Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 43 (2020) 56–63

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

17th Global Conference on Sustainable Manufacturing

An energy assessment method for SMEs: case study of an Italian mechanical workshop

Roberto Menghi[a]*, Giulia Di Domizio[a], Alessandra Papetti[a], Michele Germani[a], Marco Marconi[b]

[a] *Department of Industrial Engineering and Mathematical Sciences – Università Politecnica delle Marche, Via Brecce Bianche, Ancona 60131, Italy*

[b] *Department of Economics, Engineering, Society and Business Organization – Università degli Studi della Tuscia, Largo dell'Università, Viterbo 01100, Italy*

Abstract

Nowadays, climate change requires companies to reduce their energy consumption and make their production systems more efficient. However, the complexity of the methodologies, the lack of transparency or high efforts (personnel/time) make this challenge especially difficult for SMEs. In this context, the present paper proposes a workflow to supports SMEs in a lean energy analysis. Through the implementation of several methodologies, a comprehensive assessment of energy consumption was carried out. The application to a real case study allowed to identify energy inefficiencies and to evaluate the energy saving and performance improvement actions.

Keywords: Energy efficiency assessment; Lean analysis; Manufacturing systems; SME.

1. Introduction

The UN Intergovernmental Panel on Climate Change (IPCC) has reported that the Earth's climate system is getting warmer and predicted an increase of 1.5 degrees Celsius in the global average temperature above pre-industrial levels as early as 2030 [1]. Being responsible for about one third of total final consumption of all fuels [2], the manufacturing industry needs to support the sustainable development by reducing energy consumption and improving efficiency.

For small and medium-sized enterprises (SMEs), energy management is still an unresolved issue due to competing priorities, lack of appropriate methodologies and scarcity of specialist knowledge and financial resources [3]. However, significant savings can be achieved when companies take the time to analyze their energy consumption.

10.1016/j.promfg.2020.02.107

The knowledge of the types and the amount of energy employed by the company's equipment and facilities represents a significant step towards improving energy efficiency [4].

In this paper, a workflow to support SMEs in a lean energy analysis together with the main findings related to an energy assessment carried out for an Italian small enterprise, are reported. The analyzed factory is specialized in the production of heat generators, steam producers and heat exchangers. A new methodology is also introduced to simplify the energy audit tasks. It is based on the application of different methodologies and employs data related to asset characteristics and production process. In addition, the method allowed identifying inefficiencies in the plant caused by mismanagement of the electrical energy and the economic and technical impacts evaluation related to the implementation of the corrective actions.

Research context and methods mainly used for assessing the sustainability of a manufacturing process in terms of energy consumption are described in detail in Section 2. Section 3 describes the proposed method to help SMEs in energy analysis providing qualitative and quantitative feedback to improve the manufacturing process efficiency. Section 4 presents the case study in which the method is applied, and Section 5 closes the paper with conclusions.

2. Research background

The release of the ISO 50001 standard has established the requirements and guidelines for energy management systems [5]. Although the standard should guide the implementation of efficiency practices, it is considered to be unsuitable for SMEs. Often, it is too detailed, exhaustive and over-engineered for small enterprises [6]. The ISO 50001 has been primarily designed for larger companies with large amounts of available resources and the simply scaling down solutions of larger firms remains an inappropriate approach for SMEs [7]. In addition, energy management activities require a considerable amount of time and significant capital investments due to necessary technological upgrades, certification costs and external supports. The lack of human and technical resources is another significant barrier to the adoption of energy management policies [8]. In this context, academics and professionals have sought to develop efficient, reliable methods and tools suitable for small businesses. Kannan and Boie [9] have proposed a simplified method for energy audit using the rated power of equipment and number of operating hours, rather than onerous measurement campaigns. A similar approach is applied by Gazi et al. [10] who assessed the energy efficiency of a typical European marble mining and processing SME. The method determines the specific energy consumption and, through analysis of different operational scenarios, identifies the processes with the highest energy consumption. Cosgrove et al. [4] have presented a methodology for energy evaluation in SMEs based on a simplified audit and use of aggregated data.

