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A systematic method for increasing the energy and resource efficiency in manufacturing companies

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Abstract

Consciously considering the energy and resource consumption is of rising interest in manufacturing companies. However, especially in small and medium sized enterprises (SME) the target-oriented implementation of promising measures is impeded by different obstacles such as unattractive amortization times, lack of transparency or high efforts (personnel/time). Against this background, a guided method for the systematic identification of most promising improvement potentials is suggested in the paper. Based on a so called energy portfolio it allows the classification and prioritization of energy consumers in the company and the derivation of target-oriented action plans towards energy and resource efficiency improvement.

Keywords: Energy Efficiency, SME; Manufacturing Companies; Energy portfolio

1. Introduction

Without a doubt, the issue of energy and resource efficiency is of increasing relevance in manufacturing companies. Rising energy and resource prices are exerting strong cost pressure and diverse stakeholders (e.g. customers, shareholders) are interested in consciously analysing and improving the environmental impact of products and processes. On the one hand, different studies underline the significant potential for improving the energy and resource efficiency in manufacturing companies – certain numbers range from 10-40% of possible savings which can be achieved even with available technology [1] [2] [3]. On the other hand, other studies based on comprehensive surveys highlight that there are - specifically for small and medium enterprises (SME) - strong obstacles which impede a broad implementation of promising measures [4] [5] [6] [7]:

- relatively high investments for efficient technologies and still relatively low level of energy prices may lead to unattractive (long) amortization time
- lacking access to necessary capital for implementing energy efficiency measures
- no resources in terms of personnel and time for energy efficiency measures as well as lacking organisational responsibility
- typically restricted transparency regarding the energy consumption in the company - main consumers are rarely known and the topic as a whole is too complex or assumed to be too complex.
- lack of detailed knowledge of energy efficiency measures
- concern about potential negative influences on general production performance
- transferability and suitability of energy efficiency measures from literature are hard to determine beforehand for the specific case of a company

Against the background of existing potentials but also barriers for improvement there is a need for an easy-to-handle and systematic method which allows a fast and reliable identification of energy consumption drivers and related measures for improvement. Specifically for SME

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this would be extremely helpful in order to overcome several of the aforementioned obstacles. Without having the necessary detailed background knowledge such a method would allow a target-oriented consideration of the most relevant energy consumers. Furthermore, an appropriate method accelerates the continuous improvement cycle and fosters focusing efforts on promising fields of action with high leverage and low payback period.

2. Energy consumption in manufacturing companies

2.1. Basics

Energy is “the inherent ability of a system to generate external impact” [8] and necessary to execute any kind of designated tasks. Energy (E) is a state variable which is connected with Work (W) as process variable – as shown in equation (1) Work (W) is composed of Power (P) as the rate of energy usage and time (t).

$$W = P * t \quad (1)$$

As shown in Figure 1, the energy consumption of production related technical equipment is typically not constant over time but dynamic depending on the production process and the actual state of the machine. Machines consist of several energy consuming components that generate a specific energy load profile when producing [9] [10] [11]. This typically applies to electricity, but is also true for other forms of energy or media like compressed air, process heat, gas or coolants.

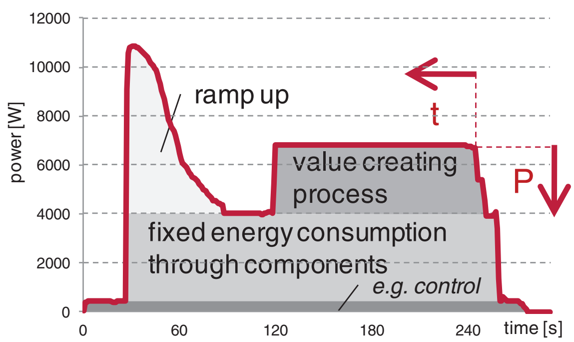


Figure 1: Typical load profile of production machines.

