Energy management in the Norwegian sawmill industry

Marcus R. Olsson, Ph.D.
NTI (Norwegian Institute of Wood Technology)
Børrestuveien 3
0373 Oslo
Norway
marcus.olsson@treteknisk.no

Keywords

energy management system, sawmills, data monitoring, visualisation, energy efficiency action plans, energy use

Abstract

In recent years, Norwegian sawmills have introduced simplified energy management systems. The current paper is based on seven of these energy management implementations. The sawmills covered in the paper produce wood products from timber using electricity and heat in the production process, the heat being produced from internal by-products. Historically, the price for electricity has been low in Norway and there has been a low demand for the by-products outside of the sawmill. Hence, the energy costs have been a small part of the production cost and energy management has not been a top priority. However, in the coming years, it is anticipated that the electricity price and the demand for by-products will rise, increasing the importance of energy management.

The primary goal of an energy management system is to reduce the energy use of the production process. In the sawmills studied, the energy savings achieved are in most cases results of structured and persistent energy management, gradually eliminating unnecessary energy use. Big investments in new and more energy efficient equipment also contribute to energy savings but are not as important as an organic evolution of an energy efficiency culture in the company. The resulting energy savings vary between the sawmills, but the typical sawmill achieves 5–10 % energy savings (kWh/m^3 sawn products) in the first 1–2 years. In the following years, the sawmills set an energy saving goal of typically 2 % per year; a goal that is normally reached. The sawmills that have successfully implemented energy management have (1) a dedicated energy team with an appropriate amount of resources, (2) an energy management approach incorporated in the daily routines, and (3) a top management that enquires energy efficiency results. These sawmills also use strategic partners in different specialised fields to support the energy team.

Introduction

There are currently 18 sawmills in Norway with a production above 50,000 m^3 of sawn products (Skogstad 2020); all of them use softwood (spruce and pine) as raw material. The Norwegian wood products industry stood for 2.6 % (2.1 TWh) of the industrial energy use in 2018 (SSB 2020). The sawmills' energy use is dominated by the drying process since almost 100 % of the products are kiln dried in Norway.

Sawmills produce wood products from timber using electricity and heat in the production process, the heat being produced from internal by-products. Historically, the price for electricity has been low in Norway and there has been a low demand for the by-products outside of the sawmill. Thus, it has been natural to use the by-products for internal heat production. Traditionally, the by-products have been considered to have a low economic value and, in some cases, it has been a question of just getting rid of the biomass to avoid additional costs.

Hence, energy costs have been a small part of the sawmill's total costs[1] and, consequently, energy management has not been a top priority. However, energy management will likely be

1. The energy costs are typically 10–20 % of the sawmill's total costs, excluding timber costs.

more important in the coming years, as it is anticipated that the electricity price and the demand for by-products will rise. As an example, the Norwegian Water Resources and Energy Directorate (Gogia et al. 2019) projects a rising electricity price, a pre-requisite being a continuously strong and well-functioning market for carbon emission trading. The reasons for an anticipated rise in demand for woody biomass are plans for biofuel refining factories (e.g. Biozin Holding AS 2020), a projected higher demand for biomass for energy purposes (Börjesson et al. 2017), and emerging other biomass-based fossil-replacing technologies.

Previous studies (Andersson et al. 2011, Olsson et al. 2013) have shown that energy management is not common as a separate organisational function in Swedish and Norwegian sawmills. It is, naturally, more common to have an energy manager in larger sawmills than in smaller sawmills. However, in recent years, energy management has been introduced more widely in Norway, mainly depending on national requirements and national support programmes encouraging energy management and sustainability. The importance of energy management as an aspect of general sustainability for the industrial sector is elaborated further in a Ph.D. thesis by Rasmussen (2020).

Many sawmills act as independent small and medium-sized enterprises (SMEs) even though they may be part of a larger sawmill group. Therefore, the discussion in Palm and Backman (2020) on ineffective communication as an important barrier to improving energy efficiency in SMEs is valid also for most Norwegian sawmills. One of the results from the study by Palm and Backman (2020) is that in projects where SMEs are actively engaged and can discuss problems and results with peers, the energy-efficiency results are better than in projects where this is not included as a part of the project.

In this paper, the current state of energy management in Norwegian sawmills is presented, as well as the typical energy use of the industry. Some important take-aways from energy management in Norway during the last eight years is also presented.

National requirements and support for energy management

There are national requirements for energy management in the Norwegian industry. As an example, Norwegian industries with a biomass boiler needs a flue gas emission permit to be allowed to use the boiler. One part of this permit states that the industry must have a system for energy management to achieve continuous, systematic, and goal-oriented assessment of measures to achieve an energy efficient production process. The energy management system must be introduced according to Norwegian standards (in this case NS-EN ISO 50001:2018, ISO 2018). The flue gas emission permit is followed-up by the county administrators.

