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Best Practices for Preparation of GHG Inventory for Industrial Processes

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The greenhouse gases (GHG) inventory is among the main issues to be reported and analysed in the National Communications submitted to the United Nations Framework Convention on Climate Change (UNFCCC). A complete and transparent national GHG inventory is an essential tool for understanding emissions and trends, projecting future emissions and identifying sectors for cost-effective emission reduction opportunities, as well as for designing appropriate climate change policies – reflective to the country specifics and, at the same time, responsive to the international requirements.
Industrial processes are among the sectors covered by the national GHG inventories, accounting for emissions produced as by-products of various non-energy-related industrial activities and are not directly a result of energy consumed during the process. Although with relatively lower contribution to the total GHG emissions compared to energy sector, the industrial processes sector is of particular interest since, in most countries, the emission calculation is challenged by high level of uncertainty and limited availability of activity data, need for new ways of data collection and management, as well as for country specific emission factors.
The main goal of this paper is to highlight the good practices and lessons learned regarding the GHG inventory for industrial processes in the case of the Republic of Macedonia. The way many of the challenges have been addressed shows solutions and initiatives, including application of more complex methodology for uncertainty estimation, establishing a network of industrial stakeholders, designing a software tool for data collection and developing country specific emission factors for the key source categories. Mapping the way towards these achievements, the paper could serve well for countries with similar national circumstances and priorities.

1. Introduction

The GHG inventory is a database of calculated direct and indirect GHG emitted to or removed from the atmosphere over a period of time. Six direct gases are taken into consideration CO_2, CH_4, N_2O, PFCs, HFCs and SF_6 and four indirect: CO, NOx, NMVOC and SO_2. The Intergovernmental Panel on Climate Change methodology and good practice guidance for preparation of the national GHG inventory (IPCC, 1997, 2000) includes the sectors Energy, Industrial Processes, Solvent and Product Use, Agriculture, Land Use, Land-Use Change and Forestry, and Waste. Applying this methodology, the countries are striving to prepare their national GHG inventories as a key element of their National Communications in order to comply with the obligation under the UNFCCC.
The Republic of Macedonia submitted the First and Second National Communications on Climate Change (Ministry of Environment and Physical Planning, 2003, 2008) while the preparation of the Third National Communication began in April 2012. The GHG inventory under the first two Communications has played a decisive role for evaluation of the economic and environmental effectiveness of climate change mitigation in general (Markovska et al., 2008), as well as in some specific sectors like power generation (Taseska et

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al., 2011), renewable energy sources (Dedinec et al., 2012) and renewable electricity (Cosic et al., 2011). Furthermore, the national GHG inventory was utilized in the analyses for the sake of sustainable energy planning (Markovska et al., 2009) including assessments of climate change impacts on the energy sector (Taseska et al., 2012). Although project-based, the national inventory team was structured so as to ensure implementation of QA/QC procedures and reliability of emissions estimates, particularly for the energy sector (Markovska and Grncarovska, 2006). Thus, with the Third National Communication the focus of the efforts for inventory improvement has been shifted towards non-energy sectors and more process-oriented-approach has been applied through establishment of a multi-disciplinary national inventory team under the Ministry of Environment and Physical Planning (Zdraveva et al., 2012). A critical need for improvement was identified in the industrial processes sector mainly due to limited availability of activity data and high level of uncertainties of emission estimates (Markovska et al., 2003).

In this paper, the uncertainties of the GHG inventory for industrial processes will be estimated. This sector is particularly interesting for uncertainty assessment since the cumulative result depends from many variables with high uncertainty. Within industrial processes there are inter-annual fluctuations, as well as significant changes from one year to the next due to introduction of new industrial production or temporary or permanent plant closures. Changes in the process, production intensity or technology are also introducing significant fluctuations. Emission trends for each category and/or sub-category are explained in terms of some type of economic or technological change. This is the reason for this sector being so sensitive to change and the uncertainty analysis would estimate if the results are within the confidence range.

Furthermore, the paper will elaborate on the practices which are introduced to alleviate the uncertainties and data gaps, contributing thus towards implementation of the principles of transparency, consistency, comparability, completeness and accuracy in the national GHG inventory.