Typically, different distinctive machine states can be distinguished (exemplary classifications can found at e.g. [11][12][13][14]; see also Figure 2):

- Off: main switch off, no energy consumption
- start/ramp-up: energy demand peaks caused by switching on certain components, heating-up phases etc.
- idle: relatively constant energy consumption after main supporting components completed ramp-up and machine is “ready for production”.
- operation: actual value creating process takes place (e.g. removal of material)

2.2. Measuring energy and resource consumption

For measuring energy and resource consumption diverse concepts, methods and tools are available (e.g. [15]). Thereby the dilemma of the level of detail and necessary effort in terms of time and costs needs to be solved. For an example of a production machine, Figure 2 shows the measured curves with different sampling rates of the measuring equipment. Quite clearly, with lower resolution of the measurement the derivable information content drastically decreases which limits the opportunities for improving the system. As disadvantage of more detailed measurements, necessary efforts for equipment and data processing increase [16].

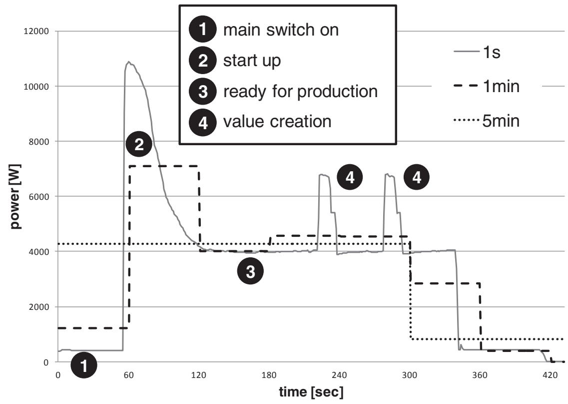


Figure 2: Effect of different sampling rates when measuring energy load profiles [17].

2.3. Fields of action for energy and resource efficiency improvement in manufacturing companies

As indicated before a diversity of possible approaches for improvement have already been identified in research and industrial practice. They shall not be presented in detail here but can be basically structured according to the following areas:

- Production machines: influencing factors are the design and control of the machine as well as process parameters (examples for certain approaches can be found in e.g. [12] [18] [19] [20]).
- Production planning and control (PPC): means for improving the energy efficiency are the avoidance of peaks of consumption (e.g. through balancing of orders) and also the optimal utilization of equipment with low shares of non value adding idling wastes (for examples see e.g. [21] [22]).
- Technical building services (TBS): TBS are responsible for the supply with necessary forms of energy and resources (e.g. compressed air) as well as

for ensuring the production environment conditions [23]. Main levels for improvement are the technical configuration of the equipment, an efficient process control as well as the avoidance of losses [24].

3. Concept description

The previous sections pointed out the challenges in context of increasing the energy and resource efficiency in manufacturing companies. Improvement measures are basically there and known but not tapped due to existing obstacles. For directly addressing these obstacles while guiding towards most promising fields of action, a unique and comprehensive SME appropriate method for systematic improvement was developed which inherits the following main characteristics:

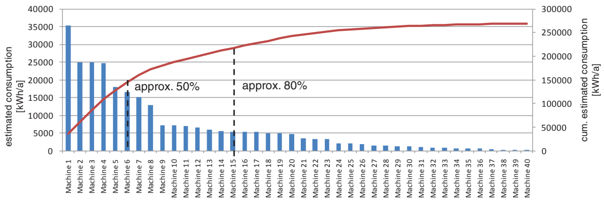
- The method does not require any detailed data at the beginning and can basically be applied by any company.
- The introduction of the value of estimated energy consumption provides systematic guidance for prioritization of actions.
- While going beyond Pareto analysis the energy portfolio as breakdown of energy consumption into power and time gives distinctive decision support for both measuring strategy and improvement measures.
- The complexity of energy cost composition is addressed while both power demand (possible peak surcharges) and energy consumption are considered.
- The method in itself is intended to work as continuous improvement process. Thus, steady improvement of the data quality is ensured. With this background, it can be also a major cornerstone of an energy management system as defined in ISO 50001.
- The method is directly connected to advanced methods and tools for modelling and simulation of energy and resource flows.

