Mitigating Requirement Technical Debt that Hinder Effective Integration of Carbon Emissions Management Software (CEMS) into ERP Systems in Egyptian Oil and Gas Sector

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ABSTRACT

Climate change mitigation is top priority for policy makers and business owners worldwide to accelerate Green House Gas (GHG) emission reduction towards achieving targets of global warming limitation below 1.5 C. Carbon Emissions Management Software (CEMS) is the tool used for managing and reporting GHG footprint for entities. Nevertheless, efficient application and integration of CEMS tools with current Enterprise Resources Planning (ERP) is now vital for achieving goals and integrating GHG inventory aspect in data driven decisions. Egyptian oil and gas O&G sector is one of the heaviest GHG sources in Egypt, meanwhile is undergoing wide digital transformation program including unifying ERP platform among its affiliates and at the same time energy transition and carbon emissions reduction program.

In this paper we target identifying requirement technical debt (TD) that hinders integration between CEMS with ERP and propose model to mitigate this debt.

To identify best requirement, we conducted interviews in Four companies representing the three main sectors in O&G upstream, midstream and downstream by interviewing professionals in operations and environment departments. Through interviews, we will explore current ERP system in each company, how they monitor, manage, and plan their GHG emissions. Explore their requirement for GHG inventory management, and potential benefits. Then propose model for integrating of CEMS in ERP.

By analyzing interview results, the study developed models that satisfies customer requirement. First new GHG parameters groups in maintenance ERP module were developed this allowed connection of CEMS to equipment details. Then CEMS libraries

were created based on assets GHG parameters. The scope according to requirement was extended to connection to Geographical information systems.

The proposed model for Integrating CEMS in ERP will improve monitoring, managing and reporting GHG emissions. In addition, help in mitigation of requirement technical dept.

Keywords: Technical Debt (TD), Green House Gas (GHG) inventory, Enterprise Resources Planning (ERP), Carbon Emissions Management Software (CEMS).

1 INTRODUCTION

Climate change is currently one of the most urgent challenges globally that has drawn much attention and is currently affecting policies and strategies worldwide (1). This has been crystalized in many carbon neutrality programs in many countries and more ambitious climate neutrality programs like European Union (EU) green deal. This has created escalating momentum for global warming action, not only for environmental benefits but also for it economic benefits. Moreover, carbon trade techniques that increased the cost of doing nothing towards GHG emissions. In addition to mechanisms such as Carbon Border Adjustment Mechanism (CBAM) that will also affect country exporting to EU (2).

GHG inventory is defined as the list that contains emission sources in an organization and its quantity according to certain standard. Robust GHG inventory is the first step in developing effective carbon emissions mitigation program (3). This program is vital for reporting emissions and carbon ledger for countries that applies mandatory GHG programs and carbon trade. Moreover, for countries that do not yet have carbon trade system, Companies should have GHG inventory and actions management to avoid export carbon adjustment tariffs under CBAM program.

There are many tools used for managing GHG inventory, however specialized systems that are based on GHG inventory standard methods are more effective in GHG reporting and management. For more effective management there is strong need For better integration of CEMS into organizations ERP to make carbon neutrality action integrated in daily operations and decision making for mitigation efforts. Tough many ERP platforms developed their carbon management modules, but most of them work as silos separate from assets on ground, or more concerned about financial aspect of carbon trade. To connect these modules effectively to other ERP modules, This will require amendments not only in CEMS but also other ERP modules

Egyptian oil and gas sector is considered one of the heaviest carbon emitter in Egypt. More effective integration of CEMS in O&G sector will play great role in reduction of its emissions. Currently Ministry of Petroleum (MOP) is applying digital transformation program all over its companies through unifying EPR platforms. Meanwhile MOP is applying energy transition and carbon neutrality program. Nonetheless, until now there is no integration mechanism between GHG inventory management and ERP used in companies (4). O&G

industry is divided into 3 main sectors the first is upstream, which is responsible for exploration and production of crude oil and gas from underground, midstream is responsible for transportation and storage of crude

oil and gas, and downstream that convert crude oil and gas into final products. In this study, we will consider companies from each sector, and one service company that provide operation services (4).

The main contribution of this paper is that it propose systematic model that proposes parameter sets that facilitates integration of CEMS in ERP maintenance module specifically and other Modules as well. The model will allow assigning GHG scope category, and quantified measurement for each asset or equipment in assets library. This will allow real time aggregation and monitoring for GHG allowing for enhanced data driven decision making for optimized operations and management of carbon footprint.

