COST-EFFECTIVE ENERGY OPTIMIZATION AT A METAL PROCESSING COMPANY

BACHELOR THESIS IN INDUSTRIAL ENGINEERING AND MANAGEMENT

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Coes Metaalbescherming

Management Summary

Coes is a metal processing company based in Vriezenveen. Metal constructions are sent to their production facility by customers, so that they can be blasted and coated by Coes. A big challenge that they face is that their energy costs are too high, even though they recently invested in a large amount of solar panels. Their total energy costs are comprised of their electricity and gas costs. To try and reduce these costs, this research will focus on solving the following problem statement: *"Coes Metaalbescherming wants a technically and financially viable investment strategy to lower their energy costs and CO2 emissions, by upgrading their heating and power systems"*

The solutions that we will be working towards will be the possible implementation of a thermal wheel and an electrical battery storage that Coes can invest in. But to be able to see the effects of such implementations, we must be able to compare the current situation to a possible future situation, in which an implementation has been made. We will do this using a simulation, in which we can create possible expected trajectories of the future electricity and gas costs. These costs consist of the energy costs and the energy consumption for the upcoming years. We simulate what the energy costs will be in upcoming years, assuming that we keep the situation the same as it is right now. Then we will simulate the situation, in which we make implementations and compare the costs of both scenarios. From the results we will draw conclusions about the viability of the proposed implementations.

First of all, we will try to reduce the electricity costs. We suggest to do this by using a battery storage system. This will give Coes the flexibility to store the electricity generated by their solar panels. They can also decide when to satisfy their own demand with solar generated electricity or with bought electricity. We will also come up with an operationalization policy that focusses on buying electricity during base hours in the morning to meet the initial electricity demand peak at the beginning of each day. We test this implementation for 4 different battery capacities ranging from 200 to 800 kWh. The results concluded that none of these implementations will be able to break-even withing the desired 20 years, which is the lifespan of the battery. The 'improvement percentage compared to the old situation' grows when the capacity of the battery is increased. This means that with a larger battery, more money will be saved per year. The 800 kWh battery yields an improvement percentage of 2.95%. But the initial investment costs also increase significantly, when the capacity is improved. This can be derived from figure 1.

	200 kWh	400 kWh	600 kWh	800 kWh
Total amount of money saved in 1 year (€):	491.06	1517.74	2563.46	3119.55
Improvement percentage compared to current situation:	0.46%	1.44%	2.43%	2.95%
Implementation Costs (€):	366000	466000	566000	666000

Figure 1: Battery Capacity Results

Second of all, we wanted to reduce the gas costs too. It was suggested that implementing a thermal wheel in the gas heaters currently used, would improve the efficiency of said heaters. Similarly to the battery, we simulated the expected gas costs when we would implement a thermal wheel. The investment in this implementation is already more promising, as can be seen from the 'Improvement percentage compared to the current situation' in figure 1B. We see that this percentage is also a lot higher compared to that of the battery system capacities. Still when we simulated the break-even point, We discovered that earning back this investment, would take 97 years. This is why this investment is also not a viable option for Coes.

	Thermal Wheel
Total amount of money saved in 1 year (€):	5173.73
Improvement percentage compared to current situation:	5.99%
Implementation Costs (€):	300000

Figure2: Thermal Wheel Results

In conclusion, We recommend Coes not to implement either a battery system or thermal wheel at this moment. We would suggest to keep a close eye on the development of battery storage systems, as it would still be a helpful implementation for Coes in the future. If the implementation costs are reduced in addition to a longer lifespan and a better operating policy, the battery might be able to break-even in the future. Regarding the thermal wheel and gas heaters, We join the ‘Energie Partners’ in recommending to replace the 3 obsolete gas heaters, with 1 new model that can handle the air supply and exhaust of the whole facility. It might also be worth it to implement a thermal wheel in this new gas heater. Due to the limited amount of time, we could not test the viability of this implementation.

Preface

Dear reader,

Before you lies my bachelor thesis ‘Cost-effective energy optimization at a metal processing company’. I wrote this as my final graduation project for the degree BSc Industrial Engineering and Management at the University of Twente. I spent my time researching and writing this thesis from January 2023 until April 2023.

Undertaking this research was an academically challenging project, which helped me improve on a personal level. My independence, initiative, adaptability and communication skills were all tested and I gained valuable experiences and insights, because of it. I am glad with the result and with the way I got there. I really enjoyed working for and with Coes and wish them the best of luck in their future endeavors.

I would like to thank my academic supervisors Alessio Trivella and Daniela Guericke for their guidance, feedback and support throughout my whole bachelor thesis. I want to thank Coes for giving me the opportunity to finish my bachelor in collaboration with them. I also want to thank Bert Elzing, the director of Coes, for providing me with valuable information and insights during my stay at the company. My special thanks go out to Hans Meinen, my supervisor at the company. He helped me feel welcome at Coes, provided me with great feedback and I really appreciated the discussions we had about the problems at hand.

Joshua Thiescheffer

Enschede, April 2023

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Introduction

1.1 Company Description

Coes Metaalbescherming BV is a company that has over 60 years of experience in blasting and coating metal constructions. In all these years they have treated a wide variety of parts and products like: steel constructions, tanks, trailers, containers, pipes and masts. They own and operate in a big facility consisting of different consecutively linked halls with a total length of 500 meter and a floor space of over 10.000 M^2All lighting within Coes is LED based. Transport within the company is also not a problem, Coes owns 2 overhead cranes up to 50 Ton hoisting capacity and several forklifts and trailers. In recent years they have developed an interest in sustainability and renewable energy, and in 2019 they have installed 2298 solar panels. These solar panels deliver approximately 600 MWh renewable energy per year.

There are several processes that Coes uses to preserve metal constructions. The preservation process at Coes starts with cleaning the steel by means of abrasive blasting. Compressed air is needed for blasting, metallizing and coating (OSHA, 2014) . Blasting can be done by hand, blasting machine or a computer controlled blasting robot. Metalizing the blasted steel constructions can be done using zinc-, zinc-aluminum- and aluminum wire. Metallization is the process of thermal spraying an aluminum- or zinc alloy onto the blasted steel to coat and protect the metal longer and to increase the corrosion resistance. Lastly, Coes also coats the metal constructions that they treat. Coating is applied in their spraying halls, which uses a modern heating and ventilation system. Coating is also applied to increase the durability of the metal constructions.

1.2 Problem Context

Coes is looking into reducing all costs related to energy use, prioritizing their gas and electricity costs. Daily, the company receives big steel constructions from their customers to either blast, metalize or coat. This protects valuable assets and secures durability of the steel constructions. After coating the steel constructions, they must dry, because most of the time they will be picked up the next morning by the customer. This means that the temperature in the production halls must be regulated throughout the night which consumes a lot of energy (decreasing the heating will have a negative influence on the end-product). Specifically, gas is used for better climate conditions in their production facilities (1 big hall has infrared lighting powered by gas and 1 smaller hall has 3 gas heaters). The metal constructions lie in these halls. Using the infrared lights and the heating consumes approximately 100.000 $\mathrm{M}^3$of gas per year. Coes would like to reduce their gas costs by reducing their gas usage.

