



THE DATA ANALYSIS SYSTEM FOR INDUSTRIAL AND ENTERPRISE GREENHOUSE GAS EMISSION

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Submitted: Mar. 10, 2013 Accepted: June 30, 2013 Published: Sep. 3, 2013

Abstract: A Data Analysis System for Industrial and Enterprise Greenhouse Gas Emission, for meeting the needs of the giant energy-consuming enterprises has been set up through a series of studies on the verification method of Greenhouse Gas (GHG) in industries such as cement, thermal power, cogeneration, transport, sewage treatment etc. The analysis system consists of six modules: Organization Structure; Facility; Activity Data Input; Emission Data Analysis; Report Generation; Parameters Configuration. The calculation process is based both on the Emission Factor Method and the Materials Balance Method; the first method performs an easy calculation for the GHG emissions released from the fuel combustion, electricity or steam consumption, general business and office activities; the last one provides a specialized calculation for the professional production processes such as cement production, exhaust desulfurization and sewage treatment etc. In order to test the system, it has been used as an example the GHG emission of a thermal boiler.

Index terms: Greenhouse Gas Emission; Data Analysis System; GHG Verification; Thermal Power; Cement.

field of goods and passenger transport. In 2010 was burned the equivalent of around 300 million tons of oil and the number will significantly increase over the next few years [10]. So the inventory work may start from the industries discussed above.

Nowadays, the data management information technology has got into a wide variety of industries, such as the carbon or GHG data management. The United Kingdom's BEST FOOT FORWARD, founded in 1997, is the first company in the world that focused on the carbon footprint area. It has helped hundreds of organizations through the carbon footprint analysis and managing to reduce the GHG emission [11]. PE-INTERNATIONAL from Germany is a consulting company mainly based on the product life cycle theory. Their self-developed software GaBi series has been updated to the 5th version following a 14 years development [12]. The GaBi database contains IKP, Codes, Eco Inventories of the European Polymer Industry (APME) and BUWAL. An analogous program, SimaPro, was in accordance with the life cycle theory as well, but the database was distinct. Dutch Input Output Database95, Data Archive, BUWAL250, ETH-ESU 96 Unit process, IDEMAT2001 and Eco Invent make up the SimaPro's database [13]. Both GaBi and SimaPro focus on the carbon footprint in the manufacture process and the data have been collected in Europe. Their advantage lay on the process design and material flue analysis. However, the operation complexity, time-consuming training, unsuitable database and language barrier become their obstacles on the Chinese market. On the domestic market, the carbon analysis and management software are still at an initial stage. The eBalance Evaluation produced by Environmental S&T Co., Ltd. is also a life cycle-based software which has achieved the basic function for the production process establishment and provided more environmental material parameters for the Chinese users (IKE IT, 2011). But the function for process establishment is not powerful enough when faced with complex industrial processes. The Carbon Accounting and Management Platform developed by Tanzuji Technology Co., Ltd. is the first management tool in China in the form of a website [14]. It can easily provide the carbon management and GHG emission calculation for most common business and industrial activities. Its simplicity is also a weak point as a customized calculation module is necessary in order to solve the

exhaust desulfurization and the two processes above mentioned.

Some interviews have been conducted in order to explore the system requirements which consisted of two parts: one is the functional requirement; while the other is the requirement for module functions. It has been drawn up a list with verifiers from the CQC and technical workers/managers from Industry/Enterprise with the CQC support. The individuals on the list depicted their work flows and responsibilities which might be relative to GHG generation and they have been asked on their needs in a data analysis system for GHG emission. The initial requirement structure has been formulated based on the interviews.

2) THE USERS' NEED FOR THE SYSTEM

The fundamental features, key modules and functions of the GHG Emission Data Analysis System have been extracted from the questionnaires and interviews, as listed in the Tables 1 and 2.

Table 1: The system scientific prototype

A GHG data analysis system for industry and enterprises should:

- be an integrated platform of a variety of calculation modules, each one of them being particularly useful to the GHG emission of one independent industrial process.
 - contain multiple versions of parameters such as the facility classification based both on IPCC and on China Energy Statistical Yearbook, Emission Factor suitable for international rules and also for national situations.
 - store the user information, input data and emissions calculation results.
 - improve the accuracy and normalization of GHG emission reports from the enterprise-users who might not be professional verifiers.
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Table 2: Requirements for the system modules and functions

Module	Functions
Organization	Creates and stores the organizational structure;
Facility	Adds the disposal facilities and selects their classification;

stationary combustion facility, mobile combustion facility, storage facility and production facility.