Methods for the analysis and modelling of energy flows within industrial processes have also been developed. An example is the energy flow analysis (EFA) [11] that allows investigating the energy consumption in a production system. This method allows analyzing the input/output relationships of production processes and providing a structured approach to identify energy hotspots in a factory. Another method is the material and energy flow analysis (MEFA) [12], which examines material and resource flows in addition to energy flows. Kluczek [13] has combined MEFA with the best available techniques. This methodology allows selecting the best strategy to improve energy efficiency starting from the evaluation of energy and material flows.

Other authors have developed methods and tools based on the lean methodology and inner logic of value stream mapping (VSM). Starting from the VSM, Muller et al. [14] and then Posselt et al. [15] presented the energy value stream mapping (EVSM), a method that correlates energy consumption with the value-added and non value-added activities. Li et al. [16] simplified the EVSM by using aggregated data and the Sankey diagram visualization, whereas other authors have incorporated VSM with both the assessment of energy flows and the material consumption or economic considerations [17, 18]. According to the plan-do-check-act cycle (PDCA), Thiede et al. [19] presented a method dedicated to SMEs for the systematic and continuous improvement of energy and resource efficiency. Table 1 gives an overview and relative comparison of the methods discussed above. From the literature review emerged that none of the analyzed methods and tools completely fulfil the identified criteria.

In particular, only few methods require low effort in terms of knowledge and time. Although these methods can be easily implemented by a SME, they do not correlate energy consumption with production data and often use aggregated data. As a result, the energy analysis is too simplified and does not allow the identification of energy saving actions. Moreover, the use of aggregated data, such as the rated power of machines, generates an overestimation of energy consumption. On the other hand, there are methods that correlate detailed energy data with production data using metering and sensing equipment. They often employ energy performance indicators (EnPI) and allow to identify the most inefficient sectors of the production system. However, the complexity of such methodologies and the investment costs prevent the real application in SMEs.

Table 1. Relative comparison of method.

	Energy data		Production data	EnPI	Improvements	Low effort
	aggregate	detailed				
Alvandi et al. [17]	✓	-	✓	-	-	-
Cosgrove et al. [4]	-	✓	-	✓	-	-
Gazi et al. [10]	✓	-	-	✓	-	-
Kannan and Boie [9]	✓	-	-	✓	-	✓
Kluczek [13]	✓	-	-	-	✓	-
Li et al. [16]	✓	-	✓	-	-	✓
Müller et al. [14]	-	✓	✓	-	-	-
Posselt et al. [15]	-	✓	✓	-	-	-
Schmidt et al. [18]	✓	-	✓	-	-	-
Smith and Ball [12]	✓	-	-	-	-	✓
Thiede et al. [19]	-	✓	✓	-	-	-
Torres et al. [11]	✓	-	-	-	-	✓

To address the above-mentioned limitations, this paper proposes a new methodology to simplify the energy assessment for SMEs, by using internal capabilities and taking into account prevailing resource limitations. It also supports the definition of the action plan and the evaluation of the economic and technical impacts of corrective actions.

3. Method

The proposed method aims to help SMEs in energy analysis providing qualitative and quantitative feedbacks to improve the manufacturing process efficiency.

The procedure to be followed for the energy assessment is composed by five steps, detailed below:

- *Step 1* consists in the definition of the objectives and system boundaries of the energy audit, together with a visit of the factory where all necessary data and documents are collected. In detail, plant layout, processes, list of machinery, the rated power, the processing activities and times of each machine involved in the manufacturing system need to be collected.

- *Step 2* allows reducing the significant discrepancy between the energy consumption calculated through the rated power value and the actual value of the power absorbed during the machining phases, by introducing corrective factors on the most energy-consuming machines.
  In detail, the energy consumption of each equipment is calculated, and the most energy consuming machines are identified through a Pareto analysis (i.e. those that consume 80% of the total energy consumption). Corrective factors are then applied to the power ratings of the identified machines, so as to improve the accuracy of the energy assessment. They are established according with the study presented by Di Domizio et al. [20] and depend on the characteristics of machines, their use (which includes working times, operating methods and set-up) and production data (which depend on the production volume and the characteristics of the product, such as dimensions and material). The energy consumption of the most energy-consuming machine (EC_m) can be recalculated as follows:

