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Optimization of energy efficiency of a production site: a method to support data acquisition for effective action plans

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Abstract

Nowadays the efficient use of energy has acquired a significant importance in the industrial sector. Moreover, stringent regulations on environmental impact lead companies to tread a path towards energy efficiency in short terms to avoid penalties. The goal of this work is to propose a structured method to perform fast and simplified energy assessments. The latter starts from a proper classification of process data, passing through an effective mapping in order to identify criticalities that have to be solved by innovative action plans. Method will be tested on a real case study.

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Keywords: energy efficiency, sustainable manufacturing, process innovation, data management

1. Introduction

One of the most important challenges that the industrial word is addressing is related to the sustainable development. It is no longer sufficient to focus efforts on emissions of final product. Indeed, it is the result of several processes, which consume resources and generate emissions on the environment. Therefore, the efficient use of resources has become a priority for industries to reduce their impact on society. They are called to identify the sources of waste and investigate opportunities for energy efficiency improvements. The regulatory pressure is one of the main drivers that lead companies in this challenge. On the one hand, they must answer to stricter requirements,

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on the other they can reduce the risk of penalties, having also access to economic incentives. Moreover, the digital revolution is offering new opportunities to companies to make their processes more efficient.

For this aim, industries need to monitor the plant energy flows and collect data about consumptions and machines operation. Only in this way, they can identify possible inefficiencies. However, data have to be properly organized and elaborated. It emerges the need for a tool that allows managing the information flow by also acquiring real-time data. Moreover, the correlation with certifications requirements and the proposal of best-practices and corrective actions is essential to make the process more sustainable.

In this context, the present paper aims to propose a method to support industries in the data acquisition process in terms of identification of necessary data, suggestion of acquisition means and definition of a proper information flow. Thus, a structured data framework for the energy plant assessment is presented. It tries to overcome the difficulties related to the inventory phase, which is a time-consuming activity. An efficacious mapping of the current production system allows understanding how consumptions are distributed along the production flow and correlate them with the company asset performances, production planning, and resources management. This is the starting point for the definition of innovative strategies. For this aim, the proposed approach takes also into account the bureaucratic and financial aspects, supporting companies to obtain certifications and reduce costs. Finally, it suggests the procedure to periodically analyze consumptions in order to reach the target and implement the continuous improvement approach. The method will help company decision makers to take into account the correct innovation strategies boosting the company sustainability.

To understand the method efficacy, it has been applied by an Italian manufacturer of heat exchangers. It allows the identification of current inefficiencies, possible solutions and benefits that could be achieved, also from an economic point of view.

2. State of the Art

The need for a transition to resource-efficient economy pushes the industrial sector toward the sustainable manufacturing, which is defined as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" [1]. As a consequence, one of its main goals is the reduction of energy consumptions in manufacturing processes. In this vision, some efforts have been dedicated to the definition of key performance indicators (KPIs) to assess the energy efficiency of manufacturing activities [2] and to the integration of energy efficiency performance in production management [3].

In this context, the standard ISO 50001 supports organizations in all sectors to improve the energy performance by specifying the requirements for establishing, implementing, maintaining and improving an energy management system [4]. In addition, there are national and regional regulations or tax breaks (e.g., White Certificates, FEMP Energy Incentive Program [5][6]) that encourage companies to achieve a certain target of energy savings.

On the other hand, to become more profitable, many manufacturers adopt the lean philosophy, which aims to reduce waste. The literature demonstrates a successful integration of lean and sustainability principles to generate actions of continuous improvement to develop sustainable manufacturing processes [7][8]. According to this, in a previous work, the authors proposed a tool aimed to assess the energy value flowing in a production system (Energy Value Stream Mapping), and drive companies toward sustainable processes through the elimination of wasted energy and the reduction of the same non value added [9]. However, the complexity of the data inventory phase of the latter is still a barrier to overcome, especially in small and medium-sized enterprises (SMEs) where many data should be unavailable. Hence, a simple and standard method should be required.

Indeed, the lack of a standardized approach for data management is recognized by Khan et al. [10] as one of the main challenges that companies have to face. They encourage the integration between the current data management systems and shop floor in order to efficiently exploit real time data. This scenario should be possible in the Industry 4.0 era, which is a great opportunity for realizing sustainable industrial value creation on all three sustainability dimensions: economic, social and environmental [11][12]. Matsuda et.al [12] describe the digital eco-factory as a valid tool for the sustainable manufacturing. It allows simulating the manufacturing processes and assessing their green performances in addition to the productivity. Moreover, it could support the pre-assessment of the configuration of the production line in terms of cost and environmental aspects.

