Key performance indicators for energy management in the Swedish pulp and paper industry

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ARTICLE INFO

Keywords:
- Key performance indicators
- Energy management
- Energy efficiency
- Pulp and paper
- Pulp and paper industry

ABSTRACT

The pulp and paper industry is one of the five most energy-intensive industries worldwide. In Sweden, most pulp and paper mills were certified with a standardized energy management system already in 2005. As Swedish mills have more than a decade of experience with energy management systems and energy key performance indicators (KPIs), studying KPIs within Swedish pulp and paper mills will enable both a state-of-the-art positioning of best-practice in relation to energy KPIs in pulp and paper mills, but also spot potential barriers and drivers in the utilization of energy KPIs.

This paper studies the current level of implementation and operationalization of energy-related KPIs in the Swedish pulp and paper industry. The results show a potential for improvement.

1. Introduction

Improved industrial energy efficiency is recognized as one of the primary means for reducing greenhouse gas emissions [1,2]. The potential for energy efficiency that is yet to be utilized is characterized as the energy efficiency gap [3,4]. Some of the barriers that constitute this gap are consequences of how the energy issue is organized within industrial companies, such as slim organization [5]. Furthermore, energy management has proved to be important in achieving the full potential of energy efficiency in industry [6–8]. For example, Backlund et al. [9] estimated the energy efficiency potential from management activities to be larger than the potential from implementing more energy efficient technology for energy-intensive industries. Energy management activities within an industrial company are comprised of several components, of which one is controlling energy end-use [10]. The controlling elements of energy management include data collection and monitoring, benchmarking energy performance, and performance evaluation. For some manufacturing companies, implementing an energy management system in accordance with the ISO 50001 standard is a natural first step. This holds true in particular for the energy-intensive Swedish pulp and paper industry, which implemented its first certified energy management systems in 2005, as a part of a Voluntary Agreement Program. This implementation was based on a Swedish energy management standard and companies were certified in accordance with that standard. However, it is important to make a distinction between energy management and an energy management system, as the latter is a tool that facilitates continuous work with energy management within a company [11].

One (of several) success factors in industrial energy management is the implementation of energy key performance indicators (KPIs) [12]. Different types of energy KPIs have to be developed and monitored to facilitate industrial companies in assessing and improving their energy performance [13,14]. By adopting energy KPIs for the continuous controlling of energy performance, areas for improvement might be identified [15]. As an energy management practice, the monitoring of energy KPIs provides a means for a company to assess its efficiency potentials and enables the visualizing of benefits from improvement measures [16].

Creating and applying relevant energy KPIs at various process levels is, however, a complex issue due to manufacturing industries’ integrated and complex production processes. This holds true in particular for energy-intensive process industries such as the pulp and paper industry. Research has emphasized specific industries’ need for appropriate energy efficiency KPIs for application at both plant and process levels [16]. The enabling of improved energy performance measurement is an important priority issue among energy-intensive industries, such as pulp and paper [17].

The pulp and paper industry is one of the five most energy-intensive industries worldwide. In Sweden, the sector uses half of the industrial energy use. Principally all the pulp and paper mills in Sweden were certified with a standardized energy management system already in 2005 within the Swedish voluntary agreement program Swedish
Program for Improving Energy Efficiency in Energy Intensive Industries (PFE). Among the Swedish pulp and paper mills, a majority have later implemented an ISO 50001-certified energy management system, within which the ISO standard requests the selection of suitable energy efficiency KPIs for monitoring energy performance (denominated Energy Performance Indicator (EnPI) in the standard) [18]. These are to be reviewed regularly and benchmarked with each company’s own established reference value. To help organizations meet this criteria, the ISO 50006 standard provides guidelines for how to establish, use and maintain KPIs [19]. A certification of ISO 50001 also requires that the company carries out an internal communication of its energy performance. The standard for energy audits of processes, EN 16247–3:2014, also states that energy performance indicators should be analyzed in the audit [20]. While this standard provides a solid general structure for the monitoring of energy performance, it does not contribute with guidance for the development of energy KPIs for specific industries. Energy-intensive industries lack the means for how to develop and define energy performance indicators, how to effectively monitor these, and how to link them with other energy management practices [17]. Although Stenqvist et al. [21] found that most Swedish pulp and paper mills monitor and report their specific energy use (SEC) for different energy carriers at a plant level, fewer mills monitor this at a process level. Hence, there is an industrial need for energy KPIs at the process level for measuring energy efficiency and supporting decision-making [16]. As the pulp and paper industry is one of the most energy intensive and the fact that Swedish mills have more than a decade of experience with energy management systems and energy KPIs, studying KPIs within Swedish pulp and paper mills will enable both a state-of-the-art positioning of best-practice in relation to energy KPIs in pulp and paper mills, but also spot potential barriers and drivers in the utilization of energy KPIs.

