PEER-REVIEWED PAPER

Energy-benchmarking within companies: insights from benchmarking practice

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Keywords

benchmarking, best practice, energy assessment, energy management, framework

Abstract

Energy benchmarking is a powerful tool for defining energy performance targets and for monitoring improvements in energy efficiency. While external energy benchmarks have intensively been discussed, the use of internal benchmarks within industrial companies has received little attention. Therefore, the aim of this paper is to address internal energy benchmarking and to provide insights on its application in practice. For this purpose, a conceptual framework for systematically structuring energy benchmarking activities is introduced. This framework is then applied to summarize the energy benchmarking practice of three companies from different industrial sectors. The results underline that internal energy benchmarks are used in many different ways within companies. They can be helpful tools to monitor energy performance of sites, processes, technical installations and other equipment, to verify whether energy targets are met and to gain a better understanding on the impact of energy efficiency measures. Yet this is only the case if the energy benchmarks are individually tailored, if they are adapted to their users, if they provide transparent information and if they evolve over time.

Introduction

Benchmarking is "a planning and management instrument for continuous improvement of the competitive situation" (VDI 4402, p. 2). It allows for a systematic and structured analysis of weaknesses with the aim of permanently eliminating them (VDI 4402). Energy-benchmarking (or energy efficiency benchmarking) is a special type of benchmarking activity focusing on energy performance. Its purpose is to establish and to compare energy efficiency between or within entities and to contribute to a reduction in energy use and related costs and emissions (DIN EN 16231). Typical goals of energy benchmarks are a) to compare the energy efficiency of similar activities or entities, b) to cluster them (e.g. most or least relevant ones), c) to provide ranges for their energy demand, d) to derive estimates on energy saving potentials, e) to identify best technical and organizational practice and/or f) to design and implement policies to improve energy efficiency and to reduce carbon dioxide emissions.

The majority of existing studies dealing with energy benchmarking focuses on activities that can be referred to as external benchmarking, i.e. a comparison of the energy performance of entities to the performance of similar entities in other organizations. Little attention has been given on how industrial companies use energy benchmarking internally, i.e. to analyze the performance within a company. This type of benchmarking, however, gains in importance with energy management systems spreading to more industrial companies.

The aim of this paper is therefore to address internal energy benchmarking in companies and to provide insights on the application of such energy benchmarks in practice. These insights originate from a working group on energy benchmarking established within the framework of the German "Effizienzfabrik" (Mattes et al. 2012). In this paper, a structured presentation of the energy benchmarking practice of three industrial companies is provided. This presentation is based on discussions within the working group, consisting of practitioners from industry, energy research as well as energy consultants.

The paper is structured as follows: As a starting point, a brief overview of different types of benchmarking approaches and related standards is provided. This is followed by the introduction of a conceptual framework for presenting the benchmarking practice of the three companies in a structured manner. Then, their energy benchmarking practice is analyzed. This presentation is followed by a discussion of insights from this analysis and by final conclusions.

Studies and standards concerning energy benchmarking

STUDIES ON INDUSTRIAL ENERGY BENCHMARKING

Literature related to energy benchmarking is abundant as this topic is closely related to studies on energy intensity, energy management and energy efficiency. Based on a sample of literature, a brief overview of different approaches to energy benchmarking is given in the following.

Energy benchmarking can be a simple way for quick and meaningful assessments of energy performance as compared to comprehensive energy audits or engineering studies (Galitsky et al. 2005; Hicks et al. 2001). Depending on the goal of an analysis, energy benchmarking is used to analyse the energy performance at various levels of disaggregation. Energy benchmarking studies for industry address among others a) entire sectors or subsectors, b) plants, sites or installations or c) specific processes or sub-processes.

Energy benchmarking at the sectoral level has been used by Phylipsen et al. (2002) to estimate the effect of the Dutch Energy Efficiency Benchmarking Covenant on energy demand and carbon dioxide emissions, for example. Another sectoral approach to energy benchmarking is used in Ramirez et al. (2003) who deal with energy intensity indicators for various non-energy intensive industries at the example of the food industry. Similarly, Saygin et al. (2011) use a benchmarking approach to conduct an analysis of energy-intensive industries both in industrialized and developing countries. Aaserud et al. (2013) analyse subsectors in the manufacturing industry in the state of New York and Chan et al. (2014) study the energy intensity of energy-intensive industries in Taiwan.

Studies concerning plants, sites or installations include energy benchmarking approaches as used in the context of the US ENERGY STAR program (Boyd et al. 2007; Boyd et al. 2013), in the studies by Adelaar et al. (2005) on textile plants in Canada, in the works by Hasanbeigi et al. (2010) on the Chinese cement industry, in the analysis on the animal feeds sector in France by Lucas et al. (2012) or in the self-assessment benchmarking tool for wineries described in Galitsky et al. (2005).

With regard to benchmarking activities for processes, Radgen (2005) introduces an internet-based energy benchmarking approach for compressed air systems. Taranto et al. (2007) discuss the use of real time monitoring to benchmark the energy performance for such systems. And furthermore, Tschudi et al. (2001) deal with the energy performance of clean rooms. Besides, there are various approaches that strive to further disaggregate processes. Laurijssen et al. (2013), for example, conduct a benchmarking study on various processes in paper mills in the Netherlands. Ruth et al. (2001) use a process-based energy benchmarking approach illustrated at the example of the cement and the iron and steel industry and Ke et al. (2013) introduce a process-oriented energy benchmarking approach from the perspective of systems engineering. While such process-based analyses help to overcome problems of incomparability, they may also require considerable effort which may come at the detriment of quick and simple benchmarking results (Schmid 2004).