The smart manufacturing is a new paradigm that supports the decision process by making the information available and accessible at different level through the introduction of several ICT technologies. The energy management is one of the main aspects involved in this challenge [13]. For example, Wei et al. [14] developed an IoT-based energy management platform for industrial facilities, which offers a simple and common strategy for exchanging energy-related information between departments. They demonstrate how it allows reducing the overall cost by properly managing the energy demand. Vikhorev et al. [15] focused on processing and correlation of energy data, measured in real time, supporting the decision making process through their standardization for future analysis and visualization. Shrouf and Miragliotta [16] presented a framework for integrating measured energy data into production management process. However, manufacturing machines and equipment, which are responsible for most energy consumption, are not permanently metered. For this aim, many researchers paid attention to energy consumption estimation at a machine level. Wang et al. [17] established a four-layer energy assessment framework of machining workshop. Hu et al. [18] proposed a new on-line approach based on an energy consumption model of machine tool and developed an on-line energy efficiency monitoring system.

This approach is efficacious to carry out focused analyses, compare alternative production scenarios or validate an innovative solution, but it is not suitable for an overall energy efficiency analysis aimed to lead company strategies.

The literature on energy management in manufacturing has been thoroughly analyzed by May et al. [19], which investigated the main drivers, barriers and lines of research in the specific context. The authors highlight the need to enable the integration of information and processes to achieve the resources saving, the key role of ICT that facilitates the real time monitoring and decision making process and the importance of normative analysis. Moreover, they observed that the existing supporting tools and methods, despite their variety, are not used effectively in current enterprises.

In this context, the present paper addresses this issue by proposing a structured approach to support a proper data acquisition and management in order to plan energy efficiency strategies taking into account the policy issues. In particular, it aims to simplify the inventory phase, which is usually recognized as a resources-consuming activity, and integrate the normative aspects in the strategies definition, being one of the main drivers that can lead companies toward sustainable action plans.

3. Method

A method for a structured data acquisition phase is now shown. This method differentiates from the ones mentioned in the previous chapter because it does not only tend to measure parameters, it is innovation oriented. Indeed, if data on consumptions are necessary for performing previous method, this one will be valid even with poor raw data taken from the shop floor. What will change it is the dimension for the proposed action. Indeed, this method is aimed at defining effective action plans thorough an effective data inventory. Through the inventory method, data will be collected in a structured manner in order to identify all the features of a production plant with a specific focus on energy consumptions. First time data acquisition could be time consuming, depending on data already available. Anyway, the method could be very effective in a lifecycle perspective though a proper data storage. Applying this procedure few times during the life of the production system permits a fast data acquisition for the rest of the life of the plant. With a structured method, indeed, a proper energy efficiency plan should be guaranteed anytime. Decision makers, after the application of the method within a factory, will have the clear overview of the energy consumption within the plant and a set of possible solutions against inefficiencies. Boosting energy efficiency of a production site could mean to improve different aspects of a production (e.g., takt time, operations sequence, auxiliary systems management, etc.). Thus, decisions by the analysis should have multiple relapses then multiple responsible. The steps of the method are the following:

1. *Set boundaries and goal of the analysis.* This task is a crucial step of the analysis. The production planner should be the promoter of the analysis. In this part of the analysis targets need to be discussed between the board and the production manager. Expected results need to be shared in order to focus the attention on specific energy aspects.