The aim of this paper is to investigate the degree to which energy KPIs are implemented in the Swedish pulp and paper industry. Following this, drivers for and barriers to developing and implementing energy KPIs are also studied. The aim has been broken down into the following research questions:

- How are KPIs developed and what type of KPIs are used for measuring energy performance in the Swedish pulp and paper industry, and how are these monitored, communicated and revised within companies?
- What drivers and barriers exist that enhance or hinder the utilization of energy KPIs in the work with improved energy efficiency within the Swedish pulp and paper industry?

The paper is structured as follows. First, an overview of energy KPIs in the manufacturing industry is presented. Second, the method adopted in this study is outlined. Third, the results and analysis, and finally a concluding discussion is presented.

2. Energy key performance indicators in manufacturing industry

The term “indicator” is used in various forms and with various definitions. An indicator can be any type of statistical value, most commonly a ratio, that provides some sort of indication [22]. In that sense, an energy efficiency indicator helps determine whether one entity is more energy efficient than another [22]. Such an indicator can have a wide variety of applications, depending on its purpose and area of use, but should provide information that facilitates the user’s analysis and decision-making. The degree of aggregation of an energy efficiency indicator can vary from the energy efficiency of a single industrial equipment up to sector-level indicators [23]. Industrial companies or public policy makers often develop and apply key performance indicators (KPIs) to achieve an indication of the performance of a process or an entity. Energy KPIs can, for example, have the purpose of monitoring change in energy performance after implementing a measure, investigate trends in energy intensity for an industrial sector, or be used as a benchmark against similar companies. In an energy-intensive company, energy KPIs generally have the role of monitoring, analyzing, and benchmarking the energy performance [24].

Energy intensity and specific energy use (SEC) are two commonly used energy efficiency indicators [25]. Energy intensity is an economic indicator for which the denominator is measured in economic terms, while SEC is a physical indicator [23,26]. Using energy intensity as an indicator is often more appropriate at an aggregated level. At any degree of aggregation, for benchmarking practices the developed KPI needs to account for structural differences in an industry. This includes the mix of activities and mix of products [26], i.e. the structure of energy end-use processes and end products of an industry implies different preconditions for companies regarding energy efficiency, which energy KPIs have to factor in. This is a difficult task due to pulp and paper companies diverging in both production processes (e.g. different types of grinder can produce the same end-product) and end-products (e.g. the same type of digester can be used for different qualities of pulp).

The ISO 50001 standard follows a Plan-Do-Check-Act (PDCA) approach, in which energy performance indicators are established during the planning phase and regularly reviewed. The types of energy indicators recommended in the standard for use range from simple parameters or ratios to more complex models. The standard also requires the organization to establish energy targets for relevant processes, consistent with its energy policy. A taxonomy for setting SMART targets was developed by Rietbergen and Blok [27] by examining different types of physical, volume, and economic targets, concluding that physical efficiency targets have a great deal of relevance for industry and allow for a comparison of environmental performance among firms. A physical efficiency target can be e.g. a benchmark target, where a company strives to belong to the top 10% most energy efficient among its peers, or a physical efficiency target, aiming to reduce the specific energy use by 20% in comparison to a reference year [27]. The ISO 50001 standard further states that the organization must have an action plan for how and when the targets are to be achieved.

Prior to developing energy KPIs in a company, a categorization for its energy end-use processes has to be defined. This include defining system boundaries, and by following the ISO 50006 standard, there are three levels of detail: (1) Individual facility/equipment/process, (2) system, and (3) organizational. The chosen level of a KPI, and its relevance, depends on the situational context and its main user [28,29]. Sommarin et al. [28] divide KPIs into three different levels: overall figures, support-process-specific figures, and production-process-specific figures. By developing a “tree” of energy KPIs and connecting KPIs at different levels of detail, factors affecting the overall figures can be identified. If KPIs are linked, a more comprehensive analysis is possible, facilitating management in deciding where to carry out improvement measures [29].

