CHALMERS
UNIVERSITY OF TECHNOLOGY

Feasibility study on electric load adjustment for Rya Wastewater Treatment Plant

Master's thesis in Infrastructure and Environmental Engineering

ABDULLA RIFAD

SIVANI KALLUVAYAL BHASKARAN

DEPARTMENT OF ARCHITECTURE END CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2024
www.chalmers.se

MASTER'S THESIS ACEX30

Feasibility study on Electric load adjustment in Rya Wastewater Treatment Plant

ABDULLA RIFAD
SIVANI KALLUVAYAL BHASKARAN

Department of Architecture and Civil Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024

Feasibility study on Electric load adjustment in Rya Wastewater Treatment Plant
ABDULLA RIFAD
SIVANI KALLUVAYAL BHASKARAN

Supervisor: Britt-Marie Wilén, Chalmers University of Technology
Ville Tanskanen, Gryaab AB
Examiner: Britt-Marie Wilén, Chalmers University of Technology

Master's thesis 2024: ACEX30
Department of Architecture and Civil Engineering
Division of Water Environment Technology
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Cover image: Rya wastewater treatment plant (Gryaab, 2024)

Department of Architecture and Civil Engineering
Gothenburg, Sweden, 2024

Feasibility study on Electric load adjustment in Rya Wastewater Treatment Plant

ABDULLA RIFAD

SIVANI KALLUVAYAL BHASKARAN

Department of Architecture and Civil Engineering
Division of Water Environment Technology
Chalmers University of Technology

Abstract

This thesis investigates the feasibility of adjusting the electric load at the Rya wastewater treatment plant (WWTP), operated by the municipal company Gryaab AB in Gothenburg, Sweden, with the goal of reducing electricity usage momentarily and contributing to the local flexibility market, Effekthandel Väst (EHV). The Rya WWPP consumes approximately 240 GWh of electricity annually, of which most of the electricity is used for inlet pumping and aeration in the activated sludge process, accounting for 70% of the total consumption.

As Gothenburg prepares for potential electricity shortages in the years ahead, this study focuses on momentarily reducing electricity usage during the peak hours (morning and evening) through short term and long-term flexibility measures. Flexibility refers to the ability to adjust electricity usage in response to market conditions or grid demands, either by reducing consumption or shifting it to different times. By analysing historical electricity usage data, the report evaluates different scenarios where Gryaab can participate in Effekthandel Väst by momentarily halting the operations or shifting the electricity demand to off-peak hours/periods.

Results show that momentary shutdowns of key processes, can lead to significant reductions in electricity consumption. The study compares the financial and operational impacts of short-term versus long-term flexibility. While short-term flexibility offers immediate responses to market conditions and financial benefits, long-term flexibility provides consistent savings and aligns with strategic goals.

The findings highlight the socio-economic and environmental benefits of Gryaab's participation in Effekthandel Väst, including momentary reduced energy consumption and enhanced grid stability.

The study concludes that optimised electricity management at the WWTP not only supports Gothenburg's sustainability targets but also offers substantial cost-savings opportunities during high demand periods.

Keywords: Effekthandel Väst, short-term flexibility, long-term flexibility, wastewater treatment

Acknowledgement

The successful completion of this project would not have been possible without the invaluable collaboration and support from Chalmers University of Technology, Gryaab, and Gothenburg Energy. We are deeply grateful to all those who contributed to making this project a success.

First and foremost, we extend our heartfelt thanks to our supervisor at Chalmers, Britt-Marie Wilén, and our supervisor at Gryaab, Ville Tanskanen, for their continuous guidance, encouragement, and expertise throughout the course of this research. We are also deeply grateful to Kai Jauhiainen and Bardh Limani for their unwavering support and valuable input, which were instrumental to the progress of this study.

We would like to offer our special thanks to Darijan Jelica and Mihail Chigrichenko from Gothenburg Energy for their cooperation and willingness to provide critical data and insights, which were essential to the success of this project. Your contributions have been invaluable, and we greatly appreciate your time and effort.

Lastly, we wish to extend our deepest gratitude to our families and friends for their unwavering encouragement and support throughout this journey. Their belief in us has been a constant source of motivation.

ABDULLA RIFAD
SIVANI KALLUVAYAL BHASKARAN

Table of Contents

1. Introduction

Energy usage in wastewater treatment plants (WWTPs) is a critical factor influencing the environmental and economic sustainability of these facilities. As the global demand for clean water increases and the need for higher wastewater treatment efficiency, so does the need to optimize the energy efficiency of WWTPs. These plants typically rely on energy-intensive processes such as aeration, which can account for up to 60% of their total energy consumption. Advances in technology and process optimization are crucial in reducing energy use and the associated greenhouse gas emissions, particularly in regions where environmental regulations are stringent. (Wang, Deng, & You, 2023; Hamawand, 2023).

Electricity consumption in WWTPs varies significantly depending on the technology employed and the region of operation. Conventional activated sludge processes typically consume around 0.269 kWh per cubic meter of treated wastewater, while more advanced methods such as membrane bioreactors can exceed 0.370 kWh per cubic meter. (Wang, Deng, & You, 2023). A substantial portion of this energy—up to 60%—is used in the aeration process, making it a key target for optimization in efforts to reduce overall energy consumption. (Wang, Deng, & You, 2023). Globally, the adoption of more energy-efficient technologies is more prevalent in regions like Europe, driven by stringent environmental regulations. (Hamawand, 2023).

Overall, the trend towards energy efficiency in WWTPs is a global imperative, with regions implementing varying strategies based on their technological, economic, and regulatory contexts. As the push for carbon neutrality and circular economy models continues, the role of energy management in WWTPs will only become more prominent, necessitating ongoing research and innovation in this critical area. (Wang, Deng, & You, 2023; Hamawand, 2023).

Sweden is facing an energy crisis, causing a big rise in electricity prices and uneven costs across the country. As prices keep going up, there is a risk that some people might have their electricity cut off (Holmberg & Tangerås, 2022). Solving this crisis requires a variety of actions, including short-term improvements to increase energy capacity and better use of the electricity grid. It also involves specific steps to reduce electricity use during times of high demand, as well as efforts to make the electricity system more efficient (Holmberg & Tangerås, 2022).

The city of Gothenburg stands at the forefront of the Nordic region's transition towards electrification, positioning itself as a pivotal area in the evolving landscape of sustainable energy practices. As a growing city with larger population and increasing demand, Gothenburg is stressing the electricity grid and causing high peak loads. As the year 2028 approaches, Gothenburg will face the looming challenge of electricity shortages, prompting the initiation of the concept of Effekthandel Väst (EHV); a facilitating trading platform where customers act as the flex suppliers. The mechanism of strong diurnal variation in electricity usage opens possibilities for both cost savings and optimization on a larger scale. The demand for flexibility is most pronounced during peak hours in the morning (8-10 AM) and afternoon/evening (4-6 PM) (Gothenburg Energi, 2024). The implementation of EHV is expected to yield significant environmental and social benefits. Direct environmental advantages stem from the correlation between high spot prices and flexibility needs during the trading season, underscoring the potential for reduced energy consumption and carbon emissions.

1.1 Background

Gryaab is a municipal company owned by the municipalities of Ale, Bollebygd, Gothenburg, Härryda, Kungälv, Lerum, Mölndal, and Partille, with Gothenburg holding approximately 71 percent ownership. Gryaab oversees the tunnel system that channels wastewater to the Rya wastewater treatment plant (WWTP). The WWTP is a substantial electricity consumer, with an annual usage of approximately 40 GWh, of which about 70 percent is dedicated to the inlet pumping station and aeration within the biological treatment process.

The goal of this study is to assess the possibility to momentarily reduce electricity usage during peak hours, while evaluating how the electricity consumption can be reduced most effectively at Gryaab. It should be highlighted that the challenging issue in WWTP energy optimization is determining an optimal and realistically feasible solution that can effectively handle the variety of objectives (such as effluent quality, energy consumption, and economic factors) and suggest a trade-off between them (Borzooei, et al., 2019).

One notable flexible resource identified within the EHV framework is the pumping station at Gryaab, a key focus area to study. Here, efforts are concentrated on optimizing energy usage by temporarily halting operations at this point and redistributing saved energy back to the EHV market. This approach involves thorough analysis of historical data to effectively gauge energy consumption patterns and identify opportunities for improvement. Through this strategy, Gryaab aims to contribute to the sustainability goals of the Gothenburg region while also reaping socio-economic benefits from participating in the EHV market.

1.2 Aim

The study aims to address the challenges posed by the increasing electricity demand in the city, with a focus on momentarily optimizing the electricity usage of the Rya wastewater treatment plant (WWTP) managed by Gryaab in Gothenburg. Specifically, it aims to reduce the electricity consumption when the grid load peaks and provide that electricity for the grid to use at times. This is accomplished by analysis of data from Gryaab and Gothenburg energy.

1.3 Limitations

The limitations and out of the scope of the thesis study include the following.

i. Due to the vast dataset analysed on an hourly basis, minor discrepancies may occur in the data, potentially attributed to factors such as seasonal clock changes during spring and autumn. These variations need to be carefully considered to ensure ethical interpretation and reporting of the results.
ii. Temporarily stopping the pump may disrupt downstream processes like biological treatment in activated sludge, moving bed biofilm reactors and trickling filters, affecting flow balance and treatment efficiency. It's essential to ensure this doesn't compromise effluent quality. This was not considered in this study.
iii. Frequent stopping and restarting of pumps could increase carbon emissions due to energy inefficiencies. Evaluating the carbon impact is necessary to assess the overall benefit. This was not taken into consideration in this study.

2. Theory

2.1 Energy consumption at wastewater treatment plants.

Swedish wastewater treatment plants' energy usage equals a total of 0.6 TWh per year. Together with the Swedish drinking water treatment, the usage corresponds to approximately 1 % of the total electrical energy consumption in Sweden. Potentials for a reduction of this usage do exist (Holmberg & Andersson, 2007).

In wastewater treatment plants, energy consumption is often correlated with flow and load of organic matter and nutrients which can influence the treatment methods and technologies used in a plant. Wastewater treatment plants that have more influent biological oxygen demand (BOD) use more energy. (EPA, 2015)

The choice of treatment process plays a major role on the energy use. Larger plants with more advanced technology generally need more energy than smaller and more simple plants (pe<5000). (Jonasson, 2007) Pumps, blowers, mechanical aerators, and solids handling systems consume most of the electrical energy in wastewater treatment plants. Conversely, larger plants can use energy more efficiently relative to the population they serve. (Jonasson, 2007)

The biological treatment process is the largest energy user for every WWTP and stands normally for 50-80 % of the total electrical energy consumption. This is because the reduction of organic matter is oxygen demanding and aeration systems require high amounts of energy. Nitrogen treatment processes consume more energy than simple COD removing processes because of the oxidation process and circulation system needed. (Kjellen & Andersson, 2002)

Primary sedimentation also plays a big role for the energy balance because it affects the amount of sludge to the biological treatment process and, consequently, the need for aeration. (Kjellen & Andersson, 2002)

The sludge treatment is the process where the energy usage varies the most between the different treatment plants. Aerobic treatment uses twice the amount of energy compared to anaerobic treatment. The reason for this is the high electrical energy demand for the oxidation process. It should also be mentioned that an aerobic treatment process does not produce any useful energy like biogas of its own, as the anaerobic sludge treatment does (Kjellen & Andersson, 2002).

Electrical motors at a wastewater treatment plant, especially those for aeration and pumping, can account for up to 80% of the facility's energy consumption (U.S. Environmental Protection Agency, 2021; National Renewable Energy Laboratory, 2019). Other electrical energy consumers at a plant are compressors, water pumps, valves and heat exchanges (Kjellen & Andersson, 2002). The geographical location of a WWTP influences the electrical energy demand for the inlet pumping station. The inlet elevation between plants can differ by more than 50 meters, which indicates a significant difference in energy demand (Kjellen & Andersson, 2002).

2.2 Processes at Gryaab

Gryaab AB, owned by the municipality of Gothenburg since 1972, encompasses the Ryaverket treatment plant situated in the southern part of Hisingen Island. Its primary responsibility is the treatment of wastewater generated by over 824,000 residents across seven municipalities in the Gothenburg region. The infrastructure includes a 130 km long tunnel and pipe system, facilitating the efficient transportation of wastewater for treatment. (Nunes, Lindqvist, & Tumlin, 2017)

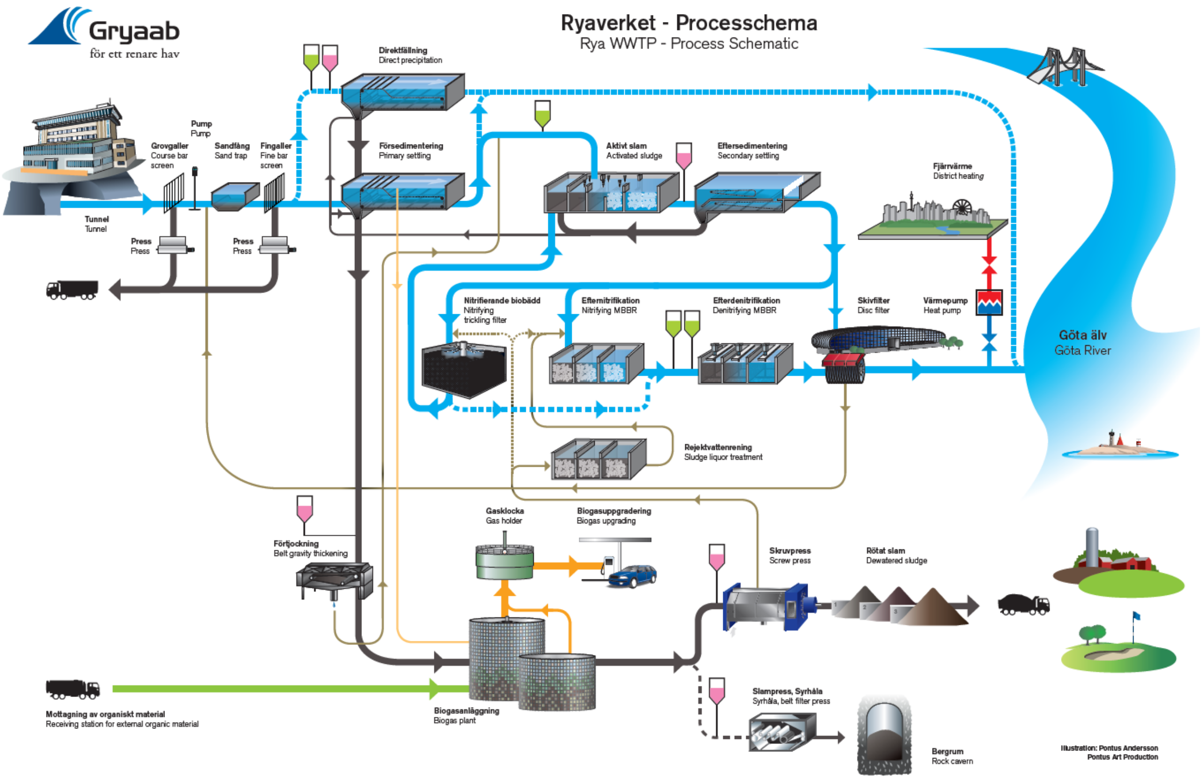

Figure 1 : Illustration of the treatment processes at the Rya WWTP (Gryaab).