2 BACKGROUND AND RELATED WORK

2.1 Requirement Technical debt

Technical debt is expression in software industry that refers to the cost of work needs to be amended at some point in better way due to choosing to do it in compromised easy way rather than the perfect method. This may happen unintentionally due to lack of full knowledge about needed task (5). TD includes 15 different types; one of them is requirement TD. Requirement TD refers to the gap between ideal software design that fulfill all user requirement and actually implemented system (5). In their paper "Identification and measurement of Requirements Technical Debt in software development: A systematic literature review", Ana Melo et al. studied different researches and concluded major reasons for emergence of requirement technical debt which are (5).

1. Low level of detail in requirements documentation
2. Ambiguous requirements
3. Non-definition of non-functional requirements
4. Vague and incomplete requirements
5. Lack of communication with the customer
6. Shortcuts and alternative solutions
7. Schedule pressure
8. Clients do not reflect what they want
9. Lack of experience
10. Inadequate prioritization of requirements
11. Inadequate writing and grammar
12. Poorly planned interviews
13. Lack of a script
14. Inaccurate or complex requirements
15. Inadequate elicitation

During design of our research, we will avoid follow methodology to avoid these root causes to reach deepest understanding of requirement of the purpose in this research.

2.2 Green House Gases GHG inventory scope categories

GHG emission reduction is the core of global warming efforts. Many energy carbon neutrality and energy transition initiatives have been launched globally to mitigate expected catastrophic effects of global warming. As we cannot control what we cannot measure, GHG inventory concept

was developed to define emission sources in an organization and its quantity according to certain standard. Robust GHG inventory is the first step in developing effective carbon emissions program (3). This program is vital for reporting your emissions and carbon ledger for countries that applies mandatory GHG programs and carbon trade. Moreover, for countries that do not yet have carbon trade system, Companies should have GHG inventory and actions management to avoid export carbon adjustment tariffs under CBAM program. The most widely accepted GHG scope categorization is according to Greenhouse Gas (GHG) Protocol, which internationally recognized and accepted standard for carbon footprint. The protocol GHG categories are defined according to source of emission in 3 scopes (6)

1. **Scope 1**: These emissions are emitted by company's owned operation. In O&G industry, this represents enormous quantity due to flaring and gas combustion for different purposes in remote fields. It is subdivided into 4 sub categories. (6)

1.1 Stationary combustion: it is combustion for non mobile equipment including turbines, furnaces, an boilers.

1.2 Mobile combustion: generated by mobile vehicles, boats and planes owned by the company.

1.3 Fugitive gas emissions: these are gas leaks of GHG from non-combusting sources, for example leaks from pipe flanges.

1.4 Process emissions: which is produced from onsite manufacturing industrial process, such as process fumes and chemicals during oil blending.

2. **Scope2**: are indirect emissions from non-owned resources such as purchased energy, from a utility, or the consumption of purchased steam, heat and cooling. (6)

3. **Scope 3:** this scope includes all other indirect emissions and is considered the biggest source in most industries other than O&G. for example in some plants it may represent 90% of emissions. It is divided into 15 sub categories, which covers upstream activities, downstream activities, wastes generated and leased assets. (6)

Categorization is the first step in the GHG inventory. At this step, each firm has defined GHG sources and its category. Next step would be quantifying, monitoring and planning for carbon emission reduction.

2.3 GHG emissions in oil and gas

Scope 1 & 2 emissions in O&G industry are enormous as they represent 15% of total energy-related emissions worldwide in all sectors, approximately 5.1 billion tons of greenhouse gas emissions (7)

This fact requires more efficient GHG inventory management in O&G industry. That is why this research's contribution will add important value not only for O&G companies but also in all fields globally. The reason for these high emissions is flaring systems in fields and static combustion for energy generation using open cycle turbines, fugitive gases and process emissions.

