
THE STATUS OF ENERGY MONITORING IN SCIENCE AND INDUSTRY BY THE EXAMPLE OF MATERIAL HANDLING PROCESSES

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Abstract. Global mega trends attract increased resource preservation as well as system efficiency and arouse growing scientific, industrial and public attention, whereas process and technologic developments still lack realisation due to inaccurate knowledge of real process energy demand, associated possible savings and a low inducement for investment. This investigation develops a generally applicable process for energy data collection focussing on material handling systems based on a predefined target model for energy monitoring in order to generate a valid reference model. The introduction of Standardised Energy Consuming Activities (SECA) model enables the development of energy based process functions as reference for its implementation to energetic investigations in various industrial applications. Analysing current and target state of energy monitoring in scientific and industrial investigations for logistics shows the developmental deficit of standardisation and realisation in energy monitoring.

Keywords: energy monitoring, process energy, energy load profile, Standardised Energy Consuming Activity, process fragmentation, material handling process, key performance indicators.

JEL Classification: R49, Q49.

1. Introduction

In recent years global megatrends such as globalisation and urbanisation as well as the ongoing electrification of industry, trade and consumption, together with demographic changes, strongly influence all fields of economy and science (Kartnig *et al.* 2012; Mueller *et al.* 2013a).

Driven by constantly increasing energy prices fostered by public and political interests, while the amount of natural resources decreases, the demand for more ecologic and resource saving technologies and procedures grows (Bandow *et al.* 2013). Due to these factors of decreasing resources and resource availability as well as the demand

for increased sustainability and availability, the traditional objectives of industry such as cost, time and quality are modified by (energy) efficiency considerations (Mueller *et al.* 2013b). The achievement of these key objectives can be realised whether on the macro level by governments and legal authorities or on the micro level by single enterprises (Humpl, Starkl 2010).

Due to companies' focus on global cooperation, vertical disintegration and the concentration on individual core competencies, the quantity of goods to be transported increased constantly by 1% – 2% throughout the last decade (European Commission 2014), already reaching the maximum performance ability of many distribution centres (Chen, Paulraj 2004: 1; Miodrag *et al.* 2012; Clausen *et al.* 2013). According to Figure 1, more than 72% of all goods that are transported on land within Europe are handled by road transportation so that these significantly contribute to the congestion of logistic hubs.

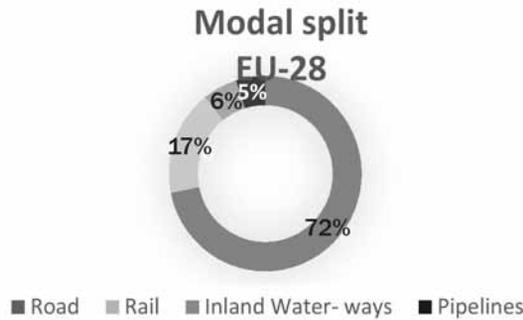


Fig. 1. Modal Split EU-28 (Source: European Commission 2014)

Investigating the above mentioned phenomena, scientists highlight the importance for highly efficient tools and technologies in order to ease the bottle-necks of logistic distribution centres and transfer hubs in order to enhance the transportation and handling of goods. Amongst others, efficient factory planning (Mueller *et al.* 2013b), performance and capacity utilization maximation by resource management (Miodrag *et al.* 2012), technical and technological improvement (Bamberg *et al.* 2012) or process monitoring (Wenzel, Bandow 2011) are considered as highly potential areas to improve material handling.

All the above are considered to be subject of sustainable Supply Chain Management which has attracted growing attention and stake in the research area (Teuteberg, Wittstruck 2010), whereas the concepts of lean manufacturing and thinking are driving approaches to foster the avoidance of waste and losses in combination with increase in efficiency and availability. While executing these approaches, due to growing product variety, shortened product life cycles and order characteristics, handling systems and processes are required to possess high flexibility and availability whereas the general target of industry consists of an overall standardisation (Kartnig *et al.* 2012). The result

of these developments is increased demand for transportation and handling distances, utilisation times of equipment and optimised process energy by trying to attain maximised efficiencies.

