

for carbon management and greenhouse gas emission calculation on one hand. On the other hand, existing software is not sufficiently mature and the room for improvement is considerable. A system, which could provide easy operation interface for both common and specific processes GHG emission calculation, with appropriate data for Chinese market should be welcomed by the customers. Under such a background, an industrial and enterprise greenhouse gas emission data analysis system was developed covering industries such as cement, thermal power, cogeneration, sewage treatment etc. The GHG emission of management, production, transportation and other aspects was well studied and the calculation process is also designed in the system. A processing mode based on ‘input – output’ model along with special industrial processes was set up and it makes verification of GHG emissions simpler and calculation more accurate.

II. SYSTEM ANALYSIS

1) THE SURVEY DESIGN AND ANALYSIS

Multiple methods were adopted for the users’ requirements of the system including document collection, site investigations and interviews.

The documents about GHG verification, gained from China Quality Verification Centre(CQC), was of great value for the system structure design and other documents such as ISO 14064, IPCC 2006 Guidelines for National Greenhouse Gas Inventories, Kyoto Protocol and State Grid Emission Factor 2011 were collected to determine the key parameters in system development.

Site investigations to Anhui Conch Cement Corporation And Huayang Power Plant of Datang Power Group enhanced understandings about cement production and thermal power processes. At the same time, a large number of materials about cogeneration, sewage treatment, exhaust desulfuration and the two processes above were acquired for the system.

Interviews were conducted to explore the system requirements which consisted of two parts: one part is the functional requirement; while the other is requirement for the

module functions. A list was formulated with verifiers from CQC and technical workers/managers from Industry/Enterprise with the support of CQC. People on the list described their work flows and responsibilities which might be relative to GHG generation and they were asked about what they wanted in a GHG emission data analysis system. The initial requirement structure was formulated based on the interviews.

2) USERS' NEED FOR THE SYSTEM

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

Table 1: The scientific prototype of the system.

An industrial and enterprise GHG data analysis system should:	
●	Be an integrated platform of a variety of calculation modules with each of them particularly useful to one independent industrial process' GHG emission.
●	Contains multiple versions of parameters such as facility classification based both on IPCC and on China Energy Statistical Yearbook, Emission Factor suitable for international rules and national situations as well.
●	Store user information, input data and emissions calculations results.
●	Improve the accuracy and normalization of GHG emission reports from enterprise users who might not be professional verifiers.

Table 2: Requirements for the modules and functions of the system.

Module	Functions
Organization	Create and store organizational structure;
Facility	Add disposal facilities and select their classification; Confirm the emission source and calculation methodology.
Activity data input	Input activity data for each facility during a certain period of time; Store every piece of information contains department,

	equipment, bills scanned copies, types and quantities of emission gases etc.
Emission data analysis	Query emission results in accordance with the conditions of organization, facilities and time range; Display the results and make a comparison.
Report generation	Automatically generates a report of the GHG emission according to the inquiry results.
Parameters configure	Parameters of Emission Factor, Calorific Value, Oxygenation Efficiency, Global Warming Potential Value etc.

3) GHG EMISSION VERIFICATION FLOW ANALYSIS

The main steps, summarized from a careful analysis of verification of GHG emissions, are as follows:

- 1) Organizational boundaries confirmation. The first step for GHG verification is to confirm organizational boundaries. It contains all possible scopes of GHG emissions and should be described by a suitable method. In accordance with Greenhouse gas protocol, equity share approach and control approach are two applicable manners. Because different results may be yielded due to different methods, so once the manner for organizational boundaries is selected, all levels within that boundary have to use the same one.
- 2) Disposal facilities verification. No matter in the production process or in the business activities, all the greenhouse gas discharged from certain facilities not directly from organizations. Disposal equipments are also of great importance in GHG verification and can be divided into four main types: stationary combustion facility, mobile combustion facility, storage facility and production facility.
- 3) Emission sources identify. Work in this stage is to identify the emission sources within the boundaries based on their characteristics and distinctions. Emission resources are classified by three categories: Category I is directly emissions from enterprises. Category II means indirectly emissions. Category III represents emissions

produced by non-energy sources. Another mission in this step is to clarify the chemical change from sources to emissions or their physical change along with production process because these are vital theoretical basis for verifiers to confirm their calculation methods.