At Ryaverket, the wastewater is treated with mechanical/physical processes as well as chemical and biological processes. The process is designed for nitrogen removal by pre-denitrification in activated sludge, nitrification in trickling filters, post-nitrification and post-denitrification in moving bed biofilm reactors (MBBRs). Phosphorous is removed by chemical precipitation by adding iron sulphate. Primary and secondary sludge is separated and taken out for sludge treatment by anaerobic digestion. The sludge liquor from the dewatered sludge after anaerobic digestion is treated in a separate MBBR applying anammox. The treated wastewater is led via a tunnel to the mouth of the Göta River at Rya Nabbe, where it is discharged. (Nunes, Lindqvist, & Tumlin, 2017)

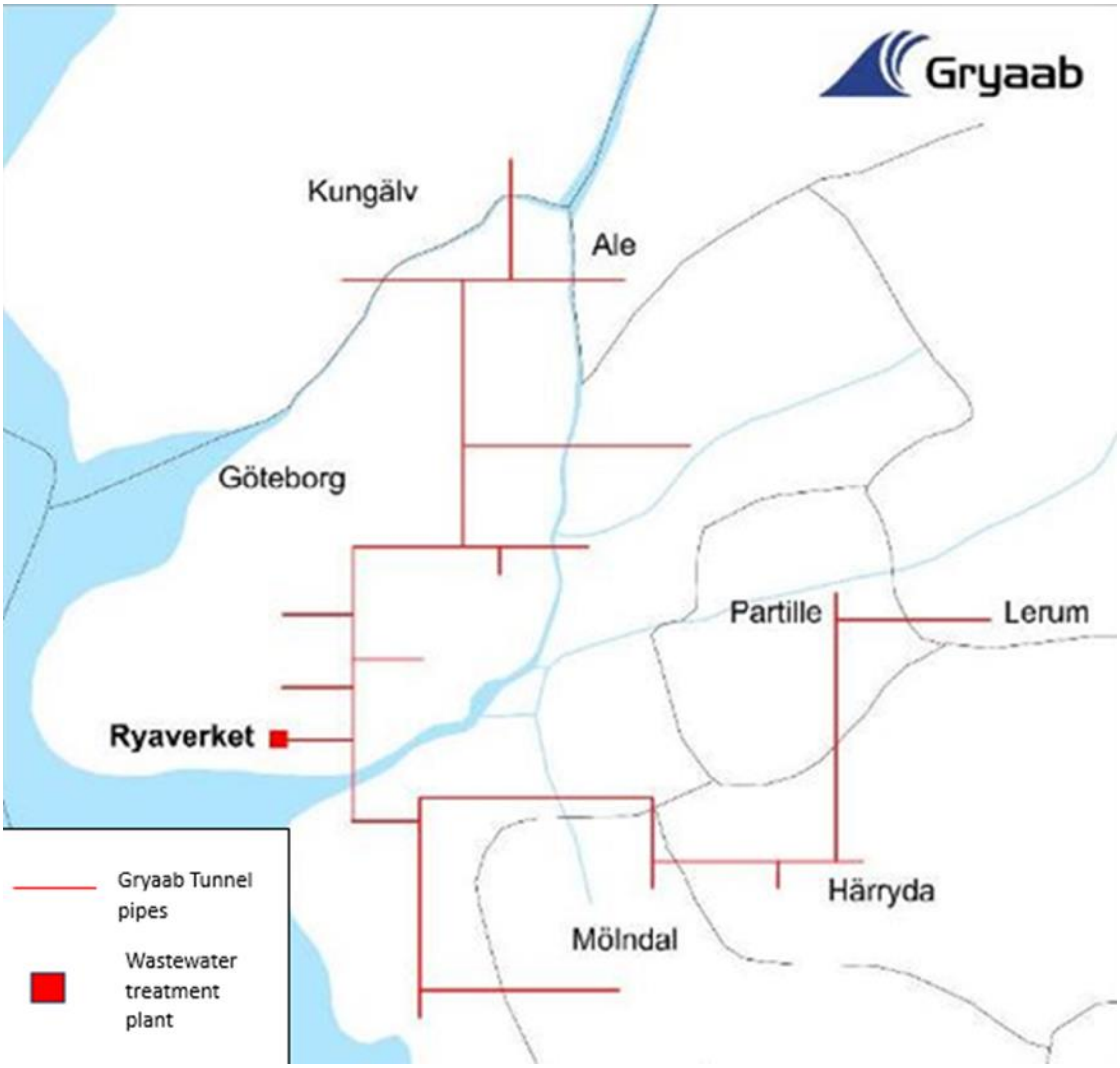

Figure 2 : Map of the tunnel system of Gryaab in Gothenburg (Gryaab, 2024)

Ryaverket receives wastewater from households, schools, offices, hospitals, and industries through a network of pipelines connecting to the tunnel system. Under normal conditions, the water inflow to Ryaverket averages at 4000 litres per second (Gryaab, 2023). However, this volume varies depending on factors such as weather conditions. During heavy rainfall, Gryaab may receive up to three times the normal volume, reaching 15000 litres per second.

Each municipality is responsible for their sewer lines up to the tunnel connections. The natural slope (0.1%) of the tunnel system allows wastewater to flow towards the treatment plant without the need for additional pumps. (Andersson, 2024) The tunnel system's catchment area covers the entire Gothenburg region. The tunnel system, largely embedded in bedrock, consists of two main branches: a northern branch and a southern branch, as illustrated in Figure 2.

The northern branch serves Angered and Hisingen in Gothenburg, as well as Kungälv and Ale. The southern branch serves Lerum, Partille, Härryda, Mölndal, and the parts of Gothenburg that lie south and east of the Göta River. These two branches converge into a common tunnel just before reaching the Ryaverket treatment plant. The incoming tunnel opens 20 meters below ground level at Ryaverket, with a total leveling volume of approximately 250,000 cubic meters. Additionally, there is capacity at Röda sten to store wastewater temporarily to manage large inflows. There is also the option for short-term storage of wastewater from the north side within the existing tunnel system.

Upon reaching Ryaverket, the wastewater undergoes initial screening at a depth of 20 meters below the main treatment plant, where large objects exceeding 20 millimeters in size are filtered out. Paper tissues and other debris are also removed, collected, pressed, finely divided, and then it is collected by Renova, for incineration to generate electricity and heat.

After this coarse filtration process, the water is pumped to ground level using four major inlet pumps. However, due to electricity constraints, a maximum of three pumps can operate simultaneously during high-flow situations. There are maintenance reasons, electricity limitations and limitations from the programming for using 4 pumps at the same time. Each pump can handle a flow rate of 6 cubic meters per second and is designed to overcome a head of 20 meters, corresponding to the depth of the tunnel system.

At Ryaverket, three major processes consume most of the total electricity, accounting for 70 percent of the total consumption. These processes include inlet pumping, aeration in the activated sludge system, and pumping to the trickling filters. (Nunes, Lindqvist, & Tumlin, 2017)

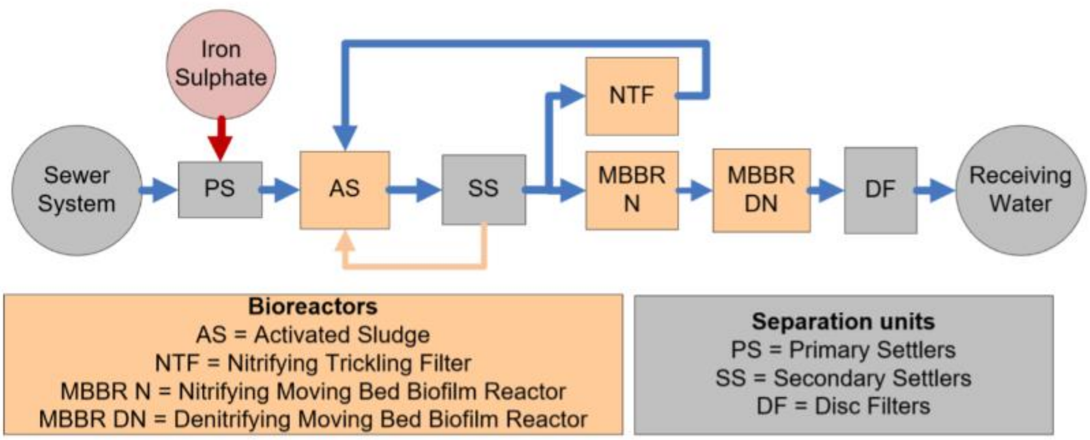

Figure 3 : Process and maximum electricity consumed processes.

2.2.1 Activated Sludge

At Gryaab, water flowing from the primary sedimentation tanks is pumped up approximately 3.8 meters to the biological treatment stage via five pumps, each with a capacity of 2 cubic meters per second. Before the water is distributed to the three activated sludge basins, it is mixed with return sludge (2 - 4 cubic meters per second) and with recirculated wastewater from the Trickling filters (1–7 cubic meters per second) in two deoxygenation basins/channels. In these deoxygenation basins, trickling filter water is mixed with return sludge to reduce the oxygen content before it is mixed with water from the primary sedimentation tanks. Return sludge is settled activated sludge, a concentrate of bacteria and other microorganisms, which is pumped back from the secondary sedimentation tanks.

As the mixture of sludge and wastewater flows through three parallel activated sludge basins with a total volume of 50,990 cubic meters, bacteria absorb the dissolved and colloidal impurities as nutrients. These bacteria oxidize the organic pollutants to obtain energy and grow. This process occurs while the sludge-water mixture passes through the activated sludge basins, taking about an hour and a half.

In the anoxic tank, the first 40-60 percent of each basin's volume is an unaerated zone where denitrification bacteria use dissolved nitrate (NO_3^-) instead of oxygen (O_2) for respiration, transforming nitrate into nitrogen gas that is released into the atmosphere. This process is known as denitrification. If necessary, ethanol can be added as an external carbon source to achieve satisfactory denitrification.

In the second part of the activated sludge basins, the sludge-water mixture is aerated, and heterotrophic bacteria break down (oxidize) organic material through respiration using oxygen. This oxidation allows bacteria to multiply via cell division, contributing to the continuous formation of new active sludge. Air is blown into the basins using three turbo compressors via membrane aerators at the bottom of the basins. The maximum hydraulic capacity with all three activated sludge lines in operation is 15 cubic meters per second, although the flow is usually limited to a maximum of 13.5 cubic meters per second depending on the capacity of the secondary sedimentation. In the activated sludge process, five compressors pump air into the aeration tanks, adding 2 milligrams per litre of oxygen to each basin.

2.2.2 Trickling filters

After the secondary sedimentation, a portion of the water is recirculated to the trickling filters at a rate of 5–7 cubic meters per second during normal flow operation. The trickling filters are divided into two parallel blocks, each with three spreader systems. With a total volume of 16,500 cubic meters and a flow capacity of 7 cubic meters per second, the trickling filters are filled to a depth of 7.2 meters with specially manufactured corrugated plastic material, providing a high air/water/plastic contact surface area of about 230 square meters per cubic meter for bacterial growth.

Wastewater returning from the post-sedimentation basins is pumped by six pumps to a level above the surface of the trickling filter. From there, it naturally flows to a combination of fixed and rotating spreaders, which distribute the wastewater evenly over the trickling filters. The wastewater trickles down through the trickling filters while air rises from below via self-draft. The ammonium rich wastewater serves as energy sources for the bacteria growing on the wet surfaces. Ammonium is converted to nitrate, which is carried along with the wastewater in a process called nitrification.

The flow to the trickling filter is a recirculation stream that is then directed back to the activated sludge process or to post-denitrification. During high inflow conditions, such as heavy rainfall, recirculation from the trickling filters to the activated sludge is reduced (down to 0.5 cubic meters per second, depending on secondary sedimentation capacity) to prevent overloading the secondary sedimentation tanks and to increase the plant’s hydraulic capacity. Wastewater from the trickling filters is pumped using eight pumps, partially to the activated sludge basins and partially to the post-denitrification basins.

2.3 Delta V and PI Link

Gryaab employs a sophisticated Distributed Control System (DCS) named DeltaV, developed by Emerson, to control and monitor various aspects of the wastewater treatment processes. The DeltaV DCS is an easy-to-use automation system designed to simplify operational complexity and reduce project risk. This state-of-the-art suite of products and services enhances plant performance with intelligent control that is straightforward to operate and maintain. The DeltaV DCS adapts to changing needs and integrates batch processing, control, change management, engineering tools, and diagnostics, without adding complexity. (DeltaV™ Distributed Control System, 2019)

2.4 Effekthandel Väst (Electricity Market Model)

Effekthandel Väst in Gothenburg operates a local flexibility market designed to enhance capacity in the local electricity grid through collaboration with customers. This marketplace enables the electricity network company to purchase power flexibility from its customers, thereby creating a more adaptable electricity grid and preventing power peaks. (Gothenburg Energi, 2024)

In practice, power trading involves customers either temporarily reducing their electricity consumption or increasing their electricity production to alleviate the load on the grid. This flexibility offers customers the potential to generate additional revenue while contributing to a more efficient and reliable electricity network.

Effekthandel Väst provides a diverse range of products that organisations can choose from depending on various operational needs and objectives. The following sections outline various types of products available, highlighting their features and potential benefits who are looking to enhance their energy management strategies.

2.4.1 Short flex

This approach is for those who want to be active and bid on an hourly basis. By adjusting their electricity usage in response to these bids, participants help balance the grid and avoid power peaks, while potentially earning revenue from their flexibility. Essentially, the electricity market will set a price for 1 MW of power, and participants can enter a higher amount in the portal if they desire a better price than what is offered. Here the bidding amount for 1 MW typically varies between 1,000 and 1,500 Swedish krona and here we've considered 1000SEK. Figure 4 is an image of the short-term flex window from the EHV portal. (Gothenburg Energi, 2024)

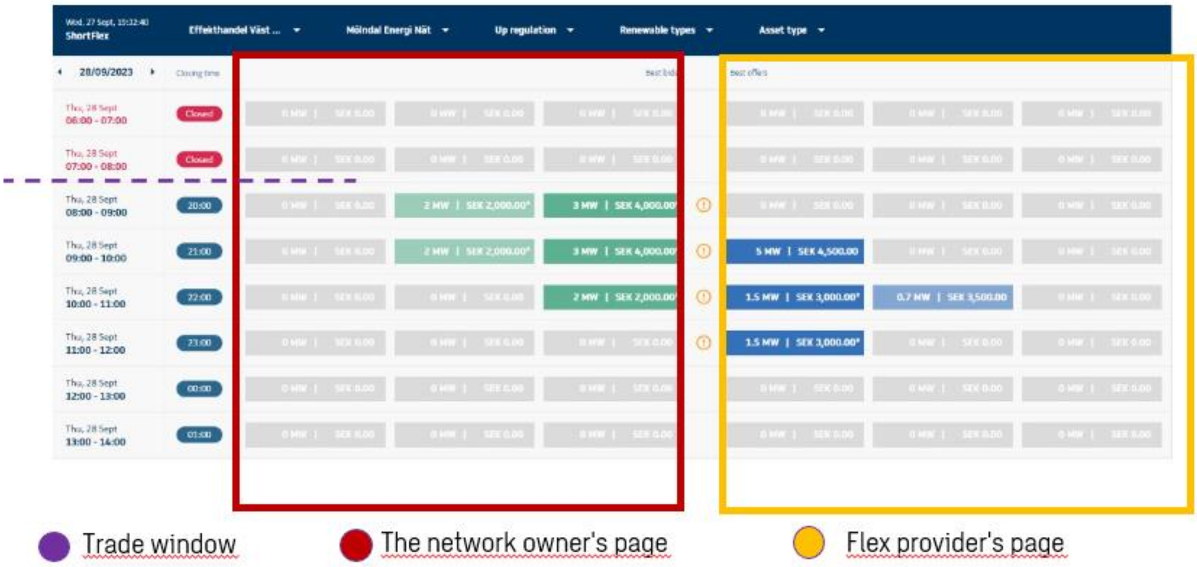

Figure 4 : Short term Flex Window

2.4.2 LongFlex

This approach enables participants to offer their availability for adjusting electricity consumption or production over extended timeframes. Rather than limiting adjustments to hourly intervals, participants can commit to providing flexibility over multiple days, weeks, or even months. These long-term commitments assist the electricity grid in managing sustained fluctuations and seasonal variations in demand and supply. By engaging in these longer-term bids, participants can effectively plan their operations while contributing to the stability of the electricity grid. Furthermore, this extended period of flexibility potentially offers participants consistent revenue opportunities. Now the price for being available is 300 SEK and for the activated hours it is 3000 SEK. Figure 5 is an example for the long-term flex window for different participants. (Gothenburg Energi, 2024)

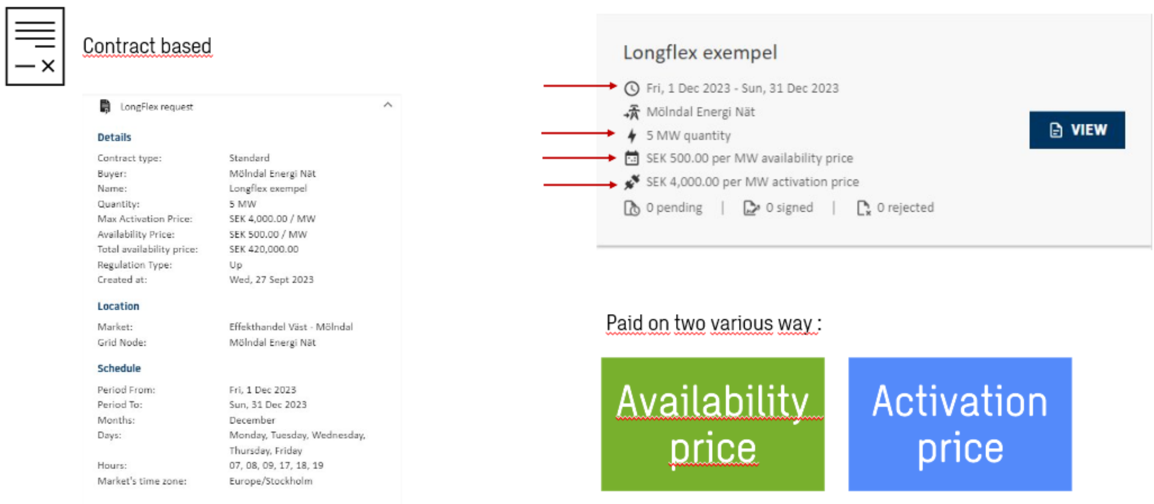

Figure 5 : Long term Flex Window

2.4.3 Max Usage

This product is suitable for those who want to participate in a simple and smooth way with minimal administration. Contract-based where you reduce your power consumption to a certain level during specific hours and receive ongoing compensation (Figure 6). (Gothenburg Energi, 2024)

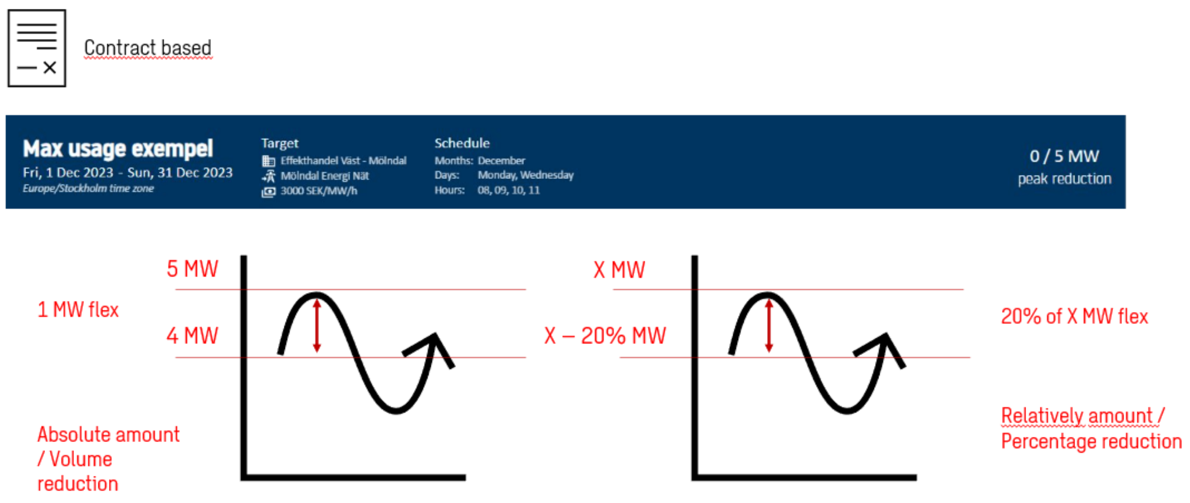

Figure 6: Max Usage Flex Window

2.4.4 Upcoming Budget for Effekthandel Väst

The upcoming budget for Effekthandel Väst to purchase electricity from companies shows significant planned increases over the next three years. These figures are presented in table 1. To put this into perspective, the Swedish government has allocated substantial resources towards its overall energy sector, particularly emphasizing energy affordability and sustainability.

