Introducing Energy Performances in Production Management: Towards Energy Efficient Manufacturing

Alessandro Cannata, Marco Taisch

Introducing Energy Performances in Production Management: Towards Energy Efficient Manufacturing

Alessandro Cannata[1] and Marco Taisch[1],

[1] Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Piazza Leonardo da Vinci, 32 – 20133 Milano, Italy
{alessandro.cannata, marco.taisch}@polimi.it

Abstract. Energy consumption is one of the main economic, environmental and societal issues. As stated by recent researches, manufacturing plays a major role in energy consumption. To react to this situation and to go towards Energy Efficient Manufacturing, several initiatives are on-going. One relevant lever that is discussed in this paper and that should be taken into consideration is production management. Present production planning and control policies, which are used to optimize manufacturing processes, do not take into consideration energy efficiency. In this paper, we investigate energy efficiency performance indicators on one side and production scheduling and control practices on the other side. The purpose is to highlight this research gap in literature and start defining next steps towards Energy Efficient Manufacturing.

Keywords: sustainable manufacturing, energy efficiency, production management, key performance indicators, energy efficient manufacturing.

1 Introduction

Nowadays, energy consumption is one of the main economic, environmental and societal issues. As stated by recent researches on energy use [6], manufacturing plays a major role in energy consumption. As a matter of fact, 33% of the global energy consumption is due to manufacturing, representing a main issue both due to increasing and volatile price of energy sources, and to the environmental impact (38% of the total CO_2 emissions are due to manufacturing).

In order to react to this situation and to go towards sustainable production, several initiatives on energy efficiency are on-going. Most of them are developing innovations in production processes and technologies, and policy regulations.

One relevant lever that is not yet considered enough to go towards Energy Efficient Manufacturing is Production Management. Production Management is core in order to ensure proper and efficient operation of production systems. Hence, one of the new challenges, which Production Management Systems are facing, is the proper inclusion of Energy Efficiency as a core objective. Moreover, considering the possibility to exploit information available at shop floor level (thanks to pervasive Information and Communication Technologies), innovative production management systems can be adopted to support energy efficient manufacturing.

In this paper, we investigate energy efficiency performance indicators on one side and production scheduling and control practices on the other side. The purpose is to highlight this research gap in production management literature and start defining next steps towards Energy Efficient Manufacturing.

2 Research focus in manufacturing domain: IMS2020

Energy Efficiency is core for manufacturing, and this can be also shown by looking at the results coming from foresight studies that focus on the identification of future topics/challenges to be addressed by the scientific and industrial community. In the manufacturing domain, some research activities are on-going (e.g. ManuFuture [18]): among them there is IMS2020 (www.ims2020.net/ - IMS2020: Supporting Global Research for IMS2020 Vision).

IMS2020 is a European funded project, whose aim is to support global European-centric research under the IMS scope. Intelligent Manufacturing Systems (IMS) is an international research & development initiative established to develop next-generation manufacturing technologies.

In particular, IMS2020 project maps and analyzes on-going major research activities and conducts foresight analyses to derive a set of recommendations for future manufacturing research. In the project, the following key areas are identified:

- **Sustainable Manufacturing:** in this key area, the focus is manufacturing approaches and technologies towards sustainable development, i.e. "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Specific topics addressed are: innovative manufacturing technologies for environmentally benign production and measurement/assessment technologies to ensure occupational safety (e.g. ergonomics, industrial disaster prevention, etc.).
- **Energy Efficient Manufacturing:** this key area focuses on efficiency improvement and carbon footprint reduction in energy utilization for manufacturing and operational processes. In this area, different approaches for energy measure, control, and management are investigated in order to define future research streams.
- **Key technologies:** this area refers to the development of manufacturing and information and communication technologies for supporting next-generation manufacturing including new materials. .
- **Standards:** in this key area the focus is on manufacturing research issues that can benefit from standardization to create open manufacturing and product standards that are accessible to everyone, enhancing innovation globally.
- **Education:** educational programs for an information based knowledge worker environment that will support manufacturing. Research topics in this key area address the development of a coherent vision of manufacturing education.