4) Activity data obtain. The fourth step is activity data collection and quantification. In order to ensure the reliability and accuracy, data file maintenance procedures are to be established contain the sources, detailed records and scanned copies for future verification and certification.

5) GHG emissions calculation. IPCC provided emission factors for various industries and the GHG Protocol also give many other conference materials for GHG emission calculation. After activity data quantification and emission factor selection, verifiers could get the GHG emissions according to certain calculation methods. For various GHG gases have different greenhouse effects on climate change, so the global warming potential value could be used to calculate the total carbon dioxide equivalent emissions.

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

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

III. CALCULATION METHOD ANALYSIS

The main functions of greenhouse gas emission data analysis system are to calculate the GHG emissions, to analysis and manage the activity and emissions data. Methodologies of the calculation, classification as well, are listed in the form below (table 3) with detailed analysis followed. The methods can be summarized as the Emission Factor Method (EFM) and the Material Balance Method (MBM).

Table 3: Classification of the calculation methodology

Methodology	Classification	Item examples
Emission factor method (EFM)	Fossil fuel	Coal\Oil\Natural gas
	Chemical materials	Acetylene\Heptafluoropropane...
	Refrigerant	CH4\HFC-R134a\R-404A...
	Purchased energy	Electric power\Steam
	Sewage treatment	Aerobic or anaerobic treatment pond...
Materials balance method (MBM)	Fossil fuel	Coal consume
	Thermal	Exhaust deslfuration
	Cement Production	Cement Production (Raw materials based)
		Cement Production (Clinker based)

1) EMISSION FACTOR METHOD (EFM)

EFM is the most popular methodology for GHG emission calculation all around the world, the emission factor mainly comes from <2006 IPCC Guidelines for National Greenhouse Gas Inventories> published by Intergovernmental Panel on Climate Change and <Provincial Guidelines Greenhouse Gas Inventories> Published by Chinese government.

Five sorts of emission resources in the system use EFM to calculate their emission amounts (listed in table 3):

a) Fossil fuel: As the undoubtedly main source of greenhouse gas, fossil fuels are widely used in every aspect of industries and enterprise businesses. The EFM for fossil fuel can be applied to calculating the emission from coal, oil and natural gas consumption. Another parameter named oxidation rate is also a key item for calculation as different boilers or automobiles have different manufacturing standards.

The formula is:

(1)

E: emission quantity (t)

Q: activity data (t)

NCV: Low calorific value (kJ/kg)

EF: emission factor value (kg/TJ)

Oxi: oxidation rate (%)

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



So the emission factor of acetylene is 88 /26.

c) Refrigerant: No matter in the office environment for company staff or for the storage of some materials which have special requirement on temperature or many other industrial situations, the refrigerant plays a vital role in controlling the temperature. However, all refrigeration facilities' common problem is the leakage of refrigerant and the only difference lies in the leakage rate. "IPCC 2006 Guidelines" has given accurate emission factor for different kinds of refrigeration equipments based on their models and how many years they have been put into use, the final formula for refrigerant's GHG emission is:

(3)

E: emission quantity (t)

Q: the quality of one unit (t)

N: unit number (n)

EF: emission factor value (%)

Y: years in use (n)

d) Purchased energy: As the emission of category II, purchased power makes up a considerable part of GHG emission from both enterprise daily office business and industrial factories. Because all forms of energy come from fossil fuel combustion so, absolutely, the emission is inevitable. For it doesn't come from the industrial plants or enterprise directly, so the emission equivalent from per KWh or per ton of steam is the key parameter for calculation. The system's emission factors for purchased energy refer to <State Grid Yearbook of 2011> and the formula is:

(4)

E: emission quantity (t)

Q: activity data (kWh)

