Evaluating Energy Efficiency Improvements in Manufacturing Processes

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Abstract. Global warming, rising energy prices and increasing awareness of "green" customers have brought energy efficient manufacturing on top of the agenda of governments as well as of industrial companies. The industrial sector still accounts for about 33% of the final energy consumption. This paper will contribute to a more energy efficient manufacturing by demonstrating how energy efficiency can be integrated into different levels of decision-making in companies. The paper will present methods for measuring and evaluating energy efficiency improvements in manufacturing processes. Different Key Performance Indicators (KPI) will be considered and economic evaluation methods will be outlined. Moreover, an example of the integration of energy efficiency aspects into the Balanced Scorecard (BSC) will show how energy efficiency improvements in the manufacturing process can be facilitated by influencing the tactical and operational level of decision making.

Keywords: Energy Efficiency, Manufacturing Processes, Decision-Making, Economic Evaluation, Key Performance Indicator, Balanced Scorecard

1 Introduction

Climate change due to greenhouse gas emissions, unsecured energy supply and rising energy prices are subjects which are becoming more and more important in today's society. Although renewable energy technologies can be the long-term solution, more efficient energy use is predestinated to make the highest and most economic contribution to the solution of these problems in the short term [1]. Moreover, the reduction of CO_2 emissions and the protection of resources and materials are some further benefits accompanied by energy efficiency.

With its 33% of the final energy consumption the manufacturing industry is the main consumer of energy (see Fig. 1). Although the industrial sector has made continuous progress in energy efficiency over time, many examples from daily practice show that the economic energy efficiency potential in the industrial sector is far from being exhausted [2]. According to the EC's Green Paper on Energy Efficiency, at least 20 percent of its current energy consumption could be saved EU-wide [3]. Companies that improve their energy efficiency and therefore also their carbon footprint are well positioned to face future challenges and costs, resulting e.g. from future CO_2-regulations.

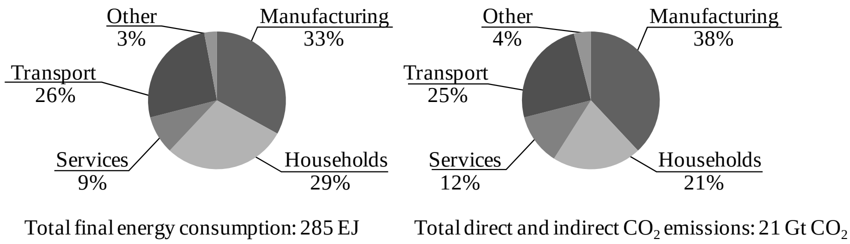

Fig. 1. Shares of global final energy consumption and CO_2 emissions by sector, 2005 [4]

Further, "green" becomes more important to the customer, which has an impact on developments in the whole supply chain and, therefore, is a significant driver of competitiveness [2]. Energy efficiency improvement is a fundamental, yet significant, way of addressing both energy security and environmental concerns [5].

1.1 Objective of the Paper

In order to achieve energy efficiency improvements in manufacturing, the benefits and cost savings have to be measured. Therefore, at first adequate KPIs and an economic evaluation method including energy efficiency aspects have to be chosen, e.g. in case of replacing equipment. Only with a solid validation by such evaluations, energy efficiency decisions can be supported and good results ensured.

The aim of this paper is to demonstrate how energy efficiency can be integrated into company activities by combining theoretical methods with practical experience. This paper presents a method to quantify the value generated by energy efficiency improvements from the perspective of manufacturing companies. This method combines several concepts from financial and supply chain management and integrates recently developed frameworks to provide the required transparency.

1.2 Methodology and Data

This paper bases on a literature research as well as on interviews and workshops with representatives of companies from the mechanical engineering and process industry. In order to assure a structured research process the approach of “Systems Engineering” [6] is applied guided by the principles of case study research. The existing approaches for evaluating energy efficiency improvements are analyzed and a proposal for a new approach to integrate energy efficiency into companies’ decision making process is outlined. The concept still has to be tested and validated with industrial partners.

This research is based on the results of the project IMS2020, which has the objective to support future manufacturing environment by building a roadmap. The roadmap highlights the main milestones for future research activities needed to achieve a desired vision for manufacturing systems. IMS2020 is embedded in the global activities of the Intelligent Manufacturing Systems (IMS) initiative. IMS is a platform for global collaborative research and experience exchange.