Next to these studies, there are others that focus on specific segments of industry. Especially small and medium-sized companies (SMEs) have been addressed in several studies. In the European BESS project (Benchmarking and Energy management Schemes in SMEs) (Wajer et al. 2007a; Wajer et al. 2007b), for example, a benchmarking and energy management scheme was developed for industrial SMEs with a focus on the food and drink industry. This approach was subsequently expanded to new member states and additional sectors in the (Ex)BESS project (Tajthy 2009). Similarly, a study by EWI (2010) focuses on energy-related indicators for small and medium companies in Austria. Another focus on SMEs in found in IREGIA (2009) where energy-benchmarking is used as a core element for developing a harmonized approach to improve energy-related competences in SMEs.

The cited studies mostly focus on external energy benchmarking activities, but they do not provide detailed insights on how energy benchmarks are used within companies. Thus, there is a need for additional information on this practice.

STANDARDS RELATED TO ENERGY BENCHMARKING

The use of energy benchmarks within companies is especially influenced by the harmonized international standard for energy management systems ISO 50001:2011. In addition, the energy efficiency benchmarking methodology described in EN 16231:2012 provides further guidance on how to implement and use energy benchmarks.

Energy management systems according to ISO 50001

The international standard on energy management systems ISO 50001:2001 was introduced in June 2011, thereby replacing various regional and national approaches to energy management systems. Since its introduction, ISO 50001 has considerably gained in importance. According to ISO (2014), approximately 2,000 certificates were issued until the end of 2012, with Germany, Spain and Denmark as leading countries in terms of numbers. ISO 50001 specifies requirements for establishing, implementing, maintaining and improving an energy management system that aims to systematically achieve a continual improvement in energy performance of an organization. The standard is based on the Plan-Do-Check-Act (PDCA) cycle as used in other management system approaches such as ISO 9001 on quality management and ISO 14001 on environmental management. Within this system, the organization has to commit itself to improve its energy performance by stating an energy policy, to establish an energy planning process, to implement the planning, to monitor its impact, to take corrective action if required and to review the management system. As part of energy planning, the organization has to develop, record and maintain an energy review, to define an energy baseline and to monitor and measure its energy performance by the use of energy performance indicators. Thus the use of energy management systems according to ISO 50001 is closely related to internal energy benchmarking.

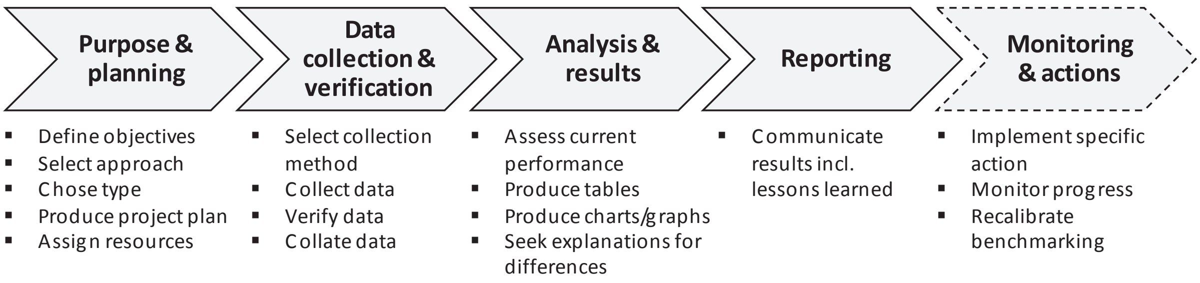

Figure 1. Benchmarking model based on EN 16321:2012.

Energy efficiency benchmarking according to EN 16321

A more specific approach to energy benchmarking is provided by the European standard EN 16231 on energy efficiency benchmarking introduced in 2012. It aims to provide organizations with a methodology for analysing energy data to compare energy efficiency between or within entities. The methodology of the standard is based on four steps (Figure 1). They include the purpose and planning of the benchmarking, the related data collection and verification, the data analysis and finally reporting. An optional fifth step concerns monitoring and taking corrective actions.

The standard mentions important aspects that have to be considered during benchmarking, but it is rather concise and provides only general instructions on how to design and use energy benchmarks. For example, it requires organizations to work with specific aims, target groups, entities, correction factors and comparable data. Due to its generic nature, the standard only provides rough insights, if any, on how to deal with such aspects in practice.

A conceptual framework for energy benchmarking

For providing structured insights on how internal energy benchmarking is dealt with in practice, a conceptual framework is introduced. This framework has been derived from practice and is based on discussions within the working group on energy benchmarking. The aim of this working group was information exchange on energy benchmarking practice of industrial companies. The discussions in the group quickly revealed that the introduction of energy benchmarks can be beneficial for companies. Yet experience from practitioners also indicates various challenges and pitfalls that companies have to be aware of when implementing energy benchmarks.

