Greenhouse Gas Inventory Information System

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ABSTRACT

The national greenhouse gas (GHG) emission inventories provide essential information for assessing the implementation of the United Nations Framework Convention on Climate Change (UNFCCC). With the adoption of the Common Reporting Format (CRF) for submission of annual GHG emission inventories, the amount and complexity of GHG inventory data reported by Parties have increased substantially. In 2000 the UNFCCC secretariat started the development of a database system to satisfy the growing need for data analysis tools.

This paper presents information on the Greenhouse Gas Inventory Information System developed by the UNFCCC secretariat. The main purpose of the system is to store national GHG inventories from Parties, support the inventory review process for Annex I Parties to the Convention, facilitate provision of data to the conferences of the Parties and provide information to the public through the World Wide Web.

The paper describes a brief history of the development and the current status of the system, which consists of several databases and software applications. It explains the complexity of GHG inventory data structure and designing an adequate relational model. The challenges in developing an information system in parallel with establishment of a new process for reviewing national inventories will also be described. Several software tools, including the Locator (a data search tool) and the Crawler (a data mining tool/table generator), will be demonstrated during the presentation of the paper.

The system is still under development. The paper explains how the system is being consolidated and improved, leading to a more expanded and sophisticated system to support and facilitate the Convention process.

INTRODUCTION

The United Nations Framework Convention on Climate Change[1] was adopted in May 1992 and presently 188 countries are Party to the Convention, including 40 Annex I Parties (industrialized countries) with specific greenhouse gas emission inventory reporting commitments. In accordance with the provisions of the Convention, Annex I Parties have a commitment to prepare and submit national inventories of greenhouse gas emissions, not controlled by the Montreal Protocol, for the consideration of the Conference of the Parties (COP) to the Convention. The inventories should be prepared using comparable methodologies agreed upon by the COP. In an effort to ensure the transparency completeness, comparability, consistency and accuracy of these GHG inventories, the COP adopted guidelines at its first session for the reporting of emission inventories from Annex I Parties, and revised these guidelines on a number of occasions at subsequent sessions. The

objectives of the reporting guidelines are to assist Parties in meeting their commitments under the Convention, to facilitate the process of consideration of inventories, and to facilitate the process of verification, technical assessment and expert review of inventory information. [2]

The national GHG inventories provide essential information for the assessment of Parties implementation of the Convention and are considered one of the basic pillars of the UNFCCC process. For this reason in October 1999, on the basis of the objectives listed above and with a view to continual improvement the GHG reporting, and the expected future information needs of the Convention, the CRF for reporting of greenhouse gas inventories by Annex I Parties was elaborated by national experts and adopted by the COP as an integral part of the reporting guidelines. The adoption of this agreed format increased the complexity of annual reporting substantially in 2000 (the first year for reporting using the CRF); the amount of data to be reported increased from approximately several hundred values to between 3000-5000 values per inventory year and the information types requested expanded from emission estimates only to associated activity data, implied emission factors, specific parameters related to calculation methods, and information on methods used and recalculations of previously submitted emission estimates.

With the adoption of the CRF in 1999, the secretariat was tasked with developing tools to support Parties in their reporting of inventories in the agreed new format and for the processing and management of these data. Over the past three years, the secretariat developed reporting software to assist Parties in meeting their CRF reporting requirements and developed a new data management system to process and maintain the reported data as well as provide data analysis tools to support the UNFCCC process. The development of the system was complicated by not only the complexity of the CRF, but also was significantly influenced by ongoing activities of the UNFCCC process.

HISTORY OF SYSTEM DEVELOPMENT AND CHALLENGES FACED

Early UNFCCC data management system and evolution post - 1999

Parties have been reporting GHG inventories to the UNFFCCC since 1994, initially in the context of their national communications, and since 1996 as annual inventory submissions. In 1995, the secretariat developed a database for maintaining inventory data following these initial submissions of GHG data. This initial database served as a basic depository of GHG data and included some limited reporting and output generation functions. The main outputs required of the initial database system were an annual compilation of emission trends and specific country data extractions in support of the in-depth review process of national communications. In addition, in 1999 in support of methodological work on inventories, and relating to upcoming revisions to the reporting guidelines, the database began to be used for more in-depth analysis. Although the database was subsequently appended with additional functionalities, by the end of 1999 with the adoption of the revised reporting guidelines (including the CRF) and the adoption of a data intensive review process of annual inventories, it was necessary to develop a more sophisticated system for the processing, storage and analysis of the inventory information being submitted by Annex I Parties.