In addition to that Coes wants to reduce their electricity costs. A lot of processes at Coes run on electricity. The hand blasting and metal blasting is done using electrical machinery and equipment. The company owns electrical cars and forklifts and the lighting and extraction systems all run on electricity. The solar panels on the roof of their facility generate a lot of electricity but Coes still has to buy a lot of electricity from their energy suppliers. Their goal is to use more of that generated electricity for their own consumption.

1.3 Identification of the core and action problem

The theory of Heerkens & van Winden (2017) will be used as a general guideline to identify the core problem. A problem cluster has been made and every time that a problem is identified, the question is asked if this problem may be the result of another problem. A fundamental problem will be found which can be influenced by the researcher and whose solution will make a real difference in the whole problem cluster. This is the core problem.

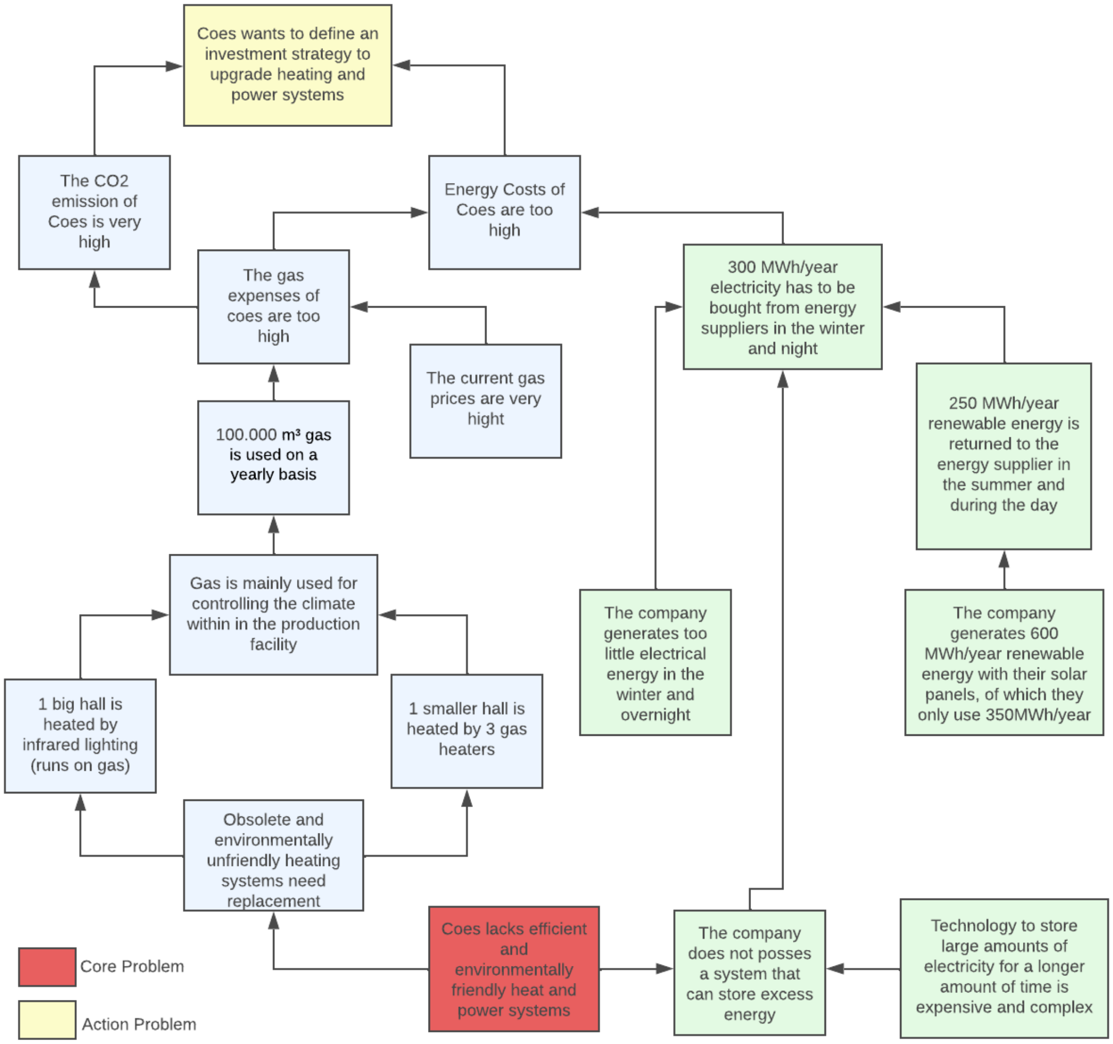


Figure 3: Problem cluster

1.3.1 Explanation of the problem cluster

In figure 3 the resulting problem cluster can be found. As has been mentioned before Coes is already interested in sustainability and they would like to reduce their energy costs and CO2 emissions further. Most of the energy that they use is consumed by the heating systems. Also previously stated, they have infrared lighting, which uses gas, to heat one big hall and they have 3 small gas heaters to heat a somewhat smaller hall. This causes very high energy costs due to the amount of gas used in the supply chain in combination with the current gas prices. Heating is essential to the supply chain because most of the constructions that Coes processes must be ready at dawn so they can be picked up. Delivering constructions with coating that has not hardened yet is horrible for customer satisfaction and image because the steel will stick together. The gas heaters that are used are environmentally unfriendly and inefficient and even though the infrared lighting is more modern, it runs on gas, which is also inefficient and also has a negative impact on the environment.

Another problem that causes high energy costs is that the company has to buy electricity in the winter and overnight. Coes buys approximately 300 MWh electricity from their energy supplier every year. This is a tricky situation because the solar panels that were installed on their roof, produce approximately 600 MWh renewable energy per year. Only 350 MWh of this energy is used by the company themselves, so

250 MWh is returned to the energy supplier at a lower price. This feels like a waste because Coes would like to use that energy themselves so they won't have to buy the electricity back. In the Netherlands there is technology available that can store large amounts of energy without suffering too much energy losses over a small period of time. The problem is that it is very expensive and complex to implement. Currently, Coes needs to buy energy in the winter months, because the solar panels do not generate enough in that period. Even though they had a surplus in peak periods, for example the summer.

1.3.2 Selection of the core problem and action problem

Taking into account all of the mentioned problems in the problem cluster we can determine 1 underlying problem, with influence on the whole cluster. Both the energy storage and the gas problem have as an underlying cause that 'Coes lacks efficient and environmentally friendly heat and power systems'. This is the core problem because this is a fundamental problem that can be influenced and changed by a researcher. This automatically makes 'Coes wants to define an investment strategy to upgrade heating and power systems' the action problem.