$$EC_m\ [kWh] = P_{rated} \times F_w \times \{n_{pieces} \times [(F_{sb} \times t_{sb}) + (F_p \times t_p)] + [F_{sb} \times (t_{totalhours} - t_{workinghours})]\}$$

  where P_{rated} is the rated power of the machine; F_w is the corrective wear factor; F_{sb}, F_p are the corrective absorption factors respectively related to stand-by and machining phase; t_{sb}, t_p are respectively the stand-by and machining times in a working cycle; $t_{totalhours}$ is the time work shift; $t_{workinghours}$ is the time working hours by order [h]; n_{pieces} is the number of pieces produced by the machine in the analyzed time frame; more detailed information about this step can be found in Ref. [20] .

- *Step 3* implements the principles of the lean methodology [21] into the energy analysis. At first, the activities are classified as: (a) value-added activities (VA), which refer to operations that are necessary to realize the product; (b) non value-added activities (NVA), which include operations that are necessary but do not transform the product and (c) waste activities (W), which include operations that do not transform the product and are unnecessary. Afterwards, the energy data collected and processed in the previous steps are correlated to the type of activity. A map of the manufacturing process is then drawn up, containing information on energy consumption and highlighting the components of VA, NVA and W. The map, called Resources Value Mapping [22], consists of process boxes that show the percentages of energy consumed by VA, NVA and W activities and two indicators. The first index (Cost Index - CI) allows identifying which process is responsible of the highest cost related to energy consumptions as follows:

$$CI = \sum c * (E_{VA} + E_{NVA} + E_W) \qquad [€/month]$$

The second index (Muda Index - MI) allows quantifying the cost of energy not related to VA activities. The more the MI value is higher, the more corrective actions are needed for the considered process [20]. It can be recalculated as follows:

$$MI = \sum c * (E_{NVA} + 2\, E_W) \qquad [€/month]$$

where c is the unitary cost of the energy, E_{VA} is the amount of energy consumed by VA activities, E_{NVA} is the amount of energy consumed by NVA activities and E_W is the amount of energy consumed by W activities.

- *Step 4* aims to define an action plan to eliminate W consumption, reduce the consumption of NVA energy and maximize the energy efficiency of VA activities. This approach allows to reduce the amount of energy used for non-value generating activities. In this way, SMEs can increase overall economic competitiveness by reducing production costs and their contribution to greenhouse gases emissions (if energy is produced by non-renewable sources) and resource scarcity. Through the map and the analysis of the MI index, the high-priority machines and/or critical processes in terms of energy efficiency are identified. In detail, for each equipment/department with a high MI value, the highest energy components of NVA and W are investigated. The assessment of the components allows to identify the sources and reasons of such inefficiencies, and then, for each of them, a series of corrective actions must be determined. Improvements are defined on the basis of the national and international available databases, such as Best Available Techniques Reference documents (BREFs) [23] and IAC Recommendation [24], preferring actions with high impact levels and that require low investment costs.

- *Step 5* enables to evaluate the economic and technical/environmental impacts of the corrective actions and help the decision-makers in the selection of actions to be implemented. In particular, once the energy saving action plan has been identified, a technical and financial evaluation of the chosen proposal should be carried out. Several evaluation methodologies are available, ranging from the simplest ones that foresee the modification of the production management policy, to the most complex ones for the evaluation of corrective actions related to equipment [25]. In the first class (e.g. switch-off the machine during standby, modify the scheduling), the evaluation considers the generated energy savings together with any possible drawbacks. In the latter (e.g. replacement of machines or parts of them), the evaluation examines the total economic value of the investment in comparison with the generated energy savings. The assessment of the economic impact has to consider the cost of the investment (e.g. design, purchase, installation), the running cost (e.g. operating cost, energy consumption, maintenance, depreciation), as well as the costs related to the end of life [26].

4. Case study

The method has been experimented in collaboration with an Italian mechanical engineering manufacturer that deals with design and construction of heat generators, steam producers and heat exchangers. The application of the method allowed carrying out the energy analysis of the factory related to a period of one year. Thanks to this analysis it was possible to underline energy inefficiencies and then present proposals for improvement.

