Reports/RTOC/index.shtml) are a great source of information regarding technologies and refrigerants used in RAC applications. However, information is provided in reports either in "pdf" or "doc" formats. The use of such information by policy makers or inventory compilers for example is time consuming and requires a good technical background which is not always available. This platform will provide a structured technical database, targeted not only to technical people, but to those who need basic information.

3.3 The Inventory and Forecast Tool and the OPEN Emissions Database

This part is the core of the platform. A tool to carry out refrigerant inventories and forecast will be proposed online. The RIEP software will be provided as well as some models regarding refrigerant evolutions and emission rates.
In a first approach, these models will be included in reference databases. The databases will not include markets and productions of equipment (when such information has been purchased) but some reference sources (statistical, governmental, marketing studies) will be indicated per country.
Each registered member will be able to download a database and modify it. Then, the user will have to upload his modified database and perform calculations on line. The calculation results could be visualized on line or downloaded in a "csv" format. Comparisons with CES estimates could be proposed in certain cases as well as cross-checking with official reported data.
The methodology will be explained and a notice for users will be available. A help tool to the achievement of inventories could be proposed. Possibilities to build forecasting scenarios are under consideration in order to provide a tool as flexible as possible. Links to reported data websites, as those of UNEP or European Commission (EC), could be considered. In a second time, this section could contain all the reported data that CES members or other users would find and notice.
In addition, the emission results database constituted by the results of CES calculations can be accessed. The Google tool is used for data visualization and comparisons: 4 kinds of graphs, time-evolution, comparison by refrigerant, by country, by application, etc. As an example, Figure 3 shows the comparison of CO_2 equivalent emissions due to commercial refrigeration in France, in Europe of 15 and in other countries of EU27 ("EUnew") on a map chart.

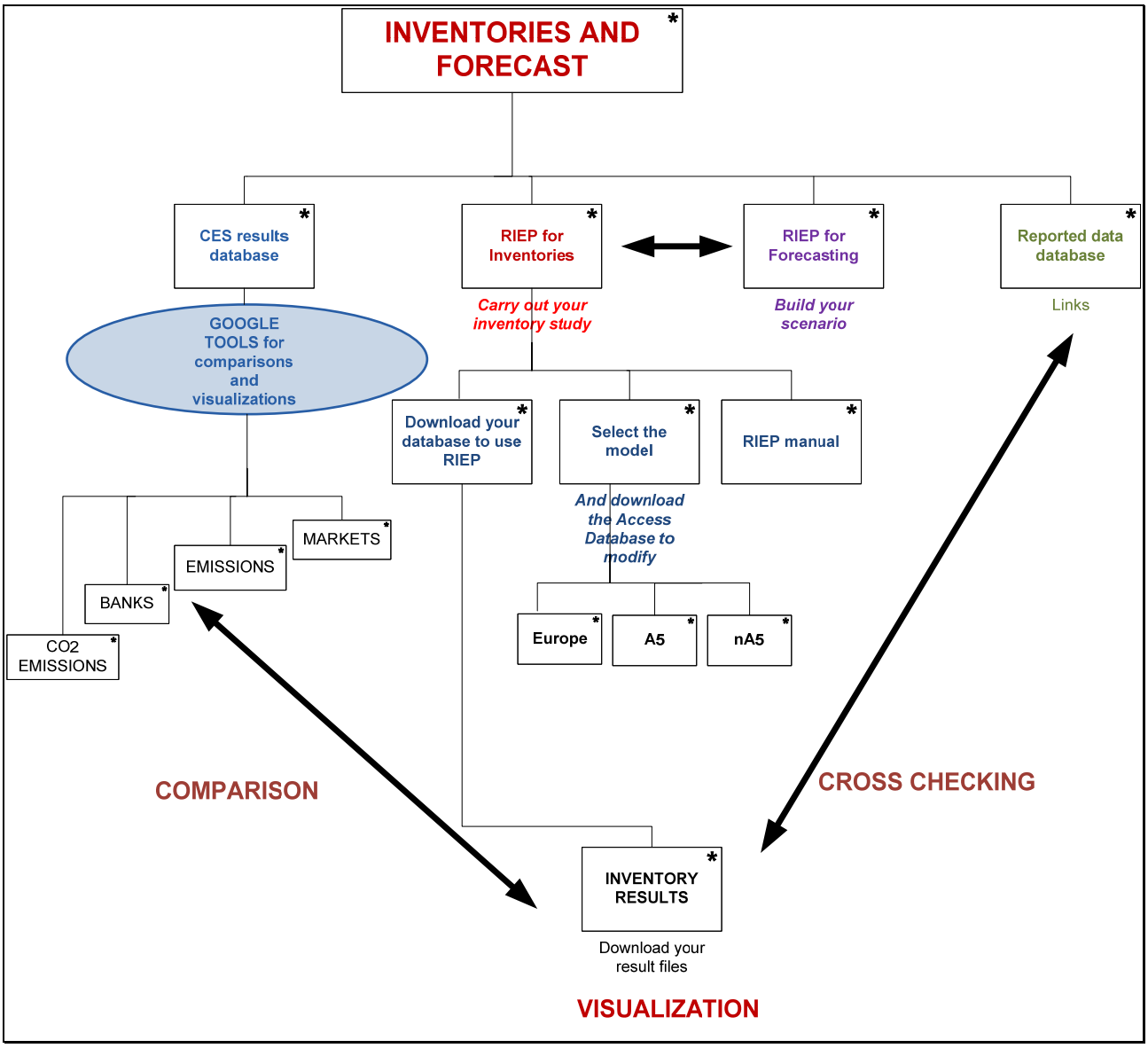

Figure 2 - Structure of the section "Inventories and Forecast" on the Open RIEP Platform

Figure 3 - Total CO_2 equivalent emissions of refrigerants in Commercial refrigeration in Europe.