For the pulp and paper sector, a thorough investigation of the development of process-level energy efficiency KPIs in a Canadian Kraft pulp mill was made by Ammara et al. [30] by using the parameters affecting each department's energy use, and proposing the KPIs to be monitored. Such monitoring can facilitate the identification of inefficiencies and potential for improvement. Mateos-Espejel et al. [31] developed energy and exergy KPIs for application in a Kraft pulping mill, and also benchmarked different process steps to the sector’s average value using the KPI thermal energy use per oven dried tonne, to achieve an indication of which steps had an energy efficiency potential. Overall figures for the whole industry are presented in various reports (cf [32,33]), but there is no common base for how these figures have been derived (e.g. system boundaries). Laurijssen et al. [34] studied SEC at the process level in Dutch paper mills, but otherwise research

1 Specific, measurable, appropriate, realistic and timed.
studies regarding process-specific and production-specific energy KPIs with specific application to the pulp and paper industry are scarce. In order to carry out energy performance benchmarking between industrial companies, standardized energy KPIs at machine, process and plant levels are necessary [16] but that also requires trust and collaboration between plants [34]. Indeed, Swedish pulp and paper industry’s most commonly practiced method of benchmarking is between mills within the same company group, together with a process-level approach [36].

3. Method

A mixed-methods approach was adopted for this study, in which a questionnaire together with semi-structured interviews were used, similar to the study by Nehler and Rasmussen [36]. This approach provides a certain level of completeness and an increased contextual understanding, compared with adopting one method alone [38]. The questionnaire served as a quantitative part of the study to elucidate the existing driving forces and barriers in the Swedish pulp and paper industry, while the in-depth semi-structured interviews aimed to achieve a deeper understanding of the drivers and barriers. Kvale and Brinkmann [39] argue that interviews provide a better understanding of solutions to a certain issue and, according to Bryman [38], quantitative data collection with a reasonable response rate presents an overall picture of a population’s views. Both data collection procedures were carried out in parallel, but the interview process started before the questionnaire was finalized; hence, the first interviews influenced the formulation of certain questions in the questionnaire. As argued by Kvale and Brinkmann [39], this is a suitable approach in this type of research. The questions for both the qualitative and quantitative data collection were categorized into a number of themes connected to the research questions; namely: how energy KPIs are developed, what KPIs are applied, how they are applied, how they are monitored, how they are communicated, and how they are reviewed. In addition, the questionnaire assessed a number of statements regarding both drivers for and barriers to the development and use of energy KPIs. It was formed in a Likert-type scale using a range from 1 to 7. The Likert scale is a useful approach to study the degree of respondents’ agreement with a set of statements [38].

The ISO 50006 standards presents three different system boundary levels for energy KPI development: Process level, System level, and Organizational level. Following this perspective for pulp and paper industry, a corresponding three-level model for the companies’ adoption of energy KPIs are applied in the present study. The levels in this study are denominated process level, department level, and mill level. The interviews were conducted between February and April 2017. In total, 11 interviews were carried out at six different mills, representing pulp mills and integrated pulp and paper mills. Eight of these were face-to-face interviews, and three were conducted over the phone. The interviewees all had some sort of energy responsibility or energy related work, ranging from energy, production, and process engineers to energy coordinators and managers.

Prior to sending out the questionnaire, an energy responsible employee at the mill was contacted. This employee made the decision about who would be most appropriate to respond to the questionnaire. All operating Swedish pulp and paper mills were contacted, 50 in total. The quantitative data collection was carried out between March and September 2017. Out of 50 mills, 28 complete sets of answers were received, a response rate of 56%. This response rate is similar to studies such as Brunke et al. [40] and is what could be expected according to Trost and Hultikker [41].

Inspired by Schulze et al. [10], a model for KPI-operationalization was created. The model is presented in Fig. 1.