There was also a support programme for introducing energy management in the Norwegian industry between 2012 and 2019 (Enova 2020). During this support programme, the industry could apply for k€20–100 funding to introduce an energy management system. The company received the funding after the one-year project was finalized, given that the energy management system was in place and that the company could present an equivalent value of in-kind man-hours. The funding could be used for purchasing and installing equipment for energy management, as well as engaging third-party energy consultancy firms supporting energy management.

SawEnMS – simplified energy management in sawmills

The simplified energy management system used in the sawmills referred in this paper is called SawEnMS, a sawmill-adapted energy management system. SawEnMS was developed during the European project Ecoinflow 2012–2015 (Lycken et al. 2015). SawEnMS is based on the international standard ISO 50001:2011 (ISO 2011), but has been adapted for the sawmill industry. The SawEnMS handbook (Lycken et al. 2015) has not yet been updated to match the latest version of the standard ISO 50001:2018 (ISO 2018). The published reports and papers from the Ecoinflow project is currently available on the homepage of the project (Ecoinflow 2015).

The core of SawEnMS is to centralise energy management around an energy team that meets regularly with participants from different departments of the sawmill. The energy management team is responsible for incorporating energy efficiency in the daily routines of the sawmill.

As a summary, SawEnMS consists of seven steps (Olsson et al. 2014), listed below and visualised in Figure 1.

1. Appoint an *Energy management team*.
2. Develop an *Energy action plan*.
3. Perform an *Energy review* (map the energy use).
4. Decide on *Energy targets*.
5. Decide on an *Energy policy*.
6. Develop *Routines for energy efficiency* in everyday work.
7. Develop routines for *Internal communication*.

The steps above should be repeated regularly to reach an ever-higher level of energy efficiency.

Current state of energy management in Norwegian sawmills

Currently, around 10 of potentially 28 sawmills in Norway have introduced some level of energy management. At least nine of these sawmills have used SawEnMS as a basis for the implementation. NTI (Norwegian Institute of Wood Technology) has been involved in seven of these implementations of energy management, and the current paper is based on these seven sawmills. To respect commercial interests of the sawmills, the text below contains sparse details on the sawmills in question.

The main reasons for the sawmills to introduce energy management were national requirements together with a national support program for promoting energy management. After introducing energy management, the sawmills have appreciated the accompanying cost savings and a generally better control of the production process and its energy performance.

ENERGY USE IN NORWEGIAN SAWMILLS

During the last years of energy management, a lot of data on energy use have been collected in the Norwegian sawmill industry. In the latest energy management projects, 35–40 elec-

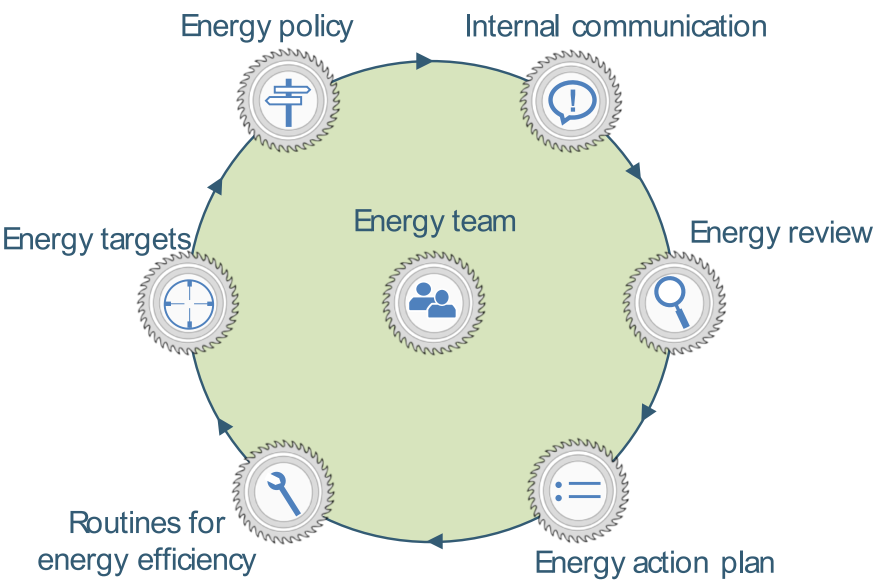

Figure 1. The SawEnMS wheel, consisting of seven steps supporting energy management (Lycken et al. 2015).

tricity meters and 10–15 heat meters were installed in sawmills producing 100,000–150,000 m^3 of sawn wood products per year. The data is normally logged once per hour, but more detailed data can be collected if desired. This setup gives an appropriate level of details to enable the sawmill personnel to follow the energy use and to divide the use between the largest energy users.

In Figure 2, a typical distribution of energy use per energy carrier is depicted based on energy measurements in four Norwegian sawmills. This chart depicts data for sawmills with a biomass boiler and diesel trucks, and a mix of progressive and batch kiln dryers. All the sawn wood is dried in kiln dryers to typically 18 % moisture content[2]. In these sawmills, the electricity, diesel and heat delivered to the processes are measured directly. The amount of biomass fed to the biomass boiler is estimated based on the measurements of produced heat in the boiler. In the conversion from heat produced to input of biomass, a typical efficiency of the boiler is used together with a typical heating value of the biomass (based on a typical moisture content of the biomass). The biomass volume fed to the boiler is also manually logged by the operators, but these numbers are considered more uncertain than the estimated numbers from the heat measurements.

