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Identifying energy and greenhouse gas hotspots in the supply network of an industrial equipment supplier company

Master's thesis in Supply Chain Management

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A study at Bror Tonsjö AB

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Abstract

In this thesis, a case study was carried out to identify the energy hotspots and greenhouse gas emissions in the supply network of the back wheel hubs, designed for buses, of the case company, Bror Tonsjö AB. The chosen research approach is analyzing the real-time data from energy usage by machines and supply operations. The case used in this thesis is the production flow from the supplier of the case company to the production processes at the industrial equipment production plant in Kungälv, Sweden.

This thesis aims to both identify the energy hotspots and GHG emissions in the supply network, and also to produce recommendations to reduce energy usage and carbon emission based on the findings from the case company. In this thesis, our recommendations are focused strictly on an environmental perspective.

The study was performed with semi-structured interviews combined with observations, and energy measurements using an energy logger. The data collected through these methods have been used to estimate the energy requirements to produce back wheel hubs and the carbon emissions generated from the processes and operations related to this.

The study concludes that there are some potential energy hotspots in the production cell. In particular related to the drilling machine of one of the investigated production cells where the effect measuring showed some irregularities that should be further investigated. The biggest difference in the energy efficiency of the compared cell was however that one of the cells had a lot more time spent in standby due to individual machines requiring attention. Due to the production being sequence-based, if one machine stops, the entire Cell production stops for an equivalent amount of time.

Another potential hotspot in terms of energy usage is that some energy spikes in the cell have been identified.

As for the GHG emissions, the transportation of the products is a potential hotspot. The fuel used by the heavy trucks is not optimal from an environmental standpoint. The study concludes that even though these conclusions should be more thoroughly investigated, decreasing these identified hotspots should be achievable.

Key words: Supply network, energy usage, Carbon emission factor, GHG emissions

Acknowledgement

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Abbreviations

- CO₂- Carbon dioxide
- CO₂e - Carbon dioxide equivalent
- EEA- European Environmental Agency
- kg - Kilogram
- KPI - Key Performance Indicator
- kW - Kilowatt
- OEM - Original Equipment Manufacturer
- SCM - Supply Chain Management
- VSM- Value stream mapping
- 3PL - Third party logistics

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1.Introduction

Chapter one introduces the background of the thesis and presents the problem statement. This chapter also provides information about the case company and the scope and context of this thesis. Thereafter, it continues with research questions and finally ends with limitations of the thesis.

1.1 Background

Climate change is undisputedly one of the greatest challenges of the human race. It is already affecting millions of people worldwide in terms of health, access to food and clean water, reducing our life expectancy (Hauer & Santos-Lozada, 2021). The most noticeable impacts can be found in developing countries where more extreme weather and natural disasters have led to humanitarian catastrophes. It is an established fact that the results of climate change are mostly caused by human actions and that it is a threat to our very existence, growing more difficult to deal with the longer we wait. In 2021, the United Nations held a climate change conference in Glasgow called COP26 where all the nations of the union reaffirmed the historic Paris Agreement (UN, 2022) that was established in 2015, but also added new deals and announcements (UN, 2021).

One of the issues from an industrial standpoint is that most businesses are driven by profit. Companies have generally not developed in terms of sustainability unless it has also been profitable. Adapting to society's demands of sustainable goals puts a huge stress on many companies to change.

As product information is becoming easier to find and compare, the end customers are making more calculated purchasing choices, increasing the pressure on sustainable products and supply chains (Gong et al., 2019). As a result of this, a global trend of companies shifting to a more sustainable focus is taking place. Many global companies have started to implement sustainability parameters such as Carbon Dioxide (CO₂) emissions equivalents and energy usage into their KPIs (CDP, 2021). Some companies have brought in external auditing of their operations in order to trace their environmental impact both as a competitive factor, but also to forestall new upcoming governmental regulations that might emerge from COP26.

Most companies are a part of a big supply chain consisting of different companies. One company's operations seldom represent the majority of the environmental impact of the product. Thus when attempting to trace the environmental impact of the product, the entire supply chain has to be taken into account, which can prove to be very complex. This does, however, not necessarily mean that individual actors cannot impact others along the supply chain of which they are operating. Due to the nature of supply chains, every link can impact the links closest to them, both upstreams towards the commodity, and downstream towards the end customer or user (Scott, 2019).

Every process and operation that takes place in the supply chain of a product has an impact on the environment. It can be directly connected to the process or operation itself. For instance, a diesel truck will release greenhouse gasses (GHG) as it is being used. There are also indirect impacts that are not as visible. They could be a consequence of fulfilling the prerequisites or external regulations regarding the process, for instance producing steel capped shoes for operators as a mandatory safety precaution or developing a production lane in order to implement the operations.

1.2 Case company

This master thesis focuses on Bror Tonsjö AB. A family-run company formed in 1962 in Kode. The company is currently owned and run by the third generation Tonsjö. Tonsjö's core values are honesty, innovation, job satisfaction and long-term business relationships. The workshop is roughly 6000m² and the workforce consists of about 100 employees. Tonsjö specializes in processing various metals and metallic compounds. Their products range between oil pumps for hydraulic uses to wheel hubs for trucks. They supply roughly 700.000 products to 50 different customers yearly. Tonsjö positions themselves to establish long-term customer relationships where they are a part of the entire process, from prototype to finished product. They tailor-make their production by using customized automated production lines to fit their customer's needs and are a tier-1 supplier to mostly the automotive industry, but also develop products towards the maritime business. Tonsjö's supply base is spread out mostly in the European Union. Most of their customers are operating in Sweden. This study concerns the production of roughly 140000 back wheel hubs per year.

1.3 Aim

The aim of this thesis is to present recommendations for reducing the emissions regarding GHG and energy usage of the processes in the supply chain by identifying potential hot spots. The recommendations will target these potential hotspots and could lead to further streamlining the operations and processes of the focal company. Hopefully, this thesis will be used to make more scientific based decisions regarding how the operations and processes can be more effective. Decreasing GHG emissions and power usage is something that we all have to consider and include in our future development, both on a private and professional level. One of the first steps towards improvement is knowing your current situation. Hopefully this thesis will shed some light and give inspiration on how one can approach similar issues and incorporate that in ones' operations.

1.4 Scope

The scope of this thesis will be analyzing the supply chain of the back wheel hubs of Tonsjö. From the material used, to the transports from supplier X, throughout the inhouse operations of Tonsjö, to the transportation to customer Y. The scope can be seen in figure 1 below.

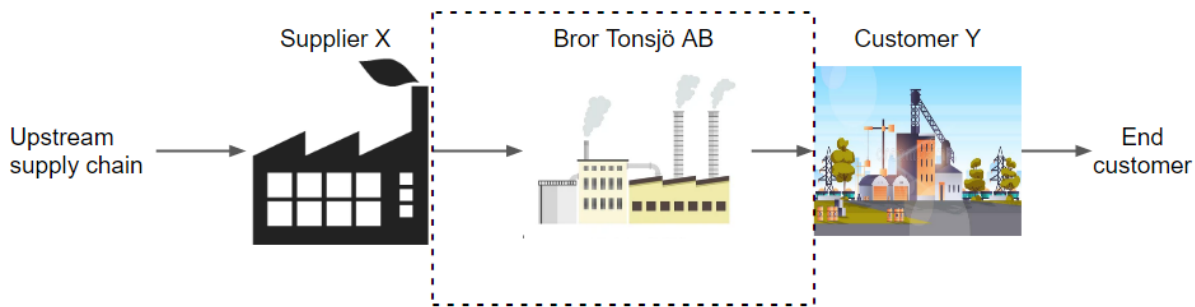


Figure 1: Schematic view of the scope of the thesis

1.5 Research questions

In order to fulfill the aim and scope of this project, a few research questions were developed.

1. How much energy is required for producing the back wheel hubs of Tonsjö?
2. How much Greenhouse gas emissions are generated by producing the back wheel hubs of Tonsjö?
3. Are there any sustainable strategies that could be recommended to reduce the energy usage and GHG emissions in the processes of the back wheel hubs supply flow?

1.6 Limitations

Due to time restrictions, this master thesis report is limited to one of Tonsjö's products, namely the truck back wheel hubs produced for Customer Y. The thesis will investigate the processes and operations of the back wheel hubs from Tonsjö's supplier (in this report referred to as supplier X) located in Arvika, to their customer (in this report referred to as customer Y) located in Södertälje. Thus not analyzing the upstream suppliers and downstream OEM impacting the product. The result is based on the extent of useful information we can gather, both from the focal company but also supplier X and customer Y. If we cannot access reliable, relevant data the result might differ from the truth. Some of the accessible information will be based on interviews and therefore the information could be subjective.

2. Theoretical framework

To accomplish the objective of this thesis, the literature review was conducted during this thesis period, which gives the foundations to do this research. This chapter will present the outcome of literature reviews to support the theories and methods used for the data collection and analysis. The structure consists of the supply network and energy consumption in the supply chain operations. First of all, beginning with the supply chain management and continuing with the topics relevant to the supply chain. After that, the fundamental understanding of supply chain management, energy value stream mapping, and process life cycle assessment would be presented.

2.1 Supply chain management

Supply chain management (SCM) has come to light during the 1980s after that it has raised awareness around the world. SCM obtained its demand in academic research and also in industrial practices; a huge number of research studies were issued within SCM regarding manufacturing, distribution, and transportation (Mentzer, J. T et al., 2010, and Ross 1998). Supply chain management has three angles based on the conceptual framework such as supply chain network structure, business processes, and management components (Lambert, D. M., & Cooper, M. C. 2000). Lambert and Cooper (2000) explain that the supply chain network structure contains the member organizations and the links between these organizations. Business processes are the tasks that make a particular output to the customer. The management components are the managerial variables that combine the processes across the supply chain.

2.1.1 Supply chain structure

The supply chain network explains the flow of goods and information that affects the supply chain. Cooper, M. C., et al., (1997) define the supply chain network structure as an uprooted tree rather than a pipeline or chain. The customers and suppliers are the branches and roots of the tree. The three features of supply network structure are members of the SC, supply network structural dimension and the different sort of process links in the SC (Lambert, D. M., & Cooper, M. C. 2000). The focal firm connects with all the supply chain members directly or indirectly. The primary members of the supply chain are the ones who work to add value to the product, and the secondary members are who provide additional support in terms of resources, knowledge, and assets like banks, third-party logistics providers, or warehouse space providers. (Lambert, D. M., & Cooper, M. C. 2000). Three dimensions of the network structures are the horizontal structure, vertical structure, and horizontal positions of the focal firm. The focal company can connect with its suppliers and customers in these dimensions. The upstream and downstream of the supply chain are interconnected with different processes across the supply chain.

2.1.2 Transport and logistics activities in the supply chain

Transport and logistics activities play an indispensable role in the supply chain. It includes all sorts of activities like packing, moving, and consolidating goods. These activities are carried out either between departments in companies or between companies and these activities are also linked with other supply chain activities. Shapiro and Heskett, (1985) explained the logistics activities that make sure to achieve the demands with the seven R's such as "right product/service, right quantity, right condition, at the right place, at the right time, for the right customer at the right price". Dubois, A., et al., (2004) explained that these activities are never secluded and this shows the relationship between the activities. It also acts as a bridge between suppliers and customers.

A traditional way of transporting solid goods is by using standardized euro-sized wooden pallets that are stacked in trailers, containers or trucks. However, as plastic pallets have become cheaper and as the availability has increased, it has become a viable option for transportation. According to V. Roso (unrecorded lecture, november 2021), there are both benefits and drawbacks with the various pallets. Some of the pros can be seen in figure 2 below.

Wood and Plastic pallets

- Cheaper than plastic
- Can hold more weight
- Can be repaired
- Recyclable
- Clean
- Durable
- Resistant to moisture
- Is not affected by bugs



Figure 2: Benefits of Wood and Plastic pallets

2.1.2.1 Internal logistics

Internal logistics contains all activities tied to moving the raw materials within the firm. It drives all kinds of management activities including storage, distribution of goods, and moving goods from storage to production lines to match the internal demands (Shepherd, C. and H. Günter, 2010). It can be divided into three aspects; processes, resources, and firm. All these three aspects are part of the logistics system. The movement of goods and information is done through a series of processes and the resources include the machines and personnel requirements to run those processes. Lastly, the firm will do all the planning and control activities to manage the internal logistics.

2.1.2.2 External logistics

External logistics is the movement of goods between suppliers and customers. It includes information sharing, coordinating package movements, and analysis between partners. To handle the external logistics operations, most firms outsource their activities to third-party logistics service providers. The different types of transport used for external logistics operations are road, rail, sea, and air; either the goods are transported by one type throughout the chain or a combination of transport types called intermodal transportation (Jonsson & Mattsson, 2016).

2.1.2.3 Transportation modes

Different modes of transportation used in logistics operations are road, rail, and sea transportation. In addition to these modes, Intermodal transportation is also used in logistics operations which is the combination of two or more modes of transportation (Mark Philpott, 2017). These modes can be chosen based on the distance, goods type, and transport cost. For example, road transportation is the most accessible and viable mode to transport the goods even in conditions like a small volume of goods and adjustments in routes, but road transportation is the most expensive than rail and sea transportation. It will also increase the environmental impacts.

2.2 As-Is analysis

As-Is analysis is a method of analyzing the current processes in a company. It can be used to focus on anything between an entire firm or one process within departments. For example analyzing one Cell manufacturing process to map the current processes in that Cell. The objective of this method includes cost reduction, process improvements, or implementation of new standards. Schwegmann, A., Laske, M. (2003) stated that the As-Is process modeling can be used in projects to identify the core processes and improvement areas. In particular, this model gives the outline of the current situation and can be used as input for identifying potential improvements.

2.3 Value stream mapping

Value stream mapping (VSM) is a process improvement tool used to visualize the flow of materials and information that makes a specific product in the chain. It creates a visual map of every process and information flow from a material supplier to a customer (Rother, Mike, and John Shook. 1999). In the earlier days, the value stream mapping tool was primarily used to minimize the production lead times and inventories in the manufacturing industries. It is established to overview the value-adding, and non-value adding activities in the value stream. The traditional value stream mapping does not include any information related to how much energy is used to add value to the processes and also logistics and transportation are not analyzed by energy efficiency and time (Muller, E., Stock, T., & Schillig, R. 2014). Muller, E., Stock, T., & Schillig, R extended the value stream mapping into an energy value stream mapping using the same logic as the original one.

To identify the material consumption and energy usage some other tools are also commonly used in industries. Shahbazi, S., et al., (2019) explained four different tools used by Swedish

manufacturing firms to assess the environmental impacts of Green performance map, environmental value stream mapping, waste flow mapping, and life cycle assessment. The authors compared all four models based on material efficiency, scrap, and environmental perspectives such as energy usage, hazardous waste and material consumption. Furthermore Shahbazi, S., et al., (2019) mentioned that no single tool to assess the impacts and each tool has both advantages and disadvantages. They suggested using a hybrid of tools that gives better results in environmental assessments. The advantage of using a value stream mapping tool is to identify and visualize the wastes in the entire flow process.

2.4 Key performance indicators

Key performance indicators (KPI) are the performance measurements for the firm and it helps to assess the firm's performance. Themistocleous and Rupino da Cunha (2019) claims that using KPIs is the most effective element for the company. KPIs are mostly based on quality, safety, delivery, and cost. Landström, Anna, et al. (2016) analyzed the performance systems in the seven different Swedish manufacturing organizations. The authors found that these systems look the same in the functional aspect but, it looks very different with respect to measurement perspective.

Chae, B. (2009) mentioned that KPIs increase the visibility of specific problems to achieve the performance objectives. Chase B (2009) also defends that it is better to focus on a limited number of KPIs to track and manage them efficiently rather than multiple that are harder to trace. KPIs can be set for individual machines, processes, or the entire company. Lindberg, C.-F et al., (2015) mentioned that various performances such as raw material usage, energy consumption, maintenance, or processes can be measured by KPIs and help identifying potential improvements.

2.4.1. Environmental performance Indicators

Environmental management systems assist the firms to go along with their environmental strategies. It contains policies, identified impacts, defined environmental goals, training, and management reviews (Jamous, N., Müller, K. 2013). Figure 3 Illustrates what kind of information companies should consider framing the environmental management system. The Environmental performance indicators help the company to assess the impacts on the environment comprising water, land, air, and ecosystems. The Sixth Environment Action Program of the European Community identified four major areas to develop the environmental performance indicators such as climate change, nature and biodiversity, environment and health, and natural resources and waste. Dada, A et al., (2013) mentioned that these areas are surrounded by indicators such as “*GHG emissions (tCo2 eq.)*, *Transport (tkm)*, *Air pollutants emissions (SO2)*”. These environmental performance indicators are split into five categories as Driving forces, Pressure, State, Impact, and Response (DPSIR) and developed the framework as the DPSIR model. The firms should consider these performance indicators connected to their tasks.

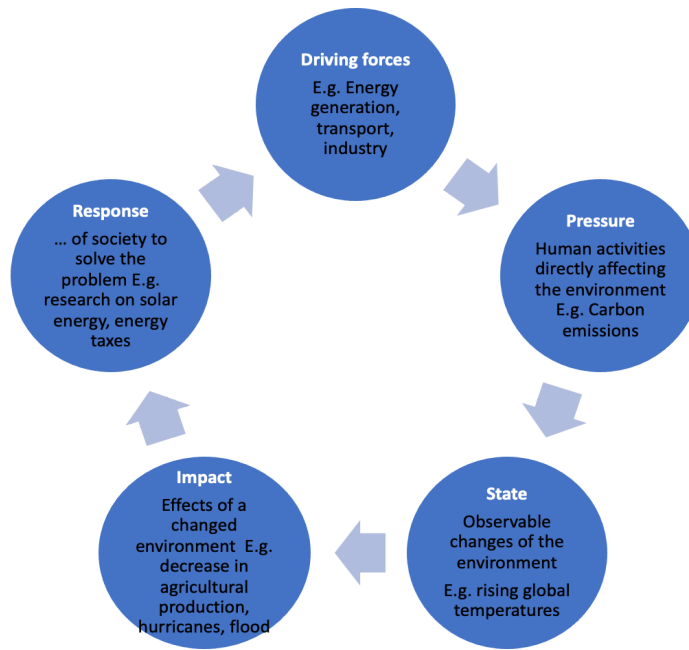


Figure 3: DPSIR model to structure environmental information (Jamous, N., Müller, K. (2013))

Jasch, C. (2000) argues that operational performance indicators play a major role in evaluating the environmental impacts. The operational performance indicators are subdivided into three categories such as electricity consumption, scrap rate, and average fuel consumption of the fleet. These operational indicators are mainly based on operations, machines, materials, services, energy, and waste.

2.5 Energy efficiencies

Energy intensity is determined as energy usage per unit (final product) and in the same way, energy efficiency increases if the same amount of product is manufactured using less energy or even more products are manufactured using the same amount of energy (Amjadi, G., & Lundgren, T. 2022). The United States Energy Information Administration, (2017) mentioned that 36% of total energy was consumed by industries in 2014. The Central Bureau of statistics of Sweden (SCB) stated that in Sweden, 45% of the energy is consumed by manufacturing companies of Sweden (2008), cited in Amjadi, G., & Lundgren, T. (2022). The manufacturing sector causes both energy usage and GHG emissions, and enhancing energy efficiencies are important to reduce the environmental impacts.

Amjadi, G., & Lundgren, T. (2022) found that energy inefficiencies may occur due to several reasons such as lacking technology upgrades, energy allocations in manufacturing operations as a consequence of irrelevant factors to energy usage or inadequate management. The energy inefficiencies of the company may be interconnected to long-term inflexibilities in production processes or temporary issues in resource allocation. Amjadi, G., & Lundgren, T. (2022) also suggested that energy inefficiencies in the Swedish manufacturing companies were connected to the structural inflexibility of the development of technology and/or administrative practices.