Fostered by the illustrated developments, industry will be forced to adjust and apply production and handling processes to these determining factors in order to maintain competitiveness in the near-term future. Handling facilities will have to be designed in accordance and new technologies will have to enhance equipment availability and efficiency. Current “lean” developments and strategies focus on the reduction of waste by increasing efficiencies and changing processes based on estimated energy consumption figures. The basis for evaluating economic reasonable reducibility of waste is a detailed knowledge of processes and process energy. This investigation develops a generally applicable process for energy data collection in material handling systems based on a predefined target state for energy monitoring in order to serve as reference standard of comparison. Comparing current and target state of energy monitoring in science and industry shows the developmental deficit.

2. The role of energy in material handling processes

In contrast to the definition of logistics which focuses on the supply-chain starting from the production of raw materials up to finished products and delivery to final customers (Humpl, Starkl 2010), intralogistics is defined as the task of organising, executing, controlling and optimising in-house material flows (Bandow *et al.* 2013).

For example, in a non-automated low-level picker-to-part system, transportation equipment has to pick the goods from different positions within a logistics facility where there is no stacking of goods on racks. In logistic distribution centres, forwarding and handling are major tasks and storage only plays a minor role (De Koster *et al.* 2006). Automated processes are often linked to highly standardised assembly lines or conveying systems for example in courier and express services. Zrnic and Rajkovic identified the essential components of non-automated intralogistic processes like lifting and handling equipment (cranes and forklift trucks), warehouse technology and software which play a key role while investigating intralogistics and its processes (2011).

In-house material handling is responsible for a big part of the total transshipment centre’s energy consumption (Humpl, Starkl 2010). According to Tsige this energy consumption can account for up to 55% of the total warehouse operating expenses (2013) whereas all investigations lack the identification and analysis of relevant consumers.

As per approach of lean manufacturing, the target is to run material handling processes by using the most energy efficient activities in order to avoid waste (Seow, Rahimifard 2011). In practice, using energy efficient activities mostly refers to implementing highly efficient state of the art technologies whereas real consumption remains unknown. Sullivan, McDonald and Van Aken specified the biggest sources of inefficiency as excess inventory, wasted time (= cost) or unavailability of equipment (2002).

According to the model of Huan, Zhu and Shen (2012) breaking down process related energy consumption to its individual components such as Target Energy ($E_t =$ exergy) and Working Energy Consumption ($E_{cw} =$ energy) including losses and auxiliary work allows to identify fixed consumption in relation to its accompanying, waste-creating side effects (see Fig. 2). For energy monitoring purposes with focus on demand and supply of energy, adding a deficit factor integrates the possibility of dissatisfaction of required energy, whereas the target of energetic optimisation is to keep the deficit factor ± 0 . A positive deficit refers to waste due to the provision of non-usable energy whereas a negative deficit results in unavailability of equipment due to energy shortage.

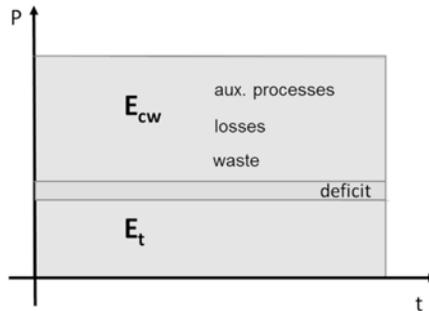


Fig. 2. Components of process energy (Source: created by the authors)

Energy management tries to reduce waste and losses by holistically analysing process chains by monitoring, structuring and documenting energy requirements such as demand and supply, so that the importance of effective performance measurement and therefore consumption grows (Mueller *et al.* 2013a). Besides closely related key performance indicators such as machinery performance and time, overall equipment efficiency is highly influenced by fleet utilisation (Mason, Lalwani 2006) which is based on availability and utilisation.

3. Energy management and the target state of energy monitoring

Energy management can be described as energetic amendment to total Supply Chain Management which holistically investigates, analyses, structures, documents and plans all process related structures and supporting functions with focus on energetic consumption. As per Figure 3, energy monitoring plays a key role throughout the total energy management process. As part of the energy management process, the results of detailed energy monitoring have a major impact on the Planning and Checking phase as the basis for a fundamental analysis which includes the evaluation of current and expected energy consumption.