The method is a four-step procedure which is described in the following.

3.1. Machine list and estimated energy consumption

Since it is assumed that no detailed consumption data is available, an appropriate way for identification and first prioritisation of consumers is needed. Therefore, a list of all technical equipment of the considered system needs to be generated (Figure 3). This involves production machines but explicitly also includes TBS related supporting equipment like e.g. compressors. Having in mind the theoretical background presented before, two values are critical to gather in this context:

- The nominal value for energy consumption (power rating) of a machine can be found in the technical documentation and/or on type plates directly on the machine. The nominal value is a standard value which is provided by the manufacturer in order to allow the dimensioning of e.g. the supplying network (e.g. electricity grid, compressed air network). Since this naturally involves maximum values (including safety factors) it is important to mention that specifically in the case of electricity the nominal value tends to be significantly too high and rarely reflects the real power demand in operation. However, it can serve as base for first estimation whereas the procedure as a whole in itself ensures a continuous evolution towards better accuracy of values.
- The operation time per year is an usual machine related key figure and available via production data acquisition or can be calculated or estimated manually (e.g. based on utilisation rates).



Typ	manufacturer	operation time	nominal value	estimated consumption
		h/a	kW	kWh/a
Machine 1	XY	736	48	35328
Machine 2	ABC	2070	12	24840
Machine 3	CY	920	27	24840
Machine 4	XZ	800	31	24800
Machine 5	XY	8200	2,2	18040
Machine 6	Z	368	45	16560
Machine *n*	...	...	...	...

Figure 3: Machine list and Pareto analysis with estimated energy consumption [17].

According to equation (1) an estimated energy consumption value can be calculated for each machine of the system. A sorting of all machines according to this value gives a clear indication of potential energy drivers. It is crucial to ensure that all potential consumers of the system are considered.

Figure 3 shows a typical result for the estimated electricity consumption distribution based on a real company case. The consumption is dominated by few consumers: in this case just six machines sum up for >50% of the estimated consumption, approx. 15 machines account for 80%. With not even 30 machines (out of a total of 80) determining consumption, the majority of consumers are most likely not worth being considered with high efforts since the potential benefits are likely to be rather low.

As mentioned before, due to the uncertainty of the nominal values the estimated energy consumption does not accurately reflect the real energy energy consumption of the considered system. Still, this prioritization is working and very helpful since 1. this uncertainty is true for all consumers and so even the relative differences between consumers are a valuable decision base, and 2. applying nominal values is a maximum ("worst case") analysis so less relevant consumers according to the estimation will normally also not be worthwhile to be considered in detail for the real case.

3.2. Energy portfolio

While the estimated energy consumption already gives a good indication of priorities, the separated presentation of the determining parts power demand and operating time bears further potential and gives precise decision support. This so called energy portfolio is shown in Figure 4 and allows the classification of energy consumers into four distinctive categories (boundaries are determined by the average values of all consumers).

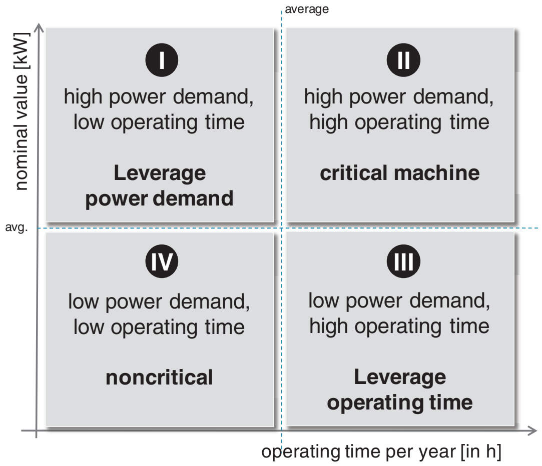


Figure 4: Energy portfolio as tool for classifying energy consumers [17].