2.6 Information sharing

Information sharing performs a major role in the supply chain operations particularly to match the supply and demand and reduce the bullwhip effect and inventory costs (Yu, M., & Cao, E., 2020). The advantage of information sharing in the supply chain has been manifested by researchers in previous research. Uncertainties emerge in the supply chain operations due to a lack of information sharing between partners. Supply chain management needs the incorporation of the movement of goods and information flow. To decrease the uncertainties in the chain, each partner should gather more information about other partners (Yu, Z., Yan, H. and Edwin Cheng, T.C., 2001).

2.6.1 Internal information sharing

Internal information exchange is sharing information within the company. The information can be shared in different ways via phone, e-mail, and internal web system which can be only accessed by employees (Mishra, K., et al., 2014). Internal information could help the employees to do their work, and develop some techniques to achieve the firm's goals.

2.6.2 External information sharing

External information sharing is information exchange with stakeholders. This kind of information sharing could help the stakeholders to perform their tasks without delays. Xue., X et al. (2021) claims that insufficient information sharing is the major reason for the problems with stakeholders in the supply chain.

2. 7 Carbon emissions

GHG emissions from materials and operations are identified using the carbon emission factor in the research. The emission factor means that the factor transforms the real-time data from activities into GHG emissions (Clim'Foot, 2016). The most common GHG emissions measuring unit is Kg/CO₂equivalent. For example, how much greenhouse gas is emitted by 1 kWh of wind energy? It is a common way of measuring GHG emissions. Swedish transport administration (2012) mentioned that emission factors are based on qualities, hence it might change based on the environmental conditions and working methods. EEA published a report about the carbon emission impacts from heavy-duty vehicles, based on that statistics 27% of carbon emissions of road transport were emitted from heavy-duty vehicles (EEA, 2020). Heavy-duty vehicles are the reason for ¼ the number of carbon emissions from the transport industry. The European Union has fixed a GHG reduction target of 55% of GHG emissions reductions in 2030.

2.8 Waste management system

In the manufacturing industries, most of the waste is produced in production. The maximum amount of waste is produced from metal scraps, cutting fluids, and paints. Other materials from pallets, papers, and warehouse products can be reused in industries. To improve the efficiency, firms can implement reuse or recycling techniques (M. Kurdve, et al., 2011). If the firm improves its performance with respect to environmental indicators this will also improve its financial performance. The environmental practices can take the firm to higher in their revenues. For example, if the firm produces auto parts with low environmental impacts, customers prefer to buy

from this less environmental impact firm. On the other hand, these practices reduce energy usage and material costs. Currently, most of the scrap materials are sent to the recycling centers to do the low recovery of materials to reduce the environmental impacts.

2.8.1 Usage of cutting fluids in parts manufacturing industry

In parts manufacturing industries, cutting fluids play a major role in different processes such as cooling, washing, and lubrication. These processes need a considerable amount of cutting fluids to do the production operations. The benefits of using cutting fluids are cooling down the tools, decreasing the energy consumption, enhancing the surface finish, and preventing corrosion. The cutting fluids also have some consequences on nature. The wrong ratio of cutting fluids might increase the energy demand, machine breakdowns, and quality issues (Kurdve, M., et al., 2008). The cutting fluids mixture affects the habitat's health and is also hazardous to the ecosystem.

3. Methodology

This chapter focuses on what methods were used to achieve the necessary level of understanding in order to answer the research questions of this project. The data collection of this thesis was initiated by an inductive approach to improve understanding and render the processes easier to overview. This was followed up and merged with a more deductive approach. Figure 4 shows the research process of the thesis project.

3.1 Research strategy

Research strategy refers to what kind of structure and design will be used in the study to achieve the results in order to answer the research questions. When developing a new study to analyze something, a mix of qualitative and quantitative data will give better results (Edmondson and McManus 2007). The academic research strategies contain surveys, case study, experiment and action research. In some research, more than one type of strategy can be used for the study (Saunders, Lewis, & Thornhill, 2009). This thesis could be considered both internal stakeholders interview and real time data collection have been the primary source for this study.

This master thesis is focusing on a case study of an auto parts manufacturing company. The aim of this study was to analyze the supply chain flow for one product and identify the energy consumption and raw material usage. This study has given a thorough insight into the supply flow and an increased understanding of processes, activities and resources usage from supplier to customer. After that, a detailed analysis at the plant level with the aim of suggesting strategies to optimize the energy and material usage took place.

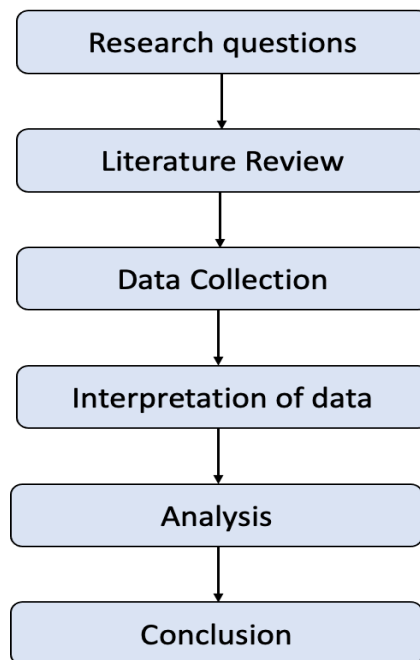


Figure 4: Research process of this thesis work

3.2 Research methods

3.1.1 Primary data

The primary data has been collected from sources such as internal reports, interviews, observations and measurements. The internal reports include total production, machine hours, and cutting fluid consumption. The conceptual data were mainly collected through literature reviews, which bring the required theoretical knowledge to perform this thesis. A case study was conducted to support attaining the research objective with quantitative data. The energy usage data were collected from a computerized energy logger and were done with our own measurements to know the product weight and pallet weight. The data have been utilized to map the process and energy usage in the supply network.

Interviews

For this thesis, semi-structured interviews have been used to collect data from both employees and managers. During this data collection, 15-18 interviews with different department managers and operators were conducted. Through these interviews, information related to the supply chain of Tonsjö and their inhouse operations were gathered. The questions are mostly related to logistics, production, energy usage, and scrap material to identify the hotspots of the supply network. Apart from these interviews, information has also been gathered from supplier X. Table 1 below, shows the position of the interviewees, the discussed topics and date.

Table 1 : List of Interviews conducted with employees

Interviewee	Topic of conversation
Production supervisor	Production flow & staffing
Logistics manager	Logistics planning & execution
Maintenance In-charge	The frequency of maintenance & daily work
Machine operator	Production operations & flow
Environmental manager	Focus area of the project, recycling
Electrical Engineer	Energy usage
Operations manager and programmer of the software for all the cell	Software & measuring approach
Warehouse/forklift manager	Inhouse logistics, loading & unloading trucks
Lean & cost engineer	Production operations & machine specifics
Economic & Administration	Electricity usage & production specifications
CEO	Scope & focus area of the project
Cutting fluid manager	Cutting fluid specifications, processes & waste management

Focus area of the project

One of the first things done after arriving at the factory was to have a guided tour led by an experienced employee. Then unsupervised observations following the back wheel hubs in accordance with the scope of the project in order to locate all the operations from door to door affecting the hubs in order to lay a foundation of the approach.

When discussing the approach of the project with the environmental manager and the CEO, it became evident that the best way to find comparable data within the time frame of the project would be to compare two of the cells in regards to their energy usage per produced product. After conducting a meeting with the electrical engineer, the programmer and the environmental manager, Cell 4 and 7 were chosen. Even though the operations are not completely identical, the differences are supposedly negligible. The reason behind the choice was that despite their similarities, Cell 4 was assembled in 1998(?) and Cell 7 was assembled in 2016(?). They figured that is where the biggest difference should be.

Observations

One of the most important ways to collect data is by personal observation. This way you are able to see how the daily processes and operations are being carried out. In many case studies, interviews are the primary approach to collect information, however, by observing and becoming more familiar with the company, one can access more information by asking more relevant questions. Knowing the context of the factory also enables you to separate useful, relevant information from irrelevant ditos, somewhat preventing information overload. Therefore more than 20 visits to the factory and the workshop have been made over the timespan of this project in the pursuit of acquiring the knowledge required to answer the research questions and achieve the aim of the thesis.

Energy measurement

The Fluke Energy Logger was connected with the power cabinet, to measure the actual power usage of the Cell and individual machines. In order to make the result more reliable, a professional electrician was hired to do the measuring. The samples were captured for 24 hours per machine and one week for the overall Cell. The logger was synchronized with the software Fluke Energy Analyzer version 1.2.1 to extract the data from each machine and compare the multiple data over a period to map a total energy usage.

By analyzing this measurement, one can identify the standby power and actual energy usage for individual machines as well as the entire cell. These measurements have been done for the power cord between the power central and Cell 4, both the lathing machines of Cell 4, the robot, the drilling machine and the washing machine. This has also been done for the same machines of Cell 7, see table 2. Table X shows the list of necessary data required to perform the analysis

Table 2: Required data to do the analysis

Type	Data needed for analysis
Machines	Power usage (standby, working)
Robot	Power usage (standby, working)

Product	Weight
Pallet	Dimension and Euro model
Transport	Distance (Km) Truck type Fuel
Scrap	Amount of scrap per product

Weight measurement

Since weight can vary due to specification requirements, operations variance and exposure to humidity or water, the pallets, the unfinished- and the finished back wheel hubs have been weighed. In order to get a good estimation to how much the products weighed, ten hubs were weighed using two identical scales positioned on the same surface. The weighing was made prior to- and after being processed. A mean value of the products, before and after processing, was calculated. The wooden pallets were weighed three times on a pallet scale and the mean value was calculated in the same way as with the hubs.

3.1.2 Secondary data

To understand the technical point of view, the secondary data related to energy usage and CO2 emissions in the supply chain operations was used. The secondary data was accumulated from journals, sustainability reports, academic lectures and company websites. Chalmers Library website, DiVa portal, Science Direct, and Scopus have been used in order to gather the desired information. Also, an app called "Idemat" was used to get the carbon emission values. Idemat is a sustainability materials selection app to get CO2 equivalents based on the materials. Keywords such as, 'supply chain performance', 'value stream mapping', 'logistics activities', 'energy consumption', 'GHG emissions' and 'waste management' were used for literature review.

3.3 Research quality

Research quality is frequently considered hardly trustworthy and reliable. To check the quality of the research, Bryman and Bell (2011) explained alternative methods to conventional methods which are established based on reliability and credibility. In this thesis, a case study to support the research, and a wide range of literature reviews was used. Many interviews with employees were conducted and combined with a quantitative data collection based on observations and measurements. The research work has been evaluated with the supervisor who has solid experience in this research area to ensure right clarity and transparency and reviewed by the examiner and the opponent group. Most of the data was gathered from interviewing employees, to avoid personal opinions and to ensure a loosened study both authors participated in all the interviews. The documentation of the interviews was used to avoid the misunderstanding of information. To ensure the credibility of the work, the supervisor gave the comments throughout the thesis period.

4. Empirical Findings

Chapter 4 provides the empirical findings during this project which includes the workshop layout, Cell process, energy usage, cutting fluid consumption, transport operation and waste management. This chapter mainly focuses on energy usage in the supply network.

4.1 Workshop layout

The workshop layout is Cell-based where each respective Cell produces one specific product. For the wheel hubs, the layout is as presented in figure 5. Cell 2, 3, and 4 produce back wheel hubs and Cell 1, 6 and Cell 7 produce front wheel hubs to the trucks of customer Y.

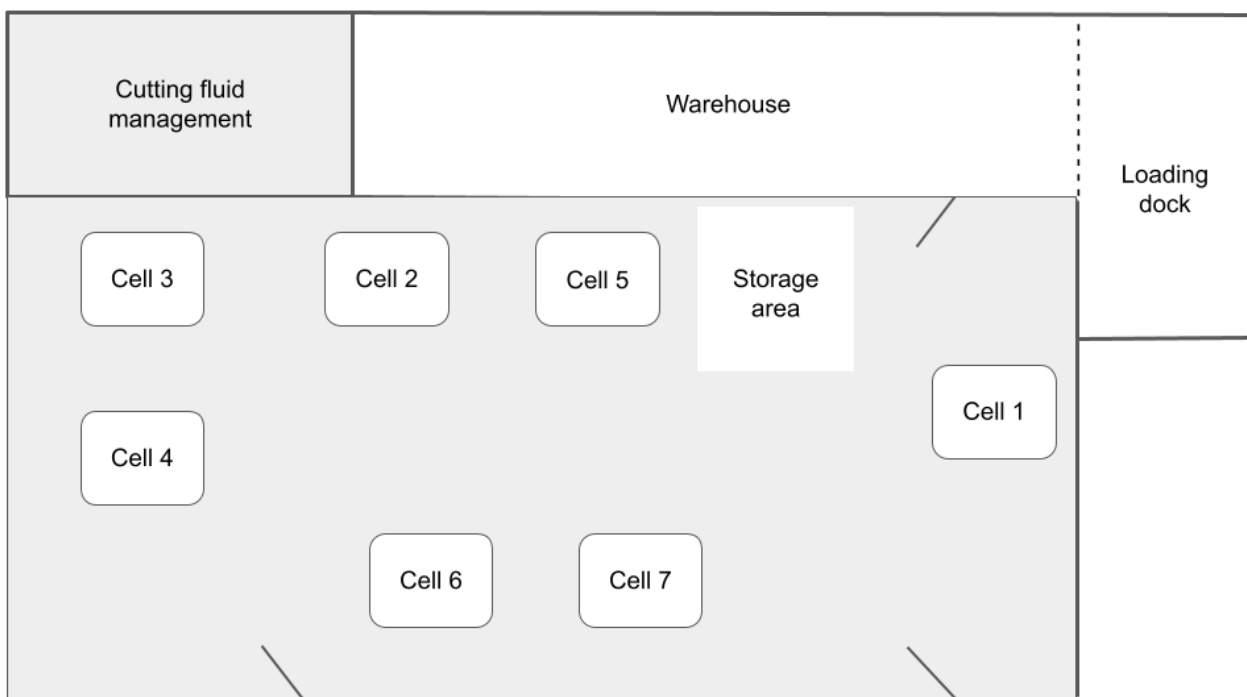


Figure 5: Workshop layout

4.2 Cell process

Tonsjö is customizing and scaling their production in accordance to the requirement of the customers, some of the cells have been added along the way. Cell 4 was developed in 2003, while Cell 7 was added in 2017. Cell 1, 2, 3 and 4 have the same layout. Cell 6 and 7 have a similar layout as the others with the exception that where Cell 1-4 has one drilling machine with two spindles, Cell 6 and 7 has two separate drilling machines. The products go through two lathing operations, two rounds in the measuring machine to guarantee the agreed quality is being achieved, one drilling machine, and one washing machine. The drilling and the washing machine process two products in parallel. There is a tool change in the lathe machine and drilling machine. As there is no specific tool change related data collected, identifying the amount of tools required for producing one back wheel hub would prove too time-consuming.

Figure 6 shows the structure of the wheel hubs producing Cell layout and operational flow. In the middle of the cell there is a robot that picks and places the products to their next operation. The unfinished back wheel hubs are initially manually placed onto a conveyor belt as can be seen in figure 5. In step one, the robot picks it up and places it inside the first lathe machine where it gets a rougher lathing. Step two, the product is picked up and put into the measuring machine. In step three, the product is moved to the second lathe which does a more delicate lathing. In step four, the product moves back to the measuring machine. In step five, the products are drilled in pairs before moved to the washing machine in step six to remove potential dust and shavings and dry the products off. Lastly the finished products are put on a second conveyor belt before being manually packed into the pallets again.

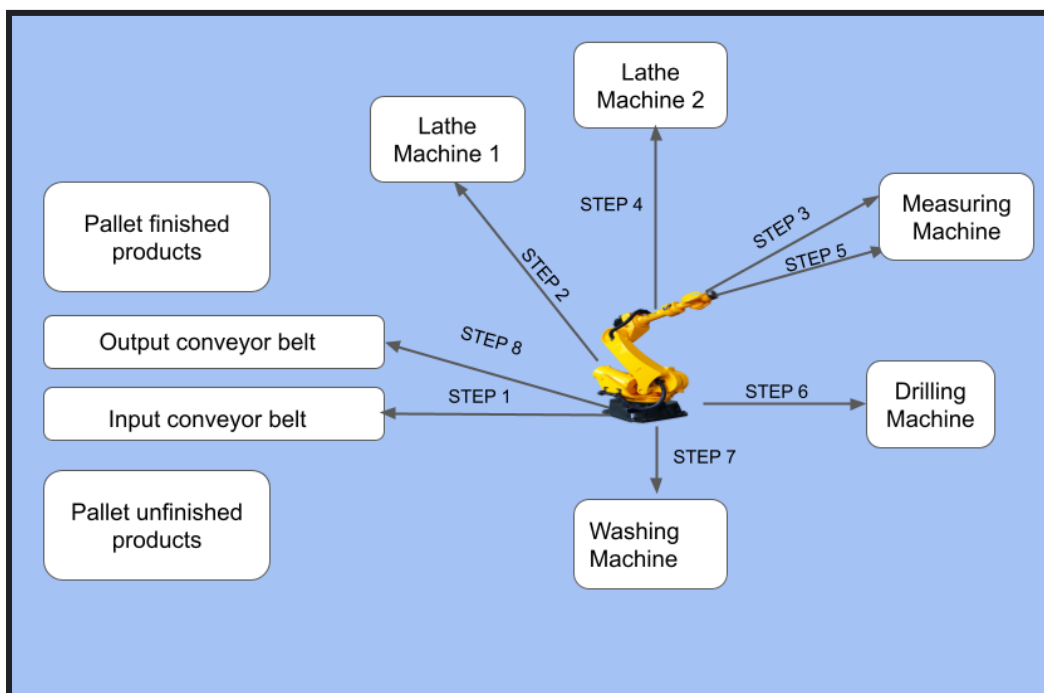


Figure 6: The structure and operational flow of the back wheel hub cell.

Product Weight & Pallets

Since the weight of the product might differ, some sampling weighings have been performed in order to find a more accurate product weight. Based on this measurement, it became apparent that the unfinished product weight is an average 31.4 kg and the finished product weight 25.5 kg. Roughly 5.9 kg of cast iron goes to waste as chips. In 2021, 805 tonnes of chips were removed from the total back wheel hubs production. Table 3 shows the results of the samplings and average product weight. In addition to this, the wooden pallets are also adding weights to the transports. Each pallet weighs roughly 59 kg. The pallet weight might vary due to the condition. According to the R&D department of Svenskt Trä (personal contact, 17th of march 2022), manufacturer of the Euro pallets, the weight of the pallets can increase by a maximum of 10% if exposed to water. The weight of the back wheel hubs also has some variations found in internal documents and confirmed by empirical measurements. For example, the weight of the back wheel hubs is 32.34 Kg in reports but in the measuring, all the back wheel hubs weighed significantly less.

Table 3: Number of samples for product weight

No of Samples	Unfinished product [kg]	Finished product [kg]	Scrap material [kg]	Wooden pallets [kg]
1	31,5	25,4	6,1	58
2	31,5	25,9	5,6	60
3	31,5	25,6	5,9	59
4	31,4	25,6	5,8	-
5	31,4	25,6	5,8	-
6	31,4	25,6	5,8	-
7	31,3	25,4	5,9	-
8	31,2	25,4	5,8	-
9	31,3	25,4	5,9	-
10	31,4	25,4	6	-
Average	31.4	25.5	5,86	59

4.3 Waste management system

The waste management is being outsourced to the waste management company Z. Company Z purchases the leftover residual materials such as scrap metal and disposable oil from the cutting fluid. They pick up the scrap in a heavy truck once a week. Company Z's trucks transport an average of 20 tons of scrap material every trip. For every trip, they pick up two containers of chips and the distance traveled is 30.5 km. Out of this, each truck carries 8,5ton metal and 5,86kg scrap from every unit. 10 tons on average contains 1.5 tons of cutting fluid mixed with the chips. This was calculated based on last year's amount of production and the total amount of chips transported to the recycling center. The below data was obtained from the internal customer websites of company Z. In 2021, the total amount of cast iron chips from the Tonsjö is 2941 tonnes. The back wheel hubs make up for 805 tonnes or 27.4% of the total amount.