1.4 Research Questions

Right now a core problem has been defined and as explained above we turned our core problem into an action problem. We can turn this action problem into our main research question. After the main research question has been composed, we can determine some knowledge questions. Knowledge problems describe problems where we have a lack of understanding or a lack of knowledge about the problem. We must conduct research to obtain information and knowledge in order for us to answer the knowledge question. "A knowledge problem is a description of the research population, the variables and, if necessary, the relations that need to be investigated" (Heerkens & van Winden , 2017). These knowledge questions are formulated as the sub-research questions of the main research question.

1.4.1 Main Research Statement

"Coes Metaalbescherming wants a technically and financially viable investment strategy to lower their energy costs and CO2 emissions, by upgrading their heating and power systems"

Right now we have formulated the core problem and we will dissect it into easier-to-tackle questions. By answering these smaller knowledge questions the research can eventually answer the main research question an solve the core problem.

1.4.2 Sub-research Questions

1. *"What is the current situation of the supply chain and the production facilities of Coes?*
    - a. *"How is gas integrated in their supply chain and facilities?"*
    - b. *"How is electricity integrated in their supply chain and facilities?"*
    - c. *In which areas of the supply chain is room for improvement in regard to reducing the energy costs of Coes?"*
2. *"How can a model be created to simulate scenarios of the future energy costs of Coes?"*
    - a. *"How can we simulate scenarios for the future energy market prices?"*
    - b. *"How does the energy supplier calculate their energy prices, based on the market prices?"*
    - b. *"How can we simulate scenarios for the future energy consumption of Coes?"*
    - c. *"How can we combine the energy consumption with the energy prices to simulate the future energy costs?"*
3. *"Which implementations can be made at Coes that will lower their energy costs in the upcoming years?"*
    - a. *"What is the influence of these implementations on the energy consumption of Coes?"*
    - b. *"What effect does the change in energy consumption have on the energy costs?"*

    c. *"Is the investment worth it when comparing the saved energy costs with the initial implementation costs?"*

4. *"Is implementing an electricity storage system a financially viable implementation option for Coes?*
    a. *"How can we formulate the use of an electricity storage system as an optimization problem?"*
    b. *"What operating decisions, policies or heuristics can be used as solutions to this optimization problem?"*
5. *"Is implementing a thermal wheel a financially viable implementation option for Coes?*
    a. *"How can we model the improvement in efficiency of the gas usage?"*
6. *"What conclusions and recommendations can we make about the proposed implementation options for Coes?"*

1.5 Report Structure

The aim of this research is to find a solution for the main research statement, by answering the sub-research questions (solving the knowledge problems). The chapters of this report are mostly structured in accordance to these sub-research questions.

Chapter 2 – The second chapter will answer the first research question. It will focus on the current supply chain of Coes and mainly on the energy use within the company. It will focus on what processes are going on, at the company and on which kind of energy is used for it.

Chapter 3 – The third chapter will provide a literature review on all the relevant knowledge, which already exists on the topics, involved in this thesis. The theories and methodologies used will be explained in here.

Chapter 4 – The fourth chapter will answer the second research question. In order for the research to reduce the energy costs of Coes, it must be able to create possible future scenarios for the energy costs of Coes the upcoming years. This will be done in this chapter by creating and combining trajectories of the future energy market prices and trajectories of the future energy consumption.

Chapter 5 – The fifth chapter will research the third and fourth research question. It will take a look at the implementations that Coes could make in their supply chain to reduce energy costs. It will also try to predict the influence of particular implementations on the energy costs of the company. Especially the implementation of an electricity storage system will be looked into, with the optimization problem that comes with it.

Chapter 6 – The sixth chapter will answer the fifth research questions. We will take a look at the possible implementation of a thermal wheel and how it would affect the efficiency of the gas usage.

Chapter 7 – The seventh chapter will answer the sixth research questions. Conclusions will be made about the viability of the implementations and recommendations will be made for Coes. This chapter will conclude this report.

2 Current Situation

In this chapter we will look into the current situation at Coes. We will take a closer look at their supply chain and how electricity and gas are used in it. This way we can try to find out in which area, lies room for improvement. Most of the industrial processes that Coes performs is powered by electricity, while the heating is mainly done using gas.

2.1 The Supply Chain

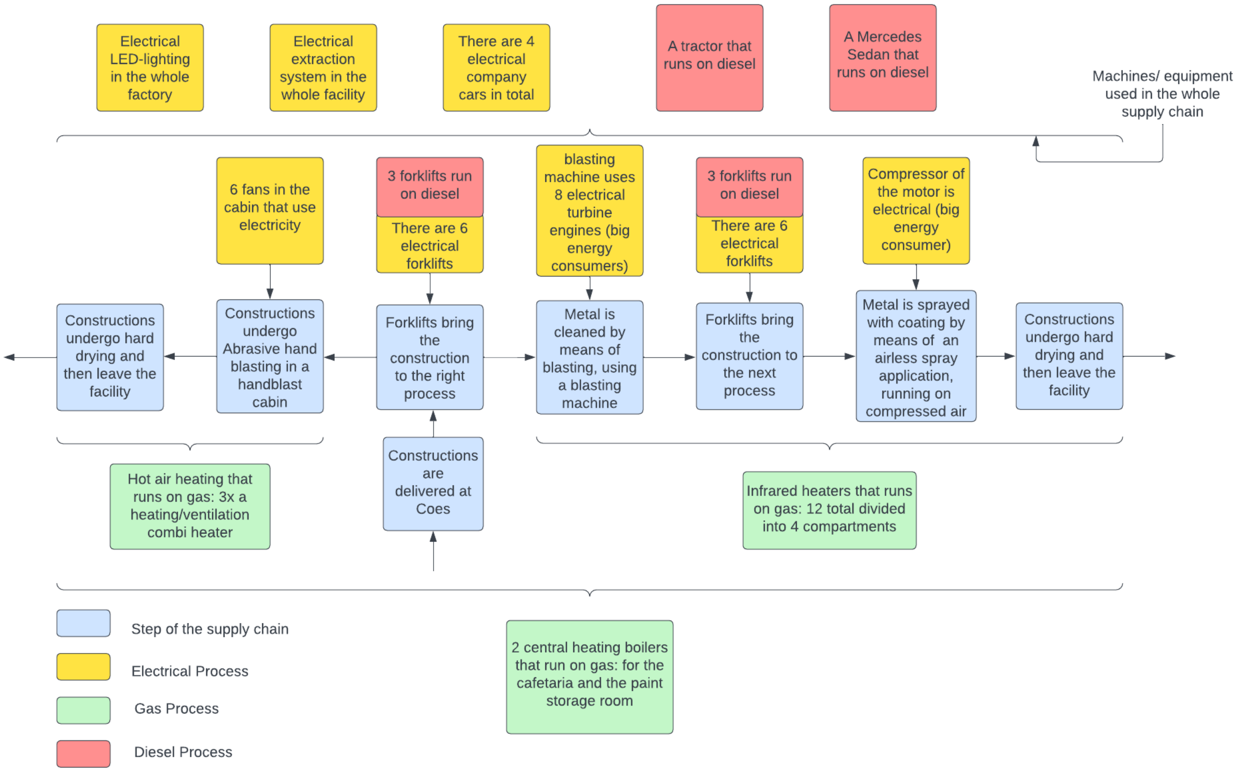


Figure 4: Overview of Coes' supply chain

We already explained that Coes is a big company that specializes in blasting and coating metal constructions. The facility that Coes works in is a very elongated building with a lot of square meters, where the metal construction are received right in the middle of the building. The company uses forklifts for the internal transport of these constructions. They are either brought to the right or the left side of the building based on the shape and size of the construction taken in. On the right side of the building the constructions are blasted by a blasting machine. This is where the constructions with more regular sizes and shapes are treated. They go through the blasting machine to clean of the metal which helps preserve it. This is done using abrasive blasting. After that the construction is brought to a big spraying hall, where the metal is sprayed with an alloy with an airless spray pump that uses the pressure provided by an hydraulic pump. This increases the corrosion resistance and further helps to preserve the metal for a longer period of time. After the metal has been sprayed it will hard dry in the spraying hall, after which the customers, mainly come and pick up the constructions the following morning.