For Norwegian sawmills with an additional boiler with diesel fuel (used in the coldest days of the winter) the share of diesel is somewhat higher, but rarely more than 6 % on a yearly basis. Sawmills with only batch kilns may have a higher share of biomass-based heat since batch kilns generally need more heat than progressive kilns. The number of old kilns versus new kilns is also important since new kilns often includes heat recycling and better insulation than older kilns.

The ratio between heat and electricity is to some degree dependent on the heating system for the sawmill. If most departments of the sawmill are heated with electric radiators, the share of electricity is naturally higher and vice versa. The numbers in Figure 2 only includes the sawmill and its internal production processes, not external heat deliveries to e.g. a district heating system.

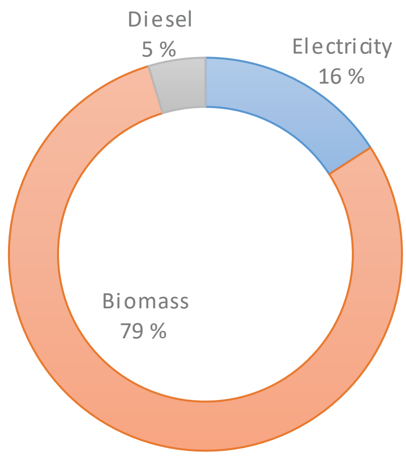

Figure 2. Measured energy use per energy carrier in four Norwegian sawmills in 2015–2019.

The specific energy use of the sawmill processes per energy carrier varies significantly between sawmills. In Figure 3, the span of energy use is plotted and compared with two previous studies in Scandinavia. It is important to note that the specific energy use may not be comparable between sawmills or within a sawmill over time depending on what is included in the specific numbers. For example, the energy use of the drying process is highly dependent on the amount of water that is removed from the wood in the kilns. Some sawmills that kiln dry may dry to 18 % moisture content whereas other sawmills may dry to 12 % or even 6 %, depending on the end-use of the products. Additionally, Norwegian and Swedish sawmills kiln

2. In the wood industry, it is common to use the definition *moisture content* = m_m/m_0, where m_m is the mass of the moisture in the wood sample and m_0 is the mass of the oven-dried wood sample.

dry close to all their products, whereas sawmills in other countries may not kiln dry at all.

Nevertheless, the specific energy use numbers show how much energy that is used to produce 1 m^3 of sawn wood products, and that is the *de facto* energy bill the sawmill must pay to produce that volume. To enable comparisons over time, the sawmill must make a more detailed analysis of what is behind the numbers. Larger sawmills have, in general, a lower specific energy use than smaller sawmills due to the comparative advantage of economy of scale.

The data presented by Horn (2008) and Andersson et al. (2011) represent 16 sawmills in Norway and Sweden, respectively. The current paper presents data from detailed energy measurements during 2015–2019 at four sawmills in Norway. Since the current study presents data from fewer sawmills than the other studies, it is natural that the span in specific energy use of the current paper is smaller. There are little data on the sawmills included in the papers (e.g. the size of the sawmills or the type of drying kilns), most likely since these data are confidential.

The previous studies (Horn 2008 and Andersson et al. 2011) include inherent uncertainties regarding the specific biomass use. The reason for this is that these studies were more general in nature compared with the current study where energy measurements were the main part of the study. In the previous studies, some of the sawmills have based their biomass use on the biomass volume fed into the boiler and some on the amount of heat produced. The biomass volumes are uncertain since they are estimated manually by each operator that feeds the boiler with biomass by wheel loader. In addition, there are uncertainties associated with varying moisture content of the biomass, resulting in varying heating values of the biomass. For the sawmills that measure the heat produced, the uncertainties lie primarily in the estimated boiler efficiency and the heat measurements themselves. In the sawmills of the current paper, deviations of 20–30 % are common between the measured heat produced and estimated heat produced before the measurements were started.