2. *Create a work team.* An accurate analysis can be done only if different skills and views are shared within a transversal "work team". Know-how is important so the production manager has to involve different competencies to cover all the aspects related to the production system. For example, production planner, data analyst, energy manager and maintenance manager could be some of the figures to involve.
3. *Create an overall map of operations and energy flows.* The "map" will represent the as-is status of the production system, embedding information about energy consumptions. The form of the map could vary depending on company needs. A framework for mapping a process was shown by the author in a previous work [9]. This is not the only way to map a process. The only attention is to develop a clear and easily editable and readable map that embeds data effectively. The sub-tasks of this step are the following:
   a. *Identify general layout of the shop floor.* This step allows a first understanding of the production system where the analysis will be performed. All previous data and analysis made by the company in the past must be collected in order to exploit data already gained. Reports should have the form of plant technical draw, IDEF0 or any other document propaedeutic to the analysis.
   b. *Classify shop-floor asset.* This task consists in classifying company production operations and service systems. Energy vectors needed for operations must be specified. Data can be collected by previous documents or through a plant walk.
   c. *Classification of machineries*. Here a deep investigation on the asset should be performed following the previous task. Datasheets of all the elements of the company production asset should be collected. Project values have to be identified. A classification according to collected data is performed. For example, it could be useful to cluster machineries according to the different installed power.
   d. *Classify shifts and working hours*. A clarification of shifts is very important to identify possible energy leaks when production should be off. Shift influences the energy consumptions (e.g., illumination, heating). Thus, it is important to understand when and where workers populate the shop floor.
   e. *Identify production flows.* This step consists in understanding product flows through the plant. This data will permit a first allocation of consumptions when the consumptions trend will be available. Indeed, operation sequence should be clear for a proper alignment between hours and consumptions. As an example, if an electric energy peak is recurrent every 2 hours, the working team must be aware of what operations are ongoing at the same time. It is important to focus only on energy consuming activities.
4. *Analyze monthly energy bills.* This step depends on the typology of production analyzed. For continuous processes or mass production systems, the allocation of consumptions should be simpler than lean productions or niche production systems where production flows vary through days.
5. *High level matching between consumptions and machineries.* This step permits to match consumption trends with operations. Through this step a first overview on most impacting processes should be provided. Indeed, matching knowledge on working hours, machine project data, production flows and consumptions, a first complete energy consumptions state of the art should be defined.
6. *Mark main consumptions.* At this step a high-level problem analysis must be performed. Biggest criticalities of the production will here emerge. Those problems must become innovation opportunities.
7. *Check thresholds, energy constraints, and energy bonus.* This step is integrated into the method but does not depend on previous steps. Bureaucratic and financial aspects must be considered at this point. A deep analysis of documents must be performed. Documents to investigate are regional norms or international standards related to industrial energy management. This will permit to understand all the constraints taken into account while developing action plans toward energy efficiency. Bonuses are also an important part of the present steps. These needs to be analyzed to understand whether energy efficiency improvements can be encouraged by national bonus policies (e.g., White Certificates for Italy). These analyses should be performed in depth once in the life of the plant. Each plant will have its own rules and standard according to region or country. It is important to monitor new standards or bonus publication in order to upgrade the knowledge when new rules will be available.
8. *Plan innovation strategies.* This step could change the analysis perspective and targets. In compliance with point 4 here process innovation and strategies should be developed. Point 4, in fact, could move the attention of the work team to some process aspects where improvements are encouraged by norms or bonus. Multiple strategies could be planned toward a long-term energy efficiency optimization.

9. *Arrange a measurement campaign to understand daily consumptions*. Here, according to step eight, specific measurement will be done. Problems identified at a high level should be investigated in order to understand real consumptions and related costs.

Steps one to six are related to a general data inventory phase. The latter could be defined "fast" because no specific measurements on plant are needed. Those steps allow gaining a general scenario in order to describe the as-is of the plant. Steps seven and eight are related to strategies definition. There, possible opportunities from regional laws and bonuses are gathered with the potential of the company asset. Step nine is related to a specific inventory phase. The latter could be improved in the context of data digitalization through appropriate sensors on the plant. The more the data are acquired and classified, the more the analysis is complete.

After conducting the method, a clear state of the art about consumptions should be defined. This method is the baseline to define an effective strategy for improving production efficiency. The method facilitates action plans by decision makers. An implementation of the latter will upgrade the system with an update of the map (step 3). This method has not a specific duration and could be iterative. It is suggested to repeat steps periodically in order to promote a continuous company improvement. Next figure represents the flow of the method.