Table 1 : Upcoming budget for Effekthandel Vast

Year	MSEK
2023-2024	2.5
2024-2025	4
2025-2026	17

In the Swedish government's Spring Budget for 2024, several measures were outlined to address the challenges posed by energy prices and to support the country's transition towards more sustainable energy sources. The government has made significant investments in renewable energy and energy efficiency, as well as measures to reduce the financial burden of energy costs on households and businesses (Government Offices of Sweden, 2024).

While the exact figures for the total energy budget are not always clearly delineated, the emphasis on energy policy and investment in sustainability shows a strong commitment from the Swedish government towards a resilient and sustainable energy future. This context highlights that Effekthandel Väst 's budget, though seemingly modest compared to national figures, aligns with broader national objectives of improving energy efficiency and ensuring reliable electricity supply.

3. Methodology

In this study we employed mixed assessment approach to investigate and understand the overall electricity usage of Gryaab AB. The methodology involved both quantitative and qualitative approaches. Quantitative research method is valuable for providing numerical insights into patterns, trends and relationships within a dataset. This approach allowed us to triangulate data from multiple sources and gain a comprehensive understanding of the research topic.

The flowchart in Figure 7 provides a concise overview of the methodology adopted in this study.

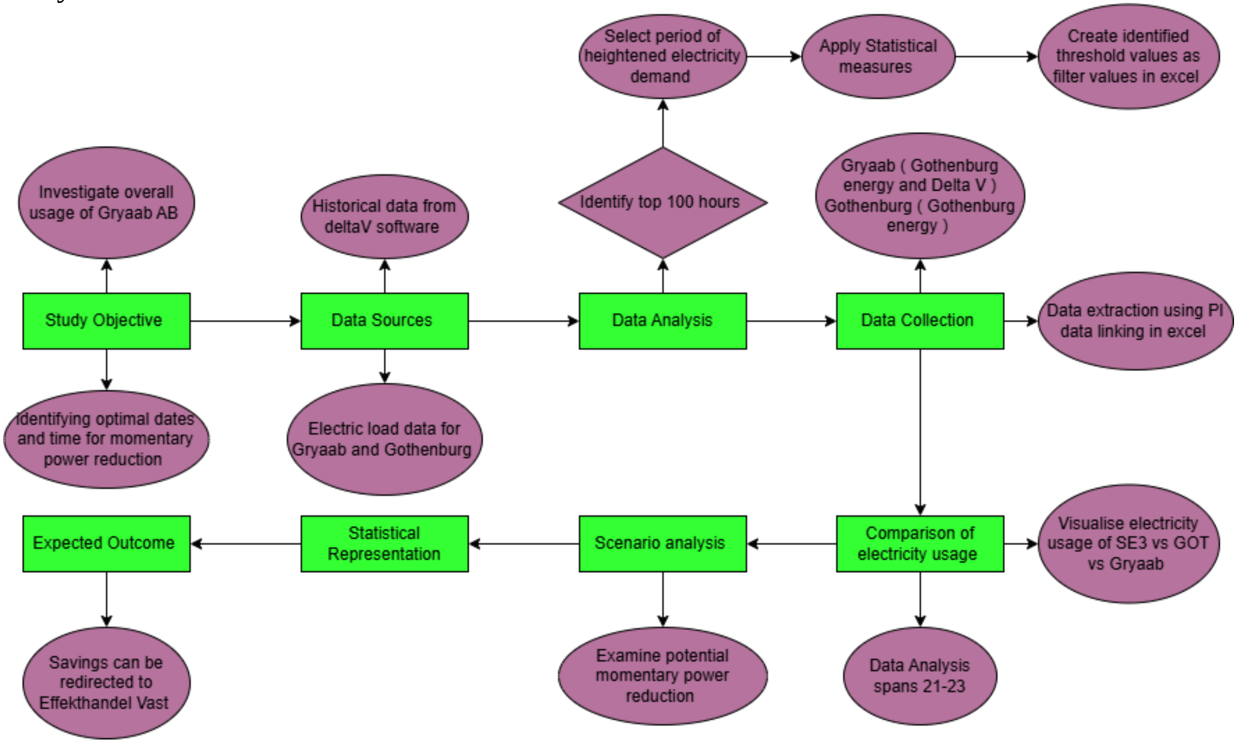

Figure 7: Methodology flowchart

The following sections will provide a detailed description of the procedures, materials and data analysis methods used in the study.

The investigation was initiated by identifying optimal dates for implementing energy consumption reduction measures at Gryaab, with the intention of utilizing this information in Effekthandel Väst. To achieve this objective, historical data sourced from Delta V software pertaining to Gryaab was leveraged, along with electric load (MW and KW) data for both Gothenburg and Gryaab obtained from Goteborg Energi. Subsequently, a thorough data analysis was conducted, focusing specifically on the top 100 peak hours of electric load in Gothenburg. These hours represent periods of heightened electricity demand in Gothenburg, thus serving as the target time frame for EHV's potential interventions.

3.1 Data collection

Electricity usage data for Gothenburg was obtained from Göteborg Energi, while data for Gryaab's electricity usage was obtained from Göteborg Energi and DeltaV. Within DeltaV, tag names are assigned to each component, facilitating data extraction in Excel through PI data linking. Following this, data corresponding to specified dates and hours are retrieved through search queries.

The primary objective of this study's data analysis was to compare Gryaab's operations during the top 100 hours of electricity usage in Gothenburg. The dataset utilized consisted of quantitative electricity usage data for both Gryaab and Gothenburg. The analysis encompassed three years, primarily focusing on data from 2021, 2022, and 2023. Initially, the entire year's dataset was considered, followed by a rephrasing of the data to isolate the top 100 hours before conducting further analysis. The top 100 hours in Gothenburg represent the highest electricity demand periods for Effekthandel Väst. Therefore, our focus is on the electricity usage at Gryaab during these 100 hours. It is important to note that these may not necessarily be the top 100 hours of electricity demand for Gryaab. To identify these top 100 hours, statistical measures such as mean, median, mode, and standard deviation were computed for the quantitative data. An exemplar of this statistical analysis is provided in (Table 2).

Table 2: Calculation for top 100 hours

Hours of the year (365*24)	8760 hrs
Top 100 hours	100 hrs
Percentile for top 100 hours	1 – (100h/8760h) = 0.988584475
98.86th percentile value	755.3080165 kW

To identify the top 100th value among the total hours of a year, which is 8,760 hours, the percentile corresponding to this value is calculated, which is 98.86th percentile value that is 755.308 kW for the year 2023. After determining the percentile of the top 100th value, that value is extracted and filtered out the remaining top values. The threshold value for the top 100 hours is now being used as a filter value in Excel.

The graph below represents the electricity consumption at Gryaab, which needs to be reduced during peak electricity usage hours in Gothenburg. This reduction is necessary for the Effekthandel Väst initiative. The top 100 hours shown on the graph indicate periods where the electricity demand exceeds a specified threshold. In Figure 8, the electricity load for Gothenburg is displayed on the x-axis, while the electricity load for Gryaab is on the y-axis. The highlighted section, marked with an arrow, indicates the specific hours that are of interest for this analysis.

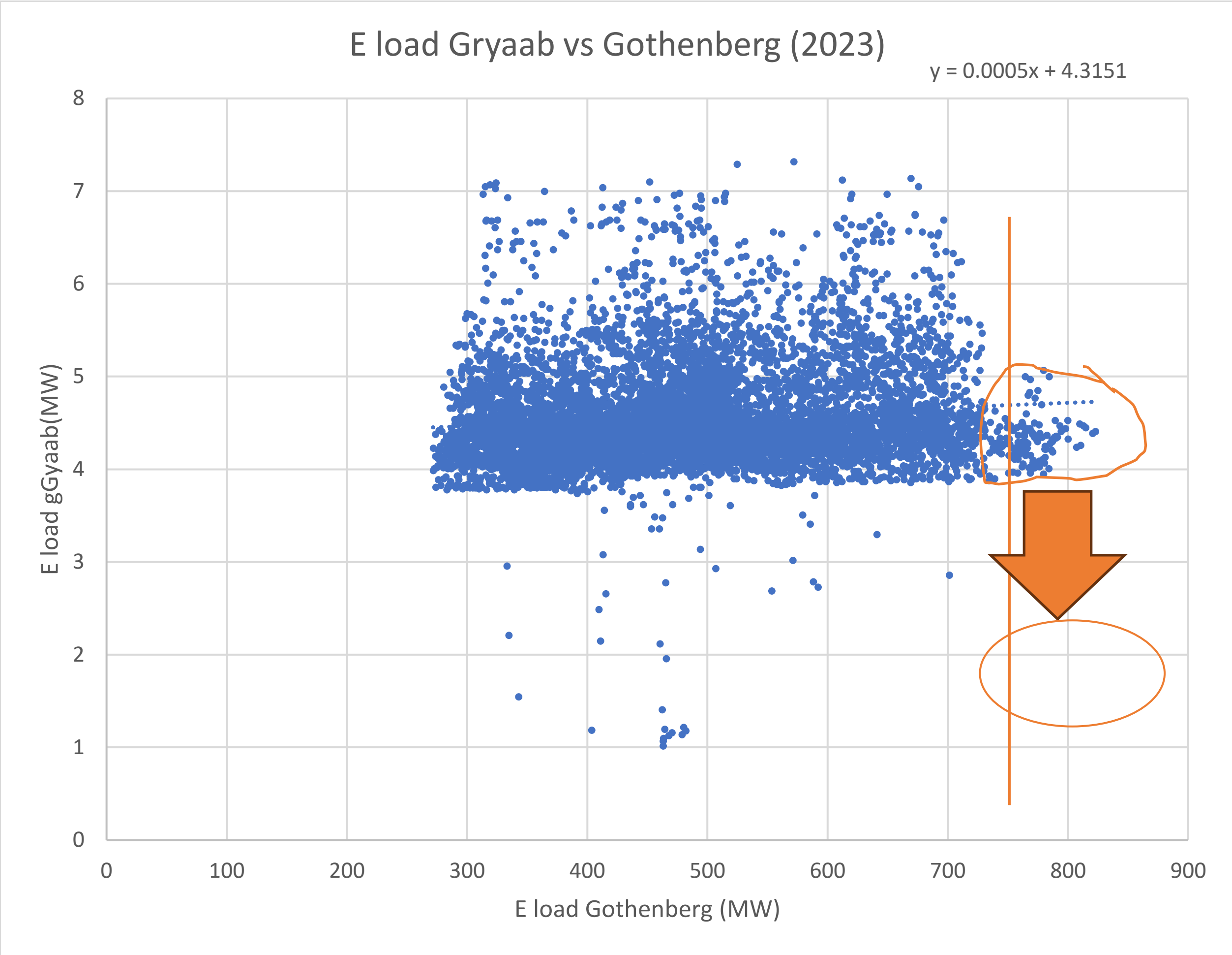

Figure 8 : Electricity load comparison Gryaab vs Gothenburg year 2023

Analyzing the top 100 hours will identify the periods or seasons during which electricity demand in Gothenburg is highest each year. When comparing the graphs across different years, electricity consumption is significantly higher during the winter months, primarily from November to March, apart from outliers (Figure 9). The months where the electricity is high in the city of Gothenburg is shaded with light red. The analysis for the years 2021 and 2022 are included in the appendix.