4.4 Cutting fluid

The cutting fluid used for the machine operations of Tonsjö is being stored in a tank, see figure 5. Tonsjö are using a cutting fluid called Hysol SL 36 XBB that is provided by their supplier A. Hysol SL 36 XBB is defined as a coolant and Supplier A claims that the CO₂ impact of producing one liter of concentrated Hysol SL 36 XBB emits 2,2 kg CO₂. Tonsjö gets 10 deliveries of 4 m³ per year and thus uses roughly 40,000 liters of concentrated cutting fluid for the entire workshop on a yearly basis. The ordering, measuring mixing and maintenance of the cutting fluid are currently being handled by one employee.

The concentration is 5-7% of cutting fluid with 93-95% of water. This however, varies with the temperature conditions, but they generally want to keep it at 9,4 pH. If less than 5% cutting fluid is used, the oil will separate, if above 7% some of the materials in the machines gets ruined. If the employee considers the mixture clean enough it goes through a paper filter and back into the

tank. If not, the water is distilled and reused while the rest goes to waste. Right now, they don't have a proper system to measure the quality of the cutting fluid when they reuse.

4.5 Transportation and logistics activities

Tonsjö uses a third party logistics (3PL) solution provided by Samskip for their transportation. The unfinished back wheel hubs arrive by truck from supplier X located in Arvika. The products arrive in linked trailers carrying 39 wooden pallets holding 18 products each, adding up to a total of 702 products or roughly 24 tonnes per truck. On average, Tonsjö receives two trucks, delivering back wheel hubs, per day. The distance traveled from supplier X to the case company is 236 km. The deliveries from Tonsjö to customer Y, located in Södertälje, are packed in the same type of wooden pallets as they arrived in. The transportation to Södertälje is being handled by another 3PL solution controlled by customer Y and the distance traveled between the case company and customer Y is 465 km.

The unfinished wheel hubs come in wooden European wooden pallets (Scania MH 1872 EUR 1). The pallets measure 1200x800mm and are divided into three layers, each containing 6 products, adding up to 18 products per pallet. The pallets arrive by truck at the loading dock. They are then transported by electrical forklifts either to the warehouse or the storage area (figure 5). Then the operators of the cell bring the pallets with unfinished wheel hubs to their respective cell. After processing, the products are packed in the same type of pallets they arrived in. The pallets are sealed and taken back to the warehouse area by the operators, awaiting shipment to customer Y.

To transport the products from supplier X to Tonsjö, Samskip uses diesel trucks. The deliveries are being carried out by different truck models and different drivers from all over the world. The trucks are being loaded the day before arrival to Tonsjö. There are no other deliveries on the way as the logistics provider that transports the goods from supplier X in Arvika would otherwise commute between Malmö and Oslo, Norway, for their deliveries. The truck drivers stay for sleep on the way between Arvika and Kode. By saturating Tonsjö's need for transportation they increase their degree of filling from 50% to 63% (Assuming they have a 100% degree of filling for their transports from Malmö).

The transportation to customer Y is being handled by the customer and is outside of Tonsjö's direct control. The supplies can arrive in Tonsjö between 07.00-16.30. There is no structure for contacting the drivers prior to the deliveries and thus the forklift operators do not know when to be expecting to unload the supplies. The transport to customer Y works in a similar manner. There is no structure for when during the day the trucks arrive and sometimes the trucks do not arrive the same day as scheduled.

4.6 Energy measurement

Electricity used in Tonsjö is supplied from Kungälv energi, Elkraft, Bixia and Kraft & Kultur. Main source of electricity is from Kungälv energi and this energy is generated by wind power. To measure the energy usage, the Fluke Energy Analyzer sampled continuously and calculated a mean value every minute. After measuring the machines as stated in 3.1.1, the data was sent to a computer to be analyzed in a software specifically developed for these analyses. The data was presented in graphs showing the current effect usage and the total energy usage over time

similar to Figure 6. Periods of stand-by mode and active mode were manually identified. In the figure 7 below, a stand-by period between roughly 15.57-16.32 kW, and an active period between roughly 16.32-18.30 kW can be identified for the lathe machine.

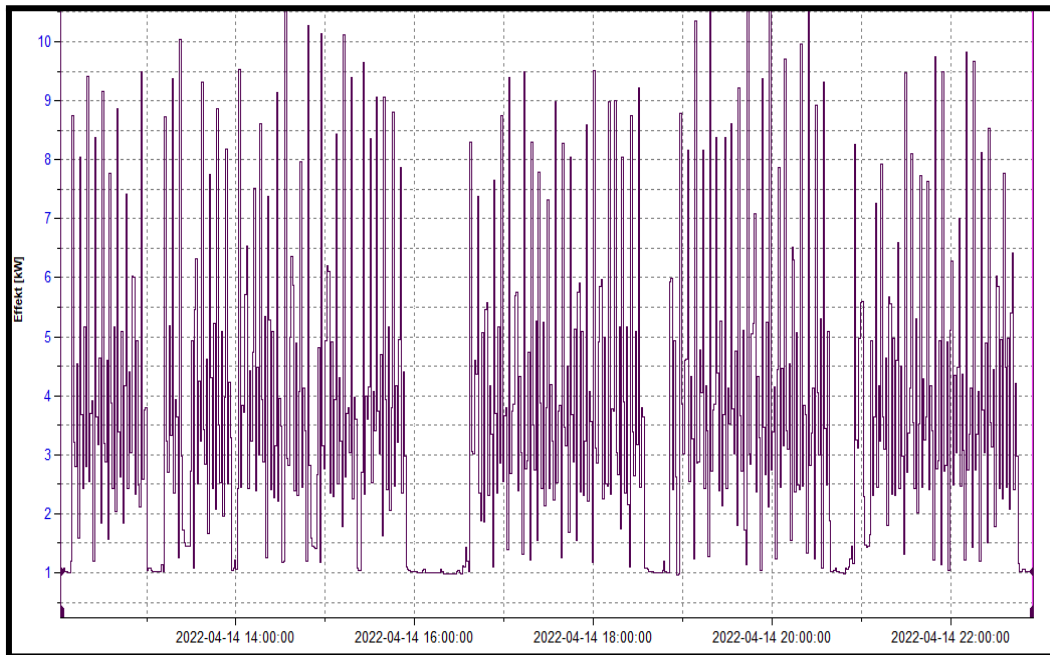


Figure 7: The results of the current effect measuring of lathe 2 in Cell 4.

To answer the first research question, the energy over a time span is required. This can also be acquired from the Fluke Analyzer software. The figure 8 below shows the previously mentioned stand-by period, here marked by the pointers, of the lathe 2 in Cell 4.

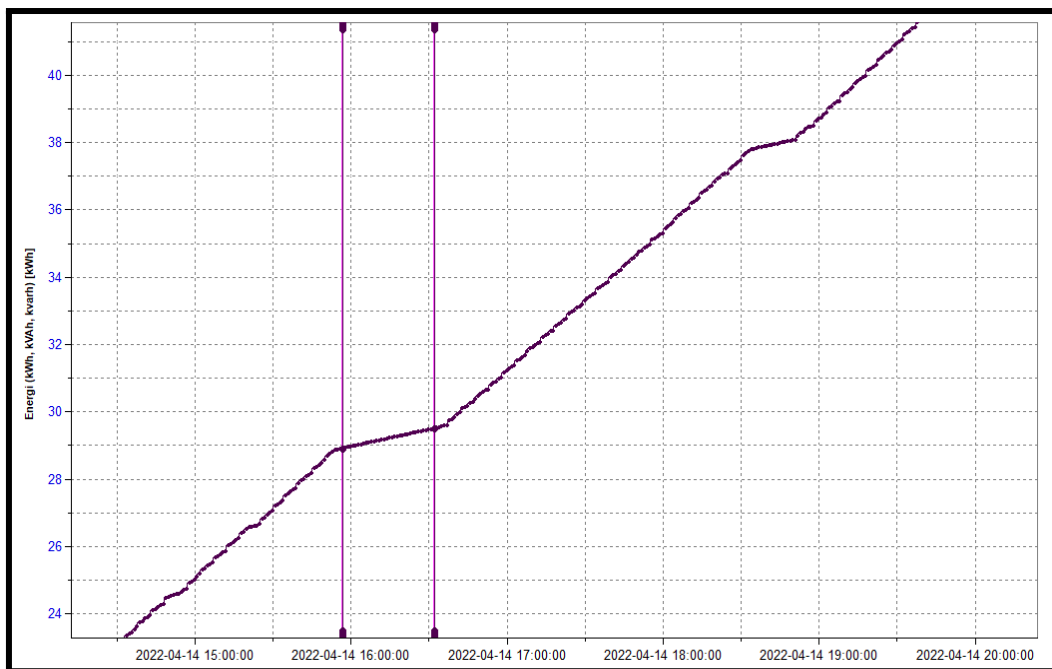


Figure 8 : Detailed view of the energy usage in Stand-by in lathe machine

To find the exact amount of effect used during a stand-by, the following equation has been used:

$$\Delta [kwh]/\Delta[h] \quad (1)$$

Or in this case

$$0,587/(35/60) = 1,0 \text{ kW}$$

Meaning that the lathe 2 of Cell 4 used 1.0 kW on average per hour during the stand-by mode. Equation 1 has been used for all the measures that are compiled in the table below. It also displays the difference between the energy used for the various operations of Cell 4 and Cell 7. Table 4 shows the average energy usage for Cell 4 and Cell 7 which were taken from the Fluke software. All the graphs obtained from the software are attached in the appendix.

Table 4: Average energy usage in Standby & Active mode for Cell 4 and Cell 7 for individual machine

	Cell 4, Stand by [kW]	Cell 7, Stand by [kW]	Difference, Stand by [%]	Cell 4, Active [kW]	Cell 7, Active [kW]	Difference, Active [%]	Cell 4 Per product [kWh]	Cell 7 Per product [kWh]	Difference [%]
Power to the Cell	16,8	12,3	36,6	39,0	41,8	7,2 %	4,1	3,1	32,3
Drilling	3,1	5,0	61,3	17,9	7,4	141,9 %	2,6	0,5	520
Robot	0,3	0,7	133	1,2	1,5	25 %	0,1	0,1	–
Lathe 1	4,5	1,6	281	10,3	5,6	184 %	1,1	0,6	83,3
Lathe 2	1,0	1,0	0	4,2	6,0	43 %	0,5	0,2	250
Washing machine	0	3,0	–	3,3	7,5	127 %	0,2	0,6	300

In order to calculate the energy usage per product, one shift per machine or Cell with as few unplanned production stops as possible were identified using the Fluke software. This was then compared to the hand-written daily reports describing how many products were produced during each shift of the day. The energy usage was then divided by the amount of products in order to calculate the energy usage per product.

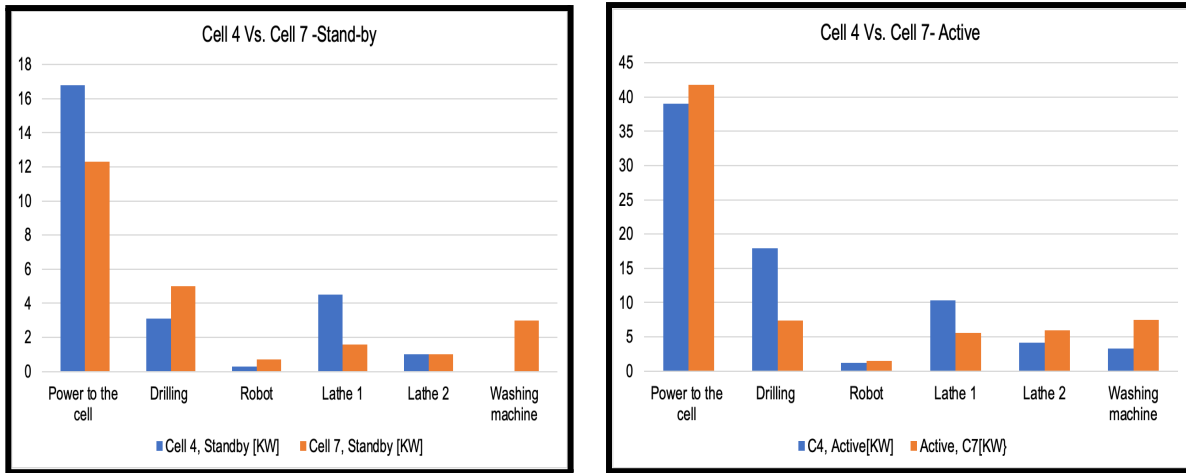


Figure 9 : Comparison of energy usage in Standby Vs Active for Cell 4 and Cell 7

Figure 9 shows how much energy is consumed by individual machines during standby and active mode. Compared to Cell 7, Cell 4 consumed a noticeable bigger amount of electricity. Especially during standby, but also per product. When comparing the individual machines, drilling machines tend to consume more than other machines over the measured timespan of roughly 24 hours. The second most energy-consuming machine is Lathe G1 in both cells. Robot and Washing machines are low energy usage machines when compared to the others and are thus not as big energy hotspots as for instance the drilling machine. In standby mode, Cell 4 washing machine energy usage is negligible. The drilling machine in Cell 4 consumes around 18 kW in 24 hours which is twice the amount of the drilling machine in Cell 7.

5. Analysis

In this chapter, relevant findings from Chapter 4 are analyzed and presented. Also, further investigations to find the carbon emissions for the supply operations such as production process, transportation, cutting fluid and scrap based on the carbon emission factors are presented.

5.1 Energy measurements

The drilling machine of Cell 4 always processes two products in parallel. If there is only one product available, it will wait until a second product is in place. It is also programmed to only run at one speed. However, some irregularities can be found in the effect of the drilling machine. There are several plateaus in the effect of the drilling machine that last for several hours and averages 12,5 kWh. After discussing this with the production managers and programmer of the Cell, these plateaus have no clear explanation. Figure 10 shows the effect of the drilling machine in Cell 4.

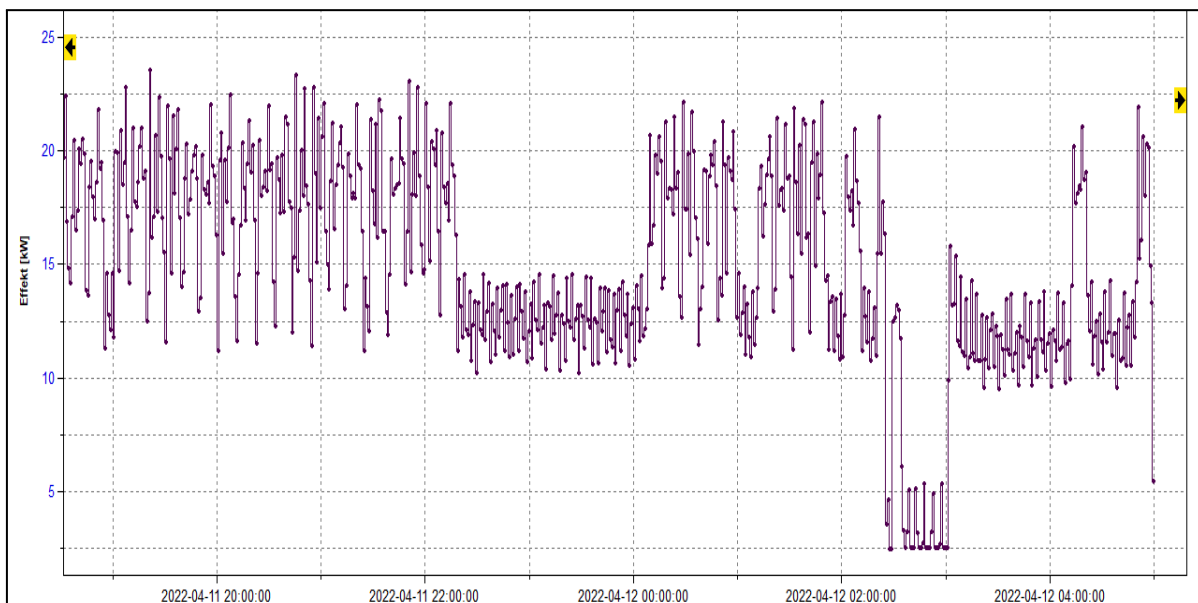


Figure 10 : The effect [kW] of the drilling machine in Cell 4.

The energy usage per product shown in table 4 has a big error margin. The hand-written shift reports only presented completely filled pallets. This means that if one shift almost fills a pallet before ending, this pallet will belong to the next shift. This leaves a big uncertainty on the quantity of products produced per shift. The more precise hand-written shift reports are being disposed of continuously.

As shown in figure 11 below, some machines had long production stoppage during the energy measurement. There are many reasons as to why the machines can stop. For instance, there are regular tool shifts, if the measuring machine of Cell 4 finds an irregularity, it will stop until inspected by an operator. As of now, Tonsjö doesn't capture the exact reasons for every production stoppage, there is, however, a digital system to monitor the actual output against the planned output per hour.

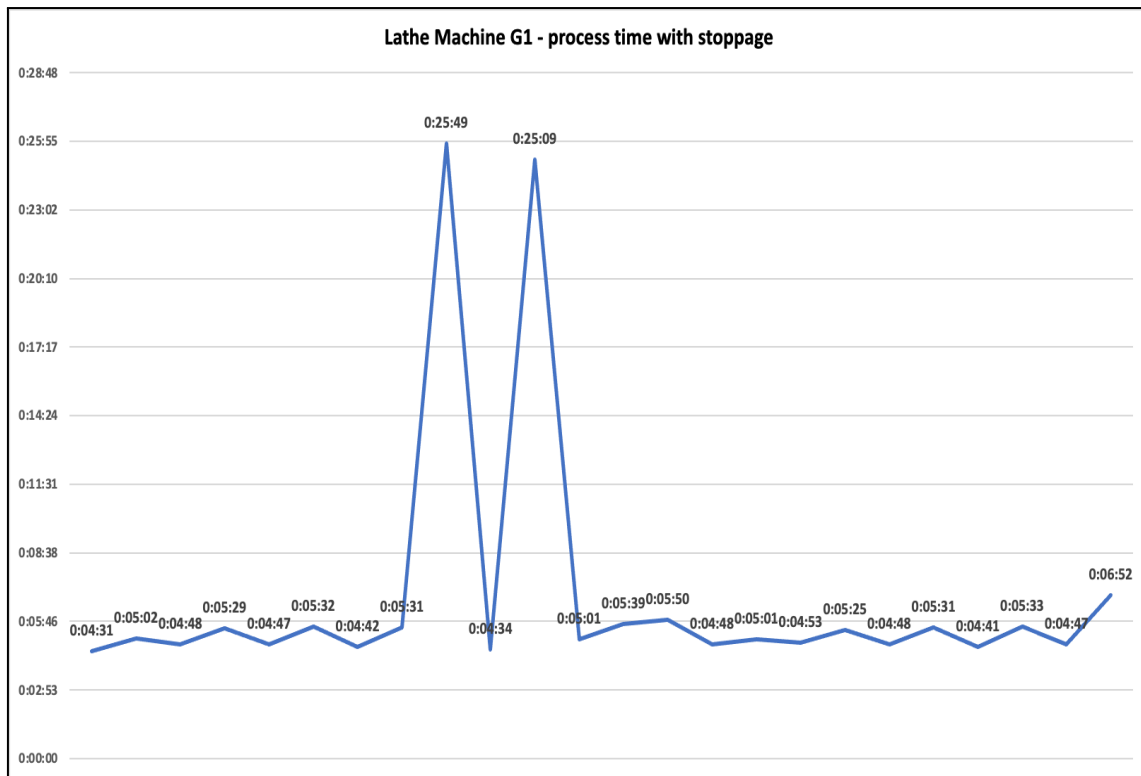


Figure 11: Process time with stoppage for Lathe machine in Cell 4

5.2 Cutting fluid

The management of the cutting fluid is currently being handled by one person. Most of the handling is manual and the check-ups are subjectively estimated. The employees have no training regarding managing cutting fluid. The amount of cutting fluid in the mixture is varying a lot which could either be damaging the equipment or be an overspending.