IMS2020 focuses on five research areas, the so called Key Area Topics (KAT), namely Sustainable Manufacturing, Energy Efficient Manufacturing, Key Technologies, Standards, and Education. This paper is based on results from the area of Energy Efficient Manufacturing (EEM).

2 Evaluation of Energy Efficiency for Manufacturing Decisions

For the evaluation of energy efficiency improvements in manufacturing environments, firstly the term energy efficiency is defined. Secondly, different methods for measuring energy efficiency are presented and finally an overview on economic evaluation approaches for energy efficiency projects is presented.

2.1 Energy Efficiency

Energy efficiency has become a central focus of energy policies as well as for industrial companies; however, little attention has been given to defining and measuring it [7]. When energy efficiency improvements are discussed for the industrial sector, quite often different definitions are used (see e.g. [5]) communicating different messages that can even be contradicting.

In the context of this paper energy efficiency is understood as reducing the energy consumption while performing the same task. This is achieved by eliminating energy waste [1]. Better energy efficiency can be accomplished by e.g. more efficient technology, better energy management, and better operational practices.

2.2 Measurement of Energy Efficiency

Companies usually accomplish changes in the operational business only if they gain a verifiable benefit. To detect such advancement in the area of energy efficiency these benefits have to be measurable. Hence, indicators are needed.

The development and application of energy efficiency indicators depend on the purpose they are applied for. Usually such indicators are ratios describing the coherence between an activity and the required energy. In the industrial sector such activity - as the production of a product - can be described in either economic or physical terms. As a result, indicators measuring the energy efficiency can be economic or physical indicators. Two typical indicators are the energy intensity and the Specific Energy Consumption (SEC). Energy intensity is called an economic indicator because its denominator is measured in economic terms like GDP. In comparison, the SEC with its denominator in units as tonne or product is a physical indicator. For both indicators the numerator measures energy consumption, which can be defined and measured in many ways, e.g. demand for primary energy carriers, net available energy or purchased energy [8]. Economic indicators are useful at an aggregated level, for e.g. comparing different sectors, but to get insight into particular manufacturing processes, physical indicators are more illuminating [8].

Increasing energy efficiency is reflected in decreasing energy intensity and decreasing SEC. Due to the amount of different industrial processes and their complexity, there exists a multitude of structural and explanatory indicators designed for the various manufacturing sectors as in the pulp and paper, cement, and iron and steel industry [9]. Special care has to be taken when comparing energy efficiency indicators internationally because the results of such an analysis can vary strongly based on different energy consumption measurements, aggregate levels, boundary definitions, and activity measurements of heterogeneous products. Depending on the goal of the analysis, it may also be required to convert net available energy consumption to primary energy or even CO_2-emissions [8].

In conclusion, there is no singular energy efficiency indicator that can be applied in every situation, but the appropriate indicators have to be defined depending on the decision to make or decision tool to be applied. Table 1 presents an overview about different energy efficiency indicators, their application and their formula or unit.

Table 1. Selection of Energy Efficiency Indicators

Reference	Indicator	Indicator type	Application	Formula/Unit
[8]	Energy Intensity	economic	aggregated level	
	Specific Energy Consumption	physical	disaggregated level	GJ per t
[9]	Energy Intensity			energy use/unit of industrial output
	Energy Use per Unit of Value Added	economic	aggregated level	
	Specific Energy Consumption	physical	comparison	energy use/tonne of product (material)
[10]	Energy Intensity	macroeconomic	aggregated level	energy consumption/monetary variables
	Degree of Efficiency	engineering view		net energy/used primary energy
	Final Energy Efficiency			energy savings by the same benefits
[11]	Energy Intensity	economic		energy/output like energy/tonne
[12]	Ratio of Energy Consumption	macroeconomic		
	Value Added	macroeconomic		
	Specific Energy Consumption		process level	energy use/physical unit of production
[13]	Thermal Energy Efficiency of Equipment		for single equipment	energy value available for process/input energy value
	Energy Consumption Intensity		broader than the thermal one: companies etc.	energy consumption/physical output value
	Absolute Amount of Energy Consumption		attended by indication of production volumes	energy value
	Diffusion Rates of Equipment		rate of deployment	
	Energy (costs)/GDP	macroeconomic		
[14]	Specific Energy Consumption	technical	for homogeneous products like cement etc.	final energy consumption/amount
	Energy Intensity			final energy consumption/real variables