2.4 Egyptian O&G sector Modernization program as opportunity for CEMS integration in ERP.

Egyptian oil and gas sector is considered one of

the heaviest carbon emitters in Egypt. Currently MOP is applying modernization program that includes digital transformation program all over its companies through employing of EPR. Meanwhile MOP is applying energy transition and carbon neutrality program. However, until now there is no integration mechanism between GHG inventory management and ERP used in companies to operation assets. (8)

O&G industry is divided into 3 main sectors the first is upstream, which is responsible for exploration and production of crude oil and gas from underground, midstream is responsible for transportation and storage of crude, and downstream that convert crude oil and gas into final products. In this study, we will consider companies from each sector. (9)

The first company is upstream company that operates offshore and onshore O&G production facilities it operates many fields with different sources of emissions. It is joint venture between EGPC and foreigner investor and is considered one of the biggest companies in terms of daily production in Egypt. The second is the midstream gas company that operates 7920 Km of pipelines, compressor stations and gas plants. (10) The third company is public sector downstream company that operates plants for producing lubricants, chemicals, oil blends and storage tank facilities. In addition to operating wide network of gas stations and transportation fleet. (11) The Fourth Company is operations Services Company that operates Different downstream sites, and provide emissions measurement services (12).

Egyptian Petroleum Corporation (EGPC), which is holding corporation with tens of companies under it, are currently deploying or migrating from current ERP to EGPC unified ERP platform. The plan is to create homogeneous interoperating environment among EGPC and all its affiliates (13).

For GHG inventory management each company follows its own procedures and tools for reporting. However, MOP is developing GHG inventory monitoring system for all companies and has already executed GHG reduction projects like zero flaring and energy efficiency.

Current situation represents great opportunity for integration of GHG inventory CEMS in ongoing ERP projects. This will not only contribute in MOP goals but also will serve in local and global fulfillment of carbon neutrality targets. Moreover, there is opportunity for cooperation between funding organizations that already funded carbon neutrality projects in EGPC. (8)

2.5 Carbon Emission Management Software (CEMS)

CEMS has evolved gradually after emergence of legislation following the GHG Protocol, which requires reporting of carbon emissions (14). CEMS continued evolution with advancements in carbon trade and development of carbon neutrality projects. CEMS scope focus on measuring, reporting, and support attaining environmental GHG mitigation goals (14).

CEMS available in market could be especially designed software dedicated for carbon management purposes or modules based on ERP

platforms. For especially designed soft wares. Few of them offers full integration option with ERP system. On the other hand, modules based on famous ERP platforms did not provide systematic approach for integration with other platform modules to get full integration with equipment on ground. This led to situation that most CEMS works in silo with limited integration to some modules especially financial module, beside its normal environmental tasks. In this paper we target provide systematic approach for integration of CEMS with ERP system employed in O& G studied companies.

3. RESEARCH METHODOLOGY

The research targets to define requirements needed for better integration between CEMS and ERP and develop model to fulfill these requirements. Through development of methodology, we took into consideration all reasons mentioned in section to 2.1 to get best results.

The research targets answering following questions

RQ1: what are the requirements needed by operations and Environment department's teams to get easier and smooth integration between CEMS and operations?

RQ2: what are other requirements that would be beneficial to CEMS integration that are not mentioned by interviewed professionals?

RQ3: How can these requirements fulfilled and applied in ERP?

To answer these questions we interviewed professionals from four companies to explore current situation for ERP in each company. In each company, we interviewed operations and environmental professionals. The four companies were selected to be giant companies covering the three sectors in O&G industry to explore wide range of challenges that might face integration of GHG inventory software in ERP. We will conduct interviews with professionals in each company to collect needed data. The scope of questions focus on exploring current ERP situation, current situation of assets library in maintenance modules and asset integrity modules, current situation of GHG inventory management and CEMS availability.

Following interview, we will design proposed model based on responses. The model will develop parameters in Computerized Maintenance Management System (CMMS) ERP module for each equipment. These parameters will communicate with CEMS to transfer GHG data of all equipment To CEMS.

Interview questions re designed to avoid

1. Ambiguous requirements
2. Lack of communication with the customer
3. Shortcuts and alternative solutions
4. Clients do not reflect what they want
5. Lack of experience
6. Poorly planned interviews
7. Lack of a script
8. Inadequate elicitation

Which are some of the causes for Requirement TD mentioned in section 2.1

Interview questions

Q1: Does your company use ERP system? Is it ERP

adopted by EGPC?

Rationale: Existence of ERP is the backbone for integration of GHG inventory to ERP, without it, we lack the infrastructure for integration. In addition, if it is not EGPC adopted ERP then it is expected that migration process will happen soon.

Q2: Does your company employ computerized Maintenance Management System CMMS, and asset integrity modules in ERP?

Rationale: Maintenance management and asset integrity modules are modules that develop detailed asset library for all plants with all included equipment, including static equipment as pipelines and tanks. These libraries includes detailed description of all equipment that could be source of GHG. Our proposed model relies on linking these libraries to GHG inventory library; therefore, existence of these modules will facilitate integration process.

