Energy Related Key Performance Indicators – State of the Art, Gaps and Industrial Needs

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Abstract. Better monitoring and control of energy consumption and effective use of performance indicators are of utmost important for achieving improved energy efficiency performance in manufacturing for current and future enterprises. This paper aims at analyzing the current state of the art on energy related production performance indicators to derive research gaps and industrial needs in the area. The research has been conducted as preliminary step before a comprehensive effort in which the authors suggest a new methodology to develop energy related key performance indicators. Therefore, the study resulted in a clearer understanding and synthesis of the research field, gaps in scientific literature and industrial needs, hence guiding further research.

Keywords: Energy efficiency, key performance indicator, energy management, sustainable manufacturing, research activities.

1 Introduction

Manufacturing has changed its focus and approaches from pure cost to quality, productivity and delivery performance in the last several decades. Currently, energy efficiency has gained significant attention from both academia and the industry due to the environmental and economic impacts associated with consumption of energy. Global warming and climate change, scarcity of resources, unsecured energy supply in conjunction with global strategies and policies such as Europe's 2020 strategy constitute the main global drivers of energy efficient manufacturing whereas industrial drivers comprise rising and volatile energy prices, ever-stricter legislations, customer demand and awareness as well as competitiveness that could be achieved through improvement in energy efficiency (May et al., 2012a).

Thus, manufacturing firms must put more efforts on in-depth analysis of energy and resource performance within their manufacturing processes and facilities. In this regard, energy efficiency monitoring is of paramount importance for effective energy management since it supports decision-makers in identifying opportunities for improvement and in recording the impacts of their decisions on energy use. For

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effective monitoring, performance indicators are necessary beyond measurement of data to evaluate energy efficiency performances.

In this vein, performance indicators play a significant role in evaluating the efficiency and effectiveness of manufacturing systems. KPI intelligence is essential for effective energy management in manufacturing since it supports energy related decision making. However, existing knowledge on energy related production performance indicators is limited and a thorough analysis of the literature is currently missing. Therefore, this study aims at analyzing the current state of research regarding energy related key performance indicators in manufacturing to find out the gaps and future research needs in the area. This analysis was carried out as preliminary to a further research that the authors have been carrying out to create a model for developing energy related production performance indicators.

To this end, this research is conducted to provide KPI knowledge in manufacturing with respect to energy efficiency. This scope has been identified by a preliminary research carried out in May et al. (2012a), which includes critical review of the literature on energy efficient manufacturing and an industrial survey complemented by interviews, carried out to highlight the gaps between theory and practice, as well as the importance of different aspects in integrating energy efficiency in manufacturing.

The paper is structured as follows. Theoretical background on the research area is provided in section 2 which precedes the research methodology and framework. In section 4, existing research studies are classified. Next, research gaps and industrial needs are derived in section 5 and consequently section 6 concludes along with an overview of further research and frameworks derived based on this particular study.

2 Theoretical Background

Traditional performance measures considered in manufacturing include factors such as quality, cost, delivery time and safety. Therefore, it is essential to investigate the impact of integrating energy efficiency as another performance dimension in manufacturing on traditional performances. Furthermore, since different performances are measured through indicators, identification and assessment of suitable KPIs for these performance measures is also necessary.

In this regard, measuring the energy efficiency performance of equipment, processes, factories and whole companies is a first step to effective energy management in manufacturing. The energy-related information allows the assessment of the optimization potential and improvements of energy efficiency measures, before and after their implementation. Thus, it is important to provide knowledge that highlights the overall state of the factory and its performance regarding energy consumption. In this sense, KPIs mainly serve as a measure to decide whether a system is working as it is designed for and to define progress towards a defined target value.