The secretariat has developed a CRF inventory database and related software to support the processing of information on GHG inventories submitted from Annex I Parties, and to support the reporting and review process established by the Parties in 1999. Immediately following the adoption of the new reporting format the secretariat began preparing an Excel-based reporting application for Parties' submissions of CRF data. The 1st version of this Excel-based CRF reporting application was released in January 2000 for use by Parties for inventories due by 15 April 2000. In the course of 2000 the secretariat developed its new data management system on the basis of the CRF structure (system was implemented using Microsoft SQL Server 7.0, later migrated to 2000). The system was designed to satisfy the immediate data maintenance requirements that had arisen as a result of the new reporting requirements of the CRF, and thus would allow for adequate data accessibility and quality for the review process. In 2001 a number of modifications were made to adjust certain data definitions and include additional administrative and data processing functions. As well, throughout 2001- 2002, system enhancements were made to ensure data quality assurance and software tools were developed to support the analytical needs of the review process and provide the expert user-community with access to basic emissions data and compilations on reporting completeness, recalculations, emission contributions and emission trends.

Simultaneous implementation of review process

In 1999 the COP adopted a trial greenhouse gas inventory review process at the same time it adopted the new reporting format. The review process was to begin on the basis of the data to be provided by Annex I Parties in the newly adopted format in April 2000. As a result, the ability to stage system developments, for example in terms of data modelling, system implementation, data management routines and analysis tools development, was not possible. By January 2000 the delivery mechanism had been developed for submission of data, but the data management system design was not complete and data processing would need to begin in April of 2000. As a result processing in 2000 was done with the existing system, to the extent possible (the existing system's structure was not fully compatible with the full range of information in the CRF), as was analysis support to the review process in 2000, while simultaneously development was undertaken on the new system.

By the second year of reporting in the new format, the system was able to respond to the basic data management and analysis needs required of the reporting and review process. As a result of the efforts made to undertake system development and implementation in parallel to assessing the data processing and management implications, as well as the analysis requirements, the secretariat was able to provide the required support to the inventory review process undertaken from 2000-2002. The secretariat has found the initial system developed so far to be essential to the provision of timely and accurate information to countries, review experts and the public, even if the implementation approach and process was not ideal from a longer-term perspective. The review experts as well indicated that the availability of the data in a user-friendly searchable format, although limited in functionality initially, greatly facilitated the process by allowing for some standard analysis and comparisons during the trial review process. One of the main conclusions of the trial review process with regard to the inventory information system was that given the time frame in which reviews are undertaken annually, the system must serve as a core element of the process and be used to a greater extent in the future to optimize both information assessment and the limited time of experts.

System development method

As a result of the timeframe and the existing resource limitations at that time, the secretariat responded to the development needs in a less than sustainable manner in terms of provision of longer-term strategic, technological solutions. Having to maintain and provide ongoing data analysis support to the review process with the existing system while developing the new system resulted in a significant resource constraint (financial and staffing). However, the method of development allowed for intense interaction with experts (user-community), ensuring almost immediate feedback on development. The experience has shown that such an approach while encouraging innovation and ensuring focus of results, it does not necessarily result in sustainable developments and can result in the creation of resource sinks in terms of support, maintenance and further expansion.

As mentioned above, the architectural system design and development approach was chosen on the basis of the immediate review process needs (basic processing, storage and output functionality within 4-6 months). The approach taken would be best defined as one of extreme programming or perhaps a mix of the "build and fix" with the "rapid prototyping" approach. However, due to the constraints of time, and initial resources, and especially due to the lack of a full requirements analysis, it was not possible to undertake a more standard, staged, approach to software development.

The development of the new system and reporting software was done by a handful of internal staff, with only limited external consultancy support. The unit tasked with the development as well simultaneously remained responsible for the work on data content management and analysis, and operation and maintenance of the existing system.

SYSTEM DESCRIPTION

This section provides a description of the system's various elements and modules. The UNFCCC secretariat has developed several databases and tools for the purpose of processing, storing, reviewing and publishing Parties' GHG inventory data. Figure 1 provides an overview of the existing database systems.

Visual Basic and Delphi programming languages were used for software development. MS SQL Server and MS Access platforms were used for storing the data.