In each of these five areas, IMS2020 is preparing a coherent roadmap for future manufacturing research, suitable to IMS cooperation. Being one of the five main pillars of this foresight activity, the central role in the future of Energy Efficient

Manufacturing is stressed. In the next section, a literature review is conducted on research efforts spent in the area of Energy Efficient Manufacturing, in order to find out some gaps to be bridged.

3 Approaches to Energy Efficient Manufacturing

In our literature review, we mapped several research activities that proposed advances for energy efficiency in the industrial domain. Here, we propose the most relevant ones clustered homogeneously in terms of objectives and approaches.

Some research activities have been performed in order to analyze and control energy efficiency in energy-intensive sectors [14]-[16]-[17]. These analyses are mostly driven by economic evaluations; as a matter of fact, in these sectors energy is responsible for a major part of the total production cost. This stream of research focuses mainly on process technology improvement, as a mean to reach energy efficiency. However, as stated by [13]-[16] studies of the non-energy intensive sector are scarce. And since non-energy intensive industry accounts for a non-negligible part of total industrial energy consumption [13], there is a need for research also in this area.

With regards to the development of performances indicators [19], some researchers addressed this topic identifying new methods to assess energy efficiency in industrial domain. However, most of these works are focused on aggregate performances suitable to be used at the top level of enterprise hierarchy. Indeed, investigation of performance indicators to be adopted at different hierarchical level in the enterprise seems to be missing.

Another relevant stream of research in Energy Efficiency [20]-[21] is related to policy and standardization. Even if this is an extremely interesting area of research, it is slightly far from traditional production management research but should be taken into consideration in order to have a holistic view on the issue Energy Efficiency.

Looking at production management as a research area, some scientific initiatives have been mapped. Most of them include energy efficiency consideration, in particular in relation to eco-efficiency analysis or environmental analysis. Methods developed from these literature streams are Life-Cycle Assessment [10]-[12], Environmental Management Systems [3], and Total Quality Environmental Management [2].

Even if these methodologies have been applied successfully, they present also some drawbacks already emerged from literature. Concerning LCA, [2] noted that "LCA has been recognized as extremely information intensive, difficult to implement, somewhat subjective and difficult to defend". Indeed, to adopt LCA much effort is required to find and analyze data. Hence, this approach could be difficult to implement in everyday operation management.

Concerning Environmental Management Systems, similar drawbacks have been identified. Moreover, some authors argue that Energy Management is not enough integrated in Environmental Management Systems: as stated by [23], "Even though Energy Management should be integrated in EMS, empirical data indicates that it is not".

TQEM can be considered an evolution of Total Quality Management, where environmental aspects are taken into consideration. Even if this approach was developed some years ago, some barriers are limiting its adoption [2]. Indeed, [2] states that managers have difficulty assessing the impact of TQEM programs, because of the lack of appropriate measures. Even if in [2], the authors perform an analysis in order to show impacts of TQEM, little attention is put on energy aspects; furthermore the analysis is mainly cost-based.

At present, few consolidated techniques are available to perform energy efficiency analyses and (near real-time) control of production systems' operation (especially in non-energy intensive industries). Only three works, which slightly address this topic, have been found: [4]-[5]-[9]. However these works still leave many open questions about production management improvements for energy efficiency.

Concluding, from this initial literature review we highlighted that performance indicators need to be further discussed in particular focusing on cross-layer adoption of different indicators for addressing Energy Efficient Manufacturing. Moreover, production management practices with focus on energy efficiency seem not to be addressed yet, e.g. production planning and control.

4 Introducing energy efficiency in Production Management

In Production Management, i.e. field of study that includes techniques and practices adopted in industrial domain to define how (when, in which sequence, by which resource, etc.) products should be manufactured, two pillars are required to support smooth and efficient operation of manufacturing systems: production planning & control practices and performance assessment.

With regards to performance assessment, three different layers of performances can be defined [22]: aggregate performances, set of indicators, and specific indicators (see Fig. 1). These three layers can be respectively linked to different hierarchical levels in the company. This means that if top management is usually interested in aggregate performances, middle management (such as plant managers, etc.) are instead more interested in set of indicators and so on. This structure could be adopted for different business performance; however, in this paper, we will focus only on relevant performances in the production management scope.

