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Energy efficiency analysis modelling system for manufacturing in the context of industry 4.0

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Abstract

Emerging rise in power costs and sustainability of the available energy has prompted industries to seek alternative solutions that could address energy consumption as the second highest contributor to business expenditure compared to salaries and rentals. Regrettably, numerous industries are still reluctant to benefit from the opportunities that exist on energy saving and consciousness, due to inadequate knowledge on energy management, resources and tools to monitor the losses. Based on these facts, this paper proposed the Energy Efficiency Analysis Modelling System (EEAMS) as a tool to provide an estimate of energy costs using rail car manufacturing plant load profiles as a case study, to provide consumer-oriented analysis to produce first-cut energy efficient program baseline costs. Furthermore, the exploration of energy efficiency baseline may benefit the life cycle cost of the overall proposed facility through energy efficient means of production, and continuous improvement practises in big data analytics towards reduction of energy costs significantly through integration of energy efficiency software (EES). To achieve this, a bottom-up approach methodology was adopted, using information on energy cost as a baseline to allow centralisation and cloud hosting of data through a web-based interacting energy efficiency sustainability framework platform, to determine the economic impacts of energy measurement and verification on energy consumption and environment. Minimum Efficiency Performance Standards established to provide opportunities for the support of the rail car manufacturing company to prepare themselves for the issuing of certificates for energy management (ISO50001).

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Keywords: Energy Efficiency; Industrial 4.0; Life cycle cost analysis; Energy Efficiency Analysis Modelling System (EEAMS)

1. Introduction

Energy efficiency is a matter of concern for manufacturing industries due to ever-increasing energy costs and strict environmental policies [1]. Energy Efficiency (EE) is the use of advanced measuring and monitoring control systems to optimize the functionality and energy performance using industry best practices and green compliance standards that affects competiveness, productivity and economic growth with reduction in energy intensity required to produce goods and services [2]. Energy Efficiency involves a reduction in the energy input of a given service or level of economic activity, according to International Energy Agency (IEA) and the World Energy Council (WEC). Energy efficiency standards provides a policy option that industries can use to save energy and money for their local or national economies. It can help assure that the machines that industries use for produce do not cause excessive negative environmental impacts or high operating costs. Information on energy cost regarding the consumption of power will provide energy efficiency baseline that may benefit the life cycle cost of the overall proposed facility through energy efficient means of production. It can continually refine the analysis as more data becomes available towards reduction of energy costs significantly, and create national economic impacts standards to assist policy makers in design and to maximize national use of energy. Increasing energy costs, new

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environmental legislation, and concerns over energy security are driving efforts in increase of industrial energy efficiency [3]. According to a report by South African, Department of Transport 2017 National Rail Policy Draft White Paper, "Energy is set to dominate the transport agenda around the world in the coming decades for two inescapable reasons; energy costs have risen dramatically in recent years and may continue, for a variety of reasons, to rise in the future". Efficient monitoring of energy consumption of machine tools is first step towards energy conservation. The carbon emissions from energy use are a matter of increasing concern as the causes and consequences of global warming become clearer. Globalization of the energy market and the inter-linking of supply networks means that everyone is affected. Both the financial pressure, and the need to manage our carbon dioxide emissions, require that personnel must improve their understanding of the energy efficiency initiatives technology. The leading cause for the operating company is the reduction of the Total Cost of Ownership (TCO), but the higher goal is the sustainable manufacturing of goods with minimal (electrical) energy [4]. The economics and the opportunity of energy efficiency management is of great importance to the reinforcement of cost effective way of managing energy cost incur by the company. Decisions that have an impact on the energy consumption of a production system are part of all phases of a factory's life cycle from production system planning to operation [5]. The environmentally friendly form of energy consumption represent up to a quarter of the total life cycle cost, around the same amount as the capital spent on buying the machineries.

Germany is leading a transformation toward fourth Industrial Revolution (Industry 4.0), which has "Big Data" as service innovation [6]. As more embedded software with integrated intelligence into industrial products and systems, predictive technologies can further intertwine intelligent algorithms with electronics and tether-free intelligence to predict product and service performance, autonomously manage, and optimize product service needs. Based on the industry 4.0 terminology, intelligent data analysis and interconnected systems are combined together to generate a brand-new aspect in factory transformation and production management. Introduction of methods and terms such as internet of things (IOT) and interconnected systems are among the efforts of researchers and industrial companies to address applicable solutions in the "Big Data" environment.

