Applied Energy 187 (2017) 203–215

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Review of methodologies and polices for evaluation of energy efficiency in high energy-consuming industry

Ming-Jia Li, Wen-Quan Tao *

[a] Key Laboratory of Thermo-Fluid Science and Engineering of Ministry of Education, School of Energy & Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

HIGHLIGHTS

- The classification of the industrial energy efficiency index has been summarized.
- The factors of energy efficiency and their implement in industries are discussed.
- Four main evaluation methodologies of energy efficiency in industries are concluded.
- Utilization of the methodologies in energy efficiency evaluations are illustrated.
- Related polices and suggestions based on energy efficiency evaluations are provided.

ARTICLE INFO

Article history:
Received 14 July 2016
Received in revised form 7 November 2016
Accepted 13 November 2016

Keywords:
Energy efficiency evaluation
Model
High energy-consuming industry
Policy

ABSTRACT

Energy efficiency of high energy-consuming industries plays a significant role in social sustainability, economic performance and environmental protection of any nation. In order to evaluate the energy efficiency and guide the sustainability development, various methodologies have been proposed for energy demand management and to measure the energy efficiency performance accurately in the past decades. A systematical review of these methodologies are conducted in the present paper. First, the classification of the industrial energy efficiency index has been summarized to track the previous application studies. The single measurement indicator and the composite index benchmarking are highly recognized as the modeling tools for power industries and policy-making in worldwide countries. They are the pivotal figures to convey the fundamental information in energy systems for improving the performance in fields such as economy, environment and technology. Second, the six factors that influence the energy efficiency in industry are discussed. Third, four major evaluation methodologies of energy efficiency are explained in detail, including stochastic frontier analysis, data envelopment analysis, exergy analysis and benchmarking comparison. The basic models and the developments of these methodologies are introduced. The recent utilization of these methodologies in the energy efficiency evaluations are illustrated. Some drawbacks of these methodologies are also discussed. Other related methods or influential indicators for measuring energy efficiency performance have also been presented. Finally, the related polices and suggestions based on the energy efficiency evaluations are provided.

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* Corresponding author.
E-mail address: wqtao@mail.xjtu.edu.cn (W.-Q. Tao).

http://dx.doi.org/10.1016/j.apenergy.2016.11.039
0306-2619/

1. Introduction

The world is witnessing a major transition from fossil energy to clean energy during the recent decades. However, fossil fuel in the form of coal, natural gas and oil are still possesses 80% of the worldwide energy usage. About half of the electricity generated is still produced in coal-fired power plants. Increasingly, the general public, researches and governments are paying more concern to energy efficiency, especially in developing countries.

Understanding the actual physical definition of energy efficiency is crucial to develop and apply different methodologies in worldwide countries. Particularly to the industries, the competition between firms can be evaluated by some kinds of energy efficiency indicators. The improvement of energy efficiency is a vital strategy, which is to maximize outputs and to decrease operational costs. Patterson who is the earlier scholar presented that energy efficiency is a generic issue and there is no quantitative measure, and it should be estimated by a series of indicators [1]. In the aspect of high energy-consuming industries, energy efficiency of performance tends to the less energy usage for more outputs. Moreover, the importance of energy efficiency in power industries is heavily linked to commercial and energy security, as well as to environmental benefits such as less greenhouse gas (hereinafter presented as the GHG) emissions. Therefore, the evaluation of energy efficiency of high energy-consuming industries plays an important role in different countries. In order to confirm the optimization of power systems, the modeling of energy efficiency should be implemented constantly and regularly to capture the pattern trend of energy usage. In recent years, more scholars proposed various quantitative models to solve the comprehensive problems of energy efficiency. Some of them adopted economic analysis depending on engineering assumptions, and the benchmarking influential factors. The others employed different kinds of methodological models to investigate the overall economic impact.

All the above mentioned are the reasons why the review paper pays attention on the methodologies and polices for the measurement of energy efficiency in high energy-consuming industries with international perspectives. It is necessary to summarize the recent trends in the energy efficiency research, the latest trends of methodologies of energy efficiency evaluation, and the classification of different approaches. Moreover, it is essential to propose the further needed and to point out the valuable topics for improving energy efficiency issues of high-consuming industries. Thus this paper, as a beneficial complement, is necessary and timely.

The reminder of the paper is structured as below. Section 2 summarizes the classification of energy efficiency in industries, and the definition of energy efficiency indicators. Section 3 discusses the major factors, which directly and indirectly affect the performance of energy efficiency in high energy-consuming industries. It will contain capital investment, environmental indicators, structural indicators (including energy consumption of plant-levels), Gross Domestic Product (hereinafter presented as the GDP), energy price and labor. Section 4 provides different types of energy modeling on evaluating the energy efficiency. It describes how and where these models can be adopted based upon manufacturing processes. Section 5 gives related policy and recommendations. Finally, conclusion is presented in Section 6.

2. Classification and definition of energy efficiency in industry

The objectives of this section involve the definition of boundaries for measuring the energy efficiency indicators at plant-level in industries. It provides different scholars' opinions with international perspectives.

2.1. Definition

The definition of energy efficiency is a complex question. Martin et al. first defined energy efficiency as that which presents the amount of human activities, such as manufacturing industry, transportation and electricity industry, provided per unit of energy used [2]. For the industrial energy efficiency, it is a quality of a system of industrial sectors. Martin et al. primarily pointed out that industrial sectors can be measured in economic terms or physical terms, such as market value, weight of products, and number of outputs [2]. It is related to costs of energy source, technological efficiency, capital investment and labor, etc. Moreover, the energy efficiency of economic procedure can't be easily evaluated precisely because it is a comprehensive activity. Hence the energy efficiency indicator of industries is a ratio of service output to energy input defined by Eq. (1)

$$\frac{\text{Useful output of a process}}{\text{Engery input into a process}} \tag{1}$$

For manufacturing industries, the issue then becomes how to precisely state the useful output and energy input. A number of indicators can be adopted to represent changes in energy efficiency. Energy efficiency can be used to evaluate industrial activities, and energy usage efficiency, especially on a macro-level. It is harder to estimate the energy efficiency variation with time [3].

2.2. Classification

Energy efficiency indicators can be divided into four main groups as below.

(1) Thermodynamic indicators. This kind of indicator displays some sort of second law efficiency, and it depends upon the sophisticated methods that can be used to estimate actual energy usage in a producing process [4]. It is the most traditional method to evaluate energy efficiency through the scientific reaction processes. The first-law energy efficiency has been early applied in macro-level energy efficiency studies,