3) The emission sources identification. The work in this stage consists of identifying the emission sources within the boundaries based on their characteristics and distinctions. The emission resources are classified by three categories: Ist Category include the direct emissions from enterprises. The IInd Category means indirect emissions. The IIIrd Category is represented by the emissions released by non-energy sources. Another goal within this step is to clarify the chemical modification from sources to emissions or their physical change along with the production process because these are a vital theoretical basis for verifiers to confirm their calculation methods.

4) Acquiring activity data. The fourth step is the collection of activity data and their quantification. In order to ensure the reliability and accuracy, the data file maintenance procedures will be established, containing the sources, detailed records and scanned copies for future checking and certification.

5) The GHG emissions calculation. IPCC provided emission factors for various industries and the GHG Protocol also supplied many other conference materials for the GHG emission calculation. After the activity data quantification and emission factor selection, the verifiers will be able to obtain the GHG emissions according to certain calculation methods. Due to the fact that various GHG gases have different greenhouse effects on the climate change, it could be used the potential value of global warming to calculate the total carbon dioxide equivalent emissions.

6) The verification report. The verification report is the summary of the previous work and the inventory for GHG consists of:

- a) The organization boundary table;
- b) The GHG source identification table;
- c) The activity data verification table;
- d) The GHG emission factors management table;
- e) The GHG emission amount calculation table.

fossil fuel can be applied to calculating the emissions from coal, oil and natural gas consumption. Another parameter termed oxidation rate is also a key item for calculating the way in which different boilers or automobiles have different manufacturing standards.

The formula is:

(1)

E: emissions quantity (t)

Q: activity data (t)

NCV: low calorific value (kJ/kg)

EF: emission factor value (kg/TJ)

Oxi: oxidation rate (%)

b) Chemical materials: During the production process will be used several types of materials which may lead to GHG emissions, such as the carbon dioxide shielded welding, acetylene shielded welding and fire extinguisher filled with greenhouse gas. Their emission factors are easy to get through the chemical changes analysis. For example, based on the acetylene combustion chemical formula:



Thus, the acetylene emission factor is 88 /26.

c) Refrigerant: Irrespective of the office environment for company staff or for storing some materials having special requirements as concerns the temperature or many other industrial situations, the refrigerant plays a vital role in controlling the temperature. However, the common issue for all refrigeration facilities is the refrigerant leakage and the only difference lies in the leakage rate. The “IPCC 2006 Guidelines” have given accurate emission factors for different kinds of refrigeration equipments based on their models and how many years they have been used, the final formula for refrigerant’s GHG emission is:

(3)

E: emission quantity (t)

Q: quality of one unit (t)

N: unit number (n)

(6)

E: emission quantity (t)

N: people number (n)

EF: emission factor value (%)

WD: work days for staff (n)

2) THE MATERIAL BALANCE METHOD (MBM)

Since every emission has an original resource, the process of chemical change could be seen as the basic foundation of the material balance method. The production processes are significant for analyzing the manner in which the resources also turn into emissions. In the light of the project request, the system contains four major calculation methods based on MBM. The first method for coal combustion is applicable to every industry and the remaining three methods are designed particularly for the thermal and cement production.

a) Coal combustion: The coal combustion is very common in the industrial manufacturing and the sticking point for calculating the emission is the determination of the accurate carbon content. Firstly, use the carbon content value of the coal and the ashes after combustion and multiply by their mass separately. Secondly, subtract the two results and the final number represents the GHG emission from the entire progress.

The formula is:

(7)

E: emission quantity (t)

Q1: coal quantity before combustion (t)

Q2: ashes quantity before combustion (t)

C1: carbon content before combustion (%)

C2: carbon content after combustion (%)

b) Exhaust Desulfurization: With the increasingly stringent environmental requirements, the government has a strict limit of sulfur dioxide in the flue gas

emissions. The desulfurization facilities are generally installed in the exhausting passage where the sulfur dioxide gas discharge occurs. From the technical point of view, Flue Gas Desulfurization (FGD) can be divided into five methods: Calcium method (CaCO_3), Magnesium method (MgCO_3), Sodium method (Na_2SO_3), Ammonia method (NH_3) and organic alkaline method. 90% of the enterprises around the world use the calcium method due to economic considerations. The calculation method is based on the chemical change:



Four parameters are needed: the total mass of limestone, the content of CaCO_3 , the MgCO_3 content and the utilization. The formula is as follows:

(9)

E: emission quantity (t)

Q: limestone quantity (t)

C1: CaCO_3 content before combustion (%)

C2: MgCO_3 content after combustion (%)

K: utilization (%)

c) Cement Production: Following a thorough study of the materials and site investigation, the cement production process could be concluded from the GHG perspective, as shown in Figure 1.

