

EstimatER, an expert system for emissions

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ABSTRACT

Estimating emissions at the level of countries, states, regions or provinces and even larger companies in most cases is a knowledge-intensive exercise. Guidelines, guidebooks and other guidance documents to prepare emissions inventories typically contain thousands of pages with emission estimation methods and specific and aggregated emission factors for large numbers of sources. The personnel responsible for the compilation of an emission inventory therefore needs to browse through large amounts of material to find the specific information needed for his application.

To support the compilation of emission inventories we developed, within the framework of the European Environment Agency's set of software tools a user friendly expert system, that makes existing knowledge and expertise directly available to the individual who is compiling the emission inventory.

The expert system consists of an application using a knowledge database to draw the estimation methods and emission factors from. Upon start of the application, the user can drag and drop one or more complete inventories for certain source sectors or parts thereof into his or her inventory under compilation. In subsequent steps, the user can replace the default values in the estimate by other values at any level of detail. Doing so, the emission estimate will be updated and an indicator of the quality of the emission estimate will be presented to the user. In an iterative process, the user can improve the estimate until a satisfactory quality is reached. The system allows for exporting the resulting emission estimation into a standard report template

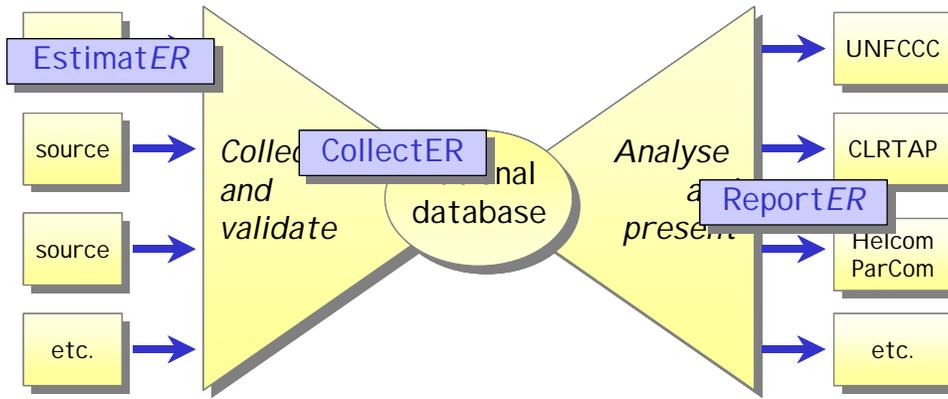
The system now is freely available from the European Environment Agency via its web site. The knowledge libraries implemented have been developed within the framework of the greenhouse inventories for agriculture and the energy sector reference approach. The report template is the Common Reporting Format as defined by the Climate Change Convention.

Additional libraries and links to reporting formats could be developed.

INTRODUCTION

The CORINAIR software system consists of a set of software tools (1) each adapted to a different use and user group respectively (2). All tools are designed for the specific users, but might contain some functionality, which is derived from the other users requirements. For instance, the collecting tool will need some limited reporting functionality to facilitate the input processes. The overall system separates inputs and outputs from the databases and specific tools are proposed for specific tasks within the data flow. This is shown in Figure 1. The system consists at present of a tool for collecting emission data and storing them into an MS Access format database (**CollectER**) and a tool to extract, interpret and aggregate the data in this database into one of the formats requested by international conventions and protocols like the United Nations Framework Convention on Climate Change (UNFCCC).

Figure 1 The Corinair system: different modules for different tasks



For a number of activities complicated emission estimation methods and large sets of emission factors are available for the inventory expert. In such cases, automated tools to provide the user with this information and to help him or her with applying it, could be desirable. Such modules are named **EstimatER**'s in Figure 1. Within the CORINAIR system such a tool now is available.