Traditionally, at the aggregate performances level, production management looked at performance such as Cost, Quality, and Speed [11]. These performances can be considered the most relevant drivers seen by the customer, among those drivers affected by production management decisions. More recently, one new dimension is more and more considered relevant: Environment. As a matter of fact, several stakeholders such as customers, policy-makers and industries themselves are highlighting this aspect.

Passing to the lower level, i.e. set of indicators, we identified some indicators categories that are widely adopted. They can be clustered in Time, Utilization, Internal Quality, and Inventory Level. As said, these are considered categories of indicators that can be represented through different specific indicators (lowest layer in Fig. 1) with slightly similar aims. For example, Overall Equipment Effectiveness

(OEE) [8] is a specific indicator that includes both Internal Quality and Utilization aspects, but Utilization could be also assessed through the sole indicator Availability (i.e. the ratio between operating time and loading time of a manufacturing system).

This performances structure, adapted depending on the industry and on the specific manufacturing company objectives, could be used to assess production management practices and decisions, at all layers. As a simple example, by introducing Kanban in a manufacturing company, WIP can be analyzed in order to assess its reduction [7]. However the plant manager, will be interested at looking at the inventory level reduction (both in economic measures and not). Finally the top management will look at the cost reduction due to lower inventory.

Looking at the middle and lowest layers in Fig. 1, in this paper we will focus on Energy as one of the main important drivers affecting Environmental and Cost performances. Indeed, energy is becoming an important issue to be tackled, and this has been stressed in the first two section of this paper.

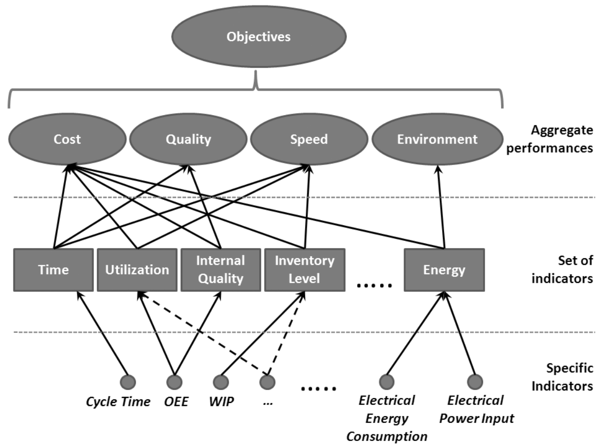

Fig. 1. Performance measurement structure.

In industrial domain, a well-known indicator that can be measured and controlled is the Electrical Energy Consumption. This indicator is measured in kWh. We consider this indicator since it is simple to be calculated/measured, it represents a relevant part of the total energy consumed by industries (especially in non-energy intensive industries) and finally, it allows elaborations in terms of both Cost and Environment (e.g. one typical environmental indicator at aggregate level is CO_2 emission that can be derived from the energy consumption). However, this indicator is required to be differentiated depending on the source of Electrical Energy. As a matter of fact, industries are more and more adopting heterogeneous sources to procure energy (and with different cost and environmental impacts): power plants, proprietary power generators, photovoltaic cell, etc. Indeed, in order to properly assess costs and environmental impact of energy consumption, the indicator Electrical Energy Consumption needs to be constructed accordingly.

Having detailed data on Energy consumption, energy efficiency indicators can also be defined as the ratio between production level (e.g. number of products processes by a production line) and energy consumption (e.g. kWh consumed). These indicators need to be assessed to describe production efficiency from the energy point of view. However, they should be analyzed thoroughly and in a comprehensive way to avoid drawbacks such as rebound or backfire effects [21].

Moreover, for effective near real-time control on the energy performance of production systems, another indicator should be considered: Electrical Power Input. With this indicator we refer to the power input required by production systems, measured in kW. Indeed, there are two aspects that affect cost and environmental impact: (i) different prices of energy consumption depending on the time-window during the day and on the instantaneous power required, (ii) different impacts depending on the type of source of electrical energy (gas, oil, wind, etc.). Hence, controlling the electrical power input is required in order to assess how different production practices may have different outputs. For example a plant manager may decide to avoid peaks of power consumption, and exploit the proprietary power generators, reducing the workload in specific time-windows and spreading the workload production on more appropriate moments (e.g. night production).