Company Z can provide the staff with the proper education to manage the cutting fluid. They could also provide a mixer that measures the concentration of the mixture and maintains the same concentration/pH-value real-time instead of first estimating and measuring, then mixing. This could reduce the maintenance required for the machines in the production area.

In this chapter, the carbon emission analysis for cutting fluid based on the percentage of the chips and cutting fluid volume was made. A commonly used parameter to calculate the amount of cutting fluid usage is fluid usage indicator (I_{FU}) (Kurdve, M., 2008). This indicator is helpful to find the amount of cutting fluid used based on the production output by using the same index in this analysis. Based on the chip's percentage, the volume of concentrated cutting fluid used to produce the back wheel hubs in 2021 can be calculated as:

The 27% in the calculation below represents the back wheel hub's part of the total production based on the scrap material.

$$\begin{aligned}
 I_{FU} &= 27\% * \text{total cutting fluid use at the workshop,} \\
 &= 0.27 * 40000 \\
 &= 10,800 \text{ ltr of concentrated fluid}
 \end{aligned}$$

Hence 10,800 liters of concentrated cutting fluid is used to produce 136582 pieces of back wheel hubs. This equals 0.073 liters of concentrated cutting fluid used in order to produce one back wheel hub.

5.3 Carbon emission analysis

Carbon emissions are emitted from the different operations in the manufacturing industries. It can be in two categories; direct and indirect carbon emissions. First, you can calculate the emissions based on fuels and gas used which are the primary reasons behind direct CO₂ emissions. Next, you can calculate indirect CO₂ emissions from manufacturing processes and products which are secondary reasons that impact carbon emissions through energy consumption. In this analysis, carbon emissions from downstream suppliers and OEM are, as mentioned in the limitations in chapter 1.6, not included. Figure 12 shows the overview of the supply network, to understand the overall operations in the supply network, the mapping to understand what kind of input materials are used and the outputs after every process were made. It also shows how much distance the trucks are traveling for their respective product deliveries.

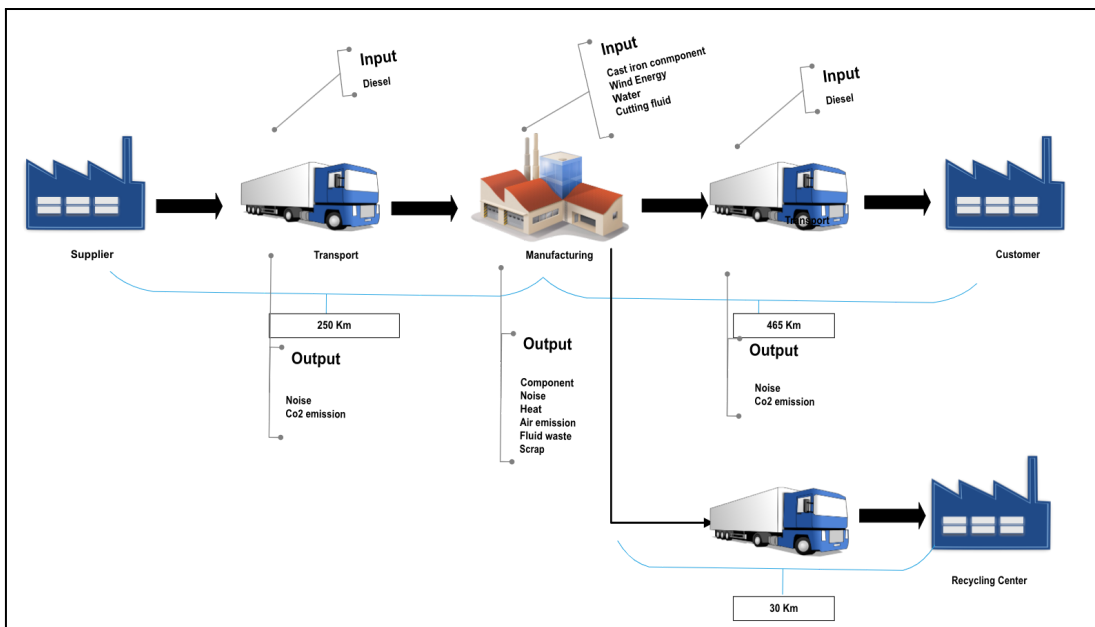


Figure 12: Overview of the supply network

After developing an overview of the supply network, the detailed carbon emission analysis at the plant level was performed. Figure 13 shows the carbon emission sources of the case company. Carbon emissions are emitted from input operations, coolants, energy usage by machines and also from scraps.

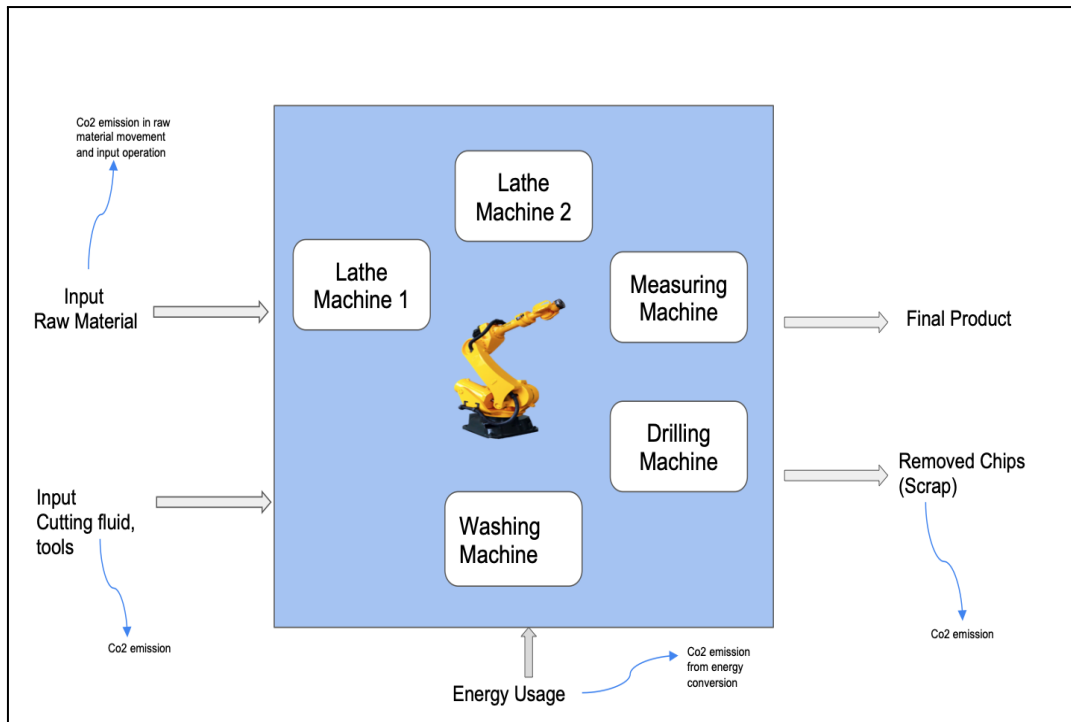


Figure 13 : Carbon emissions from the production process

To identify the amount of carbon emission in the process, there are different methods that can be applied in order to calculate the carbon emission values. In this study, it has been calculated based on the energy used by the machines to refine the final product. The carbon emission was calculated by kilowatt-hours energy usage into carbon emission in kilograms. The CO₂ emission calculation was done for all the operations in the production process. For production operations, all machines of Cell 4 and Cell 7 were analyzed. The carbon emissions factors for input material, transport, wind energy and scrap. Based on the below mentioned carbon emission factors, the carbon emission calculation was done for all the processes (Idemat, 2022-05-20).

- Wind energy 100 MJ -0.23 Kg Co₂
- Carbon emission by using 1 kWh of wind energy - 0.0082 kg Co₂
- Carbon emission from 1 Kg of Cast Iron - 1.26 Kg Co₂
- Truck trailer (24t -from supplier) - 0.091 kg Co₂e per ton. Km
- Truck container (scrap) - 0.078 Kg Co₂e per ton. km
- Cutting fluid per liter (Hysol SL 36 XBB) - 2,2 Kg Co₂, Nordics & Baltics Lubricants (personal communication, May 22th 2022).

5.3.1 Energy usage CO₂e

The analysis was based on the respective machine's energy usage per day. To calculate the carbon emission value, the 24 hours of energy usage for each machine has been used. As mentioned in Chapter 3.1.2, the carbon emission factor was taken from the Idemat application based on the materials. For example, 1 kWh wind energy emitting 0.0082 Kg CO₂e and 24t trailer releasing 0.091 kg Co₂e per ton per km. Table 5 and 6 display the numerical data which are the amount of the carbon emission emitted from each machine based on the energy usage per day.

Table 5: Energy consumption Vs. Carbon emissions from Cell 4

Machine	Stand by power consumption [kWh]	Carbon Emission [kgCo2 eq.]	Active power consumption [kWh]	Carbon Emission [kgCo2 eq.] per 24 hrs
Drilling	3.1	0.02542	17.9	0.14678
Robot	0.3	0.00246	1.2	0.00984
Lathe G1	4.5	0.0369	10.3	0.08446
Lathe G2	1.0	0.0082	4.2	0.03444
Washing machine	0	0	3.3	0.02706
Total	8.9	0.07298	36.9	0.30258

Table 6: Energy consumption Vs. Carbon emissions from Cell 7

Machine	Stand by power consumption [kWh]	Carbon Emission [kgCo2 eq.]	Active power consumption [kWh]	Carbon Emission [kgCo2 eq.] per 24 hrs
Drilling	5.0	0.0410	7.4	0.0607
Robot	0.7	0.0057	1.5	0.0123
Lathe G1	1.6	0.0131	5.6	0.0459
Lathe G2	1.0	0.0082	6.0	0.0492
Washing machine	3.0	0.0246	7.5	0.0615
Total	11.3	0.0927	28.0	0.2296

Comparing Cell 4 and Cell 7, there is a high amount of energy consumed by Cell 4 in 24 hours. When looking at individual machines, lathe G1 consumed more than the other machines. Energy and CO2 emissions have a direct connection. For instance, if the machine consumes more energy, it will emit more CO2 and Vice versa. Based on the above analysis, 8.9 Kwh energy usage doesn't add any value to the product in Cell 4 and 11.3 Kwh of energy doesn't add any value to the product in Cell 7 as well.

5.3.2 Transportation based CO2e

Transportation in the case company can be divided into three types; unfinished product transportation from Supplier X, finished product transportation to Customer Y and scrap material transportation to the recycling center. For these transport operations, calculations based on the below formula, which was taken from the Website (Cefic and ECTA, 2011), were used.

<p>CO2 emissions</p> <p>=</p> <p>(Transport volume by transport mode) x (average transport distance by transport mode) x (average CO2-emission factor per tonne-km by transport mode)</p>

Average carbon emissions from transporting the components from supplier X

$$\begin{aligned} \text{Inbound transportation} &= (24) \cdot (236) \cdot (0.091) \\ &= 515.42 \text{ Kg CO2e. per trip} \\ &= \mathbf{0.734 \text{ kgCO2/unit}} \end{aligned}$$

Average carbon emissions from transporting the components to customer Y

$$\begin{aligned} \text{Outbound transportation} &= (24) \cdot (465) \cdot (0.091) \\ &= 1015.56 \text{ Kg CO2e. per trip} \\ &= \mathbf{1.447 \text{ kgCo2/unit}} \end{aligned}$$

Average carbon emissions from transporting the scrap material per truck

$$\begin{aligned} &= (20) \cdot (30.5) \cdot (0.078) \\ &= 47.58 \text{ Kg CO2e per trip} \\ &= 17000/5.86 = \text{ca } 2900 \text{ units of scrap} \\ &= 47.58/2900 \\ &= \mathbf{0.016 \text{ kgCO2e. per unit}} \end{aligned}$$

On every trip, the trucks are transporting 702 unfinished products from supplier X to the case company, and an average of 515.4 Kg CO2e and 1015.56 Kg CO2e emits from outbound transportation to reach customer Y. As mentioned earlier, in this case, the products are transported from the local supplier, and in this thesis research focuses on one product in Tonsjö. Suppose the supplier is located outside Sweden. In that case, the CO2 impacts might increase depending on the location and transport volume. The same calculation is used for the scrap material transportation from Tonsjö to the recycling center of company Z. This center is located 30.5 km away from the case company and the scrap materials are collected in the dumper container and the pickup operations are handled by company Z. The transportation of the scrap emits 47.58 Kg of CO2e per trip and 0.016 kg of CO2 is contributed from one product in the scrap transportation.

5.3.2 Scrap material induced CO2e

As previously mentioned, this thesis is focusing on back wheel hubs production. From every back wheel hub, roughly 5.86 Kg of materials were removed as scrap during the Cell operations. In this case, the scrap materials were recycled, and it doesn't emit CO2 except for the energy used to melt down the cast iron chips, and in this case study, it's outside of the scope.

5.3.3 Cutting fluid based CO2e

As mentioned in chapter 4.4, the cutting fluids are in a common storage tank for the entire workshop. From this tank, the cutting fluid is distributed throughout every machine operating in the workshop. To identify the amount of cutting fluid usage for Cell 4, estimations have been made. Whereas, an average of 10,800 liters of cutting fluid is to be distributed per year for the back wheel hubs production. The amount of cutting fluid required to produce one back wheel hub is 0.079 liters and which emits 0.005 kg of CO2 equivalent.

5.4 Error estimation

There are some error margins with the weighings of the wheel hubs. The measurement could be affected by the ground surface, how you position the pieces and other unforeseeable malfunctions of the scales such as calibration. As for the measuring of the wooden pallet, there are some uncertainties regarding the result as well. It is an old industrial scale with a specified error margin of ± 1 kg. With a bigger sampling size weighed under more controlled circumstances the results are likely to be more precise.

6. Result

This chapter provides insight into the result of the report namely the answer to the research questions stated in 1.5.

6.1 Result of research question 1

To answer research question 1, Table 7 shows the detailed energy requirement (kWh) for each machine to produce one back wheel hub.

Table 7: Total energy required to produce one product and carbon emission

Operations	Energy Usage per product (kWh)	Carbon emission (CO2 Kg eq.)
Drilling	2.6	0.02132
Robot	0.1	0.00082
Lathe 1	1.1	0.00902
Lathe 2	0.5	0.0041
Washing	0.2	0.00164
Total	4.1	0.03362

Based on the energy measurement, it is concluded that to produce one back wheel hub requires 4.1 kWh energy which can be translated into 0.034 CO₂ Kg eq. For example, if Tonsjö produces the same back wheel hub in Poland, then it will emit 1.475 CO kg eq because still, Poland uses coal energy to produce 83% of their total electricity. 1 Kwh coal electricity will emit 0.359 Kg CO₂ eq. Compared to Poland, Tonsjö's production emits less amount of CO₂ emission.

6.2 Result of research question 2

To answer research question 2, carbon emissions are calculated for all the operations and fluids used to produce one product. In this analysis, all the operations and input material usage except the raw material production have been added as shown in Figure 14. Based on figure 14, raw material is the uttermost reason for the GHG emission, but these materials are recycled through the recycling center and sent back to production again. As we mentioned earlier in chapter 1, raw materials are not in our scope.

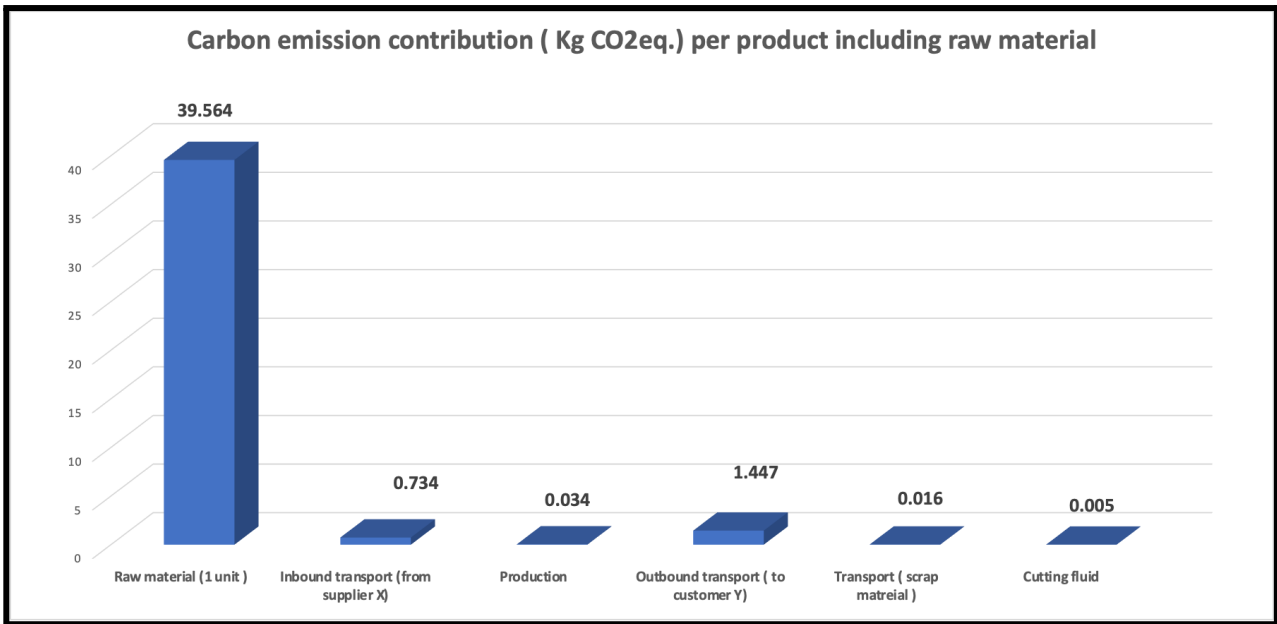


Figure 14: Carbon emission contribution including raw material

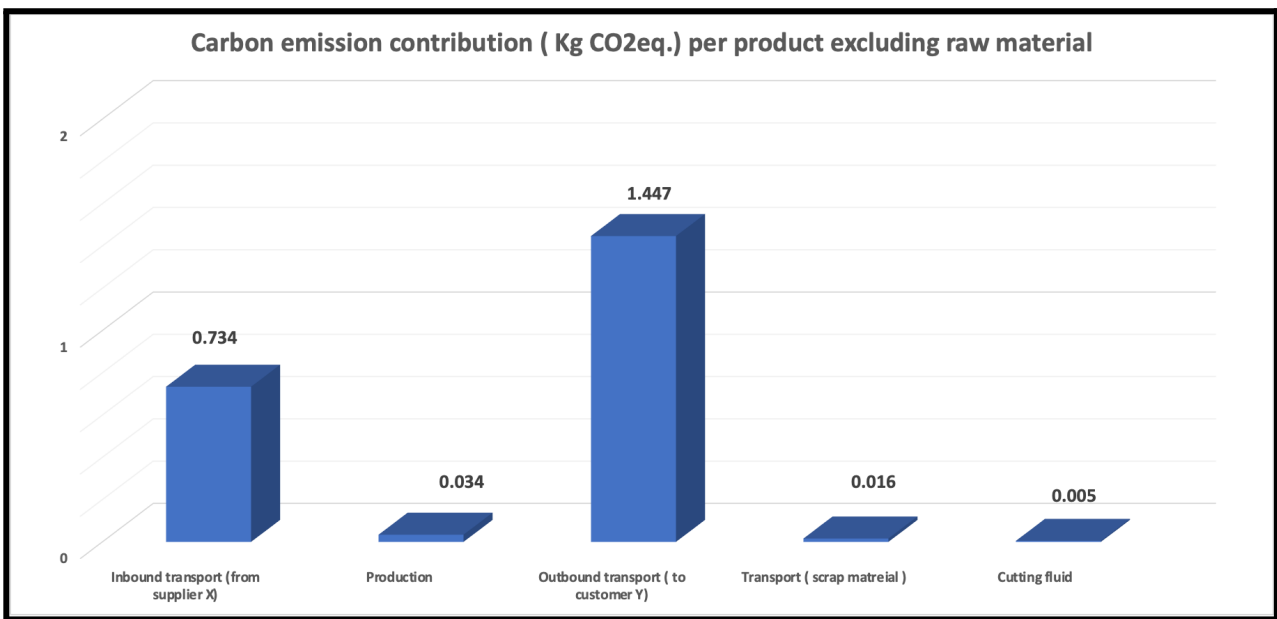


Figure 15: Carbon emission contribution excluding raw material

Figure 15 shows the carbon emission contribution excluding the raw materials and outbound transportation has the highest carbon emission and inbound transportation has the second most carbon emission value per product. Based on the above figure, transportation is the major hotspot regarding GHG emissions. Compared to them, the production process emits a relatively small amount of CO₂ emissions because Tonsjö purchases green electricity for the factory. Cutting fluid has contributed to the very less value of carbon emission 0.05 kg CO₂e. per product. The graph data's are mentioned in the Appendix which will provide a more sufficient understanding for the readers.