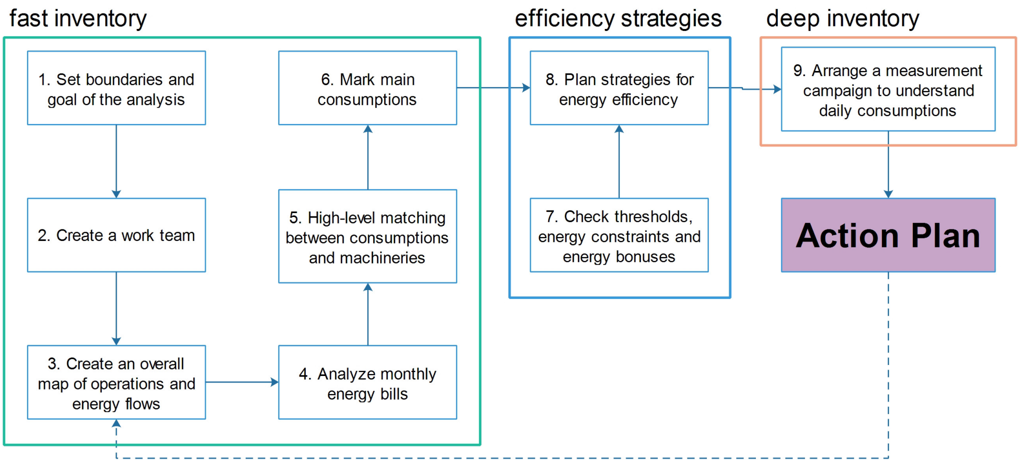

Fig. 1 Flow of the method

4. Case Study

The methodology proposed in this work has been implemented in a heat exchangers manufacturing company, located in central Italy. The objective of the analysis has been the reduction of running costs after a deep energy analysis. The only available data were the electricity and natural gas bills. No data acquisition was made previously.

1. System boundary considered for the analysis includes the energy consumption of the two main plants of the company. These are respectively the production site of heat exchangers and the separate site dedicated to components pressing. The goal was to collect data on energy consumption in a fast and organized way to carry out an energy audit and to assess the economic benefits of energy efficiency strategies.
2. After the definition of the objectives, according to the method, the work team has been created. It involved:
   - The Production Manager, during the process-mapping phase;
   - The System Manager, in the creation of the machinery database;
   - The Purchasing Manager, in finding information on energy supply contracts.
3. Once organized the teamwork, the production process has been mapped using the IDEF0 methodology. The latter can be used to analyze the functions the system performs and to record the mechanisms by which these are done [20]. The level of detail, with which the processes have been mapped, was such as to identify all the processes that require the use of machinery. In Fig. 2 the flushing process of a heat exchanger is shown.

Afterwards, a database containing all the machinery parameters involved in the operations has been created. It contains useful data for subsequent consumption estimation, such as installed capacity, working hours, and energy vectors exploited. For this purpose, manuals of machineries and plant technical projects of all the technical areas were collected. Table 1 shows an abstract of the database that has been created.

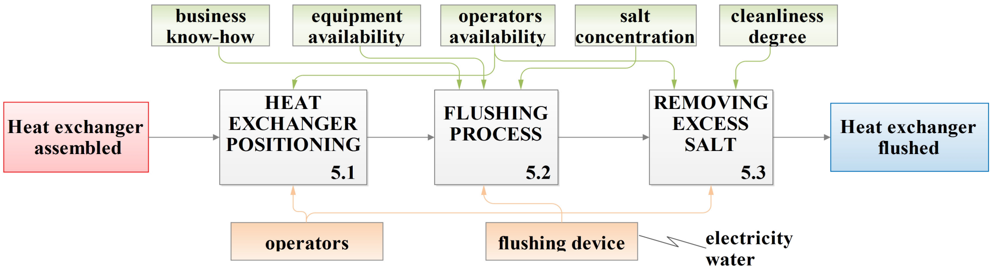

Fig. 2 Flushing process of a heat exchanger

Table 1 Machines database

Identification	Machine type	Installed power [kW]	Working hours [h]	Energy vector	Productive process
AL1644	Stacking device	70	16	Electricity	Stacking
AL1820	Industrial oven	200	24	Electricity Methane	Brazing
AL1844	Washing machine	50	16	Electricity Water	Washing
RM844	Press	7	8	Electricity Compressed air	Assembly