2. Methodology for uncertainty estimation

The uncertainty estimation is based on the Monte Carlo algorithm. This method is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large. For every variable, random values is generated for each input and used in the methodology formula to calculate the desired outputs. This process is repeated over 40,000 iterations in order to compute multiple estimates of the model output. The methodology includes the following four steps:

Step 1: Specify the category uncertainties.

Estimation of parameters and activity data, their associated means and probability density functions and any correlations.

Step 2: Select random variables.

Selection of input values. Input values are the estimates applied in the inventory calculation. This is the start of the iterations. For each input data item, a number is randomly selected from the probability density functions of that variable.

Step 3: Estimate emissions and removals.

The variables selected in Step 2 are used to estimate annual emissions and removals based on input values. Since the emission calculations should be the same as those used to estimate the national inventory, the Monte Carlo process could be fully integrated into the annual emission estimates.

Step 4: Iterate and monitor results.

Iteration and monitoring of results. The calculated total from Step 3 was stored, and the process then was repeated from Step 2. The results from the repetitions are used to calculate the mean and the probability density functions.

3. Case study: Macedonian GHG inventory for industrial processes

GHG emissions in the Republic of Macedonia range between 10,000 to 14,000 kt CO_2-eq (Figure 1), mostly originating from the energy sector (73.41 %), followed by agriculture (12.87 %) and waste (7 %). Industry sector is accountable for 6.72 % of country emissions. Land use, land use change and forestry sector is responsible for 3 – 10 % of emissions, depending on forest fires, management of soils (limestone and fertilizer application) and conversion of land in the specified year. Solvents use sector has an insignificant share (600 kg) in the overall GHG emissions. In 2009, GHG emissions show 28.42 % reduction compared to emissions from the base year 2000, mostly due to the global economic crisis lower industry production and energy demands and the abandonment of farming practices.

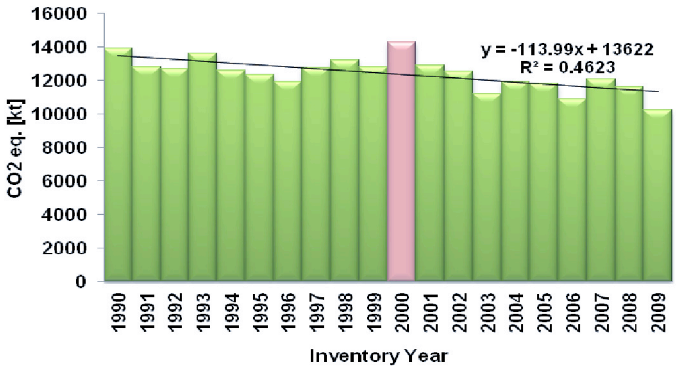

Figure 1: Total GHG emissions

As far as the specific direct GHG gases are concerned, 75 – 80 % of the emissions are CO_2 emissions (mostly from burning of fuels in energy sector), 12 – 14 % are CH_4 emissions (mostly from agriculture and waste sectors), 7 – 9 % are N_2O emissions (from burning fuels and emissions from soils) and 1 - 2 % are HFCs from industry sector.

In the industrial processes, most of the emissions are originating from both, mineral and metal products processes, in which cement industry and ferroalloys production emit over 77 % of the total emissions (Figure 2). HFCs are responsible for 23 % GHG emissions from industry emissions. The industrial production in the period 2003-2009 is stable in some sectors but, fluctuates in others. The cement production and commodities production are stable in the whole time series. The highest fluctuations are happening in the metal production category. The ferroalloy production marks an increase in 2007 and 2008 due to the availability of production data of the ferro-silico-manganese which was absent the previous year, and then a sudden downfall as a result of the world economic crisis. The iron and steel production also has increase until 2007, followed by a downfall due to the world economic crisis. Limestone use is calculated based on the steel production data.

In the key category analysis, the cement production and ferro-alloy production are identified as key categories. Also the HFCs consumption in refrigeration and air conditioning is identified as a key category in the period of 2004-2008 because of the high global worming potential of HFCs.