6.3 Result of research question 3

To answer research question 3, Tonsjö could approach their machine supplier, because metalworking machines have high costs, and their suppliers could help them to reduce the standby energy consumption. As a consequence of reducing the energy consumption, the GHG emissions and cutting fluid consumption would also decrease, and the energy efficiency would increase. As mentioned in Chapter 5.4, Cell 4 and Cell 7 used a great amount of non-value-added energy per day and the hotspot for energy consumption is the lathe of Cell 4 which represented 25% of the non value adding energy.

7. Discussion

This chapter discusses the results based on the finding and analysis, and the report. Starting with a discussion about the energy usage in the inhouse operations of Tonsjö. Then continues with the transport operations and carbon emissions impacts in the supply network and also suggests strategies to reduce the carbon emissions.

Energy usage

During 2021, 560 MWh of energy was used to produce 1,36,582 pieces of back wheel hubs. Based on the energy analysis done in chapter 5, Cell 4 consumed 32,3% more energy than Cell 7 to produce one product. The non-value adding energy was consumed in standby mode than the specified energy usage in standby. The standby mode can occur due to the production stoppage, shift change, and tool change. One potential solution to reduce the amount and duration of the standbys and in extension the non-value adding energy usage is to make sure that the cutting fluid is properly mixed for every operation. Also, as the standby time of the newer Cell 7 is significantly lower than Cell 4, updating the machines of Cell 4 points towards a more smooth production flow.

As mentioned in chapter 5, some machines had a long production stoppage. There is a possibility to reduce the production stoppages and power peaks in the future through a detailed investigation of these issues. This could be done by closer evaluating the reason why the machines stop.

Tonsjö only purchases green energy and one can argue that keeping the energy usage at a minimum can merely be reduced to a financial issue. However, with a broadened perspective to a more global level, every Joule of energy reduced at Tonsjö could be used by someone who would otherwise combust fossil fuels in order to acquire the much needed energy. In the end it becomes a matter of global community and a strive to take the lead by making responsible choices to a more sustainable future.

Transportation

The European Environmental Agency mentioned that more than 25% of GHG emissions are emitted from transport operations (EEA.,2021). When looking at the analysis, the environmental impacts from transport are different for raw materials transportation and scrap materials. Every day, two to three trucks arrive from Supplier X to Tonsjö. Each of these inbound transportation emits 515.4 Kg of CO₂e per trip. Outbound transportation emits 1015,56 Kg CO₂e. per trip. The environmental impact of transportation has a direct link to the transport volume and distance.

All the transport operations are carried out by heavy duty diesel trucks. This thesis mainly analyzed the CO₂ emissions in the supply network. Other transport emissions from transport operations are Sulfur Dioxide (SO₂), nitrogen oxides (NO_x), particles (PM), hydrocarbons (HC), and carbon monoxide (CO). In recent years, other than SO₂ these emissions are standardized in Euro Vehicles and in Sweden and other European countries, and these emissions are reduced

consistently. SO₂ emission is based on the amount of sulfur in the fuel. In 2009, European legislation introduced the new standard for PPM level is 10 PPM and also, diesel used in Sweden has only 10 PPM (EU: FUELS: DIESEL AND GASOLINE (2009)). In the EU, the authorized sulfur amount for diesel is not more than 50 PPM for road transportation. This has not been taken into consideration.

Tonsjö is currently outsourcing their deliveries to 3PL-provider. Instead of using diesel trucks they could use biofuel trucks which have a smaller environmental impact fuel. Biofuel trucks could reduce CO₂ emissions compared to Diesel trucks (ClearFlame TCO and Emissions Study, 2022). Iron and steel industries are responsible for 6% of global CO₂ emissions (Fan, Z., & Friedmann, S. J. (2021)). In regards to reducing the cast iron material usage, Tonsjö cannot modify the back wheel hubs design. The scrap materials contribute to a high environmental impact, but these materials are recycled through the recycling center of company Z. After that process, the cast iron still has a life. The amount of scrap material could possibly be impacted by their customer. Customer Y is setting the standard regarding part design. In the future, Tonsjö could approach their customer to make improvements in the part design.

Another important issue that arose during this project was that there does not seem to be a structured framework for information sharing. It became evident that many of the employers were very knowledgeable, not only in their specific domain but across other areas too. Obtaining useful information was challenging due to the fact that many of the interviewees knew parts of the relevant information. A lot of the time of the project span was spent trying to solve data gathering issues and making rough estimations when the proper, relevant information was accessible, just difficult to find. It would have been easier to put the puzzle pieces together if the roles would have been more defined.

8. Conclusion & Recommendation

The energy hotspots were identified based on the energy usage by the machines to produce the back wheel hubs. The purpose of this thesis was to identify the energy hotspots and GHG emissions. One of the identified hotspots is the energy usage during stand-by mode in machines, especially in drilling and lathing machines. These were found based on the empirical findings and analysis. Another energy hotspot was that there were power spikes and longer production stoppages during the production operations. Our recommendation to the case company is to further investigate these matters. Tonsjö should monitor the production stoppages and make more thorough measurements to find the root causes for these hotspots.

This study shows that transportation is the main reason for GHG emissions. Our recommendation from an environmental standpoint is to start updating the transportation fleet to more renewable energy-based vehicles or less environmental impact truck service from the 3PL. The advantage of purchasing a renewable energy-based truck service is it will reduce GHG emissions. The drawback is it might increase the transportation cost compared to diesel trucks. Another interesting finding from this study is truckload and packaging. As of now, Tonsjö uses wooden pallets in the logistics operations. These pallets are occupying a considerable amount of weight of the transportation. The weight is the limiting factor of the deliveries. Plastic pallets could be an alternative since it would reduce the pallet weight and increase the number of pallets per trip, but there is a trade-off in this recommendation that has to be considered. Producing plastic pallets emit more emissions than wooden pallets. If the emissions of producing plastic pallets are greater than the emissions saved by loading more pallets per truck, it would actually have a negative impact. Also, as both supplier X and customer Y use these wooden pallets, the implementation of plastic pallets would have to be in collaboration with them.

Furthermore, developing a waste management system for scrap materials and cutting fluid is recommended. This system could prove helpful to reduce all kinds of waste from the workshop. For this, some key performance indicators for each operation should be defined. Tonsjö should adopt a proper internal reuse method for cutting fluids which could be useful to improve the cutting fluid efficiency while reducing the environmental impacts. For this, Tonsjö needs to collaborate with Company Z to acquire the proper training in regards to knowing the procedure to ensure the internal reuse quality for cutting fluids. Lastly, this thesis only identified the hotspots in energy usage and GHG emissions as a basis for decision making. It did not develop any sustainable strategies during this study. The suggested strategies could be implemented in the future by Tonsjö after a detailed decision-making process.

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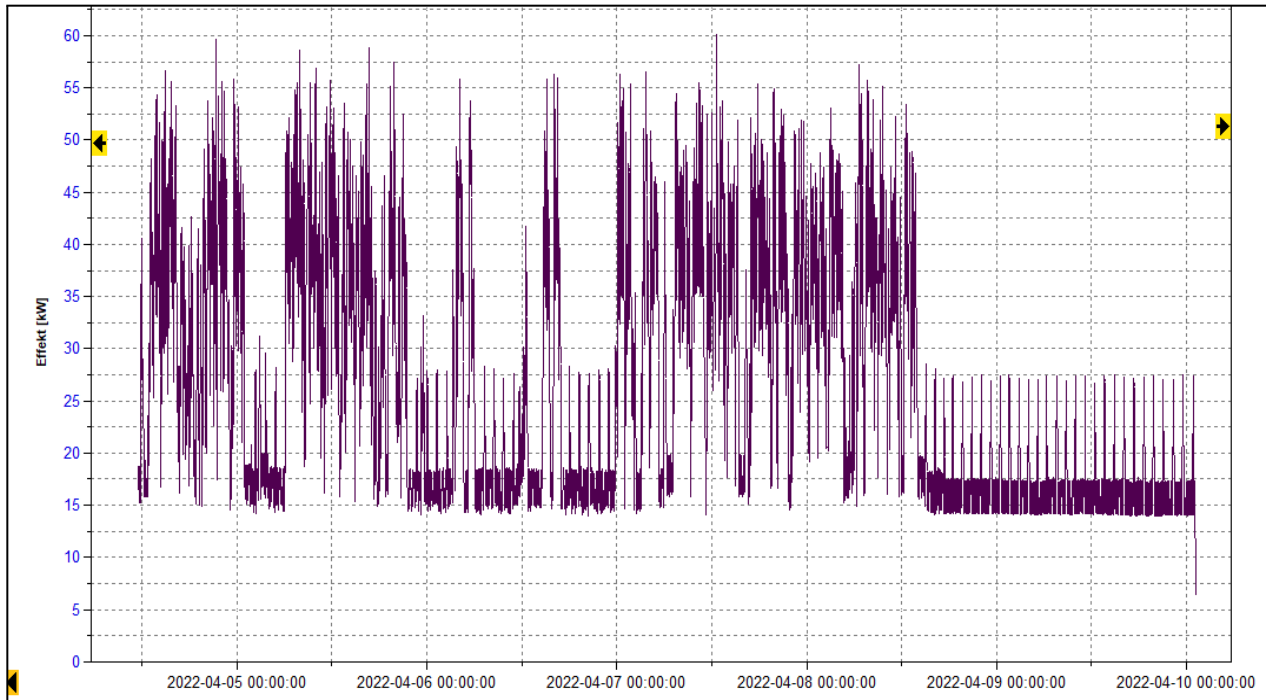
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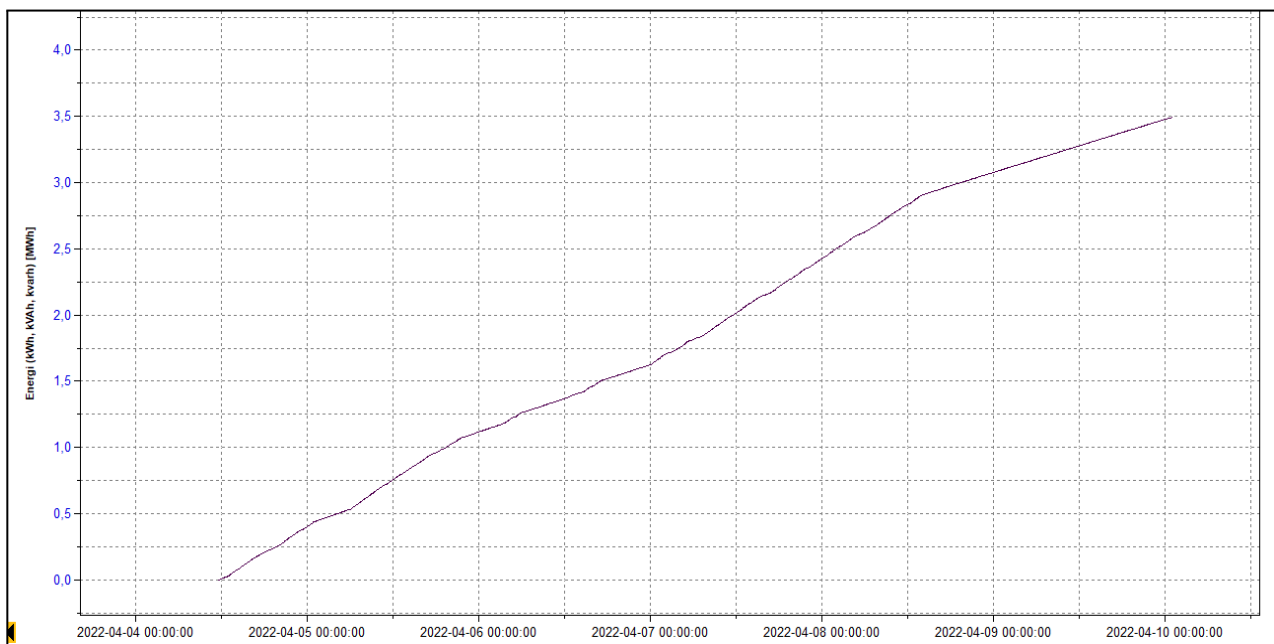
Appendix

