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Business process centric energy modelling

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Abstract

Purpose – Sustainability is an accepted measure of business performance, with reductions in energy demand a commonly practised sustainability initiative by multinational corporations (MNCs). Traditional energy models have limited scope when applied to the entire MNC as the models exhibit high data and time intensity, high technical proficiency, specificity of application and omission of non-manufacturing activities. The purpose of this paper is to propose a process centric energy model (PCEM), which adopts a novel approach of applying business processes for business energy assessment and optimisation. Business processes are a fundamental requirement of MNCs across all sectors. The defining features of the proposed model are genericity, reproducibility, minimum user input data, reduced modelling time and energy evaluation of non-manufacturing activities. The approach forwards the adoption of Industry 4.0, a subset of which focuses on business process automation or part thereof.

Design/methodology/approach – A quantitative approach is applied in development of the PCEM. The methodology is demonstrated by application to the procure to pay and electroplating business processes.

Findings – The PCEM quantifies and optimises the business energy demand and associated carbon dioxide emissions of the procure to pay and electroplating business processes, validating the application of business processes. The application demonstrates minimum user inputs as only equipment operational parameters are required and minimum modelling time as business process models and optimisation options are pre-defined requiring only user modification. As MNCs have common business processes across multiple sites, once a business process energy demand is quantified, its inputs are applied as the default in the proceeding sites, only requiring updating. The model has no specialist skills requirement enabling business wide use and eliminating costs associated with training and expert's services. The business processes applied in the evaluation are developed by the researchers and are not as comprehensive as those in actual MNCs, but is sufficiently detailed to accurately calculate an MNC energy demand. The model databases are not exhaustive of all resources found in MNCs.

Originality/value – This paper provides a new approach to MNC business energy assessment and optimisation. The model can be applied to MNEs across all sectors. The model allows the integration of manufacturing and non-manufacturing activities, as it occurs in practice, providing holistic business energy assessment and optimisation. The model analyses the impacts of the adoption of Industry 4.0 technologies on business energy demand, CO_2 emission and personnel hours.

Keywords Sustainability, Corporate strategy, Energy industry, Business process management, Modelling

Paper type Research paper

1. Introduction

Economic, environment and social sustainability is a recognised strategic priority for business, driven by consumer focus on environmentally friendly products, resource limitations, climate change and social responsibility. McKinsey's global survey on business sustainability in 2014 and 2017 identified the alignment of organisational practise to it goals as the main reason for implementation of sustainability (Bonini and Bove, 2014; Bove *et al.*, 2017). The integration of environmental, economic and social

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systems enables business resiliency, its ability to tolerate shocks and disturbances (*Financial Times*, 2018). The benefits of sustainability for businesses include: reduction of susceptibility to risk, reduced waste production and increase in business efficiency (Gunasekaran and Spalanzani, 2012). Reduction in energy utilisation is one of the most commonly practised sustainability initiative, as the impact on costs and GHG emissions are tangible (Bonini and Bove, 2014).

Businesses are categorised as small and medium enterprises (SMEs) or multinational corporations (MNCs), with each encountering unique challenges to energy assessment and optimisation. In this study, the researchers focused on MNCs, due to its complexity of operations (Munsamy and Telukdarie, 2016):

- business sites traversing international borders;
- business sites with varying objectives, such as manufacturing, logistics and research and development;
- diversity of manufacturing processes and products;
- disparity in commodity quality and costs; and
- adherence to local laws, which differ across international borders with respect to labour, environmental emissions, resource availability and costs.

Energy modelling is an established methodology for energy assessment and optimisation at MNCs. The available energy models are diverse, with each having specific objectives and area of applicability (Hall and Buckley, 2016; Bhattacharya and Timilsina, 2010). The application of these models at MCs is limited due to model requirements of extensive input data and users with high technical or specialised skills, whilst being time intensive and excluding business activities of finance, human resources (HR) and information and communication technologies (ICT). Further to this are the apparent limitations associated with change, as the business changes the models must be reconstituted. These limitations prevent a comprehensive and holistic approach to energy assessment and optimisation at MNCs.

To address the limitations, an alternative energy model is proposed. MNCs conduct business by applying business processes, which details the process to realise a business activity, ordering of goods, recruiting of personnel, payment of personnel salaries and manufacturing of goods. Business processes are applied across all hierarchical levels of an MNC, changing from low resolution at the highest organisational level to detailed and specific at the lowest level.

This study adopts business processes as the building block for the development of the process centric energy model (PCEM) for MNC energy assessment and optimisation. The model systematically determines the energy demand from the lowest business level of equipment to the corporation as a whole. The objective of this study is prove the use of business processes for energy assessment and optimisation and demonstrate key model characteristics of reproducibility, minimum user input data, minimum time requirements, moderate user technical skills set and the inclusion of all business activities. In doing so, a case study demonstrates the practical application of the PCEM.

2. Review of existing energy models applicability to MNCs

Energy models began as simple input–output balances and evolved into complex models, driven by technological development in energy production and use. Energy models are used across all spectrums of society to analyse and optimise energy systems, predict energy demand and develop energy roadmaps and related policies (Bhattacharya and Timilsina, 2010; Herbst *et al.*, 2012).

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 range of available energy models necessitated the categorisation of the energy models as either non-industrial or industrial energy system models:

- Non-industrial energy system models: these models evaluate the energy system of specific geographic areas such as city, country, region, multi-regional or global from resource extraction through transformation to final end-user requirements. The models focus singularly or cumulatively on the energy, economy or environmental sectors for specific model objectives. The model objective may be general such as forecasting, exploring and scenario analysis or specific such as least cost system configuration and energy policy analysis (Hall and Buckley, 2016). These models have three common analytical approaches: top-down which are macro-economic models, bottom-up which are detailed techno-economic models and hybrid models which are the merging of the top-down and bottom-up models.
- Industrial energy system models: these models are specific to industrial processes, equipment and utilities. The models range from simulation and optimisation to monitoring and controlling. The models may be applicable to all industries, or industry specific such as power utilities or system specific such heat exchanger systems.

A detailed desktop study is conducted to review the suitability of available energy models to MNCs.

2.1 Review of non-industrial energy system models

An initial search is conducted on ScienceDirect with the search terms "review of energy models", "review of energy system models", "energy models for the manufacturing industry" and "energy systems models", in the Abstract, Title and Keyword fields for the years 2000 to present. The relevant articles identified in chronological order are:

- "A review of energy systems models in the UK: Prevalent usage and categorisation", by Hall and Buckley (2016). This paper reviews the published literature on energy system models applied in the UK since 2008.
- "Can energy systems models address the resource nexus?" by Semertzidis (2015). This paper defines resource nexus, discusses energy system models and its limitations and identifies models to address the resource nexus.
- "Energy systems modelling for twenty-first century energy challenges", by Pfenninger *et al.* (2014). This paper identifies specific challenges encountered by energy systems optimisation models, energy systems simulation models, power systems and electricity market models and qualitative and mixed-methods scenarios and discusses how it is being addressed.
- "A review of energy models", by Jebaraj and Iniyan (2006). This paper reviews the various categories of energy models.

A further search conducted on Google Scholar with the above-mentioned search terms identified the following papers:

- "A review of energy system models", by Bhattacharya and Timilsina (2010). This paper reviews energy system models to determine its appropriateness for analysing energy related policies of developing countries.
- "Introduction to energy systems modelling", by Herbst *et al.* (2012). This paper provides a review of top-down, bottom-up and hybrid energy models.