2.3 Economic Evaluation of Energy Efficiency Improvements

The key criteria for the decision making process for energy efficiency improvements is the economic evaluation. “The objective of an economic analysis is to provide the information needed to make a judgment or a decision. The most complete analysis of an investment in a technology or a project requires the analysis of each year of the lifetime of the investment, taking into account relevant direct costs, indirect and overhead costs, taxes, and returns on investment, plus any externalities, such as environmental impacts, that are relevant to the decision to be made” [15]. Different economic measures and analytical techniques can be consulted for evaluating energy efficiency improvements.

For profitability calculations there are three common methods: the net present value method (NPV), the method of annualized value and the method of internal rate of return [16]. In addition to these three methods many companies also calculate the payback period. The simple payback period is commonly used and recommended for risk assessment. The risk of an investment is higher, if the payback period is longer, because the capital is tied for a longer time period. More specific economic measures for evaluating energy efficiency investments can be found in Short et al. (2005) [15].

In order to support energy efficiency investments it can be advisable to consider also productivity benefits that are associated with energy efficiency improvements in the economic evaluation [17]. These non-energy benefits could be for example lower maintenance costs, increased production yield, safer working conditions and many others. Some authors argue that additional productivity benefits should be included, for example in modeling parameters in an economic assessment of the potential of energy efficiency improvements [18]. Nevertheless it is not always straight forward to identify and quantify these benefits in monetary terms.

For energy efficiency investments there are normally no real future cash inflows to be considered for the economic evaluation. The costs for the investment, namely capital invested, and additional fixed and variable costs (e.g. cost for personnel, administration, insurance and taxes), have to be compared to the cost that can be avoided by implementing the improvement measure – these are mainly energy cost, but could also be other avoidable fixed or variable costs (especially when including other non-energy productivity benefits). On the other side, in the context of energy efficiency taxes play a specific role. For example, energy tax credits for energy efficient technologies can enhance after-tax cash flow and promote the investment.

3 Integration of Energy Efficiency in Manufacturing Decisions

In order to integrate energy efficiency aspects into the decision making of manufacturing companies, appropriate approaches for measuring energy efficiency and evaluating energy efficiency investments have to be applied. To structure the decision making process of a company we propose to look at three different levels of management and to enhance commonly known management tools by integrating energy efficiency indicators and measures. An example is given how to integrate energy efficiency aspects into the Balanced Scorecard (BSC).

3.1 Levels of Decision-Making in Manufacturing Companies

In management science, three levels of decision-making are generally distinguished: the strategic level, the tactical level, and the operational level. They are in hierarchical order and, therefore, reducing complexity of companies' activities [19].

An important characteristic of the *strategic level* is its long-term nature and its consideration of business areas instead of single products [20]. At this level decisions are made, on which markets with what kind of products the company wants to operate and how the resources basically will be used [21].

The *tactical level* serves the efficient and effective realization of the goals, which were determined before at the strategic level. At this level the layout and the capacities of the manufacturing process have to be planned. Task to be executed on this level comprise investment planning, equipment acquisition, and their maintenance, as well as the design of products and the preparation of their production. By the completion of these tactical tasks a basis for the operational level is provided.

With the *operational level* the third stage of the hierarchic planning system is described. The operational planning translates the targets defined in previous levels into precise activities. Decisions influence the kind and amount of the products, which have to be manufactured, and the production itself has to be organized and accomplished [21]. For the operational level disaggregated targets have to be defined in order to prove and measure the achievements.

3.2 The Balanced Scorecard as an Example for Integrating Energy Efficiency

In the following we would like to propose an approach to integrate energy efficiency on the strategic level using the BSC. Because the BSC links strategic goals to operational measures, changes in the direction of energy efficiency reach out to all levels of the decision making process (see Fig. 2).