To present energy benchmarking in the participating companies, the group selected four interrelated topics dealing with the following questions:

- **Aim and user:** Why does a company introduce energy benchmarking? Who/which function in the company uses information from the benchmarks? What purpose is the information used for?
- **Object:** Which activities or entities are analyzed in the benchmarks?
- **Performance indicators and factors of influence:** Which energy performance indicators or metrics can be used for the benchmarks? How are they influenced by other factors and how to deal with this influence?
- **Data acquisition and analysis**: How often is it necessary to sample data? Where and how often does it have to be collected and analyzed?

In the following, each of the topics is described more closely based on views expressed in the working group.

AIM AND USER

A starting point when dealing with energy benchmarking is clarifying what energy-related aim it is used for and who actually uses the information it provides. Both questions are closely interrelated because the aim of the benchmarking activities depends on the role or function of the user in the company. Discussing this aspect in the beginning is important as the aim and the user determine the subsequent design of the benchmark and influence the selection of the benchmarked objects, the choice of performance indicators, the way how factors of influence are dealt with as well as the setup of data acquisition and analysis.

For users in strategic planning like top management, for example, the main aims of energy benchmarking are to analyze aggregated historic energy performance of the company, to define long-term overall performance targets for the future and to create framework conditions that these targets are achieved. For users on operational levels, benchmarking focuses on monitoring the actual short-term energy demand of a machine and serves to implement corrective action to adjust energy demand if needed (e.g. by modifying operating parameters). Thus, it is necessary to distinguish benchmarks for different user groups clearly and to align benchmarks to their aims. Some sample user groups and their aims in industry are summarized in Table 1. Of course, both users and aims will vary from company to company and depend on factors such as their size, their energy intensity or their energy costs.

OBJECT

With aims and users clarified, it is necessary to discuss the objects or entities that are analyzed by the energy benchmarks. They include among others products, processes, machines, equipment, technical installations, buildings, areas or sites. The selection of the objects depends on the users and their aims and is closely linked to the type of benchmark that is used. These types include benchmarks based on past performance, on reference values and on comparisons of multiple objects.

Benchmarking the energy performance of a single object against its past energy performance is a relatively simple way of benchmarking. A typical aim associated with this type of benchmark is to monitor the relative improvement in energy

Table 1. Examples of user groups and aims in energy benchmarking.

User group	Aims
Top management	development of the energy strategy of the company; analysis of past energy performance; information acquisition for the definition of long-term energy targets and for establishing general programs to improve energy performance in the company
Site management	analysis of energy demand at the site; breakdown of long-term energy targets into short-term targets and sub-targets for sites and areas; implementation of local efficiency improvement programs; review of site performance data
Shop floor worker	general monitoring of energy efficiency of machines and processes; condition monitoring; implementation of corrective action and adjustment of operating parameters
Efficiency team	monitoring of energy demand to identify energy efficiency measures; enforcing the implementation of specific measures as corrective action; sensitizing of other staff members
Energy management	specific and cross-cutting monitoring of short, medium and long-term energy performance on different levels; design and implementation of the specific programs to improve energy performance; development of metrics; energy reporting to management
Controlling	follow-up of energy performance in the company; aggregation of information on energy performance for energy/general management; prediction of energy demand for purchase

performance over time, e.g. to verify whether a target for improvement has been achieved. Establishing this type of benchmark requires that the energy performance of the object has been monitored for some time (e.g. hours, days, years). As this type of benchmark is based on the analysis of a single object, it reduces problems that arise when comparing several similar but not perfectly corresponding objects. However, the use of time series for benchmarking is always subject to the risk of structural shifts (e.g. new processes are introduced at a site). When such shifts occur, the benchmarking results may no longer only reflect changes in energy performance, but they partially mirror the effects of the shifts as well.

A second way of analyzing the energy performance of a single object is to compare it to some reference value. The aim of such benchmarks is to analyze the distance from this value. There are many references that can be used for benchmarking including theoretical minima (e.g. due to physical constraints), modelling results (e.g. the energy demand according to an energy demand simulation) or best practice values (e.g. the consumption under reference conditions). This type of benchmarking requires that both the energy performance of the object is monitored and that reference values can be determined. The challenge of using this type of benchmark is to find a suitable reference value for the benchmarking.

A third way of using energy benchmarking is to compare the energy performance of multiple similar objects to each other (e.g. homogeneous products, machines, production lines, buildings, sites). Typical aims served by this type of benchmarking are to rank objects by their performance, to sort them into groups or to identify the spread between the best and worst performing object. The application of this type of benchmarking obviously requires analyzing or monitoring several similar objects at a time. While in the first mentioned type, the challenge lies in the change of the object over time, this multi-object type of benchmarking has its challenge in overcoming differences between not perfectly corresponding objects. Thus, this type of benchmarking will always reflect differences in the energy performance of an object as well as other differences between the objects.

As pointed out, all these types of benchmarking approaches come along with some challenges. In practice, users often rely on combinations of these three types of benchmarks, e.g. benchmarks based on past performance and benchmarks with multiple objects.