The most important steps for evaluating process energy performance of material handling systems can be derived from Mueller *et al.* (2013b):

- Definition of field of observation;
- Implementation of energy monitoring;
- Analysis of energy performance and energy consuming activities/functions;
- Forecasting of future energy demand based on reliable consumption specifications;
- Identification of possible energy improvements.

| | |
|------------------------------|---|
| General requirements | <ul style="list-style-type: none">• Establishing, implementing and improving the energy management system |
| Management responsibility | <ul style="list-style-type: none">• Providing the necessary resources• Ensure compliance requirements |
| Energy policy | <ul style="list-style-type: none">• Commitment to continual improvement of energy performance• Obligation to comply with legal requirements• Support the purchase of energy-efficient products and services• Documentation and communication within the organisation at all levels |
| Energy planning | <ul style="list-style-type: none">• Energetic evaluation by identifying areas with significant energy use with the help of measurements and identification of ways to improve the energy performance• Record and update of energy basis• Determination of energy performance indicators• Definition of strategic and operational energy goals and action plans |
| Implementation and operation | <ul style="list-style-type: none">• Creating awareness and training employees• Control of documents and processes of critical energy areas• Consideration of the energy performance in purchase and design of systems and devices |
| Checking | <ul style="list-style-type: none">• Regular monitoring, measurements and analysis• Internal auditing• Initiation of corrective and preventive actions |
| Management review | <ul style="list-style-type: none">• Regular review of energy management system |

Fig. 3. Energy management requirements according to ISO 50001

Energy monitoring in highly automated and therefore standardised work environments and processes such as automotive manufacturing or mechanised production processes can be implemented at the connection points of energy transfer. Most of the energy considerations for these processes are based on theoretical figures based on data sheet calculations, which, in the case of high standardisation, are characterised by realistic and valid results. Where there is less standardisation and high demand for

flexibility due to less projectable process sequences, the fraction of energy increases due to increased appearance of auxiliary work and start-up processes. The increased number of peaks in this arrangement raises energy consumption.

The influence of an increased number of start-up processes and process interruptions becomes clear while investigating the progress of performance curves. The start-up processes can require more than three times the electric power consumption as constant operations (see Fig. 4). Detailed knowledge about process structures of flexible systems as well as interlinked energy consumption deduced from process specific load profiles are therefore an essential part of monitoring and analysing process energy.

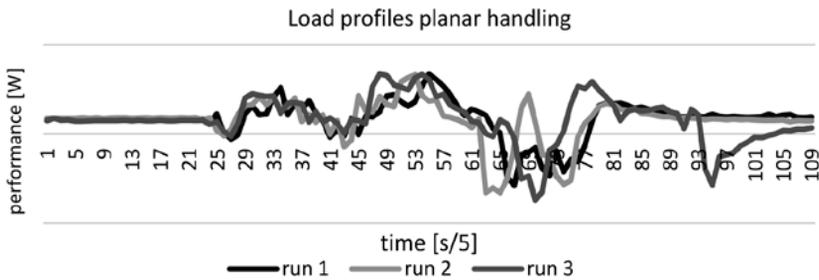


Fig. 4. Load profile planar handling (Source: created by the authors)

An important influence for energy management is highlighted by the standard deviation from notional and real consumption figures that highlights the importance of energy monitoring in order to generate a reliable calculation basis. As per Figure 5, standard deviation of flexible material handling processes differs for up to 27% from calculated values in planar handling processes. When lifting is required real consumption is up to ten times higher than calculated due to increased dissipation losses and auxiliary processes of the support system. With rising mass of goods to be conveyed or lifted, the value of deviation increases due to increased inertia of mass, so that lifting processes suffer greater impact.

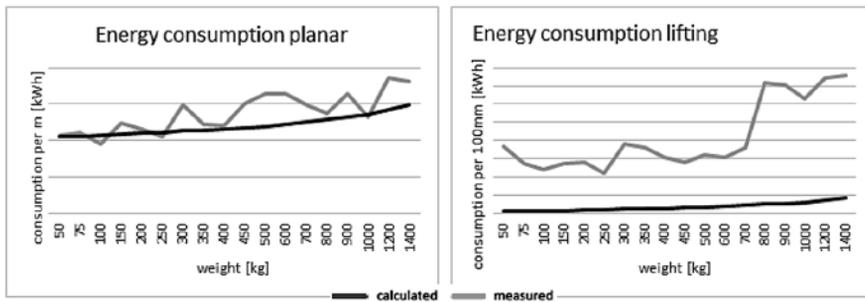


Fig. 5. Deviation of process energy consumption in planar handling and lifting (Source: created by the authors)