In the analysis, the assumption is made that, if an energy KPI has been developed, and is monitored as well as visualized and communicated, this implies that it is possible for all mills to undertake this type of action. This assumption implies that the “best practice” will be energy KPIs that are highly granulated, if such exist. Inspired by Thollander and Ottosson [42], an attempt is made to categorize the pulp and paper mills in terms of success, as regards the degree of adoption of energy KPIs in relation to their energy management practices. This is done by evaluating whether energy KPIs are monitored at the process level, and how frequently energy KPIs are revised. Given that most pulp and paper mills in Sweden monitor energy KPIs at the plant level [21], it is relevant to study the progress of process level monitoring. Measuring degree of success like this is a rough assessment, but it does provide an indication of potential improvements and ways forward. A majority of the pulp and paper mills in Sweden have implemented an energy management system already in 2005, due to participating in the Swedish Program for Improving Energy Efficiency in Energy Intensive Industries (PFE). ISO 50001 requires mills to follow up their energy performance with relevant energy KPIs, which makes it a relevant indicator to measure. The ISO 50001 standard does not specify at which aggregated level energy KPIs should be applied, nor does it state the frequency of visualization, therefore it is of interest to investigate how the pulp and paper mills have chosen to implement this part of continuous energy management work. Following the PFE came the Swedish Act on Energy Audits in Large Enterprises (EKL), which is the national implementation of the Article 8 of EU’s Energy Efficiency Directive (2012/27/EU). EKL requires companies to conduct an energy audit every fourth year, further motivating the monitoring of energy performance.

4. Results and analysis

4.1. Developing and monitoring of energy key performance indicators

The quantitative data collection shows that 93% of the responding pulp and paper mills have energy KPIs for their sites’ total energy efficiency, and 93% also had KPIs to monitor the most energy-intensive production processes. Energy KPIs for less energy-intensive processes were less common, with 39% of the responding mills monitoring these processes. The type of processes/equipment monitored were diverse, and both support and production processes are represented, a few examples being: space heating, certain process sections, and compressed air.

In the interviews, it became apparent that energy KPIs for monitoring energy end-use have been developed as an indirect consequence of the setting of energy targets. Setting energy performance targets for relevant functions and processes is mandatory for mills if the energy management system is certified according to ISO 50001. Thus, a better-structured energy target indirectly enhances the use of energy KPIs, as these are coupled with the energy targets. The questionnaire showed that 89% of the mills’ energy KPIs were connected to their energy targets. Energy targets are often set and updated annually for the mills, while a long-term energy target is more commonly set at the company group level. Furthermore, the energy targets for the mills are almost exclusively a volume target or a physical target. Economic targets, according to the taxonomy of Rietbergen and Blok [27], do not occur. Consequently, the companies’ energy KPIs are also, often, volume and/or physical efficiency KPIs.

It is important for process industries, such as manufacturers of pulp and paper, to minimize the number of failures and disruptions in their production lines. Production downtime can be either planned, e.g. for maintenance, or unplanned, e.g. when there is a lack of sufficient pulp
for the paper machine. By reducing the number and length of disruptions, the company benefits in terms of both energy efficiency and production rate. Thus, maintaining a high degree of uptime in production (availability), by reducing the number of production disruptions is important for pulp and paper mills to monitor, and consequently KPIs connected to this are applied. Table 1 shows that this is the most important indicator for the mills on department level. A majority monitor KPIs connected to uptime at the department level, which usually corresponds to e.g. a paper or pulp line. All of the non-integrated pulp mills monitored the rate of downtime at the department level. This correlates with Thollander and Ottosson [5], who found that technical risk, such as production disruptions, is regarded as the largest barrier to energy efficiency.

All non-integrated pulp mills and all non-integrated paper mills monitored the electricity use per tonne of produced pulp/paper for the entire mill, in contrast to integrated pulp and paper mills, where only 63% monitored this KPI. Physical indicators, i.e. steam or electricity use per tonne, are more commonly monitored by the mills than economic indicators, i.e. energy cost or added value per tonne. Generally in industry, it is less relevant to monitor economic indicators on a disaggregated level, in contrast to physical indicators (see e.g. Phylipsen et al. [26]). The results in Table 1 emphasize this.