METRICS AND FACTORS OF INFLUENCE

After discussing the users, aims and objects of energy benchmarking, suitable metrics or energy performance indicators (EPI) have to be identified. EPI should allow users to analyze the energy performance of the considered object or objects as transparently and objectively as possible to provide helpful conclusions. The EPI can be considered as helpful if they allow the users to reach their energy-related aims. This is either the case if the benchmarks allow identifying inefficiencies or if they trigger further investigations on why certain results point into one direction or another.

The main challenge when defining suitable EPI lies in the separation of helpful information on the actual development of energy performance from other factors of influence that affect the benchmarking results but that are irrelevant for the aims of the users (Table 2). This separation requires a careful examination as EPI bundle complex, real-world information into strongly aggregated figures. Finding a suitable separation between helpful and irrelevant information is complicated and rendered even more complicated by changes in the framework conditions. If for example a) the production programme is altered, b) when stand-by periods of production sites are changed, or c) when production volumes increase or decrease, benchmarking results will change as well. This does, however, not necessarily indicate any change in the energy performance of the monitored objects. Therefore, such factors of influence should be eliminated from EPI. If this is not possible (e.g. because it is too complex or if corresponding data for historic time series is not available), additional information has to be provided along with the energy benchmark to help users with the interpretation of results.

DATA ACQUISITION AND ANALYSIS

The last step concerns data acquisition and analysis. Evidently, the data required for setting up benchmarks depends on the above-discussed topics. Data acquisition in companies usually does not start from scratch. In an ideal case, defining the required data usually includes the following steps:

1. Based on the set of requirements from the previous analysis, data requirements have to be stated.
2. Already existing and collected data has to be summarized
3. A gap-analysis between required and existing data has to be carried out to identify additionally required data.
4. It has to be determined in how far the required data can be provided with available funds.

An important question linked to data acquisition and analysis is how to obtain missing data best and how to analyze it. Data acquisition and analysis can be based on manually operated and automated benchmarking systems. Both approaches have specific advantages and disadvantages as listed in Table 3.

Independently of the specific solution, it is important to note that energy-benchmarking systems are dynamic systems that evolve over time. Experience shows that companies will only rarely develop a comprehensive concept for energy benchmarking from the very beginning. They will rather gradually pass through several stages of development as sketched in Table 4. As an extension of the use of energy benchmarks usually means to extend system infrastructure successively, it is crucial to consider reserves for future extensions right from the start.

Implementations of energy benchmarking in practice

Based on the outlined framework for energy benchmarking, this section illustrates energy benchmarking activities in companies from metal processing, the automotive and the rubber and plastics industry. For each company, a summary of their energy management activities is provided first and then information is given on how they structure and use their energy benchmarking activities using the framework described above.

WESO-AURORAHÜTTE GMBH

WESO is a member of Viessmann Group and a manufacturer of iron casting products with an annual output of about 30,000 tons, about 400 employees and an annual turnover of over 60 million Euros. The company is certified and audited according to several environmental and quality management standards. Since 2012, this includes a certification according

Table 2. Examples of influential factors affecting energy benchmarks.

Factor	Factor
Product-related factors (e. g. number of pieces, weight, length, volume, material)	Organizational factors (e.g. shift model, staff at site, frequency of energy analysis)
Process-related factors (e.g. operating time, cycle time, speed, number of different setups, quality rate)	Personnel (e.g. user behaviour, intensity of instruction and education, presence of specialized staff members)
Ambient conditions (e. g. external and internal temperature, humidity, pressure, light)	Location-specific factors (e.g. area, space, refurbishment, age of equipment, status of supply infrastructure)
Production structure (e.g. degree of vertical integration, product segments, number of different products)	Economic factors (e.g. turnover, production costs, energy costs)

Table 3. Advantages and disadvantages of automated and manual data acquisition.

	Manual data acquisition	Automated data acquisition
Advantages	High degree of flexibility Little or no investments	High resolution (time, disaggregation) High quality of documentation
Disadvantages	Intensive in terms of personnel Rough resolution as limited number of data points Competence requirements for proper acquisition	Limited to predefined assessments Costs for infrastructure, integration and operation Competence requirements for proper operation

Table 4. Evolution of energy benchmarking systems.

Phase	Orientation	Expansion	Maturity
Focus	Gathering first experience with energy benchmarking	Expansion of energy benchmarking in the company	Anchoring, reviewing and adjusting energy benchmarking
User	Test user	Pilot users in several areas of the company	Established user groups in all areas of the company
Object	Selection based on readily available data	General consumption and pilot applications	General consumption and all relevant applications
Metric	Consumption data of main energy carriers and simple EPI	Elaborated EPI for overall and pilot applications	Elaborated EPI within an overall performance monitoring system
Data acquisition	Manual data acquisition	Semi-automated data acquisition	Comprehensive automated data acquisition
Data analysis	Analysis as required	Regular manual and semi-automated analysis	Regular systematic analysis and automated reporting

to ISO 50001. The first centralized energy control system for collecting, visualizing, analyzing and archiving energy data was established in the mid of the 1990s. Since then, energy management activities were successively extended. The responsibility for energy management lies with maintenance due to historical reasons. As a mean to introduce and maintain a continuous improvement of energy management, the company has a dedicated energy manager. In addition, an energy efficiency team supports his activities. Energy purchase and management are part of an overall central energy management system of the Viessmann Group.