- Classification of energy models by Van Beeck (2000). The paper provides a summary of the various classification categories for energy system models and details the application of the classification categories.

These articles provide a detailed overview of the available energy models, facilitating the selection of the models reviewed in this paper. The nine models selected vary from applicability to the energy sector only to the energy-economy-environment and are (Bhattacharya and Timilsina, 2010; Hall and Buckley, 2016; IEA, 2016):

- E3ME-Global is a hybrid model applied for policy assessment, forecasting and research purposes.
- LEAP is a hybrid model applied for integrated resource planning, development of GHG mitigation strategies and policy analysis.
- MARKAL is a bottom-up model applied for scenario analyses and evaluation of the effects of regulations, taxes and subsidies.
- MESSAGE is a bottom-up model applied for energy system planning, energy policy analysis and scenario development.
- NEMS is a hybrid model applied in creating the USA Annual Energy Outlook and analysis of GHG control measures. This model is specific to the USA.
- OSeMOSYS is a bottom-up model applied for energy systems analysis, prototyping new energy models and development of energy strategies.
- POLES is a hybrid model applied for developing and analysing global energy demand/supply scenarios up to 2050.
- TIMES is a bottom-up model applied for policy analysis and identification of feasible energy system configurations.
- WEM is a hybrid model applied for scenario analysis and energy projections.

The approach of non-industrial energy system models is illustrated in Figure 1.

The analyses of the non-industrial energy system models reveal: complexity in energy system representation and model computation, high input data and time intensity, long time horizons, large geographic dimensions and high user technical skills, as common characteristics among the energy models. These characteristics, which are fitting for the specified applications and end users hinders application at MNC's due to:

(1) Geographic dimensions: MNCs focus on specific sites across various geographic locations, with the non-industrial energy models focusing on geographic areas such as city, country, region or world. The scale of energy systems influences the endogenous models assumptions and user input data. The smallest scale of a non-industrial energy model is a locality such as city or town. The scale of operation of MNCs and non-industrial energy models are vastly different and not comparable.

(2) Long time horizon: the impact of change on GHG emissions and energy reduction in the national to global spheres is typically realised after a time period as change is not immediate. The readiness of different cities, countries and regions for the implementation of greener technologies and policies are different, requiring different implementation times. This is in direct contrast to MNCs, where the impact of change is rapid with respect to emission and waste discharges, product quality and availability, profit, business sustainability and investments and operational costs. The POLES model is the only model with a short-term time horizon, with the remaining eight having medium to long-term time horizons.

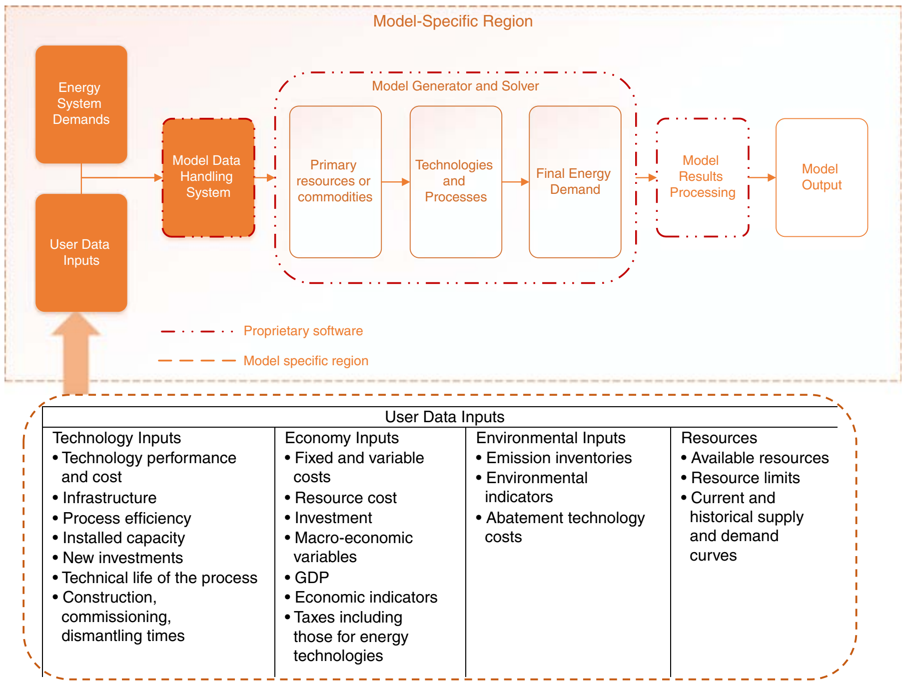

Figure 1.
Non-industrial energy system model approach

(3) Extensive data requirements: seven of the nine model have extensive data requirements, requiring quantitative and disaggregated data. The exceptions are the LEAP and OSeMOSYS models which can run with limited data inputs. The high data requirements of non-industrial energy system models have been acknowledged in literature:

- Hall and Buckley (2016) note that bottom-up models are reliant on the availability of historic data and optimisation models are data intense.
- Semertzidis (2015) note that bottom-up models are highly data dependent, econometric models are reliant on long time period data and multi-agent models require empirical data.
- Bhattacharya and Timilsina (2010) note that data limitations hinder scenario analysis, technology evaluations and policy impact analysis in developing countries. ETSAP (2016) recognises data sourcing as being arduous and time consuming, possibly extending over years. This is not preferred by MNCs. Recorded data availability is inconsistent among MNCs and the data requires validation.

(4) High technical skills requirement: seven of the nine models have high to very high skills requirement, restricting the number of users of the model. It also increases the probability of the user's requiring training, increasing MNC costs and time. This poses a business risk as personnel turn-around times are becoming shorter, especially among those with highly specialised skills. The return on investment in equipping personnel with the required skills is not assured. The exceptions are the LEAP and OSeMOSYS models, which require limited technical skills.

(5) Diversity of operations of MNCs: with global migrations and technological advances, telecoms, buildings and ICT may be significant contributors to an MNC's

energy demand. Thus, all operational activities ranging from HR to manufacturing has to be evaluated and optimised. Whilst this is captured by the end-user demands in the non-industrial energy models, it does not apply to MNCs which have business sites across varies cities, countries and regions. The extrapolation of energy data for the MNC from a single city, country or region is not representative due to the endogenous assumptions of the model, user specific technical inputs and the differing end-user demands of first world, third world and developing countries.

2.2 Review of industrial energy models

Six industry partners providing energy assessment and energy system optimisation services are identified: Aspen Technology, Honeywell, General Electric Company (GE), ABB, Rockwell Automation and Schneider Electric. The energy assessment and optimisation tools of the above-mentioned companies are reviewed as per the purposes detailed earlier in Section 2. The data sources are the individual company websites, which include product brochures, operating manuals and case studies. The review also included monitoring and controlling software as it is a tool for energy assessment and optimisation and is common practise in industry. The 11 industrial energy system models reviewed are:

- Aspen Activated Energy Analysis: it is a simulation and optimisation software used in reducing process energy consumption and costs and in costing of heat exchanger networks (Aspen Technology, 2016a).
- Aspen Energy Analyzer: it is a simulation and optimisation software used for reducing process energy utilisation by optimising heat exchanger networks (Aspen Technology, 2016b).
- Aspen Utilities Planner Technology: it is a simulation and optimisation software used for the optimisation of process utilities (Aspen Technology, 2016c).
- ARENA: it is a simulation software developed by Rockwell Automation. It is applied for logistics improvement, process optimisation, cost analysis and improved resource utilisation (Rockwell Automation, 2016a).
- Concorda Software Suite: it is a simulation software developed by GE. It is a designed specifically for the power utilities industry and is used for the simulation of power electric grids, evaluation of generation reliability and assessment of economic performance of large electricity systems (GE, 2016a).
- FactoryTalk EnergyMetrix: it is an energy management software developed by Rockwell Automation. It captures, stores, analyses and reports energy data for energy monitoring and management and optimises energy procurement and cost accounting based on energy use (Rockwell Automation, 2016b).
- Honeywell Energy Dashboard: it is an energy monitoring and decision-making software. It captures and records energy consumption of instruments and systems for comparison against targets and identification of opportunities for reducing energy consumption and emissions (Honeywell, 2016a).
- Sentient System: it is an optimisation and asset management software developed by Honeywell. It is used for reducing energy consumption and improvement of environmental performance (Honeywell, 2016b).
- GE Envisage: it is an energy management software. It is used for monitoring, analysing and profiling of energy demand, advanced harmonics analysis, allocation of energy costs and identification of cost savings (GE, 2016b).

