Process Centric Energy Modelling for Multinational Manufacturing Corporations

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Abstract

The industrial sector has traditionally utilised energy models and control and monitoring software for energy system evaluation and optimisation. A limitation of this approach is that the focus is primarily on manufacturing processes, not necessarily providing a comprehensive enterprise evaluation. The non-manufacturing activities require evaluation as the contributions of associated services such as technical building services, ICT and other on energy demand continues to increase. This limitation is especially concerning for Multinational Manufacturing Corporations (MMC's) with business sites across various geographic locations, which can vary from manufacturing to warehousing to corporate. This research introduces the Process Centric Energy Model, which utilises business processes for energy evaluation and optimisation at MMC's. MMC's conduct business by enablement of business processes, which supports the energy evaluation of any business activity on any site. The concept and methodology of application of the Process Centric Energy Model is demonstrated with the procurement and electroplating business processes. The results demonstrate that business processes can be applied for energy quantification and optimisation of both manufacturing and non-manufacturing business activities, thus providing a comprehensive MMC energy evaluation.

Keywords
Process centric, energy models, business processes and multinational manufacturing corporations

1. Introduction
Historically as economic growth increased energy related greenhouse gas (GHG) emissions increased, however the delinking between economic growth and GHG emission is being observed (IEA, 2015). However, even with this observed change, the IEA has stated that energy is central to combatting climate change, as energy production and use is accountable for approximately 67% of global GHG emissions(IEA, 2015). The IEA reported that industry was accountable for 38% of global final energy consumption and 24% of the total CO_2 emissions in 2014 (IEA, 2017).

McKinsey and Company have reported that manufacturers have the potential to reduce production energy consumption by approximately 20 - 30% (Mohr et al., 2012). Thus this study focuses on the manufacturing sector with specific reference to Multinational Manufacturing Corporations (MMC's). MMC's encounter challenges with energy quantification, thereby hindering optimisation opportunities, which include(Munsamy and Telukdarie, 2016):

- Business sites across various geographic regions spanning international borders.
- Sites with varying business activities ranging from manufacturing to warehousing to distribution to corporate.

- Diversity of manufacturing processes and products.
- Adherence to local laws and regulations, which differ across international borders with respect to labour, environmental emissions, resource availability and costs.

Energy modelling is one of the toolsets available for energy evaluation and optimisation at MMC's. The existing energy models are diverse, with each model having its own specific features and application. For this study, the researchers have classified the existing energy models into two categories, the non-industrial and industrial energy models as detailed in Table 1.

Table 1. Comparison of the non-industrial and industrial energy models

Non-industrial energy models	**Industrial energy models**
Evaluates the energy system from primary energy resource through conversion technologies to final energy demands for specific geographic regions and time horizons.	Specific to industrial processes and equipment.
Focuses on either the energy sector only, the energy-economy or energy-economy-environment.	Models range from simulation and optimisation to monitoring and control.
Requires user inputs for a range of parameters that includes economic, technological, social and environmental.	The models may be generic to be applied to any industry or specific to an industry or system.

However, these energy models have limited application at MMC's. This presented the researchers with the opportunity for the development of a MMC specific energy model, the Process Centric Energy (PCE) Model. The PCE model adopts a novel approach of utilising business processes for energy quantification and optimisation at MMC's.

This paper reviews the existing non-industrial and industrial energy models applicability to MMC's, priority ranks the energy models suitability for application at MMC's, introduces the framework of the PCE model and demonstrates the concept by application to the procurement and electroplating processes.

2. Review of Energy Models

Energy modelling is complex and dynamic, driven by the rapid evolution of energy systems due to policy developments, emissions targets, technology and resource restrictions and socio-economic changes. The scope of application of an energy model is reliant on the model objective, extending from a single operational unit to an economy wide analysis (Bhattacharya and Timilsina, 2010).The purpose of the desktop review is to identify the non-industrial and industrial energy models applicability to MMC's (Munsamy and Telukdarie, 2017).

Due to the vast number of available non-industrial energy models, nine energy models across the spectrum of energy sector only, energy-economy and energy-economy-environment is selected: E3ME, OSeMOSYS, NEMS, MARKAL, MESSAGE, POLES, TIMES, WEM and LEAP.