Regarding energy efficiency measurement, the development and application of energy related indicators depend on the purpose for which they will be applied There is no singular energy efficiency indicator that can be applied in every situation and it changes according to the decision to make or decision tool to be applied. Therefore, different measures of energy efficiency performances have been applied to manufacturing energy use. For this reason, many scholars focused on measuring energy efficiency performances [e.g. (Feng and Joung, 2011), (Tanaka, 2008)]. Feng and Joung (2011) proposed a sustainable manufacturing measurement infrastructure and Tanaka (2008) explored different ways to measure energy efficiency performance. In his analysis, Tanaka excludes the economic indices and focuses on indices that are possibly used in policy processes for a specific industry sector. He proposes the use of thermal energy efficiency of equipment, energy consumption intensity, absolute amount of energy consumption and diffusion rates of energy efficient facilities of equipment as measures of energy efficiency performance. These measures can be used for comparisons between plants and countries, policy-making and also for evaluation of policy measures but it is important to know for sure how the indicators are computed (Tanaka 2008).

Measuring the energy consumption of a process enables assessing the optimization potentials and supports visualizing verifiable benefits from improvement measures. Consequently, it is essential for all the manufacturing companies to count on a reliable system to address energy efficiency in production management and the performance after energy efficiency improvements. Performance indicators are necessary beyond measurement of data to evaluate energy efficiency performances. Thus, several energy efficiency indicators have been developed and applied for different purposes [e.g. (Ramirez et al., 2006), (Patterson, 1996)]. These indicators represent supply efficiency and energy consumption. Mostly, the relationship between energy used for an output and the output itself presented in ratios from these KPIs. There are economic and physical indicators depending on the description of the output (Ang, 2006). Economic indicators for energy efficiency are often used on an aggregated level, for instance, to compare different sectors or countries. Physical indicators are more suitable to analyze specific processes (Phylipsen et al., 1997). Besides, Patterson (1996) proposed four groups of indicators: thermodynamic, physical-thermodynamic, economic-thermodynamic, and economic.

Phylipsen considers that economic indicators are useful at an aggregated level (entire economy or industrial sector) and physical indicators for giving insight into manufacturing processes (Phylipsen, Blok and Worrell 1997). This last statement is also confirmed by Worrell that shows in his study for the iron and steel industry, that using physical indicators improves comparability between countries and provides more information regarding intrasectoral structural changes while economic indicators are not very useful for analyzing changes in the production structure of an industry (Worrell, Price, et al. 1997). Nevertheless, the more common indicators for measuring energy efficiency are Energy intensity (EI) defined as the ratio of energy consumption to a monetary value and Specific energy consumption (SEC) defined as the ratio of energy consumption to units (Ramirez, et al. 2006, Neelis, et al. 2007). Regarding the energy consumption, it can be defined and measured in many ways such as demand for primary carriers, net available energy, purchase energy, etc. (Phylipsen, Blok and Worrell 1997).

In addition, some researchers propose indicators to measure energy efficiency across plants and among countries. Aguirre proposes the use of energy-production signatures (EPPs) to measure relative industrial energy efficiency across plants. These EPSs relates total energy consumption to production output and can be used for proactive benchmarking and diagnostic purposes leading to improvements in energy consumption for individual companies. As well, the results show that the proposed methodology identifies energy and production inefficiencies within a manufacturing segment (Aguirre, et al. 2011). Meanwhile, Zhou develops an approach for monitoring energy efficiency trends over time in a country or comparing the economy-wide energy efficiency performance among countries. The proposed approach uses the Shephard distance function to define an energy efficiency index and applies the stochastic frontier analysis (SFA) technique to estimate the index (Zhou, Ang and Zhou 2012).

To conclude, proper methods for measuring energy efficiency are essential to enhance decision making of manufacturing companies by energy efficiency aspects. Thus, measuring the energy efficiency performance on different levels (i.e. machine, process and plant) is a first step to effective energy management in manufacturing. Implementation of an appropriate KPI and monitoring system is of paramount importance for enhanced energy management in a manufacturing plant since it supports energy related decision making.

3 Research Methodology and Framework

In this study, first step concerned investigating research areas in sustainable manufacturing and highlighting the role and place of energy related key performance indicators in a global view. Figure 1 below thus provides the result of such an analysis as a diagram.