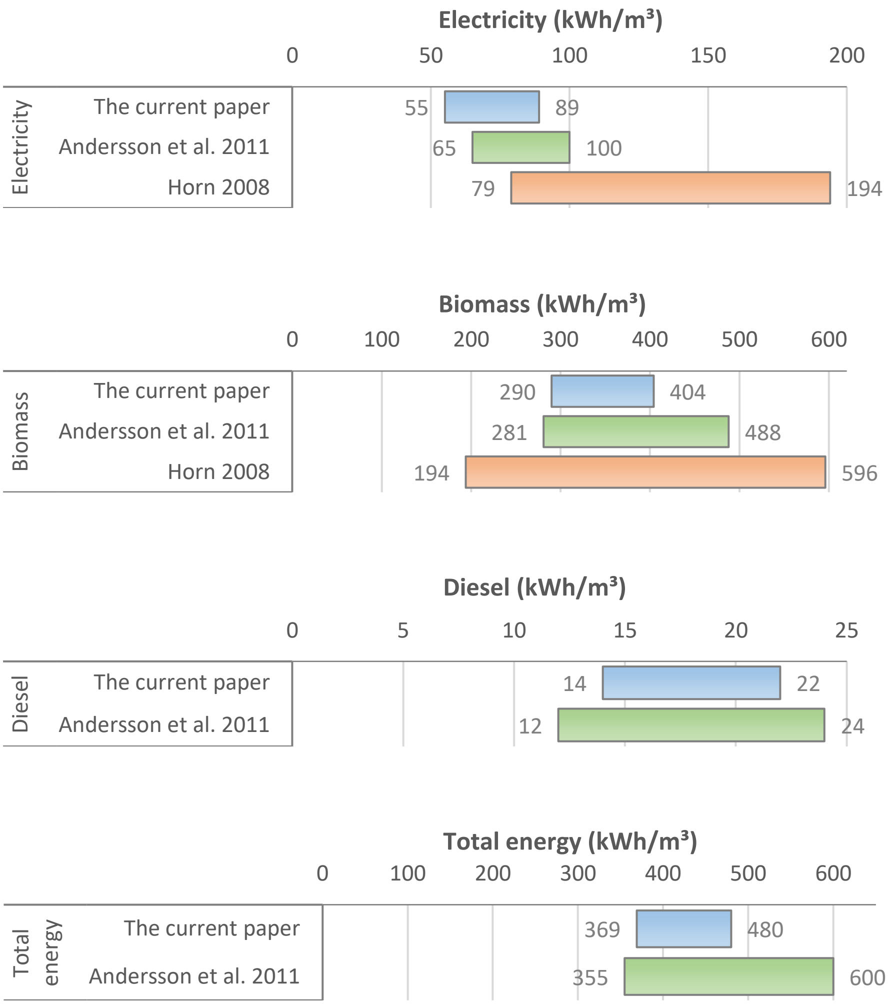

Figure 3. Span of specific energy use (kWh/m^3 sawn wood) in the current study, compared with two previous studies. The biomass energy represents the amount of biomass fed to the biomass boiler, applying a boiler efficiency of 80 % for the current paper and Andersson et al. (2011). The data presented by Horn (2008) was expressed explicitly in biomass fed to the boiler.

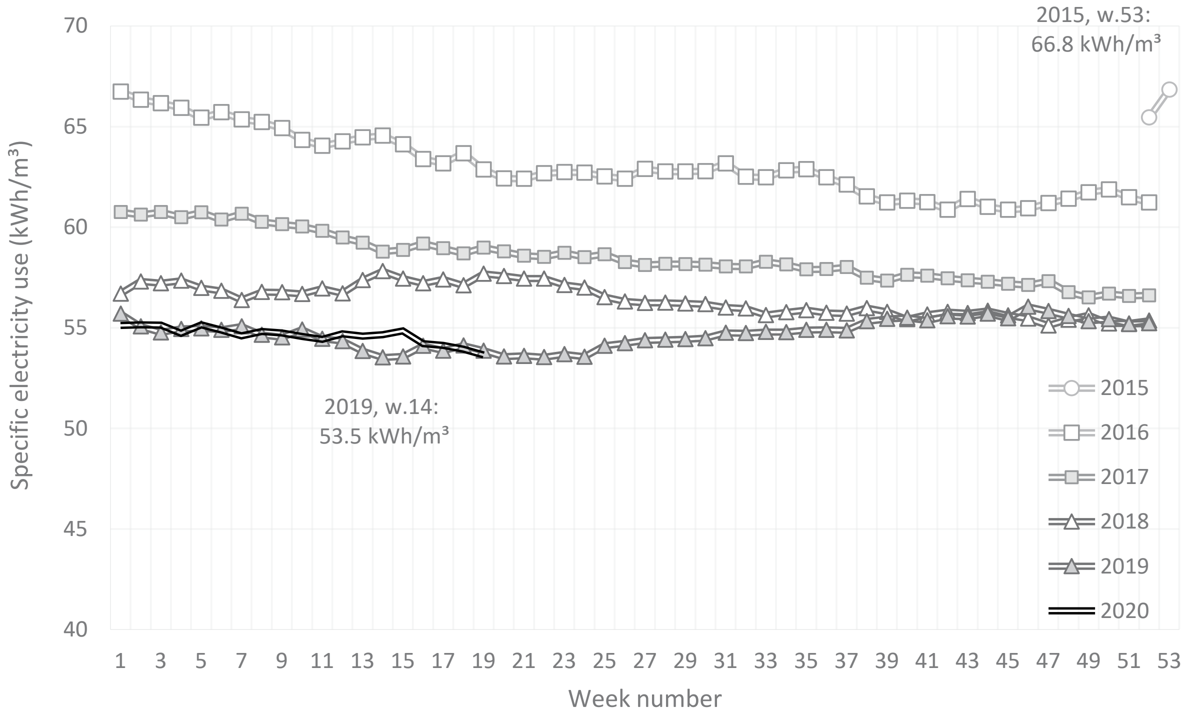

Figure 4. Specific electricity use (kWh/m^3 sawn wood, moving average for 52 weeks) in 2015–2020 for the sawing department in one of the sawmills that have successfully introduced energy management. The ordinate is truncated to elucidate the differences between the years.