An overview of the energy benchmarking activities of WESO is summarized in Table 5. As outlined in the conceptual part of this paper, several user groups in the company use information from the benchmarking. Top management uses benchmarking as a basis for evaluating the energy performance and targets in the company. These targets are followed up in different areas of the company. On the level of processes and equipment, benchmarking is used to analyse and compare energy efficiency and to perform condition monitoring. The task of the energy efficiency teams is to provide skills and knowledge to the other staff members and to sensitize them for energy-related issues. The most energy-relevant processes in the company are the melting process, the molding, blasting and de-dusting plants, compressed air generation, process and building heating, drives and general lighting. Primary energy carriers in the company include foundry coke, electricity and natural gas. As electricity costs have a comparatively high share in overall costs, they are in the focus of analysis. With regard to metrics, a central EPI in the company is the energy demand per ton of good product. Other indicators include the overall produced products, costs, turnover and other values. Due to the heterogeneity of the products, benchmarking is usually based on past performance. Where applicable, reference values are used as well. For data acquisition and analysis there is no general rule. All energy-data is however stored in a dedicated energy module within a larger database system that can be flexibly retrieved and used for the required analyses.

ADAM OPEL AG

Opel is one of the largest car manufacturers in Europe with about 37,000 employees at eleven sites and sales of more than one million cars and light-duty vehicles in Europe in 2012. Opel is among others certified according to ISO 14001 with an ongoing certification process for energy management according to ISO 50001. Opel is aiming at a reduction of energy demand due to rising energy costs and environmental concerns for quite some time. Monitoring became especially important during the economic crisis of 2008 when the specific energy costs per car drastically increased due to a drop in production. After labour costs, energy costs are the second largest block of costs that can be influenced by Opel. Opel's holding company

Table 5. Structure of energy benchmarking at WESO.

User	Top management	Areas in the company	Processes and equipment	Staff (shop floor)	Maintenance	Energy efficiency team
Aim	Compliance with energy policy; basis for valuation; target definition; cost reduction	Compliance with targets; identification of saving potentials	Identification of efficiency and energy optimum; general comparison	Awareness raising; corrective action	Optimization of operating conditions; maintaining grid quality	Local multiplier providing skills and knowledge; identification of potentials
Object	Primary and secondary energy carriers; areas in the company	Primary and secondary energy carriers in the area; energy intensive processes and equipment	Energy consumption of every energy carrier; process data	Generally relevant objects directly at the workplace	Consumption of equipment; quality of supply networks	All relevant energy consumption; load curves
Metric	Ton of good & produced cast iron; energy costs	Ton of cast iron; number of pieces; process time; operating hours	Theoretical minimum; share of stand-by	Number of pieces; process time; operating hours; share of stand-by	Output of products; share of base load	All relevant reference values
Data acquisition	Main measuring point(s) of every energy carrier; ERP	Measuring points at the equipment and processes in this area	Measuring points in the process per energy carrier; process control systems	Workplace in general	Main measuring points(s) of every energy carrier; process control systems	All relevant measuring points; ERP; process control systems
Data analysis	Daily to annual; mainly automated, sometimes manual	15 minutes to monthly; mainly automated	Real-time; automated	Real-time/shift; mainly automated	Real-time to annual; mainly automated, sometimes manual	Real-time to annual; automated and manual

GM has issued an overall target for 2020 to reduce worldwide specific energy demand per car by 20 % until 2020 as compared to 2010.

The energy management system of Opel has several levels. On a top level of energy management, an "energy and utility service group" develops strategies, it defines annual and monthly energy targets and breaks them down into energy targets for individual sites. Other responsibilities of this group include the collection, analysis and reporting of energy demand to technical management once per month, the coordination of benchmarking activities and best-practice sharing as well as European energy purchase. On the level of a site, a "site utility manager" coordinates the energy-related activities occurring there. This includes a breakdown of site targets to the production areas, the coordination of energy saving activities and the provision of locally produced energy like heat and compressed air. On the level of each production area, there is a staff member for energy-related issues, usually belonging to maintenance. His tasks include suggesting measures for improvements and to sensitise shop floor workers to energy related issues.

These and other users in the company use information from energy benchmarks (Table 6). Main energy carriers covered there are electricity, gas oil and heat. Corresponding central EPI for Opel are based on the energy consumption per car or unit. The above mentioned overall target value is translated to targets for individual sites and areas. Reporting at the level of sites generally takes place on a monthly basis. Experience of Opel has shown that older production sites can compete with newer sites in energy benchmarks if they have a sufficient discipline to shutdown consumers when not needed. However, due to differences in vertical integration, in supply infrastructure and due to differences in the structure and age of production equipment and buildings, a direct comparison of energy performance is not considered as a suitable option for benchmarking.

FREUDENBERG SEALING TECHNOLOGIES GMBH

Freudenberg Sealing Technologies (FST) is one of the leading suppliers for sealing technology with 22 sites in Europe, about 13,000 employees and an annual turnover of about 1.7 billion Euros. The continuous improvement of energy efficiency in the company is based on the FST-Energy-Saving-Cycle. This approach spans all 22 sites of FST and includes workshops, self-evaluations of sites, site-specific programs, a monthly cross-site monitoring and knowledge transfer between sites. A certification process according to ISO 50001 is currently ongoing.