Step 1. The limestone is crushed and mixed with other substances, such as clay, in order to be formed the raw materials.

Step 2. The raw materials are pre-homogenized through raw mill to get raw meals. Part of it will be collected by the dust filter and return to the raw mill.

Step 3. The raw meals with additional materials able to change the cement properties and that have no effect in terms of GHG emissions, are fed into a pre-heater in order to raise its temperature for the calcination process.

Step 4. The raw meals along with the fuel ashes are fed into the kiln from both ends and the calcination process starts. The product is the clinker and by-product is regarded as dust, which will be collected and set back into the dust filter. The

percentage of bypass dust called kiln dust cycling rate is a key parameter for evaluating the calcination efficiency and it is an influence factor for the GHG emission.

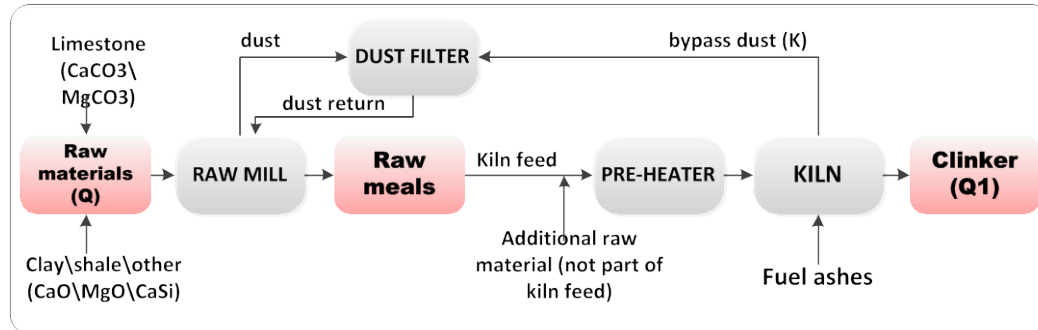


Figure 1. The cement production process in brief

The original materials for cement are limestone, clay, shale and other organic carbon; on the one hand, the carbon element in these materials is the main source for CO₂ release. On the other hand, the usage of fuel ashes is the other emission source for the cement production. The raw materials and fuel ashes are mixed up by a certain percentage according to the products demand, so as the coal combustion could be reckoned both from the raw materials and the clinker amount.

On the strength of this basic acknowledgement for the cement production, two methods for the GHG emission calculation are available: one based on raw materials and the other based on clinker. The first method needs data on raw materials and their chemical content percentage. The second method requires the amount of raw materials, clinker and the Calcium/Magnesium content percentage. In addition to this, the kiln dust cycling rate is also important for both methods and if the real number cannot be defined, the default value is assumed to be zero.

The raw materials-based formula is the following:

(10)

E: emission quantity (t)

Q: raw materials quantity (t)

K: bypass dust proportion (%)

C1: CaCO₃ content in raw materials (%)

C2: MgCO₃ content in raw materials (%)

C3: FeCO₃ content in raw materials (%)

C4: organic content in raw materials (%)

The clinker-based formula is:

(11)

E: emission quantity (t)

Q: raw materials quantity (t)

Q1: clinker quantity (t)

K: bypass dust proportion (%)

C4: organic content in raw materials (%)

C5: CaO content in clinker (%)

C6: MgO content in clinker (%)

THE SYSTEM DESIGN AND IMPLEMENTATION

1) THE SYSTEM INTERFACE DESIGN

To make the operation more convenient to the inspectors, the design of system operating steps is similar to the verification procedure. Six corresponding operating interfaces are shown in Figure 2 and the configuration interface is designed for checking or setting the parameters.