EF: emission factor value (t/kWh)

e) **Sewage treatment:** According to “IPCC 2006 Guidelines”, sewage is divided into industrial wastewater and daily life wastewater. However, the main emissions for both of them are methane (CH₄) and the EFs are mostly decided by the equipments and treatments. Besides, the BOD/COD value of sewage before and after treatment is very important for the calculation of CH₄ emission. The formulas of these two kinds of sewage are:

Industrial wastewater:

(5)

E: emission quantity (t)

Q: activity volume (m³)

Q₁: sludge volume (m³)

C₁: COD Value before treatment (kg/m³)

C₂: COD Value after treatment (kg/m³)

C₃: COD Value of sludge volume (kg/m³)

EF: emission factor value (%)

Daily life wastewater:

(6)

E: emission quantity (t)

N: people number (n)

EF: emission factor value (%)

WD: work days for staff (n)

2) MATERIAL BALANCE METHOD (MBM)

Since every emission has an original resource, the process of chemical change could be seen as the basic foundation of material balance method. The production processes are significant for analysis about how the resources become emissions as

well. In the light of project request, the system contains four major calculation methods based on MBM. The first one for coal combustion is applicable for every industry and the other three are mainly designed for thermal and cement production.

a) Coal combustion: Coal combustion is very common for industrial production and the sticking point for emission calculation is to determine the accurate carbon content. First, use the carbon content value of coal and the ashes after combustion times their mass separately. Second, subtracting the two results and the final number is the GHG emission from the complete 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 desulfuration: With the increasingly stringent environmental requirements, the government has a strict limit sulfur dioxide in flue gas emissions. So desulfurization facilities are generally installed in the exhaust passage where sulfur dioxide gas discharges. From technical view, Flue Gas Desulfurization (FGD) can be divided into five methods: Calcium method (CaCO₃), magnesium method (MgCO₃), sodium method (Na₂SO₃), ammonia method (NH₃) and organic alkaline method. 90% of the enterprises use calcium method in the world because of economic considering.

The calculation method is based on the chemical change:



Four parameters are needed: the total mass of limestone, CaCO₃ content, MgCO₃ content and the utilization. The formula is:

(9)

E: emission quantity (t)

Q: limestone quantity (t)

C_1 : CaCO_3 content before combustion (%)

C_2 : MgCO_3 content after combustion (%)

K: utilization (%)

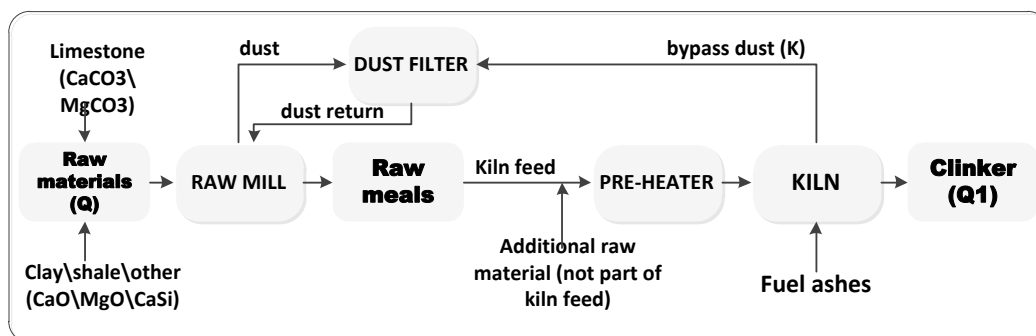
c) **Cement Production:** After meticulous materials study and site investigation, the cement production process could be concluded, from the GHG perspective, as in Figure 1.

Step 1. Crush the limestone and mixed it with other contents, like clay, to form raw materials.

Step 2. Pre-homogenize raw materials through raw mill to be raw meals. Part of it will be collected by dust filter and return to raw mill.

Step 3. Raw meals with additional materials, which could change cement property and have no effect for GHG emissions, are fed into pre-heater to make its temperature ready for calcination process.