Six corporations offering energy management and energy system optimisation services are identified; Aspen Technology, Honeywell, General Electric Company (GE), ABB, Rockwell Automation and Schneider Electric. The following energy management and optimisation tools of the above mentioned companies are reviewed:

- ASPEN Technology: Activated Energy Analysis, Energy Analyser, Utilities planner
- Rockwell Automation: Arena, FactoryTalk EnergyMetrix
- GE: Concorda Software Suite, Envisage
- Honeywell: Energy Dashboard, Sentient System,
- ABB: Energy Manager
- Schneider Electric: Power Logic ION EEM 4.0

The review identified the following characteristics prevalent in the identified model categories.

Table 2. Characteristics of the non-industrial and industrial energy models

Non-industrial energy model	Industrial energy models
Specific to a geographic area such as a city, country, region.	Focuses primarily on manufacturing activities and processes.
Data intensive - The exceptions are the LEAP and OSeMOSYS models, which can work with limited data inputs.	Software are propriety and potentially expensive.
Time intensive - Time for data collection and preparation and time to learn the model software.	Moderate to high level of engineering/ technological skills and knowledge is required.
Use of propriety software for data handling and the model solver.	
High level of technical skills - The exceptions are the LEAP and OSeMOSYS models.	

The model characteristics detailed in Table 2 corroborates the industrial energy efficiency challenges identified by May et al. (2017) and Schulze et al. (2016); complexity of industrial systems, lack of generalizability, scale of operation and wider application of energy assessment tools than simulation and benchmarking tools. Additionally, the model input data requirements are a significant challenge due to the range and depth of data required. It is acknowledged that data sourcing can be arduous and sometime extending over a number of years (ETSAP, 2016).

Whilst the characteristics identified in Table 2 does not negate the use of these models at MMC's, it does hinder application and does not provide a comprehensive energy evaluation. This review emphasises the necessity of a comprehensive MMC specific energy model, with the PCE model building on the limitations on the non-industrial and industrial energy models. The defining features of the of the PCE model are (Munsamy and Telukdarie, 2017):

- Independent of geographic area
- Minimum user data inputs
- Minimum skill requirement and specialised knowledge
- Inclusion of all business activities; manufacturing, HR, IT, finance and logistics
- Generic
- Reproducible
- Integration of human behaviour
- Transparency of the evaluation process

In the following section the Analytical Hierarchy Process (AHP) is utilised for ranking the PCE and non-industrial energy models appropriateness for application at MMC's. The industrial energy models are excluded as the focus is in on manufacturing processes only, hence not providing a comprehensive energy evaluation.

3. Analytical Hierarchy Process

The first step in the AHP process is the development of the hierarchy, which comprises criteria for evaluation of the alternatives. The alternatives are the nine non-industrial energy models and the PCE model. The criteria for evaluation of the ten energy models are:

- Data intensity: The scope and volume of user input data.
- Time: The time required for data collection, software learning and model computation.
- Skills requirement: The technical proficiency and knowledge requirement of the model users.
- Model reproducibility
- Use of proprietary software

The criteria are pair-wise compared using the Saaty rating scale to identify the extent of influence of each criteria in selection of an energy model. Reproducibility is identified as having the highest influence in selection of an energy model, followed by data intensity and time respectively. The consistency ratio (*CR*) is calculated to confirm the consistency of the pair-wise comparisons. The *CR* is calculated as 3%, validating the pair-wise comparisons. A *CR* greater than 10% indicates a high inconsistency in comparisons (Saaty, 1987).

The next step is the pair-wise comparison of the alternatives for each criteria. For each criteria the calculated *CR* is below 10%, confirming the consistency of the pair-wise comparisons. The ranking of the ten energy models are detailed in Table 3.

Table 3. Priority ranking of energy Models appropriateness for application at MMC's

Model	Priority Weighting (%)
PCE	15,9
NEMS	10,9
MARKAL	10,9
POLES	10,9
WEM	10,9
OSeMOSYS	9,8
E3ME	8,6
MESSAGE	8,6
TIMES	8,6
LEAP	4,9

The priority ranking of the PCE model further validates the necessity of a MMC specific energy model. The next section details the framework of the PCE model.