Q3: Does your company use CEMS, or have GHG inventory management plan, is it integrated in ERP system?

Rationale: Existence of GHG inventory management plan or system will facilitate integration process, as we will not start from scratch. Moreover, if it is already integrated in ERP we could benefit from lessons learnt.

Q4: Is there any way that allow operation teams to visualize, monitor, or know sources and quantity of GHG in their plants?

Rationale: this could be good point if existed as it will help in developing integrated system.

Q5: From your point of view what are the requirements or options that will help operation/ Environment teams to participate in GHG inventory management?

Rationale: Proposed model targets taking one more step ahead of current CEMS. The model targets making GHG integrated in decision making even at operation level to get most benefit from integration through reduction of emissions from its source.

Q6: Do you think that connecting CEMS to CMMS asset library will be good approach to link assets to CEMS?

If not, what are other options do you recommend?

Rationale: CMMS asset library is the location in ERP that contains all asset details, linking CEMS to library will allow it to have detailed GHG sources. If there is another location that we do not recognize, interviewees will mention it.

Q7: What are the data you want to get about GHG for the scope of your work?

Rationale: this question will clarify what data the user needs.

Q8: What are the obstacles that could face integration of GHG inventory MIS in ERP?

Rationale: Knowing threats facing integration would be vital for integration process management.

Based on responses, proposed model will be designed, then introduced to interviewees to be sure that we understood their requirements clearly. Then according to responses, final model will be introduced for final review with customers.

4 Interview responses

We conducted interview with professionals in the Four companies. All interviewees knows that their responses were going to be used in research

work related to integration of CEMS integration in ERP in O&G. and the following is the summary of responses

Q1: Does your company use ERP system? Is it ERP adopted by EGPC?

Upstream Co.: ERP system has been used in this case since years. However, it is different than EGPC adopted ERP, therefore currently there is migration project from old to new ERP. In the new project, ERP will be implemented for all enterprise activities on same platform.

Midstream Co.: This Company employs ERP system adopted by EGPC

Downstream Co.: Currently the company is migrating to new ERP adopted by EGPC.

Downstream operation services Co.: Yes ERP system is employed in our operations. ERP type depends on the owner of the site that the company provide services in.

Q2: Does your company employ computerized Maintenance Management System CMMS, and asset integrity modules in ERP?

Upstream Co.: Yes, maintenance management and asset integrity activities, work orders and asset libraries are managed through computerized maintenance management system (CMMS). However, currently the company will migrate to new ERP system.

Midstream Co.: CMMS is employed in ERP system and contains details of all asset hierarchy

Downstream Co.: in phase of Migration to new CMMS module in new ERP is in progress.

Downstream services Co.: Yes, CMMS is applied in all their sites as well as asset integrity.

Q3: Does your company use Carbon Emissions Management Software (CEMS), or have GHG inventory management plan, is it integrated in ERP system?

Downstream services Co.: Yes in some of refineries that this company operates, they employ continuous emissions monitoring system. It continuously monitors emissions and send it to plant control system. It is connected to plant distributed control system (DCS) but not the ERP system.

Upstream Co.: Carbon emissions reports are prepared frequently using spreadsheets, and the process involves wide estimations. GHG inventory is not integrated in ERP system and no CEMS is employed.

Midstream Co.: Carbon emissions is measured or estimated, and reported frequently. for central gas plants emissions it is reported and monitored accurately, however The vast expansion of pipeline network for more than 7000 kilometers represents challenge for full monitoring of the network specially concerning fugitive gas.

Downstream Co.: The Company measures emissions and air quality frequently, and prepare reports.

Q4: Is there any way that allows operation teams to visualize, monitor or know sources and quantity of GHG in their plants.

Downstream services Co.: Yes, the continuous emissions monitoring system shows all needed quantified data in distributed control system (CS).

Upstream Co.: There are portable gas detectors that are used for safety purposes, but its quantifying capabilities are limited.

Midstream Co.: for central gas plants Health and safety team monitor using gas detectors.

Downstream Co.: Portable detectors and service companies do frequent inspections.

Q5: What are the requirements or options do you think will help operation teams to participate in GHG inventory management.

Upstream Co.: Interviewees mentioned that Ease of use through integration in operation soft wares like CMMS, we need clear list and categorization of sources Measurement tools, descriptive interface, automated GHG calculators and training for using system. Moreover, they mentioned that if the system would have the ability to advice for solutions based on previous projects would be helpful in emission mitigation.