Step 4. Raw meals and fuel ashes are fed into the kiln from both ends and the calcination process starts. The production is clinker and the by-product is regarded as dust which will be collected and set back into dust filter. The percentage of bypass dust called kiln dust cycling rate is a key parameter to judge the calcination efficiency and it is an influence factor for GHG emission.



Step 5. Figure 1. Brief cement production process

The original materials for cement are limestone, clay, shale and other organic carbon, the carbon element in these materials is the basic coming source for CO_2 on one hand. On the other hand, fuel ashes usage is the other emission source for cement production. The raw materials and fuel ashes are mixed up by a certain percentage

according to products demand, so the coal combustion is able to be reckoned both from the raw materials amount and the clinker amount.

Based on these basic acknowledge for cement production, two methods for GHG emission calculation are available: Raw materials based and Clinker based. The former one needs raw materials data and its chemical content percentage. The later method requires raw materials amount, clinker amount and the Calcium/Magnesium content percentage. Besides, 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 formula based on raw materials is:

(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 formula for clinker:

(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: MgC content in clinker (%)

SYSTEM DESIGN AND IMPLEMENTATION

1) SYSTEM INTERFACE DESIGN

To make the operation more convenient to the inspectors, the design of system operate steps are similar to verification procedure. Six corresponding operate interfaces are showed in Figure 2 and the configuration interface is designed to check or fix the parameters.

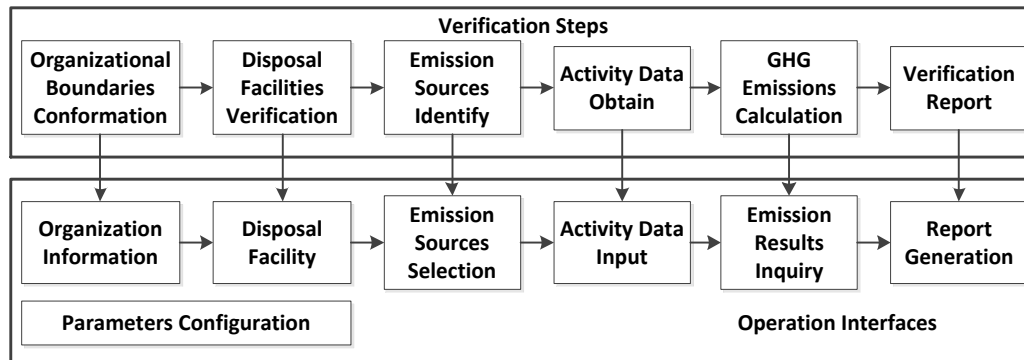


Figure 2. Operate interfaces design

Users could establish enterprise structure and fill information for every department in the Organization Information interface, then add facility details to any sector in the Disposal Facility interface and choose their emission source and calculation method in the Emission Sources Selection interface. After doing that, activity data is able to input in the next interface and the emission results are available in the Emission results Inquiry interface. If the results are satisfied, clients could adjust their report format and get it from Report Generation interface.

2) SYSTEM DATABASE DESIGN

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

a) EnterpriseInfo: Organization structure and their detailed information in this table especially disposal facilities are of great significance. It is the fundamental table for structure establishment and adding facilities.

b) FacilityInfo: Since the facilities are direct emission equipments and some properties are also key influence for calculation, the FacilityInfo table also plays an

important role. FacilityKindInfo affiliated to it contains several common classifications of GHG emission equipments and the value of oxidation rate or utilization rate will be used in calculation process.