The left side of the building operates in a similar manner, but uses hand blasting or blasting by means of a robot to blast the constructions. So after Coes receives a construction, they transport it using a forklift to a blast cabin. Here they blast the constructions by hand or they let a blasting robot do it for them. This process is also done using abrasive blasting. In a similar way these constructions are transported to the spraying hall and also undergo hard drying after which the customer can come pick up their constructions on the left side of the building.

2.2 Electrical processes in the supply chain

Electricity plays a very important role in the supply chain and manyprocesses make use of this energy form. First of all, the blasting machine on the right side of the building is a big electricity consumer. The machine uses 8 big electrical turbine engines to provide power to the machine and to make automated blasting possible. The hand blasting and robot blasting process on the left side of the building also uses electricity. The blasting cabin in which the constructions are blasted has 6 fans to provide an airflow through the cabin, all of these fans run on electricity. Furthermore the metal spraying and coating is done using an airless spray application pump. These airless spray application pumps make use of compressed air. The compressors of the motor of these pumps also runs on electricity. This compressor is also a big energy consumer. As mentioned before, the internal transport is done using forklifts. Coes owns 9 forklifts in total, 6 of these forklifts are electrical and can be recharged. The company also owns a total of 4 electrical company cars, all of these cars can also be recharged. Lastly, Coes also has a big air extraction system in the whole facility that solely runs on electricity and all of the lighting in the whole factory is LED-lighting, which of course also makes use of electricity.

We discovered a couple of interesting points regarding the electricity behavior of Coes of last year. When we look at seasonal differences, we can compare the winter and autumn months (October till March) with the summer and spring months (April till September). We can tell that the electricity usage is lower in the summer months and spring months. We think that the heightened electricity usage in winter and autumn months is due to the longer use of LED-lighting in those months. The amount of natural light is limited in these months, meaning that Coes must rely more on electrical lighting in this time period. If we look at the average daily electricity consumption, we noticed that at the start of everyday around 7 o’clock in the morning (during peak hours), there is always a peak in electricity consumption. This is when all the machines that Coes uses, mainly the blasting machine, are started up. Coes confirmed that starting up the electrical machines costs more electricity than keeping them running.

We were able to analyze the data of the amount of electricity that Coes generated and returned last year to Qwint, their supplier. The data consists of the amount of electricity returned to Qwint, meaning that Coes’ own demand is already subtracted from it. It is very logical that the amount of electricity generated in the summer and spring months is far larger than the amount generated during the winter and autumn months. This is due to the sun shining for a larger part of the day and the sun shining more intense during these months. From this we can conclude that Coes sends a lot of energy back to Qwint, a lot of this energy can be used for their own demand if they are able to store it for some time.

2.3 Processes that run on gas in the supply chain

We already mentioned that Coes already made many investments to transition processes that previously used gas to electricity. We also explained that the main function of gas for Coes lies in heating the facility. Heating the factory plays an important role in the supply chain because it makes the hard drying of the coating on the constructions possible. On the right side of the building the big spraying hall is heated using infrared lighting. This lighting runs on gas. The 12 infrared heaters are switched in 4 different compartments. These compartments can be used independently of each other. This way there is no unnecessary gas wasted. For example if there is only a limited amount of constructions that needs to hard dry, then these constructions can be placed under 1 of the 4 compartments. Then only this compartments has to be switched on to hard dry the coating on the constructions. Furthermore, the left side of the building is heated using 3 hot air gas heaters. These heaters are a combinations of heating and ventilation systems. These heaters have quite a high gas consumption. Lastly, the company owns 2 central heating boilers. Both of these boilers run on gas. The main function of these boilers is to provide heating for the employee cafeteria and the painting room. It is very important to maintain a certain constant temperature in the painting room.

In the file ‘Gas Consumption Data’ we find the historical data on the gas consumption of last year. In the summer and spring months, Coes uses almost no gas. While during the winter and autumn months the gas usage is relatively very high. This is because all of the gas consumption is used for heating different parts of the facility, as can be seen in the figure described earlier. In the summer and spring months the heaters are not in use, because the temperature outside is sufficient. Additional heating is not necessary. On an average day in the winter, the heaters are started up around 4 o‘clock in the afternoon, and they run until around 4 o’clock in the morning. This means that they run throughout the whole night.

2.4 Processes that run on diesel in the supply chain

Finally, the company owns some vehicles that run on diesel. These vehicles will not be looked into in this research. But in order for us to give a complete view of the current energy situation of the company we will briefly discuss the vehicles that run on diesel. First of all, the remaining 3 forklifts that Coes owns run on diesel. Besides that Coes also owns a tractor and a Mercedes Sedan, both of these use diesel as fuel.

3 Literature

Now that we have analyzed and explained the current situation at Coes, we will discuss the literature that we will use to solve the research questions, in this chapter. We will explain the methods that will be used to create future trajectories for the energy prices and consumption. Furthermore we will discuss, how we intend to calculate the value of an investment in todays money. Lastly we will also settle on which implementations will be simulated and why.

3.1 Modeling Scenarios of Future Energy Prices Based on Historical Data using the GBM

The Geometric Brownian Motion is a continuous-time stochastic process, which is used in mathematical finance to model future market prices. It creates continuous future sample paths, which can be defined as possible outcomes of the stochastic process. These paths can be used to make estimations for the behavior of market prices. The GBM assumes that market log-prices follow a wiener process. The Wiener process assumes that it has independent increments for every time unit, so future increments are independent of past values (Chello, A. 2020). There are some examples with relevance regarding this research. Mainly the research performed by Borovkova, S. & Schmeck, M. D. (2017) where they try to model electricity price changes with stochastic time change.

We will use a GBM in this research mostly, because the calculations are relatively easy to make and understand. Beside that the GBM only assumes positive values, which is also expected from real market prices. However the Geometric Brownian Motion also has a drawback. It is not a completely realistic model and compared to reality it falls short in the following point. In real market prices, volatility changes over time (possibly stochastically), but in a GBM the volatility is assumed as constant.