Midstream Co.: Interviewees agreed with previous point. Moreover, they highlighted here the challenge of wide expansion of their transmission network for more than 8000 kilometers. This Company also has Geographical information system that is spread allover Egypt. That is why they think that link of CEMS to their GIS would benefit their operation for more efficient GHG management.

Downstream services Co.: Interviewees mentioned same point as in upstream company. In addition, they mentioned that their continuous emission monitoring system integration with this system will allow CEMS system to get real time data instantaneously.

Downstream Co.: Interviewees agreed with same points as in upstream company.

Q6: Do you think that connecting CEMS to CMMS asset library will be good approach to link assets to CEMS?

If not, what are other options do you recommend?

All operations respondents agreed that maintenance management, asset integrity activities, and work orders are managed through computerized maintenance management system (CMMS). It contains detailed hierarchy tree of assets and would allow operation teams to get real sense of impact of equipment on GHG emissions.

Q7: What are the data you want to get about GHG for the scope of your work?

Operations teams requested to know

- Quantity of emissions
- Types of emissions
- Standard for GHG management
- work orders related to maintenance and operations activities that contributes in GHG management
- Teams needed guidance and training for reduction techniques
- Connection to continuous monitoring system if available in their plants
- Connection to GIS if available

Environment teams requested

- Ability to create automated reports based on real time metered or updated estimation
- They needed automated system that automate creation of work orders for monitoring, measurement and estimation. Smart metrics capabilities to avoid double calculation
- Advanced analytics to spot most promising chances for improvement
- Suggestions for improvement based on similar projects for similar equipment

Q8: What are the obstacles that could face integration of GHG inventory MIS in ERP?

Replies were concerned about financial aspect in terms of ROI versus benefits, Standardized procedures for GHG management, and management support.

4.1 Interview analysis and feedback with interviewees

Following interview, responses were analyzed and requirement list was created as shown in question seven. Then to avoid following causes mentioned in section2.1

1. Non-definition of non-functional requirements
2. Vague and incomplete requirements
3. Lack of communication with the customer
4. Shortcuts and alternative solutions
5. Clients do not reflect what they want
6. Inadequate elicitation

We developed hand out for proposed model based on GHG protocol (6). Interviewees reviewed it and mentioned needed amendments that were considered during model design. Next section discuss proposed model.

5 Proposed model

The proposed model rely on existence of ERP maintenance management module known as computerized maintenance management system CMMS. CMMS is used for asset management by facilitating planning and execution of maintenance, and optimizing inventory management. One of the main steps in implementation of CMMS is preparing asset library.

Asset or Equipment library is hierarchal tree that contains all equipment in the plant. Whenever you go deeper in the tree, you get to smaller component until you reach simplest component. Each component has its information characteristics that includes all equipment characteristics (13), figure1 shows

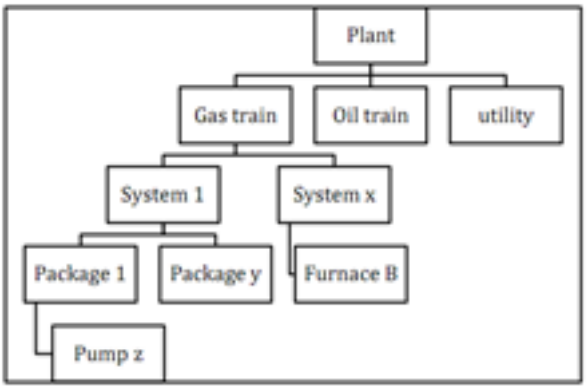

Figure 1. CMMS asset hierarchy

Equipment hierarchy example.

Equipment information Contains its characteristics including for example:

- Nameplate information (manufacturer, serial number)
- Asset criticality level
- Spare list
- Location
- Preventive maintenance frequency
- Hierarchy for cost aggregation from bottom up to facility
- Asset assemblies
- Configurable class / type
- Cost codes
- Asset price
- Job plan
- Warranty
- Meters (used to trigger PM's)

• Safety procedures

• The ability to attach documents or images

• User defined fields

To integrate with CEMS we will add new GHG parameters group for equipment in asset list following fields to characteristics.

5.1 GHG parameters group

1. **Scope category**: this parameter will define scope of emissions related to equipment as in categories explained in section 2.2. Some Equipment could have more than one scope category.