- ABB Energy Manager: it is an energy management software. It is used for calculating energy efficiencies, comparison of actual performance data to set targets and optimisation of energy supply and demand with respect to scheduled demands and costs (ABB, 2016).
- PowerLogic ION EEM 4.0: it is an enterprise energy management software developed by Schneider Electric. It is used for the allocation of energy costs, emissions reporting and validation of power quality compliance as per energy contracts (Schneider Electric, 2016).

The industrial energy models focus on manufacturing processes and equipment, utilities and costs, with some models being industry specific such as the GE Concorda Software Suite. The models require quantitative and highly disaggregated data. The limitations of the industrial energy models for application at MNCs are:

- the focus is on manufacturing activities, which are recognised contributors to an MNCs energy demand, but it neglects the non-manufacturing activities of HR, finance, sales and marketing and health safety and environment;
- the software is proprietary and potentially costly;
- a moderate to high level of engineering and technical skills is required; and
- the models need to be recalibrated or reconstituted for every new change.

Whilst these limitations do not negate the application at MNCs, it does not provide a holistic energy evaluation of an MNC.

The review of the non-industrial and industrial energy system models highlighted the need for a comprehensive MNC-specific energy model. The researchers identified the following limitations an MNC-specific energy model must address:

- Geographic area: the model must be independent of geographic area as MNCs have business sites across various geographic locations.
- User data inputs: data inputs must be significantly reduced. The required user inputs should be easily obtainable.
- Modelling time: this encompasses the time for data collection, software learning and model computation and must be at a minimum. Results must be timeously available for effective utilisation of the MNC-specific energy model.
- Moderate technical skills set: the model must be comprehensive while requiring a moderate technical skills set. The model users should not be restricted to specialists or technical experts.
- Inclusion of all business activities: the model must include the non-manufacturing activities of customer services management, logistics and procurement.

Garwood *et al.* (2018) and Schulze *et al.* (2016) recommended two approaches to industrial energy management:

- systematic approach to energy management; and
- holistic modelling considering interdependencies and interactions of equipment, processes and systems.

To address the identified limitations and recommendations, the researchers considered the operational practice of MNCs and the adoption of Industry 4.0 technologies. MNCs across all sectors operate by the enablement of business processes. Business processes are cross-industry and a universally accepted business management tool. Business processes define each step in achieving a business activity output, enabling the quantification of the energy demand of each business process step, hence the business activity.

Business processes are applied to all aspects of a business; manufacturing, HR, finance and ICT. In the current context of the 4th Industrial Revolution, Industry 4.0 adopts business processes as a key navigator. The impact of Industry 4.0 technologies on business energy demand has to be evaluated. Thus, business processes provide a fitting basis for the development of an MNC-specific energy model, the PCEM.

The paper now seeks to provide a framework for the development of the MNC-specific energy assessment and optimisation tool: the PCEM.

3. Process centric energy model

MNCs are hierarchically structured, with the organisation at the top and the equipment at the base. A hierarchical business energy framework is developed for the adoption by the PCEM, as illustrated in Figure 2.

Business processes interlink the various organisational levels with integrated information technology (IT) systems (Munsamy and Telukdarie, 2016). These systems include enterprise resource planning, manufacturing execution systems and plant control networks (Munsamy and Telukdarie, 2016). Key features of business processes supporting its application for business energy assessment and optimisation are: inherently detailed and technical nature, analytical approach, process emphasis and cross-functionality (Chapman, 2016).

The adoption of business processes as the basis for the development of the PCEM enables the following model characteristics:

- Generic: to be applied to any type of MNC ranging from steel, automotive and health care.
- Reproducible: for a manufacturing MNC, various sites may manufacture the same product as per the same manufacturing process. The advantage is realised in the proceeding evaluation of the identical manufacturing process, where only input data relating to variables such as equipment and process operating parameters require updating, hence the time and effort required is greatly minimised. Reproducibility ensures each model application does not start from base zero but builds on previous applications. It facilitates model development, as the learning achieved is utilised in improving successive model applications. Confidentiality of information across MNCs is acknowledged and respected.
- Ease of use: the model has no specialised knowledge requirements. The key user inputs are operating parameters and process and equipment capacities, which are readily available.

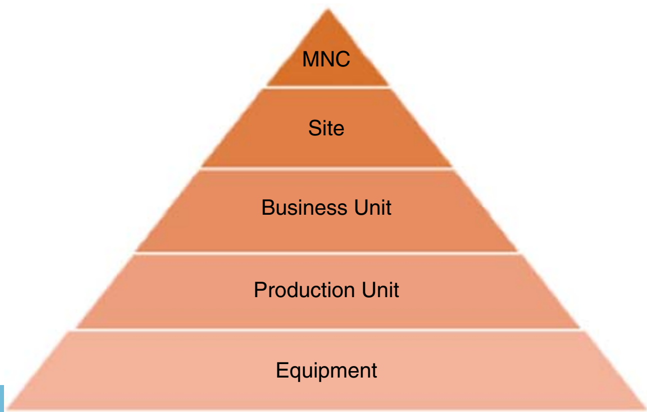

Figure 2.
Business energy hierarchy

- Minimum modelling and data collection time: the clear definition of each business process step enables specification of the resource requirements of equipment and personnel and the associated time requirement, allowing quantification of each business process step energy demand. As these are operational activities being conducted at the *n*th level of the business energy hierarchy, this information is readily available.
- System thinking approach: a holistic approach is undertaken, with the MNC considered as a single system, with each site a subsystem. The interrelationships and interdependencies are identified and analysed for feedback effect on MNC energy demands; in the recruitment of personnel, a personnel may decline the offer requiring a different path to be followed as compared to when the candidate accepts the offer, each affecting the business energy demand.

To quantify the energy demand of an MNC via business processes, two elements are required: the business process itself and the resources to execute the business process. As energy demand is quantified at the business process level, similarly energy optimisation must occur at the business process level. Optimisation is achieved by reengineering or modifying business processes and substituting of existing resources with energy efficient resources. This results in three primary elements of the PCEM: business processes, resource requirements and optimisation. These three elements are integrated to develop the PCEM approach, as illustrated in Figure 3.

3.1 Developing the business processes database

The business processes database is the entry point into the model, where the user selects the business process for energy assessment and optimisation. A four-level hierarchical structure is developed for the PCEM business processes database, as illustrated in Figure 4.