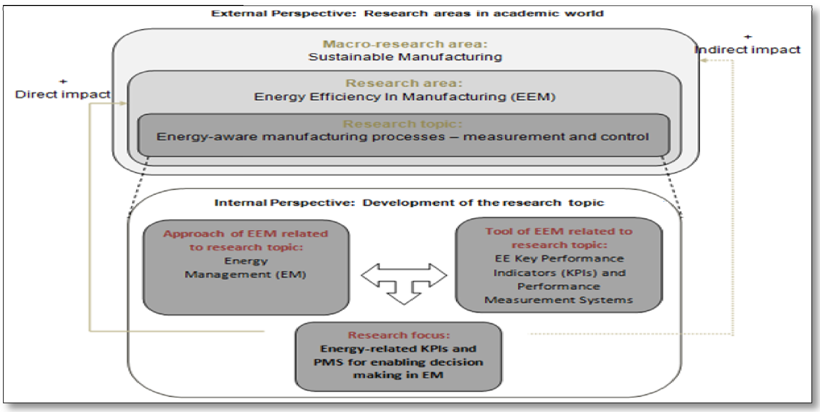

Fig. 1. Research area and focus

In Figure 2, the main approach and elements of the literature review and gap analysis are highlighted.

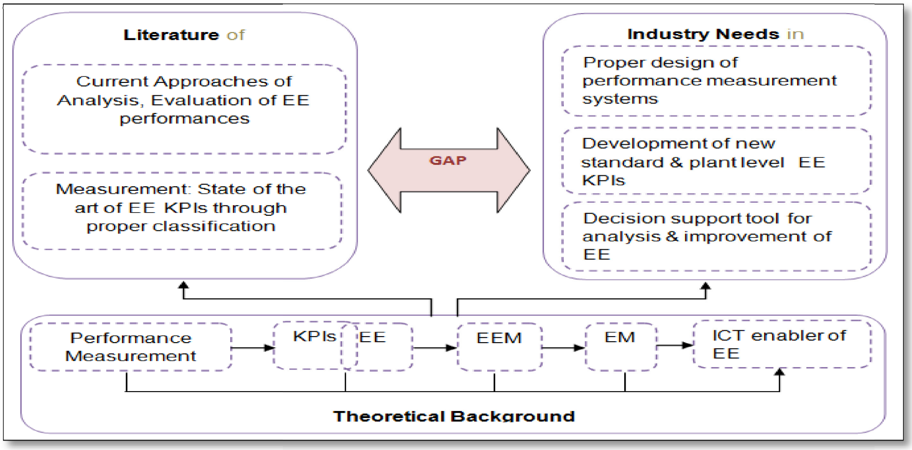

Fig. 2. Literature review and gap analysis

Theoretical background, placed at the bottom of the figure, provides the essential energy themes regarding energy efficiency performance, concerning topics of *Performance Measurement, Key Performance Indicators, Energy Efficiency, Energy Efficiency in Manufacturing, Energy Management, and ICT as enabler of Energy Efficiency*. Figure 2 thus shows current relations between the different topics within theoretical background and GAP in the figure is the conclusive output of bibliographic review. According to information collected from literature and from rising needs, it formerly highlights the existing problems through research gaps.

In the analysis of literature, a careful overview of EE KPIs has been conducted. Their state of the art has been classified through proper dimensions of classification.

Table 1 shows the three dimensions used for classification of EE KPIs, and the relations between attributes of these dimensions. In this regard, a state of the art study on energy efficiency KPIs has been conducted ranging from sector and national level, to machine and process level.

Table 1. Dimensions used for classification of energy related KPIs

Aggregation Level	Decisional Level	Scale
Aggregated	Strategic	Enterprise Site
Disaggregated	Tactical	Work Center
Process/Appliance	Operational	Work Unit

As seen in Table 1, scope of EE KPIs is as wider as possible. Furthermore, all *categories* of EE KPIs already existing into literature were explored and differences between categories depend on quantity present in calculation formula of indicator. Categories of existing EE KPIs are: thermodynamic, physical-thermodynamic, economic-thermodynamic, economic-physical, and eco-efficiency. Literature does not provide very comprehensive review of EE KPIs. As a matter of fact, the majority of them just make lists of general type of indicators, such as Specific Energy Consumption (SEC). Carried out review not only classified general type of indicators, but it also matched each one with relating and "specific" KPIs reviewed (with reference to the previous example, one specific KPI is the Specific Cutting Energy) exploring bibliographic sources such as academic papers, standards and reports made by institutes and organizations, document available on internet related to projects and initiatives. An exploration of current approaches to monitoring, measurement, analysis and evaluation of EE performances by firms was conducted, in particular regarding manufacturing firms. The result of bibliographical review and interviews with industry resulted in the gap analysis showed in section 5, which refers both to EE PMS and KPIs.