For each category, different strategies for further actions can be derived:

- High power demand, low operating time (category I): these consumers are specifically important to address if peaks of consumption are relevant in context of costs or dimensioning of infrastructure [21]. More detailed measurements should be made to understand if and in which operation mode demand peaks occur and whether these peaks are cost relevant (billing interval is typically 15 minutes). Means for improvement can be technically or organisational in nature. Since the relatively low operating time indicates a certain amount of flexibility, energy sensitive PPC or load management will most likely be promising measures.
- High power demand, high operating time (category II): these consumers are most critical as they are responsible for most of the energy consumption and should be analysed in detail through measurements to understanding the exact composition of consumption (sampling rate e.g. 1 second). Means for improvement will typically be more technical driven, e.g. the improvement of machine components to reduce energy demand.
- Low power demand, high operating time (category III): these consumers can contribute significantly to total energy consumption due to their relatively long operating time over the year while demanding little power (typically simpler equipment like a pump or electric drive). Due to the low order of magnitude, detailed measurements are not even necessary or worth the effort. However, these kinds of consumers might offer some feasible approaches for improvement: with relatively low necessary investment and high leverage effect through operating time, attractive payback periods are very likely.
- Low power demand, low operating time (category IV): these consumers are less relevant in context of the energy consumption of the system. No further efforts should be spent for detailed consideration.

For the same case presented before, Figure 5 shows the energy portfolio with the diversity of consumers. The example underlines the improved information quality compared to the simple Pareto analysis (Figure 3).

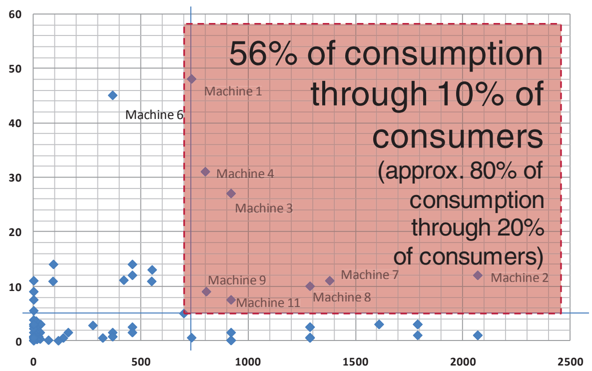


Figure 5: Exemplary application of energy portfolio based on real company case [17].

3.3. Implementation and (continuous) update of machine list

Based on the aforementioned method, critical energy consumers can be clearly identified and measuring strategies as well as means for improvement can be derived and analysed in a target-oriented manner. As important third cornerstone towards a continuous improvement process in companies, the machine list - in terms of power, time and the estimated energy consumption - has to be updated on a regular base. Due to the set-up of the method, any changes (e.g. implemented measures, measurements available) will directly lead to an updated energy portfolio with possible new hotspots and priorities for further action. Therewith, this procedure also addresses the potential drawback of using nominal values in a first step since the quality of analysis will increase automatically over time.

3.4. Modelling and simulation of energy flows of manufacturing systems

The data which is being acquired in the first three steps is also the ideal prerequisite for extended approaches like the modelling and simulation of energy and resource flows in manufacturing systems. Based on this now available structured data base, the logic interdependencies of processes and flows within the factory can be considered and further potentials for improvement can be derived. As example, energy and resource flow models based on e.g. Umberto™ allow the visualisation and evaluation of all flows for a certain period of time as well as the derivation and assessment of distinct improvement measures. Furthermore, energy oriented simulation approaches approaches enable to consciously take into account the dynamic interdependencies within the factory system in order to improve the energy efficiency [17].