4. Subsequently, the monthly electricity and natural gas bills of the last two years were recovered in order to study the consumption trend and to compare it with the production values. For this case study, the trends consumption and production have the same trend throughout the year.
5. Following step consisted in comparing the consumption arising from bills with an estimated consumption of the machinery, calculated considering related operating hours and actual power demand. The assumption was evaluated by both the production manager and the system manager. To estimate machinery-working hours, production time of each component was compared with monthly production. At this stage, information of production process has been correlated with the machinery involved and the relative consumption was estimated to identify the energy-intensive processes that are the brazing and flushing of the heat exchangers.
6. Thanks to the previous step it has been possible to identify various inefficiencies of the plant such as the failure to recover heat from the brazing smokes and the obsolescence of compressed air system and pumping system, in addition to the total lack of energy meters.
7. An analysis of the current legislation and opportunities for industries was performed. Through a preliminary screening, three savings opportunities were identified. These are listed as follows: (i) exemption of excise duty thanks to certain processes; (ii) obtaining white certificates (TEE) improving obsolete machineries; (iii) installation of energy meters to obtain the ISO 50001 certification.
8. A comparison between opportunities and specifics of production processes allowed the identification of processes and machineries on which the attention should be focus in order to reduce current inefficiencies. The common approach to achieve all the opportunities is related to the measurement of the energy vectors, and related data modelling. Then, an evaluation of all data collected is performed to understand real efficiency opportunities. This will lead to a fast development of effective action plans. To proceed with the efficiency strategies, data from machine database were collected. Data to be considered are those mentioned by the standards (e.g. specific energy consumptions).
9. The last step consists in defining parameters to be measured. The latter should be collected through structured

measurement campaign.

5. Results and discussion

Results of the case study are now presented. Considering the method, the case study concludes at step eight. However, thanks to the method, efficiency strategies were carried out even at this stage. Significant results can be gained without completing the method. The scalability of the latter is one of the strength of the proposed methodology. With the completion of the method it is possible to develop more specific plans. A consistent measurement campaign was planned and is actually on going (step 9). Strategies supposed are summarized in Table 2.

Table 2 Strategies available

Process	Goal	TEE	Excise exemption	Energy vector
Brazing	Heat recovery from waste smokes	X		Electricity Methane
Assembly	Add inverters to the compressors	X		Electricity
Flushing	Add inverters to the pumps	X		Electricity
Pressing	Excise recovery to the bills		X	Electricity
Heat exchangers production	ISO 50001 certification			Electricity Methane

To validate strategies, different scenarios were investigated. These should eliminate problems and achieve the mentioned goals:

- in the brazing oven, the missing recovery of the heat of smokes, resulting from the aspiration system, generates leaks. Therefore, a measurement campaign was scheduled to evaluate the dispersed calories;
- the compressors in the technical rooms are outdated and do not have an inverter. Hence an electricity meter was implemented to assess the compressed air demand and to evaluate gains with an upgrade with inverter;
- the pumping system for the oval cooling system and for flushing machine has the same problem of the compressors room. Electrical energy meters were applied to evaluate the possible implementation for the benefit of an inverter;
- a structured and correct acquisition of data was planned. Data to be collected are: energy consumptions, machinery features, and production value. These should be correlated with each other for future energy analysis;
- counters of electric power were applied to map the energy flows. All plant production lines, classified by product, will be monitored;
- in the pressing site, since the totality of consumptions were related to the pressing operations, it was quantified a recovery of excise duties of 10% on energy costs.

Some of these scenarios were already implemented and advantages were measured. Those scenarios confirm the effectiveness of the method. Indeed, without a structured method, all these strategies are unknown for a company. After this study, some of the above-mentioned actions have been already implemented within the plant, meaning a reduction of consumptions and the achievements of bonuses by the Italian laws. Then, it could be stated that the method should be considered valid. In fact, a correct application of the latter drives decision makers toward good solutions for energy waste.

Two main features of the developed method are flexibility and scalability. If a company has already achieved one or more objectives of the constituent phases, the method can be implemented starting from the previous knowledge, without repeating performed phases (e.g. starting from step 7), and giving the opportunity to companies to conduct a study on their energy consumption.

6. Conclusions

The purpose of this work is to propose a method for the collection and organization of data through a fast and simplified procedure, with the aim of planning strategies toward energy efficiency. The method allows companies, both large and small, to implement an energy audit by considering the regulations and opportunities for incentives. The method suggests how to exploit information already available, but not organized, and how to acquire new data in an efficient way. The iteration of the method encourages the implementation of the continuous improvement process towards more sustainable plants from an environmental and economic perspective.

As demonstrated by the case study, the method supported a heat exchangers company to identify some opportunities for: improving the energy efficiency of its processes, obtaining certifications, and receiving financial benefits. Future works will be proposed for a complete method validation. The latter will report the measurement campaign results and related efficiency actions that will be more specific, according to data quality.