4 Pertinent Literature – Classification

The pertinent literature have been analyzed and classified based on the dimensions developed specifically to understand the contribution to the content discussed in this study. In particular:

- The particular section of this study, for which the concerning work from literature (represented by the single row of the matrix) has made a contribution, is represented by the dimension "dim i" ($1 \leq i \leq 5$) which constitutes the single column of the matrix;
- The importance of the contribution from the source for a particular section is represented in the matrix cell through a circle in grayscale. A darker color indicates higher importance of the contribution of the concerning work from literature.

The dimensions in the column are defined as follows:

- Dim 1: Literature to identify the research focus
- Dim 2: Literature for theoretical background
- Dim 3: Literature to define state of the energy related KPIs
- Dim 4: Literature that contributes to gap analysis and/or future trends
- Dim 5: Literature to support the development of a new KPI methodology

The circles are defined based on criteria developed to balance quality and extent of the information provided. Each source may be associated to different columns with circles of different colors, depending on the extent of the contribution made.

- White circle - marginal contribution; Gray circle - modest contribution; Black circle - decisive contribution

Pertinent literature included relevant papers published in the last 15 years and important documents of related organizations such as IEA, EC, CECIMO, etc. The analysis concerned more than 100 papers and a summary of the list is shown in Table 2 below (The whole list is not presented in this paper due to page limit).

Table 2. Classification of pertinent literature

Reference	Dim 1	Dim 2	Dim 3	Dim 4	Dim 5
(Ang, 2006)			◍	◍	
(Artley, Ellison e Kennedy, 2001)		◍			◍
(Azapagic & Perdan, 2000)	○				
(Bourne, Mills, Wilcox, et al., 2000)		○			
(Boyd, Dutrow, et al., 2008)			◍		
(Braglia, Zanoni, & Zavanella, 2003)				◍	
(Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011)				●	
Chryssolouris (2006)		◍			
(Diakaki C., 2006)		○			
(Eichhammer W. , 2004)	○				
(Erlach, 2010)		○			
(Groot, 2011)	○				
(Gutowski, Dahmus, & Thiriez, 2006)					●
(Hendrik & Verfaillie, 2000)			○		
(Kannan & Boie, 2003)				◍	
(Ishikuma, 2011)	◍				
(Karnouskos, Colombo, Lastra, & Popescu, 2009)				●	
(May et. al, 2012a)	●	○		◍	
(May et al., 2012b)			◍		◍
(Muchiri & Pintelon, 2008)					◍
(Najmi, Rigas, & Fan., 2005)		○			
(Neely, 1999)		○			
(Patterson, 1996)		◍	●		
(Phylipsen, Blok, & Worrell, 1997)		○			
(Worrell, Price, et al. 1997)		○	◍		
(Prindle, 2010)			○		
(Rahimifard, Seow, & Childs, 2010)				◍	
Reich-Weiser et al. (2008)			◍		
(Slizyte & Bakanauskiene, 2007)		○			◍
(Sutherland, 2008)	○				
(Tanaka, 2008)			○		
(Tyteca, 2002)			○		
(Van Gorp, 2005)			○		
(Veleva & Ellenbecker, 2001)			○	◍	
(Yildirim, 2007)					◍

5 Research Gaps and Industrial Needs

As mentioned in section 3, thorough review of the literature and interviews with the industry guided us to research gaps and industry needs with respect to energy efficiency performance indicators and performance measurement systems as highlighted in Figure 3.