Graphs from Fluke Software

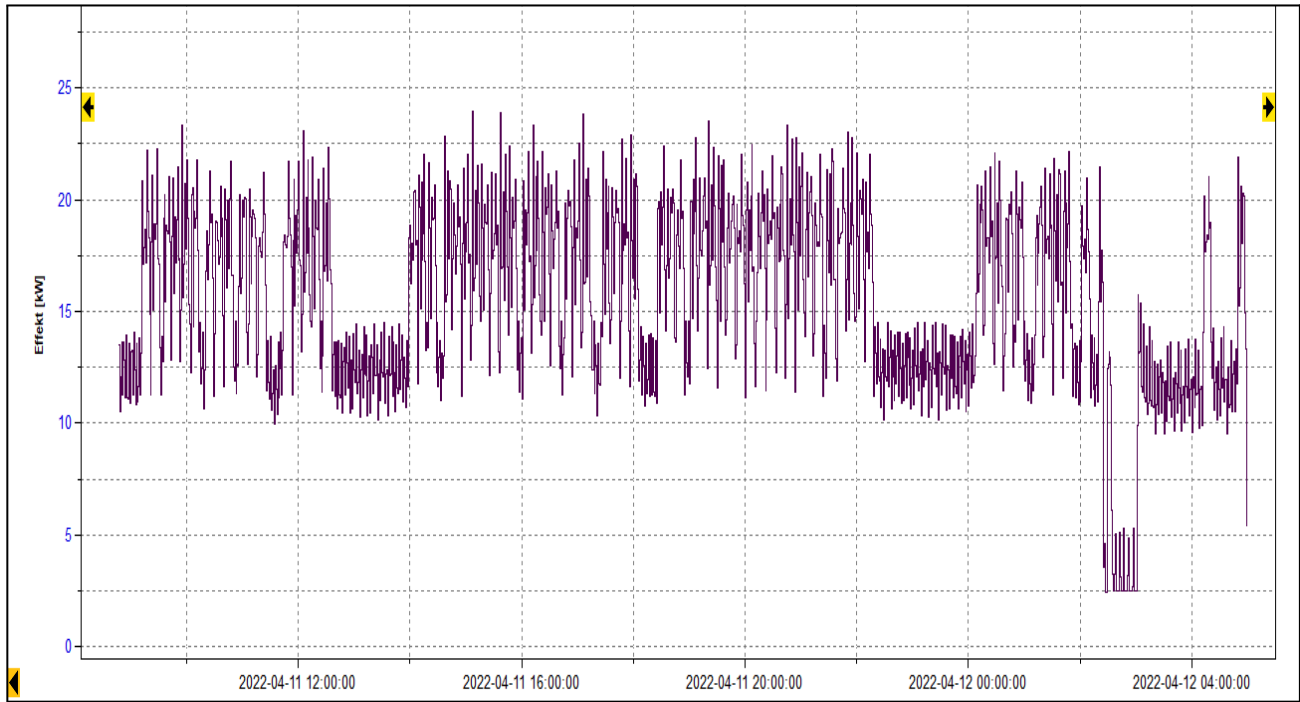
Cell 4 - Power Cord Effect



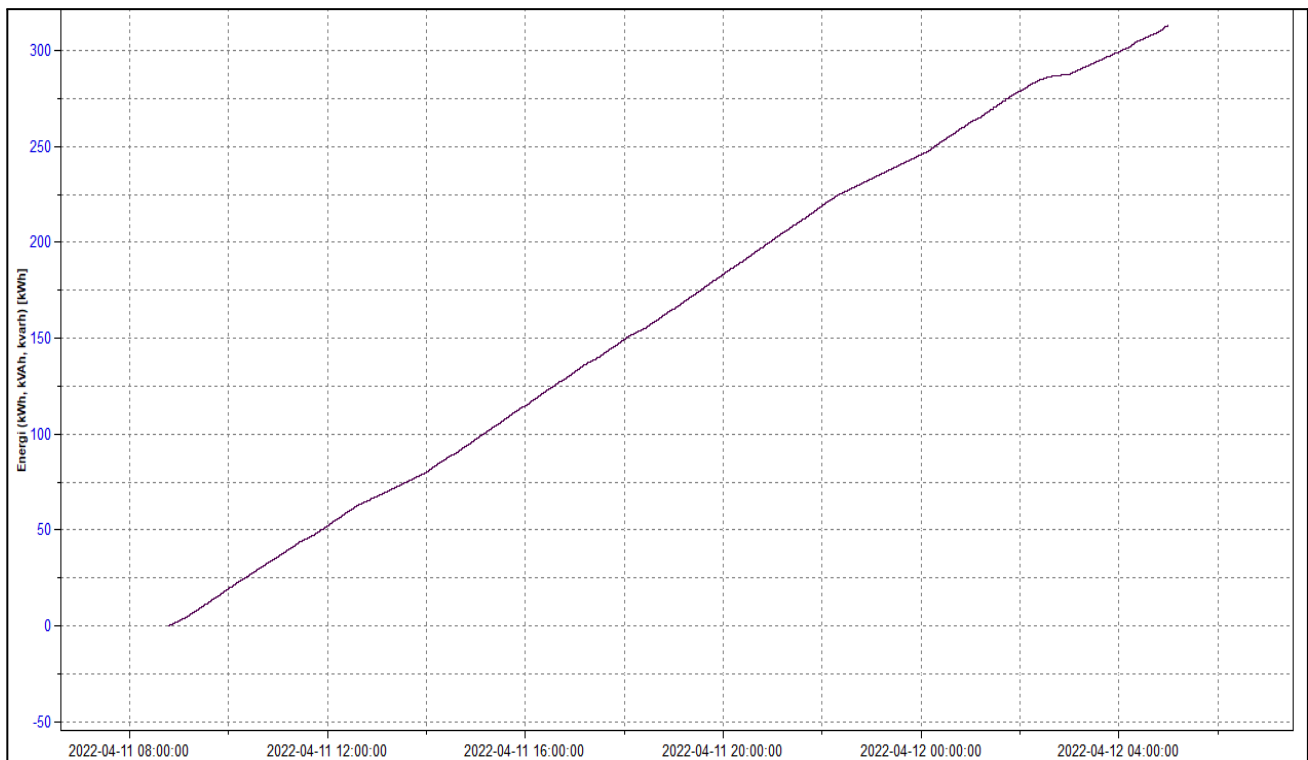
Cell 4 - Power Cord Energy



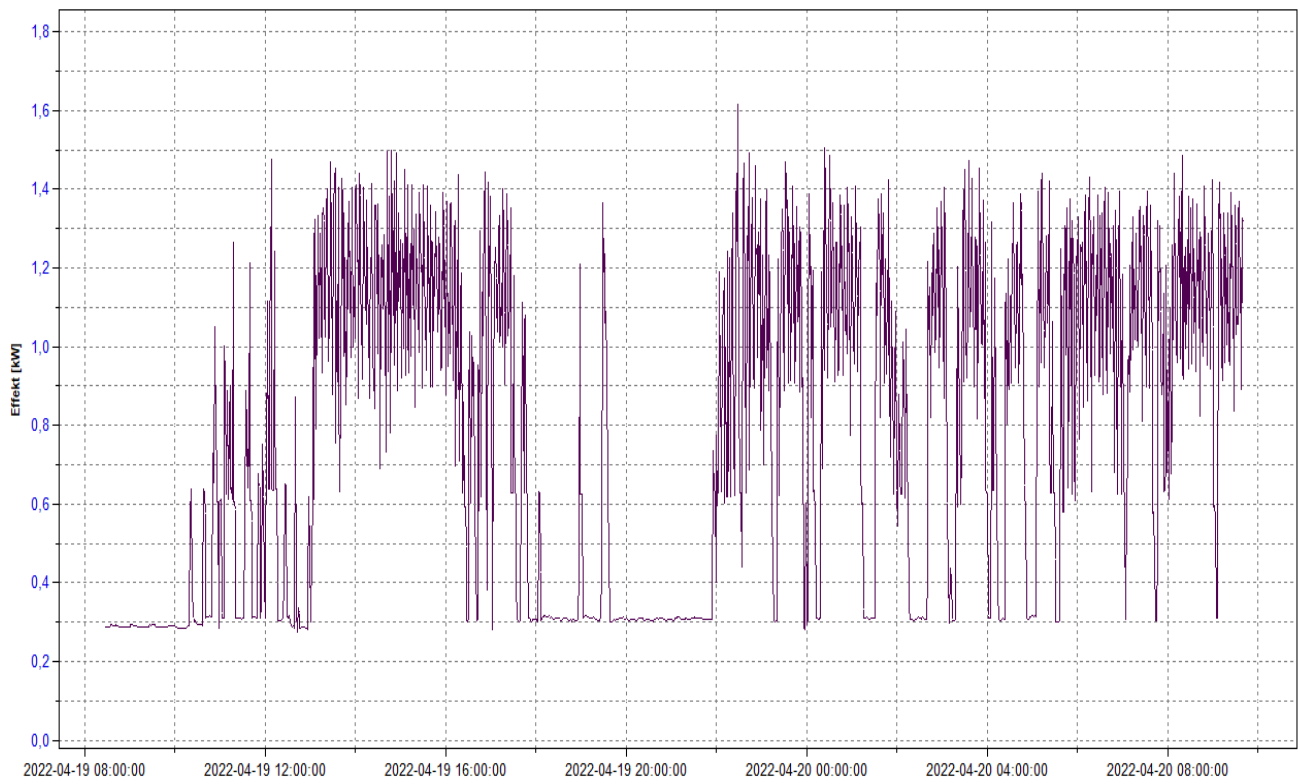
Cell 4 - Drilling Machine Effect



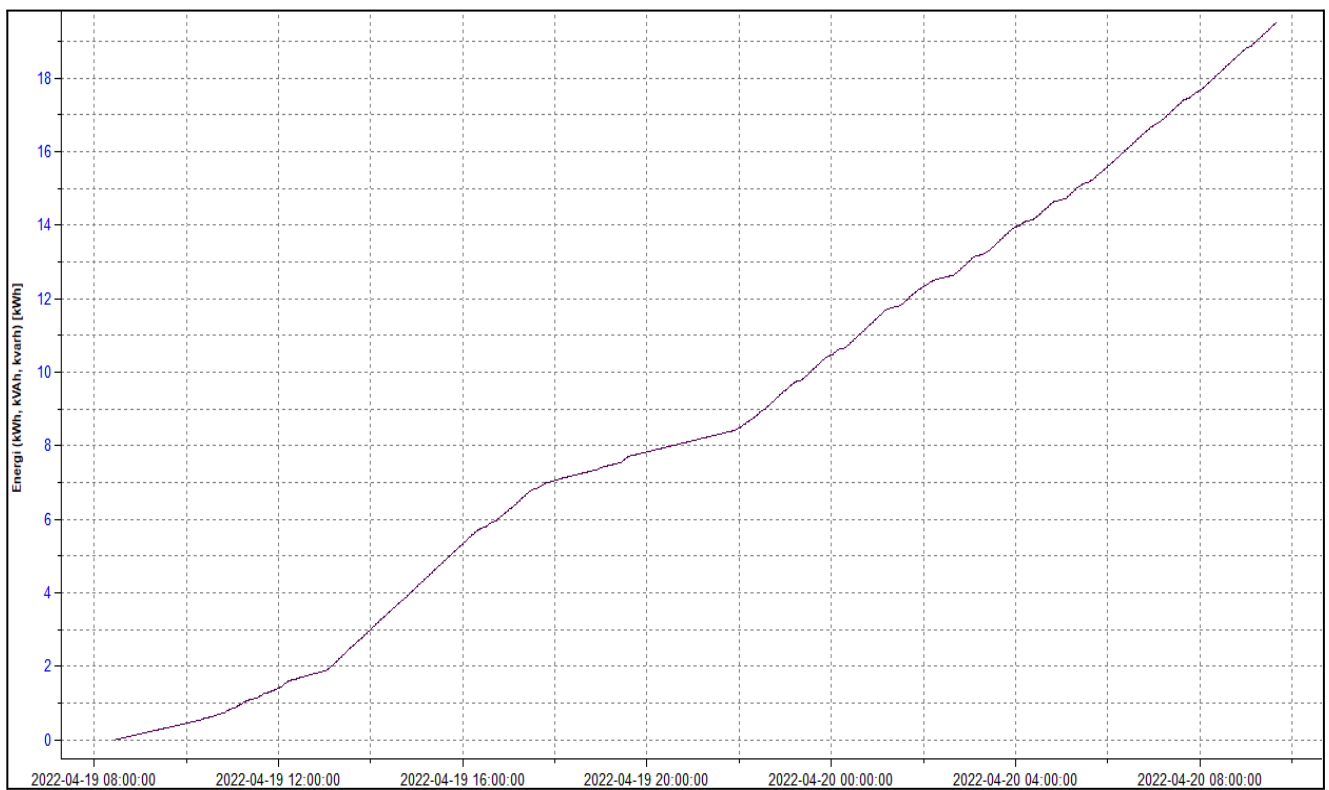
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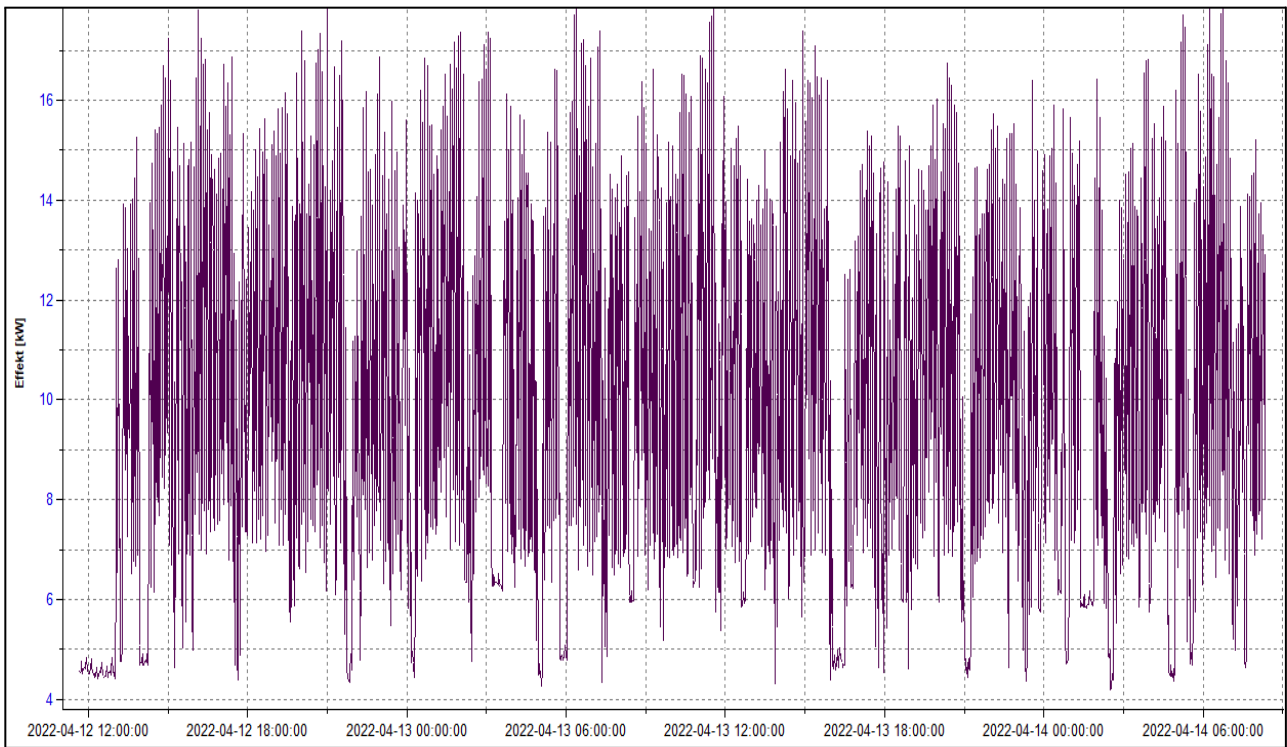
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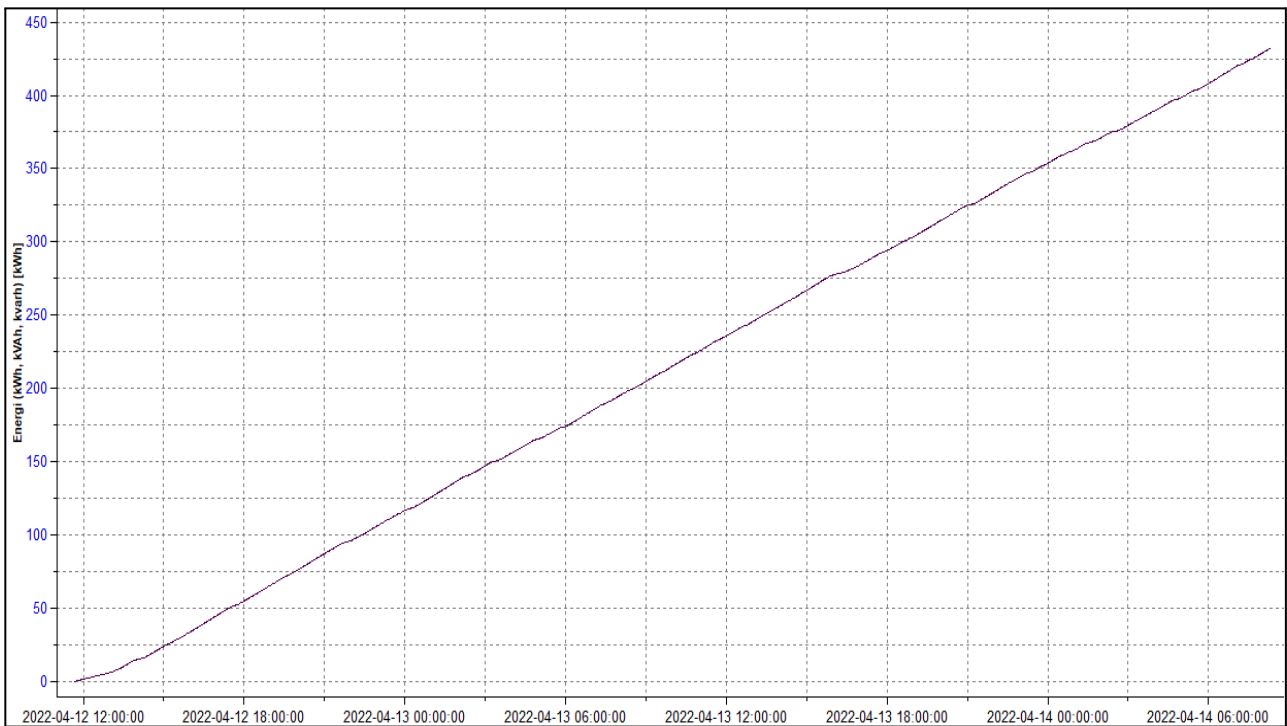
Cell 4 - Robot Energy



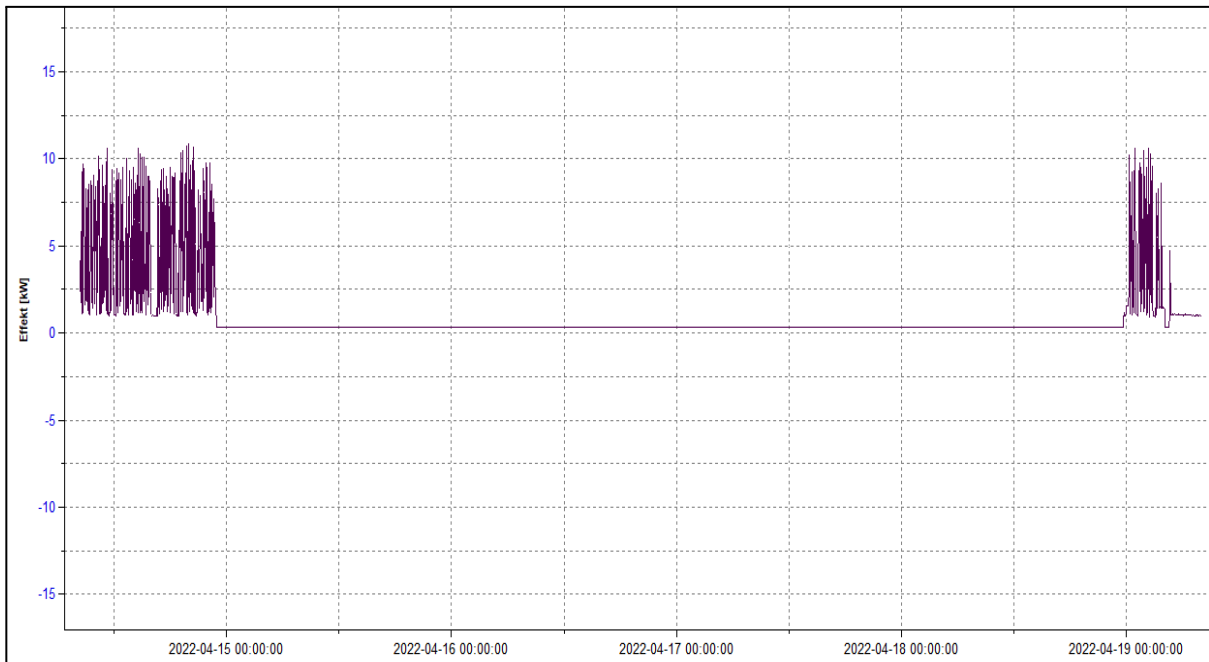
Cell 4 - Lathe Machine (G1) Effect



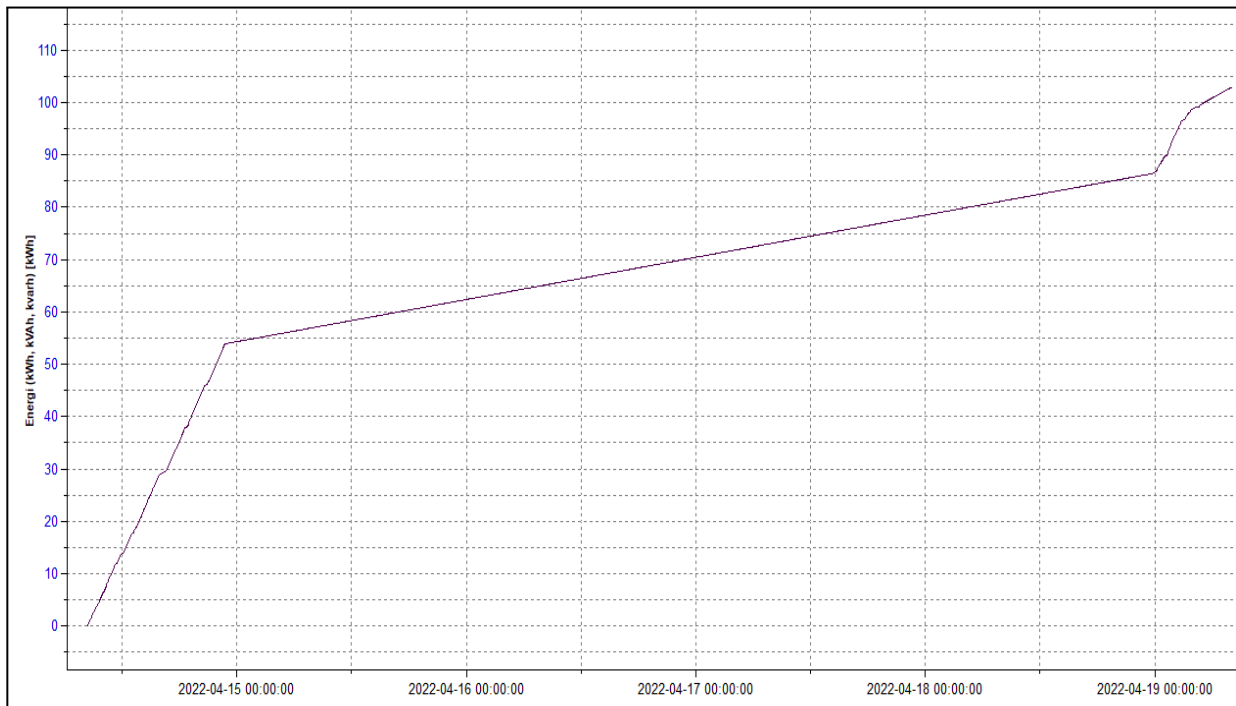
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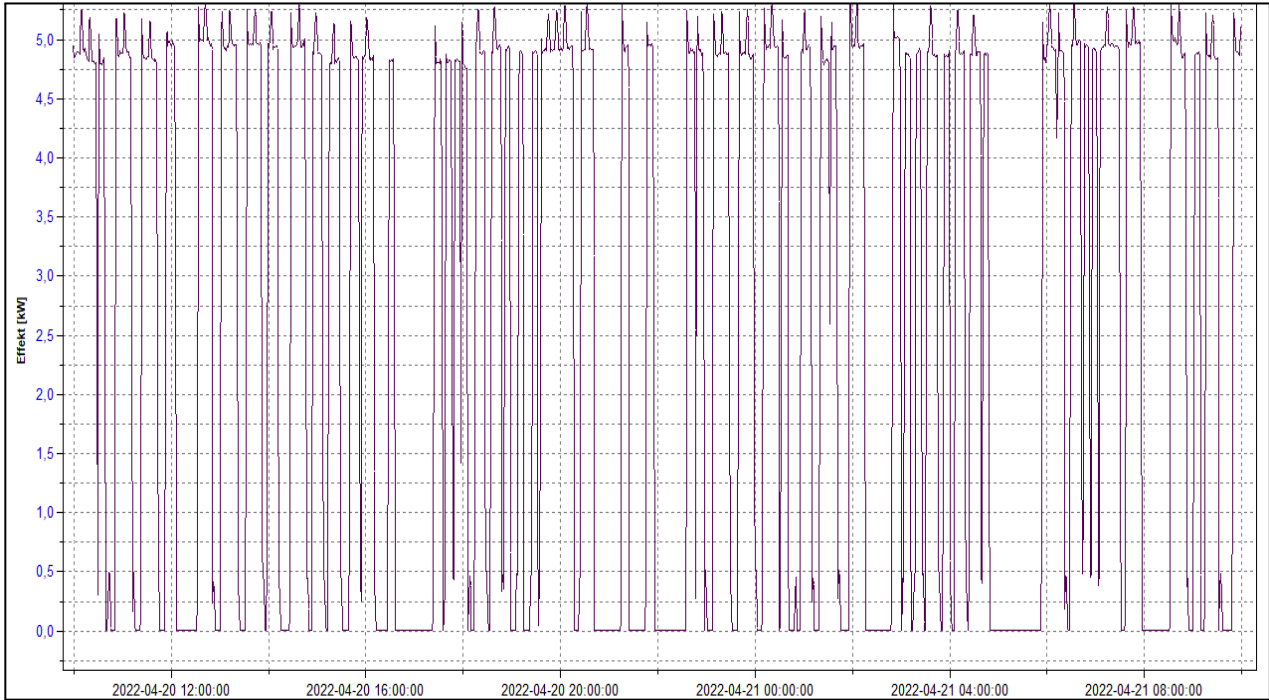
Cell 4 - Lathe Machine (G2) Effect