RESULTING ENERGY SAVINGS FROM ENERGY MANAGEMENT

The resulting energy savings vary between the sawmills in the study, but the typical sawmill achieves 5–10 % energy savings (kWh/m^3 sawn products) in the first 1–2 years. In the years to come, the sawmills set an energy saving goal of typically 2 % per year; a goal that is normally reached.

One of the sawmills that have implemented SawEnMS has managed to reduce the electricity consumption steadily since the start of the project in 2015 to the late spring in 2019, see Figure 4. The moving average of the specific electricity use (∑ electricity / ∑ production for the last 52 weeks) for the sawing department was reduced from 66.8 kWh/m³ in 2015 (week 2–53) to 53.8 kWh/m³ in 2019 (week 14, 2018 to week 14, 2019). This is a reduction of 20 %, or on average 6.6 % per year. Since then, the energy use has been more constant around 55 kWh/m³.

In this case, the sawmill has not invested in any large energy efficiency measures. The most important measure has been to visualise the energy use and to follow it up regularly to avoid unnecessary energy use. There is no apparent reason for the more constant energy use after the spring in 2019. It may be that the sawmill has reached the energy efficiency limit for the current production process. To achieve a higher energy efficiency, it might be needed to make investments in new and more energy efficient equipment.

THE ENERGY TEAM'S WORK PROCESS

In the following sections, a general work process for the energy team is suggested. Different variations of this work process have been proven successful in the sawmills studied, but the work process must be adapted to the sawmill in question. Each individual sawmill has already established routines and other work processes, and it is important that the energy management system is integrated with the existing systems as much as possible. In this way, it is more likely that the energy management work will be applied and successful.

The general work process of the SawEnMS approach is previously described in Figure 1. The energy team should review each part of "the SawEnMS wheel" at least once a year and adapt them to the current strategy of the sawmill. In many cases, the documents representing each step of the process is left unchanged, but it is nevertheless useful to get back to them for a refreshed overview.

The SawEnMS wheel gives a framework for energy management, but a more detailed work process is needed to increase the likelihood of successful energy management. In the list below and in Figure 5, a general work process is presented for introducing an energy management system and maintaining it.

1. The top management should appoint an energy team (3–5 people).
   - Pick people from different departments of the sawmill.
   - Pick open-minded people with an interest in efficiency and improvements in general.
2. Visualise and discuss concrete targets for the project.
   - What are ideal plots of energy use that can be used daily by the sawmill personnel?
   - What departments of the sawmill are a natural basis for energy mapping?
   - In what level of details should the energy use be presented to different departments of the sawmill?

Start of a new year

- Update the energy management documents.
- Update the energy map of the sawmill.
- Compile and analyse the most successful energy-saving measures.
- Follow-up yearly energy use versus energy use targets.
- Update the energy use targets.

Energy team meetings

- Follow-up current energy use versus targets.
- Follow-up the task list and prioritize tasks for the next meeting.
- Discuss lessons learnt since the last meeting.

Between the meetings

- Carry out tasks according to the task list.
- Visualise and analyse energy use per department.
- Collect suggestions for energy-saving measures.
- Implement energy-saving measures.
- Estimate energy savings and profitability of significant measures.

Figure 5. A typical, yearly work process for the energy team.

3. Set a framework for meetings in the energy team.
   - Decide on a meeting frequency.
   - Appoint a person in charge of convening the meetings and schedule the next three meetings in the calendar.
   - Appoint a person in charge of taking notes during the meetings. Most sawmills use a task list as meeting notes to reduce the administration of the team.
4. Use a task list between the meetings to ensure progression of the work.
   - Each task should have a person in charge of the task and a deadline.
   - Use realistic deadlines and specific, manageable tasks. It is better to complete at least one task than to plan for ten tasks that are not even started.
5. Divide the sawmill into departments for an energy mapping draft.
   - Examples of sawmill departments are given in Lycken et al. (2015).
6. Decide on an approximate number of metering locations.
   - At this stage it is important to include an electrician if he/she is not part of the energy team.
   - Include the existing energy measuring equipment from e.g. the electricity supplier.
7. Decide on what energy data information system should be used for data collection and visualising the energy use.
8. Begin the installation of energy meters.
   - Begin with the meters that are easy to install and most important for the energy mapping.
   - The in-house personnel should know as much as possible on the installation and locations of the energy meters since this knowledge is invaluable during the energy use analysis at a later stage.
   - Visualise the location of the energy meters in summarising schematics to prepare for an easier energy use analysis.

MANAGEMENT OF ENERGY DATA

The management of energy data is important to ensure smooth data analysis. The workflow should be as automatic as possible with little manual input to reduce the possible sources of error. In the studied sawmills, the data analyses are made in Excel or directly in the cloud portal. The reason for Excel is primarily that the sawmills have other data tables and analyses in Excel. Future enhanced data visualisation could include Power BI or any other tool for visualising datasets from different sources. In this case, the cloud portal has simple capabilities of data analyses, which is enough for some sawmills.