The article presents the benefit of energy efficiency baseline on the life cycle cost for the overall railcar production facility and the significance of data analysis and the integration of energy efficiency software (EES), and continually refine the analysis as more data becomes available towards reduction of energy costs significantly. The EESF will integrate vast quantities of energy-consumed data from disparate sources (machines in the manufacturing industry) to improve throughput, quality, and cost. The framework will provide the Energy Efficiency (EE) Management Team with guidelines to establish energy policy; audits, trend of energy use; saving data estimations; benchmark data for other sectors to optimize resources for EE, enforce the implementation of energy policy and make decision on energy efficiency plans. The next section of this manuscript presents related works on energy management systems, energy efficiency analysis modelling system (EEAMS) as well as analytical results of the EE modelling system.

2. Related work on energy efficiency management systems

The manufacturing sector is responsible for about 33% of the primary energy use and 38% of the CO2 emissions globally [7]. Moreover, the increasing price of energy and the current trend of sustainability have exerted new pressure on manufacturing enterprises to reduce energy consumption for both cost saving and environmental friendliness, as well as Life-Cycle Inventories initiatives [8-9]. Energy savings expected to be achievable from increasing both the energy efficiency of production [10]. Innovative energy monitoring and management approaches [11], leading industries to a way of producing "more with less". The dynamics in price setting generates uncertainties for organization schemes with respect to accurately energy costs calculation. IEA highlighted the need for energy efficiency measures to achieve a reduction by two-thirds in the energy intensity of the global economy by 2050 [7]. Lunt and Ball [12] work on the main issues of energy reduction projects/initiatives in an aerospace manufacturer revealed that the key barriers are lack of accountability (who owns the project) and lack of understanding regarding energy reduction. Greening of manufacturing systems has become much more significant to pursue sustainable manufacturing with reduction of CO2 emission and energy costs, which warrant the setting of ambitious targets for reducing greenhouse gas output by 2020, while G8 group of nations is contemplating a target of halving emissions by 2050. Overall, energy use accounts for 80% of all such emissions, and even railways and nations that source their energy from low-carbon generation have a part to play in a global market, while energy saved by one customer frees up 'green' supplies for others to use.

South Africa is one of the most energy-intensive countries globally and since electricity tariffs have tripled over the past eight years, energy costs have become unaffordable as they constitute 15- 50% of total operating costs in most companies. The South Africa department of energy strategy approach on energy efficiency vision [13], is to promote EE as the ''first fuel'' with targets for the transport 20%; industry 16%; residential 33%; electricity production & generation 8%; commercial 37%; municipal services 20%; public buildings 565, while mining has not being quantified. According to the country's Energy Intensive User Group, productivity and employment placed at risk due to rising energy tariffs as other industrial and mining companies either have already shut permanently or temporarily, or have even emigrated. It is further, stated that a framework needs to be established to assist companies to apply for incentivized tariffs. The data management and analysis model require the determination of the baseline power, which is the establishment of energy flow and pattern of energy performance necessary, reasonable and excessive for consumers. It is a provision by the Energy Efficiency Analysis Modelling System to claim the 12L tax reduction initiatives for incentives to combat climate change and address South Africa energy supply security. For manufacturing company to manage its energy use, it must have

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.

a clearly stated energy policy framework for energy-efficient systems, and plan to deliver that framework. Aspects of the framework should include avoiding wastage of energy; maximizing the 'productivity' of the energy; procuring energy at an economic price; Investing in energy efficient solutions for stations and plant; Using energy from renewable or sustainable sources and measure and verify the use of energy. A formalized approach to energy management should include a register of opportunities for energy saving by setting the targets to determine the baseline to know how much energy is being used; understanding where and how it is being used; recognizing the 'drivers' which determine the consumption; enhance the operational skill of staff and plan for future production energy needs. The EEAS focuses on big data analytics generated from machines by sensors, coordinated by controllers in the manufacturing systems operations to help in providing an overview of the drivers and platform for energy efficiency awareness, develop, agree and communicate all the roles to the implementing team members.