FUNCTIONAL DESIGN

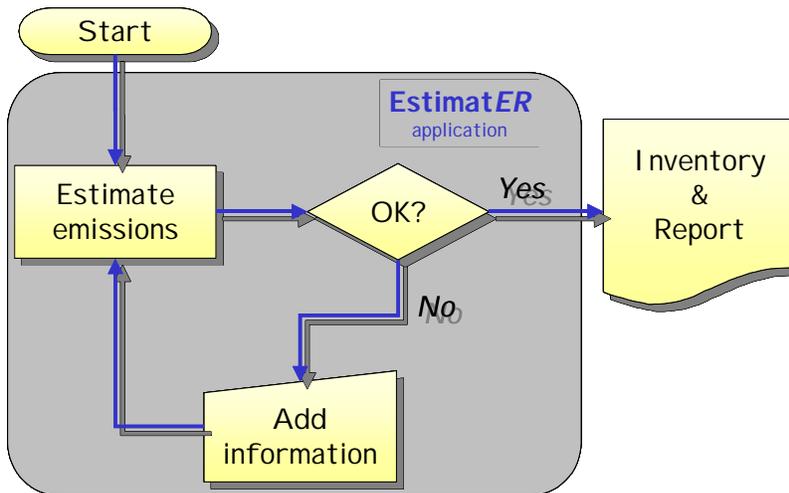
Overall functionality

The **EstimatER** emission estimation procedure is a cyclic process as drawn in Figure 2. At the start of the estimation procedure, the tool is loaded with a full set of default data, needed for this estimate and the tool presents this estimate to the user. These default data include default activity rates, so a first estimate of the emissions is directly available.

If the user accepts this estimate, **EstimatER** will store the information in the emission inventory and will produce, upon request by the user, an emission report.

If the user does not accept the estimate as produced by **EstimatER**, the user needs to input extra information. This allows the tool to produce a new estimate and to present this to the user. This cyclic process will improve the estimate until the user is satisfied with the quality of the result.

Figure 2 Procedure of EstimatER emission estimation



The procedure as described here can only be performed if the following conditions are met:

1. The tool must be able to produce a full estimate at the very start of the procedure. It therefore needs “to have default knowledge” of the sector and all its sub-sectors and the relevant emission estimation methods, including the parameters (emission factors etc.) in these methods
2. The user must be able to judge whether or not the resulting emission estimate is acceptable. To enable this, the tool needs to keep track of the quality of the estimate and needs to present the quality of the estimate together with the estimate itself.

Below we will describe these issues in some more detail.

The knowledge library

The library contains all knowledge that is necessary for the estimation of emissions in a certain branch of the economy. In emission inventories, the emissions are estimated from known intensities of relevant processes in the economy and society. All emission estimation methods are of the form:

$$Emission_{process, pollutant} = f(Activity Rate_{process}) \quad (1)$$

In most, but not all, cases the function is a simple linear equation:

$$Emission_{process, pollutant} = Activity Rate_{process} \times Emission Factor_{process, pollutant} \quad (2)$$

Examples of more complicated algorithms can be found in the IPCC methods for agriculture or for the emissions of volatile organic compounds from storage tanks. Hence, the knowledge, which must be available to the **EstimatER** tool, consists of two parts:

1. Knowledge on the “Activity Rates” (AR) of the relevant processes
2. Knowledge on the methods (functions and parameters like “Emission Factors”, EF) to be used.

In **EstimatER** this latter knowledge is derived from available emission estimation methods in the UNECE / CORINAIR Guidebook (3) and the 1996 IPCC revised Guidelines (3). These references provide the algorithms and default values for both emission factors and, if necessary, other parameters in the estimation algorithms. In addition default activity rates are needed.

While improving the estimate the user will replace default activity rates and emission factors by the national data, if available, thus increasing the “knowledge” of the system and hence the quality of the estimate, until the user is satisfied.

Quality of the estimate

In the procedure described above, the implicit assumption is made that any value, provided by the user, will be “better” than the default values. For the activity rates, this is easily understandable, since the user in most cases will use recent statistical information. In case of emission factors this is less clear. The user might propose emission factors that are not really applicable in his or her country’s circumstances.