CRF system

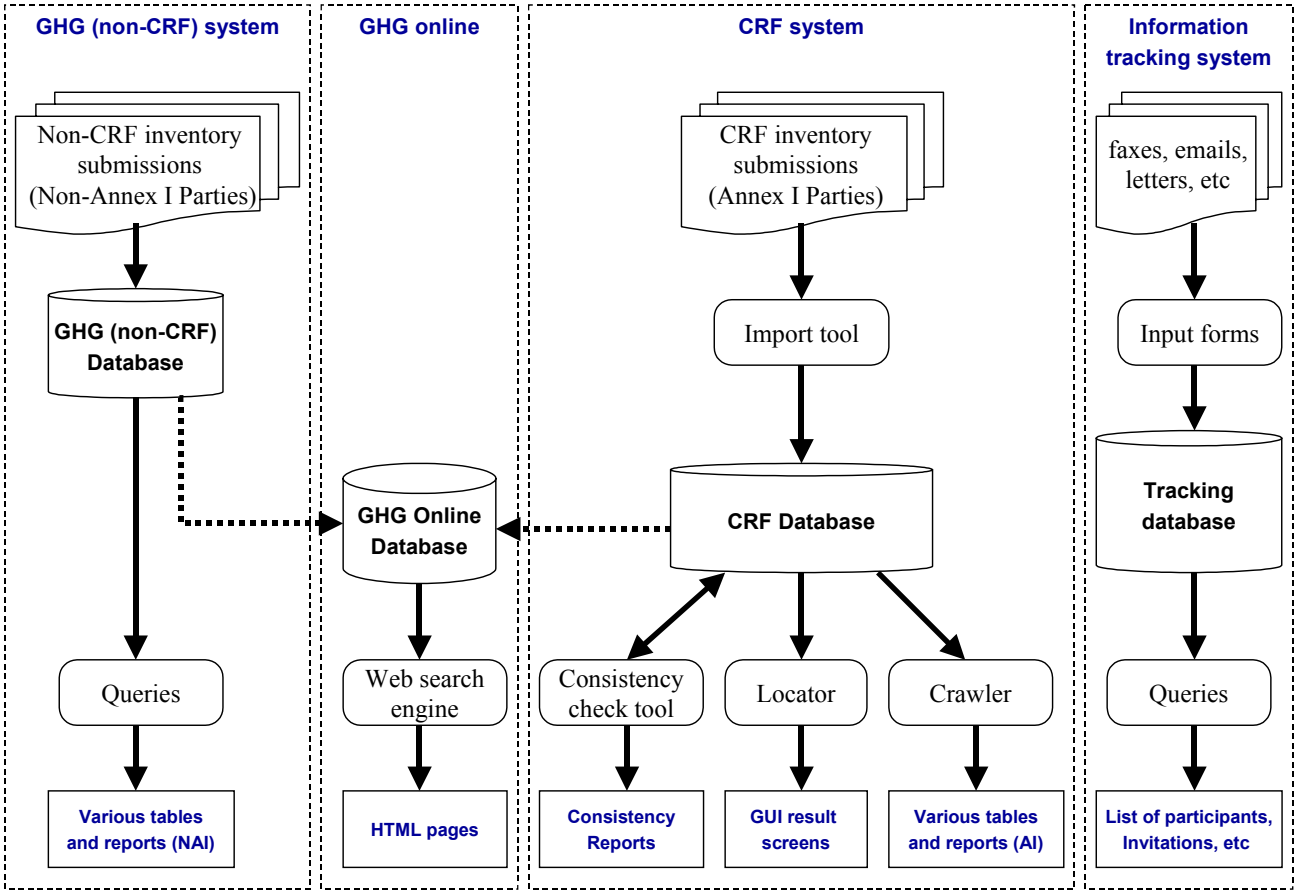
The CRF system consists of data collection software, import program, consistency checks, search tool and table generator.

CRF software

The CRF was adopted at the 5th Conference of Parties (October 1999) as a standardized format for reporting estimates of greenhouse gas emissions and removals and other relevant information to be reported annually by the Annex I Parties. In response to the request by Parties, the secretariat developed a software application to facilitate reporting by Parties using the CRF. The CRF application is based on Microsoft Excel and reflects directly

the structure of the CRF as it was adopted. The CRF application consists of 43 tables, organized in 64 Excel worksheets, with required information, including GHG emission estimates and the related background data. It is not intended for the estimation of greenhouse gas emissions and removals.

Figure 1. GHG-related systems in the UNFCCC secretariat



The CRF tables are built up on four levels: Sectoral background data tables (Level 1), Sectoral report tables (Level 2), Summary and other tables (Level 3) and Checklist (Level 4). In general, the figures from the lower levels are propagated to the higher levels. The higher the level is, the more data are aggregated. The highest level of aggregation is repeated in several tables, e.g. emission estimates from Fuel Combustion (Sectoral approach) are contained in Table1.A(a), Table1, Summary1.A, Summary1.B, Summary2, Table8 and Table10.