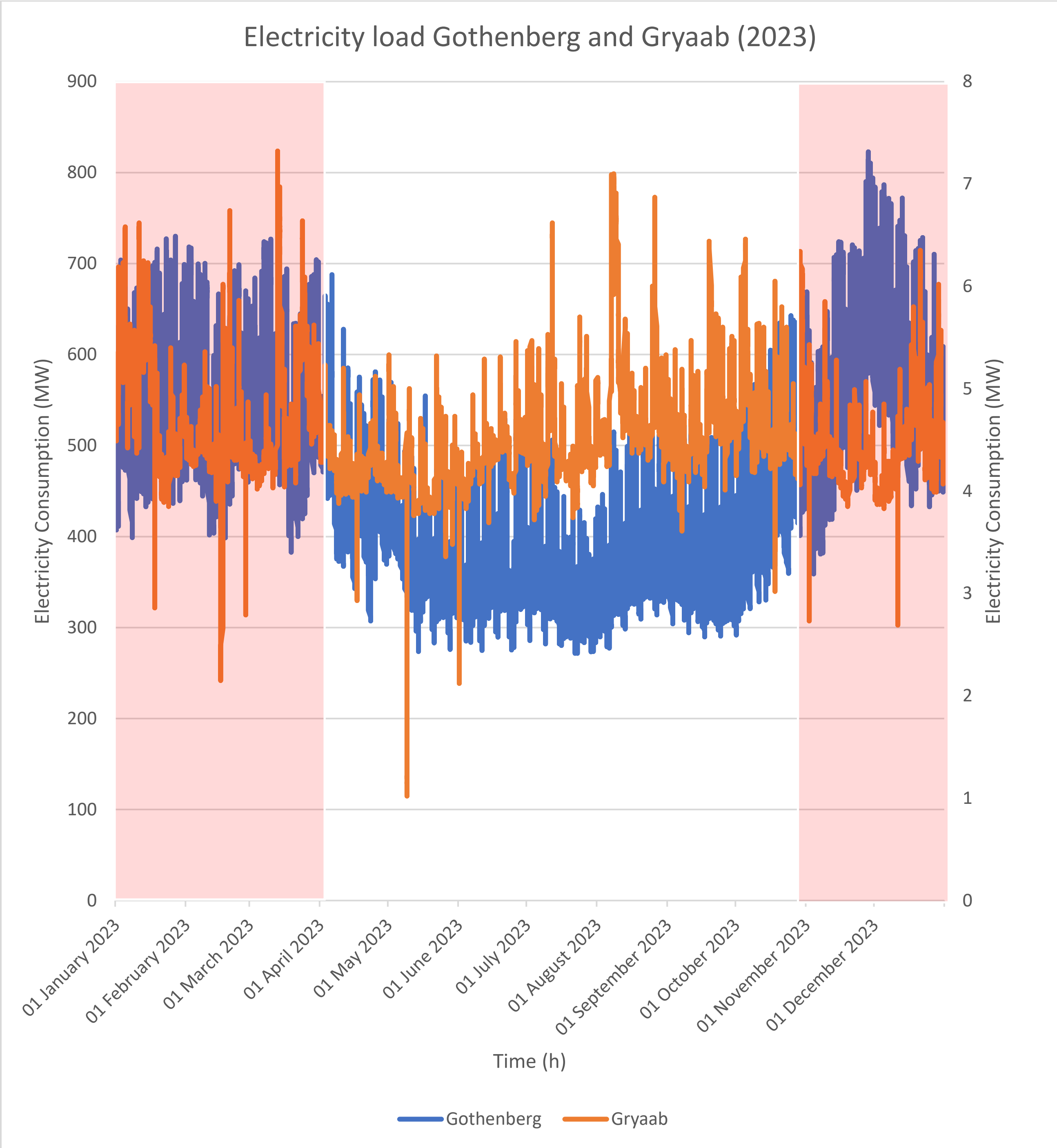

Figure 9 : Electricity in MW for Gothenburg and Gryaab

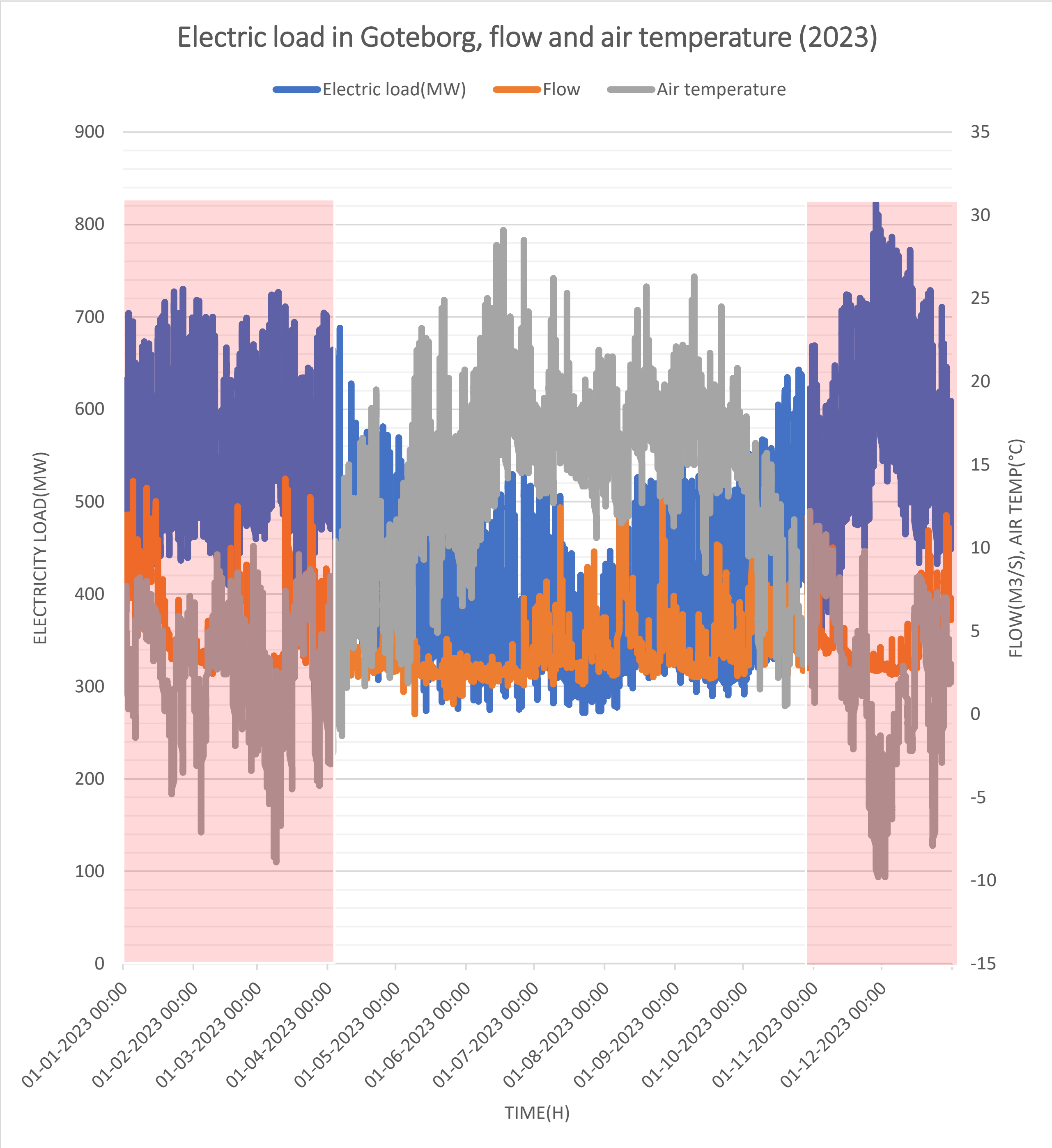

Figure 10: Electric load in Gothenburg, air temperature vs flow towards Gryaab in year 2023

It is possible for Gryaab to momentarily halt the operation of the proposed measure. From Figure10, it is evident that during the winter months, from November to March, the flow to Gryaab, which is marked in orange, decreases. In other words, during cold days with sub-zero temperatures, there is a reduction in inflow, creating the necessary margin for the proposed measure to momentarily pause. During these periods, electricity consumption is also higher, as seen in the graph. The analysis for the years 2021 and 2022 are included in the appendix.

3.2 Electricity comparison

To enhance our understanding of the outcomes, we initiated a detailed comparison among SE3 (SE stands for country's electricity price zones, which are divided geographically), Gothenburg, and Gryaab (Illustrated in Figure 11 & Figure 12). SE3 zone encompasses of the Stockholm metropolitan area and surrounding regions including Stockholm, Uppsala, and Gotland (Electrical area, 2024). The electricity data for SE3 zone is taken from entos-e (European Network of Transmission System Operators for Electricity), which is in hourly format. From this comparison, it is evident that Gryaab's electricity usage constitutes a minimal proportion compared to that of Gothenburg and the broader SE3 zone, given that Gothenburg's electricity usage encompasses the entire city and SE3 zone covers a wider area. Specifically, the observation indicates that Gryaab's electricity usage amounts to less than 1% of Gothenburg's total electricity consumption (Figure 13). SE3, represented by the blue bar, shows a significantly higher electricity consumption at 9463.70 MW. In contrast, Gothenburg, shown by the orange bar, consumes 486.54 MW. Gryaab, depicted by the grey bar, has the lowest consumption at 4.56 MW.

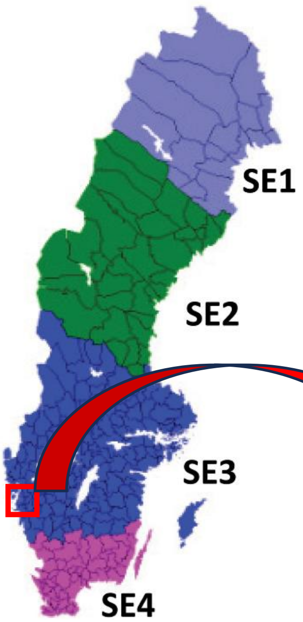

Figure 11: Zones of Sweden

Figure 12: Map of Gothenburg

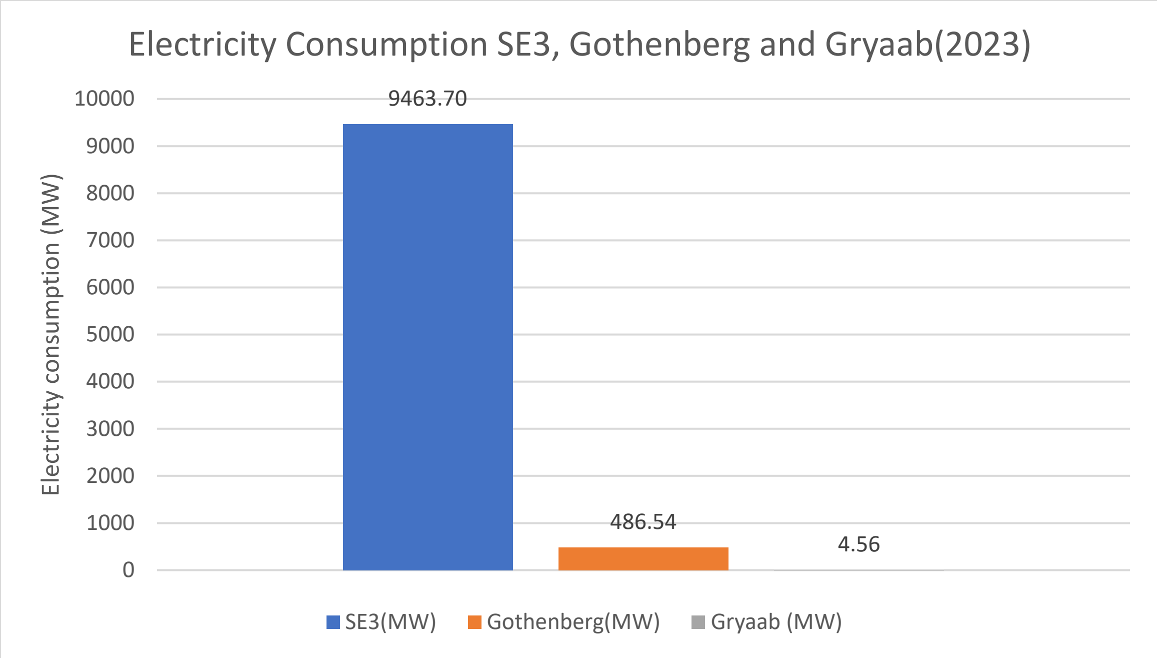

Figure 13 : Electricity Consumption for SE3,Gothenburg, and Gryaab in MW

3.3 Scenario

A thorough analysis of Gryaab's individual treatment steps, namely the pumping station, activated sludge, and trickling filters, employing a scenario-based approach to further clarify our findings was performed. Different scenarios were set up where certain components of the treatment plant were completely shut down for a period of time to assess the potential reduction in electricity consumption. In the Ryaverket treatment plant, 70 percent of the electricity is consumed by the inlet pumping, aeration and trickling filter. Thus, our focus in this scenario is to consider these specific processes.

To facilitate data comprehension and ensure sufficient data for analysis and observation, data from the years 2021 to 2023 was aggregated, focusing on the top 100 hours combined from these three years. For this study, these 100 hours have been condensed into a single fictional day using statistical measures such as averages, maximums, and minimums.

From the analysis in the previous chapter, we know that Gryaab's electricity consumption accounts for less than one percent of the total electricity consumption in Gothenburg. However, it is noted that during the top 100 hours of electricity consumption in Gothenburg, the flow to Gryaab was low, indicating that Gryaab's electricity consumption was also low. For instance, only one or two pumps were in operation, compared to the usual three pumps.

In figure 14 the graphical representation of the Inlet Pumping Station's data from 2021 to 2023 is shown. This graph is derived using the average, maximum, minimum values, and the population size of the top 100 hours of all the three years and it has 300 timestamps (a recorded indication of the date and time when an event occurs), converged into a fictional day i.e, 24 hours. On the graph, the x-axis represents time in hours, while the y-axis represents both population size and electricity consumption in kW. The population size in the graph is the number of times a particular hour has occurred in the top 300 hours. For instance, the hour 10 have occurred 26 times in the top 300 hours and same for all the hours are there in the population size. Similar graphs are derived and studied for Activated sludge and Trickling filter, figure 15 and figure 16.

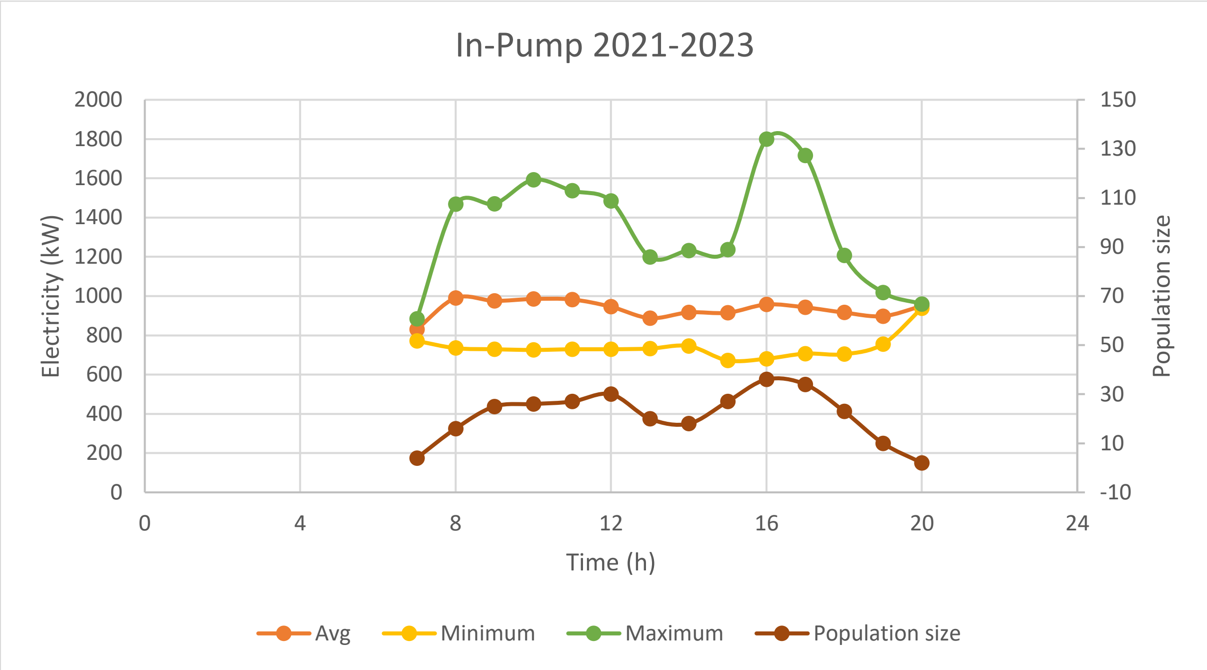

Figure 14 : Statistical measures representation of In-Pump 2021-2023.

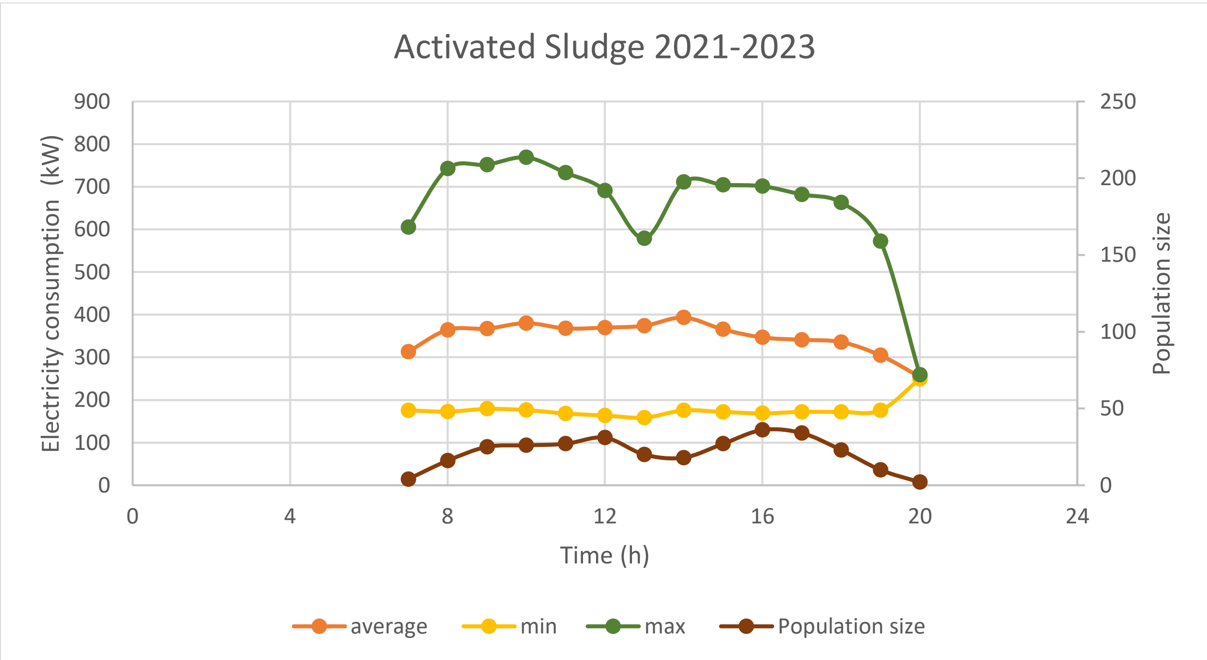

Figure 15 : Statistical measure representation of Activated Sludge 2021-2023

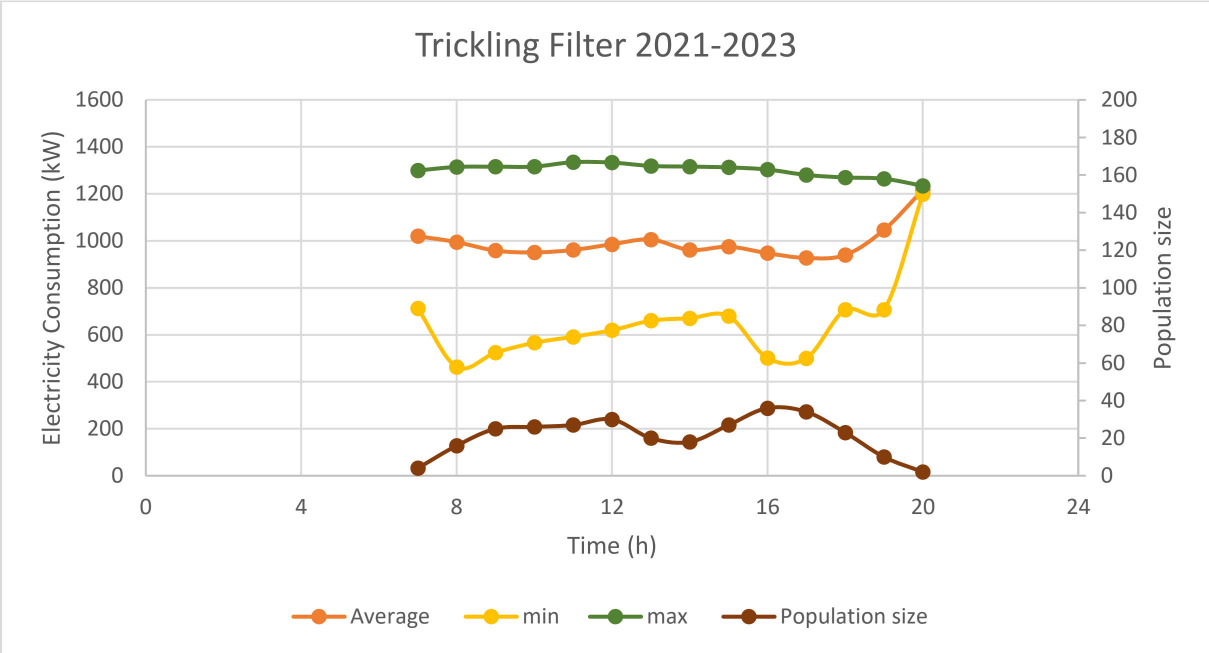

Figure 16 : Statistical measure representation of Trickling filter 2021-2023

When interpreting the graphs, it is important to note that some maximum value points have been removed. These outliers, which occur only once or twice, can distort the overall representation.