The first phase has provided the goal and boundaries definition. The goal of our study is the energy sustainability [27], analyzing the production area and his energy consumption linked to the electricity vector. As a result, it has been required to have an overall vision of the plant to understand the available machineries, their allocation and how the energy vector is used within the plant. The successive step has been the collection and classification of the data. Like several SMEs the only data available were: nominal power, working time, set-up time, stand-by time, preventive maintenance time and corrective maintenance time. Thanks to this data it was possible to derive the first energy consumption estimation for each machinery, necessary to create a Pareto chart (Fig. 1) and identify the machinery responsible for the 80% of the total factory energy consumption.

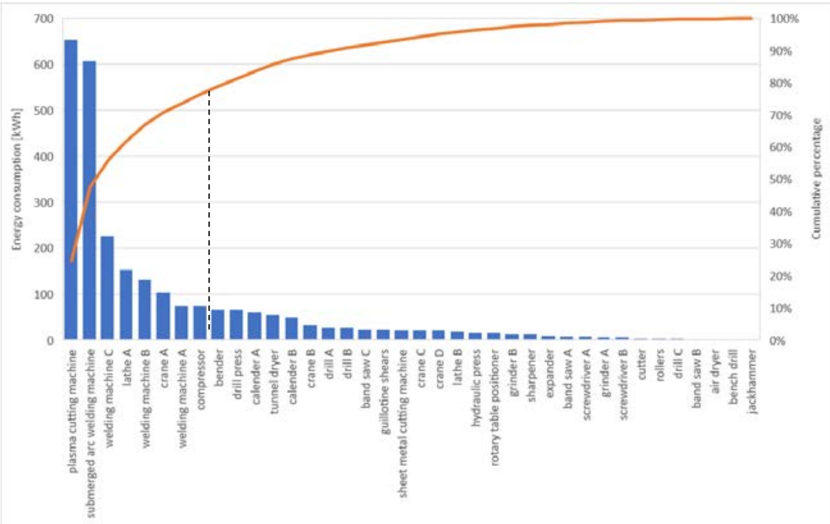

Fig 1. Pareto chart related to case study

From this first analysis the most energy-intensive machines were identified, and the corrective factors were applied to them. They have been set based on machine characteristics, machine use and production data and are summarized in Table 2.Thanks to this correction, the factory's energy consumption was recalculated and it emerged that the percentage error between the calculated energy consumption and the bill's consumption has been reduced (Table 3). As a result, an energy analysis closer to the reality was obtained without the need of a measurement campaign.

Table 2. Corrective factors of the case study

Machines	F_w	F_{sb}	F_p
Compressor	-	0,500	1,00
Crane A	1,20	0,020	0,66
Lathe A	1,20	0,029	0,66
Plasma cutting machine	1,18	0,510	0,72
Submerged arc welding machine	1,20	0,029	0,66
Welding machine A	1,20	0,029	0,66
Welding machine B	1,20	0,029	0,66
Welding machine C	1,20	0,029	0,66

Successively, the analysis of the production flow allowed classifying each activity. In particular: actual working operations as VA; workpiece handling operations, machine tooling both when running and in stand-by, new arrangement of the piece on the machinery (in the case of mobile machinery), handling of the equipment with respect to the piece and preventive maintenance operations as NVA; and incorrect movements made when fixing the piece on the machinery and corrective maintenance actions as W.

Table 3. Factory annual energy consumption.

Energy consumption from electricity bill	Energy consumption based on rated power	Energy consumption based on rated power and corrective factors
20887,2 kWh	31801,2 kWh	23361,24 kWh
-	+ 52,2%	+ 11,8%

Thanks to this classification it was possible to split the overall energy consumption of the machinery among the activities. In the present case study, the factory is composed by nine lines, each of them with particular equipment, and the consumption of all activities was calculated by lines, as reported in the Resource Value Mapping (Fig 2). This latter includes the process boxes with the calculated values for the Cost and Muda Indices, showing how each process contributes to the energy consumption.