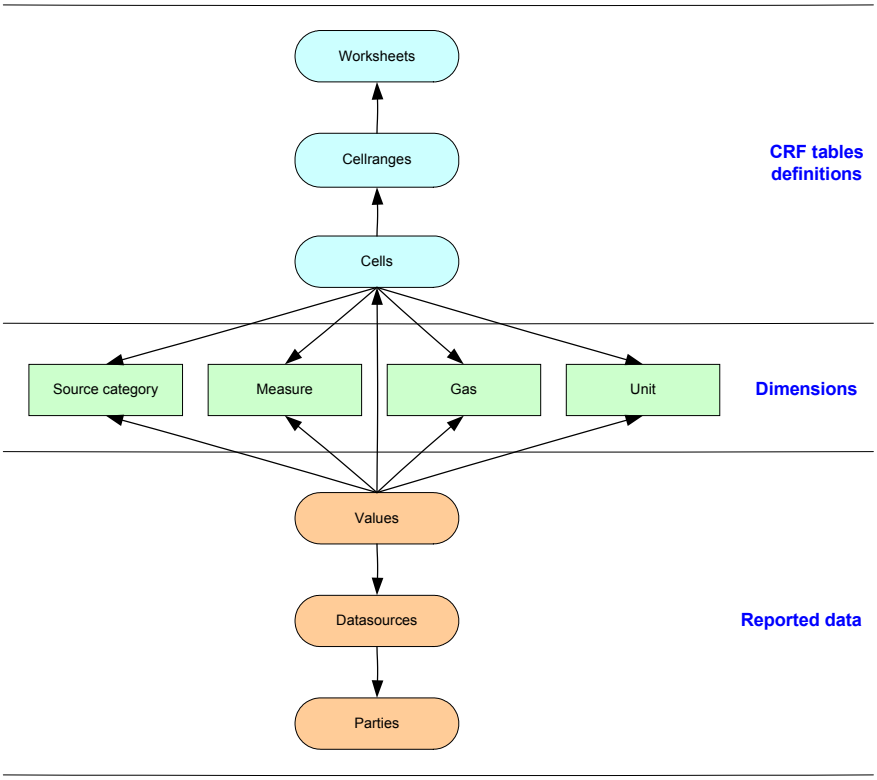
GHG inventory data are processed by the secretariat in the second quarter of each year following the receipt of submissions, which are due by 15 April of each year. As the data processing is closely linked to the initial checks stage of the review process, some data quality assurance is undertaken, thus allowing the possibility for resubmission or submission of additional data to address any issues raised.

CRF Database

The CRF database was developed initially for importing and storing the GHG inventory data submitted in the CRF. Therefore the underlying data model is based on the

CRF table template and is tightly bound to the Excel worksheet structure. The initial data model is presented in Figure 2.

Figure 2. The initial CRF data model



Subsequently the database design was enhanced to meet the requirements of software tools developed for consistency checks, queries and analysis that work on the database. Also two additional dimensions were introduced later to meet the variability of national reporting and for better representation of the CRF data.

The historical development of the CRF database reflects a problem oriented sequencing of iterative improvements to meet growing requirements. The CRF database currently offers a flexible model to store information coming from the CRF submissions in Excel format. The database model stores information as provided, including numerical data and textual information (for example, cell comments and documentation boxes reported in the CRF).

In general, the CRF database structure models the CRF format and therefore it is input, but not output oriented. This is also a limitation of the model, because producing analysis and reports from this database structure includes a complex selection process, which has to consider that the data contain redundant datasets and inconsistencies. Another limitation of the model is that all data have a fixed number of dimensions (currently 6) associated with them, which in some cases is not enough to adequately describe the complex nature of CRF data.

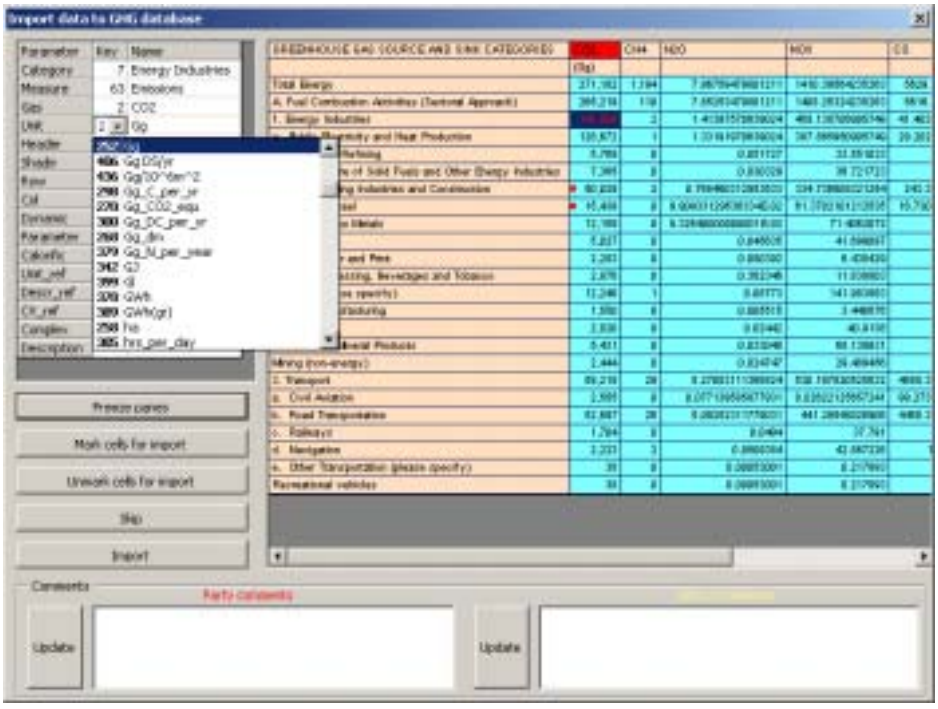
CRF import program

The purpose of the import program is to transfer national inventory data submitted by Parties in the CRF format into the CRF database. The program imports data from the Excel CRF files and provides an interface for the user to check data identification, insert comments and review progress status. The import program has the following main functionalities:

1) Determines and stores in the database administrative information such as inventory year, year of submission, version of the CRF application, etc.;
2) Uploads data into the CRF database in three modes:
   - Automatic mode: the program uploads data from all sheets with no structural modifications detected. The skipped sheets have to be imported in manual mode;
   - Manual mode: the sheets are loaded into a data grid form for user verification and, if necessary, allows for manual adjustments of dimensions and attributes assigned to data by default;
   - Party template mode: this mode facilitates importing data from worksheets following previously defined country-specific patterns.

A minimum import unit is a named range of cells that are predefined in the CRF reporting software. A worksheet may contain one or more such named cell ranges. The Import Data form (see Figure 3) shows the determined values to be imported and allows for changing various parameters assigned to them by the program.

Figure 3. Cell range import data form



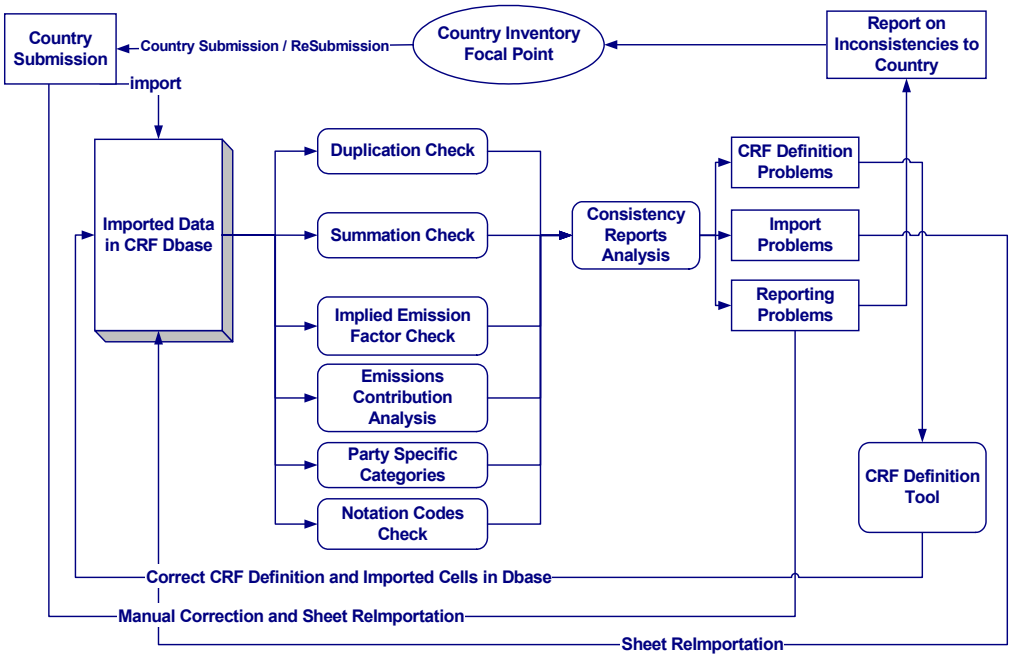
In case there are modifications in the table structure identified by the program, the importer has to carefully adjust necessary parameters for all the affected data. This task is not trivial and requires some expertise in the GHG inventory field and good knowledge of the

CRF tables. A mistake made at the import stage can sometimes be very difficult to catch at later stages.

Consistency check

The Consistency Check program is intended to identify possible inconsistent data resulting from mistakes during data import, database definition problems, or a Party's inconsistent reporting. It is an efficient tool to validate the importations of a submission. Equivalences between numbers resulting from reporting redundancy, unit conversions, category and gases aggregations, are systematically checked. Non standard notation codes, Party's specific categories, emission profiles as well as other aspects are also investigated.

Figure 4. Import monitoring and consistency check workflow



Every inconsistency encountered is analyzed, documented and processed. The Party's inconsistencies are compiled and sent to the Parties as a data consistency check report. The steps of the consistency check are presented in Figure 4. The current consistency check approach is an empirical stepwise process, which requires significant manual interactions, and analytical expertise, due to the fact that the expression of an inconsistency is often distinct from its actual cause.