For inlet pumping, in this scenario, the pumps at the inlet will be completely shut down, using the tunnel system as a buffering volume. Since Effekthandel Väst requires a reduction in electricity demand for a maximum of 1-2 hours, stopping the pumps during these hours is advisable. Stopping of pump is further discussed at the end of this chapter. (Stop at the Plant).

Considering inlet pumping, this scenario involves stopping the operation of the pump station. The maximum electricity that can be saved in this scenario would be the average electricity usage shown on the graph (figure 14), i.e, up to that limit we can reduce our consumption. The average line in the graph can be used as a reference for reducing electricity consumption if we stop pumping. The population size is also considered to provide a more comprehensive understanding of the data, as it helps illustrate the relationship between electricity consumption with that number of times in a particular hour.

The total electricity that could be saved and redirected to Effekthandel Väst during these top 100 hours is detailed in the results section of the next chapter.

Similarly, this is the case for trickling filters and activated sludge systems. However, not much in-depth assessment has been done on these topics, as it is part of the limitation of this thesis.

The analysis for the years 2021 to 2023 are included in the appendix to help the reader understand.

3.4 Stop at the plant

Stopping processes is an important part of the maintenance work at Gryaab. Inspection and repair of channels, basins and underwater equipment is essential to maintain safe and stable operation of water treatment. As the weather plays a major role in the possibility of carrying out a planned stop at all, foresight and planning are important so that the work can be carried out efficiently and safely during the limited time allowed, even under the most favorable conditions.

During the spring, the operations department plans three to four occasions (weeks) depending on the amount of work that is planned. Normally, three occasions are the minimum to be on the safe side, even if only one specific working day is necessary. A graphical representation of the rise in volume in the tunnel during the stoppage of pumping is provided below (Figure 17).

In the tunnel system, it is essential to note that there exists a critical level of -5.85 meters. If this level is reached, the treatment plant will automatically shut down. Therefore, it is imperative for the operational teams to take all necessary precautions to avoid reaching this threshold.

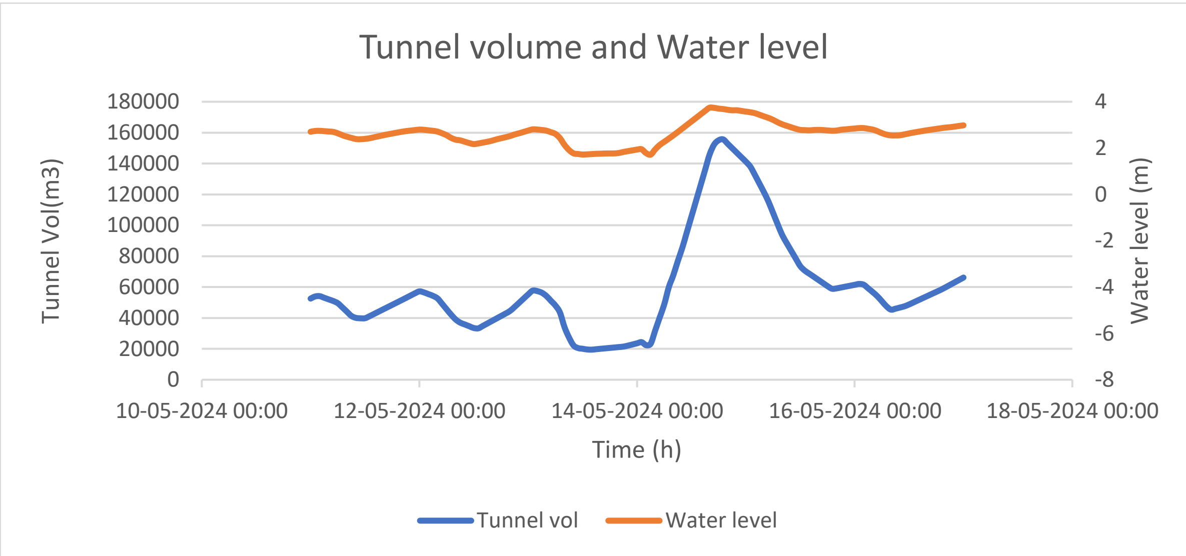

Figure 17 : Tunnel volume and water level representation during stopping of the inlet pumping

The graph represents the changes in tunnel volume and tunnel height during the stop at the treatment plant, which occurred on May 14th, 2024, from 4:00 to 16:00. For a clearer understanding, the graph also includes data from the day before and the day after the stop of the plant. This shows that the volume of the tunnel went up to 155000 cubic meters in 12 hours during the stoppage of treatment plant this summer, also to compare the maximum volume on the day before work stoppage was around 57000 cubic meters. During work stoppage, within 12 hrs volume of water became three times higher than normal volume. This indicates the potential for stopping of pumping for few hours and storing it in tunnel.

4. Results

This section presents the findings of the analysis conducted on the optimization of momentary power reduction options for Gryaab for societal benefits and how Gryaab can leverage these options for significant financial savings as well.

It was observed that the electricity usage in Gothenburg typically peaks during the winter months, prompting to focus the study on the period from November to March i.e, 5 months, when momentary power reductions at Gryaab will be most needed. Additionally, power demand tends to be highest during the mornings and evenings, guiding us to schedule these reductions during specific hours of the day. Therefore, the optimal times for implementing momentary power reductions will be between 8:00 and 13:00, as well as 15:00 and 18:00 each day, aligning with the city's peak electricity demand. The results underscore the importance of strategic electricity consumption management, highlighting the interplay between operational efficiency and broader sustainability goals within the context of Sweden's energy market. Ultimately, these findings provide valuable insights into how Gryaab can contribute to energy efficiency initiatives, supporting the stability of the national grid.

The data analysis indicates that during a pump stoppage, there is potential to temporarily store wastewater in the tunnel system, allowing for a momentary power reduction. By turning off the pump for one hour, as shown in Figure 14 from the scenario section, it is understood that we can decrease power usage by 1 MW, while the wastewater remains within the tunnel. It is evident from pump stoppage that the water can be stored in the tunnel for few hours i.e. up to three times. The graph below (figure 18) shows the initial hours of pump stoppage and effect on tunnel volume and tunnel water level. Following the pump stoppage, the water volume in the tunnel steadily increases, rising by 8,000 to 10,000 cubic meters per hour.

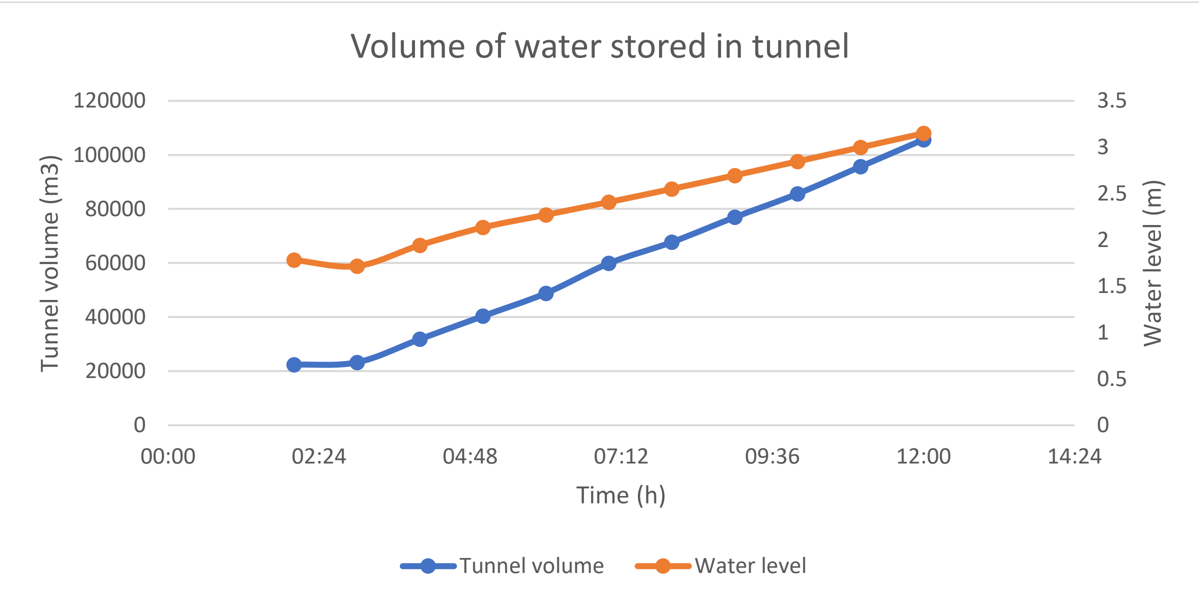

Figure 18: Volume of water stored in Tunnel at initial hours of pump stoppage.

From Figure 14 it is evident that power can be momentarily reduced by up to 1 MW per hour, and the data analysis suggests that the financial benefit corresponds directly to the power reduction achieved each hour. Figure 19 illustrates a potential momentary reduction that offers financial advantages for Gryaab.

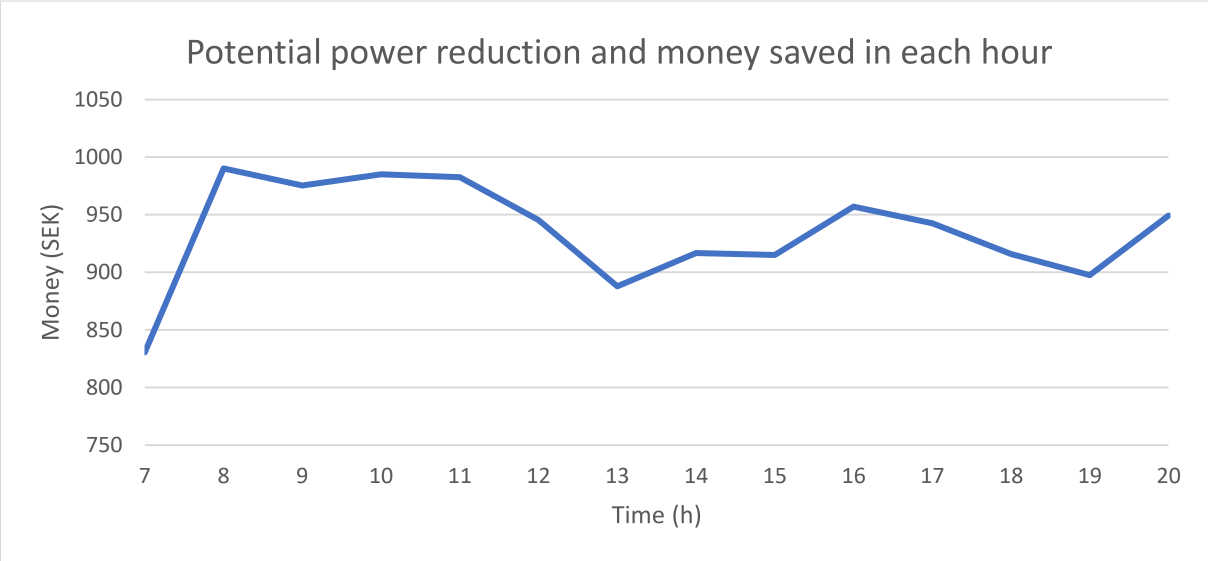

Figure 19: Potential momentary reduction possible at Gryaab in terms of money

According to Effekthandel Väst, the local flexibility market aimed at improving Gothenburg's electricity grid, Gryaab can play a key role in ensuring the smooth flow of power through the city's grids. The following sections outline Gryaab's potential contributions to both short-term and long-term flexibility within the market, as well as its ability to reduce power usage during critical periods. This analysis will provide a clearer understanding of how Gryaab can support the grid during peak demand times.

4.1 Short Term Flex

In the context of short-term flexibility, the process operates on an hourly basis, as detailed in the methodology section. The bidding amount for 1 MW typically varies between 1,000 and 1,500 SEK and here we've considered 1000 SEK. It should be noted that bids exceeding the specified amount can be submitted via the flex providers' platform. Typically, 1 MW or 2 MW is requested per hour. The revenue generated is contingent upon the timing and the bid amount on the given date. The data in Table 3 and Figure 20 illustrates Gryaab's potential financial savings resulting from various levels of electricity consumption reduction over different periods.

Table 3: Example for short term flex

Momentary Power reduction/hr in 1 day	SEK saved in 1 day	SEK saved in 30 days	SEK saved in 150 days
1 MW/hour	1000 SEK	30000 SEK	150,000 SEK
2 MW/hour	2000 SEK	60000 SEK	300,000 SEK
3 MW/hour	4000 SEK	90000 SEK	600,000 SEK

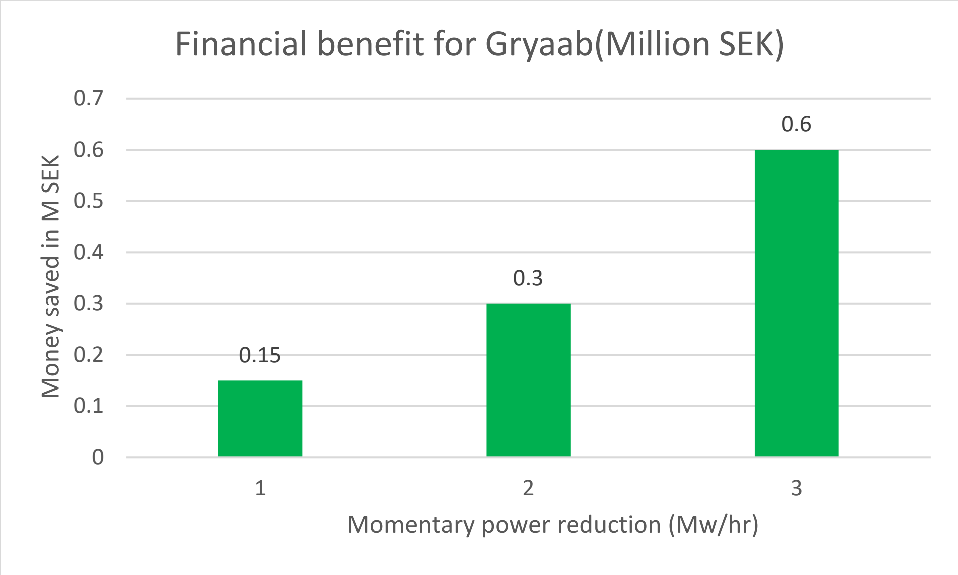

Figure 20: Graphical representation of financial benefit for Gryaab from short term flex

For example, a 1 MW/hr reduction in electricity usage can save the company up to 150,000 SEK over 150 days, while a 2 MW/hr reduction can save up to 300,000 SEK in the same period. A more significant reduction of 3 MW/hr offers potential savings of 600,000 SEK over 150 days. These figures emphasize the importance of energy-efficient practices and strategic consumption management for substantial financial benefits at Gryaab.