4. Process Centric Energy Model

This research introduces a new paradigm to energy modelling; business processes for energy systems quantification and optimisation. All MMC's conduct business by applying global or regional business processes depending on the functional enablement, thus an appropriate platform for MMC energy systems evaluation(Munsamy and Telukdarie, 2016). Business processes enable the energy quantification of all MMC activities; manufacturing, IT, logistics and HR, hence providing a comprehensive energy evaluation. Figure 1 illustrates the PCE model.

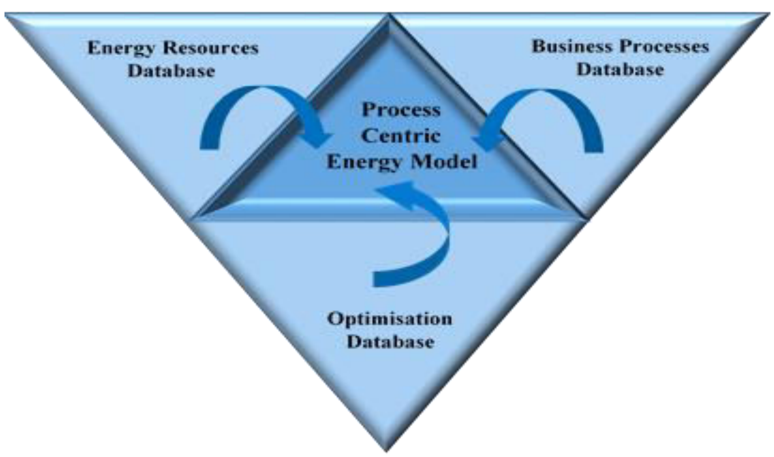

Figure 1. PCE model approach

4.1 Business Processes Database

Business processes are categorised into various levels. The researchers reviewed three business process hierarchies; ARIS process architecture, SAP process hierarchy and APQC process classification framework. A four level hierarchical structure is developed, refer to Table 4. It is expected that Levels 0 and 1, are fairly standard across

MMC's, with the greatest variance occurring at Level 3, which details the actual steps to complete a business function.

Table 4. Hierarchy of the business processes database

Level	Description	Size of database
Level 0	Enterprise function	A minimum of 12 enterprise functions
Level 1	Business function	A minimum of 120 business function
Level 2	Business process	A minimum of 1000 business processes
Level 3	Business process steps	A minimum of 10000 business process steps

4.2 Energy Resources Database

This database comprises the resources required to complete any business activity, which can range from ordering material to manufacturing a product to recruitment of personnel. Due to the vast range of resource requirements, the database is broken down into four categories: ICT, manufacturing, logistics and building. In addition, some resources are also classified as:

- Global resources: The resources characteristics are identical across all the business sites of a MMC.
- Site Resources: The characteristics are specific for a single site only.

4.3 Optimisation Database

This database is specifically utilised for the optimisation of the baseline energy demand. It allows the user to select potential optimisation technologies and evaluate the impact of the selected technology on the business energy demand and CO_2 emissions.

5. Demonstration of the Concept of the PCE Model

The methodology of application of the PCE model is illustrated in Figure 2. To demonstrate the concept of business processes for energy evaluation and optimisation, the business activities of procurement and electroplating is selected. These activities demonstrate the range of application of the PCE model as both manufacturing and non-manufacturing activities is considered.

For the demonstration of the concept the model is initially developed in Microsoft VBA, however the fully enabled PCE model is in MatLab.