The primary data source for Levels 0–3 is the APQC process classification framework due to its genericity and extensive detail (APQC, 2015). Levels 0 and 1 are expected to be fairly standard across MNCs, with the greatest specificity expected at Level 2 for the value-chain activities. It is expected that support functions of finance, ICT and HR are fairly standard across MNCs. The order of the magnitude of business processes increases as the business processes expand from L0 to L3.

Business processes are not unique to a single business activity but are applied to a number of business activities, thus interrelationships can be identified, analysed

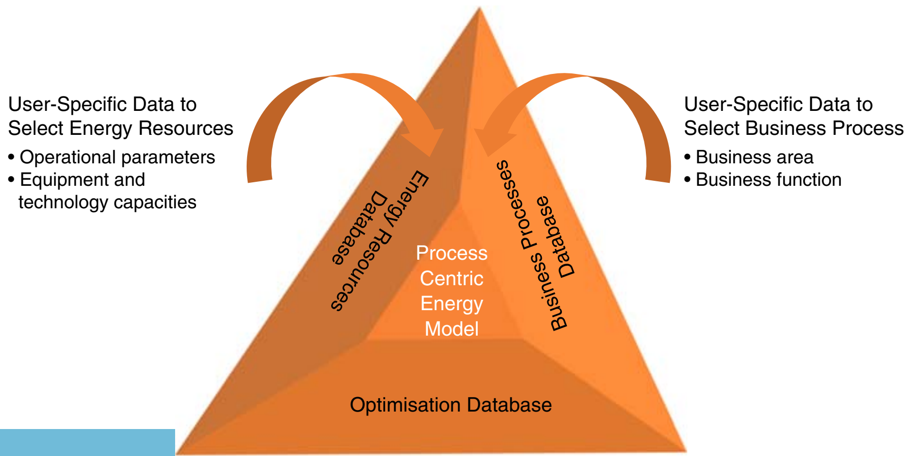

Figure 3.
Process centric energy model approach

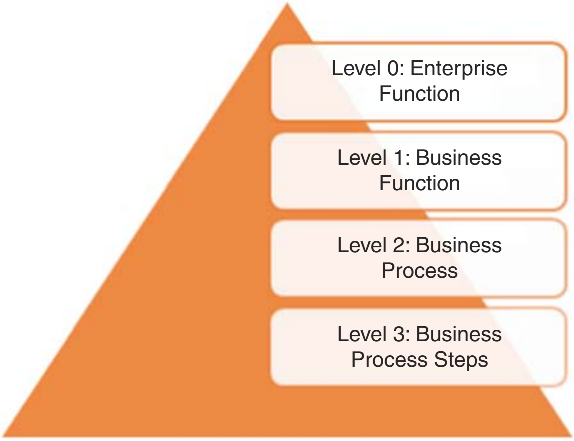

Figure 4.
Business process hierarchy

and quantified. Business activities are also interdependent as explained with a maintenance task, which requires collaboration with the production and planning departments and extends to the logistics and finance departments should material procurement be required. The hierarchical ranking of the MNC energy demand and the business processes provide a methodical approach to MNC energy evaluation, as each business level (Figure 2) and business process level (Figure 4) builds to the proceeding one. The relationship between the business energy framework and business process hierarchy is detailed in Figure 5.

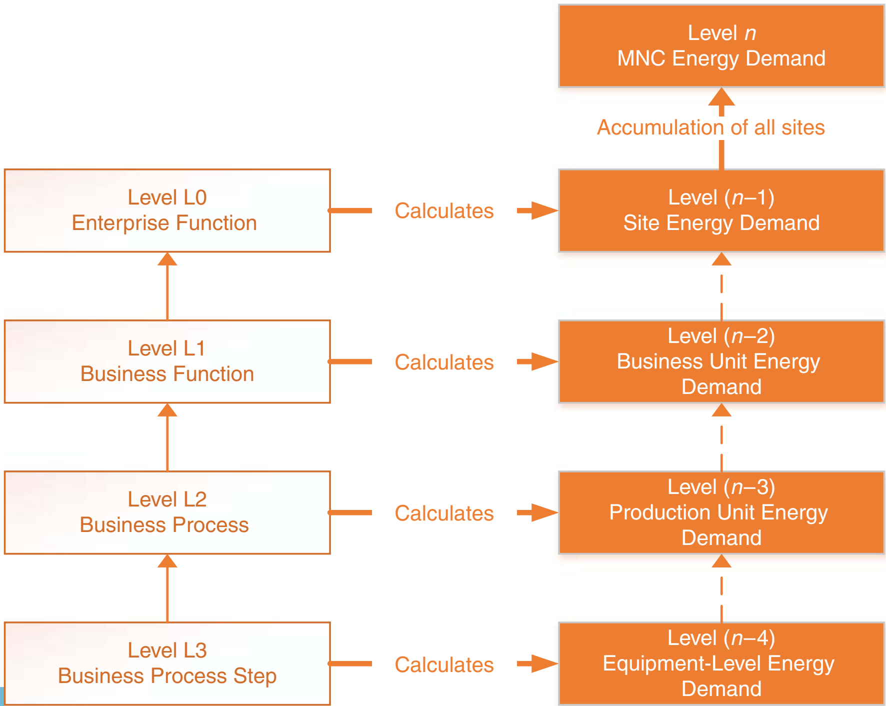

Figure 5.
Relationship between business processes and business energy framework

3.2 *Developing the energy resources database*

This database comprises all resources required to enable execution of a business process. Each resource in the database has an associated energy demand and operational parameters, if applicable. The database contains an extensive range of energy resources, hence is categorised into:

- Building: lighting, heating, ventilation and air-conditioning.
- ICT: wireless and wired network devices, servers, laptops and printers.
- Logistics: barcode scanning devices, hysters and fleet vehicles.
- Manufacturing: all production equipment required for the conversion of raw materials to final products; turbines, boilers, reactors, absorption columns, pumps and instrumentation.

The energy resources for each category are classified on functional requirement and design characteristics. The classification of a specific resource is halted when the difference in power demand between two levels is negligible. A condensed reactor classification illustrates the structure of the energy resources database, with the reactor being Level 0.

- Level 1: Batch Operation
    - Level 1.1: Catalytic
        - Level 1.1.1: Gaseous
        - Level 1.1.2: Liquid
        - Level 1.1.3: Gas-liquid
        - Level 1.1.4: Gas-solid
        - Level 1.1.5: Solid-liquid
- Level 2: Continuous Operation
    - Level 2.1: Continuous Stirred Tank Reactor
        - Level 2.1.1: Catalytic
            - Level 2.1.1.1: Liquid
            - Level 2.1.1.2: Gaseous
            - Level 2.1.1.3: Gas-liquid
            - Level 2.1.1.4: Gas-solid
            - Level 2.1.1.5: Solid-liquid

The classification methodology provides each energy resource with a unique descriptive such as "Batch Operation_Catalytic_Liquid". The unique resource descriptive and categorisation of the database streamlines data processing, enabling faster modelling times and efficient database management. Energy resources can be further categorised as global or site resources. Global resource characteristics are identical across all business sites of the MNC and site resource characteristics are specific for a single site.

3.3 *Developing the 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 GHG emissions.

3.4 *Developing the model methodology*

The simplicity of the PCEM methodology enables resolution of the complexity of business energy systems. The PCEM modelling methodology is illustrated in Figure 6.