Nevertheless, for the time being, we assume here that the default values, as proposed by the Guidebook or Guidelines are always less specific than the ones the user wants to apply. Since only very limited information on the uncertainties of emission factors is available, there is no general knowledge available that could be used to assess the applicability of the emission factors the user enters. This is an issue for future development of the tool.

As is indicated above, the user needs to have insight into the quality of the emission estimate produced by **EstimatER**, to be able to judge whether or not this estimate is satisfactory. In this respect two aspects of “quality” are relevant: the scientific and the procedural quality. **EstimatER** has to follow the

Guidebook and Guidelines, since it is part of a software system that is designed to support national experts in compiling emission inventories in response to international conventions and protocols.

The IPCC Guidelines propose for many sectors different “Tiers” to estimate the emissions. Higher tiers are assumed to have higher quality but require more detailed input information. In **EstimatER** these tiers are available and different Tiers can be applied at different sectors or sub-sectors.

In some cases direct measurements of emissions can be available. It is assumed that, whenever this will occur, a measurement has higher quality than an estimate using emission factors and activity rates. This is probably not true when a mass balance approach is feasible (CO₂, SO₂), but in such cases measurements will in general not be considered. **EstimatER** allows input of a measured value at any level of the estimate.

The Good Practice and Management of Uncertainties guidance calls for QA/QC systems to be implemented in the national systems for greenhouse gas inventories. Part of such systems is the documentation of the estimation process: what method has been used, what inputs (Activity Rates) and what parameters (Emission Factors etc.) have been applied. **EstimatER** therefore is equipped with a logging function, storing information of all information provided to the system by the user.

Against this background, the simplest way to quantify the quality of an estimate, produced by **EstimatER** is the fraction of default values in the estimate, which has been replaced by “better” knowledge being the national values, inputted by the user.

TECHNICAL DESIGN

Application and libraries

As explained above, the **EstimatER** tool is designed to be a generic tool, allowing application of its concepts and methods in different fields. This has led us to a design in which the knowledge library is separate from the application. All sector specific information is stored in this library and the application uses this information when applied to a specific sector, sub-sector or source.

The **EstimatER** tool therefore consists of two major parts and some auxiliary files (Figure 3):

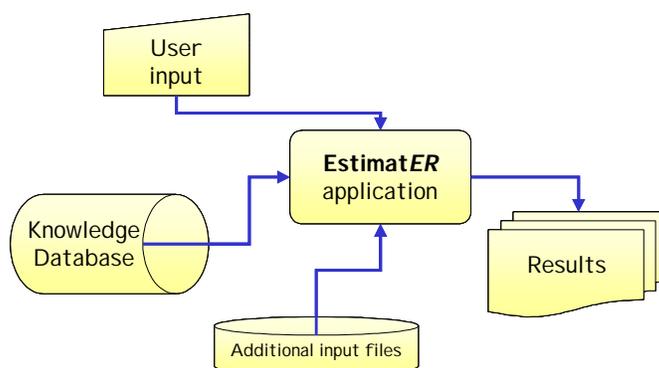


Figure 3 Architecture of EstimatER

The EstimatER application

The **EstimatER** executable could be viewed as an interpreter and editor on the knowledge stored in the library. Upon starting the application and commencing a new inventory model, the tool will copy all knowledge needed from the library in the partial inventory for the sector under study as a starting point for the user’s own estimate. The application will allow the user to replace the default values in the estimate by national values, keeping track of these changes in a log and producing the estimates including a quality indicator for all information.

The application is designed such that it could be in two distinct modes:

1. The definition mode: the user can drag and drop sectors, sub-sectors or even individual processes into his country's emissions inventory, thus defining an emission inventory model for the sector under study, using the information as stored in the library.
2. The calculation mode: the application presents the user with the emission estimates, obtained from the inventory model and quality indicators, showing in detail how the estimate has been made; the software allows the user to change input variables (activity rates) and parameters (emission factors etc.) in order to improve the inventory model and hence the emission estimates.