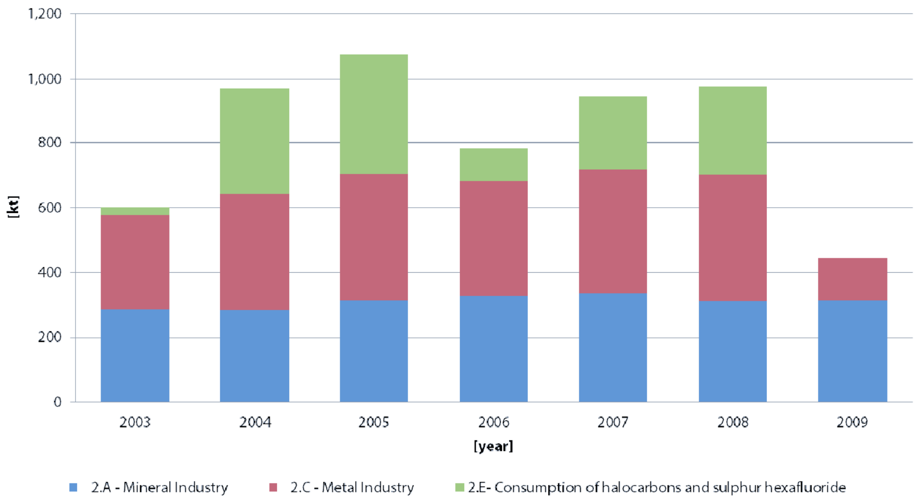

Figure 2: GHG emissions from industrial processes

The emissions for indirect GHG are calculated for each sub-category. The highest emitters of SO_2 are the mineral and the metal industry, while the NMVOCs are mostly emitted during the road paving process and production of food and beverages. The emissions of indirect GHGs are not included in the calculation of the total CO_2-eq emissions, as prescribed by the IPCC Good Practice Guidelines (IPCC, 2000).

4. Results and discussion

4.1 Uncertainty estimation

The results of the Monte Carlo Simulation have shown that the uncertainty level of the industrial processes GHG emissions ranges between 9.71 % and 16.12 %

Table 1: Results of the Monte Carlo simulation for the years with lowest and highest uncertainty level

	MAX	MIN	MEAN	ST.DEV	DEV/MEAN
2008					
Cement production	445.65	137.58	266.93	65.51	24.54%
Lime production	5.47	4.35	4.89	0.28	5.72 %
Limestone and Dolomite Use	17.31	5.41	11.03	3.04	27.60 %
Iron and Steel Production	63.44	43.10	52.82	4.65	8.80 %
Ferroalloy Production	0.00	0.00	0.00	0.00	0.00 %
Ferro-nickel	65.82	55.09	60.15	2.37	3.94 %
Ferro-silicon	195.96	162.37	178.48	7.32	4.10 %
Ferro-silico-manganese	93.50	77.31	85.25	3.46	4.06 %
Ferro-manganese	18.68	15.41	17.02	0.76	4.46 %
Aluminium production	6.23	5.16	5.71	0.24	4.14 %
TOTAL	**880.30**	**548.07**	**682.28**	**66.23**	**9.71 %**
2009					
Cement production	450.77	143.80	269.99	68.17	25.25 %
Lime production	5.45	4.36	4.88	0.29	5.91 %
Limestone and Dolomite Use	17.52	5.26	11.07	3.22	29.07 %
Iron and Steel Production	63.10	43.09	52.49	4.36	8.31 %
Ferroalloy Production	0.00	0.00	0.00	0.00	0.00 %
Ferro-nickel	53.01	43.63	48.15	2.01	4.17 %
Ferro-silicon	34.99	29.10	31.95	1.33	4.17 %
Ferro-silico-manganese	0.00	0.00	0.00	0.00	
Ferro-manganese	0.00	0.00	0.00	0.00	
Aluminium production	6.23	5.18	5.70	0.23	4.11 %
TOTAL	**609.40**	**295.51**	**424.24**	**68.39**	**16.12 %**

Some causes of uncertainty may generate well-defined, easily characterized estimates of the range of potential uncertainty. Other causes of uncertainty (e.g., biases) may be much more difficult to identify. It is good practice to consider the uncertainties and clearly document if some causes of uncertainties have not been included. The causes for uncertainty occurrence in each sector are as follows:

Cement production: Since most of the CO_2 emissions are occurring during the calcination process for the clinker production and there is no official data for the clinker production, these data were derived from the cement production data from the State Statistical Office. Additionally, to improve the clinker production estimation, data for total imports and exports of clinker are needed. This data were provided for the most recent years but not for the most of the years included in this GHG inventory and this is the main reason for the uncertainty in this subcategory. Since there is only one cement plant in Macedonia the nationally estimated emission factor and Cement Klin Dust (CKD) are considered to be more reliable.