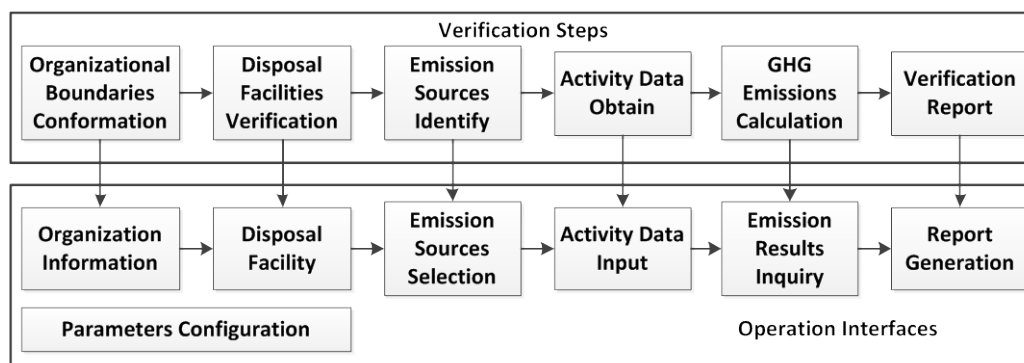


Figure 2. The design of operating interfaces

The users could establish the enterprise structure and enter the information for every department in the Organization Information interface, then will be added facility details to any sector in the Disposal Facility interface and will also be chosen their

emission source and calculation method in the Emission Sources Selection interface. After doing this, activity data can be entered in the next interface and the emission results will be available in the Emission Results Inquiry interface. If the customers are satisfied with the results, they could adjust their report format and get it from the Report Generation interface.

2) SYSTEM DATABASE DESIGN

From the system and calculation methods analysis above described, 9 tables have been established in the database for meeting the basic needs (Figure 3). The EnterpriseInfo, FacilityInfo, EmissionRecordInfo and EmissionFactorInfo are four main tables and other five are their affiliated tables.

a) EnterpriseInfo: The organization structure and its detailed information in this table, especially the disposal facilities, are of great significance. This is the table essential for establishing the structure and adding facilities.

b) FacilityInfo: Since the facilities are direct emission equipments and some properties have a key influence on the calculation, the FacilityInfo table also plays an important role. FacilityKindInfo related to it contains several common classifications of the GHG emission equipments and the oxidation rate or utilization rate value will be used in the calculation process.