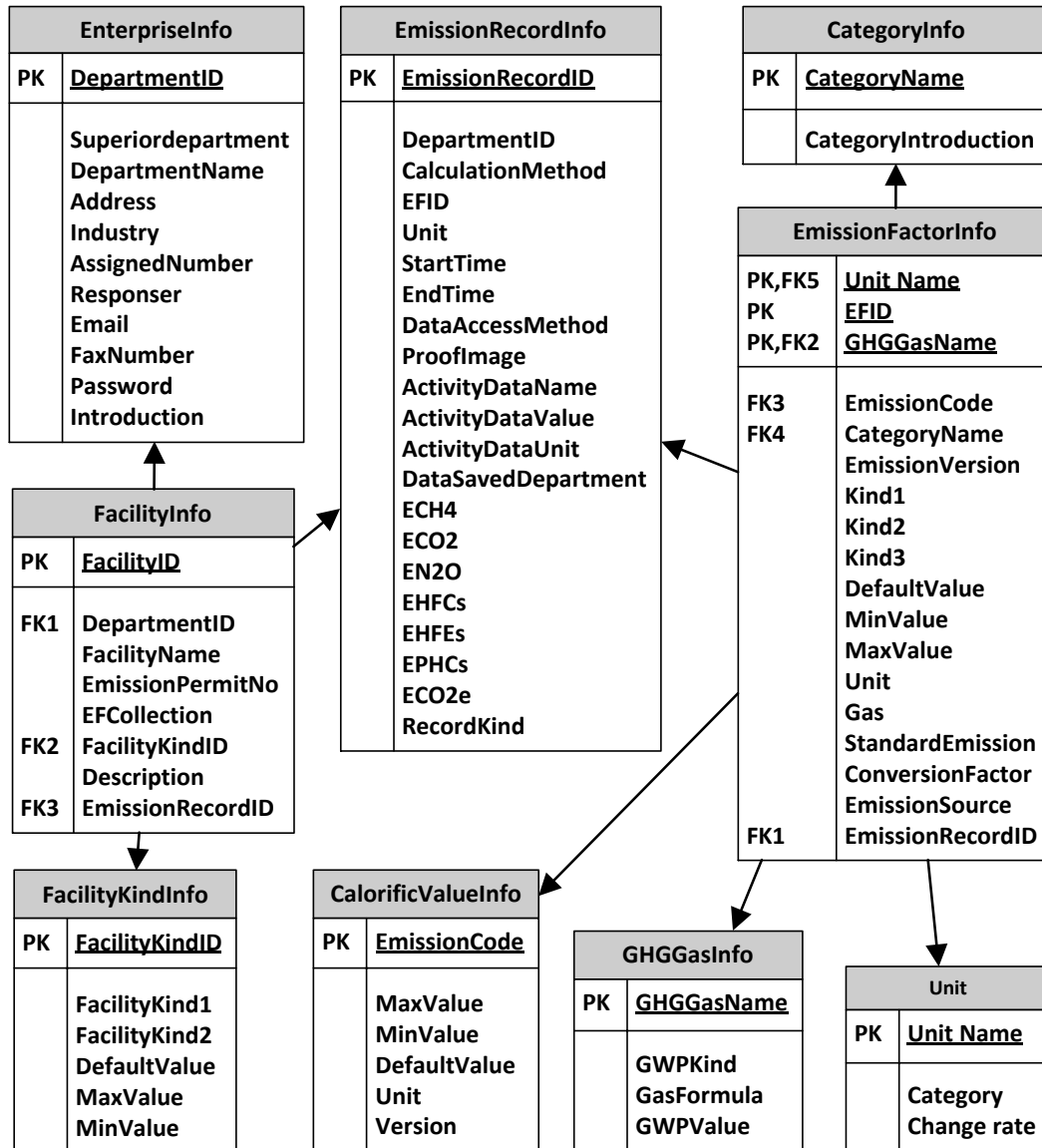


Figure 3. System database

c) **EmissionFactorInfo**: This table contains a lot of vital information for GHG emissions calculation. The emission factors classification, the value for various emission sources, the category and which gases have been produced etc. Four affiliated 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**: Every piece of emission record information is recorded in

this table. Including the calculation method, emission factor, time period, activity data value, data record copies and so on. The emission gases species and their detailed value are stored in the table as well.

e) Most of the default values in these tables are accompanied with max value and minimum value. Only default values are used in the data analysis system and the other two values are designed for further evaluation function.

3) SYSTEM DATA FLOW DESIGN

In accordance with the interface design and database structure which has been set up. The system data flow was designed to be made up by three stages: Preparations for analysis; Analysis process and Analysis results (Figure 4).