Lime production: The accuracy of lime production emission estimates primarily depends on determining the total amount of CaO and CaO•MgO produced in the country. Since these minerals are also used as feedstock for other industrial processes, complete production statistics might be difficult to obtain. The great uncertainty in this category originates from the assumption that only lime for commercial trade is included within the State Statistical Office yearbooks and that implies only this amount to be included in the GHG inventory, omitting the quantities that are produced on the industrial plants for their own use. There is little uncertainty associated with the emission factor component since the stoichiometric ratio is an exact number, and therefore, the uncertainty of the emission factor is the uncertainty of lime composition which for the purpose of this analysis was gathered as default value.

Limestone and dolomite use: The State Statistical Office which is used as official data source for the preparation of the GHG inventory incorporates only production data but not data from the feedstock usage. The uncertainty in this sub-category is due to calculations that are used to estimate the limestone and dolomite use from the production data (e.g. metal production).

Iron and steel production: The most important type of activity data is the amount of steel produced which is derived from the State Statistical Office and with estimated uncertainty of ± 10 %. The calculation of the country specific emission factors is based on the use of data about consumed raw materials, including the quantities of reducing agents in the production of iron and steel. This method is based on tracking carbon in the production process through the mass balance and carbon content in the respective materials that have been used. Emission estimates are based on specific data about each plant. Therefore, the uncertainty of the emission factors estimates is ± 5 %.

Ferroalloy production: Uncertainties for ferroalloy production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainty related to the emission factor. The activity data of ferroalloy production by product type originated from the State Statistical Office which is a reliable source of information for the metal production. The uncertainties were estimated to ± 5 %. The emission factors for each ferroalloy are calculated with the method for emissions estimation that uses data for input raw material, as well as about the consumption of reducing agents which are used in ferroalloy production. Emission factors would be expected less than 5 % uncertainty level since plant-specific carbon content data are used.

Aluminium production: Since the closure of the most important industrial installation for aluminium production in 2003 in the country, the emissions from this sub-category do not influence much the overall emission. The activity data are estimated to have ± 5 % uncertainty. It can be noticed that the uncertainty is steady over the period 2003-2008 but there is spike in 2009 due to the economic crisis in 2008. The uncertainty is higher since the production of the goods with lower uncertainty has decreased.

4.2 Industrial stakeholders engagement

Most of the data provided by the State Statistical Office were not collected under the requested nomenclature. This led to possible unintentional discounting of some of the products and uncertainty whether some products belong under the IPCC requirements. The biggest problem occurred for the collection of feedstock usage instead of production (e.g. Soda Ash Use) since the the State Statistical Office does not report this kind of data. Furthermore these data were not well segregated which is a primary requirement for choosing adequate emission factors. In order to overcome this issue most of the bigger industrial installations were contacted and were asked to provide relevant information about the emission factors and ongoing process in the plants. This communication was conducted via the Macedonian Chamber of Commerce. However, the attempt achieved limited success since only several installations reported the required data in the given time frame. For additional collection of activity rate data the National Committee for Climate Change was gathered on a workshop in order to identify other potential sources for data. The working group for industry identified the Ministry of Environment and Physical Planning and the State Statistical Office as primary data providers, and the Ministry of Economy, Custom Duty, Chamber of Commerce as secondary sources.

4.3 Software tool for data collection

The Ministry of Environment and Physical Planning was additionally supported by developing a new software solution EMI (Emissions Monitoring in Industry) for the industry sector. EMI is a web based platform that gathers data directly from the industry installations about the annual production, feedstock usage, and specific production process details in distributed manner. EMI effectively speeds up the process of data collection for three inventories required from the industry sector, i.e. GHG inventory, Air pollutants cadastres and Cadastre of polluters. This software provides just one user friendly on-line form that appointed representatives from the industries fill only once per year, instead of many questionnaires sent sporadically throughout the year. Moreover, the experts from different departments can have access to the raw data and the reports with a separate administrative account.

