Energy Economics 40 (2013) 146–154

Contents lists available at ScienceDirect

Energy Economics

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

Economic analysis of alternatives for optimizing energy use in manufacturing companies

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ARTICLE INFO

Article history:
Received 14 July 2011
Received in revised form 1 June 2013
Accepted 7 June 2013
Available online 22 June 2013

JEL Classification:
C02
C61
L6
L69
Q42

Keywords:
Economic analysis
Energy optimization
Mathematical modeling

ABSTRACT

The manufacturing companies are one of the main consumers of energy. The increment in global warming and the instability in the petroleum oil market have motivated companies to find alternatives to reduce energy use. In the academic literature several researchers have demonstrated that optimization models can be successfully used to reduce energy use. This research presents the use of an optimization model to identify feasible economic alternatives to reduce energy use. The economic analysis methods used were the payback and the internal rate of return. The optimization model developed in this research was applied and validated using an electronic manufacturing company case study. The results demonstrate that the main variables affecting the economic feasibility of the alternatives are the economic analysis method and the initial implementation costs. Several scenarios were analyzed and the best results show that the manufacturing company could save up to $78,000 in three years if the recommendations based on the optimization model results are implemented.

1. Introduction

The increase in global temperatures and the volatility of the petroleum oil market share a common factor, energy use. These are two of the principal reasons for governments and manufacturing companies to seek alternatives to reduce energy use. An Environmental Protection Agency (EPA) 2010 in study on CO_2 emissions demonstrates that since the Industrial Revolution in the 1700s the concentration of CO_2 in the atmosphere has increased by 35% (Climate change — Greenhouse gas emissions, 2010). This study further demonstrates that the principal emitters of CO_2 are manufacturing companies. This is one of many problems that companies face today. In addition, the instability in the petroleum market causes increases in the price of fuel thus affecting the energy costs and, therefore, the cost of the manufacturing processes. For these reasons, many companies are considering the use of alternate methods of energy generation to reduce the energy they use.

Currently, it is a common practice for manufacturing companies to hire a consulting agency to evaluate alternative energy projects that allow companies to save on energy use with the possibility of risking a considerable investment. However, using external consultants represents an additional investment in which the subsequent benefits are uncertain. The analyses that were examined were based on the investment, economic benefits, and the period of return on investment and included studying the variables related to energy costs, the equipment necessary for the alternatives, and the cost of the appropriate equipment. However, companies also have the option of in-house analyses to identify energy-saving alternatives that use systems and tools for monitoring the energy performance of their equipment. Therefore, manufacturing companies need to evaluate whether any analysis of energy use should be in-house or external by a consulting company.

Studies related to energy use show that optimization models are effective tools for reducing energy use in many industries thereby reducing CO_2 emissions. These optimization methods are presented in the following literature review. In addition to analyzing alternatives for reducing energy use, an economic analysis has to be considered for the analysis to have an effect on the results. The most commonly used economic analysis methods for this type of problems are the internal rate of return (IRR) and the payback method. The difference between these two economic analysis methods and examples of application will be presented in the literature review.

The objective of this study is to analyze the application of optimization models in the process of selecting alternatives to reduce energy use within a manufacturing environment. For this purpose, an optimization algorithm was developed to identify feasible economic alternatives for replacing current equipment with that which reduces energy use in the following areas of the company: offices, production, warehouse, and exterior. Five systems were identified as major energy consumers

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http://dx.doi.org/10.1016/j.eneco.2013.06.001

in manufacturing companies; which are air conditioner, compressed air, lighting, exhaust, and machines. The optimization models presented in this study focus on alternatives for the first three of these five systems: air conditioner, compressed air, and lighting since these systems use most of the energy in a manufacturing facility. The objective function of the optimization models is to maximize the net economic benefits by saving on energy use after implementation of the identified alternatives. Constraints associated with the systems in the analyzed areas (i.e. offices, production, warehouse, and exterior) were considered in the model. Also, constraints related to established limits of energy demand were included. This optimization model represents an efficient and cost effective tool for companies to internally monitor alternatives to reduce their energy use.

This paper is organized as follows: Section 2 summarizes the relevant literature; Section 3 describes the optimization algorithms for the selected systems; and Section 4 presents the algorithm performance evaluation and sensitivity analyses. The last section includes the conclusions and opportunities for future research.

2. Literature review

Review of the relevant literature was divided into the two major sections: optimization models to reduce energy use, and economic analysis methods to evaluate feasible alternatives to reduce energy use.