An important issue of energy monitoring is to determine process parameters which influence individual processes and by this to identify generalizable functions in order to make a process-based energy monitoring approach applicable to similar, comparable functions. Therefore energy monitoring has to focus on processes broken down to standardised handling steps and functions that also occur in other processes or redundant in the same process in order to make it generally applicable. The target is to define Standardised Energy Consuming Activities (SECA) that fulfil congruent or redundant functions. A SECA therefore has to be clearly defined and as specific so that it can also be defined as “not reasonable divisible”. A SECA in material handling of logistic hubs can be defined as the task of forwarding a certain weight over a certain distance by measuring the required energy. The distance can be set to one meter, as average transport distances are generally given on a metric basis. Breaking it down to a smaller unit does not provide any further benefit to energy calculations.

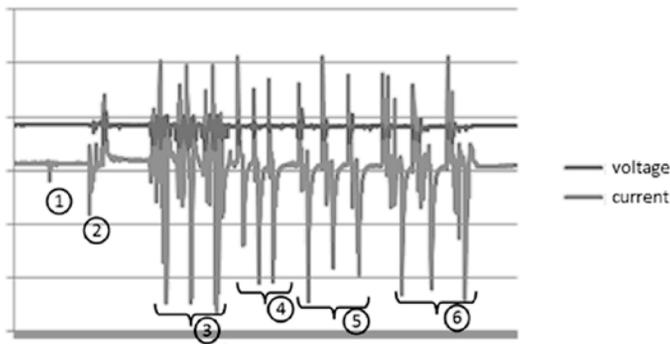


Fig. 6. Load profile fragmentation (Source: created by the authors)

Figure 6 shows energy components of a material handling process including a total of six different standard functions such as:

- System activation and provision;
- Free lift (unloaded);
- Material handling (planar);
- Free lift (loaded);
- Stacking 1100 mm;
- Stacking 2100 mm.

Breaking down energy monitoring to smallest material handling functions allows to defragment single steps of material processing into a comprehensive energy consumption profile of individual processes based on empirical consumption figures which includes the standard deviation for start-up processes and different process encroachments. The defragmentation of processes by using SECAs allows a flexible adaption to fast changing processes what enables the desired flexibility for process energy calculations and simulations.

4. Energy monitoring in science

In order to define the current status of energy monitoring in science, scientific articles and publications from SJR-ranked journals or books (69%), recognised international conferences (19%) or accredited university institutions (12%) were reviewed. The search process was performed in a back- and forward Keyword Search focussing on energy consumption, supply and efficiency in material handling processes and its inherent environments. Correspondent synonyms and alterations led to increased results, so that search results and articles were sorted and checked for relevance to the subject matter.

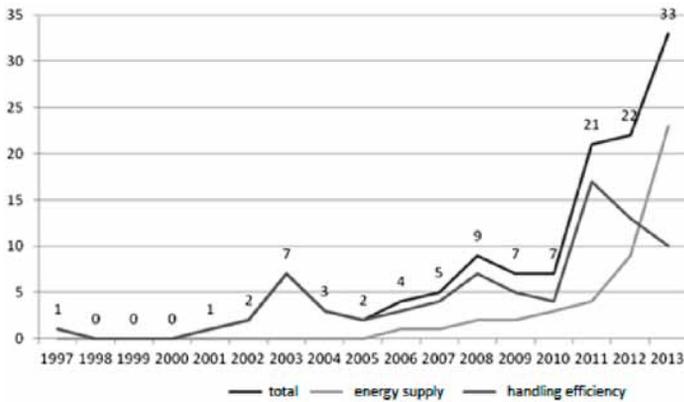


Fig. 7. Distribution of literature over time (Source: created by the authors)

Energy monitoring in (intra-) logistics, i.e. material handling, hasn't gained much relevance in last decades' publications or scientific considerations. According to Figure 7 the number of publications considering material handling efficiency with relevance to energy management and energy monitoring increased. Research focuses on technological developments in order to minimise waste and losses by material handling equipment. Energy supply in material handling gained more attention starting from 2010. Focus of research in this field is the balancing and monitoring of energy provision to industrial production and production lines, i.e. highly standardised processes whereas material handling processes only play an ancillary role.