Since 2009, the electricity demand of each site is monitored and benchmarked. The corresponding monitoring system aims at a transparent analysis of energy demand and it is used for planning, monitoring and controlling energy-efficiency measures. The aggregate information is also used by management for defining energy performance targets. Next to these users, there are different other groups that use benchmarking

Table 6. Structure of energy benchmarking at Opel.

User	Top management	Central energy management	Central energy management	Site Utility Manager	Staff member for energy in area	Staff (shop floor)
Aim	Reduction of energy costs; compliance with energy targets	Calculation of annual energy demand targets (based on long-term targets) und follow-up of targets	Analysis of current energy efficiency and progress of sites	Reduction of consumption; follow-up of site and area targets	Reduction of consumption; achievement of area targets; enforcement of discipline for energy-savings	Sensitizing staff members; enforcement of organizational energy saving measures
Object	Monthly/annual energy consumption per vehicle and site and throughout Europe	Monthly/annual energy consumption per production output	Hourly consumption values; averages of consumption during and outside production	Monthly/energy consumption per vehicle/unit, site and area; energy saving projects	Monthly energy consumption per car/unit; energy saving projects	Information for staff members; best practice; behavioural rules; visualization
Metric	Number of produced cars	Budgeted and current production schedule	EPI on consumption compared to average production	Number of produced vehicles resp. motors and gears	Number of units; process time; operating hours; share of stand-by	Number of information (internal brochures, group sessions)
Data acquisition	Monthly demand per energy carrier	Monthly demand per energy carrier	Interval data from suppliers or measuring points / energy management	Monthly demand and sub-metering per energy carrier	Sub-metering per energy carrier	Production areas; site
Data analysis	Monthly	Once a year; monthly follow-up	Weekly/when required	Monthly	Real-time to shift; mainly automated	Several times per year/when required

Table 7. Structure of energy benchmarking at FST.

User	Top management	Controlling	Energy purchase	Maintenance	General staff	Energy efficiency team
Aim	Target definition	Accounting control	Estimation of future energy demand	Condition monitoring	Sensitizing	Identification of saving potentials
Object	Electricity	All forms of energy	Electricity/ heating/ cooling	Machine/ process/ equipment; electricity/ heating/cooling	All forms of energy	All forms of energy
Metric	Energy analysis	Invoices/energy analysis	Energy analysis	Specific for machine/ process/ equipment	Energy analysis	Energy analysis
Data acquisition	Central	Central	Central	Local	Central and local	Central and local
Data analysis	Quarterly	Annual	Annual	Continuous	Quarterly/ annual	Monthly

information within the company (Table 7). The focus of the benchmarking activities is on electricity demand as this adds up to about 80 % of the overall energy demand at FST. A central EPI at FST is therefore the specific energy consumption per production cost. Overall site benchmarking information is collected on a monthly basis. Due to the heterogeneity of the production sites, no comparison between individual sites is carried out. Nevertheless, a historic benchmark is provided at a site and at aggregate level. This information is also used for sensitizing staff members.

Discussion

The application of the framework in the different companies illustrates that internal energy benchmarks are used in different ways. Some users in the companies apply benchmarks to monitor long-term strategies, others use it to analyse the development of energy performance for tasks closer to the operational level. This underlines the necessity to have a differentiated view on internal benchmarks when discussing them. Furthermore, it can be noted that despite the heterogeneity of the analyzed companies, there appear to be many similarities in how they use energy benchmarking – at least at the level of disaggregation that is considered in the analysis. The companies have, for example, similar user groups, aims and objects as well as approaches for data acquisition and analysis. The energy performance indicators, on the contrary, appear to depend on the specific activities of the companies. Yet it has to be noted that the commonalities may partly be a result of the common discussions in the working group and the common structure of the analysis.

In addition to such similarities in the description of the benchmarking activities, the following overall observation were made by the working group:

- Firstly, energy benchmarks should be oriented towards their users: If energy benchmarks shall provide helpful information to users, it is required to know the user and what he does with the results of the benchmarks. Otherwise, benchmarks may provide insufficient or in the worst case misleading information.
- Secondly, energy benchmarks require transparent information: If users are meant to take reasonable decisions, they have to be able to understand how an EPI was derived and what information it contains. If it is not possible to eliminate certain factors of influence from the EPI, the EPI should be accompanied by additional information describing effects that were not being eliminated.
- Thirdly, energy benchmarks are individual solutions: To a certain degree, it is possible to set up energy benchmarks across several companies using common guidelines. However, the level of detail and complexity considered in an energy benchmark are depending on the specific conditions in a company. Every company has to find an individual balance between benefit from the benchmark and the effort for setting it up and using it.
- Fourthly, energy benchmarks are living systems: In general, there are no stable or optimal implementations of energy benchmarking. They are always subject to changes in framework conditions and they have to evolve continuously to keep up with these changes.

With regard to the conceptual framework, its main benefit depends on its ability to provide insights on energy benchmarking practice in industrial companies. The framework has been derived from discussions on real-world energy benchmarking practice. Given that it was applicable to three companies of different industrial sectors, it likely allows covering the most important issues related to energy benchmarking practice in a structured way. It furthermore shows how some issues generally mentioned in EN 16231 can be implemented in practice. In this sense, it can help practitioners to gain a better understanding of energy benchmarking practice in general and to structure their own energy benchmarking activities in their companies, if needed. As the framework originates from practical experience and discussions on a working group, there is of course still much room left for additional research on how to extend it, how to refine it and how to further link it into theory. Nevertheless, it can serve as a first step to discuss energy benchmarking practice in industrial companies in more detail.