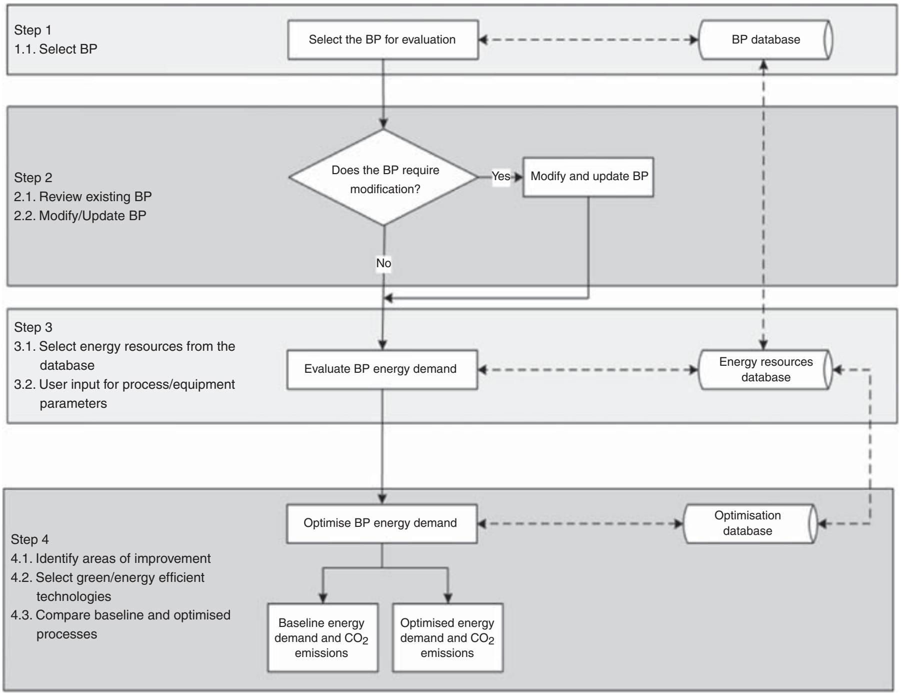

Figure 6.
PCEM methodology for energy assessment and optimisation

3.4.1 Calculation methodology. The Victor *et al.* (2014) reported that carbon dioxide emission (CO_2) contributes to 76 percent of GHG emissions, hence the PCEM focuses on CO_2 emissions only. The PCEM calculates the energy demand and CO_2 emissions for business activities and each MNC hierarchical level:

$$\text{Level}(n-4)\text{ energy demand} = \sum_{l=1}^{N_3}\sum_{m=1}^{P}\text{Resource energy demand} \times \text{Resource usage time}, \tag{1}$$

$$\text{Level}(n-3)\text{ energy demand} = \sum_{k=1}^{N_2}\sum_{l=1}^{N_3}\sum_{m=1}^{P}\text{Resource energy demand} \times \text{Resource usage time}\,, \tag{2}$$

$$\text{Level}(n-2)\text{ energy demand} = \sum_{j=1}^{N_1}\sum_{k=1}^{N_2}\sum_{l=1}^{N_3}\sum_{m=1}^{P}\text{Resource energy demand} \times \text{Resource usage time}\,, \tag{3}$$

$$\text{Level}(n-1)\text{ energy demand} = \sum_{i=1}^{N_0}\sum_{j=1}^{N_1}\sum_{k=1}^{N_2}\sum_{l=1}^{N_3}\sum_{m=1}^{P}\text{Resource energy demand} \times \text{Resource usage time}\,, \tag{4}$$

$$\text{Level}(n) = \sum_{g=1}^{S}\text{Level}(n-1)\text{ energy demand}, \tag{5}$$

$$\text{Level } x \text{ } CO_2 \text{ emissions} = \text{Level } x \text{ Energy demand} * CO_2 \text{ emissions factor}, \tag{6}$$

where N_0 is the number of enterprise functions, N_1 the number of business functions, N_2 the number of business processes, N_3 the number of business process steps, P the number of energy resources per business process step, S the number of business sites of the MNC and $\times$ the MNC business energy level

The simplicity of the equations are due to the hierarchical approach to MNC energy modelling and the quantification of the energy demand of each energy resource in the energy resources database. The application of the proposed PCEM stands as a new concept that can be reiterated via a proof of concept. The following section demonstrates the application of the PCEM as per the methodology detailed in Figure 6.

4. Demonstration of the application of the process centric energy model

The PCEM is developed with Microsoft Excel VBA, with the front end-user interface created with VBA user forms. A tool manufacturing facility is selected for demonstration of the PCEM, with specific application to the procure to pay and electroplating processes. The procure to pay process is an established cross-industry business process that is widely applied at MNCs. In a typical tool manufacturing facility, the final production step is the electroplating of components for aesthetic and protective purposes.

4.1 Purchasing of electroplating raw materials with the procure to pay process

The procure to pay process is an integrated cross-functional business activity. It combines three business activities, each with its own business process. The three activities in sequential order are: order placement for raw materials, receiving of raw materials and payment for received raw materials. The output of each business activity is an input into the proceeding one; following order placement of raw materials, a notification is issued to the warehouse for expected raw materials delivery and after acceptance of the delivered raw materials the invoice is issued to finance for payment. The proceeding business activity cannot occur, if the preceding business activity fails to be completed successfully. The three business processes required to achieve the final output are:

(1) Order material from vendor: this business process sequentially details all the steps to be followed for placement of an order with a vendor. This is a procurement activity, a subset of the financial function.

(2) Manage external inbound receipts: this business process details all the steps to be followed in receiving and acceptance of goods. This activity is subset of the logistics function.

(3) Accounts payable: this business process details the steps to be followed for payment of goods accepted. This activity is subset of the financial function.

The energy demand and CO_2 emissions of the procure to pay process are the cumulative summation of the three afore-mentioned business processes. The functional unit for calculation of the baseline energy demand of the procure to pay process is successful placement of an order for raw materials. The methodology followed is illustrated in Figure 6.

4.1.1 Select the business process for assessment (Step 1 in Figure 6). The selection of the business process follows the business process hierarchy detailed in Figure 4. The user first selects the enterprise function, followed by the business function and lastly the business process. For the first activity of ordering raw materials, the user would select the finance enterprise function, followed by the procurement business function and lastly the order material from vendor business process, as illustrated by the user interface in Figure 7. The manage external inbound receipts business process is not selected as per the above-mentioned procedure, as the last step of the order material from vendor business process is a direct link to manage external inbound receipts, similarly for the accounts payable business process.

4.1.2 Review and updating of the business process (Step 2 in Figure 6). The selection of the business process opens an active Microsoft Visio document containing the business process model. A business process model is a graphical representation of a business process. Figure 8 displays the order material from vendor business process model, with the two user options of modifying or not modifying the business process. The modification is completed on the open and active Visio document.