De Koster, Le-Duc and Roodbergen highlight maximisation of equipment usage for optimising process design and process energy demand, as well as travel distances (2006: 10). In agreement with this Klumpp, Clausen and ten Hompel (2013) mention the growing importance of increased availability of existing handling resources as well as the approach of decreasing the size of the provided handling equipment fleet. The potential of optimisation, while trying to minimise the resources and its capacity, needs to be monitored and analysed precisely, as quality within supply chains highly depends

on its reliability, which is majorly dependent on negative impacts such as unplanned breakdowns and unforeseen downtimes, some of which can be a result of energy shortage (Wenzel, Bandow 2011). Bunse *et al.* (2011) highlight the importance of investigations on energy usage profiles in reference to processes and machines (and associated equipment) in order to compare individual performance numbers, whereas Seow and Rahimifard (2011) criticise the lack of accurate data as well as scientific publications in this field (Mueller *et al.* 2013b). Available data of intralogistic processes were majorly generated by energy audits and energy balance sheets (Bunse *et al.* 2011) so that there is a lack of comprehensive real environment data (Miodrag *et al.* 2012). The focus of research in the field of energy monitoring is on manufacturing processes which rarely considers intralogistic activities such as handling (Neugebauer *et al.* 2011). Negative impact of designing investigations on purely statistic data, which is based on highly inexact overall consumption figures, is the negligence of inefficiencies of transmission and storage as well as real performance requirements due to the reference on average numbers, which prevents the calculation of real process relevant energy (Borcherding *et al.* 2013). In line with the above mentioned points, Asadi (2012) stresses the absence of universally applicable key performance indicators and benchmarks in intralogistics.

Research is investigative and therefore limited to one or a few aspects only, so that research on technological improvement neglects energy supply, whereas research on energy and process monitoring does not consider technological aspects.

Three major perspectives of science on the field of energy monitoring were identified such as technological, organisational and economic perspectives. Criteria for categorising and assignment are shown in Table 1.

Table 1. Perspectives on energy monitoring (Source: created by the authors)

| Technological | Organisational | Economic |
|-------------------------|--------------------------|----------------------------|
| Performance calculation | Process optimisation | Energetic calculations |
| Efficiency optimisation | Routing | Efficiency calculations |
| Reduction of losses | Guidance systems | Benchmarking |
| System requirements | Supply Chain Management | Key performance indicators |
| System classification | Warehouse planning | Waste |
| | Equipment implementation | |

The technological perspective analysed handling technologies and its efficiencies for intralogistic applications such as AGVs (Schulze, Wullner 2006) and conveying systems which bear the character of high standardisation rates (Yu 2008). Factors and results such as system design, machinery efficiency etc. can partially be used as basis for economic and process calculations. These and similar technological aspects play an important role for developing relevant key performance indicators for an energy process analysis.

Moreover, economic considerations of applied research should focus on benchmarking and optimisation matters in accordance to the lean approach. Starting from 2008, energetic investigations and the avoidance of waste energy gained importance and attention but were considered more as a side topic in material handling processes of manufacturing and production industries.

Process and routing optimisations are central aspects of organisational parts of energy monitoring. He *et al.* (2012) introduced the combination of single process steps of a manufacturing supply chain and its inherent energy consumption in reference to a highly standardised production line. Energy consumption of different operating modes are analysed in order to result in the most economic compromise of energy consumption and process velocity. This approach goes in line with Mueller *et al.* (2013b) and the described approach of introducing SECA. Key aspect is to investigate the basic energy consuming activities and to define a standard for energy data preparation in order to design a generally applicable and comparable data base. Existing approaches form an initial step for detailed energy analysis but still lack the process-required particularity in energy monitoring execution. Material handling process energy monitoring can be based and conducted according to the following scheme by segmenting handling activities into single redundant SECAs (see Fig. 8); its defragmentation into a periodic load profile enables detailed process analysis and evaluation. Defragmentation is the first step of calculating process energy consumption and therefore needs to be based on more accurate consumption figures which include standard deviations for all considered functions. According to this approach, the basis for developing process energy analysis is a detailed energy monitoring on predefined Standardised Energy Consuming Activities.