Locator

Locator is a search instrument developed for visualizing the data contained in the CRF database. It provides two ways of searching data. In the Data Search mode, the search parameters are independent from each other. The Data Search form has several controls with dimension descriptors and search options. The user can select a specific dimension descriptor to limit the search or leave it as "ALL" (the default), which means that there is no restriction on that dimension. In this mode it is possible to define any combination of the search parameters. The resulting grid has multiple grouping and sorting abilities to help users to navigate and organize resulting datasets in a desirable way.

The second search mode is the Time Series. It has a step-by-step ordered selection of search parameters. Content of the selection lists is dynamic, narrowed down to the available choices. The results are presented for all Annex I Parties in a time series manner.

Locator shows the data existing in the database "as-is" including possible duplications and inconsistencies and does not manipulate or calculate the data in any way. Originally, this tool was developed for internal purposes, but external experts for the inventory reviews also used it extensively. Locator is available for MS SQL server and MS Access database platforms.

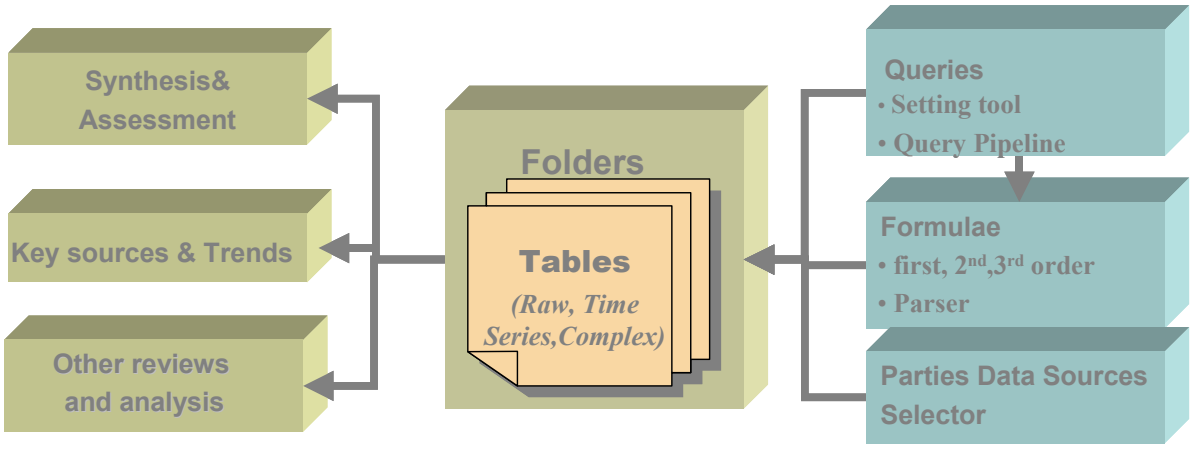
Crawler

The Crawler is a data mining software on the top of the CRF database to support the production of Excel numerical tables used in the process of inventory review and analysis, as well as daily internal and external data requests. The Crawler stores all steps of table production, simple or complex, in such a way that they can be reproduced at any time, following import of new inventory data.

The user is provided with an elaborated interface for data query definition facilitating every step, by adjusting the possible parameters. The data query mechanism integrates a user configurable data-mining pipeline, which takes into account all the complexity inherent in the inventory submissions (e.g. complex selection process resulting from CRF data model).

A formula definition interface actively assists the user in building Excel like formulae on the top of its data queries (formula parser, elaborated functions, etc.). The Excel output tables clearly show the relation between the formulae and the queries. Different types of tables can be produced, including raw tables, trend tables as well as more complex tables (e.g. key-sources and trends analysis). The Figure 5 shows the architecture of the Crawler.

Figure 5. Crawler architecture



Emphasis has been put on ensuring that the Excel tables have the following important characteristics:

- Transparency - clear data processing for the end user

- Traceability - well identified pedigree of every data used
- Consistency - inter-country comparability of data at all levels taking into consideration the variability in reporting
- Scalability, re-usability, communicability and ownership - the output (tables) can be scaled, re-used in a different context as required, easy to manipulate and gives the end user full flexibility and control.

Tables and folders can be managed in a very similar way as files and folders in a windows environment. The Crawler has been extensively used for the last six months at UNFCCC and already contains more than 500 tables incorporating about 10,000 queries and formulae.

Despite that it has so far proved to be an efficient tool for the above functions, the Crawler meets some limitations in the following aspects:

- It is hard to browse through the data as compared to the Locator
- It is lacking portablility to support in-country review activities
- Production of charts and graphics needs to be handled in Excel

GHG (non-CRF) Database

The GHG database was developed in the secretariat prior to the adoption of the CRF in response to the internal needs for GHG data storage and production of various reports. This is a simple MS Access database, which was designed to store only emissions data on an aggregate level, replicating the structure of the IPCC Reporting Table 7. This database existed in two separate versions. One was used for GHG inventories of Annex I Parties and another for non-Annex I. At the moment, this database is being used only for processing non-Annex I Parties' data, since the Annex I Parties are providing data in CRF format and therefore are stored in the CRF database.