Even if it sounds that all equipment are in scope 1 as these equipment are owned and operated by company but this is not the fact. That is why detailed classification is important in spotting heavy emitting equipment. For example if Electric motor is operating in plant depending on purchased power. Then its related emissions lies in scope 2 not Scope1.

2. **Power source:** this parameter will define source of power for example.

• Plant Produced gas

• Purchased gas

• Diesel

• Purchased Electricity

• Solar energy

• Plant Produced steam

• Purchased Steam

3. **Efficiency of Equipment:** spotting low efficiency equipment will highlight most influential areas for GHG reduction.

4. **Single/Parent/ Child/ Sink GHG source:** This category target is to avoid GHG emission duplication in calculation.

• **Parent source:** emission source that produces power used by child source.

• **Child Source:** Equipment that uses power sources generated by parent source.

• **Single Source:** GHG emitting equipment with no parent or child.

• **Sink Source:** is source that can absorb carbon like carbon capture usage and storage CCUS system (16)

For example, a steam pump that is powered by in house produced steam that is generated in gas boiler. Then only emissions from gas boiler will be counted as parent Scope1 static combustion source and the pump is considered as child source. On the other hand, electric motor that powered by purchased electricity is Single source for scope 2 emissions.

The benefit of this parameter is to avoid double counting and to help in studying different options for emissions mitigation thorough studying alternative options for suppling power to child emission sources.

5. **Emission Quantity (Scope 1), (Scope 2),**....: this parameter represents the quantity of emissions from each equipment. Number of emission scopes depend on number of scope categories emitted from the equipment.

For example, Equipment that emits scope 1 static combustion and Scope 1 fugitive gas will have two emission quantities for each scope.

6. **Measured/Estimated/Monitored**: this is sub parameter for emissions quantity, which tells the source of mentioned quantity.

Measured: Means measured by devices at certain

date

Estimated: Means estimated by some source of estimation

Monitored: Means it is continuously monitored and measured as one of the cases discussed in interviews. Monitoring requires continuous emission monitoring system

• **Measurement/Estimation date:** this represents date of last estimation or monitoring.

7. Last Fugitive gas survey date/ Next Fugitive gas survey date/ Fugitive Survey Frequency

fugitive gas is considered significant GHG source in O&G (17). Intensity of fugitive emissions depends on condition and age of equipment that is why it should be monitored frequently for detection and treatment. Frequency of survey will be decided according to condition and age of plant and equipment (18).

8. Auxiliary emissions percentage: the main purpose of this parameter is simplification of emission aggregation. Asset hierarchy shown in figure 1 could contain hundreds of measurement transmitters and actuators that consume relatively negligible power. For CMMS this detailed hierarchy is needed to plan maintenance for all these equipment. Nevertheless, using same depth in hierarchy for GHG would be waste of resources. That is why GHG aggregation will stop at certain level according to GHG planner judgement, and subsequent levels emissions' will be considered one mumber in this parameter as percent from its level.

9. GPS coordinates (optional): for midstream company case, they requested ability to connect to GIS system. Their GIS system is already connected to DCS system, and further integration with CMMS and CEMS will be facilitated through this option (19).

CMMS uses asset library parameters to generate work orders for preventive maintenance and inspection, In addition it link work orders material to inventory management module in ERP for smooth monitoring of cost maintenance. GHG monitoring activities should also be included in work orders to ensure optimal GHG inventory monitoring.

5.2 GHG Inventory activities work orders.

Work order system ensures that all needed activates are performed on time and record log for future usage. To ensure appropriate management of GHG inventory. Work orders parameters should be defined for accurate implementation and tracking. This parameters includes (15)

• Work order number
• Work order description
• Work order priority
• Work order type (Preventive, Corrective, etc)
• Equipment that is going to be maintained
• Materials recorded and inventory location
• Manpower planning
• Record planned vs. actual labor, materials and cost
• Safety procedures
• Attached documents
• User defined fields

Each work order will request to perform certain task. Therefore, tasks will be created for GHG activities. Each task contains Job plan and needed resources for the task. GHG tasks would be

1. Measurement task Job plans
2. Estimation task job plans
3. Fugitive gas survey job plans

According to equipment types, there could be more than one job plan. Frequency of work order generation for each equipment will be determined according to equipment condition, type, age, and reporting requirements.

CMMS is inherently connected to inventory and material management and ERP environment allows smooth integration with Finance ERP modules. Therefore, upon integration of GHG tasks in CMMS, companies will have accurate information about cost of GHG inventory management activities, allowing for more cost optimization.