5.2 Long Term Flex

Considering Gryaab's operational conditions and Effekthandel Väst's requirements, Gryaab could establish long-term flexibility by signing a contract for a total of 2 hours per day; 1 hour in the morning and 1 hour in the evening throughout the winter, providing a power reduction of 1 MW per hour. Alternatively, scenarios involving 3 hours of flexibility per day could be explored, with 1.5 hours allocated to both the morning and evening, or 1 hour in the morning and 2 hours in the evening, or vice versa. In another scenario, Gryaab could commit to a 4-hour daily flexibility—2 hours in the morning and 2 hours in the evening—for the entire winter, maintaining consistent momentary power reduction during these periods.

The table 4 and graph (figure 21) describe potential financial implications for Gryaab when participating in a long-term electricity demand flexibility program. The scenarios outline different levels of daily active hours where Gryaab can reduce or shift its electricity usage, resulting in savings.

Table 4: Example for Long term Flex.

Active hours a day (Morning and Evening)	2 hours	3 hours	4 hours
Money for activation SEK/hr	300	300	300
For activated hours SEK/MW	3,000	3,000	3,000
Per Day	6,600	9,900	13,200
One Month	198,000	297,000	396,000
Nov-Mar	990,000	1,485,000	1,980,000

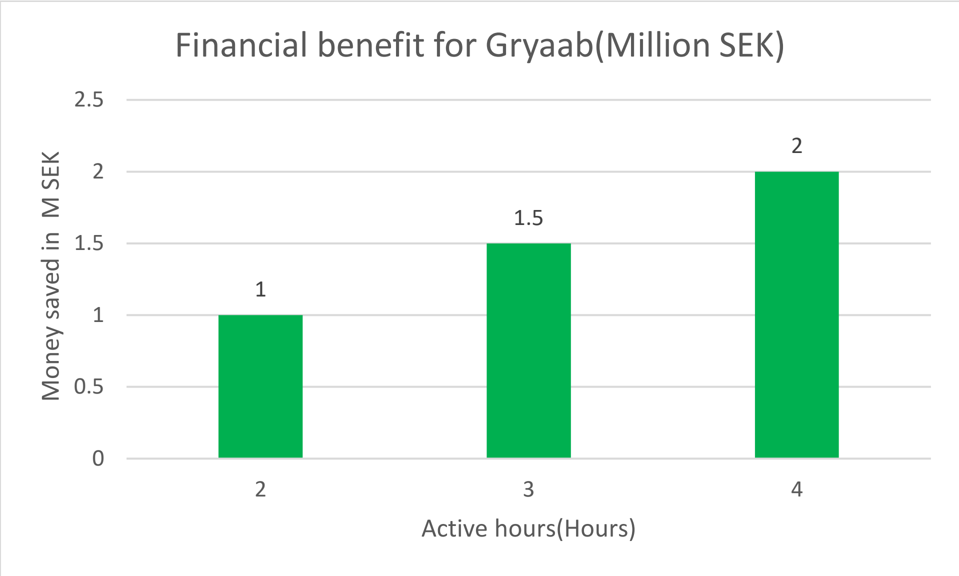

Figure 21: Graphical representation of financial benefit for Gryaab from Long term flex

Each scenario presents a different level of participation in a long-term flex program, where Gryaab AB can reduce or shift its electricity demand to off-peak times, specifically during winter months. The compensation includes a fixed rate for activation and an additional rate based on the hours of reduced consumption, with higher participation leading to greater potential earnings. This arrangement not only helps Gryaab save costs but also supports the stability of the electricity grid during high-demand periods.

5. Discussion and Conclusions

This study aimed to address the challenges of reducing electricity consumption at the Rya wastewater treatment plant (WWTP) managed by Gryaab in Gothenburg, particularly in the context of the rising electricity demand in the city and the upcoming introduction of the Effekthandel Väst (EHV) local flexibility market. By analyzing historical electricity usage data and evaluating operational adjustments during peak load periods, this study sought to identify actionable strategies for reducing Gryaab's electricity consumption momentarily and contributing to the broader goal of enhancing grid flexibility.

The findings indicate that Gryaab’s electricity consumption constitutes a minimal fraction of Gothenburg’s overall electricity usage, but strategic momentary reductions during peak demand periods can have a significant effect. Key processes at Gryaab, including inlet pumping, aeration in the activated sludge system, and trickling filters, account for approximately 70% of the total electricity usage. By optimizing these processes and exploring scenarios such as momentarily halting operations during peak periods, substantial reductions in electricity consumption are feasible. The scenario analysis revealed that temporary shutdowns, particularly of the inlet pumping stations, could align with the demands of the EHV market, allowing Gryaab to participate effectively while supporting the local grid.

5.1 A Comparative Examination of Short-term versus Long-term Flexibility

Short-term flex is generally advantageous for immediate financial returns without long-term commitments. It allows the company to respond dynamically to short-term market conditions, potentially maximizing savings during periods of high electricity prices.

Long-term flex involves more consistent energy usage adjustments, which can be beneficial for long-term financial planning and stability. It offers higher cumulative savings over extended periods and aligns with strategic goals, such as supporting grid stability and contributing to energy sustainability.

Table 5: Comparison of long-term vs short term flexibility.

Financial Perspective	Both short-term and long-term flex options offer significant savings, but the exact choice depends on Gryaab's operational flexibility. Long-term flex offers higher potential cumulative savings during the winter months, particularly in scenarios with higher daily active hours.
Operational Considerations	Short-term flex is ideal for companies needing flexibility to adjust operations based on market conditions. It provides immediate savings and allows Gryaab to capitalize on high electricity price periods. On the other hand, long-term flex requires a consistent reduction in energy use over a more extended period, which can be challenging but offers more predictable and potentially larger financial returns
Strategic Alignment	Long-term flex may align better with Gryaab's strategic goals of energy efficiency and sustainability. By committing to long-term contracts, Gryaab can contribute more significantly to grid stability and support Sweden's national energy goals.

5.2 Socio Economic Benefit

By saving electricity in a WWTP, people and society can benefit socio-economically in many ways

- **Environmental impact**: Decreased energy usage in the WWTP can contribute to the lower greenhouse gas emissions and overall environmental footprint, aligning with the sustainability goals.
- **National energy grid stability**: By reducing electricity demand from the industrial sector like WWTP, the strain on the national energy grid can be lessened, ensuring a more stable and efficient electricity supply for the entire country.

- **Energy market impact**: lower energy consumption at WWTP can have broader implications on Sweden’s energy market, potentially influencing energy prices and market dynamics.
- **Contribution to national goals**: Energy savings at the WWTP align with Sweden's national targets for energy efficiency, greenhouse gas emissions reduction, and increased use of renewable energy sources, making a significant contribution to the country's sustainable energy transition

Ultimately these efforts can pave the way for a more sustainable future for a society.

Gryaab, as a key player in wastewater treatment, has a significant role in contributing to sustainable energy management by participating in electricity-saving initiatives for Effekthandel Vast, a subsidiary of Gothenburg Energy. This participation is critical for several reasons. Firstly, it demonstrates Gryaab's commitment to environmental sustainability and aligns with best practices aimed at reducing the carbon footprint associated with wastewater treatment processes. Optimizing energy consumption not only leads to cost savings and enhances operational efficiency but also supports Gothenburg's energy policies. Furthermore, active involvement in such initiatives enhances Gryaab's reputation within the community and strengthens stakeholder relationships, underscoring the company’s role as a responsible corporate citizen. Thus, Gryaab's engagement in these efforts is a strategic approach that aligns with its commitment to sustainable development, community engagement, and operational excellence.

6. Bibliography

(n.d.). Retrieved from https://www.naturvardsverket.se/en/international/swedish-environmental-work/swedens-climate-act-and-climate-policy-framework/

(n.d.). Retrieved from Naturvardsverket: https://www.naturvardsverket.se/en/international/swedish-environmental-work/swedens-climate-act-and-climate-policy-framework/

(n.d.). Retrieved from IEA50: https://www.iea.org/countries/sweden

Alp, A., Filik, Ü. B., & Gere, E. E. (2023). Renewable Energy Usage in Wastewater Treatment Plants: A Case Study. In A. Alp, Ü. B. Filik, E. E. Gere, M. Z. Sogut, T. H. Karakoc, O. Secgin, & A. Dalkiran (Eds.), *Springer Proceedings in Energy.* doi:https://doi.org/10.1007/978-3-031-30171-1_36

Andersson, K. (2024). *Technical description to Permit application according to the Environmental Code for Ryaverket.* Gothenburg: Sweco.

Borzooei, S., Campo, G., Cerutti, A., Meucci, L., Panepinto, D., Ravina, M., . . . Zanetti, M. (2019, November 15). Optimization of the wastewater treatment plant: From energy saving to environmental impact mitigation. *Science of the Total Environment, 691*, 1182-1189. doi:https://doi.org/10.1016/j.scitotenv.2019.07.241.

(2019). *DeltaV™ Distributed Control System.* Emerson.

Electrical area. (2024). Retrieved from ElavtalDirekt: https://elavtaldirekt.se/elmarknad/elomraden/

EPA. (2015). *Energy use in waste water treatment plant.* Retrieved from https://www.energystar.gov/sites/default/files/tools/DataTrends_Wastewater_20150129.pdf

Gothenburg Energi. (2024). Retrieved from https://www.goteborgenergi.se/foretag/elnat/effekthandel-vast#om

Government offices in Sweden . (n.d.). Retrieved from https://www.government.se/government-of-sweden/ministry-of-finance/central-government-budget/

Government Offices of Sweden. (2024, April). Retrieved from https://www.government.se/articles/2024/04/the-2024-spring-budget-in-five-minutes/

Gryaab. (2023). *Environmental Report, Gryaab Ryaverket .* Gothenburg.

Gryaab. (2024, November). Retrieved from www.gryaab.se.

Hamawand, I. (2023, May). Energy Consumption in Water/Wastewater TreatmentIndustry—Optimisation Potential. *Energies 16(5):2433, 16*(5). doi:10.3390/en16052433

Holmberg, M., & Andersson, R. (2007). *Energy conservation in wastewater treatment operation.* Retrieved from https://www.tidskriftenvatten.se/wp-content/uploads/2017/04/48_article_2357.pdf

Holmberg, P., & Tangerås, T. P. (2022). The Swedish electricity market – today. 36.

Jonasson, M. (2007). *Energy Benchmark for wastewater treatment process .* Retrieved from https://www.iea.lth.se/publications/MS-Theses/Full%20document/5247_full_document.pdf

Kjellen, B. J., & Andersson, A.-C. (2002). *Energy handbook for sewage plant.* Retrieved from https://vav.griffel.net/filer/VA-Forsk_2002-2.pdf

Nunes, J., Lindqvist, P., & Tumlin, S. (2017). *Technical description- Permit application for Ryaverket.* Gryaab. Gryaab.

Statista . (2023). Retrieved from https://www.statista.com/statistics/1027078/electricity-consumption-in-sweden/

Wang, C., Deng, S.-H., & You, N. (2023). Pathways of wastewater treatment for resource recovery and energy minimization towards carbon neutrality and circular economy: technological opinions. *Front. Environ. Chem, 4*. doi:10.3389/fenvc.2023.1255092

7. Appendix

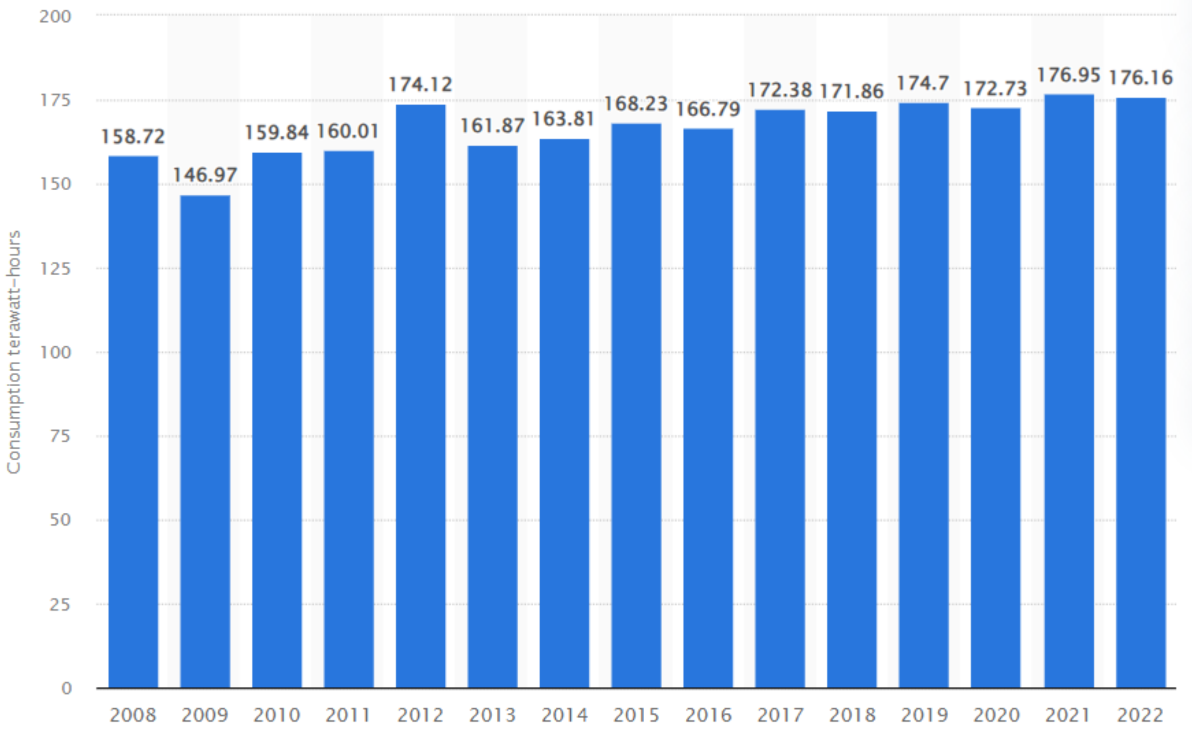

Figure A1: Electricity consumption in Sweden in terawatt-hours

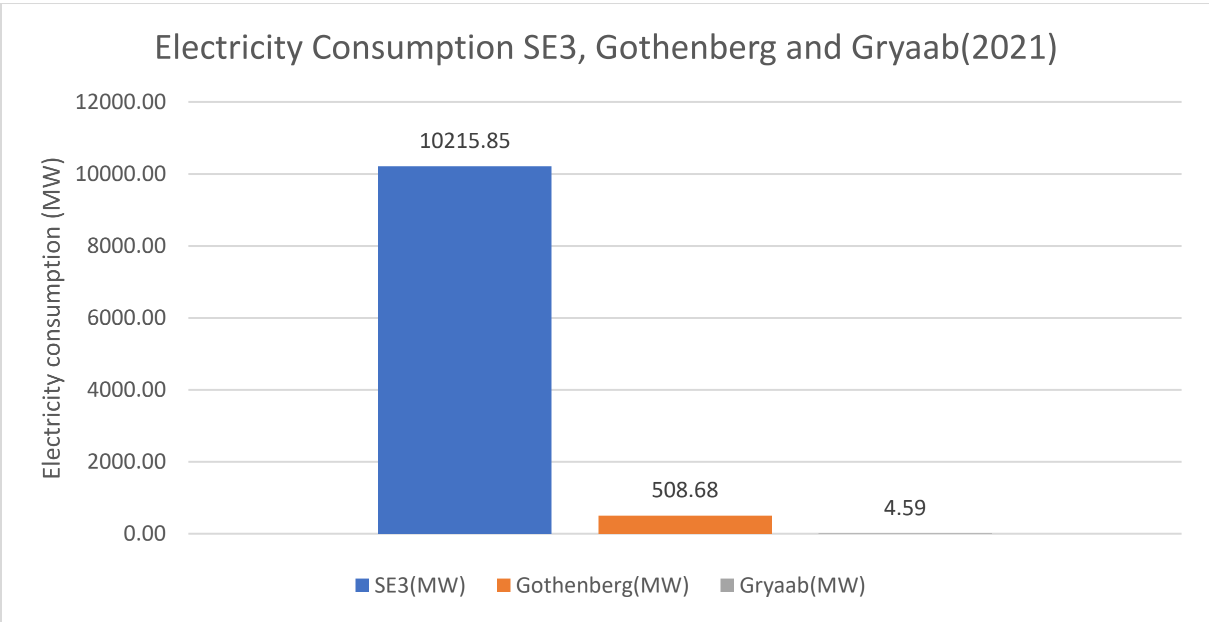

Figure A2 : Electricity consumption SE3, Gothenburg and Gryaab in 2021.