4.1.3 Evaluation of the baseline energy demand of the business process (Step 3 in Figure 6). Every business process comprises business process steps, with the number of business process steps dependent on the complexity of the business process. For each business process step, the user has to select the required resource from the energy resources database to enable execution. Due to the wide range of energy resources, the user first selects the category of the resource: logistics, manufacturing, building and ICT. The user may select resources from multiple categories per business process step, but can only select a single category at a time. Once a resource is selected, further specificity may be required as explained with the selection of a computer from the ICT database. After selecting a

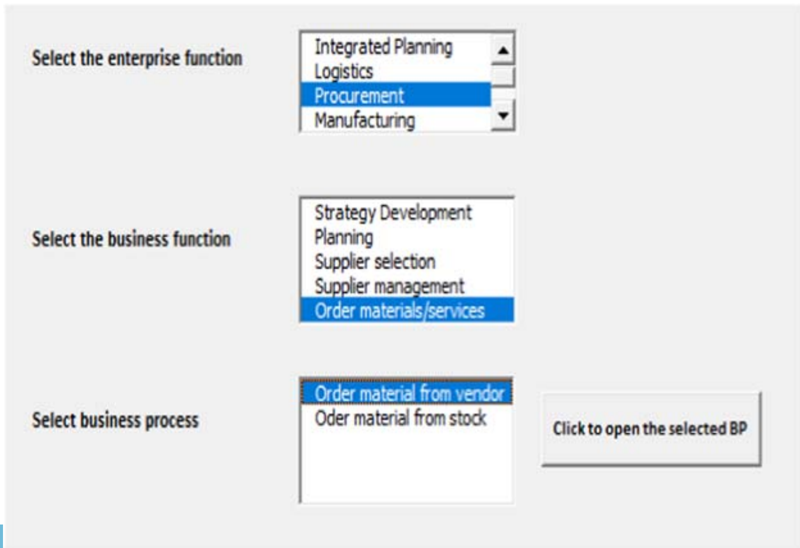

Figure 7.
User interface for selecting the business process for assessment

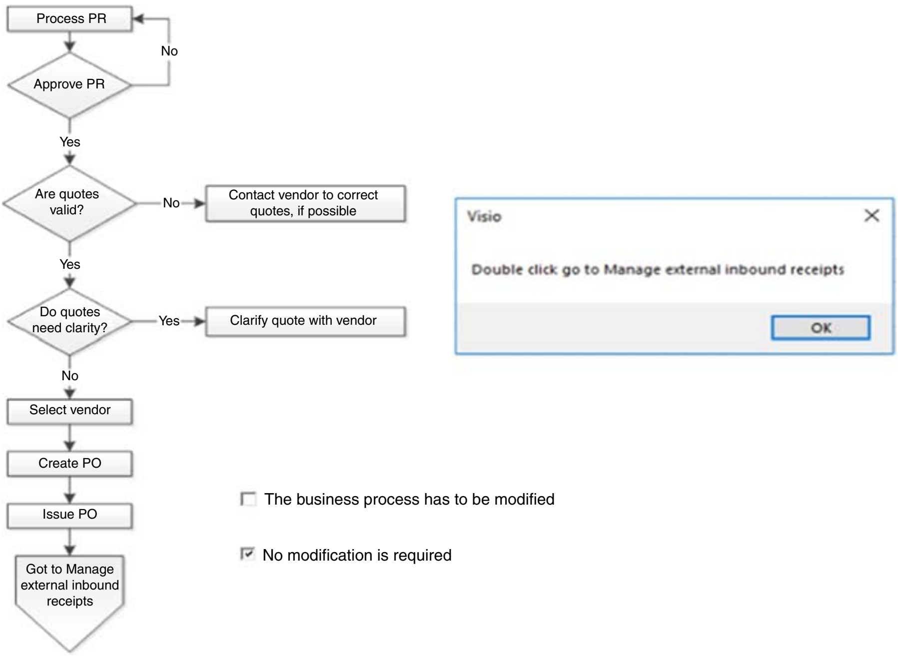

Figure 8.
Review of "order material from vendor" business process

computer, the user has to specify if it is a laptop or desktop and should desktop be selected, the user has to select the type and size of the screen as illustrated in Figure 9. For each resource selected the user has to specify the operational time. For shared resources such as telephone or networks, the user only indicates access to the shared resource, as the energy demand is determined at a site level and distributed among the total number of users on site.

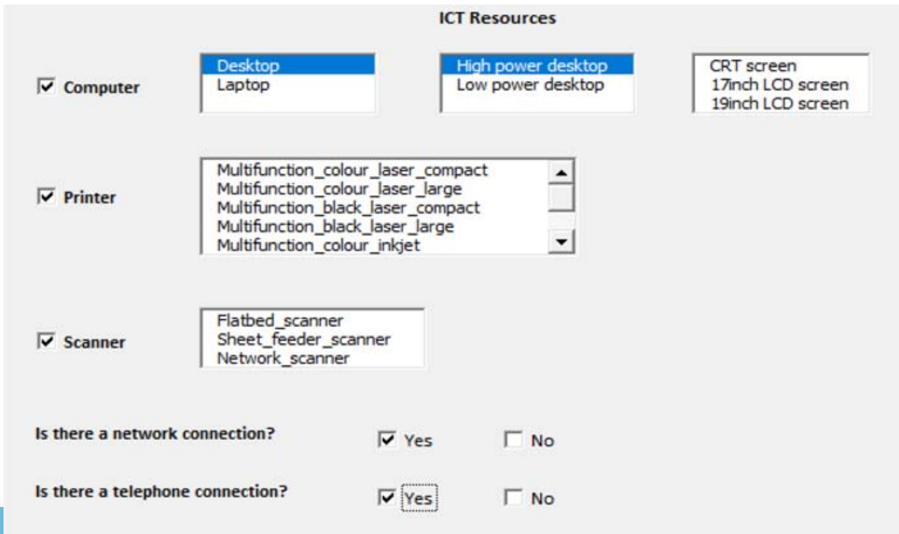

Figure 9.
User selections for the business process step of process PR

A sample of the user selection for the first business process step of Process PR in the order material from vendor business process is illustrated in Figure 9. A sample of the backend calculation of the energy demand of each business process step is detailed in Table I for Process PR business process step.

The order material from vendor and accounts payable business processes only require ICT resources, whilst the manage external inbound receipts business process requires resources from both the ICT and logistics databases. As electroplating raw materials are not quality tested on delivery, the only resource required from the logistics database is hysters for movement of raw materials. The user is never required to input a resource energy demand, only specify operating parameters to enable selection of the correct resource.

The summation of the energy demand of the selected resources for each business process step cumulates into the business process energy demand, with the summation of the energy demand of all three business processes, the energy demand of the procure to pay process.

The model displays the calculated energy demand of each business process and total energy demand of the procure to pay process, as illustrated in Figure 10.

The results show diesel consumption, indicating that the hysters selected use diesel as the fuel. The results enable the user to identify the high energy demand activities for the focus of optimisation activities.

4.1.4 Optimisation of the baseline energy demand (Step 4 in Figure 6). The final step is the selection of technologies and operational practices from the optimisation database to reduce energy demand and CO_2 emissions. For each of the resources, there is an associated optimisation option, such as new energy efficient servers, variable speed motors for compressors and super critical boilers. As the order material from vendor and accounts

Table I.
Sample backend calculation for business process step of process PR

Business process step	Resources required	Power consumption of resource (W)	Operational time of resource (hr)	Energy Consumed (W.hr)
Process PR	Desktop – High powered	160	2	320
	19" LCD	25	2	50
	Black laser printer	995	0.02	20
	Network connection per user	9.9	2	20
	Telephone	1.96	0.5	1
	Process PR energy demand			411

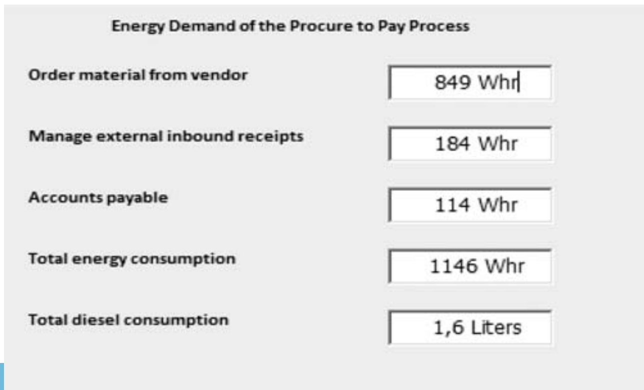

Figure 10.
Energy demand of the procure to pay process

payable business processes have only ICT resources, contributing 84 percent of the total energy demand, the focus is on ICT resources. The printers are identified for optimisation, as it is one of the largest energy consumers. The current practice has each personnel with an individual desktop black laser printer, with a single multifunction black laser office printer identified as the optimised option. The model details the energy demand of current practice alongside that of the optimised option together with the CO_2 emissions, as illustrated in Figure 11. This enables the user to evaluate the feasibility of the optimised option from a technical and statutory perspective.