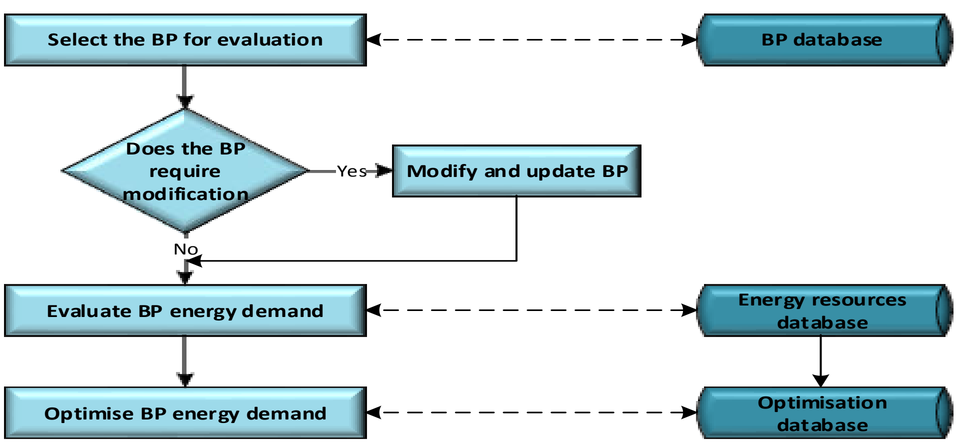

Figure 2. Framework of the PCE model approach (Munsamy and Telukdarie, 2017)

5.1 Procurement Process

The scope of the procurement activity can range from procurement of consumables such as laboratory chemicals and raw materials to process assets such as compressors and distillation columns.

The first step is the selection of the business process for evaluation. The next step is the review of the selected business process. An active Microsoft Visio document opens, where the user has the option of modifying the business process or not. In Figure 3, the procurement business process is cross-referenced to the "Manage external inbound receipts" business process. This cross-referencing supports a system's thinking approach, where the interconnectedness of business processes allows the identification of the impact of change of a single business process on the whole organisation. In a MMC, the procurement business process is not only used within the procurement enterprise function;

- Maintenance activities: In a maintenance process there is typically a process step for purchasing of parts, with the maintenance activity a subset of the manufacturing enterprise function.
- Recruitment of new personnel: In a recruitment business process there may be the option of contracting external consultants for conducting assessments, with the recruitment activity a subset of the HR enterprise function.

These are just two examples of inter-linking but demonstrates the holistic approach that business processes support.

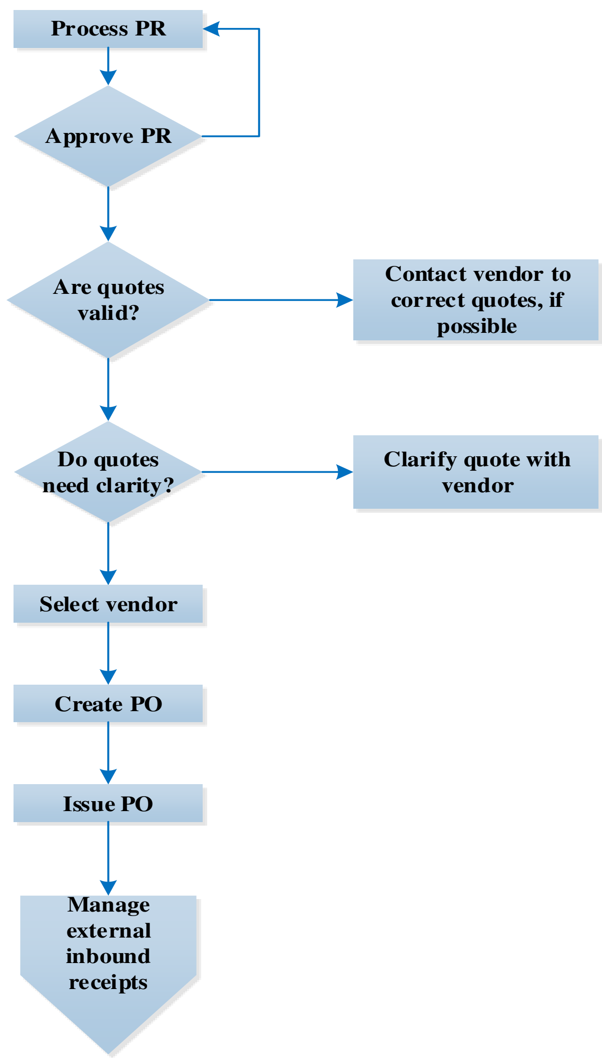

Figure 3. Business process for procurement

The next step is the evaluation of the baseline energy demand. The user selects the business process step and the associated category from the energy resources database. A user interface displays the energy resources of the selected category, allowing the user to select the energy resources required for each business process step. The user is required to input the operational time for each selected energy resource. The baseline energy demand is the cumulative energy demand for each business process step.