While KPIs monitoring at the department level is common, fewer mills monitor energy KPIs at the process level. Only 50% of the non-integrated pulp mills monitored the rate of uptime at the process level. About 57% of all mills monitor at least one type of energy KPI from Table 1 at the process level. This contradicts the abovementioned results that 97% of the mills monitor energy KPIs for the most energy-intensive production processes. Depending on the size of the mill (i.e. integrated or non-integrated), this could conform to either the department or the process level, as shown in Table 1. Also, respondents might have responded positively to the general question for any type of monitoring of energy-intensive production processes they might have, or it may be that they monitor other types of KPIs than those present in Table 1. It was not possible to derive a specific reason for this discrepancy.

As mentioned by an interviewee, the most common KPI for energy performance benchmarking is SEC, i.e. energy use per produced tonne of pulp or paper, aggregated at the plant level, but where different end-product qualities are distinguished. Such figures can be found, for example, in the reference document for best available techniques (BAT) in the pulp and paper industry [33], or divided into different product grades, as in e.g. Worrell et al. [32]. Benchmark values at the process-level can also be found, often provided by the suppliers of equipment, but also present in research studies (cf [34]).

### 4.2. Visualization, communication, and revision of energy key performance indicators

The energy performance must be internally communicated according to the ISO 50001 standard. Regarding the pulp and paper mills’ energy KPIs, the questionnaire showed that the most common way of communicating them was through the company’s intranet (64%), followed by orally through meetings (54%). Other, less common, ways were through mail (11%), newsletter (11%), and other ways (11%). The last three were often complementary to the first two. In one mill, energy KPIs were not communicated at all (since none were monitored).

Fig. 2 shows that most mills visualize their energy KPIs on a monthly basis, for all employees, top management, and process operators. It is notable that, consistently for all paper mills, energy KPIs were visualized either on a monthly basis or not visualized at all. Hence, the continuous or daily visualization of energy KPIs are present in pulp mills and integrated mills only.

Regarding the revision of energy performance indicators, the majority of companies, 68%, stated that they revised annually. For 29%, the KPIs are revised monthly, and for one mill it was not applicable as

<table>
<thead>
<tr>
<th>Percentage of mills monitoring type of energy KPIs at three different aggregated levels.</th>
<th>Electricity use/tonne</th>
<th>Steam use/tonne</th>
<th>Energy cost/tonne</th>
<th>Added value/tonne</th>
<th>Uptime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill level</td>
<td>75%</td>
<td>64%</td>
<td>46%</td>
<td>11%</td>
<td>43%</td>
</tr>
<tr>
<td>Department level</td>
<td>71%</td>
<td>64%</td>
<td>25%</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>Process level</td>
<td>32%</td>
<td>18%</td>
<td>7%</td>
<td>7%</td>
<td>29%</td>
</tr>
</tbody>
</table>

**Fig. 2.** Number of mills visualizing energy KPIs for different groups, and frequency of visualization (N = 28).
they did not monitor any energy KPIs. This result follows the pattern of the annual energy target setting, but also shows that some companies revise their energy KPIs more often during the year.

4.3. Drivers for energy performance measurement and development of indicators

The most-mentioned important purpose, from the open question in the questionnaire regarding application of energy KPIs, is to monitor energy efficiency and energy end-use. This is also shown to be the largest driver among the given statements in the questionnaire (Fig. 3). Other commonly stated benefits, from the open question, are to receive input on how to reduce energy costs, observe trends, and identify and handle deviations in production.

As evident from Fig. 3, energy targets serve as the second largest driver for the development and use of energy KPIs. For mills to be able to monitor their progress towards the set targets, energy KPIs at the department level are necessary. The energy targets, set at the company group level or management level of a mill, generally have to be divided up and made relevant to each department. Given a physical, absolute target, this might imply a division of how large a share of the overall target each department should achieve.

Notably, the energy management system is only regarded as the fifth largest driver. This should be considered relevant due to the fact that a majority of the mills are ISO 50001-certified (and all mills have been certified in accordance with the former Swedish energy management standard), and that this standard states that energy performance indicators are to be implemented and monitored. Since the standard is of a general character, aimed at all industries, and lacks specific guidelines for how to adopt and apply energy indicators, energy managers at pulp and paper mills might not perceive it as particularly useful in this regard.