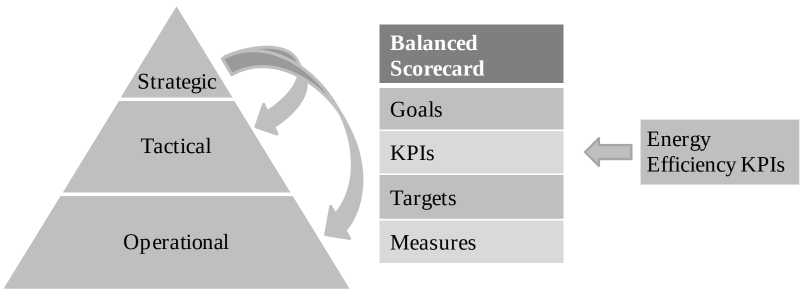

Fig. 2. The Balanced Scorecard and the different levels of companies' decision making

On the strategic level various tools exist which can assist mangers in decision-making. As an example the widely-known and -used “Balanced Scorecard” is chosen to show how energy efficiency can be included into management tools. Referring to an already existing variation of the BSC, the Sustainability Balanced Scorecard (SBSC) [22], there are three possibilities to integrate energy efficiency into the traditional BSC.

In the first option, new aspects of energy efficiency can be integrated into one, several, or all of the four existing perspectives. Therefore energy efficiency goals have to be defined and linked to each other by cause and effect relationships. Afterwards appropriate indicators and measures have to be defined.

As second option an additional fifth perspective as “energy efficiency” can be added to the existing four perspectives. This extension is adequate if energy efficiency represents an important success factor for the business model of a company. Energy efficiency can serve as competitive factor, if customers ask not only for efficient products but also for efficient production processes.

Additionally, a specific energy efficiency scorecard can be formulated. But this variation is not independent but rather just an extension to one of the earlier described options. The energy efficiency goals, indicators, and measures are transferred and detailed into a separate scorecard. The type of integration depends on the importance a decision-maker is paying to energy efficiency.

Although the BSC is a tool of the strategic level it has consequences on all three levels. By the application of the BSC a strategy is developed out of the company's mission and vision. Consequently, through gradual specification of strategic goals measures and actions are deduced. Thus, an operationalization of the company's vision and strategy is gained. Moreover, indicators are determined. These indicators that are collected at the operational level are available for upper levels to control the achievement of the strategic goals of the BSC. A possible strategic goal like "saving 10% energy during the next year" could be detailed on the tactical level by building up a new more efficient production line or modifying the capability utilization. The corresponding Energy KPI could be the SEC. This could imply on the operational level that if a company has different machines varying in their efficiency, the more efficient machine should be scheduled first and the remaining capacities needed should be assigned to the less efficient machine. Hence, energy efficiency indicators are transferred into measures and actions.

4 Conclusion and Outlook

This paper is based on first results from the project IMS2020 in the area of energy efficient manufacturing. It defines a structured concept how to measure energy efficiency improvements and how energy efficiency aspects can be included in companies' decision making. Moreover, an approach to use the balanced scorecard to integrate energy efficiency on the strategic level of a company, with impacts on the tactical and operational level is presented.

There are many technologies available, which can contribute to the objective of reduction of energy consumption in manufacturing. A detailed knowledge and analysis of the production processes is a prerequisite to find energy saving potentials in manufacturing industries. The objective is to overcome existing process limitations by developing new production processes integrating innovative energy efficient technologies, e.g. the utilization of waste heat.

In the project IMS2020 different research topics that address research needs on all three levels of decision making are developed. On the operational level, for example, an effective measurement system for energy use has to be developed (including sensors and visual systems for in-process measurements and Energy KPIs), followed by energy control concepts, which facilitate the evaluation, control and improvement of energy efficiency in production.

The analysis is restricted to an outline of a concept for evaluating energy efficiency improvements in the environment of the mechanical engineering and the process industry. The results could be transferred to other industries as well. The proposed integration of energy efficiency on all levels of decision making has to be validated in an implementation phase. Further research can enhance the presented concept by detailing the economic evaluation of energy efficiency improvements in the production process and to develop a method to quantify non-energy benefits gained from energy efficiency improvements. This paper provides the basis for measuring, evaluating and improving energy efficiency in manufacturing processes, which is crucial for companies to meet the challenges imposed by environmental regulations, scarce resources and a rising oil price.

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