GHG Online Database

For the purposes of information dissemination the UNFCCC secretariat has developed a Web based search database, which provide public access to the GHG information via the World Wide Web (available at http://ghg.unfccc.int). This web database was also developed prior to the CRF and is based on the same aggregate level of IPCC Reporting Table 7 as the Access GHG database. The online database is being updated twice a year with the most recent GHG emission data both from Annex I and non-Annex I countries. The inventory data presented via the search engine on the web site presently only reflect the aggregate IPCC source category structure (summary level emission estimates) and not the detailed level of information provided in CRF submissions. To obtain user-defined results a simple process of selecting four search parameters (party, sector, gas and year) is required.

Information Tracking System

The tracking database has been developed in parallel with the CRF system, for the purpose of tracking information related to GHG inventory submissions and inventory reviews. It contains, for example, the dates of inventory submissions, contact information of the focal points, communications with Parties and inventory experts, contact and related information for experts participating in the inventory reviews, and other similar information.

The database output consists of list of participants in reviews and workshops, invitation letters, participation statistics, inventory submission statistics, etc.

LESSONS LEARNED AND FUTURE ACTIVITIES

Where we are now

During the trial review process and initial period for use of the CRF, the Parties and the secretariat experienced difficulties and limitations with the present reporting guidelines and related software.[3] It was concluded that most of these problems could be overcome through revision to the guidelines, thorough adherence to them, and/or through development of new reporting software to replace the existing Excel-based CRF reporting application.

With the conclusion of this almost three year period for submission of information in the new format and its review by experts, and giving consideration to the future importance and complexity of the management of GHG inventory data in the UNFCCC process, the secretariat decided to organize an external peer-review of its data management system and activities by experts in the field of information technology and GHG inventory reporting and management. The review took place in September 2002 and the results of the review and planned further developments were presented to the Parties at the eighth session of the COP in October 2002. The main conclusion of the external review was that the existing GHG inventory information system is not flexible and scalable enough to meet the needs of the Convention in the future and, eventually, the Kyoto Protocol.

On the basis of the experience of Parties in the last three years[4], and the confirmation provided by the external experts of the secretariat's concerns, the secretariat has initiated activities for the enhancement of the GHG inventory information system and development of the new software for reporting, analyzing and presenting GHG information. With the adoption of revised reporting and review guidelines at the recent COP session and the evolving requirements with respect to the Kyoto Protocol, not to mention the lessons learned concerning the complexity of software and database development to meet the GHG inventory reporting and processing requirements, it was felt both by the secretariat and Parties that adequate resources would need to be made available and substantial development would need to be undertaken to continue to be able to meet the commitments of the UNFCCC process in coming years. In 1999, most Parties and the secretariat did not recognize that the changes undertaken constituted a fundamental shift in the nature and size of information to be reported, processed, managed and analyzed. This was one reason for the difficulties, or less than optimal approach taken so far. However, efforts are being made now to adopt sustainable paths for future system development and related support to Parties.

Future developments

As the main focus of development and support has been the maintenance and provision of data required for the review process, the present system and software tools are limited in their ability to meet all the needs arising in terms of the inventory reporting and review process, as well as the increasing public interest in accessing inventory data and related information. The immediate priorities are to continue to ensure the provision of data accessibility and quality requirements, integration of related information and data for the review process, the production of standard data analysis and publications, and

implementation of modifications to the database in line with the revised guidelines agreed in 2002. However, the experience gained so far has shown that there is a need to develop much more robust data analysis tools that would provide multi-functional access to the inventory data, including graphical representations, information on major sources of emissions and trend assessments, statistical functions, and incorporate relevant external datasets for comparability.

With all these elements in mind, the secretariat has outlined a plan for system consolidation and further development, as well as for increased and improved data support and dissemination. In the current year, and through the next biennium, the various developments have been planned taking into account the available resources, ongoing support needs of the process and internal development capacities. With respect to the latter, the secretariat has already begun to identify areas of development suitable for outsourcing.