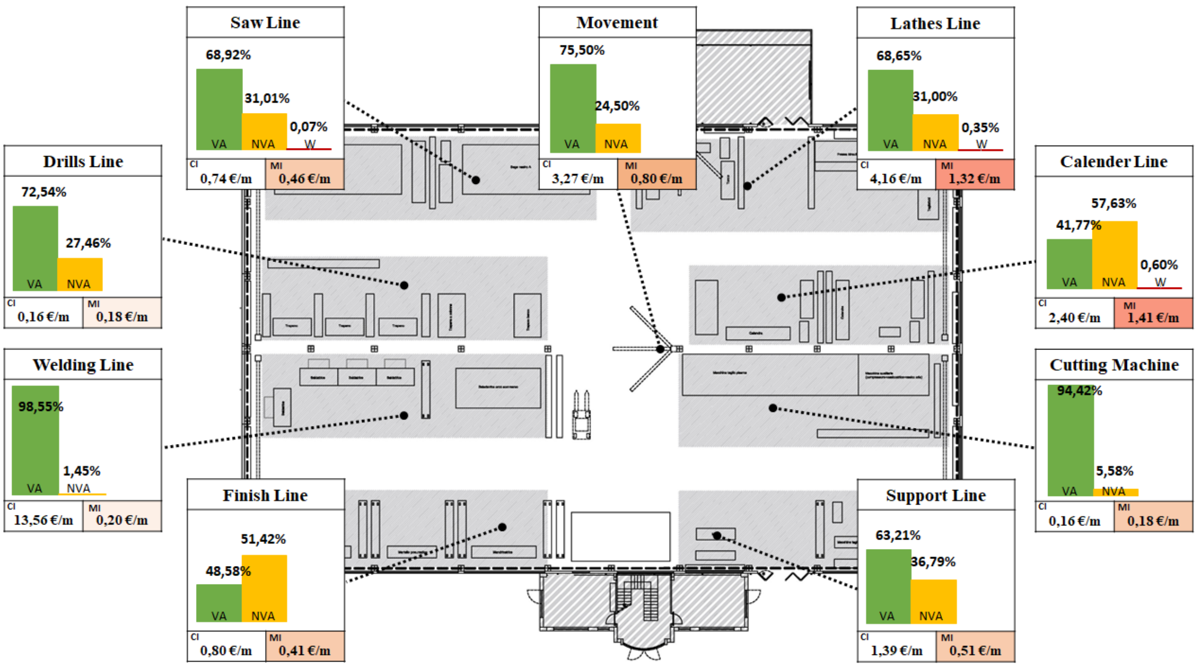

Fig 2. Resource Value Mapping

An ideal process would be marked only by VA activities. However, in the reality the scenario is different, and it is necessary to create an action plan to eliminate the W activities and to reduce the NVA ones. In detail we can see how each line presents different contributions of VA, NVA and W energy. In particular, the calendering and lathes lines presented high values of non value-added energy, components of waste energy and the most important values of MI. This is the reason why the action plan has been focused on these two lines.

In the lathes line, the lathe A was subject to frequent interruptions that did not guarantee the respect of delivery times agreed in the contracts stipulated with customers. For this reason, the company decided to intervene with a new management policy that provides to purchase semi-finished parts (already turned) from external suppliers. This solution has been implemented after a positive comparison between the actual production cost and outdoor production cost and brings to a lower value of MI. Instead, on the second lathe (lathe B) the implemented corrective action has been the reduction of stand-by time, taking the machine on OFF mode during the breaks. It leaded to an annual energy saving of about 624 kWh with a resulting economic saving.