In the current study, the energy data is sent directly from the data loggers in the sawmill to a cloud portal. As for the production volume, these data were previously sent by email (using Excel attachments) to the head quarter for compilation. A goal of the current study was to change as little as possible in this routine. The solution was to use a macro in Excel to send two emails: one to the head quarter and one to the cloud portal. In this way, the manual work was reduced compared with the previous workflow of manually attaching the file to an email, add recipients and then send it. To extract data from the cloud portal, data reports are automated by email weekly. The visualisation process is automated by using Power Automate, Power Query and Pivot tables with slicers in Excel.

The somewhat cumbersome data workflow described above has been in use in different versions since 2015. There are certainly smoother workflows available today, however, this workflow has been concluded as the most cost-efficient and flexible solutions for these sawmills at the time of implementation. The data analyses and data workflow could be enhanced if the cloud portal could perform all analyses needed.

TYPICAL ENERGY-SAVING MEASURES

A general conclusion of the current study is that energy savings are the result of structured and persistent energy management, gradually eliminating unnecessary energy use. Naturally, big investments in new and more energy efficient equipment also contribute to savings. However, in the current study, big investments are not as important as the organic evolution of an energy efficiency culture in the company.

An implementation of energy management in a company goes through different phases. In the beginning of the work, the important thing is to get a grip of the energy use. Where are the greatest energy users and where do we need more detailed energy measurements? Some steps can be taken in the beginning of energy management to find unnecessary energy use:

- Perform a night owl walk (Räftegård et al. 2014) around the sawmill. This means to visit all departments to find unnecessary energy use after production hours. The reason for performing the night owl walk after production hours is to make it easier to hear and see hidden energy users.
- If a night owl walk of the entire sawmill is too daunting, start with one division of the sawmill. Investigate if the energy use could be reduced all the way to 0 kWh off-production hours. Prioritize the biggest energy users of the sawmill in the start.
- The energy team should develop a systematic approach for handling suggestions on energy-saving measures. The simplest systems could in many cases be the best systems. Several of the sawmills in the current study use an excel table as to-do-list for energy efficiency. Other sawmills already have a task list system that energy management is integrated with. There are often many suggestions on energy savings from the operators around the sawmill. Experience from the sawmills in the current study shows that suggestions that have been lying around for years have finally been realized when the structured work of energy management is in place.
- Begin the installation of measurement equipment as early in the project as possible. As soon as measurements are available, visualise the energy use and try to break it down as detailed as possible to enable a better understanding of the numbers. In the current study, measurements alone accounted for 5 % savings in the first years. Awareness of the energy use changes behaviour and can create a healthy competition within the company to reach the set targets for energy efficiency.

General energy efficiency tips for industrial factories are also valid for sawmills:

- When the measurement system is in place, unnecessary energy use can be found by plotting the energy use of the sawmill divisions off-production hours. What must be running and what should be turned off? Pay special attention to energy use during start and stop of equipment and during breaks of the workdays.
- Pneumatic air systems: Only use pneumatic air systems when there are no other solutions to the specific operation. When this is ensured: Seal leakages, use valves to section the pneumatic air system, and use pneumatic air specialists for investigating if different pressure may be possible in different sections of the system. There could also be economic savings by using an optimisation system for controlling when different compressors should be turned on and off.
- Does the sawmill pay the electricity provider for reactive electric power? If that is the case, there could be significant savings by installing capacitor banks to reduce reactive power. In the sawmills of the current study, the pay-back period of capacitor banks was below one year. It is preferable if the energy measurements of electricity can visualise reactive electric power.

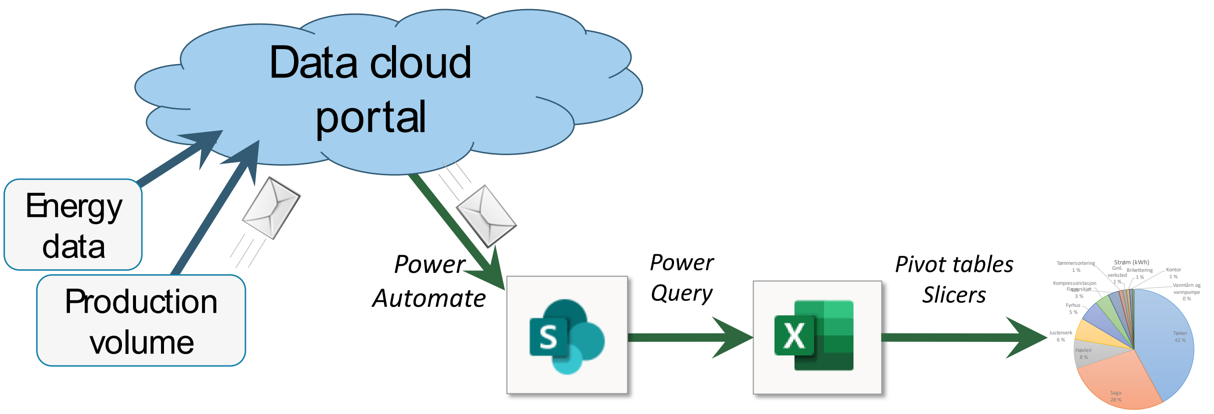

Figure 6. Data flow from energy data and production volume to visualisation of key performance indicators. The sawmills in question prefer Excel for the data analyses.

