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Toward Energy Efficient Manufacturing: A Study on Practices and Viewpoint of the Industry

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Abstract. The main objective of this study is to assess current situation and applications in the industry with respect to energy efficiency. From literature, a four pillar framework (strategy, tool, process, technology) has been developed, outlining the essential elements to successfully integrate energy efficiency in manufacturing. Based on the framework, a questionnaire is developed to assess manufacturing companies in Europe. How and what companies are doing currently to integrate energy efficiency in their manufacturing is under investigation through surveys and complementary case studies. This paper presents a fact finding study, aimed to understand the main motivations, limitations, and effectiveness of integrating energy efficiency in manufacturing. Hence, this study intends to establish a basis for the companies and academia to have a holistic understanding on energy efficient practices as a first step on the way to integrate energy efficiency in manufacturing. Consequently, the gaps between theory and practice are revealed.

Keywords. Energy efficient manufacturing, energy management, industrial viewpoint, manufacturing plant, sustainability

1 Introduction

Manufacturing has changed its focus and approaches from pure cost to quality, productivity and delivery performance in the last couple of decades [1]. Currently, the new topic of interest that has gained significant attention from both academia and the industry is energy efficiency due to the significant environmental and economic impacts associated with consumption of energy. The change of approach in the industrial world stemmed from the global drivers for improving energy efficiency such as climate change, scarcity of resources and energy supply as well as the industrial drivers including rising energy prices, ever-stricter becoming legislations, customer demand and awareness along with competitiveness have pushed energy efficient manufacturing to the top of the agenda for both governments and companies.

Companies have been feeling the pressure and urge to examine how their processes, methods and structures could become more energy-efficient considering global and industrial drivers forcing them to do so. Since energy consumption

advances in having paramount importance for manufacturing companies, continuous improvement in energy management is now integrated into strategies of companies. In this regard, taking action (e.g. adopting energy management standards such as ISO 50001) to build a continuous improvement process to use energy resources more efficiently becomes essential [2].

In this manner, this research is based on a fact finding study, aimed to understand the main motivations, limitations, and effectiveness of integrating energy efficiency in manufacturing. In this vein, we investigate the current practices and approaches of the companies regarding energy efficiency where we suggest an evaluation framework in order to successfully integrate Energy Efficiency (EE) in manufacturing in a systematic way, with the aim of gaining insight into energy efficiency in manufacturing and finding out the gaps between theory and practice.

Thus, the main objective of the study is to assess current situation and applications in the industry with respect to energy efficiency improvement measures using the proposed framework to help companies to integrate energy efficiency in manufacturing. How and what companies are doing currently to integrate energy efficiency in their manufacturing is investigated through surveys and case studies.

Hence, this study intends to establish a basis for the companies and academia to have a holistic understanding on energy efficient practices as a first step on the way to integrate energy efficiency in manufacturing. In this context, we identify the main objectives as below:

- Understand how and what companies are doing currently to integrate energy efficiency in their manufacturing
- Determine the priorities of companies and stimuli for energy efficient manufacturing
- Understand the level of consideration given to integration of energy efficiency in manufacturing on the industry side
- Develop insight into the use of ICT and other supporting tools/methodologies for improving energy efficiency
- Identify the gap between the theory and the practice

2 State of the Art

Nowadays, energy consumption is considered as one of the key item for sustainable development due to its environmental, economic and social impacts. Brundtland Commission [3] defines sustainable development as “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. In this regard, IEA [4] considers energy efficiency improvements as a principal component for sustainable development. Thus, energy efficiency becomes a core issue for policy-makers, industries, and society. Indeed, improving EE has been mentioned as paramount by several communities of research, industry and policy-making in order to overcome the challenges of today stemmed from both global and industrial drivers of energy efficiency (e.g. [5]). Aligned with 3 pillars of sustainability, improving EE provides benefits in environmental (e.g. reduced GHG

emissions), economic (e.g. reduced costs, improved competitiveness) and social (e.g. increased security of energy supply) dimensions. Hence, above mentioned gains prove powerful interdependence between energy efficiency and sustainable development [6].

Energy efficiency is a key target for the factory of the future stemmed from both global and industrial drivers and hence many studies have been carried out in the field of industrial energy efficiency. In fact, Chow et al. [7] points EE as the “lifeblood of technical and economic development”.