Conclusions

In this paper, internal energy benchmarking in companies was addressed and insights on the use of these benchmarks in practice were provided. For this purpose, an overview of literature and standards was given and a conceptual framework to structure energy benchmarking practice in companies was introduced. Based on this framework, it was possible to outline the energy benchmarking practices of three heterogeneous companies in a structured manner. The use of the framework can help practitioners to better understand their own energy benchmarking activities on the one hand and it may serve as a basis to structure energy benchmarking practice of companies on the other hand. In general, the analysis of benchmarking practice indicates that energy benchmarks in companies have to be analyzed and discussed from different perspectives. Suitably designed energy benchmarks can be helpful tools to monitor energy performance, to verify whether energy targets are met and to gain a better understanding on the impact of energy efficiency measures in practice. Yet this is only the case if the energy benchmarks are individually tailored, if they are adapted to their users, if they provide transparent information and if they evolve over time.

In addition, the practitioners in the working group pointed out some specific challenges that have not sufficiently been addressed:

- First, the costs and benefits of energy benchmarks seem to be largely unexplored. On the one hand, there is practically no limit for adding details to benchmarking systems. With the level of detail, the effort for data acquisition and analysis increases. Yet additional details only provide marginal additional benefits. It remains unclear how to find the most suitable level of detail for energy benchmarking systems.
- Secondly, it remains open how to best link EPI to other performance indicators or other benchmarks that are already established in companies.
- And finally, along with the aggregation of complex real-world data into single EPI, there is a risk to loose essential information to fully understand the meaning of an EPI. While it is possible to improve the quality of EPI by eliminating factors of influence or by supplementing information to the benchmarks, it is difficult to determine the suitability of certain EPI for specific objects. Therefore, there is a need to determine and assure robustness of EPI.

These challenges may serve as a basis for future research activities.

References and standards

Aaserud, S. B.; Sabo, S. L. (2013): Benchmarking Electricity Consumption and Carbon Dioxide Emissions from New York State's Industrial Sector. Proceedings of the eceee 2013 Summer Study on Energy Efficiency in Industry, 23th–26th July 2013, Niagara Falls, New York, pp. 2-1–2-12.

Adelaar, M.; Kynoch, B.; Lemoine, Y.; Robinson, T. (2005): Energy Benchmarking & Best Practices in Canadian Textiles Wet Processing. Proceedings of the ACEEE 2005 Summer Study on Energy Efficiency in Industry, 19th–22nd July 2005, West Point, New York, pp. 6-1–6-13.

Boyd, G.; Tunnessen, W. (2007): Promoting Energy Efficiency through Industrial Sector Benchmarking: The ENERGY STAR Approach. Proceedings of the ACEEE 2007 Summer Study on Energy Efficiency in Industry, 24th–27th July 2007, White Plains, New York, pp. 6-19–6-27.

Boyd, G.; Tunnessen, W. (2013): Plant Energy Benchmarking: A Ten Year Retrospective of the ENERGY STAR Energy Performance Indicators (ES-EPI). Proceedings of the ACEEE 2013 Summer Study on Energy Efficiency in Industry, 23rd–26th July 2013, Niagara Falls, New York, pp. 6-1–6-16.

Chan, D. Y.-L.; Huang, C.-F.; Lin, W.-C.; Hong, G.-B. (2014): Energy efficiency benchmarking of energy-intensive industries in Taiwan. Energy Conversion and Management, 77, pp. 216–220.

DIN EN 16231 – Energieeffizienz-Benchmarking-Methodik. Beuth: Berlin. 2012.

EWI 2010 (ed.): KMU-Initiative zur Energieeffizienzsteigerung. Begleitstudie: Kennwerte zur Energieeffizienz in KMU. Endbericht. Energieinstitut der Wirtschaft GmbH: Vienna.

Galitsky, C.; Radspieler, A.; Worrell, E.; Healy, P.; Zechiel, S. (2005): Benchmarking and Self-Assessment in the Wine Industry. Proceedings of the ACEEE 2005 Summer Study on Energy Efficiency in Industry, 19th–22nd July 2005, West Point, New York, pp. 4-36–4-47.

Hasanbeigi, A.; Price, L.; Lu, H.; Lan, W. (2010): Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: A case study of 16 cement plants. Energy, 35, pp. 3461–3473.

Hicks, T. W.; Dutrow, E. (2001): Energy Performance Benchmarking for Manufacturing Plants. Proceedings of the ACEEE 2001 Summer Study on Energy Efficiency in Industry, 24th–27th July 2001, Tarrytown, New York, p. 35–46.

IREGIA (ed.) (2009): Verbesserung der Energiekompetenz in KMU (Improving Energy Competence on SME-level). IEC-SME. Intelligent Energy – Europe (EIE). EIE/06/023. SI2.452319. Leitfaden für das Energie-Benchmarking. Mai 2009. IREGIA e.V.