- Plot the specific energy use (kWh/m³) versus the production volume. The usual pattern is that the higher production volume, the lower specific energy use. Pay extra attention to data points where the pattern from the other data points is not followed: What was special during this production period? It is preferable to follow-up this plot at least weekly to increase the likeliness of remembering what was done during the analysed period. In general, the best way of reducing the specific energy use (kWh/m³ sawn wood) is to achieve a higher production rate; one of the reasons being that the energy base load is spread on more m³ of sawn wood.

Important factors for successful energy management

The author's experience from introducing energy management in sawmills during the last eight years shows that the start of an energy management project is incredibly important. The start of the project often sets the pace for the rest of the project. Thus, the sawmill's most important topic regarding energy efficiency must be top priority in the start. In this way, the likeliness of an engaged energy team and top management is higher. Furthermore, the author recommends that a third-party project leader is driving the introduction of energy management. In this way, the energy management introduction can be driven in parallel with the production at the sawmill, and the energy management system can be woven gradually into the daily routines.

The results from the study by Palm and Backman (2020) is in alignment with the current paper: in projects where SMEs (small and medium-sized enterprises) are actively engaged and can discuss problems and results with peers or a third party, the energy-efficiency results are better than in projects where this is not included as a part of the project. In the current work, the most successful sawmills are part of a sawmill group that share experiences openly within the group.

During the last eight years, the Norwegian Institute of Wood Technology has been involved in seven implementations of energy management in Norwegian sawmills. Some of these sawmills have been successful in achieving a structured energy efficiency culture and some have failed to some degree. Based on these experiences, it is concluded that important factors for successful energy management are:

1. The energy team should consist of engaged team members, and the team should have a high degree of autonomy.
2. The energy management approach should be incorporated in the daily routines.
3. The top management should be interested in the work and enquire about energy efficiency results.
4. Strategic external partners should be used as support.

ENERGY TEAM

The energy team should consist of engaged staff with an ability to spread the word on energy efficiency within the company. The energy team should have the mandate and resources to act with a high degree of autonomy regarding implementation of energy efficiency measures. It should be clear for all employees how to propose energy efficiency measures to the energy team and the employees should be informed on the progress on the specific measure. If suitable, the employees should take an active part in implementing the efficiency measure.

The energy team is responsible for carrying out cost-benefit analyses before and after an efficiency measure. It is important to evaluate if the measure actually achieved the profitability that was initially estimated. These evaluations should then be used to enhance future cost-benefit analyses.

Some sawmills feel it is essential to use a task list system that is jointly shared across the sawmill. The tasks are then tagged with sawmill division and type of task, e.g. maintenance, energy management or daily production operation. In this way, it is possible for all employees to get an overview of planned work in different parts of the sawmill and thereby decrease friction between work that goes on in parallel. This can raise the general awareness and sense of mutual co-operation and teamwork in the sawmill.

To ensure a progression of the work, it is normally appropriate that the energy teams meets at least once a month. To simplify the administration around the meetings, the task list is commonly used as meeting notes. Each task is appointed to one person in charge of the action, a deadline for the next follow-up, and an estimation of the finalization date for the task.

INTEGRATION OF ENERGY MANAGEMENT IN THE DAILY ROUTINES

It is important that energy management is incorporated in the daily routines. Otherwise, energy management risks being an off-duty activity performed in parallel with the ordinary work.

- All employees should feel that they can take active part in specific energy efficiency measures and propose enhancements along the way.
- Energy measurements and energy use visualisations should be automatized with a minimum of manual input.
- The energy measurements should be detailed enough to enable a follow-up of energy efficiency measures. A minimum level of details is to enable follow-up of the main energy using divisions of the sawmill.
- Markings or celebrations should be arranged to recognize when energy efficiency goals are met and exceeded. This is important to show all personnel that energy management is on-going and appreciated by the top management.
- There should be routines in place for continuous reporting to all employees on the energy efficiency progress. It is normally appropriate to include energy efficiency discussions in weekly morning meetings.

TOP MANAGEMENT INVOLVEMENT

There should be routines in place for the energy team to report on progress to the top management. The top management should enquire about progress and be interested in the progress. To show the importance of energy management, all employees should feel that the top management prioritizes and values the energy efficiency work.

USE OF STRATEGIC EXTERNAL PARTNERS AS SUPPORT

Frequent advice from companies which have implemented energy management is to contact strategic partners in different specialised fields to save time and frustration. Suitable strategic partners can also be a good source for training the employees to increase the competence in-house. The experience from the participating sawmills is that it is often cheaper and faster to learn from the appropriate experts in specialised fields than for the employees to train themselves. As an example, equipment vendors are in many cases interested in being more tightly included in the improvement work.