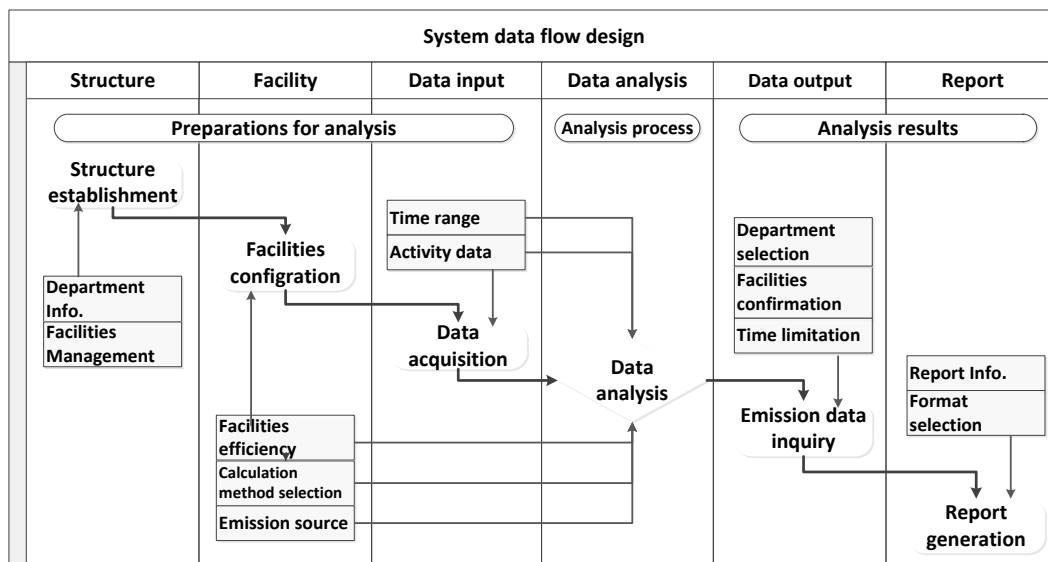


Figure 4. System data flow

In the first stage, data was collected and stored in three database tables. The organization structure detailed information, such as departments relationship, address and responsible person, were in the table EnterpriseInfo. The facilities are linked by a primary key called FacilityID in table FacilityInfo with the department. All the other relative columns are affiliated to describe the facility or ensure its parameters. The link between table FacilityInfo and table EmissionRecordInfo were the emission source and the corresponding calculation method or emission factor. The later table contains activity data, store record copies and time period etc.

The key stage is Analysis Process. For EFM, all the information for departments and

facilities with their emission sources, parameters including facility oxidation rate, emission factor and caloric value, along with activity data gathered or confirmed before will be used to calculate the GHG emission amount. For MBM, the result will come from particular data and the contents value input in this stage for special facility and process. The results consist of emission categories and numbers for each are also saved in the table EmissionRecordInfo.

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

4) 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 develop tool.

Figure 5 shows the main interface of GHG emission data analysis system. Users may open any of the seven main operational interfaces though these buttons.



Figure 5. Main Interface



Figure 6. Organization Interface

Figure 6 is the interface of organization information. Organization structure can be set up in the left panel and detail information could be added or amended from the right panel for selected department. Click the “Disposal facilities management” button in the center, a new interface will pop up (Figure 7). Right clicked the top panel to add new a facility and filled the basic information in the blanks below. The most important step is to select calculation method and the corresponding emission factor (Figure 8) or production process for the facility because it is directly connected to the data analysis module. It should be noted that two methods can be selected for one disposal

equipment, at the same time, such as an industrial boiler whose GHG emission could be calculated by either of them.