3. Energy Efficiency Analysis Modelling System (EEAMS)

The overall cost benefit accounting model described in terms of several component provide important inputs for the final aggregate cost/benefit calculation. The design of EEAMS is model around the impacts of Minimum Efficiency Performance Standards (MEPS), which contain a number of requirements for an energy-using device that effectively limits the maximum amount of energy consumed by a product in performing a specified task. MEPS provides an opportunity for manufacturing industries to prepare for the issuing of certificates of energy management (ISO50001), an energy management systems used by organization to integrate energy management into the overall efforts in improving quality and environmental management through energy measuring and monitoring tools. The tool is prepared in such a way that wide varieties of energy profiles for the railcar manufacturing buildings through significant energy users (SEUs) selection provide data for a quantitative assessment of the costs and benefits for several different forecast data. EEAMS assumes that before energy efficiency standards can be implemented, a well-defined baseline efficiency have to be established. The energy consumer examines costs and benefits from the perspective of the individual production. The energy consumer perspective is Operational energy cost component of Life-Cycle Cost (LCC) calculation.

Energy Efficiency Sustainability Framework (EESF) is a framework within the EEAS platforms; it uses sensors and transmitters, which provide energy consumption data from the industrial machines through measuring devices (smart meters, AMI power meters) for optimized energy demand. The generated data are highly unstructured and etymologically form an explosion of energy demand data that may become very complex and large depending on the granular nature of the energy consumption data with a wide range of networked machines and huge transfer of data expected over the operational period. EESF is proposed to give a shift towards increasing use of sensors, data, software and analytics across the energy value chain to increase efficiencies, improve business outcomes, and reduce downtime, maintenance and will provide a fully functioning pilot form, supported by custom software and power purchased monitoring hardware components. It is an internet-accessible application programmable interface (API), required to download half-hourly kilowatt-hour profile readings, which will be implemented as an XML web service using the SOAP (Simple Object Access Protocol). The API allows profile data to be retrieve from the Meteringonline server for a single meter, and presents the result as a well-formed XML string of profile readings with a header of additional information. Currently half-hourly active (kWh) and reactive (kvarh) both import from the API, accessed through any SOAP client such as NuSOAP (PHP) or the .NET framework, which supports export energy.

The huge operational data which can grow to petabytes or exabytes based on the diversity and volume of the data with high speed require data mining and analytics techniques such as clustering (rule) algorithm [14], analyse and develop a pattern for the data with the associated life cycle cost. The EESF modelled around cloud-based predix platform to use the EE initiatives efficiently to reduce the operational energy consumption.

The analyzed data provides good understanding of the reality about energy consumed data, which contain the libraries (a collection of data sources accessible through the energy flow process and pattern), and the diagrams (which holds analysis for one or more of the data sources). The library connects to the generated data and data mining/learning/analytics techniques, which began with the predictive analysis being establish. The decision makers can as well use any of the predictive modelling such as decision tree, neural networks, regression analysis, statistical analysis, causal analysis, optimization and text mining tools to analyze the data as representative of the large chunk big data. Energy Efficiency sustainability framework (EESF) can be adopted advanced monitoring systems in real time for continuous improvement tactics to make action plans, which will be manage with ISO50001 and SANS 50001 guidelines (a standard that is intended to provide a standard approach to measurement and verification of energy savings and energy efficiency and is intended for use in the voluntary and regulatory domain) [15].

There is also a status field, which are a status of zero generally indicates good data, and a status greater than zero, meter-specific and indicates an event of some nature that occurred during the interval, such as a power loss. The Internet of Things (IoT) [16] gateway allows communication of the Internet and various webs. EESF provided a fully functioning pilot form, supported by custom software and purchased power monitoring hardware components [17]. The collaborators achieve the integration and demonstration of the EESF; analyze outlooks for cheaper hardware and markets beyond South Africa. The upper layer concerns big data analytics, where a large amount of data received from sensors are stored in the cloud and accessed through big data analytics applications. These applications contain API management dashboard to help in the interaction with the processing engine. The study was apply in a new railcar manufacturing company, mandated to replace ageing metro fleet with a modern service with equipment lists data shown in Figure 1 is EESS architectural framework through cloud hosting and systems.