ISO (2014): The ISO Survey of Management System Standard Certifications – 2012. Online. http://www.iso.org/iso/home/standards/certification/iso-survey.htm. Accessed: 18/03/2014.

ISO 9001 – Quality management systems – Requirements. International Standardization Organization (ISO). 2008.

ISO 14001 – Environmental management systems – Requirements with guidance for use. International Standardization Organization (ISO). 2004.

ISO 50001 – Energy management systems – Requirements with guidance for use. International Standardization Organization (ISO). 2011.

Ke, J.; Price, L.; McNeil, M.; Khanna, N. Z.; Zhou, N. (2013): Analysis and practices of energy benchmarking for industry from the perspective of systems engineering. Energy, 54, pp. 32–44.

Laurijssen, J.; Faaij, A.; Worrell, E. (2013): Benchmarking energy use in the paper industry: a benchmarking study on process unit level. Energy Efficiency, 6, pp. 49–63.

Lucas, F.; Putier, F. (2012): Energy benchmarking for the animal feeds sector in France. Proceedings of the eceee 2012 Summer Study on Energy Efficiency in Industry, 11th–14th September 2012, Arnhem, Netherlands, pp. 733–738.

Mattes, K.; Hirzel, S.; Schröter, M.; Rainfurth, C.; Rohde, C. (2012): Improving the research and knowledge transfer as a means to improve energy efficiency in production – the German approach Effizienzfabrik. Proceedings of the eceee 2012 Summer Study on Energy Efficiency in Industry, 11th–14th September 2012, Arnhem, Netherlands, pp. 63–71.

Phylipsen, D.; Blok, K.; Worrell, E.; Beer, J. d. (2002): Benchmarking the energy efficiency of Dutch industry: an assessment of the expected effect on energy consumption and CO_2 emissions. Energy Policy, 30, pp. 663–679.

Radgen, P. (2005): Comparing Efficiency: Internet-Based Benchmarking for Compressed Air Systems. Proceedings of the ACEEE 2005 Summer Study on Energy Efficiency in Industry, 19th–22nd July 2005, West Point, New York, pp. 3-119–3-129.

Ramirez, C. A.; Patel, M. K.; Blok, K. (2003): Energy Intensity Indicators for Non-Energy Intensive Industries: An Analysis for Germany, the Netherlands, and the United Kingdom. Proceedings of the 2003 ACEEE Summer Study on Energy Efficiency in Industry, 29th July–1st August 2003, Rye Brook, New York, pp. 1-97–1-108.

Ruth, M.; Worrell, E.; Price, L. (2001): A Process-Step Benchmarking Approach to Energy Use at Industrial Facilities: Examples from the Iron and Steel and Cement Industries. Proceedings of the ACEEE 2001 Summer Study on Energy Efficiency in Industry, 24th–27th July 2001, Tarrytown, New York, p. 149–160.

Saygin, D.; Worrell, E.; Patel, M. K.; Gielen, D. J. (2011): Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. Energy, 36, pp. 6661–6673.

Schmid, C. (2004): Energieeffizienz in Unternehmen. Eine wissensbasierte Analyse von Einflussfaktoren und Instrumenten. Zurich: vdf.

Taranto, T.; McKane, A.; Amon, R.; Maulhardt, M. (2007): Measure It, See It, Manage It: Using Real Time Data to Benchmark, Optimize, and Sustain System Energy Efficiency. Proceedings of the ACEEE 2007 Summer Study on Energy Efficiency in Industry, 24th–27th July 2007, White Plains, New York, pp. 2-155–2-172.

Tajthy, M. (ed.) (2009): (Ex)BESS. Expanding the Benchmarking and Energy management Schemes in SMEs to more Members States and candidate countries. Publishable Final Report. Grant Agreement number: EIE/07/103/S12.466702. Utrecht.

Tschudi, W.; Benschine, K.; Fok, S.; Rumsey, P. (2001): Cleanroom Energy Benchmarking in High-Tech and Biotech Industries. Proceedings of the ACEEE 2001 Summer Study on Energy Efficiency in Industry, 24th–27th July 2001, Tarrytown, New York, p. 209–219.

VDI 4402 – Benchmarking. Beuth: Berlin. 2000.

Wajer, B. H.; Helgerud, H. E. (2007a): Energy Management and Benchmarking in Small and Medium Enterprises. Proceedings of the ACEEE 2007 Summer Study on Energy Efficiency in Industry, 24th–27th July 2007, White Plains, New York, pp. 6-48–6-59.

Wajer, B. H.; Helgerud, H. E.; Packner, P. (2007b): Benchmarking and energy management schemes in SMEs. Proceedings of the eceee 2007 Summer Study, 4th–9th June 2007, La Colle sur Loup, France, pp. 1573–1582.

Acknowledgements

We gratefully acknowledge the support of Marvin Binder (RWTH Aachen), Christoph Kausch (perpendo GmbH) and Martin Grismajer (TU Berlin) for their support for elaborating and refining our work. We are further grateful for the support of the German Federal Ministry of Education and Research (BMBF) for its support under the joint project "Innovationsplattform Ressourceneffizienz in der Produktion – Effizienzfabrik" (project number 02PO2551) within the framework programme "Forschung für die Produktion von morgen". The responsibility for the content of this publication lies with the authors.