Market prices are often defined as the sum of the deterministic drift (the growth rate) and a random number with a mean of 0 and a variance that is proportional to dt. This is what we call a Geometric Brownian Motion. A Stochastic process S_t follows a GBM if it satisfies the following stochastic differential equation (SDE):

$$dS_t = \mu S_t dt + \sigma S_t dW_t$$

With a given starting value of $S_0 > 0$

In this formula:

- dS_t is the infinitesimal change
- μ is the drift
- σ is the volatility
- W_t is the Wiener Process, which is used to define the Brownian Motion

Now that the SDE has been defined, the solution to it can be calculated. (Chello, A. 2020) This is:

$$S_t = S_0 e^{\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \sigma W_t}$$

Where we know the distribution of the random variable S_t at future times.

The formula introduces the following values:

- S_t is the random variable that represents the future market prices
- S_0 is the market price at time 0
- Δt is the time step taken

- W_t is the Wiener Process

The drift of a market price can be seen as a general trend that a certain market has. Ignoring the daily, weekly or even monthly shifts in value, the drift determines if the market price increases or decreases over a long period of time. The volatility adds the price shocks to the prediction. The GBM model assumes that the market price follows a log-normal distribution, which means that the logarithm of the market price is normally distributed. We will be using this equation as a fundament for the logic used in the simulation that will provide trajectories of the future energy prices.

3.2 Discounted Cash Flow Analysis

Discounted Cash Flow Analysis (DCF Analysis) uses the expected future cash flow to make an estimation of the value of an investment. “DCF analysis helps to assess the viability of a project or an investment by calculating the present value of expected future cash flows using a discount rate.” (Hayes, A. 2021). This DCF analysis starts with making an estimation of the initial investment that a certain project or implementation will require. After that the future returns that are expected to be generated by this investment are taken into account. Using a discount rate, we can determine the current value of future cash flows. Now that we know the current value of the cashflows that the investment will generate and the costs of the initial investment, we can compare the two to find out if the investment will be worth it.

3.2.1 Discount Rate

The discount rate can also be seen as the interest rate used to determine the present value. This is only in the context of a DCF analysis. For example if we make an investment of €1000,- with an interest rate of 5% over a time span of a year. Then next year our €1000,- will be worth €1050,-. Now if we switch it up and say that €1050,- is our future cash flow of next year and we have the same interest rate, then the present value of our future cash flow is €1000,-. If we can predict the future cash flows of our investments at Coes, we can determine their Net Present Value if we know the interest rate.

So it is very important to determine an appropriate interest rate that we can use. ‘If a business is assessing the viability of a potential project, the weighted average cost of capital (WACC) may be used as a discount rate.” (Hayes, A. 2021). The WACC is the average cost that a company will have to pay for capital if they want to borrow or sell equity. It is based on the cost of capital, debt and equity. Because of this We have decided to not use the WACC as an interest rate because it would make it very elaborate and complex to determine if We have to determine the capital and debt of Coes. What WE will be using is the risk free rate of return.

“The risk-free rate is the minimum return an investor expects for any investment because they will not accept additional risk” (Hayes, A. 2022). In practice, a truly risk-free rate does not exist because even the safest investments carry a certain amount of risk. This is why most of the time a proxy is used as an indication for the risk free rate return. ‘The short-term government bills of highly rated countries, such as Germany and Switzerland, offer a risk-free rate proxy for investors with assets in euros (EUR) or Swiss francs (CHF)’ (Hayes, A. 2022). So we will be using the risk free rate of Germany because of their stable economy. The average risk free rate in Germany from 2015 to 2022 was 1.2% according to Statista(2022), so we will be using this as our discount rate. This may not be completely accurate, as the rates have climbed over the last year.

3.2.2 Net Present Value

“The net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time.” (Fernando, J. 2022). It is widely used in investment planning to analyze the profitability of certain investments and projects. It uses the predicted future cashflows of an investment and determines the current value of them using the discount rate. We have just determined the discount rate that we will be using, and the future cash flows will be amount of money that Coes will save over the next few years. This is all the information that we need to calculate the Net Present Value (Fernando, J. 2022):

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

In this formula we have the following parameters:

- NPV is the Net Present Value, the current value of the future cashflow.
- *n* is the total number of periods and thus the number of years in which we expect to have a cashflow.
- *t* is one of the *n* possible periods in which we expect to have a cashflow.
- R_t is the net cash inflows and outflows during a single period *t*.
- i is the discount rate

When we know the present value of the amount of money that Coes can save with a certain implementation, we can compare it to the initial implementation costs. The goal is to find the year t for which NPV becomes bigger then the initial investment. If this happens the current value of the future cashflows is bigger than the costs of the implementation. So when this happens we have found the breakeven point.

3.3 Implementation Options

Now we will discuss the main problems that Coes has and which implementations could help solve their problems. We will choose the implementation that will offer the most improvement, in regard to lowering the energy costs of Coes.

3.3.1 The options

When we look at the first problem, we have concluded that Coes generates a lot of electricity without being able to use it for their own demand. So implementing a storage system is a logical solution to this problem. Now we must decide on which kind of storage system to implement. There are three main options for energy storage: Electrical energy storage using a battery, thermal energy storage and mechanical energy storage. Thermal energy storage transforms the generated electricity into heat and stores it into an heat absorbing material. This option is great for seasonal storage but the electricity is not easy dispatchable, because the heat needs to be transformed back into electricity. Besides that the costs of this technology are quite expensive and the efficiency of the system is very dependent on the isolation around the absorbing material. Then, mechanical storage transforms the electricity into kinetic energy, and stores it for example into a rotating wheel. The dispatchability of this system is better than that of the thermal storage system. But the big drawback is that cutting edge technology is needed to implement such a system. This means that it will be expensive, making it not a viable option for Coes. Lastly, the battery energy system has a very fast dispatchability because it does not transform the electricity into another energy form. The costs of implementing a battery are quite high, but the technology is rapidly growing and there are quite a few suppliers already in the Netherlands. This is why we chose to research the battery storage system.

For the second problem, Coes would like to reduce their gas costs. First we looked into replacing the infrared gas heaters with electrical heaters or heaters that run on hydrogen. We looked into hydrogen heaters because Coes mentioned that it would maybe be possible to reuse the gas pipes that were already in use. But it is a technology that is very up and coming and it cannot yet be implemented on an industrial level in the Netherlands. The infrared gas heaters were an investment that was made relatively recently, so

Coes preferred not to change up the whole infrared grid again, to install electrical infra-red heaters. We ended up with the suggestion from Coes to look into thermal wheels that could be implemented into the gas heaters. These gas heaters seemed to be an easy to implement option. Besides that Coes has already looked into thermal wheels themselves. Meaning that they already had contact with a company that could implement them. This gave me the opportunity to get information more easily on for example implementation costs and efficiency.