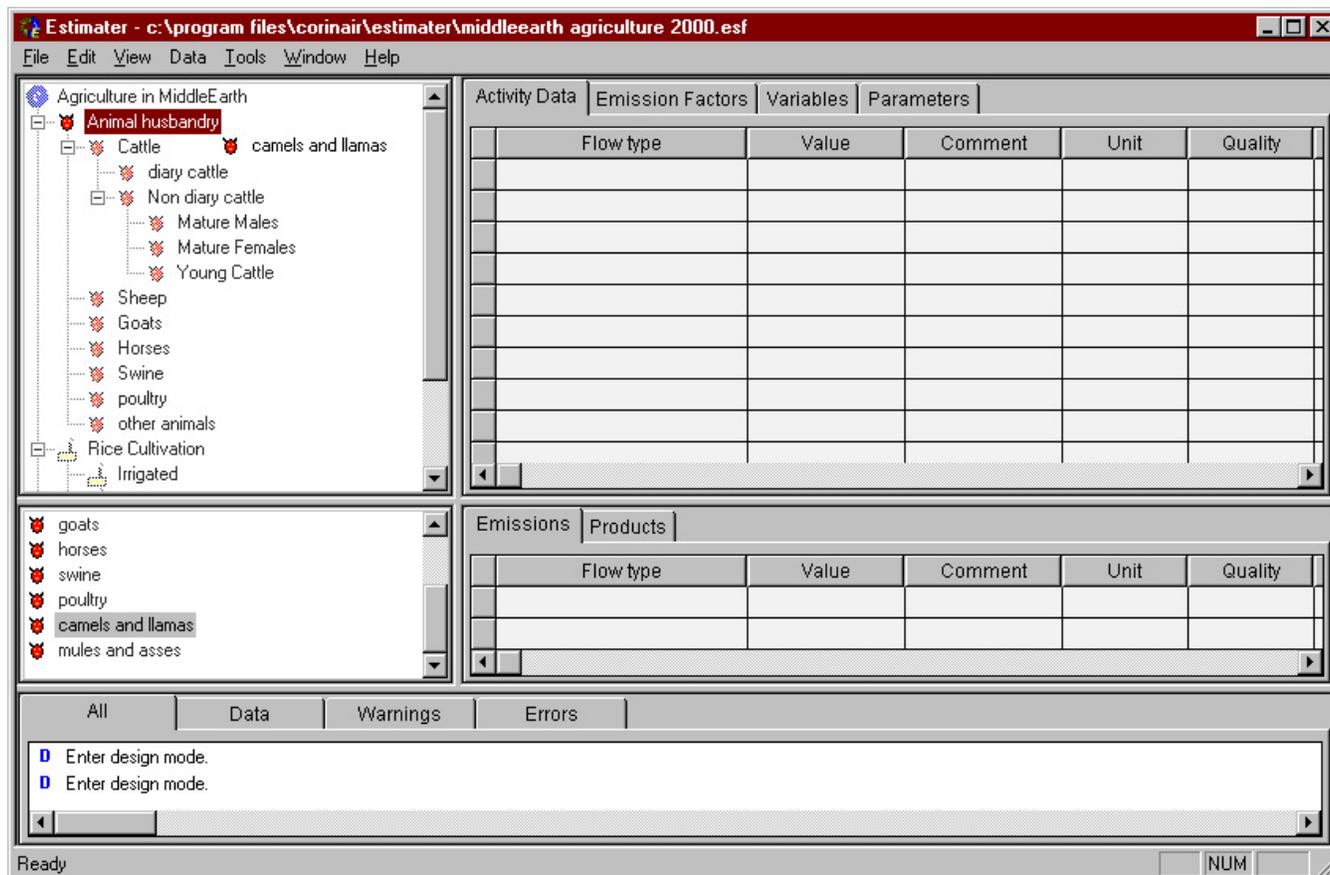
The application furthermore takes care of export of the emission estimates and relevant background information to the CRF report.