Even though finding opportunities to reduce energy costs was mentioned in the open question as an area of use for energy KPIs, the allocation of energy costs was ranked low as a driver. If allocation of energy costs does not exist, there is a risk that department managers will lack incentives to pay attention to energy management due to the fact that energy efficiency measures will not benefit the single department [42]. One reason for the lack of interest in energy cost allocation might be that cost management generally is a task for controllers, not energy managers (who are the respondents in this study). Also, allocation of energy costs in the pulp and paper industry is a complex issue [21]. One means to address this is to simplify the calculations, making the energy cost value less accurate, but still useful as an indicator of motivation. For example, one interviewed production engineer in a mechanical pulp production department stated, regarding the on-line monitoring of energy costs: “For this kind of cost monitoring, electricity would be the major affecting factor. If we could include only the electricity [cost], then we would be quite close to the truth.” When managers monetize and visualize the energy cost of energy end-use processes, and expose cost-saving potential in managing activities (finding the right operating ranges in parameters), operators are much more likely to act accordingly.

The EU reference document for BAT is ranked as the lowest driver and is not perceived as relevant for pulp and paper mills. This document faces difficulties as its purpose is to provide figures for all mills in one type of product manufacturer (Kraft mills, for example). The figures in the BAT document might not be relevant for a mill to benchmark with, due to the uniqueness of their processes, or other small differences. Another issue is outdated figures, and even though the reference documents are updated regularly, providers of equipment can offer more up-to-date figures for a certain production process.

The interviews discerned a variety of drivers for the application of energy KPIs, not necessarily aligning with the results in Fig. 3. The answers included: increasing the structure, reducing the total energy costs, and allocation of costs. Generally, it seems that implementing relevant energy KPIs for monitoring energy end-use and energy costs is under development, both in the wake of the PFE, and also due to the Swedish Act on Energy Audits in Large Enterprises (EKL), which imposes a structured energy review on the companies.

4.4. Barriers to energy performance measurement and the development of indicators

The most-mentioned important barrier, from the open question in the questionnaire regarding the application of energy KPIs, is lack of resources to monitor energy efficiency and energy end-use. Other commonly stated barriers were that energy KPIs are not prioritized, and lack of skills.

Sivillet al. [17] found lack of skills, lack of resources, and information overload to be challenges to the development of energy performance measurement in Finnish energy-intensive industry. The results of this study show that lack of resources is the major barrier in the Swedish pulp and paper industry; however, too much available data is ranked low.
Due to the complexity of production processes, defining accurate KPIs that provide usable information for both energy managers and operators takes a lot of time. In line with this, the second largest barrier is not prioritized, implying that developing and applying energy KPIs is less important than other energy management activities. It is notable that all the studied barriers, except lack of resources, had a mean value of less than 4.

The lack of relevant energy KPIs is not perceived as a major barrier. This was found by Bunse et al. [16] to be a need for industry in general, with few KPIs being suitable at the plant or process level, and there is a lack of standardized indicators. However, the findings by Bunse et al. [16] are mostly useful for the non-energy intensive industry such as mechanical engineering companies. Therefore, energy managers at pulp and paper mills may believe that it is better to develop them in the context of the specific mill rather than using a standardized indicator. This is the approach taken by, for instance, May et al. [15]. Furthermore, as indicated in Table 1, a majority of the mills seem to not monitor KPIs on process level, which according to the ISO 50006 standard is an important mean for manage energy performance. This implies that the mills may not perceive monitoring of KPIs as beneficial for the energy management system. Adding to this is the fact that the largest barrier to adopt energy KPIs is lack of resources, and the management seems to not find it beneficial to adopt relevant energy KPIs as they do not allocate resources to the matter.

However, the process of implementing energy KPIs that is possible for the user to act on is quite difficult. While setting an aggregated energy target for the entire mill is straightforward, defining relevant energy KPIs at a detailed level demands knowledge and competence, and knowledge was mentioned as one of the greatest barriers, alongside lack of competence. The result that lack of relevant KPIs is not an important barrier suggests that it is more important for the pulp and paper industry to acquire a higher level of knowledge of the processes rather than having a pre-defined set of energy KPIs to monitor.