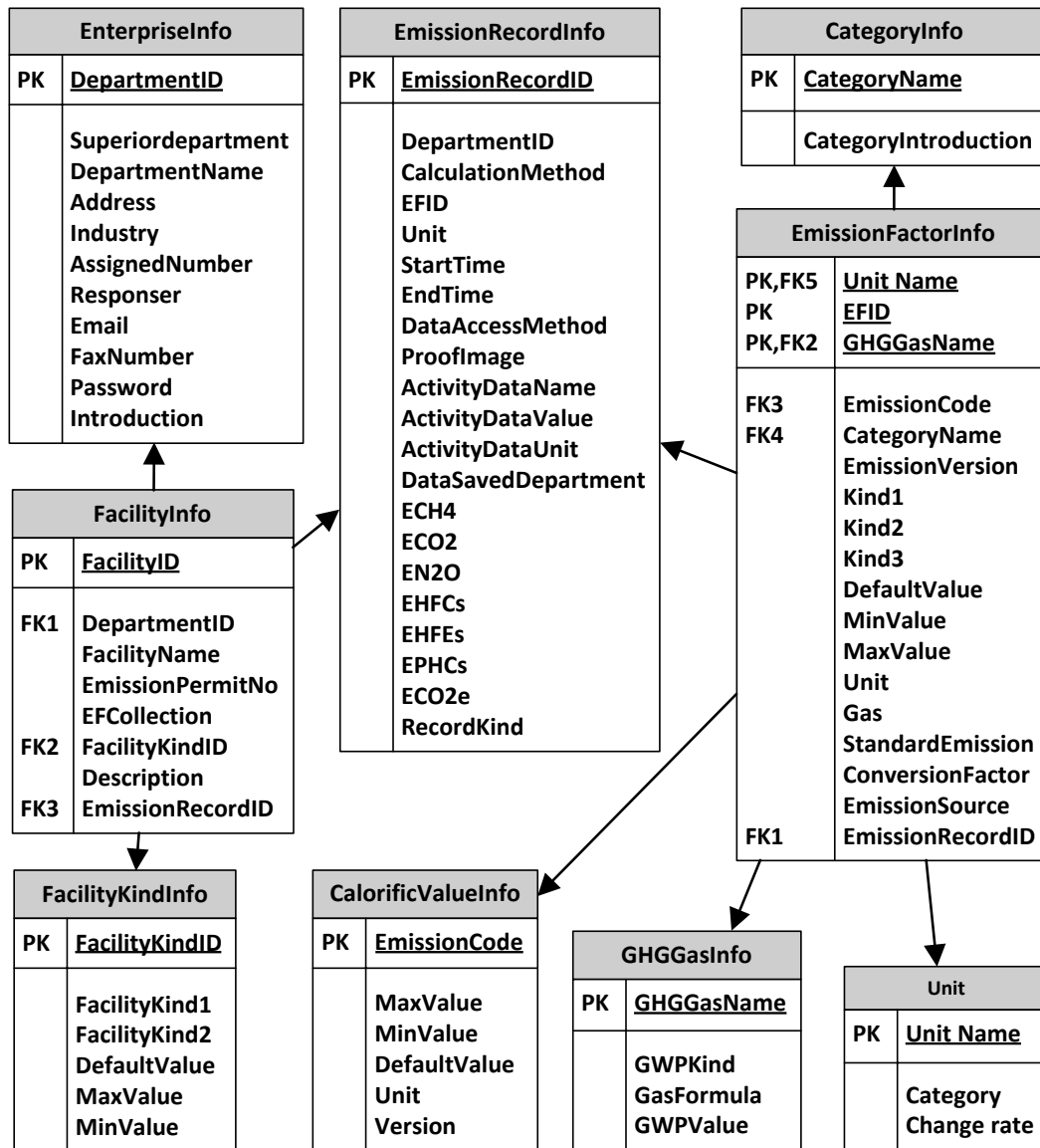


Figure 3. The design of system database

c) **EmissionFactorInfo**: This table encompasses plenty of vital information for the calculation of GHG emissions. The emission factors classification, the value for various emission sources, the category and gases that have been produced etc. Four related tables, whose names are **CategoryInfo**, **Unit**, **GHGGasInfo** and **EnergyCalorificValueInfo**, provide other key parameters for calculation such as the calorific value and units for all the results.

d) **EmissionRecordInfo**: Each piece of information on emissions is recorded in this table, including the calculation method, emission factor, time interval, activity data, copies of data recorded etc. The sorts of emission gases and their detailed values are also stored in the table.

e) Most of the default values in these tables are accompanied by the maximum and minimum value. Only the default values are used in the data analysis system and the other two values are intended for a further evaluation function.

3) THE SYSTEM DATA FLOW DESIGN

According to the interface design and database structure that has been set up, the system data flow has been conceived to include three stages: preparations for analysis; analysis process and analysis results (Figure 4).

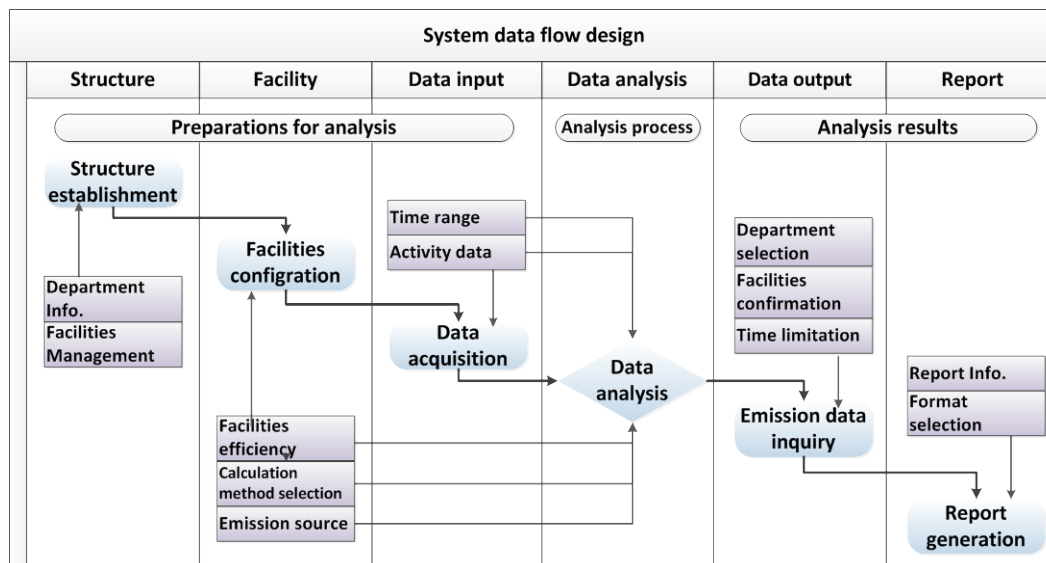


Figure 4. The design of system data flow

At the first stage, data has been gathered and stored in three database tables. The detailed information on the organization structure, such as relation among departments, address and responsible persons, has been listed in the EnterpriseInfo table. The facilities are linked by a primary key called FacilityID in the table FacilityInfo with the department. All the other relative columns are affiliated to describe the facility or ensure its parameters. The link between the FacilityInfo and EmissionRecordInfo tables was the emission source and the corresponding method of calculation or emission factor. The last table contains activity data, store record copies and time interval etc.