Library: a knowledge database

In an **EstimatER** library one or more default sectors, sub-sectors or even individual sources are made available to the user. Each of these sectors is at the same time a description of processes and sub-processes included in the sector and an emission estimation mechanism for this sector. In object oriented terms, one could say that this library is a collection of objects, defining a process with default properties and knowing how to estimate the emissions of greenhouse gases from this process.

Each entry in the library therefore describes a sector, sub-sector or sub-process that might occur in the source sector under study. In the definition mode of the application, the user drags and drops any number of copies of each of these into his inventory model. This also means that the objects have to "know" where they might and where they might not fit into the sector. This is shown in the example of Figure 4 for the IPCC method to estimate greenhouse gas emissions in agriculture.

Figure 4 Defining a country's agriculture by EstimatER in design mode.



When a user wants to add some animal type (“camels and llamas”) to the country’s agriculture, the object “camels and llamas” need to know that this activity must be part of “animal husbandry” and should be added at the correct place in the structure. The object will also include a default number of camels and default values for all parameters needed to calculate the emissions of greenhouse gases, connected to keeping camels in a farm.

EstimatER is equipped with one or more sector specific libraries. The libraries are compiled during design of the application and cannot be directly changed or approached by the user. The user selects one of these at the start of an emission estimation procedure and all relevant objects can be dragged into the inventory.

Additional input and output data files.

Apart from the main parts of **EstimatER**, the system might be completed with additional files with country specific default activity rates (e.g. energy balances for the Reference Approach or animal counts and crop productions for agriculture). This information is not strictly necessary, but might make the use of the system simpler. It is meant to enable the user to include a first estimate of the country’s activity into the emission inventory model for the sector. These files will be of a commonly used spreadsheet format, allowing the user to prepare or edit such information whenever needed. The format implemented at present is a format directly derived as an export from the IEA energy data.

The results of an estimation procedure can be saved and reopened for further processing at any time.

The library is build by the supplier of the system. It is stored in a special format readable by the application. This library must be consistent with the Guidelines or Guidebook that is implemented into the library. The user therefore cannot edit the library. Editing the library is in principle only necessary when the guidelines or the guidebook changes.

Since an **EstimatER** session starts with copying all information that is needed for the specific task into the country’s estimation and all input values and parameters are accessible for reading and editing by the user, the user can adapt the system to all specific circumstances that might occur in the country. Then there is indeed no need to change the library. An **EstimatER** data file can always be used as a starting point for a next estimation activity avoiding any duplicate work.