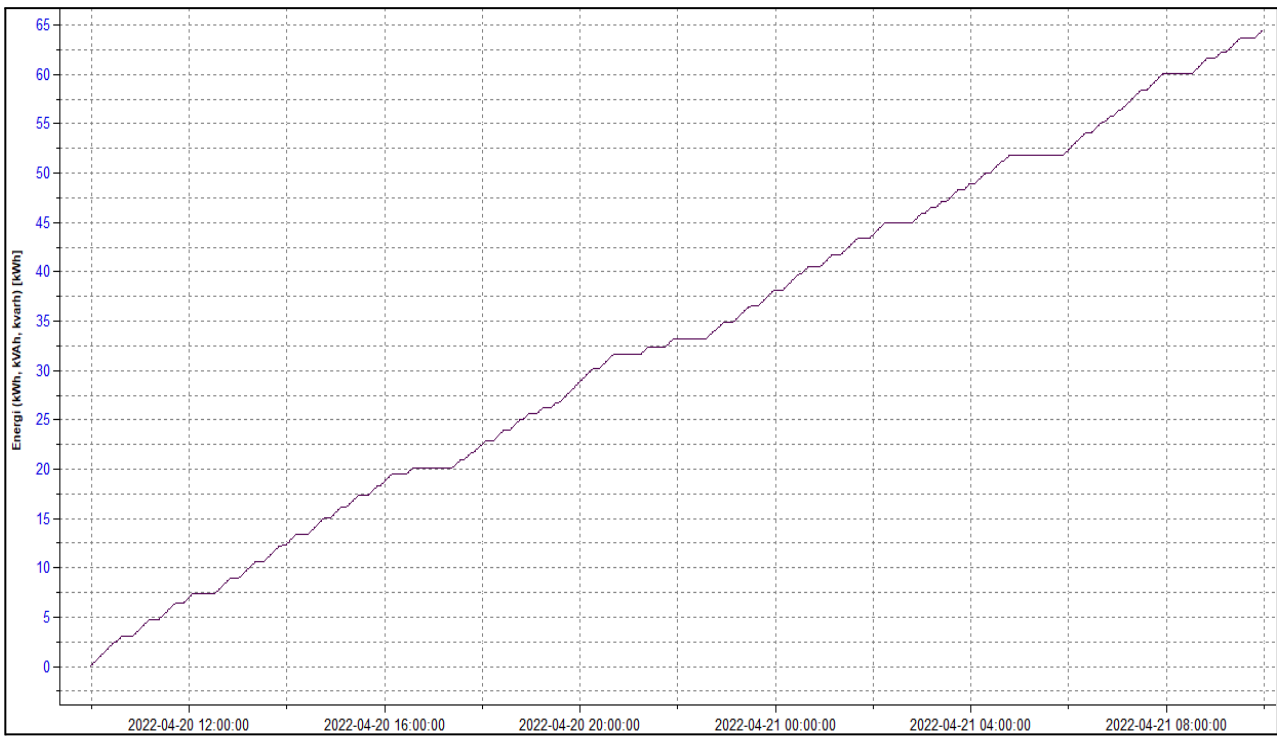
Cell 4 - Lathe Machine (G2) Energy



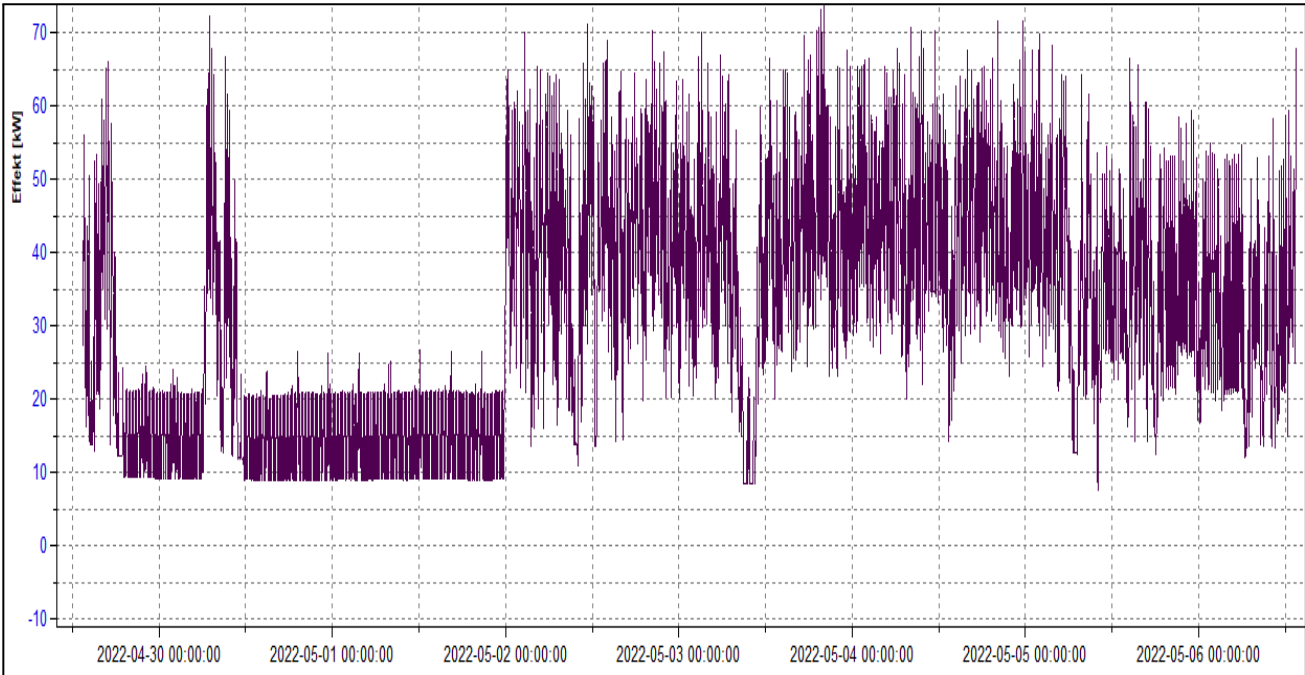
Cell 4 - Washing Machine Effect



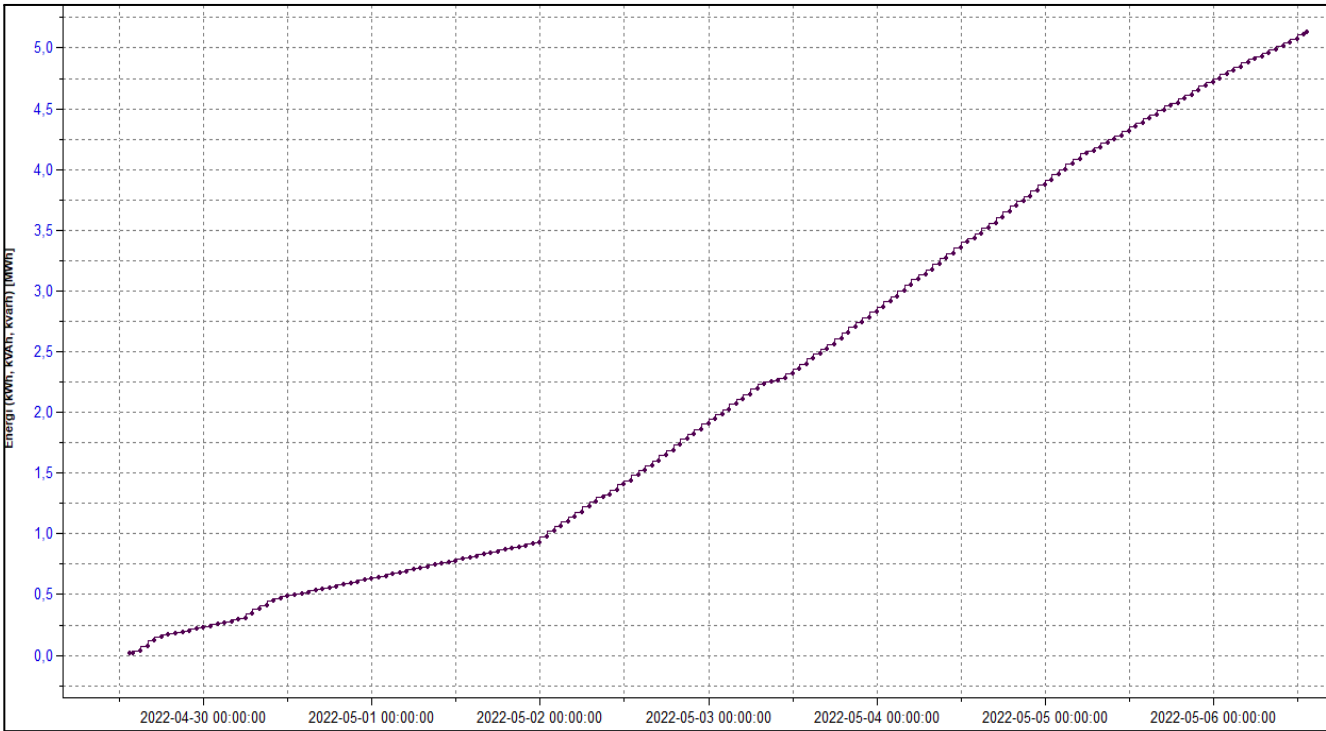
Cell 4 - Washing Machine Energy



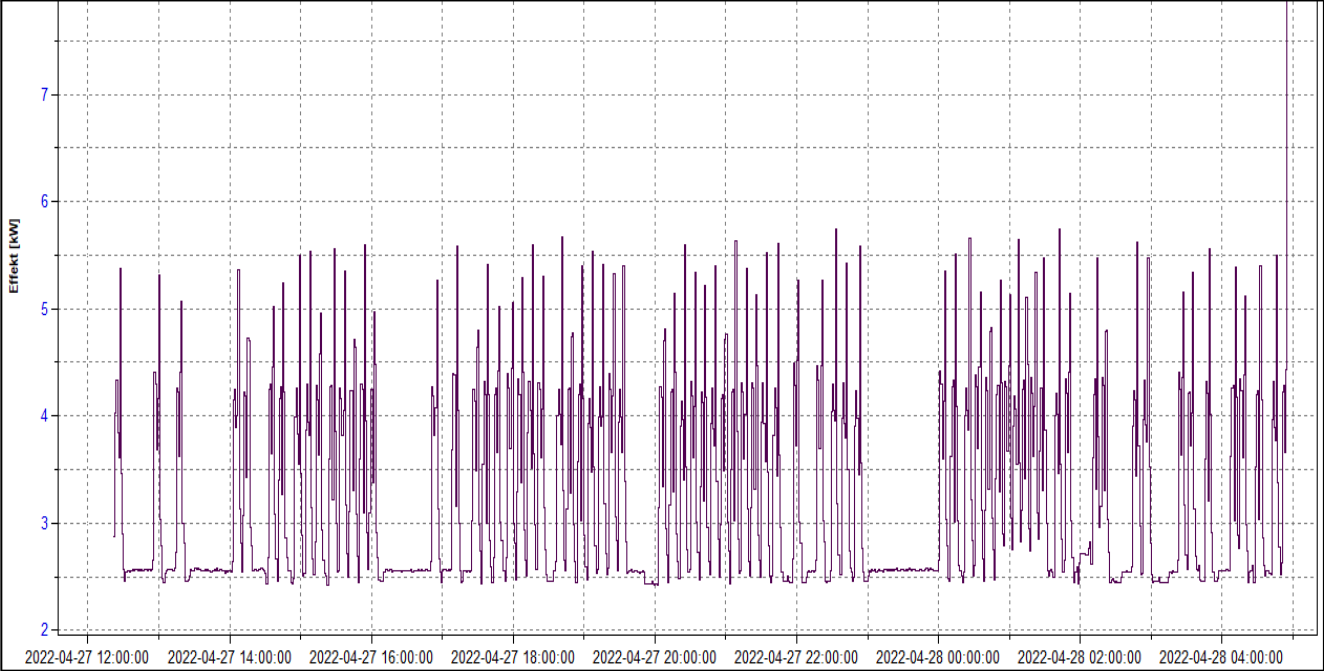
Cell 7 - Power Cord Effect



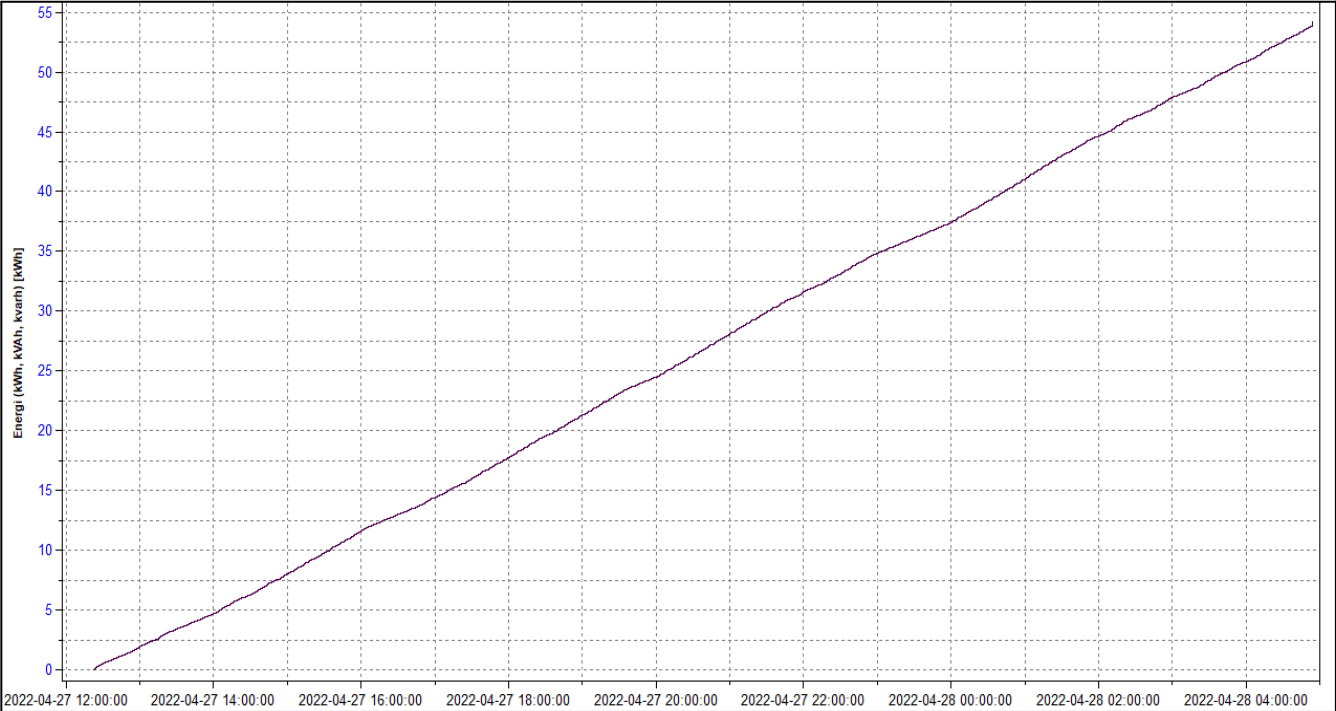
Cell 7 - Power Cord Energy



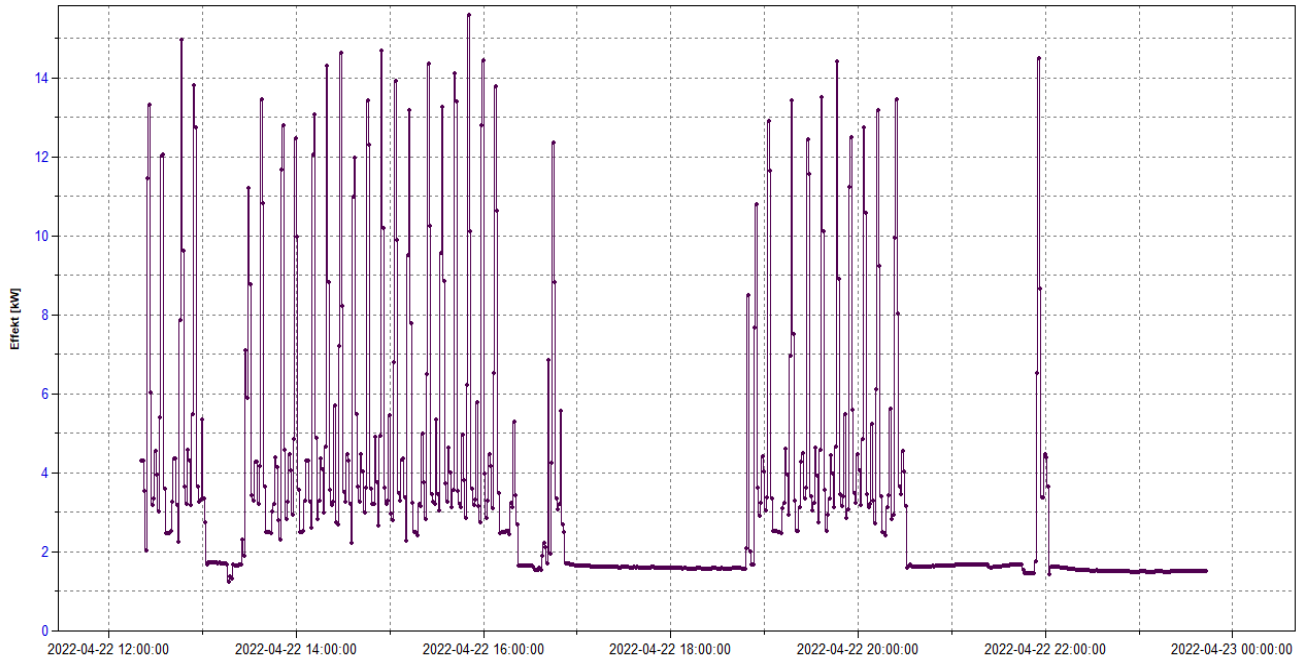
Cell 7 - drilling machine (G3) Effect



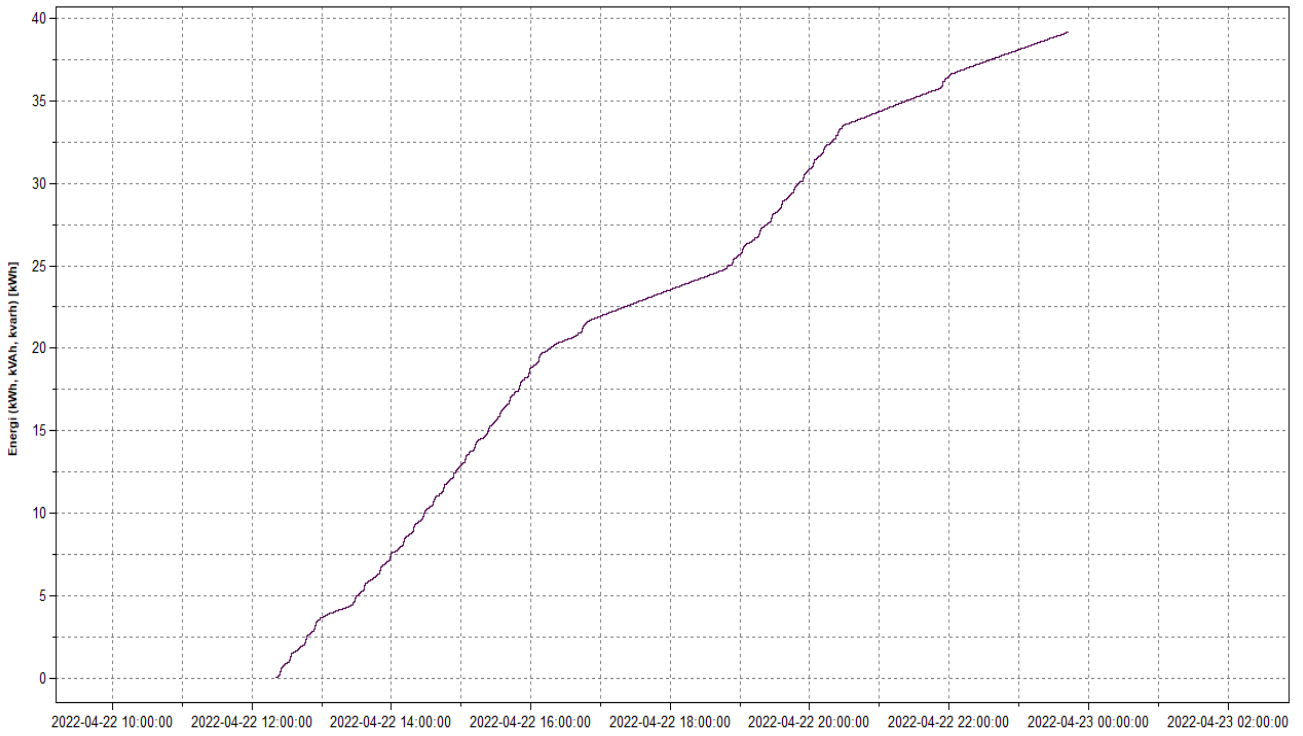
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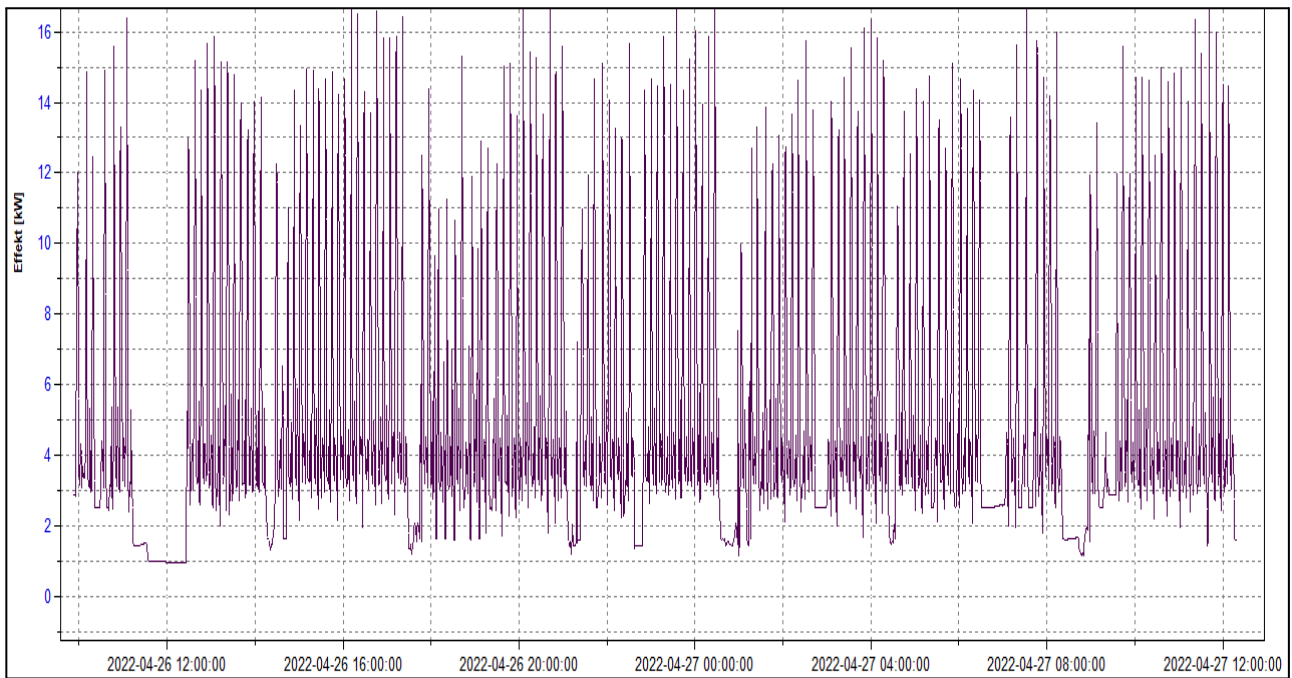
Cell 7 - Lathe 1 Effect



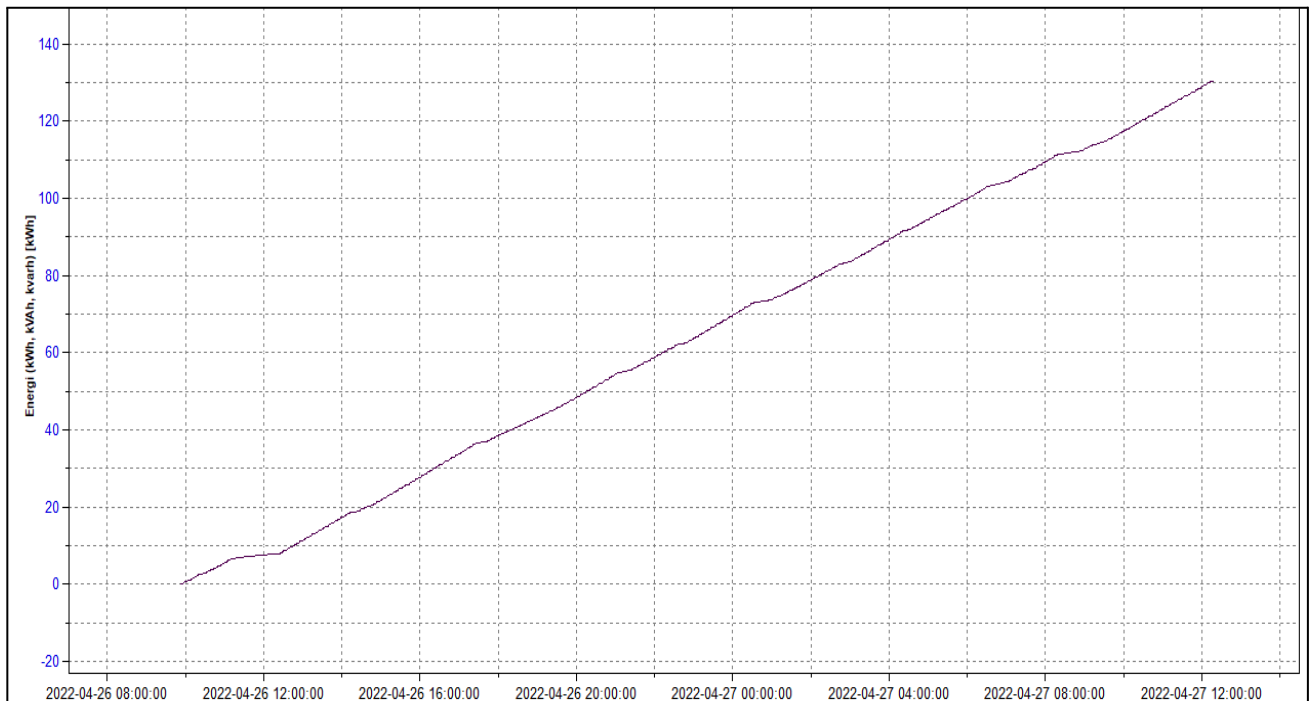
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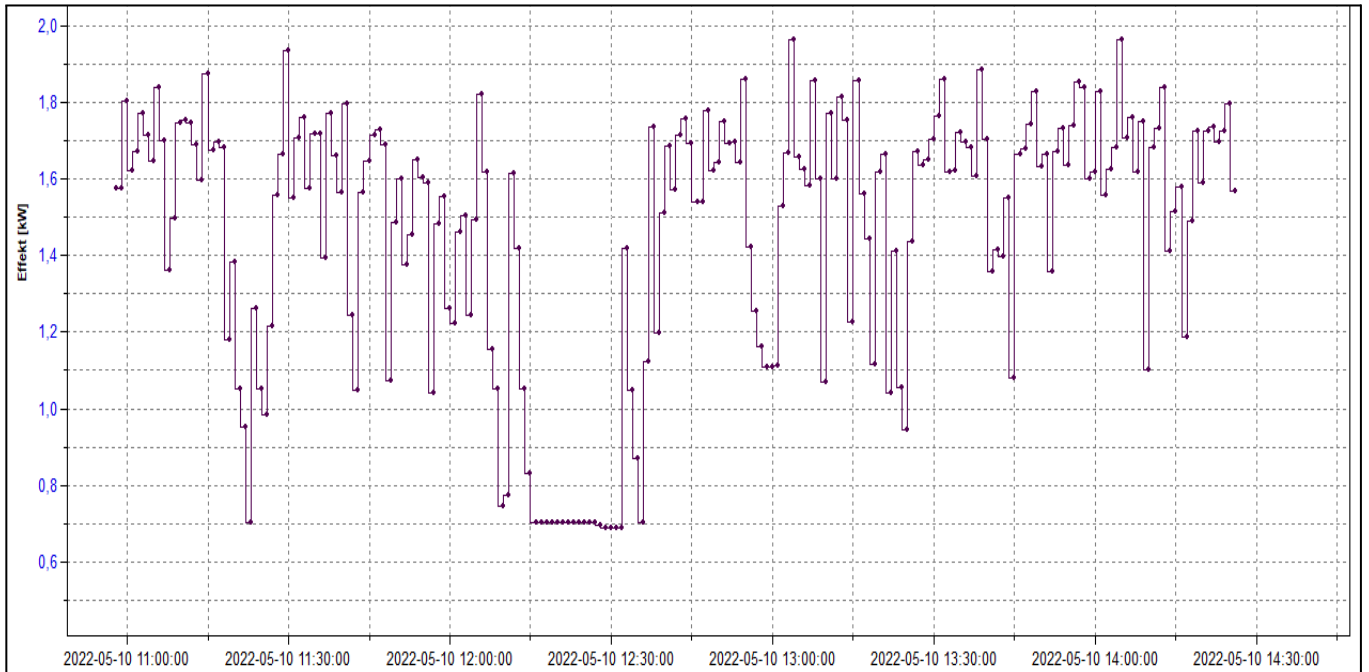
Cell 7 - Lathe 2 Effect



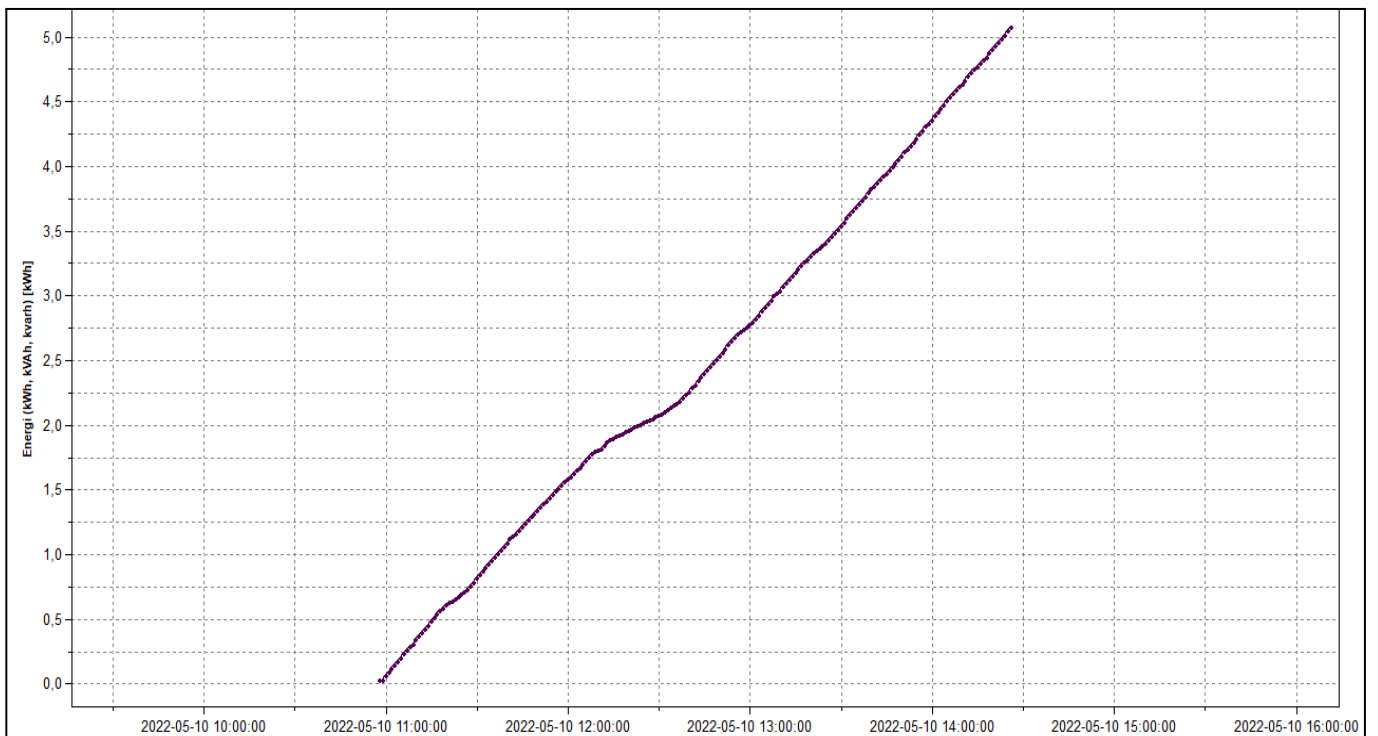
Cell 7 - Lathe 2 Energy



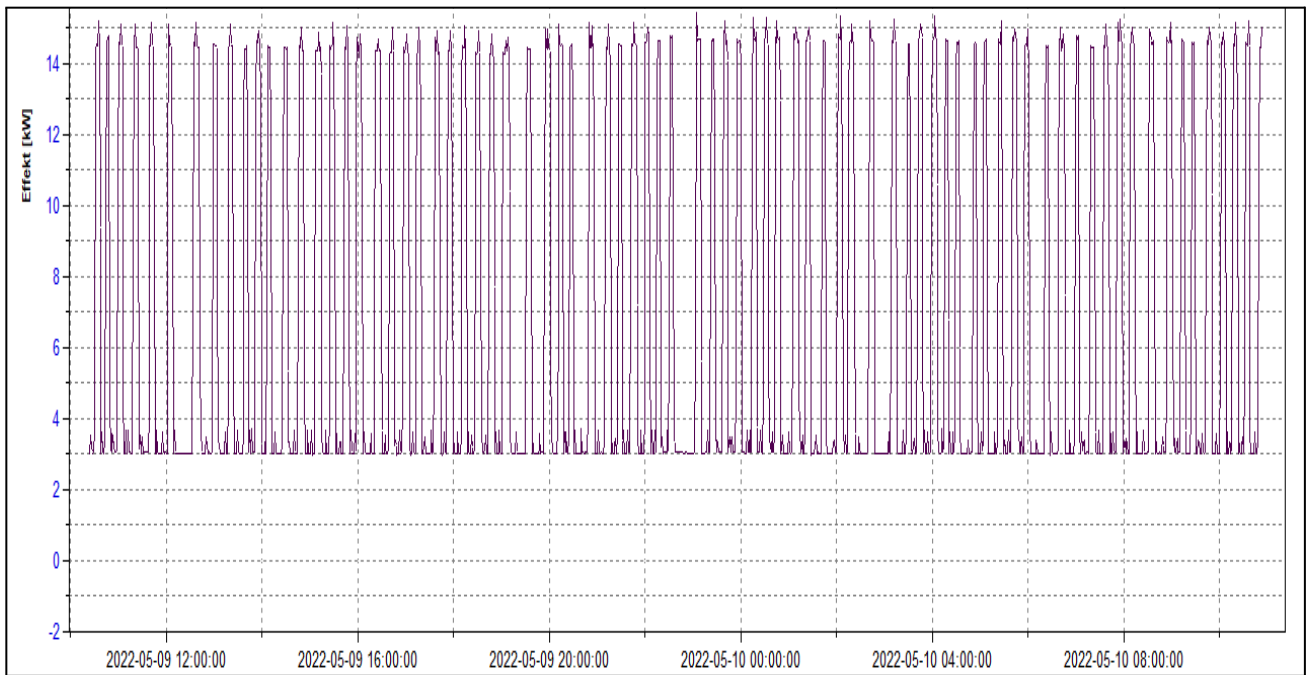