3.1. Calculating the railcar manufacturing plant operational energy cost

The aggregated and analyzed data for the rail car factory buildings diversified power and consumed power used to enhance and automate decision-making process on the opportunities to explore the energy efficiency ideas, which in the fourth industrial revolution, has big data as prospect. The buildings M02, M03, MC3, M04, M05, M07, M08, T01, W07 and Others housed the Supply Park, car body shell, training center, office block, lightings, canteen, facilities management building, car body wash, fitting deck and water testing respectively. They are regarded as the continuous significant energy users, majorly concentrated energy used for welding purposes, and are intermittent in use according to operational demand for railcar manufacturing subject to the functionality of the all the other machines. Based on reports, the equipment lists of the energy consumption data collected include the following sum: Socket, Cranes, Auxiliary Converter, Battery Charger, Car Turn table and Coupling jig (1T), Cathedral (1 & 2) series spot welding machine, Instruments for Testing, General Power 1100m²@50VA/m², Hot Water Generation, Lighting, Spot welding machine, Welding tools and Ventilation Fans.

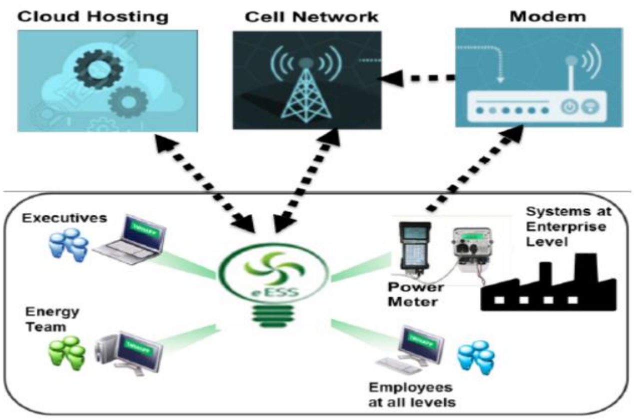

Fig. 1. EESS architectural framework through cloud hosting and systems.

The cost of energy consumed over each year of the equipment lifetime in production buildings.

$OEC = UEC * P$ ……………………………......................(1)

OEC is Operational Energy Cost; UEC is Unit Energy Cost in kWh), P is price of energy in ZAR per kWh

$OH = S * d * n$ …………………………………...............(2)

OH is operational hours; S is shifts/day= 3; d is days/week = 5; and n is weeks/year =52; Incentives rate (i) is ZAR0.95 per kWh implies OH = 24*5*52 = 6240 hours.

Baseline Power (bP)

$bP = cP * OH * P$ ………………………………………....(3)

cP is consumed baseline power; P is price (ZAR/ kWhr)

2417.64kW *6240 hrs* ZAR1.66kWhr = ZAR 25, 042,882.2

Production Power (pP)

pP = $tP * OH * P$ …………………………………………(4)

7085kW x 6240 hrs.* ZAR1.66kWhr = ZAR73, 389,264

Utilized Total Power (uP)

uP = pP $- bP$ …………………………………………… (5)

ZAR73, 389,264 + ZAR 25, 042,882.2 = ZAR 98, 432,146.2
With the 16% reduction target
Tax incentive: ZAR 98, 432,146.2* 0.95 = ZAR 93,510,538.89.
Total energy cost savings: ZAR 98, 432,146.2 - ZAR 93,510,538.89 = ZAR 4,921,607.31.

3.2. Industry 4.0 context of the Energy Efficiency Analysis Modelling System

Industry 4.0 technologies is coming to maturity right now through the combination of several major innovations in digitization, customization, optimization of manufacturing systems, adaptation and automation, communication and automatic data exchange, which include the application of sophisticated sensors using smartphones, mobile devices, advanced robotics, artificial intelligence (AI) and use of software-as-a-service in IOT. Cloud computing, data capturing with other Big data analytics models aim to immediately extract knowledgeable information that helps in finding hidden information, making predictions, identifying recent trends, and ultimately making decisions through the energy savings initiatives [18]. EESF will add value and knowledge management through Industry 4.0 applications in industrial process using cluster (rule) algorithms [19], to support improvement of energy performance and conduct reviews. The data generated from sensory devices (power meter) will integrate and save data into cloud space as they grow beyond petabytes or exabytes and pre-process, analyse and extract value as a service to effect the application of the following energy efficiency initiatives (Figure 3) such as

1. Use variable speed drive (VSD), energy efficient electric motor; right sizing and checks for mis-alignment for electric motors.
2. The use of energy efficient lights, read sensors and

wearables devices for lightings.