	Actual calender cost			Solution C1 cost			Solution C2 cost		
	h	kWh	Cost [€]	h	kWh	Cost [€]	h	kWh	Cost [€]
Energy	80	42.0	672.0	80	18.4	294.2	80	11.0	176.5
Maintenance (fixed)	-	-	5000.0	-	-	-	-	-	-
Maintenance	10	42.0	84.0	-	-	-	-	-	-
Set-up	10	42.0	84.0	10	18.4	36.8	10	11.0	22.1
Stand-by	40	8.4	67.2	40	3.6	28.8	40	2.3	18.1
Lost production	55	-	2750.0	-	-	-	-	-	-
TOTAL			8657.2			359.8			216.7

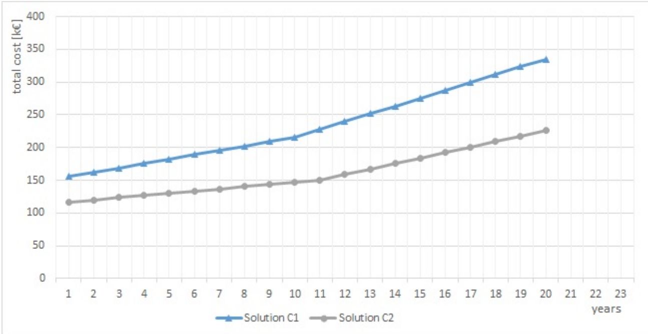

Fig 3. left: Comparison between different calender solutions; right: TCO chart

In the calendering line the intervention focused on the machine which has undergone more maintenance interventions. The implemented action consisted in the machine replacement, and the choice of the new machine was driven by a TCO model [24].

In the TCO analysis two machines of the same type proposed from different suppliers, were compared. The best solution to adopt has been chosen comparing the annual costs of the actual and new calendering machines. Figure 3 reports this comparison. The direct and indirect costs over the machine's useful life have been calculated, to determine the best solution. The two lines never intersect, meaning that there is a technology more advantageous than the other. Indeed, the purchase cost of one machine is far less than the other, like the costs of annual years are lower.

Finally, the choice of installing two calenders, which start with a lower purchase cost and over the years have lower operating values, was evaluated. Thanks to two distinct machines, the company can carry out several processes at the same time, since a calendering machine could be used for the processing of harder materials, while the other one for more common metals. However, this solution was not finally implemented due to the high initial investment required for the purchase of two machines. However, the company will evaluate this possibility during the next years.

5. Conclusion

The paper effectively integrates multiple methodologies to support SMEs in improving their energy efficiency. It tries to overcome the main obstacles and barriers related to the energy assessment process that emerged in the research context analysis. It does not require investment in technology and capital and, the effort in terms of time and human resources is reduced. In particular, the proposed method requires few data as input that are usually collected by all companies (i.e., machines' nominal power, working time, maintenance interventions), simplifying the inventory phase. The use of corrective factors allows improving the allocation accuracy of energy consumptions resulting from the bill and makes measurement campaigns unnecessary. The construction of the Resource Value Mapping favors an easy identification of the most energy intensive processes and the definition of the most proper action plan.

The case study demonstrated the method applicability in a small enterprise that produces heat generators, steam producers and heat exchanger. It allowed identifying the most critical lines from an energetic point of view (i.e. calender and lathes) and evaluating possible intervention strategies also from the economic perspective. Although the energy consumed by NVA and W activities have been significantly reduced, wide margins for improvement still exist. Indeed, further analyses should carry out to identify hidden wastes. It is obviously due to the trade-off between a simplified analysis and its level of detail.

Further works will be conducted to improve and automate the energy assessment method. In detail, the phase of identifying corrective actions will be automated to make the process simpler and easier to use for SMEs. Furthermore, the method will be implemented in a software tool to support the user in data management, index calculation and automatic generation of resource value maps.