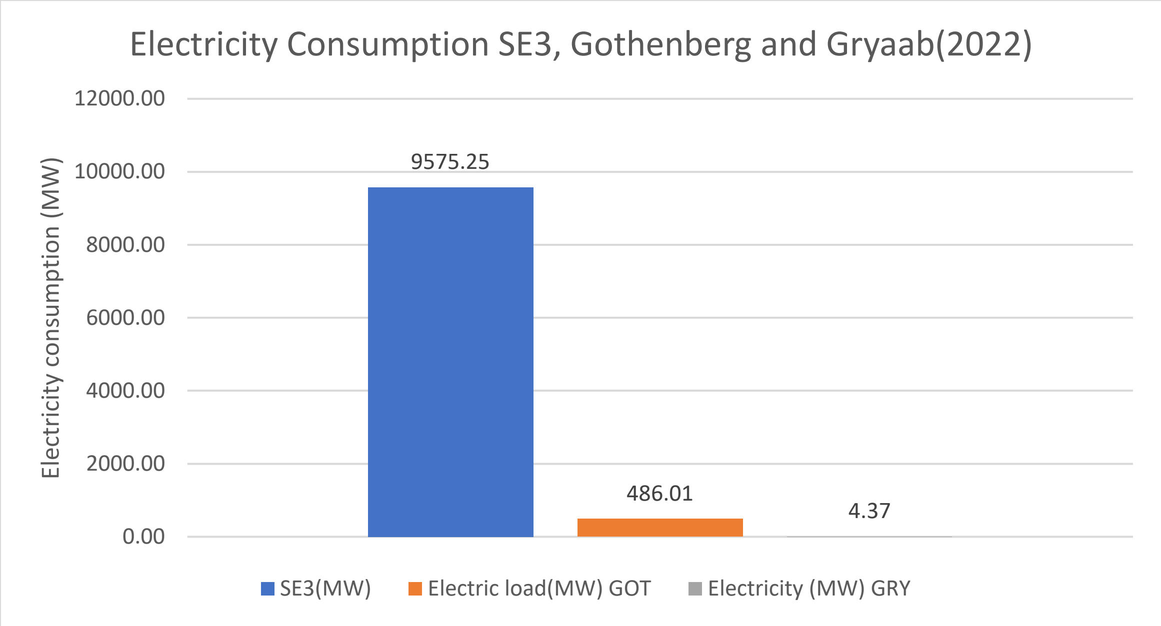

Figure A3 : : Electricity consumption SE3, Gothenburg and Gryaab in 2022.

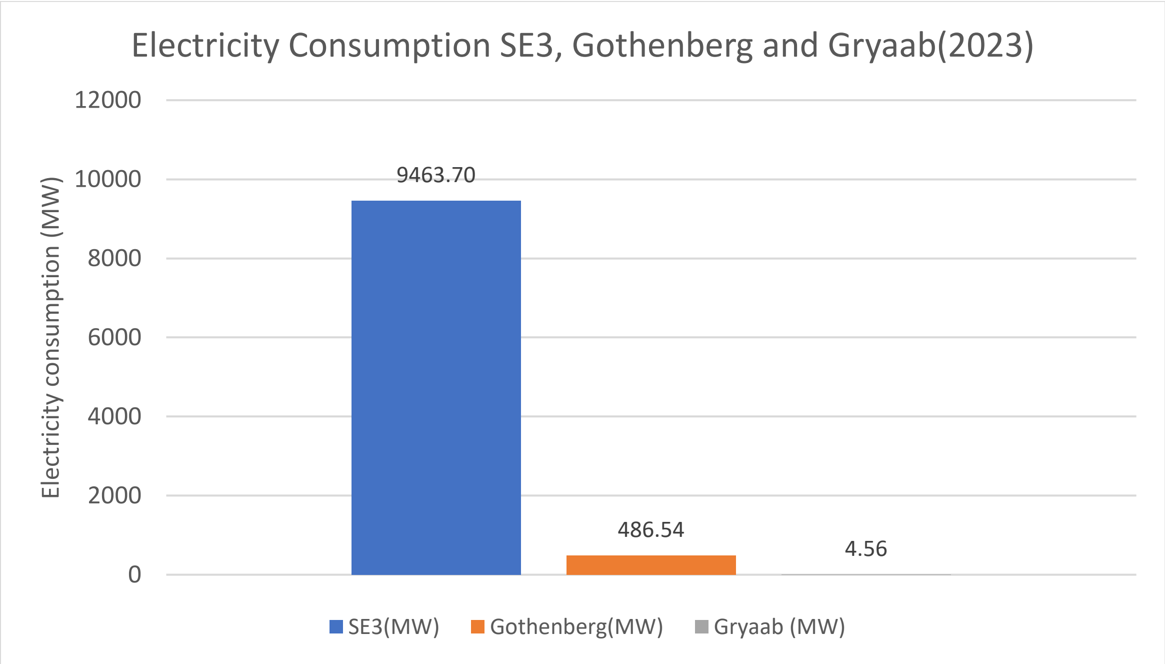

Figure A4: Electricity consumption SE3, Gothenburg and Gryaab in 2023

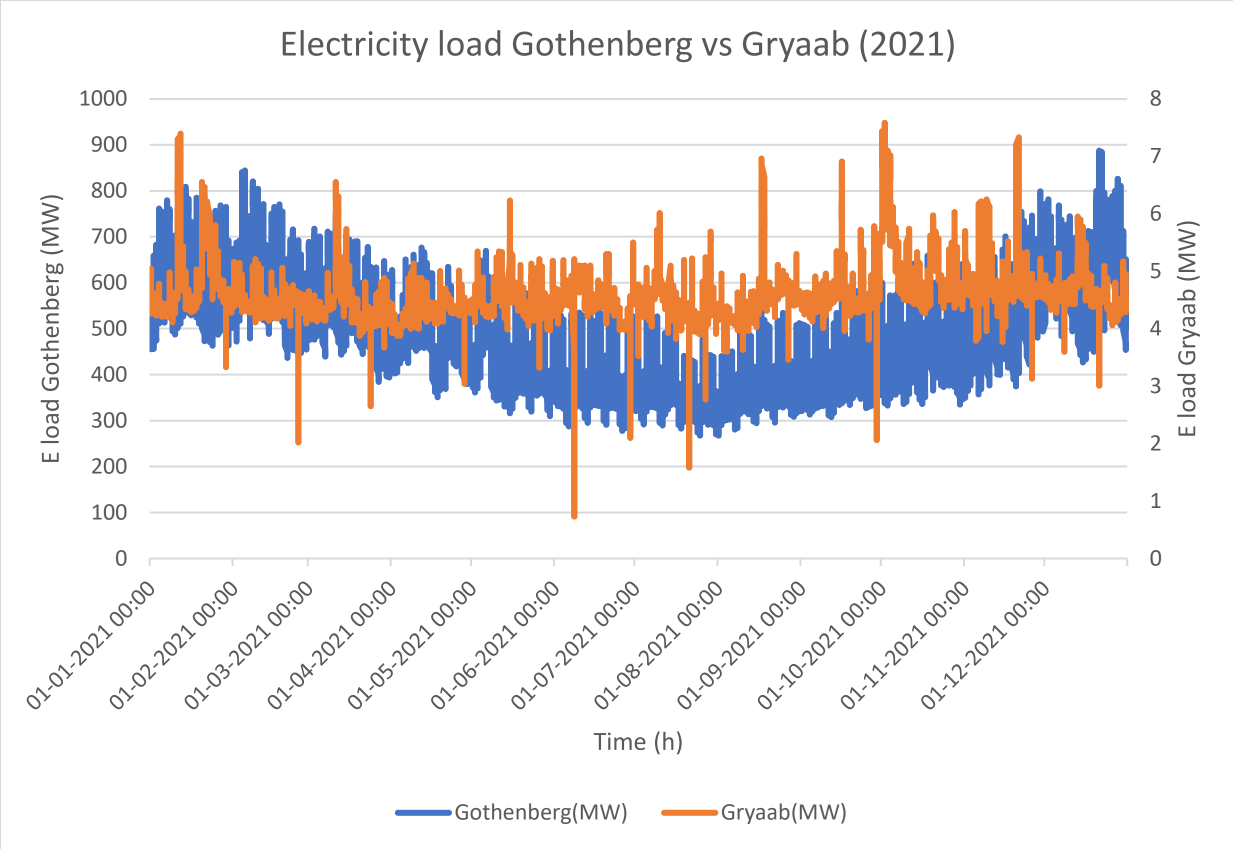

Figure A5 : Electricity load Gothenburg vs Gryaab 2021

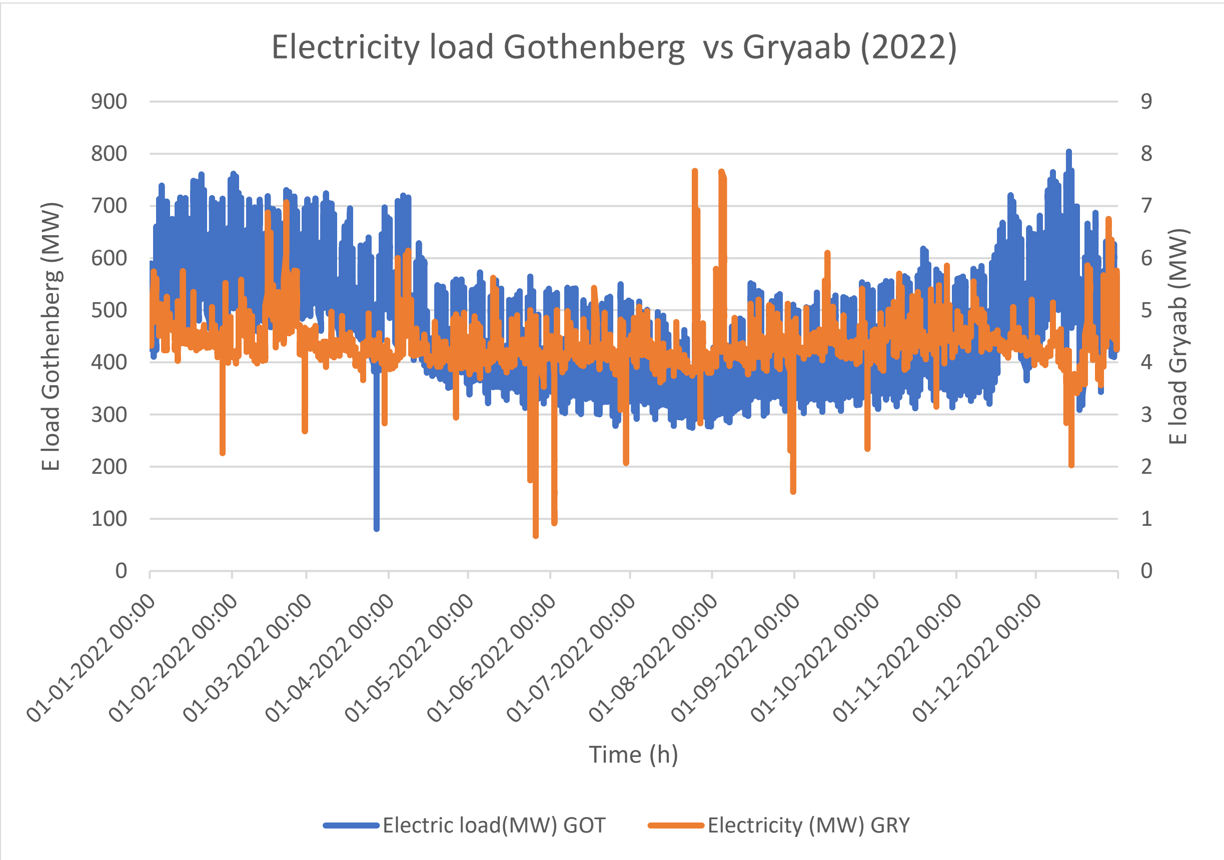

Figure A6: Electricity load Gothenburg vs Gryaab 2022

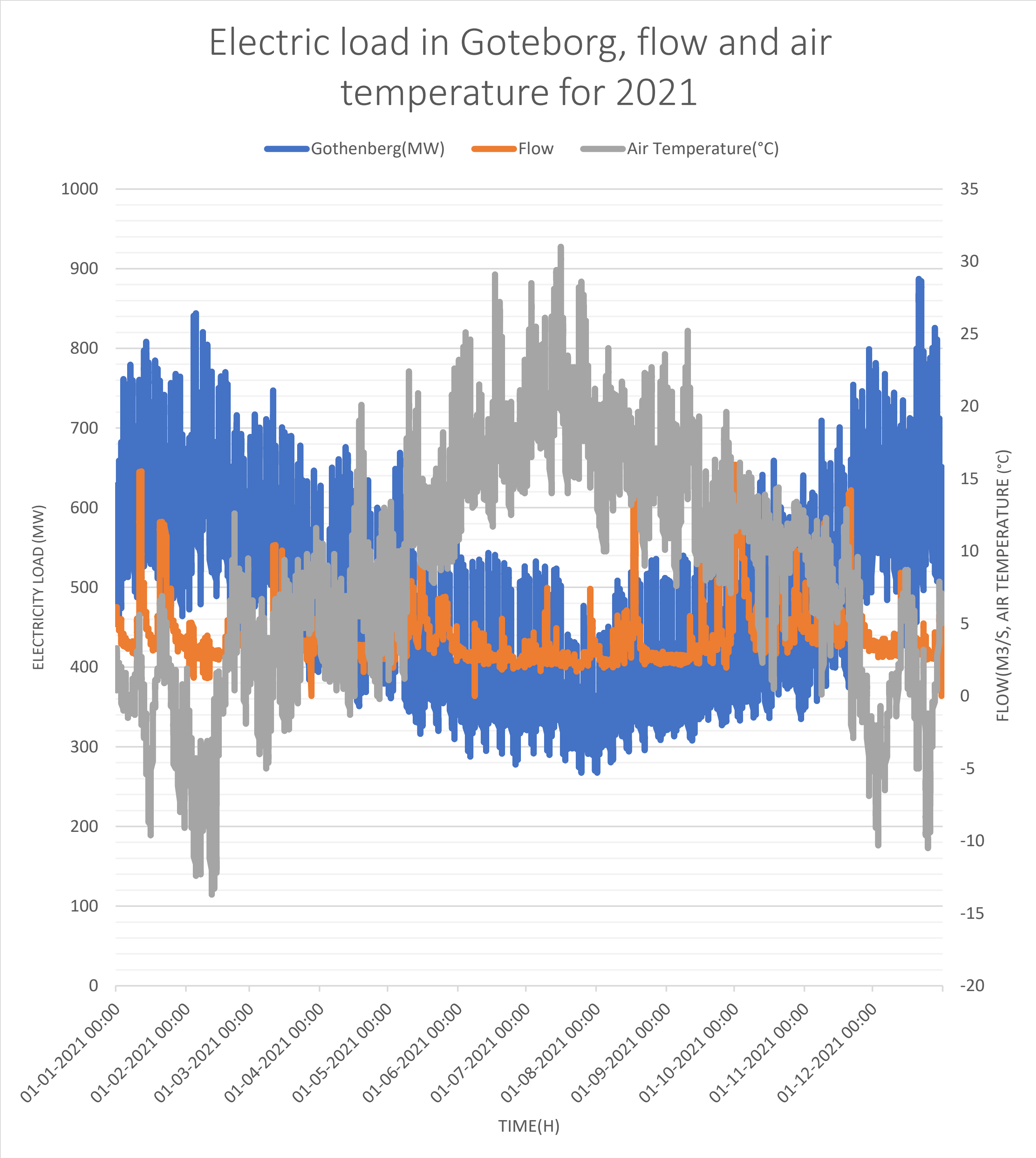

Figure A7: Electricity laod in gothenburg, flow to Gryaab and air temperature in 2021

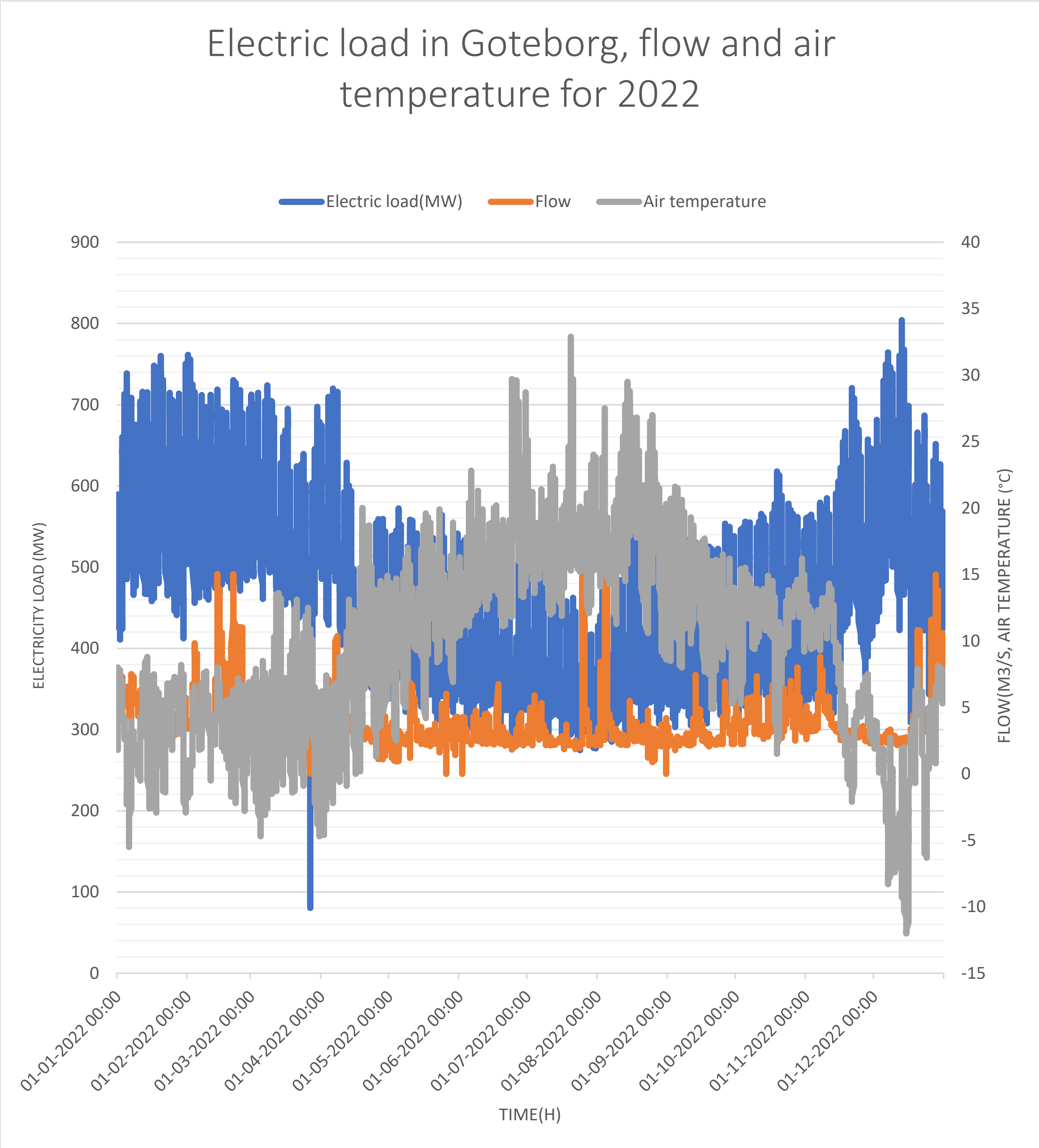

Figure A8 : : Electricity laod in gothenburg, flow to Gryaab and air temperature in 2022.