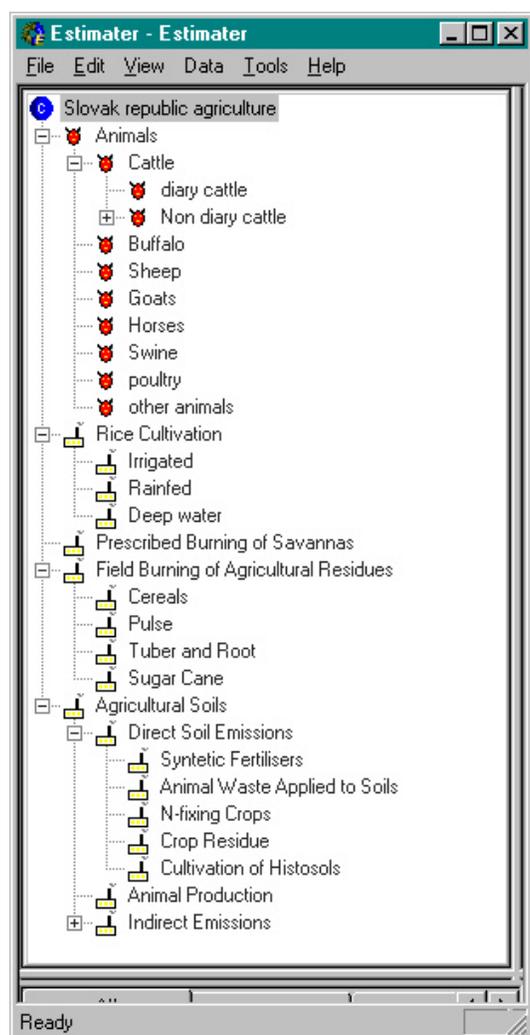
MODELING THE SECTOR

In **EstimatER** the sector under study is modelled into a hierarchical tree. An example of such a tree is given in Figure 5. This tree partly represents a country’s agricultural sector. We will use this tree to explain the mechanisms of information input into the estimate and how this information is distributed throughout the estimate.

The hierarchical tree links processes in such a way, that every process might consist of one or more sub-processes. In terms of emissions the sum of emissions of such sub-processes must be equal to the emissions of the process itself. The emissions of the total sector then end up as emissions of the top-level process in the structure. Such structures have been implemented in the new CORINAIR software system.

In **EstimatER** a further step in the development has been set by applying an object oriented approach. Each of the “processes” now represents an “object” having certain properties and “knowing” certain functions and procedures. Apart from properties characterizing the process (sector code, fuel type, location, etc.) and procedures for loading, saving and printing, the following are essential for the emission estimation:

Figure 5 Example of an EstimatER data structure for Agriculture



- 1) Properties:
 - a) The intensity of the process (“activity rate”): the variable of the emission estimation (“inflows”);
 - b) The resulting emission: the output of the emission estimation (“outflows”).
- 2) Functions and procedures: the emission estimation method, including the parameters, used for the process

This section will shortly describe these properties and functions and how they are interconnected. The next section will describe what happens if the user changes default values for variables and parameters by country specific values.

The **EstimatER** application copies any number of hierarchically related objects, as described above, into the emission estimation and allows the user to change the properties and the parameters of the functions and procedures of each of these objects.

Emissions

Calculated as the sum of the emission of the emission property of all of the underlying sub-processes.

Activity rates

The property “activity rates” represents the input to the emission estimation algorithm. Also in this case the tree must be consistent.

Functions and procedures

The function and procedures are the elements of the objects that know how to estimate the emissions and how to keep the tree consistent. The emission factors and other parameters are stored with these functions.

At the start of an **EstimatER** application all properties and parameters of functions and procedures are preloaded with the default values.

The behaviour of the objects, describing the processes, in case the user enters new information is crucial for the way **EstimatER** operates. The user enters new information into **EstimatER** by replacing default values by the own national values. This information both needs to be carried upwards in the tree structure and distributed downwards to more disaggregated levels.

To disaggregate information to more detailed levels, additional assumptions must be made. **EstimatER** assumes that the relative contributions of sub processes to a higher-level process remain the same when new information is added at the higher-level process. The resulting data at such more detailed levels might in some cases depend on the order in which the information at higher levels is entered. The system however is designed such that all data provided by the user will not be changed anymore when new information is added at either higher or lower levels.

AVAILABILITY OF THE SOFTWARE

The software described in this paper has been developed within the work programme of the European Environment Agency and is freely available via the Internet (1). At present two knowledge libraries are available:

- 1) The methods for the agricultural sector as described in the revised 1996 IPCC guidelines (4) as shown above; and
- 2) The so-called reference approach for the CO₂ emissions from energy.

REFERENCES

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- (2) M.P.J. Pulles, J. Skákala, J. Svetlik, M. Linek The new CORINAIR system: an integrated set of tools for national emission inventories, in: *Emission Inventory: Living in a Global Environment*, proc. AWMA/EPA Emission Inventory Conference New Orleans, December 8 - 10, 1998, pp 257-266.
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