3.3.2 Battery Energy Storage System (BESS)

Batteries store and release energy using an electrochemical process. So technically they can act as an storage system. Recently, batteries have become a very viable option for industrial use. This is due to their fast responding dispatchable power. Batteries can almost instantly switch from standby to full power when energy is needed. This is why they are widely used by companies that generate their own electricity. The battery can instantly take over the energy demand and fulfill this for up to a few hours. 'Various megawatt-scale projects have proved that batteries can respond more quickly and accurately than conventional resources such as spinning reserves and peaking plants' (World Nuclear Association, 2021). The shortcoming of BESS is that the energy can only be stored for a limited amount of time due to the energy losses, making it not a viable option for long term energy storage. In the case of Coes this is quite a drawback because we cannot solve the seasonal variations with a BESS. It would still be very useful to implement a BESS, because Coes still needs daily storage so they can use more of their own generated electricity. It could also be used to sell excess generated electricity during peak hours and maybe even buy electricity from the energy supplier during base hours.

3.3.3 Thermal Wheel

A thermal wheel is an energy recovery heat exchanger that is positioned between the exhaust and the air supply tube of an industrial process. In the case of Coes it could be implemented in the 3 gas heaters that they have on the left side of the building. A thermal wheel consists of a circular matrix that is made out of a heat-absorbing material. This wheel is then rotated between the exhaust air stream and the supply air stream. The input air or supply air is fresh air from outside which will be heated by the gas heaters. The exhaust air is air that has been heated by the gas heaters and is expelled. As mentioned before these air streams are positioned next to each other and the wheel rotates between the two. The waste heat from the exhaust air stream is transferred to the matrix material of the wheel. After that the wheel transfers the heat to the supply stream of fresh air. This way the input air is already heated before it enters the heaters. This way less gas is needed for the gas heaters to heat the air to the desired temperature. This saves gas usage and thus gas costs. The picture below (Dwyer, T. 2020), shows a simplified schematic of the workings of a thermal wheel. Coes could implement thermal wheels in their gas heaters to save gas costs.

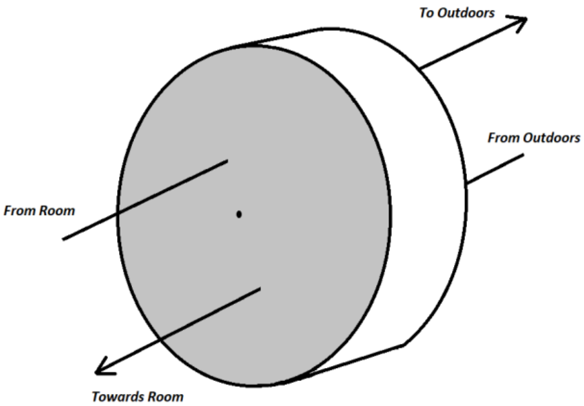


Figure 5: Simplified schematic of a thermal wheel

4 Modeling Scenarios of Future Energy Prices and Demand

4.1 Simulating Scenarios For the Energy Prices using the GBM

The main goal of this research is to reduce the energy costs of Coes. The energy costs are mostly dependent on the energy behavior and the energy consumption of the company, but the energy prices are just as influential. The gas prices and the electricity prices cannot be assumed as constant. This is because the energy provider bases their energy prices on the gas and electricity prices of the market. This was confirmed in a phone call with one of the employees of the energy supplier Qwint. These market prices are very fluctuating and are constantly changing. This means that the research must take this into consideration when it tries to simulate the future energy costs of Coes. In order to account for this, we will have to make some sort of estimation on the future gas and electricity prices. We will do this using a Geometric Brownian Motion (GBM). As mentioned, we chose this particular model because it is easy to use and widely used in similar problems.

4.1.1 Finding and Analyzing Historical Energy Market Price Data

Next we will discuss how we will simulate trajectories of the future energy prices (using Excel and VBA). First of all, in order to make one trajectory of the future prices, we must calibrate the parameters of the GBM processes using the historical price data of gas and electricity. In a conversation with Qwint the energy supplier of Coes, they confirmed that Qwint uses the historical data of the electricity and gas markets/exchanges to determine their own prices. For the Electricity prices Epexspot is used, which is a part of the EEX group, a major international energy market. The electricity price data consisted of 2 datasets, one for the peak electricity load and one for the base electricity load. The filters used on their site are:

- ‘Trading Modality’ = ‘Auction’
- ‘Market Segment’ = ‘Day-Ahead’
- ‘Market Area’ = ‘Netherlands’

These filters were recommended this way by Qwint. They also recommended to just search for a general market or exchange to find historical data on the gas prices. Investing.com was used and the historical data of ‘Dutch TTF Natural Gas’ was extracted from this website. These 3 datasets were all data of the year 2022.

Now we must find the volatility, the drift and the initial market price of the datasets. Every dataset was approached in the same manner and these values were calculated from the datasets in the same way. First of all, we will take the daily prices and calculate the average monthly prices for the year. Initially, we wanted to use the daily prices but the trajectories that we got as a result had a lot of extremes and were to divergent. Using a time interval of a month instead of a day for t countered this and resulted in more viable trajectories. Besides that, Coes is charged monthly for their energy costs, based on monthly rates. Now that we have the monthly prices, we find the logarithmic price changes for every month, compared to the previous month. So, if we want to calculate the price change of the market price for next month S_t compared to the market price of the current month S_0, we will divide S_t by S_0 and then take the natural logarithm of it:

$$LN(\frac{S_t}{S_0})$$

This way we create a new dataset consisting of the logarithmic price changes per month. If we calculate the mean of this dataset we get the monthly drift for the GBM. Similarly, if we calculate the standard deviation of the price changes we get the monthly volatility for the GBM. Lastly, the initial market price will be the average market price of January for either gas or electricity, depending on the dataset that is being analyzed. It is the initiating value and it will be the beginning of the trajectories. Having extracted volatility, drift and initial market price from the 3 datasets, the trajectories can be simulated. We will also do this in the file ‘Historical Energyprice Data’.

4.1.2 Simulating trajectories of the future energy prices

To start off, we will explain how we intend to predict the future energy prices. In the literature we already explained the theory behind the GBM. As stated before, the GBM needs some input values before it can generate trajectories. In the previous paragraph we explained how we extracted these input values from the historical data. Now we can combine all this knowledge to simulate the price trajectories. We take a quick look at the GBM formula again:

$$S_t = S_0 e^{\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \sigma W_t}$$

First S_0 is taken, this is the energy price of the previous month. This value is multiplied by Euler's number e. This number e is to the power of another formula: the drift μ minus the volatility μ squared and divided by 2. Then it is multiplied by Δt which in this case is 1 because the time intervals between t are a month and the time steps we take are also a month. Finally this is added to the volatility times the Wiener Process W_t. W_t is determined by drawing from a normal random variable. This random value will be the W_t value. Using this formula and the values that we already obtained we can calculate the energy price of one month dependent on the energy price of the previous month, because the volatility, drift and Δt stay constant. In the table below, the parameters used, can be found.