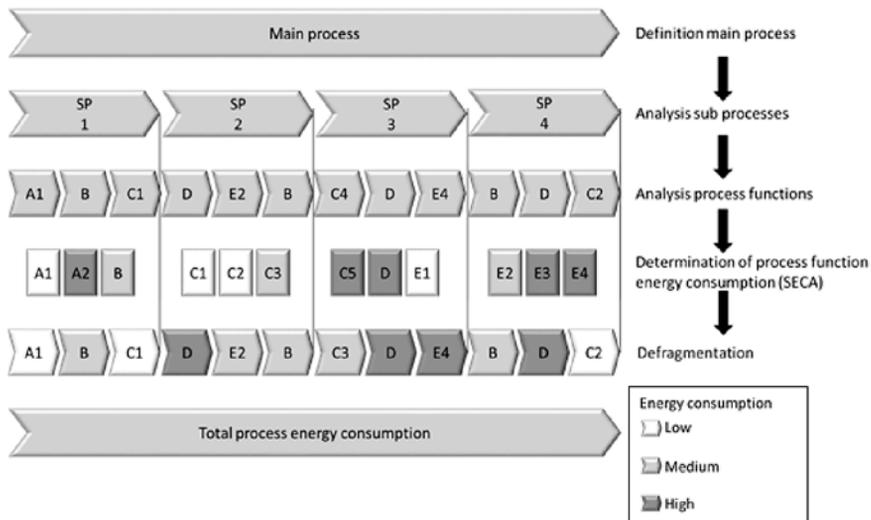


Fig. 8. Energy monitoring process (Source: created by the authors)

5. Energy monitoring in industry

As global competition is constantly rising same as the prices for energy, producing business units strive to decrease their overall expenses. Closely linked to this, material handling is required to be more and more efficient in order to lower energy consumption and cost. Overall subject perspectives in this field of investigation have already been described in science and literature so that industry seems to be aware of this upcoming issue.

In a representative investigation about energy consumption and efficiency in material handling facilities and logistics companies, Germany-based material handling facilities were inspected and surveyed. All the surveyed distribution centres defined material handling, i.e. unloading, loading and forwarding as their core functions with 95% to 97% of all shipments to be transhipped without any storage. 72% defined their core business as road transportation. Others deal with sea freight (13%), air freight (7%) or in-house logistics (7%) by operating in company owned distribution centres.

In reference to energy efficiency in material handling facilities, more than 75% of all participating parties stated that energy efficiency is of high importance within their companies. The remaining parties evaluated the subject's influence on business as medium (3%) to low (21%).

German logistics companies that have put focus on energy optimisations (79%) have implemented business units that partly deal with energy issues. Energy management, if existing, is majorly implemented in departments such as “environmental management”, “health safety environment” (HSE), “quality management” or “technical department”, whereas the degree of subject specialisation is descending due to department's focus.

In one out of four logistics companies energy monitoring was performed, but all approaches were limited to counter reading on electricity meters. This results in cursory knowledge about general energy consumption of office buildings, warehouses or outdoor areas without gathering information about individual energy consumers and energy consumption characteristics. More specific counter reading in reference to material handling or conveying equipment and its related energy transmission applications, as performed by only 10% of the participating hubs, foster basic energy consumption understanding but still lacks particularity. Overall results estimate the major functions of energy consumption in material handling facilities such as illumination (36%), handling equipment (32%), IT (28%) and climate control (5%). This indicates that the results of energy monitoring according to the scientific subject understanding based on the development SECA is underperformed.

The cost of energy consumption accounts for up to 7% of the overall cost of material handling processes. Participating companies estimated that another 2% to 10% of possible savings can be realised economically. 57% of the surveyed group took action to improve energy efficiency, e.g. to decrease energy consumption such as the installation of energy saving illumination, what accounts for 56% of all energy saving measures to be taken and which is seen as most potential source for additional economies. A small

fraction of realised actions is based on process optimisations, staff training and/or more efficient technical equipment. By these actions, companies have realised annual financial surpluses from € 4.800 to € 70.000.