4.4 National emission factors

Country specific emission factors are developed in close collaboration with the industrial plants. A leap forward is made in the used methodology especially in the metal production sub-category where the emissions are calculated applying more complex methodology (Tier 2) and the exact amount of feedstock used and its carbonate content data was taken into account. The plant specific data for the iron and steel production is taken from the A integrated environmental permit and the data for the ferro-alloys production are gathered directly from the industrial plants. Country specific emission factors are also developed for the cement industry.

5. Conclusions

The key for successful building of industrial GHG inventory is to provide relevant data with good quality. In order to establish a sustainable data collection it is important to develop transparent, comparable, coherent, complete and accurate measurement, reporting and verification (MRV) national system.
The reporting system should be robust, flexible, transparent and most importantly country driven so it can respond to national circumstances. On the other side, it must be in line with the most recently adopted or recommended IPCC Guidance and Guidelines (migration from IPCC Guidelines 1996 to IPCC Guidelines 2006). Institutional arrangements shall be based, where possible, on existing institutions (efficient usage of already existing staff), with the relation of new ones being the result of necessity. Deeper and stronger relation and collaboration with the industry installations and linkages with other relevant projects should be encouraged. It is difficult, but not impossible to incorporate GHG emissions in the reporting scheme of the A and B IPPC installations. It may be a matter of a separate project to train the responsible staff within the industry on the IPCC methodology
Finally, the inventory system must seek out the most cost effective solutions at all stages and structural levels, including multifunctional approach, i.e. the reporting under different conventions (e.g. CORINAR, PRTR) should be possible with one centralized data collection.

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References

Cosic B., Markovska N., Taseska V., Krajačić G., Duić N., 2011, The potential of GHG emissions reduction in Macedonia by renewable eectricity. Chemical Engineering Transactions 25, 57-62.
Dedinec A., Taseska V., Markovska N., Kanevce G., Bosevski T., Pop-Jordanov J., 2012, The potential of RES for GHG emissions reduction, Thermal Science, 16(3), 717-728.
Intergovernmental Panel on Climate Change (IPCC), 1997, Revised 1996 IPCC guidelines for national greenhouse gas inventories (Volumes I, II and III), IPCC, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, United Kingdom.
Intergovernmental Panel on Climate Change (IPCC), 2000, Good practice guidance and uncertainty management in national greenhouse gas inventories, IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, Institute for Global Environmental Strategies (IGES), Hayama, Kanagawa, Japan.
Markovska N., Grncarovska Obradovic T., 2006, QA/QC procedures in national GHG inventory process - Macedonian case, Proceedings of the workshop “Fulfilling the monitoring and reporting requirements under the UNFCCC and Kyoto Protocol” Budapest, October 9-10, 2006, VERTIC/REC.
Markovska N., Taseska V, Pop-Jordanov J., 2009, SWOT analyses of the national energy sector for sustainable energy development, Energy 34, 752–756.
Markovska N., Todorovski M., Bosevski T., Pop-Jordanov J., 2003, Assessment and mitigation of environmental impacts of industrial processes in Macedonia, Critical Reviews in Analytical Chemistry, 33(4), 1-6.
Markovska N., Todorovski M., Bosevski T., Pop-Jordanov J., 2008, Cost and environmental effectiveness of climate change mitigation measures, in: Sustainable energy production and consumption, (Barbir F. and Ulgiati S., Eds.), Springer Netherlands, 67-73.
Ministry of Environment and Physical Planning of the Republic of Macedonia, .2003, First national communication on climate change under UNFCCC, UNDP/GEF.
Ministry of Environment and Physical Planning of the Republic of Macedonia. 2008, Second national communication on climate change under UNFCCC. UNDP/GEF.
Taseska V., Markovska N., Callaway J.M., 2012, Evaluation of climate change impacts on energy demand, Energy 48, 88-95,.
Taseska V., Markovska N., Causevski A., Bosevski T., Pop-Jordanov J., 2011, GHG emissions reduction in a power system predominantly based on lignite, Energy 36, 2266-2270.
Zdraveva P., Grncarovska Obradovic. T., Markovska N., 2012, Macedonia: Good practices in the preparation of the greenhouse gas Inventories and V&A assessment, in: Country papers: Preparation of national communications from non-annex I parties to the UNFCCC; A compilation of lessons learned and experiences from selected countries, National Communication Support Progr. (NCSP), 48-54.