	Volatility	Drift
Peak Electricity	0.42	-0.00056
Base Electricity	0.28	-0.00062
Gas	0.32	-0.02

Figure 6: Values used for the volatility and drift

If we repeat this process for every month for the upcoming 2 years, it will result in 1 trajectory of the market price of either gas or electricity for 2 whole years. This means that one trajectory contains 24 datapoints. Then if we repeat this whole process for a 100 times, we get a 100 different trajectories of the market price for 2 years. We do this whole process for all 3 uncertain quantities: the gas market price, the peak electricity market price and the base electricity market price. We will end up with 3 different datasets, for every datatype one. Every dataset consists of 100 trajectories for the market price over the next 24 months, which means 100 x 24 = 2400 datapoints per set. In the figure below you can see a visualization of the 100 different trajectories for the simulated future electricity prices for the peak load.

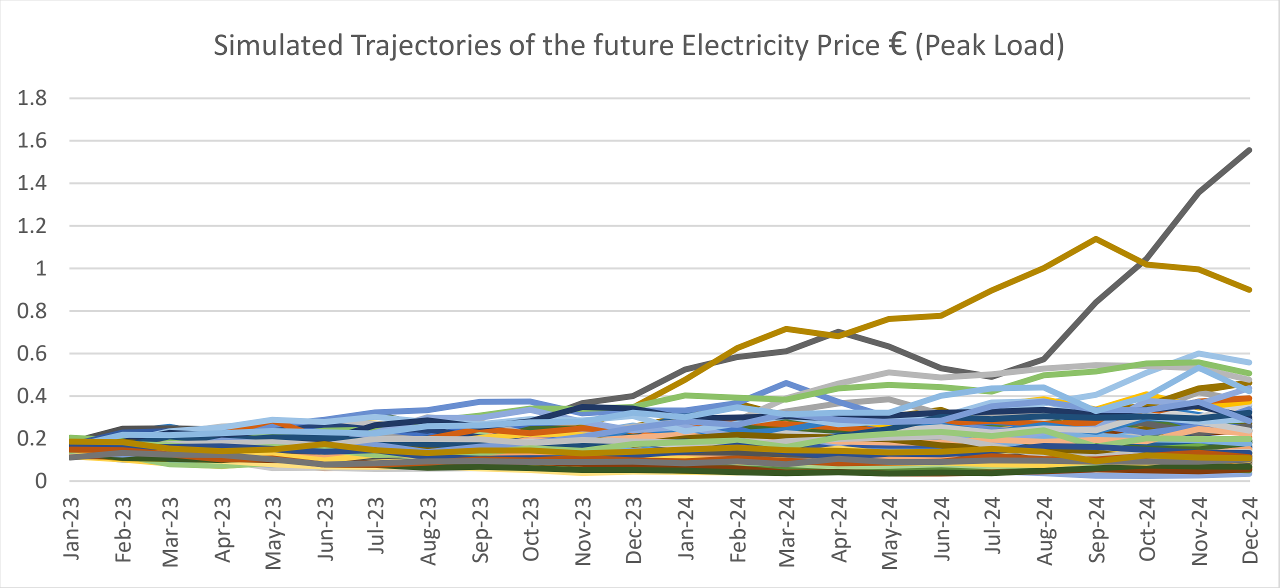


Figure 7: Graph of 100 simulated peak electricity trajectories

4.2 Making an Energy Profile Based on Historical Energy Consumption Data

As previously mentioned, the main goal of this research is to reduce the energy costs of Coes. We have already explained the role of the gas and electricity market prices in the future energy costs. But now we will try to cover the energy consumption of Coes. The energy consumption is dependent on the energy behavior of the company and it can be influenced or changed by actions or implementations of the company. In order to analyze the energy behavior of Coes, raw data was extracted from the smart trackers that Coes has installed and an energy profile will be created for the company. Based on this, future energy consumption scenarios can be simulated.

4.2.1 Treating the Raw Energy Consumption Data

Coes has taken the initiative to install smart trackers at the company that keep track of how much gas and electricity is used per time unit and when it is used. These smart trackers also track the amount of electricity that has been generated by the solar panels on the roof of the Coes facility and how much of that electricity is returned to the energy supplier Qwint. In an online application the recorded data can be found. Per category: electricity, gas and electricity returned can be found how much kWh or M^3 is used per time unit over the previous year.

We chose to use a time unit of an hour, so for each hour of the day for the entire previous year a datapoint was shown. This gave us a vector of 24 (hours) times 365 (days) = 8760 datapoints per data type. All of these datapoints where copied to excel and then arranged in an clear and comprehensible way in the 'Gas consumption Data' and Electricity Consumption Data' files.

4.2.2 Creating Energy Profiles for Coes

Now that a clear overview has been created for the energy consumption of Coes for a whole year, an energy profile can be designed for Coes. Based on this we can create possible future energy consumption scenarios. In talks with the Business manager of Coes it was confirmed that Coes stays open almost every day of the year. They work through all weekends and all holidays, although sometimes they are understaffed. This all is with one big exception: the Christmas break. During week 51, 52 and week 1 of the new year Coes is closed. The director of Coes explained that almost every day the energy use is the same throughout the day, this combined with our knowledge that Coes is open on weekends and holidays made the decision easy to create a daily energy profile instead of a weekly energy profile. But when assessing the data it became almost immediately clear that the energy consumption of Coes was also dependent on seasonality. For example the gas usage was very high in winter months and almost non-existent during the summer months. This is why it was decided to create a month-specific daily energy profile. So for every month a new profile would be created for ‘an average day in month x’. This would account for the fact that regarding energy consumption an average day in January would look completely different to an average day in August. These daily profiles are created by calculating the average energy usage at each hour of the day for the whole month.

There is only one exception. As previously mentioned, Coes is open throughout the whole year, except during the Christmas break then they are closed. So we take the days from weeks 51, 52 and week 1 out of the calculations for the daily profiles of December and January. This way, they won’t influence the daily profiles of these respective months. Using the same method, we create a daily energy consumption profile of the Christmas holiday in a 13th sheet. So now we end up with the daily profiles of every month of the year plus a daily profile for the Christmas holiday. All of these energy consumption profiles are created in the same manner for gas usage and electricity usage. In the figures below the energy profiles of January and August can be seen and compared with each other. These are also the average peak electricity consumptions of an average day in January and August respectively in 2022.