While scanning material handling key performance indicators with basic relevance to energy consumption within distribution centres, reliable figures were available to only 54% (see excerpt as per Fig. 9).

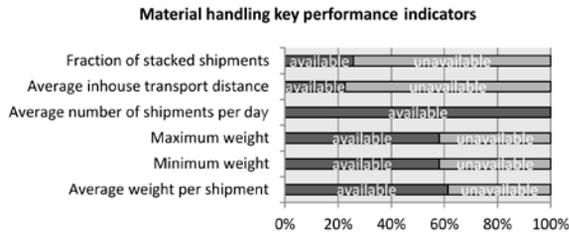


Fig. 9. Key performance indicators with relevance to energy consumption (Source: created by the authors)

The investigations showed that the importance of energy efficiency in material handling is limited to easy accessible energy saving measures with low risk and low demand for investment, so that in a second survey reasons for the deficient realisation were investigated (see Fig. 10).

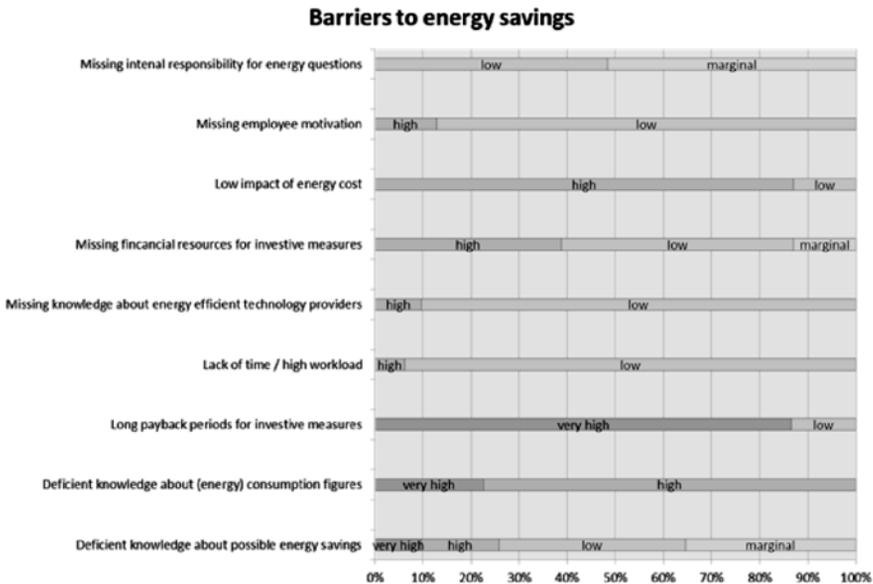


Fig. 10. Barriers to energy savings (Source: created by the authors)

6. Conclusions

A scientific consideration of the focus of energy monitoring and measuring lies on warehouse-based processes of manufacturing and production (Bandow *et al.* 2013). Currently industrial application of energy efficient technologies in material handling is limited to low risk and low investment applications with short amortisation cycles. Consideration of short-term economic considerations outweigh the long-term saving of resources.

It is seen in the text that energy optimisations in the area of material handling focus on the minimisation of proceeding times such as picking-, travel- or search times (Tsige 2013). The defined target according to the lean approach is to minimise losses such as waste times and distances in order to increase the use of labour and equipment (Bunse *et al.* 2011; Tsige 2013), whereas the common ground is the utilisation of statistical and theoretical time averaged values (Dufflou *et al.* 2012; Bunse *et al.* 2011). The development of comparable energy consumption data (SECA) with validity to different applications will increase and standardise scientific results on energy issues and by this increase the understanding and implementation of energy saving measures in industry.

Moreover, a strong growth of energy prices and, by this, the potential to save financial resources should increase the willingness to apply specific human resources and capital investment in low margin sectors too. A strong growth of energy prices due to the higher cost of the projected green energy policy of the German government, will give a potential to save financial resources and encourage willingness to apply specific human resources and capital investment in low margin sectors too. Therefore, the introduction of Standardised Energy Consuming Activities (SECA) model is shown as enabling the development of energy-based process functions as references for its implementation to energy investigations in various industrial applications.

Disclosure statement

Authors herewith declare not to have any competing financial, professional, or personal interests from other parties.

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