Based on the critical review of the literature, the studies on energy efficient manufacturing can be grouped in six main dimensions which are essential to integrate energy efficiency in manufacturing.

- **Drivers/Barriers:** As the name implies, these are the stimuli/drivers for energy efficient manufacturing which are the main reasons for the industrial companies to implement energy efficiency measures in manufacturing.
- **Strategic approach:** The main issue here is the alignment of energy efficiency in manufacturing with corporate goals. Commitment of top management is a crucial part for implementation of any kind of measures in the industry and establishes the base for strategic focus. The concepts under scrutiny regarding the strategic focus of the companies are e.g. policies & standardization; strategic decisions (e.g. buy-sell, demand management, location decisions, etc.); technology selection, development and deployment; Investments on R&D and innovation; and eventually voluntary initiatives (e.g. CSR, etc.).
- **Information and Communication Technologies:** ICT has the potential to play a very significant role in improving energy efficiency in manufacturing and its share and importance has been growing during recent years. Hence, ICT as a supporting tool and an enabler for achieving energy efficiency in manufacturing needs a further consideration.
- **Supporting tools and methodologies:** This part comprises the methods and tools available which mostly provide support in making energy related analysis and decisions in manufacturing environment. Examples to this dimension could be modeling and analysis (e.g. simulation, DEA modeling, etc.), energy assessment tools, sustainability tools (e.g. LCA), emission calculation tools and benchmarking tools & techniques.
- **Manufacturing Process Paradigms:** To manufacture any product, some set of processes should be followed and types of processes depend on the type of products as well as companies’ considerations of different aspects and related decisions in manufacturing. Manufacturing technologies (e.g. development of technologies & materials), manufacturing process management (MPM), process design & optimization, switching energy modes of machines (i.e. on, off, stand-by, etc.) and scheduling are examples to paradigms to be considered.
- **Manufacturing Performances:** Traditional performance measures considered in manufacturing include factors such as quality, cost, delivery time and safety. Thus, it is essential to investigate the impacts of integrating energy efficiency as another performance dimension in manufacturing on traditional performances.

3 Research Design and Framework

Taking the concepts to support and foster energy management in manufacturing such as processes, methods along with standardization and combining them with the significant role of ICT also stressed out in the literature as mentioned before, we come up with a 4-pillar framework comprised by the enablers for energy efficient manufacturing (i.e. Strategic approach, manufacturing process paradigms, supporting tools/methodologies and ICT). Integrated with the drivers/barriers on one side and attained manufacturing performances on the other side, we propose the framework (see Figure 1) for successfully integrating energy efficiency in manufacturing that can also be of use for assessing the current practices in the industry with the aim of finding out the gaps between the concepts in theory and industrial practices in the area.

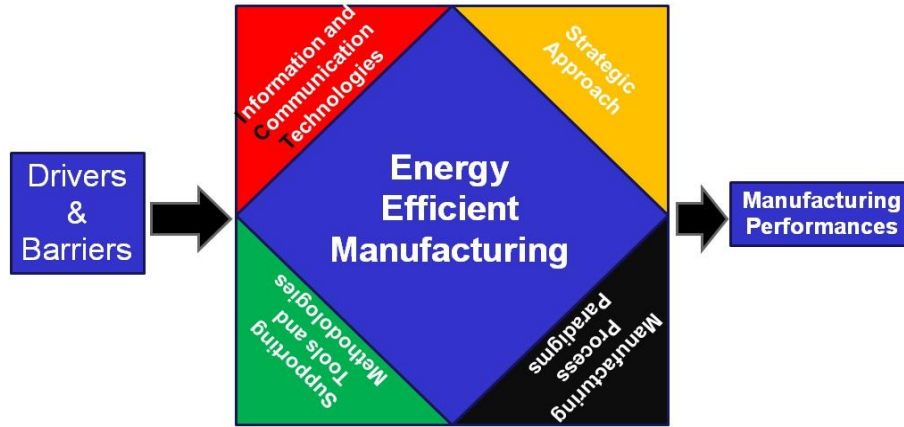


Fig. 1. Framework for successfully integrating energy efficiency in manufacturing

The framework provides a holistic view on all the aspects to be considered for implementing energy efficiency measures in manufacturing. The model can as well be of use for assessing the current practices of the industrial companies from an energy efficiency perspective and for understanding how and what companies are doing currently to integrate energy efficiency into their manufacturing processes. Thus, it provides support in identifying the gaps between the available solutions in theory and companies' current actual practices.

