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Measuring energy performance: A process based approach

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HIGHLIGHTS

- This study develops processes to continuously measure energy performance.
- Performance indicators are integrated into an Extended Enterprise framework.
- The production process is the fundamental unit where energy performance is measured.
- Energy performance is represented by a longitudinal input–output process model.
- A hierarchy of indicators is proposed from the energy source to extended enterprise.

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ABSTRACT

Companies are looking for actual information regarding the productivity of their energy resources, as this production factor plays a distinct role in their value chain. The objective of this study is to develop processes to continuously measure energy performance, considering its full integration into an Extended Enterprise framework. The problem of energy efficiency is related to sustainability research, not only for its scarcity and environmental impact, but for the condition which necessitates defining efficiency as a dimension of operational performance. The production process is the fundamental unit where energy performance is measured, since the transformation of inputs into outputs occurs in processes. In the design of this study, energy performance is represented by a framework, a map of indicators, and a longitudinal input-output process model. The problem is influenced by the concept of enterprise efficiency, and direct and indirect energy efficiency indicators are developed to continuously monitor energy performance. Based on a demonstration of its application using Monte Carlo simulation to test the performance indicators, it is shown that the indicators can be integrated at three hierarchical levels: (i) energy efficiency by source; (ii) energy co-efficiency of the process; and (iii) energy co-efficiency of the extended enterprise. The result is a modular architecture showing how energy performance can be measured and integrated into a network of processes such as the extended enterprise.

1. Introduction

The perception that energy is a singular resource has become increasingly clear since the oil crisis of the 1970s. Despite the growth of renewable energy, which reached 6.7% in Organisation for Economic Co-operation and Development (OECD) countries and 2.7% in other countries by 2011, fossil fuels account for 80% of global energy use [1,2]. The main problem associated with non-renewable energy is its long-term sustainability (economic, social and environmental). The investment required in the transition to clean energy has been estimated at 1% of the gross world product (US $0.8 trillion for a gross world product of US $83 trillion) [3].

Energy efficient manufacturing can be a critical step towards a more rational and sustainable use of energy, because, as Napp et al. [4] show, industrial processes consume one-third of global energy. Although this rate varies between countries, reaching 70% in China for example [5].

The main concern of the research is with the energy performance of the manufacturing, modeling energy efficiency as a flow, upstream and downstream processes can be involved in the so-called Extended Enterprise (EE), enabling the measurement of aggregate energy performance for the Extended Enterprise [6–8]. The manufacturing area was chosen because it has a central position in the production chain,

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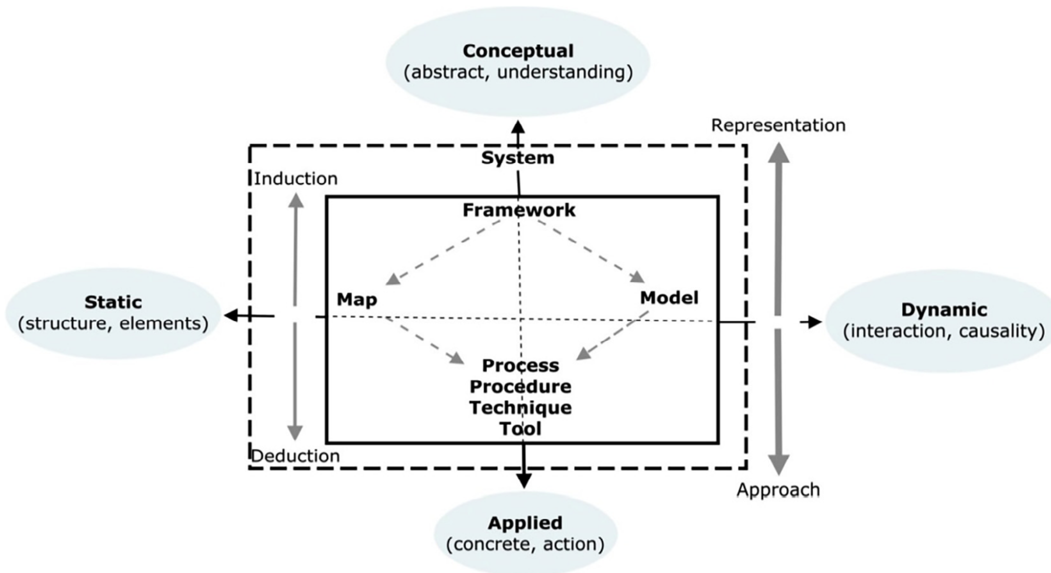

Fig. 1. Methodology of representation of and approach to research.
Source: Adapted from Shehabudden et al. [24].

making it possible to exercise a leadership position in the energy management of the productive processes [9,10]. In the extended enterprise context, manufacturing can be the link between upstream and downstream processes.