Future developments will focus on the automation of data management by implementing on-board sensors and developing a dedicated tool to support the acquisition and elaboration of data. It will aim to provide an update mapping of energy flows to make companies easily and constantly aware about current inefficiencies. Moreover, social aspects will be included in the approach through the identification and monitoring of those variables, also related to energy consumptions, that should influence the worker on a plant level (e.g. temperature, humidity, luminance, etc.).

References

[1] U.S. Department of Commerce, Sustainable Manufacturing Initiative (SMI) and Public Private Dialogue, 2010.
[2] C. Schmidt, W. Li, S. Thiede, B. Kornfeld, S. Kara, C. Herrmann, Implementing Key Performance Indicators for Energy Efficiency in Manufacturing, Procedia CIRP 57 (2016) 758–63.
[3] K. Bunse, M. Vodicka, P. Schönsleben, M. Brülhart, F.O. Ernst, Integrating Energy Efficiency Performance in Production Management – Gap Analysis between Industrial Needs and Scientific Literature, Journal of Cleaner Production 19 (2011) 667–79.
[4] ISO 50001:2011 Energy Management System, International Organization for Standardization, Geneva.
[5] Legislative Decree 2 February 2007 n. 26, Implementation of Directive 2003/96 / CE restructuring the community framework for the taxation of energy products and electricity
[6] Federal Energy Management Program's (FEMP) Energy Incentive Program, 42 USC 8253 : Energy management requirements, 2017
[7] A. Cherrafi, S. Elfezazi, A. Chiarini, A. Mokhlis, K. Benhida, The Integration of Lean Manufacturing, Six Sigma and Sustainability: A Literature Review and Future Research Directions for Developing a Specific Model, Journal of Cleaner Production 139 (2016) 828–46.
[8] A.L. Helleno, A.J. Isaias de Moraes, A.T. Simon, Integrating Sustainability Indicators and Lean Manufacturing to Assess Manufacturing Processes: Application Case Studies in Brazilian Industry, Journal of Cleaner Production, 2016.
[9] F. Gregori, A. Luzi, A. Papetti, M. Germani, F. Camorani, An Innovative Tool to Monitor and Represent Energy Value Stream of a Production System, in Volume 4: 21st Design for Manufacturing and the Life Cycle Conference; (ASME, 2016).
[10] A. Khan, K. Turowski, A Perspective on Industry 4.0 : From Challenges to Opportunities in Production Systems (2016) 441–48.
[11] T. Stock, G. Seliger, Opportunities of Sustainable Manufacturing in Industry 4.0, Procedia CIRP 40 (2016) 536–41.
[12] M. Matsuda, F. Kimura, Usage of a Digital Eco-Factory for Sustainable Manufacturing, CIRP Journal of Manufacturing Science and Technology 9 (2015) 97–106.
[13] H.S. Kang, J.Y. Lee, S. Choi, H. Kim, J.H. Park, J.Y. Son, B.H. Kim, S.D. Noh, Smart Manufacturing : Past Research, Present Findings, and Future Directions 3 (2016) 111–28.
[14] M. Wei, S.H. Hong, M. Alam, An IoT-Based Energy-Management Platform for Industrial Facilities, Applied Energy 164 (2016) 607–19.
[15] K. Vikhorev, R. Greenough, N. Brown, An advanced energy management framework to promote energy awareness, Journal of Cleaner Production 43 (2013) 103-112.
[16] F. Shrouf, G. Miragliotta, Energy management based on Internet of Things: practices and framework for adoption in production management, Journal of Cleaner Production 100 (2015) 235-246.
[17] Q. Wang, F. Liu, C. Li, An integrated method for assessing the energy efficiency of machining workshop, Journal of Cleaner Production 52 (2013) 122-133.
[18] S. Hu, F. Liu, Y. He, T. Hu, An on-line approach for energy efficiency monitoring of machine tools, Journal of Cleaner Production 27 (2012) 133-140.
[19] G. May, B. Stahl, M. Taisch, D. Kiritsis, Energy Management in Manufacturing: From Literature Review to a Conceptual Framework, Journal of Cleaner Production, 2016.
[20] National Institute of Standards and Technology (NIST), Integrated Definition for Function Modeling (IDEFØ). Gaithersburg: Federal Information Processing Standards Publications (1993).