This section has detailed the application of the PCEM to a process typically not considered in energy evaluations. In the following section, the methodology is applied to a subset of the manufacturing enterprise function to illustrate the scope of the PCEM for energy assessment and optimisation.

4.2 Chromium electroplating process

In manufacturing processes, the energy demand is classified based on functional requirements as each equipment cannot be considered in isolation. A change in the specification of one equipment can change the dynamics of the whole process effecting process performance. The functional energy requirements of an electroplating process are: start-up heating energy, operational heating energy, air blower energy demand, crane energy demand and degreaser and plating bath electrical demand. The electroplating energy demand is determined per single cycle, with 100 cycles occurring per year.

4.2.1 Selection and modification of the business process for evaluation (Steps 1 and 2 in Figure 6). Similarly to the process detailed in Section 4.1.1, the user selects a single rinse chromium electroplating process for evaluation. A Microsoft Visio file of the single rinse chromium electroplating process model is opened for review by the user.

Optimisation of the Procure to Pay Process

	Baseline	Optimisation by the use of a MFD Office Laser Printer
Order material from vendor energy demand	849 Whr	665 Whr
Order raw material from vendor carbon dioxide emissions	0,9 kg CO2	0,7 kg CO2
Manage external inbound receipts energy demand	184 Whr	131 Whr
Manage external inbound receipts carbon dioxide emissions	0,2 kg CO2	0,1 kg CO2
Manage external inbound receipts diesel consumption	1,6Liters	1,6Liters
Carbon dioxide emissions from diesel consumption	4 kg CO2	4 kg CO2
Accounts payable energy demand	114 Whr	87 Whr
Accounts payable carbon dioxide emissions	1,2 kg CO2	0,9 kg CO2

Figure 11. Optimisation of energy consumption and CO_2 emissions of the procure to pay process

4.2.2 Evaluation of the baseline energy demand of the business process (Step 3 in Figure 6). The required resources for the electroplating process are selected from the manufacturing database. Together with selecting the resources such as the crane for movement of plating barrel and the air blower, the user also selects the operating parameters of the electroplating process such as dimensions of the process baths, operating temperature and air flowrate. The process baths are the acid, degreaser and plating baths. The user interface for the selection of the plating bath operating parameters is illustrated in Figure 12, with similar user interfaces for the remaining process baths.

The process tanks start-up and operational heating demand is calculated using the Spirax Sarco methodology for energy consumption of tanks and vats, based on conductive, convective and radiative heat transfer (Spirax Sarco, 2017). The electrical consumption of the degreaser and plating bath is sourced from Telukdarie and Overcash (2008). The results are displayed as per the user interface illustrated in Figure 13.

The results indicate that the start-up energy heating requirement is accountable for 85 percent of the energy demand, and should be the focus area for optimisation.

4.2.3 Optimisation of the baseline energy demand (Step 4 in Figure 6). The optimisation database has options specific to a process such as electroplating or ammonia production, to a business process such as order materials from vendor and to equipment such as compressors or boilers. The optimisation options are further aligned to the specific categorisation of the energy demand; the electroplating process optimisation options are based on the functional energy requirements. In this case, the user selects the electroplating process, which displays the possible optimisation options as illustrated in Figure 14.

As the heating energy demand, including heating at start-up, start-up heat losses and operational heating, is accountable for 99 percent of the energy demand, the heating system of the process tanks is selected for optimisation. In this case, the application of a floating cover is selected. The model now calculates the energy demand of the optimised process and the results are displayed in Figure 15.

The results demonstrate that the application of floating covers reduces the energy demand to 7.2 MW.hr and CO_2 emissions to 7.7 tons, savings of 5 and 3.7 percent, respectively. At this stage, the user can conduct a costing analysis and determine its feasibility of application.

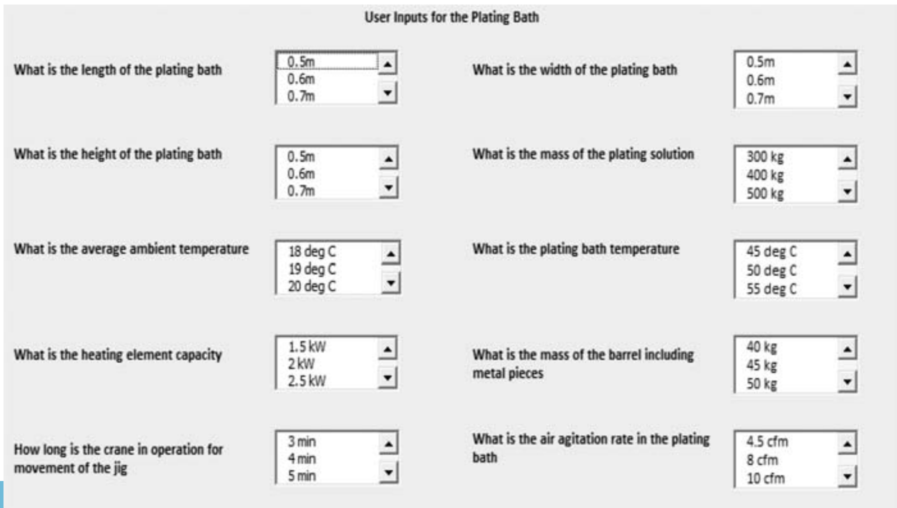

Figure 12.
User interface for the selection of plating bath operational parameters

Electroplating Process Energy Demands	
Energy required at start-up for heating	65 kWhr
Energy required at start-up due to heat losses	8 kWhr
Energy required during operation due to heat losses	2 kWhr
Air blower power requirements	0.12 kWhr
Crane motor power requirements	0.06 kWhr
Degreaser and plating baths electrcial requirements	0.04 kWhr
Total energy requirements	76 kWhr

Figure 13.
Electroplating process baseline energy demand

Optimisation Options for Plating System		
Heating system of process tanks	☑	Insulation of tanks Rigid cover Floating cover (selected) Immerisble heaters
Steam system	☐	
Air compressor/blower system	☐	
Rinse system	☐	
HVAC system	☐	

Figure 14.
Potential areas for optimisation

Optimisation of Baseline Plating Energy Demand	
Baseline energy demand per plating cycle	76 kWhr
Number of plating cycles per year	100 cycles
Baseline energy demand per year	7.6 MWhr
Bseline carbon dioxide emissions per year	8 tons
Energy demand with floating media cover per year	7.2 MWhr
Carbon dioxide emissions with floating media cover per year	7.7 tons

Figure 15.
Energy demand after the application of floating cover

The application of the PCEM to the subsets of logistics, financial management and manufacturing in Sections 4.1 and 4.2 demonstrates business processes appropriateness for assessment and optimisation of an MNC's energy demand.