2.1. Optimization models to reduce energy use

Optimization models seek to find the values of the decisional variables that maximize or minimize an objective function among the set of all possible values for the decision variables that satisfy the given constraints (Winston, 2004). The basic components of the optimization models are: objective function, decisional variables, and constraints. The restrictions on the values of decision variables are known as constraints. The decisional variables are those variables whose values influence the performance of the system and the objective function which is to be maximized or minimized (Winston, 2004).

Studies related to energy use show that the results of implementing energy optimization models are effective tools to reduce energy use in some industries thus reducing CO_2 emissions. For example, G. Ordorica-Garcia (2008) in collaboration with other colleagues developed an energy optimization model with CO_2 emission constraints for the Canadian oil sand industries. In this study, they developed an optimization model that determines optimal combinations of power and hydrogen plants to satisfy energy demand of oil sand operations at minimal cost while reducing CO_2 emissions. This study demonstrated that this model has the potential to reduce the energy use cost by 2–7% and to reduce the CO_2 emissions by up to 30% (Ordorica-Garcia, 2008). Moreover, a non-linear programming model was developed by Ortadis to identify a load management strategy that minimizes the total operating cost of a typical factory. The results obtained from the model show the optimal values and times for the electrical energy use based on doing activities and operations in a factory (Ortadis, 2007). The model considered the energy used by the factory per period, the maximum value of energy determined through energy suppliers, the minimum needed value of energy, the value of excess energy, and the penalty associated with excessive use. Optimization models can be used for both energy use analyses and as a means to solve energy problems. In his work, *Optimization methods applied to renewable and sustainable energy*: *A review*, R. Baños (Baños, 2011). presented that the number of research papers that use optimization methods to solve renewable energy problems has dramatically increased in recent years, especially for wind and solar energy systems. His research presents a review of more than two hundred papers from major referenced journals in the fields of renewable energy and computational optimization.

Based on the findings of the literature review related to optimization models and energy use, a gap in the academic literature was found. In this paper, the proposed algorithms will be applied to analyze the feasibility of modifying current equipment in manufacturing industries, instead of replacing existing equipment with more costly energy reducing equipment. The methodology presented in this paper was not found in the review of relevant literature.

2.2. Economic analysis methods: Internal rate of return versus payback method

The decisions that a firm makes about budgeting their capital investments have an impact in the success of the firms for several reasons (1) capital expenditures which typically require large outlays of funds (2) the best way to raise and repay those funds, and (3) considerations of the long-term commitment (Cooper, Morgan, Redman and Smith, 2001). The analysis presented in the article *Capital budgeting models*: *theory vs. practice* showed that 57% of the companies studied used the internal rate of return as their primary method to analyze their project, while 20% of the companies used the payback method (Cooper, Morgan, Redman and Smith, 2001).

The internal rate of return (IRR) is used to find the break-even interest rate that equates the present worth of a project's cash outflows to the present worth of its cash inflows, taking into consideration all the estimated cash flows throughout the life of the project (Park, 2007). This rate is compared with the cost of capital to determine if the project is feasible (Fares, 2008). The payback method is defined as the period it takes the cash inflows from an investment project to equal the cash outflows and is usually expressed in years (Aidan Berry, 2006). The main advantage of the payback method is its ease of understanding and use, but its main limitation is that this method does not consider the cash flows throughout the lifespan of the project; it only considers the estimated cash flows up to the moment the capital investment is recovered (Fares, 2008). Examples of both methods were used in the analyses of the economic feasibility of the photovoltaic systems. For example, Hillmon P. Ladner-Garcia (Ladner, 2009) used the payback method to analyze the economic feasibility of a grid-tied photovoltaic system in Puerto Rico. However, Eyad Ali Fares (Fares, 2008) used the internal rate of return method to analyze the economic feasibility of installing a photovoltaic system in a residence in Puerto Rico.

In this study the IRR method was chosen because of the high level of precision and the payback method because of its ease of use (user friendly).

3. Optimization algorithm

The objective of the optimization algorithm is to select cost-effective methods for replacing current equipment for that which reduces the energy used by a company, thus maximizing the net economic benefits in each evaluated area for a desired period of time. The model evaluates the alternatives by area and identifies the feasible economic alternatives that comply with the constraints to maximize the obtained economic benefits. As stated above, in order to simplify the process of interpreting the results the manufacturing facility has been divided into four areas: offices, production, warehouse, and exterior. However, it is necessary to consider that some of those areas are not necessarily limited to a single building. In the mathematical model this situation is considered and these areas are subdivided accordingly. The notation i is used to index the facility areas and the notation a is used to index the subdivisions per area.

For each area alternatives to reduce energy use were considered, as well as any qualifying constraints. The assumptions considered in this research are the following:

General assumptions:

- ✓ The kilowatts per hour (kWh) consumed by all equipment are known.