The final step is the optimisation of the baseline energy demand by selecting alternative resources to complete the activity or varying operational parameters. For the procurement process, the printers are identified for optimisation, with individual desktop black laser printers replaced with a single multifunction black laser office printer. The model displays the results as illustrated in Figure 4.

Optimisation of Procurement Business Process Energy Demand

	Baseline	Optimised
Process PR	195 Whr	156 Whr
Approve PR	40 Whr	40 Whr
Are the quotes valid	271 Whr	205 Whr
Contact vendor to correct quotes, if possible	21 Whr	21 Whr
Do quotes need clarity	N/A	N/A
Clarify quote with vendor	21 Whr	21 Whr
Select vendor	156 Whr	117 Whr
Create PO	134 Whr	95 Whr
Issue PO	10 Whr	10 Whr
Total Energy Consumption	849 Whr	665 Whr
Total Carbon Dioxide Emissions	0.9 kg CO2	0.7 kg CO2

Figure 4. Optimised energy demand of the procurement process

This section has detailed the application of the PCE model to a process typically not considered in energy evaluations. In the following section, the methodology is applied to the electroplating process, which is a subset of the manufacturing enterprise function.

5.2 Electroplating Process

As per the methodology in detailed in Figure 2, the user selects and reviews the electroplating process. The user thereafter selects the operational parameters from the manufacturing resources database. The next step is the quantification of the baseline energy demand by selecting the energy resources required for each step of the electroplating process. The final step is optimisation of the baseline energy demand. A user interface displays the optimisation options, which is based on functional systems and operational equipment. The heating system is selected for optimisation by use of a floating media cover. The results are displayed as illustrated in Figure 5.

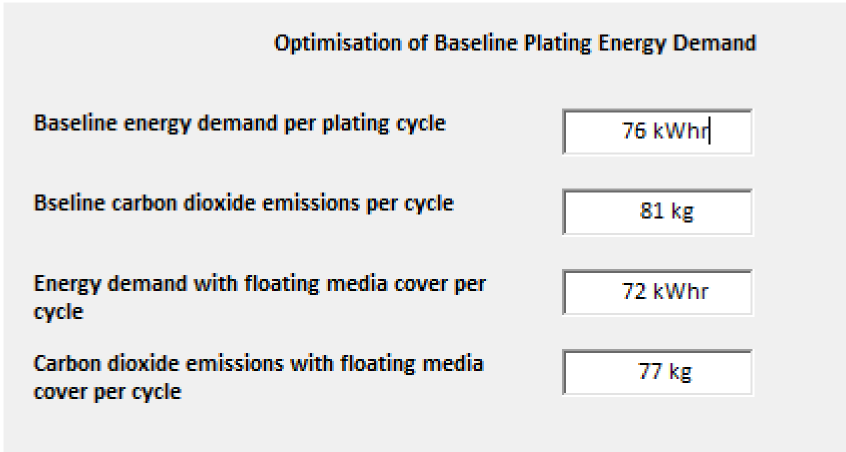

Figure 5. Optimised energy demand of the electroplating process

6. Conclusion

To achieve the "below two degree" rise in global temperature, industry has to be a leader in the reduction of energy use and CO_2 emissions. MMC's encounter challenges to energy quantification and optimisation due to inherent complexity and the lack of a MMC specific tool. The desktop review of non-industrial and industrial energy models revealed its limited applicability to MMC's, further affirming the need for a MMC specific energy model. The PCE model adopts a novel approach of business processes for energy evaluation and optimisation, as all MMC's conduct business by employing business processes at various levels of functional enablement. The defining features of the PCE model are; reproducibility, genericity, ease of use, limited user data inputs and modelling time and comprehensiveness. The paper demonstrated the concept and methodology of application of the PCE model by application to the procurement and electroplating business processes. The results demonstrate that business processes can quantify and optimise the energy demand of both manufacturing and non-manufacturing activities of a MMC. However, this is the initial stage of development, with the fully enabled PCE model providing a holistic and integrated methodology for MMC evaluation and optimisation. Detailed application of the PCE model is expected in in the sequel paper, following the enablement and validation of the PCE model.

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