References

[1] IPCC (Intergovernmental Panel on Climate Change), Global warming of 1.5◦C, Summary for Policymakers (2018).
[2] IEA (International Energy Agency), World energy outlook, International Energy Agency, Paris (2013).
[3] A. Trianni, E. Cagno, S. Farné, Barriers, drivers and decision-making process for industrial energy efficiency: A broad study among manufacturing small and medium-sized enterprises, Applied Energy, 162 (2016) 1537-1551.
[4] J. Cosgrove, F. Doyle, J. Littlewood, P. Wilgeroth, A methodology for electricity monitoring and targeting (M&T) in an Irish precision engineering SME, International Journal of Sustainable Engineering, 10 (2017) 233-240.
[5] ISO 50001:2018 – Energy Management System, International Organization for Standardization, Geneva (2018).
[6] M. P. Johnson, Sustainability management and small and medium-sized enterprises: Managers' awareness and implementation of innovative tools, Corporate Social Responsibility and Environmental Management, 22 (2015) 271-285.
[7] M. Richert, An energy management framework tailor-made for SMEs: Case study of a German car company, Journal of Cleaner Production, 164 (2017) 221-229.
[8] V. Biondi, M. Frey, F. Iraldo, Environmental management systems and SMEs, Greener Management International, 29 (2000) 55-69.
[9] R. Kannan, W. Boie, Energy management practices in SME—case study of a bakery in Germany, Energy Conversion and Management, 44 (2003) 945-959.
[10] A. Gazi, G. Skevis, M. A. Founti, Energy efficiency and environmental assessment of a typical marble quarry and processing plant, Journal of Cleaner Production, 32 (2012) 10-21.
[11] M. T. Torres, M. C. Barros, P. M. Bello, J. J. Casares, J. M. Rodriguez-Blas, Energy and material flow analysis: Application to the storage stage of clay in the roof-tile manufacture, Energy, 33 (2008) 963-973.
[12] L. Smith, P. Ball, Steps towards sustainable manufacturing through modelling material, energy and waste flows, International Journal of Production Economics, 140 (2012) 227-238.
[13] A. Kluczek, Application of best available techniques in an enterprise producing heating devices, Journal of Cleaner Production, 83 (2014) 444-453.
[14] E. Müller, T. Stock, R. Schillig, A method to generate energy value-streams in production and logistics in respect of time-and energy-consumption, Production Engineering, 8 (2014) 243-251.
[15] G. Posselt, J. Fischer, T. Heinemann, S. Thiede, S. Alvandi, N. Weinert, S. Kara, C. Hermann, Extending energy value stream models by the TBS dimension–Applied on a multi product process chain in the railway industry, Procedia CIRP, 15 (2014) 80-85.
[16] W. Li, S. Thiede, S. Kara, C. Hermann, A Generic Sankey Tool for Evaluating Energy Value Stream in Manufacturing Systems, Procedia CIRP, 61 (2017) 475-480.
[17] S. Alvandi, W. Li, M. Schonemann, S. Kara, C. Hermann, Economic and environmental value stream map (E2VSM) simulation for multi-product manufacturing systems, International Journal of Sustainable Engineering, 9 (2016) 354-362.
[18] M. Schmidt, C. Raible, R. Keil, M. Graber, Energy and material stream mapping, Recovery of Materials and Energy for Resource Efficiency. Davos 7 (2007) 1-5.
[19] S. Thiede, G. Posselt, C. Herrmann, SME appropriate concept for continuously improving the energy and resource efficiency in manufacturing companies, CIRP Journal of Manufacturing Science and Technology, 6 (2013) 204-211.
[20] G. Di Domizio, R. Menghi, A. Papetti, M. Germani, M. Marconi, A method for lean energy assessment of manufacturing systems, Procedia CIRP, 81 (2019) 1447-1452.
[21] T. Ohno, Toyota production system: beyond large-scale production, CRC Press, 1988.
[22] A. Papetti, R. Menghi, G. Di Domizio, M. Germani, M. Marconi, Resources Value Mapping: a method to assess the resource efficiency of manufacturing systems, Applied Energy, 249 (2019) 326-342.
[23] The European IPPC Bureau, Reference documents under the IPPC Directive and the IED, http://eippcb.jrc.ec.europa.eu/reference/, accessed on 3 May 2019.
[24] IAC University, IAC: Industrial Energy Assessments, https://iac.university/recommendationTypes, accessed on 3 May 2019.
[25] T. Fleiter, S. Hirzel, E. Worrell, The characteristics of energy-efficiency measures–a neglected dimension, Energy Policy, 51 (2012) 502-513.
[26] L. M. Ellram, Total cost of ownership: an analysis approach for purchasing, International Journal of Physical Distribution & Logistics Management, 25 (1995) 4-23.
[27] A. R. Neves, V. Leal, Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework, Renewable and Sustainable Energy Reviews, 14 (2010) 2723-2735.