3. For high heating equipment, it will use of solar water heaters, pre-heating of boilers and pipe insulation; high efficiency and use of inverter on welding machines, computer control, electric robot and frequency DC machine, while variable voltage controls for air conditioners and efficient ventilation system for heating ventilation air conditioner (HVAC).

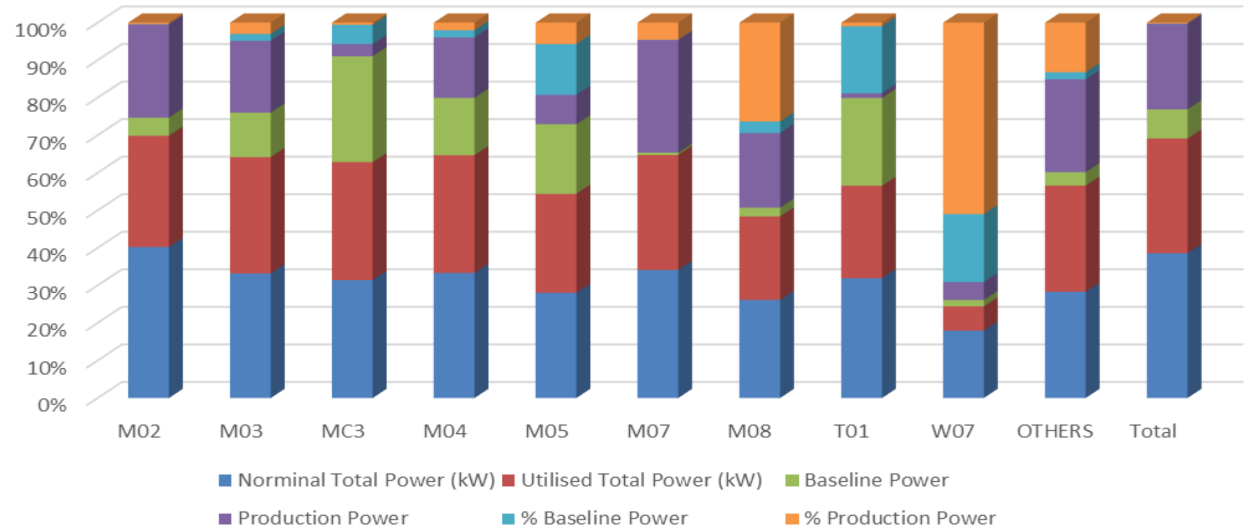

Fig. 2. Rail car manufacturing plant equipment energy graphical load profiles for buildings rated power.

4. Analytical Results of the EE Modelling System

Figure 2 shows the respective railcar manufacturing plant equipment energy graphical and load profiles for buildings rated power respectively. The total percentage ratio of the utilized total power to nominal total power is 79.16, which gives save operational limit over the overall power supply provision. The percentage of the baseline power to utilized total power at 25.44%, and required to help the management to prioritize the decisions on the greatest influence of the baseline power on the company overall goals. Energy efficiency initiatives is suitable for the various equipment's, and also determine which factors will have the least amount of impact on the energy saving. The percentage of the production power at 74.55% shows minimum energy performance standards and provide business decision opportunities to support the railcar manufacturing company to prepare themselves for the issuing of certificates for energy management (ISO50001) through the adherence to the determination of energy usage baselines in accordance with SANS 50010. With the total production power percentage of 74.55, energy efficiency software framework, shows the potential to promote energy efficiency strategy for the South Africa department of energy approach on vision of using energy efficiency as the ''first fuel'' going by 16% reduction targets for the industry. It is to determine each high equipment load profiles in real-time data, with smart energy meters, used to boost or enhance machines performance, as well as increasing throughput with reduce tariff through the energy efficiency initiatives. The interaction between IoT and big data is currently at a stage where processing, transforming, and analyzing large amounts of data at high frequency are necessary. The authors conducted this survey in the context of big IoT data analytics component of the industry 4.0 with structured approach to energy management involvement and technological option for industry are presented in Figure 3.