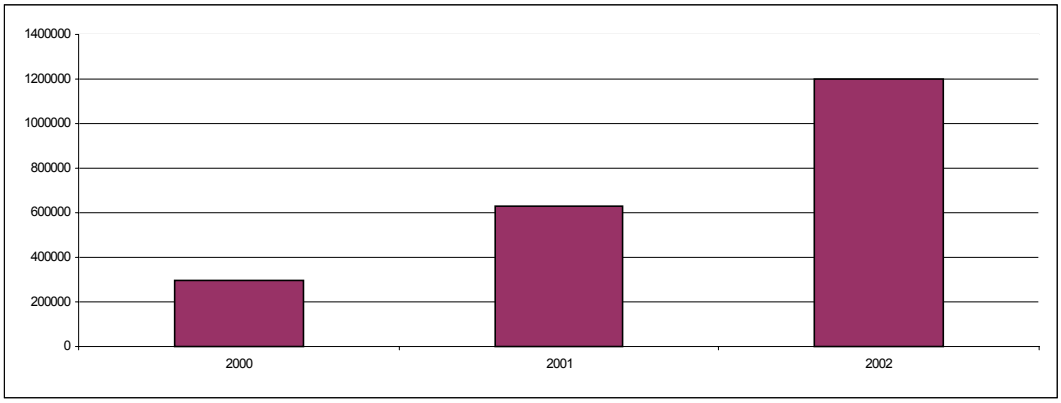
System consolidation and evolution

The existing CRF application was designed to serve both input and output purposes at the same time. Due to various technical limitations, as well as the CRF table structure, the CRF application contains several data processing traps. It contains redundant information, creating the possibility for inconsistent data. The CRF application tries to avoid these restrictions by defining a huge number of formulae within a single inventory file and by using the Excel protection features. But users are able to remove protection and change headers, units and formulae according to their needs.

In addition, the CRF inventory submissions contain cross-inventory (trend tables) and cross-submission (recalculation tables) information. For this kind of information the CRF application only offers a manual input facility, but no means of consistency checking. Furthermore, some of the CRF submissions are provided in a CRF similar structure without using directly the CRF application. All these different formats (from a technical point of view) and the large variety of inconsistencies and ambiguity, which an inventory submission may contain, logically increase the complexity of the importation and further data processing in the secretariat. As a result, inconsistencies are not directly detected by the Parties, but by the secretariat during data importation and consistency checking. Therefore several cycles between the secretariat and the Party are necessary, before the CRF submission quality meets the agreed goals.

In spite of the fact that the secretariat developed quite sophisticated software tools, the CRF data processing remains a very complex and resource intensive process. The current way of collecting data leads to significant complications at the data processing and verification stages. The amount of data being submitted to the secretariat increases significantly each year (Figure 6). It is very difficult for the secretariat to process the inventory data submitted using the current collection format within a limited period of time while ensuring data quality. Having completed the initial three-year trial period, the Parties and secretariat have understood that an improved data collection system is needed. For this purpose the secretariat is planning to develop new software for reporting GHG inventories by Annex I Parties.

Figure 6. Number of values reported by submission years



The new reporting software will avoid the problems of the existing CRF Excel-based application and will have a consistency checking functionality built-in, which should help the Parties to avoid technical inconsistencies in their inventory submissions. By resolving the technical inconsistencies directly at a Party level, many importation problems and cycles between a Party and the secretariat can be avoided. This will help to save time, resources and costs on both sides.

The existing CRF database is designed for importing data from CRF tables and storing all submitted national inventories as received (unmodified) and contains redundant, inconsistent and versioned data. It serves perfectly as an archiving database, but is quite difficult to use for data analysis purposes. The secretariat is planning to develop an analysis-oriented data warehouse with a more flexible, n-dimensional data model, which will provide greater flexibility and will reduce needs for structural changes to incorporate possible revisions to the CRF in the future, as well as the expected needs related to analysis for the review process and additional data management requirements of the Kyoto Protocol. The new approach will allow for integration of data from the existing CRF, non-CRF and information tracking databases into a single system.

CONCLUSIONS

During the last three years the secretariat developed an information system to support the trial periods of national reporting in the CRF and the inventory review process. The development strategy can be characterized as a "demand-driven" approach. The system was built up by ‘continuous prototyping’, where software developers worked very closely with inventory experts. It was not possible to clearly separate the development process into a design, development and test phase, due to the demands of the review process, and as a result the process was only short-termed oriented. This approach was the only option available taking into account that both the CRF reporting and inventory reviews were only in the process of being established, and thus the requirements were not clear at the initial stage and continuously changed in the course of the reporting and review trial periods. Despite these difficulties, experience has shown that the development of the GHG inventory information system, in spite of its limitations, greatly facilitated the implementation of both the reporting and review guidelines, and thus helped contribute to the preparation of reliable and high quality inventories under the UNFCCC.

Through the use of the system the critical nature of high quality data support to the inventory review process and importance of advanced preparation to meet future needs has

become clear to all concerned. The secretariat has taken heed of the experience and over the last year in a number of presentations at the official sessions of the UNFCCC, and through various informal opportunities, has kept the inventory community informed as to ongoing processes and planned developments. The response from Parties has indicated that there is a good deal of confidence in the work done so far and support for the secretariat's plan for the future enhancements underway.

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KEY WORDS

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Database
Software
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