### 4.5. Assessment of successful key performance indicator operationalization

Similar to the procedure employed by Thollander and Ottosson [42], a categorization of the successful practice of monitoring energy KPIs as a management practice is shown in Fig. 5. The highest category comprises the high performing mills where energy KPIs are monitored at a process level and revised monthly or more often. The second category includes medium performing mills that meet the same criteria, but where the energy KPIs are only revised annually. The remaining companies represent the third category (low performing).

With the assumption that, if one mill can undertake an energy KPI, it is possible for all mills, Fig. 5 shows that about 25% of the pulp and paper mills can be considered successful according to the stated criteria, indicating a large potential for improvement. At the same time, a large proportion monitors the most energy-intensive production processes (93%), and about 90% have related KPIs to their energy targets, but few mills revise KPIs on a monthly basis. Instead, the most common procedure is annual revision, resulting in most mills being medium performing.

### 5. Concluding discussion

The development of relevant energy KPIs and procedures for monitoring energy performance in industry is an essential element of successful energy management work. The pulp and paper industry is of particular interest to study as it is one of the five most energy intensive industrial sectors. A unique methodological approach to studying energy KPIs for an industrial sector is employed in this paper, which covers the Swedish pulp and paper industry. Existing drivers for and barriers to the development and implementation of energy KPIs are investigated, as well as the current status of revising and monitoring energy KPIs. The success of energy KPI operationalization is also assessed, and while the pulp and paper mills in Sweden have a consistent monitoring of energy KPIs, the results indicate that there is still vast potential for improvement.

Many of the monitored energy KPIs are physical indicators measured at an aggregated level, e.g. the specific energy use of a pulp mill. Research shows that establishing clear KPIs that can be followed up, is an important factor for successful in-house energy management in industry [12]. The model used in this paper for evaluating success in the Swedish pulp and paper industry shows that only 25% of the studied mills are considered to apply sector best practice regarding the
establishment of energy KPIs. Hence, there exists a large potential for improvement, which is hindered primarily by a lack of resources and lack of knowledge and competence.

The Swedish pulp and paper industry raise the difficulty to identify energy KPIs that expresses the actual performance of a certain process. Indeed, indicators that show explanatory factors to low performance and opportunities to improvement are missing. This adds on to previous research in energy-intensive industry in general [17]. The development of relevant KPIs is hindered by lack of resources which in the present study is found to be the largest barrier. While studies, such as [30], provide important contribution to the development of relevant KPIs, it is also highlighted both in interviews in the present study as well as in other research studies [17] that each mill is unique and needs individual treatment in this regard. To overcome the barrier to developing new energy related KPIs, Swedish pulp and paper mills could be encouraged to engage in joint research collaborations e.g. through networking policy programs. Also, given the Swedish policy program PPE’s improvement of pulp and paper mills’ energy management, and specifically the monitoring of electricity use, future policy programs addressed towards pulp and paper industry could require companies to adopt energy KPIs for specific company department, or even individual processes, as defined by the mills themselves. This would encourage mills to actively work with energy efficiency improvement for certain areas in the mill that are deemed important by the mills in terms of energy efficiency.

An important limitation to this study is the interpretation of the term “process”, as included in the questionnaire; i.e., the use of the term can refer to an entire set of production processes within a mill, such as the Kraft pulping process [30,33], but it can also refer to an individual step, such as cooking in chemical pulping [21,33]. It was not determined which perspective the respondents in this study were applying when answering the questions, which leads to uncertainty in the results derived from process level questions.

Our study outlines a preliminary model for evaluating the best practice levels of energy KPIs. The model was applied in the Swedish pulp and paper industry, but the developed model is potentially suitable for application in other industrial sectors.

The developed preliminary model is the major general outcome of our paper. One generalization of the paper’s result is that if the pulp and paper industry, one of the most energy-intensive sectors in the world, only to a limited extent have adopted best-practices when it comes to monitoring energy KPIs, this finding most likely holds for other industrial sectors as well. Further research is emphasized for studying energy KPIs and its adoption in other sectors and countries as well, together with further development of the preliminary model for energy KPIs.

Acknowledgements

This work was supported by the Swedish Energy Agency, research project no. P40491-1, and the Swedish Environmental Protection Agency, research project Carbonstruct, project no. 802-0082-17. We also thank the respondents for giving freely of their time to answer our questions.

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