5. Evaluation of impact of Industry 4.0 on business energy demand

As businesses adopt Industry 4.0 technologies, the execution of business processes is being transformed, impacting business energy demand. The PCEM is able to quantify this impact as demonstrated with a recruitment business processe.

One of the subsets of Industry 4.0 is the automation of business processes. The automation of business processes can require substantial cost investment, thus the ability to quantify the tangible benefits of automation is essential. Recruitment of personnel is a time intensive activity, with automation recommended to streamline and fast track the process.

The PCEM calculates both the energy demand and personnel hours of the manual and automated recruitment business process. The basis for evaluation is: recruitment of a single personnel, 100 applications are received for the post and 6 individuals are selected for interview. Figure 16 illustrates both the manual and automated business process. Following the processes detailed in Sections 4.1 and 4.2, the energy demand, CO_2 emissions and personnel hours are calculated and comparatively analysed.

Figure 16 and Table II illustrate that in this occurrence automation of the business process does not alter the process flow path but significantly reduces the energy demand, CO_2

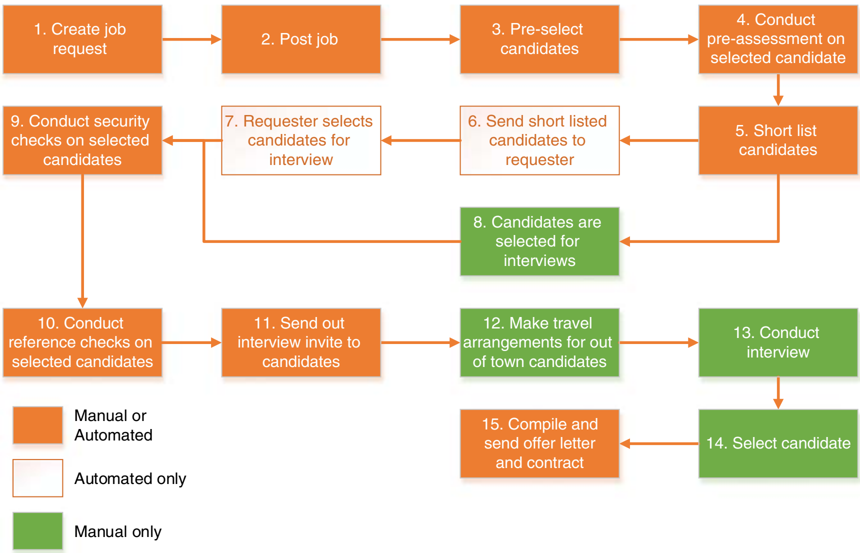

Figure 16.
Business process for recruitment of a new candidate

Table II.
Comparative analysis of the automated and manual recruitment processes

	Process flow path	Energy demand (W.hr)	CO_2 emissions (kg)	Personnel hours (hr)
Manual process	1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15	1,646	1.8	56
Automated process	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15	770	0.8	12

emissions and personnel hours. Automation streamlines the business process with built-in decision gate keepers. In an automated process, the received applications are automatically scanned and applications not meeting the user specified minimum requirements are discarded whilst in a manual process personnel has to review each application, electronically or paper based, to select candidates meeting minimum requirements.

The results of the comparative analysis detailed in Table II enable evaluation of the application of Industry 4.0 technologies.

6. Limitations of the PCEM

This is an independent study, with no association to any MNC, hence the business processes applied in the model are developed by the researchers. There may be missing details in the business processes but it is sufficiently detailed to be representative and enable evaluation and optimisation of its energy demand.

The business process interlinkages and independencies must be clearly detailed on the respective business process and business process model to be modelled by the PCEM. If the interlinkages and interdependencies are not indicated, the energy demand is not representative of the MNC. In manufacturing facilities, raw materials are quality tested prior to being accepted, hence the inbound material flow business process is dependent on the raw material quality testing business process. If this interdependency is not indicated, the model calculates the energy demand of the inbound material flow business process on the assumption that all raw material deliveries are accepted and the energy demand of the quality testing business process is underestimated.

The business processes, energy resources and optimisation databases are not exhaustive and there may be missing information. However, these databases are continuously being updated.

7. Practical implications of the PCEM

The PCEM provides an alternative approach to MNC energy assessment and optimisation, with significantly reduced time and user input requirements. The three databases enable minimum time and user inputs as detailed below:

(1) The user is not required to construct the business process model, but only selects and modifies the business process model. This is critical as MNCs have in excess of 100, 000 thousand business process steps. The time saved in not constructing each business process model is significant.

(2) The user is not required to enter performance characteristics or energy demand of any resource, be it ICT, manufacturing, building or network. The user only specifies the operating range of the equipment and selects the equipment for execution of the business process step.

(3) The model pre-defines the optimisation options for business processes and resources, hence the user only selects the option to be applied. This eliminates the time required to review the options applicability or not.

A MNC has numerous business sites, each with its own energy demand profile. Once the energy demand assessment and optimisation of the first site is completed, it is used as a default for the following sites. In the following sites, where the same business processes are applied, the user only has to update the resources required and its operational parameters and personnel requirements.

The lack of the requirement of specialist skills and knowledge enables multiple users of the energy model whilst eliminating the need for extensive staff training or contracting of specialists. It also enables the appropriate personnel to complete the associated business process; a suitable HR personnel completes the HR business processes, an engineer completes the manufacturing business processes and a suitable finance personnel completes the finance business processes.

The model can be applied to determine feasibility of the application of Industry 4.0 technologies by evaluating the impacts on business energy demand, CO_2 emissions and personnel requirements. As business process is interlinked and independent, it allows analysis across all effected business activities.

8. Conclusion

Energy demand reduction is a commonly practiced initiative by MNCs but is hindered by the limited tools available. Energy models, an established tool for energy system assessment, demonstrate limited applicability to MNCs as the operational practice of MNCs is neglected, the focus is on manufacturing activities, the requirement of extensive user input data and high technical skills and the lack of evaluation of non-manufacturing activities.

These limitations highlighted the need of an MNC-specific tool and stemmed the development of the MNC-specific energy model, the PCEM. The model is based on a fundamental of the operation of MNCs: business processes. The application of business processes enables all interlinkages and interdependencies present in a business to be captured and its impact on business energy demand assessed. The PCEM comprises three databases forming the foundation of the model: business processes, energy resources and optimisation. These databases facilitate the defining features of the model: reproducibility, genericity, ease of use, minimum user input data and modelling time, comprehensiveness and the inclusion of non-manufacturing activities. It is these features that support its appropriateness for the application at MNCs. The simplicity of the PCEM methodology enables the resolution of the complexity of business energy systems.

The paper successfully demonstrates the capability of the PCEM to assess and optimise the energy demand and CO_2 emissions of the procure to pay and chromium electroplating business processes. It also demonstrates minimum user inputs as the user is only required to enter operational parameters of required resources; minimum time as business process models only require updating and the optimisation options for each business process and equipment are pre-defined and genericity as it is applicable to both manufacturing and non-manufacturing business activities. The ability of the PCEM to evaluate the impacts of the application of Industry 4.0 technologies on business energy demand and CO_2 emissions is demonstrated with the automation of the recruitment business process.

A limitation of the model is the development of the business processes by the researchers and is not those of an actual MNC. The databases are not exhaustive of all business processes, energy resources and optimisation options.

This paper demonstrated application to a thin slice of the operation of MNCs. In application to a full MNC, the impact of interdependencies and interlinkages will be fully realised. It will enable comparative analysis of sites for the identification of best practices within the MNC to applied to all sites and knowledge transfer.

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