This concept is becoming more impactful with the exploitation of real-time information, available thanks to Information & Communication Technologies (ICT).

5 Energy Efficient Manufacturing in Real-time Enterprise context

As said in section 4, the other pillar of production management is production planning & control. Nowadays, production planning and control systems usually take into consideration time and cost in order to define specific plans and they do not take into consideration energy efficiency as an objective or as a decision driver. To go towards energy-aware factories this aspect need to be included.

Without performing a thorough analysis on energy requirements due to production, energy availability, and related impact, production planning and control cannot be appropriately performed with respect to energy efficiency.

As an example, we consider loading rules that define when material should be loaded in a manufacturing system. Instead of using traditional rules based on time requirements, new energy-driven rules could be adopted in order to avoid energy peaks, and to better distribute energy consumption. Dispatching rules could also be constructed to reduce energy consumption due to set-up activities (i.e. activities performed to prepare a specific machine for the next production). Moreover, exploiting the possibility of switching off machines instead of keep them in stand-by mode, reduction of energy consumption can be obtained through appropriate production scheduling. It is interesting that this could lead to define batch production, with possible drawbacks (i.e. time or cost) that should be assessed in a holistic way.

Thanks to availability of information enabled by ICT, production management practices for energy efficient manufacturing could be more easily implemented. Indeed, nowadays through ICT, near-real time information can be provided to interest targeted persons in the enterprise [24]. As an example, a scenario is depicted in Fig. 2. In this scenario a plant manager exploits real-time information coming from the field, through appropriate indicators such as WIP, Cycle Time, but also Electrical Energy Consumption and Electrical Power Input, in order to take proper decision in terms of production planning and scheduling. The plant manager needs to adopt modeling techniques in order to support his decision-making process, and on the other side will compare different production management practices (i.e. different schedules, different production plans, etc.) in order to assess them in terms of energy efficiency.

This kind of ICT support will be fundamental due to variability and dynamicity of energy consumption in complex manufacturing systems operation.

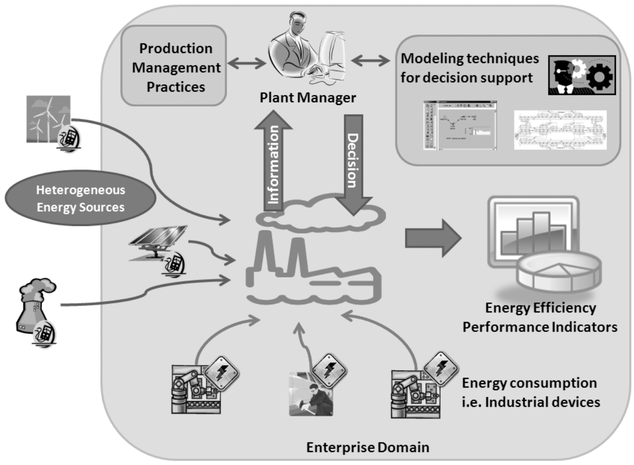

Fig. 2. Energy Efficient Manufacturing in Real-time Enterprise. Adapted from [24].

6 Conclusions

We highlighted in this paper the need to introduce Energy Efficiency in Production Management. As a matter of fact, it is clear that energy consumption is a core issue that industries have to face nowadays, and on the other hand from literature review it emerged that this aspects is not completely tackled in the context of production management.

Several further research actions are needed in three main streams: modeling techniques for production processes, production planning and control practices, performance indicators. Modeling techniques for production processes need to be investigated in order to include energy performances aspects. Moreover, best suited models for energy performance representation in manufacturing domain should be identified and validated. Finally, production planning and control need to be further investigated in terms of energy efficiency together with performance evaluation in order to find out trade-off among performances and improve present practices.