Utilizing the proposed framework, it is possible to gain a profound insight into current practices in the industry that might reveal the gap with theory as well as into overall integration of energy efficiency in manufacturing. Besides, we investigate the importance of ICT as an enabler for energy efficient manufacturing along with the non-energy benefits associated with energy improvement measures. Further, the impact of energy efficient way of thinking and implementation on traditional manufacturing performances is highlighted.

4 Research Methodology

To pursue the objectives of the study, an explorative research is carried out through the development and use of an on-line survey in order to assess manufacturing companies operating in Europe and is further supported by complementary case studies.

Survey method is mainly followed in the study to assess the energy efficiency related practices in the industry with the aim of gaining insight using the developed framework. Based on the research objectives and framework described previously, a questionnaire of 10 comprehensive questions has been developed to assess the companies. This survey was composed of questions about company characteristics, energy efficient strategies and applications of the company, supporting tools and relevant manufacturing processes.

Questionnaire is thus based on the main components of the framework which comprises four enablers for energy efficient manufacturing, drivers/barriers and attained manufacturing performances. So, questions are identified related to these sub-points. On-line version of the questionnaire has been created using Survey Monkey and was sent to companies via the following link: <http://www.surveymonkey.com/s/Y59Y36C>.

Questionnaire was sent to a combination of large companies and SMEs. Sample firms were selected from manufacturing companies operating in Europe in mechanical, electric and automotive sectors. The respondents were all relatively large companies. This survey includes questions about company characteristics, energy efficient strategies and applications of the company, supporting tools and relevant manufacturing processes.

Furthermore, case study methodology is used as complementary to surveys to further analyze and validate the gathered data. The principal way of data gathering through the case study is conducting interviews and analyzing sustainability related reports.

5 Results and Discussion

As explained in Part 4, the questions are organized in three parts (i.e. drivers/barriers; enablers; manufacturing performances in trade-off). The discussions of the results are also presented in this structure:

5.1 Drivers and Barriers

Companies considering energy efficiency performance measures in manufacturing could have many reasons or drivers to do so. Among them, reduction of costs, reduction of the environmental impact (commitment to reduce the environmental impact), image improvement due to enhanced reputation and achieving sustainability targets are the most important reasons provided by companies interviewed. Changes in customer behavior and compliance with legislations are considered relatively less

forcing factors whilst reducing carbon footprint is not considered as a driver in most of the companies. However, companies' responds regarding their commitment to reduce environmental impact here might not reflect the reality as they tend to show/think their companies more committed than they actually are. In reality, most of the decisions and interest depend on either costs or long term plans like image improvement.

From the study it has been found that companies are feeling responsible for considering energy efficiency as a new performance target area in manufacturing. However, insufficient investment paybacks (e.g. ROI), the lack of fund to pay for improvements and insufficient government incentives are considered by them as the most important barriers to implementing energy efficiency in manufacturing. Some companies mention the weakness of current legislations and policies on forcing the industry to become more energy efficient since they are mostly easy to tackle and not challenging enough especially for large enterprises. In this manner, manufacturing firms do not aim toward energy efficiency by considering it as one of the key target areas unless they find strong financial motivation in doing so.

5.2 Enablers for Energy Efficient Manufacturing

Most of the companies interviewed have high level sustainability and energy related initiatives such as CSR (corporate social responsibility) strategic scheme, ISO14001 (Environmental management system) and ISO 50001 (Energy Management System). This shows that top managements are also committed for overall sustainability and energy efficiency in the industry. However, when it comes to the ground level, as of manufacturing, there is not enough evidence that energy efficiency is properly integrated in top-down approach.

To better understand if top managements have genuinely cascaded energy efficiency into manufacturing, other questions have been asked such as the way they integrate energy efficiency in manufacturing, level of investments, and implementation of different options for improvements in energy efficiency, how tradeoffs between traditional performances (cost, quality, delivery and functionality) are considered and finally the type of methods they follow.