Figure 4 shows another example: the evolution of the total bank of HFC-404A in France, EU15 and EUnew on a line chart. Menus are based on the structure of RIEP outputs: the type of refrigerant inventory result can be chosen as well as the country, the application and the refrigerant or family of refrigerants. At the moment, the comparison may be done between countries, refrigerants, applications or type of refrigerants.

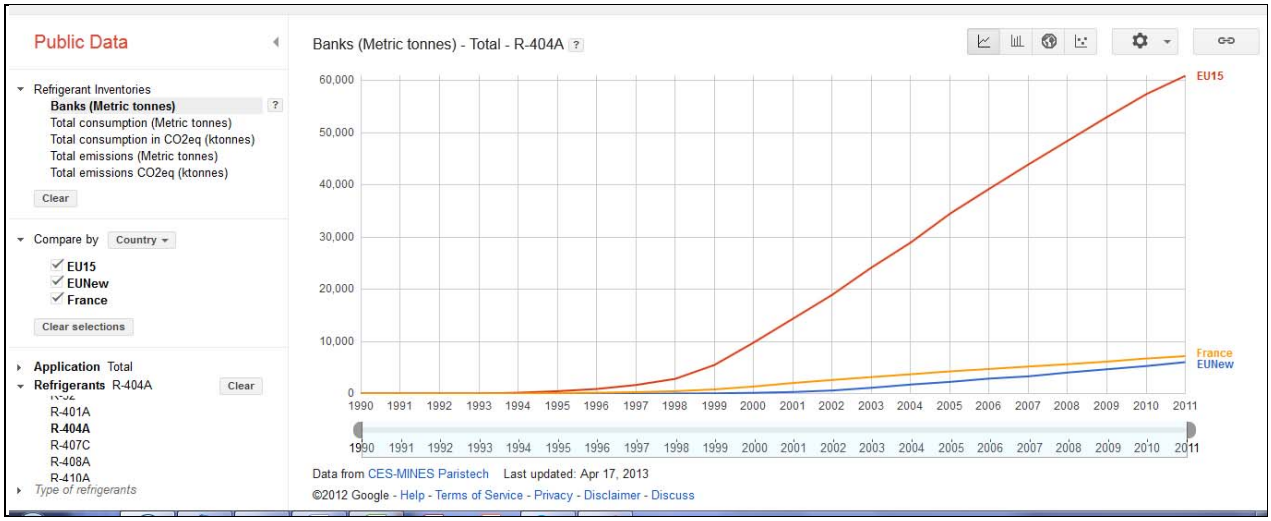

Figure 4 - HFC-404A bank in Europe from 1990 to 2011.

3.4 The Regulations and Good Practices section

An explicative section regarding regulations and good practices will be written. The main existing and historic regulations will be reminded, from Montreal Protocol to the under review Fgas. Gradually, this section will be extended to national regulation per country. The implementation of the Kyoto Protocol or Fgas regulation per country could be analyzed.

Existing good practices will be mentioned, per application and per country: certifications, specific reporting, associative support of industrials, producers, environmental agencies, best technologies for recovery equipment, specific recovery networks, etc.

A dynamic good practice guide could be implemented to provide a concrete answer to technical users who would want to know the best way to operate in specific application cases.

3.5 The Blog

All sections could be gradually enhanced by comments, exchanges of information and data among users and experts, which would allow the share and improvement of knowledge related to equipment technologies and inventories within refrigeration and air-conditioning applications. In order to facilitate these possibilities, a blog will beopen and user accounts can be created.

4 Conclusions and perspectives

Building a large data exchange network related to the field of refrigeration and air conditioning can be of interest and used by technical people as well as policy makers. The Open RIEP platform is intended to be used by a wide range of professional profiles and educational systems that could:

- be able to compile their own inventories with a uniform tool for all countries, based upon CES model databases,
- visualize their results in user-friendly graphic formats and export these results in tabular forms,
- compare their calculation results to those of the CES or to other reported data,
- be able to access emissions and banks data from the CES results database, visualize them and compare data between countries, refrigerants, applications,
- be able to access, review, and modify the public global databases on technologies and refrigerants,
- be able to consult and compare regulations, know the practices, habits, and regulations in other countries, find advice regarding new installations and refrigerants, take note of the best practices in order to reduce refrigerant emissions, and
- be able to develop emission-reduction scenarios.

The first part of the platform developed by the CES will be the inventory section containing the CES results on emissions and banks. Gradually, the other parts will be built. In a second step of development, a tool to support the choice of the most appropriate refrigerant for a new or a retrofitted installation could be implemented. Both refrigerant

and technology databases could be linked to the model tool for forecasting. Introducing new technologies or refrigerants in a scenario will imply evolutions in emission rates or refrigerant charge models. This article presented the proposed structure of the Open RIEP platform and some perspectives. The blog will be soon available and suggestions from users are welcome.

5 Nomenclature

E	emission	(tonnes)
t	year	(year)

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