Acknowledgments. The authors would like to thank the European Commission and the partners of the IST FP6 project "Service-Oriented Cross-layer infRAstructure for Distributed smart Embedded devices" (SOCRADES - www.socrades.eu) and of the NMP FP7 project "IMS2020: Supporting Global Research for IMS2020 Vision" (IMS2020 – www.ims2020.net) for their support.

References

1. Brundtland, Report at World Commission on Environment and Development, (1987)
2. Curkovic, S., Sroufe, R.: Total quality environmental management and total cost assessment: An exploratory study. Int. J. of Production Economics 105(2), 560-579 (2007)
3. D., R., G., V.: Panacea, common sense, or just a label? - the value of iso 14001 environmental management systems. European Management Journal 18, 499-510 (2000)
4. Devoldere, T., Dewulf, W., Deprez, W., Willems, B., Duflou, J.: Improvement potential for energy consumption in discrete part production machines (2007)
5. Dietmair, A., Verl, A.: Energy consumption modeling and optimization for production machines. In: Proc. IEEE International Conference on Sustainable Energy Technologies ICSET 2008 574–579 (2008)
6. IEA, Worldwide trends in Energy Use and Efficiency, Energy Indicators, (2008) (http://www.iea.org/Textbase/Papers/2008/indicators_2008.pdf)
7. Khojasteh-Ghamari, Y.: A performance comparison between kanban and conwip controlled assembly systems. Journal of Intelligent Manufacturing 20, 751-760 (2009)
8. Muchiri, P., Pintelon, L.: Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. International Journal of Production Research 46(13), 3517-3535 (2008)
9. Gutowski, T., Dahmus, J., Thiriez, A.: Electrical energy requirements for manufacturing processes. In: Proceedings of the 13th CIRP Int. Conf. on Life Cycle Engineering (2006)
10. Pennington, D.W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., Rebitzer, G.: Life cycle assessment part 2: Current impact assessment practice. Environment international 30(5), 721-739 (2004)
11. Hopp, W.J., Spearman, M.L.: Factory Physics. Mc Graw-Hill Int. Ed., 2nd edition (2000)
12. Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.P., Suh, S., Weidema, B.P., Pennington, D.W.: Life cycle assessment: Part 1: Framework, goal and scope denition, inventory analysis, and applications. Environment international 30(5), 701-720, (2004)
13. Rohdin, P., Thollander, P.: Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. Energy 31(12) (9 2006) 1836-1844
14. Solding, P., Petku, D.: Applying energy aspects on simulation of energy-intensive production systems. In: WSC '05: Proceedings of the 37th conference on Winter simulation, Winter Simulation Conference 1428-1432 (2005)
15. Sun, H., Hong, C.: The alignment between manufacturing and business strategies: its influence on business performance. Technovation 22(11) 699-705, (2002)
16. Thollander, P., Karlsson, M., Sderstrm, M., Creutz, D.: Reducing industrial energy costs through energy-efficiency measures in a liberalized european electricity market: case study of a swedish iron foundry. Applied Energy 81(2) 115-126, (2005)
17. Utlu, Z., Sogut, Z., Hepbasli, A., Oktay, Z.: Energy and exergy analyses of a raw mill in a cement production. Applied Thermal Engineering 26(17-18) 2479-2489, (2006)
18. ManuFuture website - http://www.manufuture.org
19. Veleva, V., Ellenbecker, M.: Indicators of sustainable production: framework and methodology. Journal of Cleaner Production 9, 519-549, (2001)
20. Geller, H., Schaeffer, R., Szklo, A., Tolmasquim M.: Policies for advancing energy efficiency and renewable energy use in Brazil. Energy Policy 32, 1437–1450 (2004)
21. Herring, H.: Energy efficiency—a critical view. Energy 31, 10–20 (2006)
22. MESA Metrics that Matter Guidebook & Framework - International Guidebook (2006)
23. Amundsen A.: Joint management of energy and environment. Journal of Cleaner Production, 8, 483-494, (2000)
24. Karnouskos, S. Colombo, A. W. Lastra, J. L. M., Popescu, C.: Towards the energy efficient future factory," in 7th International Conference on Industrial Informatics - INDIN (2009).