The key stage is the Analysis Process. For EFM, all the information for departments and facilities with their emission sources, parameters including the facility oxidation rate, emission factor and caloric value, along with the activity data previously

gathered or confirmed will be used to calculate the GHG emission amount. For MBM, the result will come from particular data and the contents value input at this stage for special facility and process. The results consist of the emission categories and numbers which are also saved in the table called EmissionRecordInfo.

Analysis Results is the last stage within the system data flow. Based on the data stored in the EmissionRecordInfo table, the detailed results can be checked on condition that the limitations are selected.

4) THE SYSTEM DEVELOPMENT AND DEMONSTRATION

The system was mainly developed using C# language in Microsoft Visual Studio 2010 integrated with SQL Server 2008 R2 as the database development tool.

Figure 5 shows the main interface of the data analysis system for GHG emission.

Users may open any of the seven main operational interfaces through these buttons.



Figure 5. Main Interface



Figure 6. Organization Interface

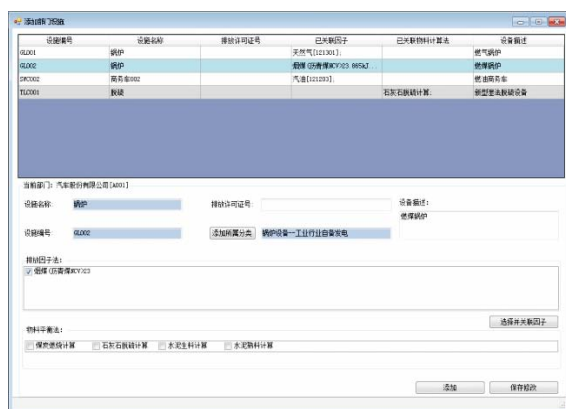


Figure 7. Facility Interface

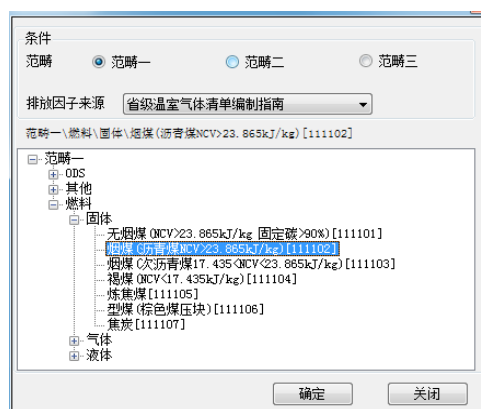


Figure 8. Emission Factor Selection

Figure 6 is the organization information interface. The organization structure can be set up in the left panel and the detailed information could be added or amended from the right panel for the selected department. Click on the “Disposal facilities

management” button in the center, a new interface will pop up (Figure 7). Right click on the top panel to add a new facility and enter the basic information in the blanks below. The most important step is to select the calculation method and the corresponding emission factor (Figure 8) or the production process for the facility because it is directly connected to the data analysis module. It also should be noted that two methods may be selected at the same time for one disposal equipment, such as an industrial boiler whose GHG emission could be calculated through either of them.

Figure 9 provides an example of the operation interface for activity data input. The existing organization structure is displayed in the left panel, the information for the selected department is shown in the middle-upper panel and the disposal facilities may be chosen from the drop-down list. Once defined the facility, its method and emission source, the users can fill in the start time, end time, data acquisition and upload data bills picture or copies to the database. The last step is adding activity data for the selected facility during a certain period. Different forms will pop up according to the different method or process.



Figure 9. AD Input Interface

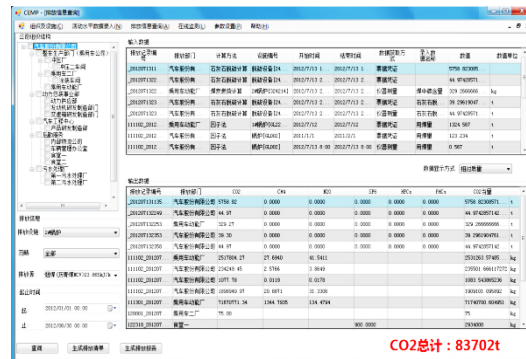


Figure 10. Emission Data Inquiry Interface

Figure10 shows the Emission Data Inquiry interface. After choosing the departments, selecting the facilities/categories and inserting the time range, then clicking the “query” button, the detailed input activity data and output emission data will be demonstrated on the right panels divided into two parts. The total amount of emission for the query appears on the right side, below the area in the form of red font. A report could be generated for the emission data if the “GHG Inventory generation” button is clicked,

based on the query results not on all the data in the database. Once the query conditions are changed, the report will be different.