5. Conclusion

The paper proposed an "Energy Efficiency Analysis Modelling System" (EEAMS) as a tool to provide an estimation of energy costs in a manufacturing plant. Therefore, a bottom-up approach is adopted, which uses information on energy cost as a baseline for a web-based interacting platform. EESF is proposed to determine the economic impacts of energy measurements. The established Minimum Efficiency Performance Standard (MEPS) specification, which contain a number of performance requirements for an energy-using device, that effectively limits the maximum amount of energy that may be consumed by a product in performing a specified task. MEPS provides an opportunity for manufacturing industries to prepare for the issuing of certificates of energy management (ISO50001), an energy management systems used by organization to integrate energy management into their overall efforts to improve quality and environmental management through measuring and monitoring tools in managing energy. This article has sought to justify the establishment of Minimum Efficiency Performance Standards, which provide opportunities to support the rail car manufacturing company to prepare themselves for the issuing of certificates for energy management (ISO50001). The adherence to the determination of energy usage baselines in accordance with SANS 5001 and determination of energy efficiency saving potentials through the use of the Energy Efficiency Sustainability Framework (EESF) as the means of energy performance indicators for monitoring energy performance, helps in the preparation of reports on the implementation of the energy management plans, and achieved energy savings. The article provides a platform for the digitalization of the use of energy, which is beginning to have a significant impact on the energy sector and energy efficiency is emerging as a key arena for innovation. The efficient use of electricity at its end by a production equipment is a useful output on the demand-side energy efficiency policies. Moreover, the authors proposed an Energy Efficiency Sustainable Software through IoT architecture and big data analytics model and allow centralization of data for cloud hosting, through a web-based interacting platform, using EESF to determine the economic impacts of energy measurement, and verification on energy consumption and environment.

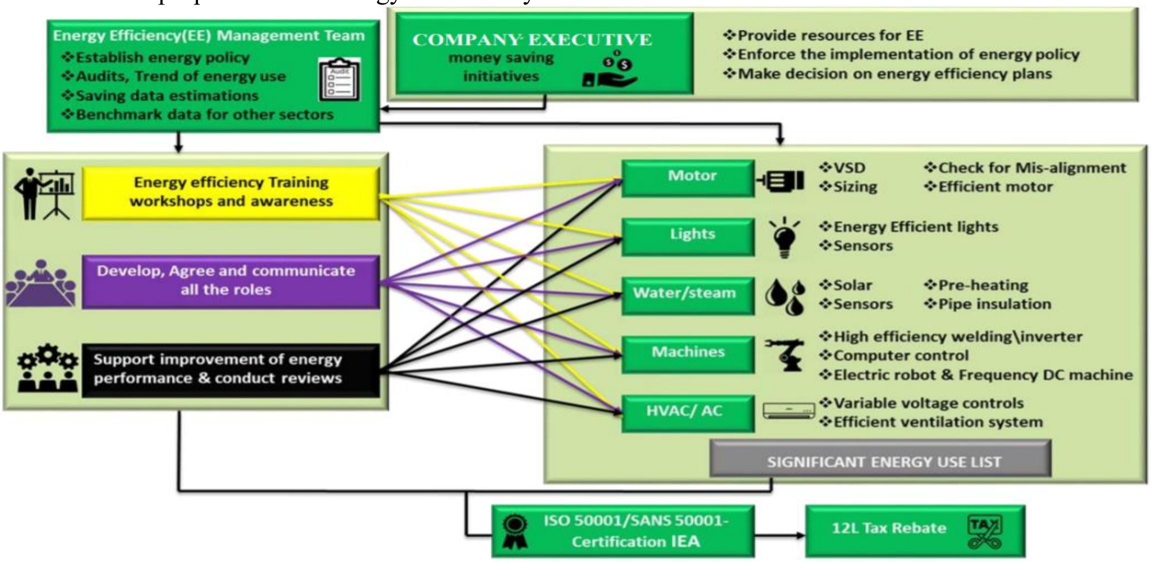

Fig. 3. Structured approach to energy management involvement and technological option for industry.

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