Bunse et al. [11] emphasizes that an industry/manufacturing need to develop frameworks and indicators to measure energy performance in production. Recently, scientific studies have developed models of energy performance measurement in productive environments, but these do not address the integration of indicators into the extended enterprise [12–16]. Therefore, the main problem addressed by our work is: how can the energy performance be measured from an integrated perspective involving an Extended Enterprise? In the context of this study, better energy performance is associated with lower energy consumption in processes, which according to Abdelaziz et al. [17] and Trianni et al. [18] is derived from the application of energy efficiency measures (EEMs) and energy efficiency technologies (EETs). Here, "processes" refer to production processes, which are the mechanisms responsible for transforming inputs into outputs [19,20].

The objective of this study is to develop a processes approach, integrated into an extended enterprise, for the continuous measurement of energy performance. The production process is the flexible unit in our representation, since the transformation of inputs into outputs occurs here. The transformation consumes different forms of energy, including electricity, thermal, oil, diesel, natural gas, among others. The processes are considered the base for energy performance, making it possible to create indicators for the processes and integrate these into the extended enterprise. Supported by the literature our research assumes three fundamental axioms: (1) the problem of energy efficiency is part of the positive heuristic of the protective belt of sustainability research; (2) it is possible to split an extended enterprise into a finite number of main processes; and (3) it is possible to identify both measures and technologies that, when implemented, can improve the energy efficiency of the processes.

The main objective is broken down into the following complementary objectives: (a) propose a process framework for measuring energy performance; (b) create a map of process energy efficiency indicators; (c) propose a longitudinal input-output process model for the continuous measurement of energy performance; and (d) develop hierarchical indicators to continuously measure energy performance based on the proposed processes approach.

The following sections are organized to meet the complementary objectives. Section 2 presents a methodological discussion, Section 3 develops the energy performance representation with the support of a systematic review, Section 4 presents an approach for the continuous measurement of energy performance and Sections 5 discussion and conclusion.

2. Research design: representation and approach

The objective of proposing a processes approach to continuously measure energy performance is complex because it involves a multidisciplinary approach. The explanation for why several study areas are related to the theme of energy performance/efficiency can be explained, generally, as the pursuit of sustainable production and consumption of goods and services [21]. Energy efficiency is related to the emerging sustainability paradigm [22]. Using Lakatos' methodology [23] as an analogy, the energy efficiency hypothesis is part of the core of the sustainability paradigm. Energy efficiency is a prerequisite for sustainability.

The complexity of developing a processes approach to continuously measure energy performance must be seen from a systemic perspective. The engineering department of the Institute for Manufacturing at the University of Cambridge presented definitions of how complex problems could be represented or approached from the engineering point of view and the manufacturing management perspective. Fig. 1 illustrates this representation and approach to problems.

The starting point is the energy efficiency problem positioning within the emerging sustainability paradigm. As defined by Shehabudden et al. [24], "[a] paradigm describes the established assumptions, and conventions which underpin a particular perspective on a management issue". A paradigm thus defined is similar to the Lakatos [23] research program. In Fig. 1, the representations and approaches are positioned in four dimensions: conceptual, applied, static, and dynamic. The representations (framework, map, and model) are ways to report problems that are conceptual and inductive. The approaches (process, procedure, technique, and tools) are practical and deductive ways to implement the concepts in the representations. Another relevant dimension is the interaction between the compositional elements of the problem, which look more like a map if static and more like a model if dynamic . The dynamic nature of a model involves the creation of indicators encompassing processes, procedures, and techniques for its operationalization. A map has a positioning function, while a