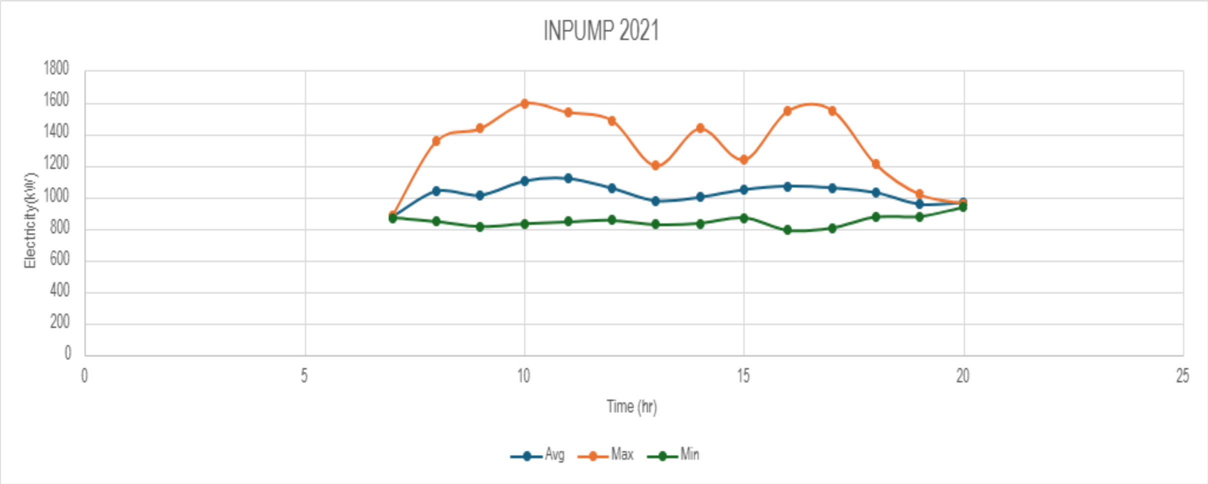

Figure A9: Avg ,Min and Max of INPUMP 2021.

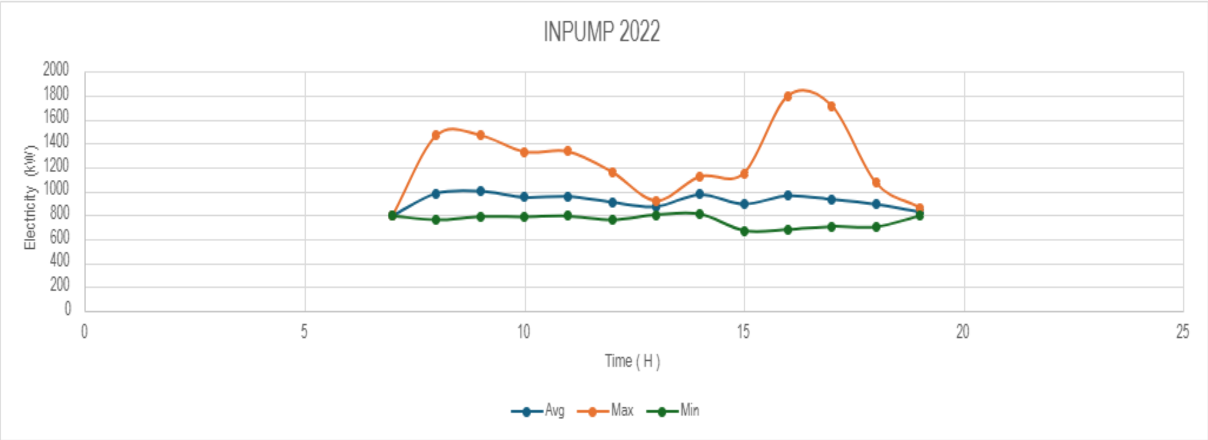

Figure A10:Avg, Min and Max of INPUMP 2022.

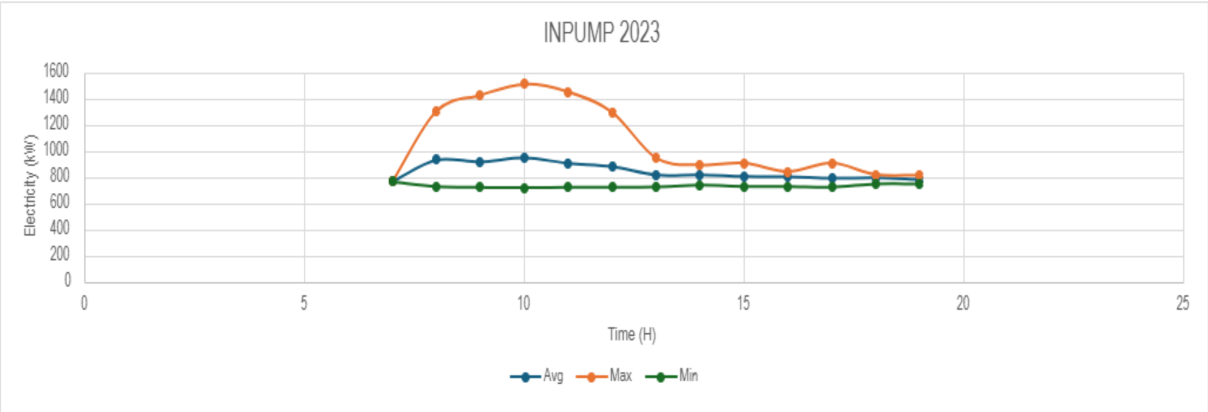

Figure A11: Avg, Min and Max of INPUMP 2023.

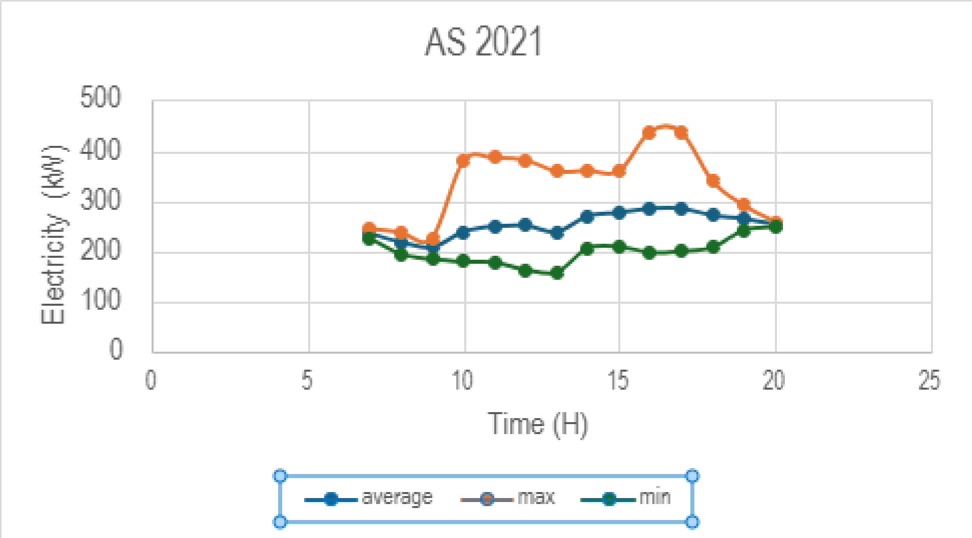

Figure A12 : Avg, Min and Max for Activated sludge 2021.

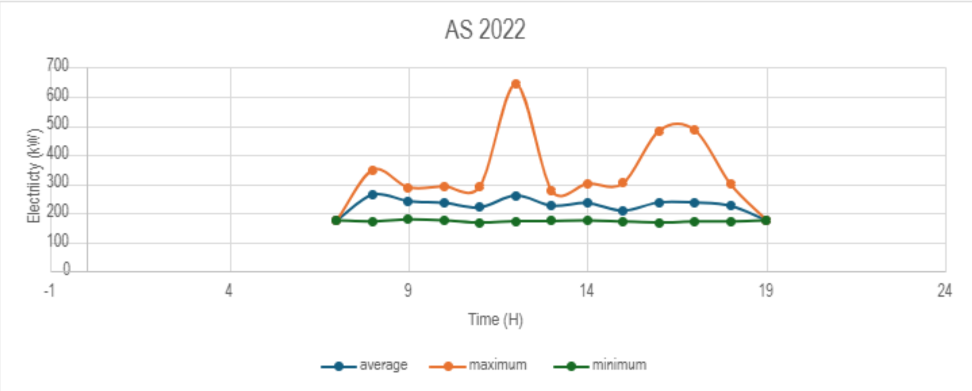

Figure A13: Avg, Min and Max for Activated sludge 2022.

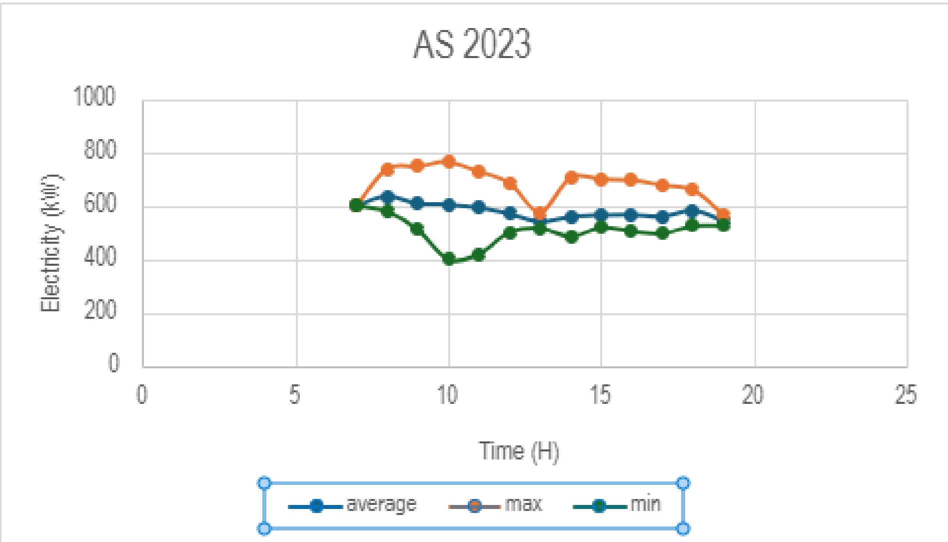

Figure A14: Avg, Min and Max for Activated sludge 2023.

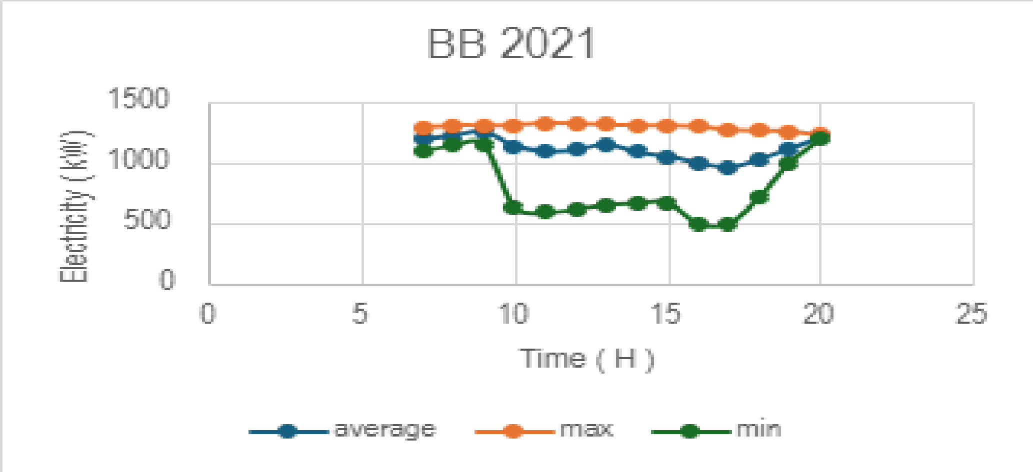

Figure A1514: : Avg, Min and Max for Trickling Filter 2021.

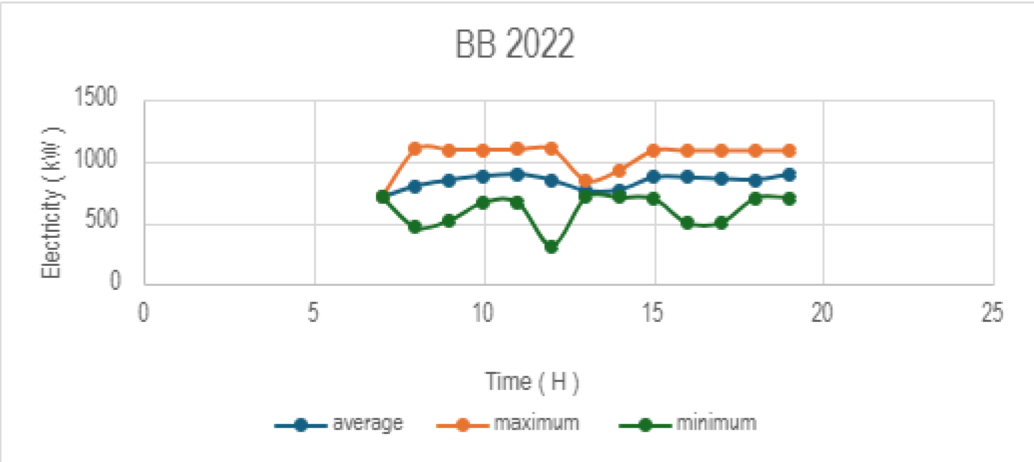

Figure A1615 :Avg, Min and Max for Trickling Filter 2022.

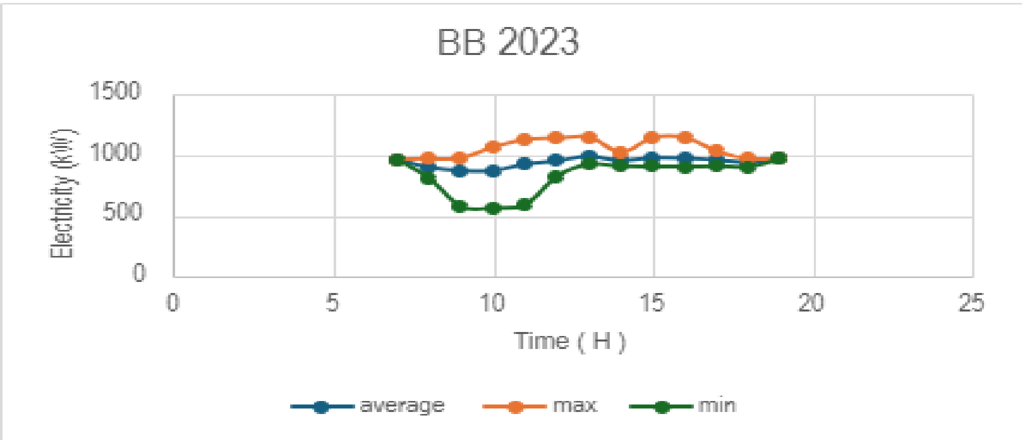

Figure A1716: Avg, Min and Max for Trickling Filter 2023.