IV. THE SYSTEM TESTING AND EVALUATION

1) GHG EMISSION CALCULATION, ENTERPRISES SELECTED

With the support of the project partner: China Quality Certification Centre , the thermal power factory located in Sanmenxia, Henan province has been selected for the system testing and evaluation; the factory has four main power-plants. Each one is independent of the others and the power-plant No.3 has been chosen as the calculation model.

2) THE SYSTEM TEST DATA AND RESULTS

The relative data have been directly gathered from their production records and divided into two parts. The first part is the coal combustion weighed by the electronic conveyor-weigh and recorded in the control center; the second lot of data is the limestone amount for desulfurization. The system has been tested for calculating the GHG emission at the power-plant No.3 between July 1st and September 30th (Table 4).

Table 4: Data on coal and limestone combustion

Month	July	August	September
Coal combustion (t)	110023.51	132041.90	109423.12
Average NCV (MJ/kg)	18.35	18.01	18.59
Limestone usage (t)	1294.6	1578.4	1204.9
CaCO ₃ content (%)	88.4	87.6	86.2
MgCO ₃ content (%)	5.8	6.2	5.9

The coal combustion was used for testing the EFM calculation and limestone usage amount for the MBM method. Finally, the automatic generation function has been applied in order to be obtained a report for the GHG emission results. The GHG emission results are displayed in Table 5 and Figure 11 (a/b).

Table 5: The GHG emission results

Month		July	August	September	GHG emissions
Coal combustion	CO ₂ (t)	183551.13	216202.7	184937.15	584690.98
	CH ₄ (t)	2.02	2.38	2.03	6.43
	N ₂ O (t)	3.03	3.57	3.05	9.65
Limestone	CO ₂ (t)	1247.75	1521.28	1161.29	3930.32
Total	eCO ₂ (t)	184532.33	217358.3	185925.67	587816.40

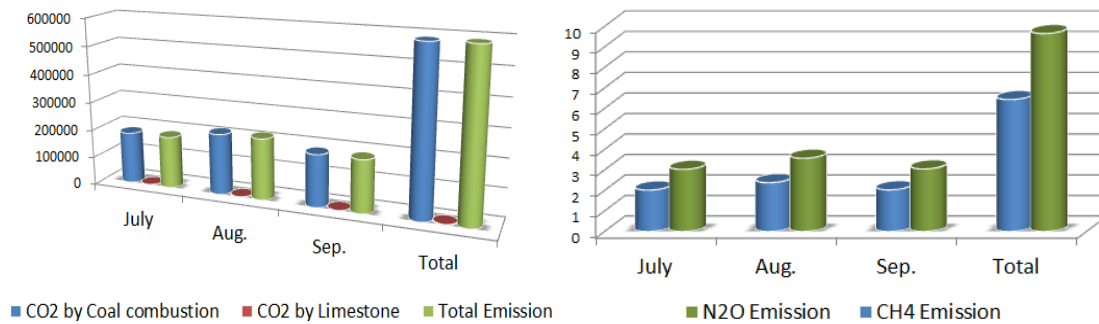


Figure 11 (a): CO2 emission results

(b): CH4 and N2O emission results

3) THE SYSTEM EVALUATION

The system evaluation measures the current performance and provides the basis for the future improvement of the system. The system evaluation on data analysis system was implemented after it has successfully verified the thermal GHG emission and generated the final report.

Three people from the Beijing Information S&T University, four from the China Quality Certification Centre and two from the enterprise have been invited to participate in a committee to form an evaluation framework for the data analysis system based on the views of system building, maintenance and user experience. They have also reviewed and suggested proposals related to the software. The system improvement suggestions included: (1) an automatic acquisition of the activity data, (2) an accuracy evaluation of the data analysis, (3) more modules for industrial production processes which would covering the most part of the GHG emission sources.