4. Application

As addition to the short example shown before, another case study shall underline the applicability and benefits of the presented method. The case study focuses the improvement of the energy efficiency of a SME weaving mill. According to the presented procedure, a machine list was generated and the estimated energy consumption was calculated. The data was transferred into the energy portfolio illustration as shown in Figure 6.

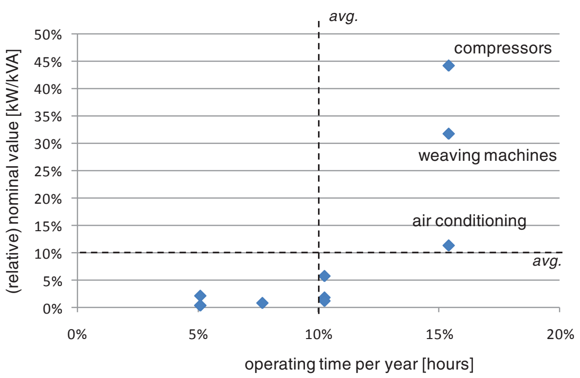


Figure 6: Energy portfolio analysis for a SME weaving mill [17].

Again, the energetical priorities can be clearly identified. In this case, the item “weaving machines” (which includes in total >40 machines of 4 different types), the compressors and air conditioning are of main relevance. Interestingly, those three main drivers are directly connected since the weaving machines are by far the main consumers of compressed air and also stand in an air conditioned production environment.

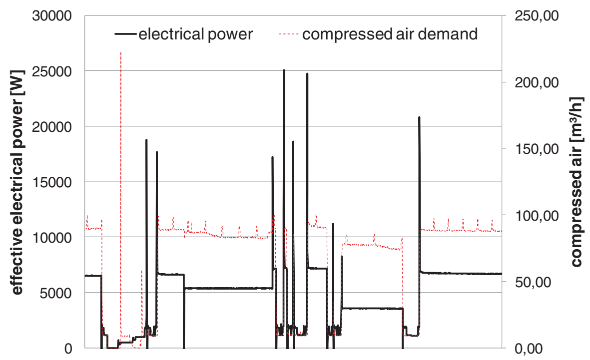


Figure 7: Detailed measurement of electrical power and compressed air demand of weaving machine [25].

For all types of weaving machines, detailed measurements of both electricity as well as compressed air consumption were conducted (Figure 7). While being of high priority also the energy consumption of compressors and air conditioning was analysed in more detail. Based on that a comprehensive energy and resource flow model could be developed (Figure 8).

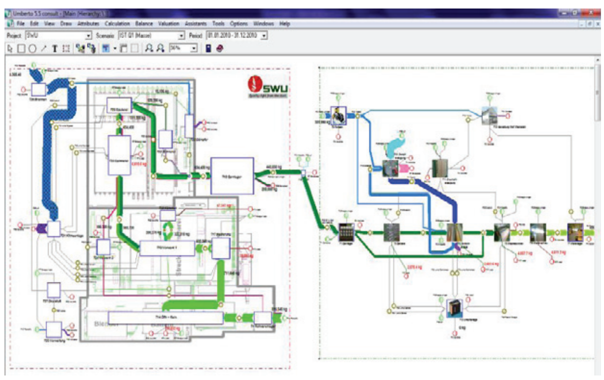


Figure 8: Energy and resource flow model of weaving mill based on Umberto™ (Example for material flows in kg).

This model allowed the clear identification of hotspots, the calculation of product and process based costs and environmental impact but also the derivation and virtual assessment of distinctive potential improvement measures. The most promising measures were actually implemented and with this first step energy savings of about 6% could already be verifiable realised.

5. Summary and Outlook

This paper presents a method for the systematic improvement of the energy and resource efficiency of manufacturing companies. While the examples focus on electricity as important energy carrier, the method is basically also easily applicable for other forms of energy or media. Further research work is focusing on connecting the presented methods with a continuous monitoring of energy and resource flows and the more detailed integration of different machines states in the energy portfolio.

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