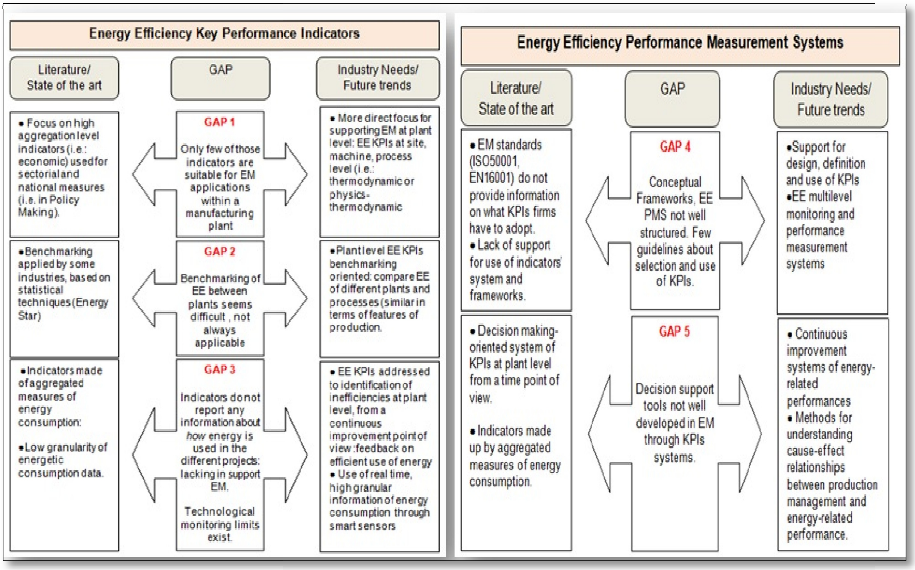

Fig. 3. Gaps and industrial needs

6 Conclusion and Future Work

In this research, we thoroughly analyzed the pertinent literature and industrial needs regarding energy related production performance indicators and came up with two main frameworks, first one highlighting the role of KPIs in an overall view of energy management and a second framework that guided a new methodology for developing KPIs to close the gaps identified. Thus, Figure 4 below is the framework that presents an overview of energy management in production and relationships between its different components.

Besides, a second framework has been derived based on the gaps identified in this research and led us to a further work in which the authors developed a new methodology to develop energy related production performance indicators based on the identified gaps.

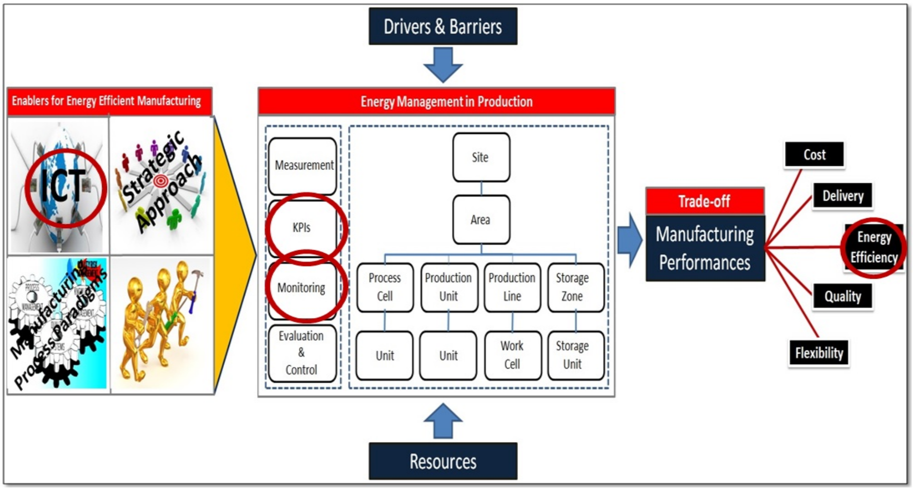

Fig. 4. Energy Management in Production and role of KPIs

Finally, some basic research motives for our further works have emerged:

- KPI model to create appropriate energy efficiency measures to be used in the different levels (e.g. tool, equipment, process and plant level) of a manufacturing facility. The main focus in this part will be on the machine level to change the traditional time based view to energy based view
- Set of guidelines for effective design and use of Energy related KPIs in manufacturing facilities to improve energy efficiency
- An approach to increase the visibility and transparency of energy related KPIs in a manufacturing facility, facilitating ICT as an enabling factor. This approach is expected to provide a decision support mechanism for enhanced energy management and hence support improvement of energy related performances

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