Figure 7. Facility Interface

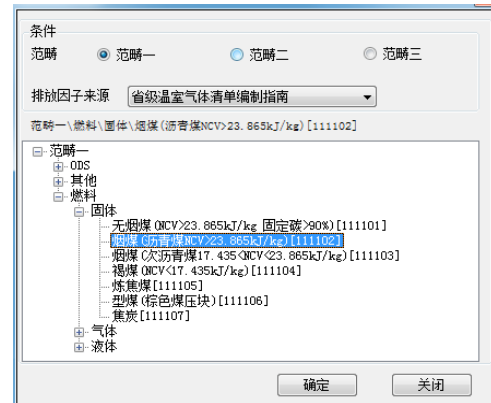


Figure 8. Emission Factor Selection

Figure 9 gives an example for activity data input operation interface. The existed organization structure is displayed in the left panel, information for selected department shows in the middle up panel and disposal facilities can be chosen from dropdown list. Once the facility, its method and emission source are defined, users could fill 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 selected facility during a certain period. Different forms will pop up according to different method or process.



Figure 9. AD Input Interface



Figure 10. Emission Data Inquiry Interface

Figure 10 shows the Emission Data Inquiry interface. After choosing the departments, selecting the facilities/categories and filling the time range, then click the “query” button, the detailed input activity data and output emission data will be demonstrated on the right panels divided into two parts. Total emission amount for the query appeared on the right below area in form of red font. A report could be generated if

“GHG Inventory generation” button is clicked for the emission data based on the query results not all the data in the database. Once the query conditions changed, the report would be different.

IV. SYSTEM TEST 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 is selected for the system testing and evaluation, the factory has four main power-plants. Each one is independent from the others and the No.3 power-plant is chosen to be the calculate model.

2) SYSTEM TEST DATA AND RESULTS

Relative data was directly gained from their production records and divided into two parts. The first part is coal combustion weighed by the electronic belt weigher and recorded in control center, the second part of data is the limestone amount for desulfurization. The system was tested to calculate No.3 power-plant’s GHG emission between July 1st and September 30th (Table 4).

Table 4: Coal and limestone combustion data

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

Coal combustion was used to test EFM calculation and limestone usage amount for MBM method. Finally, automatic generation function was applied to give a report for the GHG emission results. The GHG emission results are displayed in Table 5 and Figure 11 (a/b).

Table 5: 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

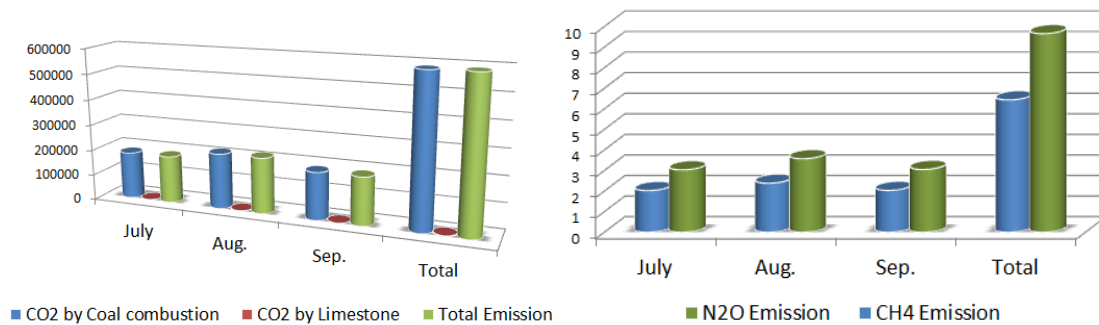


Figure 11 (a): CO₂ emission results

(b): CH₄ and N₂O emission results

3) SYSTEM EVALUATION

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

Three people from the Beijing Information S&T University, four from China Quality Certification Centre and two from the enterprise were 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 also reviewed and suggested proposals to the software. System improvement suggestions included: (1) activity data automatic acquisition, (2) evaluation of data analysis accuracy, (3) more modules for industrial production processes covering most part of GHG emission sources.

V. DISCUSSIONS AND CONCLUSIONS

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

The test and experiment evaluation for industrial and enterprise greenhouse gas emission data analysis system proved itself an effective GHG emission management tool that leads to improve the data calculate efficiency and to norm the operate process. In addition, it does not only be helpful for verification agencies but also provides a platform for common enterprises staff to know and understand GHG emission verification.

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