Previous steps prepared CMMS module for generating data needed by CEMS. Accuracy of data relies on current development of CMMS in each company, in addition to GHG information availability for each equipment. It is recommended that plants recruit consultants at initial implementation to assist and train in GHG measurement and estimation to complete GHG parameter group for all equipment.

5.3 Carbon Emissions Management Software (CEMS) Integration

The target is to integration of CEMS into ERP through CMMS module, and financial module. This will allow CEMS to get detailed data to the level of each equipment on the ground. Moreover, in cases that employ continuous emission monitoring system, there would be a chance for live data access.

CEMS selection:

Most of Interviewed companies in this study mentioned that they do not have CEMS integrated with ERP. Therefore, selection of CEMS module would be the first step. First criteria in selection would be compatibility with ERP. EGPC selected ERP platform that already has its own carbon footprint management module but lack full integration with CMMS. In addition, other ERP companies offer carbon management modules whether separately or embedded in financial modules. Moreover, tens of CEMS exist in market with wide range of prices. For efficient choice, companies should consider compatibility with ERP, cost and define requirement needed carefully. In this case for EGPC companies, CEMS module based on same adopted ERP would be first considered candidate.

5.3.1 First phase of integration (DCS to CMMS)

Then comes modules integration, this model will consider existence of Continues emissions monitoring system physically installed on equipment. This would be the most complex case in companies. Other cases that lack this option would apply starting from second phase of integration.

Continuous monitoring management systems are usually connected to plant distributed control system (DCS). All control systems are currently sophisticated enough and support wide range of communication protocols. Communication link would be established between plant distributed control system DCS and CMMS asset library to monitored equipment emission quantity parameter.

For Example: Monitoring system installed on

fired heater stack record readings on DCS, DCS engineer will establish link with appropriate data mapping to CMMS. Figure 2 illustrates the link between DCS and CMMS.

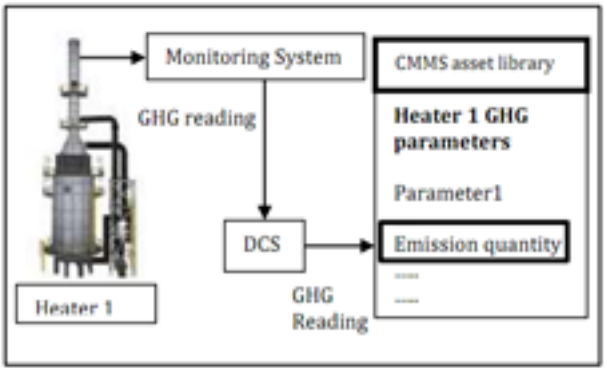

Figure 2 Connection between monitoring system to CMMS

Other option for accurate measuring of emissions is through fuel metering of combustion equipment. For example Diesel generator fuel meter that is connected to DCS. Fuel meter reading can be used to calculate emissions. Through automated equation in DCS then exported to CMMS asset library on the same communication link as in previous example.

5.3.2 Second phase of integration (CMMS to CEMS)

Second Phase of integration would be integrating CMMS with CEMS modules. For companies that do not yet have continuous emission monitoring system this would be the first step. CEMS will use GHG parameters group introduced in this paper to aggregate GHG categories emissions and get detailed accurate quantification for better reporting. Moreover, this would enhance system capabilities for spotting areas of improvement and contribute in reduction of emissions.

Each parameter discussed before will be aggregated to create GHG libraries that includes

1. **Scope category libraries:** For example, Scope 1 static combustion will contain all sources of this category.
2. **Fuel Source libraries:** This will contain GHG sources powered by each fuel and their efficiencies.
3. **Aggregated emission quantities:** this will be beneficial in reporting.
4. **Method of quantification libraries:** Coupling this library with Scope category and fuel source libraries will allow spotting best equipment to apply continuous monitoring systems, which will improve efficiency of GHG projects spending.
5. **Fugitive gas monitoring activities libraries:** with proper tools, analysis of this library will adjust monitoring activities schedule, and improve predictive maintenance capabilities.
6. **GHG emissions per areas emissions libraries**: according to GPS coordinates in asset library in widely dispersed facilities, list of sources in each geographical area will be generated.