V. DISCUSSIONS AND CONCLUSIONS

This paper reports a data analysis system for the industrial and enterprise GHG emission. The system focuses on the actual need in the verification of GHG emission and performs an automatic data analysis. Compared to the existing calculation tools, the system is much closer to the verification work and management for organizations, as well as disposal facilities, and has a more professional feature. The operational parameters configuration interface provides more convenience for verifiers and the function of automatic reports generation could save more time and energy.

Following the testing and experiment evaluation of the data analysis system for industrial and enterprise greenhouse gas emission it has been proved to be an effective GHG emission management tool that would lead to the improvement of data calculation efficiency and the normalization of the operating process. In addition, it is not only helpful for the verification agencies but also provides a platform for the common enterprise staff to know and understand GHG emission verification.

ACKNOWLEDGEMENTS

This work is funded by "Twelfth Five-Year" national scientific and technological support project: Key technology research and demonstration of carbon emissions and reduction certification and accreditation (2011BAC04B00), National Key Technology R&D Program (2012BAH10F01, 2011BAC04B02), the New Century Excellent Talent Foundation from MOE of China under Grant (No.NCET-11-0893), Funding Project for Academic Human Resources Development in Institution of Higher Learning under the Jurisdiction of Beijing Municipality, Project of Research Center for Knowledge Management and, Beijing Higher School Science and Technology Innovation Platform. We also wish to thank all the participants for their contributions.

REFERENCES

- [1] C. R. Monroy, "Renewable and sustainable Energy Review – Chinese energy and climate policies after Durban Save the Kyoto Protocol", *Renewable and Sustainable Energy Reviews*, vol.16, pp.3243–3250, 2012.
- [2] S. Subbarao, BobLloyd, "Can the Clean Development Mechanism (CDM) deliver?", *Energy Policy*, vol.39, pp.1600–1611, 2011.
- [3] S. Seres, E. Haites, K. Murphy, "Analysis of technology transfer in CDM projects: An update", *Energy Policy*, vol.37, pp.4919–4926, 2009.
- [4] K. M. Lerstena, S. Gronkvist, "All CO₂ is equal in the atmosphere – A comment on CDM GHG accounting standards for methane recovery and oxidation projects", *Energy Policy*, vol.35, pp.3675–3680, 2007.
- [5] R. Geres, A. Michaelowa, "A qualitative method to consider leakage effects from CDM and JI projects", *Energy Policy*, vol.30, pp.461–463, 2010.
- [6] J. Yuan, Z. Hu. "Low carbon electricity development in China – An IRSP perspective based on Super Smart Grid", *Renewable and Sustainable Energy Reviews*, vol.15, pp.2707-2713, 2011.
- [7] Y. Lei, Q. Zhang, C. Nielsen, K. He, "An inventory of primary air pollutants and CO₂ emissions from cement production in China, 1990–2020", *Atmospheric Environment*, vol.45, pp.147-154, 2011.
- [8] D. Dodman, "Forces driving urban greenhouse gas emissions", *Current Opinion in Environment Sustainability*, pp.121–125, vol.3, 2011.
- [9] E. Pérez-Miñana, P.J. Krause, J. Thornton, "Bayesian Networks for the management of greenhouse gas emissions in the British agriculture sector", *Environmental Modelling & Software*, vol.35, pp.132–148, 2012.
- [10] W.K. Lai, M.F. Rahmat and N. Abdul Wahab, Modeling and Controller Design of Pneumatic Actuator System with Control Valve, *International Journal on Smart Sensing and Intelligent System*, vol.5, NO.3, pp.624–644, 2012.
- [11] Z. Liu, S. Liang, Y. Geng, B. Xue, "Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cities The case of Beijing, Tianjin, Shanghai and Chongqing", *Energy*, vol.37, pp.245–254, 2012.
- [12] Xu Xiaobin, Zhou Zhe, Wen Chenglin, Data Fusion Algorithm of Fault Diagnosis Considering Sensor Measurement Uncertainty, *International Journal on Smart Sensing and Intelligent System*, vol.6, NO.1, pp.171–190, 2013.
- [13] S.Y. Lee, "Existing and anticipated technology strategies for reducing greenhouse gas emissions in Korea's petrochemical and steel industries", *Journal of Cleaner Production* vol.01, pp.1–10, 2011.
- [14] A. M. El-Sayed, F. M. Ismail, M. H. Khder, M. E. M. Hassouna, S. M. Yakout, Effect of CeO₂ Doping on the Structure, Electrical Conductivity and Ethanol Gas Sensing Properties of Nanocrystalline ZnO Sensors, *International Journal on Smart Sensing and Intelligent System*, vol.5, NO.3, pp.606–623, 2012.