Cell 7 - Robot Effect



Cell 7 - Robot Energy



Cell 7 - Washing Machine Effect



Cell 7 - Washing Machine Energy

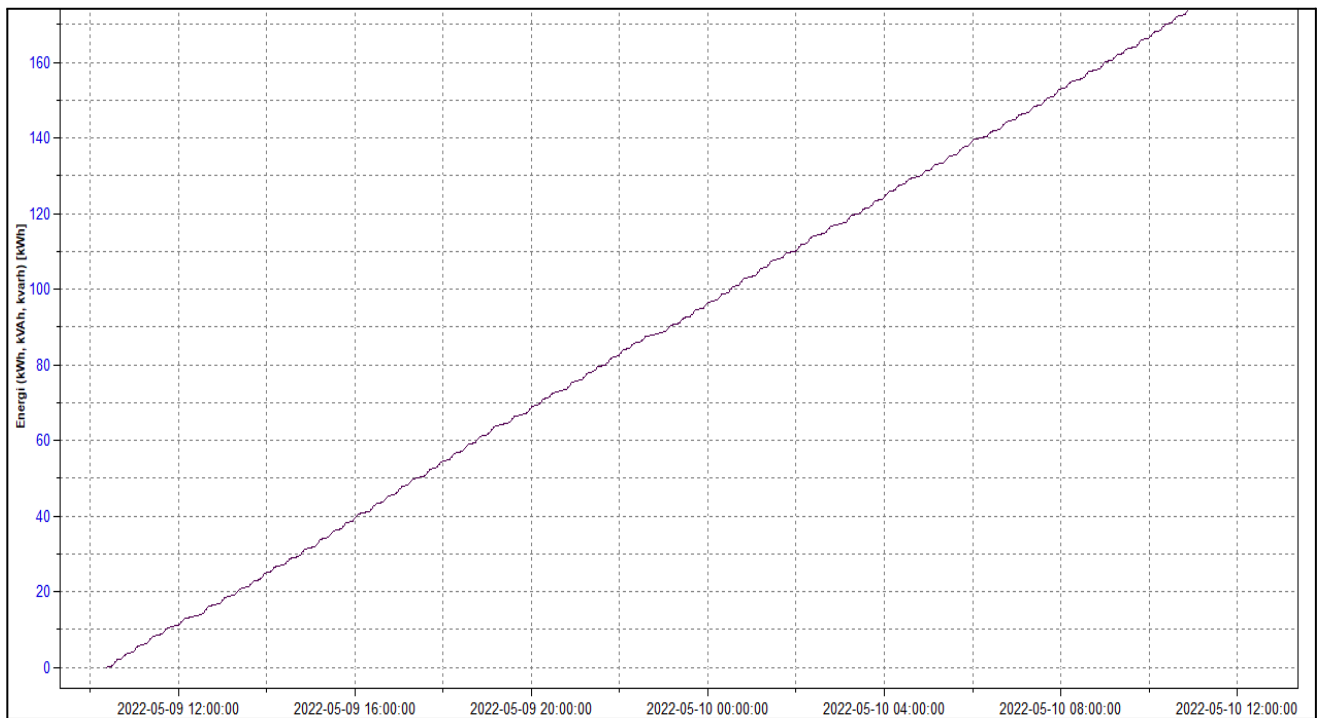


Table A1: Carbon emission contribution per product including raw material

Type of Operation	Carbon emission (Kg CO2 eq.)	Percentage
Raw material (1 unit)	39.564	94.7%
Inbound transport (from supplier X)	0.734	1.8%
Production	0.034	0.1%
Outbound transport (to customer Y)	1.447	3.5%
Transport (scrap matreial)	0.016	0.0%
Cutting fluid	0.005	0.0%
Total	41.800	

Table A2: Carbon emission contribution per product excluding raw material

Type of Operation	Carbon emission (Kg CO2 eq.)	Percentage
Inbound transport (from supplier X)	0.734	32.8%
Production	0.034	1.5%
Outbound transport (to customer Y)	1.447	64.7%
Transport (scrap matreial)	0.016	0.7%
Cutting fluid	0.005	0.2%
Total	2.236	



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