The significance of different methods and ways in integrating energy efficiency in manufacturing was one of the key concerns of the study. In this context, companies reported "optimization of current production processes" and "aligning production planning with energy efficiency practices (e.g. switching energy states of the equipment)" as two key factors to be followed effectively. "Integrating energy efficiency in product and process design" along with "combining energy efficiency with manufacturing strategies (e.g. resource planning)" are considered as important however with a less impact compared to former ones.

The companies were interviewed also for the activities they have been following to improve energy efficiency in their manufacturing plants. They mentioned energy monitoring and control, use of new technologies and consultancy with energy experts among the mostly adopted ways in their company. Energy recovery and renewable energy use, on the other hand, are not considered and do not take place in most of the

firms. In fact, these are the two areas for energy improvement in manufacturing facilities which have been somehow ignored to date but are considered as two important future streams both for academia and industry as far as energy efficiency in manufacturing is concerned.

When companies were asked to rate the importance of different ways for improving energy efficiency regardless of they have been following or not, the most important activities highlighted were “more efficient equipment and technologies for improving production processes”, “optimizing the plant level activities by using technical services (e.g. HVAC control system), “enhanced monitoring and control of energy consumption” and “use of energy related performance indicators”. Above mentioned activities are indeed aligned with the two ways for reducing energy consumption as defined by Rahimifard [11]. The latter two are in fact the main essential elements for an effective energy management in a manufacturing plant. On the other hand, ICT support on energy efficient manufacturing and consideration of energy efficiency in long term decisions are not considered as essential and important by contacted companies. Taking into account the importance of ICT related stream for research in energy efficiency and so for academia, we might say that the viewpoint of the industry is not aligned with academia at this point. However, this might be due to the fact that industrial contacts might have thought regarding the current practices and needs whereas academia is more into potential solutions for future aligned with the vision for Factories of the Future.

With regards to ICT support for enhanced energy management, “improving the reliability of the data” and “evaluation software for process performance with respect to energy efficiency” are the main aspects companies stressed out. Especially, the latter one is of good use since it helps evaluating the trade-off between traditional performances in manufacturing such as cost, quality, delivery and flexibility and improvements in energy efficiency as well.

Besides, there are several tools used in manufacturing to support decision making with regards to energy efficiency, as also mentioned in part 3. Companies interviewed mostly use energy assessment tools and cost calculation & energy tracking tools whilst benchmarking and simulation tools are used relatively less compared to former mentioned ones. However, carbon footprint measurement tools and sustainability assessment tools such as LCA are not adopted by majority of the companies for energy related decision making.

5.3 Manufacturing Performances

Till now, the main drivers and barriers for companies towards improving energy efficient manufacturing then the main enablers to integrate energy efficiency in manufacturing have been discussed. Now, in this section the impacts of integrating energy related issues on traditional performances are investigated. This is a crucial issue, since it is seldom that companies worry about energy efficiency issues if the traditional manufacturing performances such as cost, quality, delivery and flexibility are jeopardized.

Companies interviewed stressed that fully integrating energy efficiency in manufacturing might sometimes cost more than the gained they could have achieved. Moreover, quality could be affected due to some strategies towards energy efficiency (e.g. shutting down the equipment to reduce energy consumption).

But, they also stress that non-financial gains have been achieved such as improved company image, new skills and competences, increased customer acceptance and raised overall sensitivity towards environmental impacts inside the company. Therefore, the main challenge here is how to structure manufacturing strategy, tools, processes and information systems in such a way those traditional manufacturing performances are either unaffected or even improved.

To sum up, the developed framework can easily be used to evaluate how energy efficiency is effectively addressed in manufacturing industries. As also highlighted with the key findings of the study, the consideration of energy efficiency is not matured enough to attain the general energy performance goals expected by multiple stakeholders. In that vein, academia should not only focus on developing solutions for key aspects (i.e. 4 enablers) in a disparate manner but also on need to investigate new way of holistic and integrative design of manufacturing systems, better aligning strategy objectives with energy improvement goals.

6 Conclusion

In this research, we investigated practices and viewpoint of the manufacturing industry with regards to energy efficiency. The findings revealed that although there has been a consistent progress in the industry toward energy efficiency, the implementation of the concept is still not mature enough. There is no sign of strong evidence regarding the integration of energy efficiency in manufacturing as a new performance target area.

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