It is also evident that having an external project leader on regular visits keeps the energy efficiency work going in a better way than having an in-house project leader. This is especially important in the first part of the energy management implementation when a third party can help setting deadlines and appointing responsible persons for each measure. When the energy measurement system is in place, the need for an external project leader is not as evident. Nevertheless, yearly visits can give important advice for the ongoing work to solve specific problems and ensure the continuation of the work. A third party can give feedback from the outside without constraints and sometimes present ideas to drive the work forward. In some cases, a first-assumed "dumb question" can help the work going forward.

Conclusions

In the current paper, implementation of energy management in seven Norwegian sawmills have been analysed. The sawmills that have successfully implemented energy management have (1) a dedicated energy team with an appropriate amount of resources, (2) an energy management approach incorporated in the daily routines, and (3) a top management that enquires energy efficiency results. A common piece of advice from the sawmills is to use strategic external partners as support for specialised fields of knowledge.

The resulting energy savings vary between the sawmills in the study, but the typical sawmill achieves 5–10 % energy savings (kWh/m^3 products) in the first 1–2 years. In the years to come after implementing energy management, the sawmills set an energy saving goal of typically 2 % per year; a goal that is normally reached. The energy savings are in most cases results of a structured and persistent energy management work, gradually eliminating unnecessary energy use. Big investments in new and more energy efficient equipment also contribute to energy savings but are not as important as an organic evolution of an energy efficiency culture in the company.

References

Andersson, J.-E., A. Lycken, R. Nordman, M. Olsson, O. Räftegård and T. Wamming (2011). State of the art – Energianvändning i den svenska sågverksindustrin. Stockholm, Skellefteå och Borås, Sverige, SP Sveriges tekniska forskningsinstitut.

Biozin Holding AS. (2020). "Clean energy from Norwegian forests, http://biozin.no/." Retrieved 2020-04-20.

Börjesson, P., J. Hansson and G. Berndes (2017). "Future demand for forest-based biomass for energy purposes in Sweden." *Forest Ecology and Management* 383: 17–26.

Ecoinflow. (2015). "The homepage of the Ecoinflow project, http://www.ecoinflow.com/." Retrieved 2020-04-20.

Enova. (2020). "Energiledelse for transport, industri og anlegg (Energy management for transport, industry and buildings)." Retrieved 2020-03-16, from https://www.enova.no/download/?objectPath=upload_images/E60CAC1D-F1294134A99489A0FDE6D626.pdf.

Gogia, R., H. Endresen, I. E. Haukeli, J. Hole, H. Birkelund, F. H. Aulie, A. Østenby, M. Buvik and B. Bergesen (2019). Langsiktig kraftmarkedsanalyse 2019–2040 (Long-term power market analysis 2019–2040), NVE, Norges vassdrags- og energidirektorat (The Norwegian Water Resources and Energy Directorate).

Horn, H. (2008). ENØK i varme- og tørkeanlegg i trelastindustrien, Norwegian Institute of Wood Technology.

ISO (2011). NS-EN ISO 50001:2011 Energy management systems – Requirements with guidance for use. T. I. O. f. Standardization.

ISO (2018). NS-EN ISO 50001:2018 Energy management systems – Requirements with guidance for use. T. I. O. f. Standardization.

Lycken, A., D. Nilsson, M. Olsson, S. Diederichs, J. Welling and T. Guennec (2015). SawEnMS Handbook.

Olsson, M., A. Lycken, H. Horn, Y. Kleiven, M. Vuillermoz, X. Blaison, S. Diederichs and J. Welling (2013). Description and evaluation of existing Energy Management Systems in sawmills.

Olsson, M., A. Lycken, D. Nilsson and H. Horn (2014). *A sawmill-adapted energy management system*. eceee 2014 Industrial Summer Study: Retool for a competitive and sustainable industry, Arnhem, the Netherlands.

Palm, J. and F. Backman (2020). "Energy efficiency in SMEs: overcoming the communication barrier." *Energy Efficiency*.

Rasmussen, J. (2020). *Management control for sustainability Activities and procedures for energy management in industrial companies*.

Räftegård, O., M. Olsson and D. Nilsson (2014). Night Owl Walk: A quick guide for finding low-hanging energy fruits, SP Technical Research Institute of Sweden, the guide is part of the Ecoinflow SawEnMS handbook.

Skogstad, P. (2020). Internal statistics at the Norwegian Institute of Wood Technology.

SSB. (2020). "Energibruk i industrien (Energy use in industry)." Retrieved 2020-03-16, from https://www.ssb.no/energi-og-industri/statistikker/indenergi.

Acknowledgements

This paper was financed by the Norwegian Institute of Wood Technology. The previous projects on energy management in Norwegian sawmills were financed by the participating sawmills and Enova (the Energy Agency of Norway). The author wants to thank Enova, the sawmills and all the staff participating in the energy management projects during the last eight years. I also want to thank Henning Horn (Norwegian Institute of Wood Technology) for quality assurance in all the above-mentioned projects and for proof-reading the current paper.