Next step would be generating smart reports and queries for example

1. GHG dashboard
2. Highest emission sources
3. Highest emission sources per fuel
4. Emissions per area
5. Any user requested report
6. Highest change in emissions sources
7. Proposed mitigation technologies for emission sources

5.3.3 Third Phase of integration between (CEMS, CMMS and GIS)

Mid-Stream Company highlighted importance of

GIS integration for their geographically dispersed network. Emissions per area is one of the lists generate by CEMS. Through exporting this list to GIS with proper user interface, visualization of emissions map will be available. For more exact GIS information link to CMMS asset library will communicate equipment, their emissions and exact location. Creating a real map of carbon emissions intensity will allow visualization of emission map. Figure 3 shows different system links among ERP modules, GIS system and DCS.

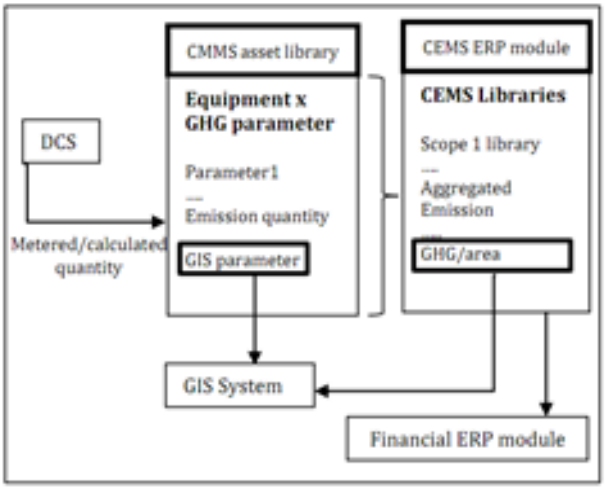

Figure 3 Integration between CEMS and different ERP modules and GIS

5.3.4 Fourth phase of integration to financial system

Financial system ERP module integration in is vital for financial reporting, carbon trade, and carbon credits schemes (20). Nonetheless this is out of scope of this paper as carbon trade and carbon credits systems in Egypt is still in primitive phase. Therefore financial requirement in Egypt would not be enough to cover requirement TD, and will not eliminate TD in this issue.

6 DISCUSSION

Requirement technical debt in case of CEMS modules raised due to various reasons as discussed in section 2.1. Moreover, complexity of technical details in ERP's inter connected modules of operations, DCS, maintenance modules, CEMS, GIS system and financial modules. This raised major challenge to tackle this TD and improve efficiency of integration.

To avoid misunderstanding of requirement we started with customer and ended with customer. Customer selection depended on who actually produce GHG and who is the one responsible for environmental activities. That is why we interviewed operation and environment professionals in all considered companies. To get wide range of requirements we chose companies covering all the 3 sectors of O&G. we designed interview questions to explore current ERP and CEMS conditions in each company. Explore requirement needed by customer, capture challenges for CEMS integration into other ERP modules and ask for their other perspectives that may serve this cause.

Based on interview responses we developed model that is reviewed by customers. Then amended after customer review to ensure full understanding for requirements.

Asset library in CMMS ERP module introduced solid foundation for connection of CEMS to equipment on ground physically. CMMS asset library contains detailed asset list with all related parameters, however it lacked GHG parameters that can link data to CEMS. Therefore first step was creating GHG asset parameters that facilitates integration.

From operations interviewees responses we figured out new options like linking to DCS that will allow real time metering, and linking to GIS to integrate transmission network. From Environment professionals responses we figured the need for parameters for preventing double counting in addition to fugitive gas emissions activities follow up. Then Proposed GHG asset parameters and GHG work orders were introduced in section 5 after interviewees review. From CEMS ERP module side we developed libraries based on equipment GHG parameters to serve customer requirement. Then the model introduced 3 phases of integration starting from monitoring and metering systems in DCS until reaching CEMS through CMMS. Moreover fourth step of integration to ERP financial system that is beyond the scope of this paper.

7 CONCLUSIONS AND FUTURE WORK

Requirement technical debt that hinder effective integration of CEMS to other ERP modules represents major obstacle facing effective integration. This TD was raised unintentionally as most ERP modules were developed for other purposes. System developers and integrators would face this TD during integration of CEMS ERP modules into other ERP modules, otherwise CEMS would work in separate silos with just limited interfaces needed for reporting and carbon trade systems.

Requirement TD mitigation should start with customer and end with customer, and there should be feedback loop until reaching agreed requirement description.

Customer review created new horizons that were not considered before like avoiding double counting, and GIS integration.

CMMS readymade asset library offered foundation that facilitated effective integration of CEMS to assets, and offered link path between DCS and CEMS., through developing GHG group parameters that were designed according to customers requirement .

Future work would include considering requirement TD for integration with Financial ERP modules.

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