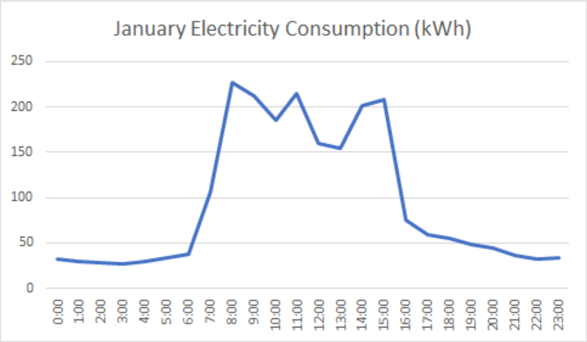


Figure 8: Average peak electricity consumption in January

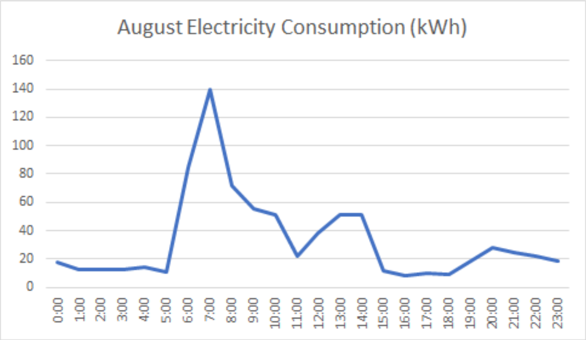


Figure 9: Average peak electricity consumption in August

4.2.3 Constructing Scenarios for the Future Energy Consumption of Coes

Now that we have created a daily energy consumption profile for every month for gas and electricity, we can try to construct different scenarios for future energy consumption. These future scenarios will all be based on the energy profiles that have been previously created and every energy profile will create data for one month. The idea is that every day of that month is based on the daily energy profile but with noise added to the values. So a random day in month x will be calculated by taking the energy profile of month x and adding noise to it, which is based on the data of month x.

We create new energy consumption scenarios by taking one datapoint of the daily profile of a particular month x and adding noise to it. After that, the next hour (datapoint) of the daily profile is taken and the cycle repeats. This way we construct one day of a future month. Putting this in a loop will give us a scenario of a whole month. Then if we take another daily profile of a different month, we can construct a scenario for the next month. Finally, if we do this for all the daily profiles, we get a possible future energy consumption scenario of a whole year.

The noise is added in the following way: we call the datapoint taken the average (Avg) and then we add the volatility times Z:

$$NewValue = Avg + (Volatility * 0.2) * Z * \Delta t$$

Z represents in this case the standard normal cumulative distribution function. It draws a random number from a standard normal distribution. In other words, it produces a random value that follows a normal distribution with a mean of 0 and a standard deviation of 1. It is multiplied by Δt the time steps taken. The volatility is the hourly volatility taken from the daily profiles, so Δt is equal to 1 because we also make timesteps of 1 hour. This means that the noise that we will be adding is independent.

The volatility is based on the standard deviation of the daily consumption profile used. But when taking the standard deviation, it was discovered that it was too high to use. Based on experimentation We settled on a factor of 0.2. This resulted in data that was not too similar to the energy profiles, but also not too random. This gave use overall a better and more realistic energy consumption scenario.

We again have to take into account the Christmas holiday when creating these scenarios. So when we simulate a scenario for either January or December using the daily energy profiles of these respective months, we simulate only the non-holiday days. The holiday days themselves are created using the exact same method but the only difference is that they are based on the daily energy consumption profile of the Christmas break. Doing this will give us better and more realistic scenarios.

Lastly, the total consumption per month will be calculated. Up until this point this whole method is used to predict gas usage and electricity usage. So scenarios for every energy form are created in the same way, using the same method. Now the only thing left to do is calculate the total energy consumption per month. For gas it is easy, all the created datapoints of one month are summed up and this will be the total energy consumption of that month in M^3. For electricity we have to deal with peak and base hours. Qwint says on their website that their peak hours are between 7:00 and 23:00 meaning that their base hours are between 23:00 and 7:00. We calculate the total peak hour electricity by only summing up the rows of the hours between 23:00 and 7:00 and in the same manner we sum up the rows of the peak hours.

Resulting from this we have one trajectory for each datatype (gas, peak electricity and base electricity). Each trajectory consists of 24 points, the energy consumption of that specific datatype per month for 2 years. Both years are calculated in the same way using the same daily energy profile per month. As mentioned, this is only one trajectory of the energy consumption of 2 years. We repeat this process also for a 100 times, creating 100 trajectories per data type. Which means that we get 100 x 24 = 2400 datapoints per dataset.

4.3 Combining the Energy Consumption Data with the Energy Price Data

For the 3 datatypes: Peak electricity, Base electricity and Gas, we have per data type a dataset for the energy consumption and the energy market price. We will combine and multiply the trajectories of these datasets to calculate the total energy costs that Coes will have to pay per month.

4.3.1 The Gas Data

All of the following calculations will be done in the ‘Combining Consumption and Price Data’ file. We start off with the gas consumption data set that the research has created. It is a dataset consisting of 100 trajectories of the gas consumption per month over the upcoming 2 years. This means that it has 100 (trajectories) x 24 (months) = 2400 different datapoints of what the gas consumption will be in total per month. This will be in M^3 per month. We combine this with the gas market price dataset that has been created. This dataset consists also of 100 trajectories of what the gas market price will do per month over the upcoming 2 years. This also gives us a 100 (trajectories) x 24 (months) = 2400 datapoints. This market price is the price in € per M^3.

In the conversation with Qwint, the energy supplier mentioned that they charge the gas costs monthly, and only after the whole month is over. This means that they know how much to charge, because they know how much gas Coes has consumed in the previous month. The gas market price that they use is an average of the values that the gas market price has taken on during that month. This works great with the simulated trajectories that we have, because they are also monthly market prices. Furthermore, Qwint also charges extra costs for the delivery of the gas, extra energy taxes and BTW. BTW is the Dutch version of VAT (Value-Added Tax), which is the payable on sales og goods or services within countries that are member states of the EU. The overview of these extra costs can be found in the figure below:

Extra Costs	Value	Unit
Gas Delivery Costs	0.03	€/M3
Energy Taxes Bracket 2	0.36322	€/M3
ODE Taxes Bracket 2	0.0865	€/M3
Standing Fee	6.99	€/Month
BTW normally	21%	
BTW between 1 July and 31 december 2022	9%	

Figure 10: Additional gas costs added by Qwint to the market price

The gas delivery costs, energy taxes and ODE taxes are added on top of the average gas market price per M^3 for every datapoint because these costs are also charged per M^3. Then this fee is multiplied by the energy consumption of that particular month (using the gas consumption data). Afterwards, a standard fee of €6.99 is added on top of these costs (monthly costs charged by Qwint). And finally the BTW over this summation of costs is calculated and added. This will be the monthly total costs charged at Coes for gas. This is an example of 1 trajectory of the gas consumption data, times 1 trajectory of the gas market prices. But as mentioned before we have 100 trajectories for each dataset so in the end we get 100 (gas consumption trajectories) x 100 (gas price trajectories) = 10000 monthly gas cost trajectories, each consisting of 24 months. This will give us 24 x 10000 = 240000 different datapoints. Finally we take the average per month over all the trajectories to give us a final 'prediction' of what the gas costs of Coes will be over the next 2 years if the situation is kept the same and no implementations are made. In the figures below you can find the resulting expected gas costs per month. In the graph, there has been included a 90% confidence band around the average.

Month	Monthly Average Gas Costs (€)
Jan-23	15,268.44
Feb-23	19,403.42
Mar-23	17,434.13
Apr-23	9,133.53
May-23	951.29
Jun-23	414.52
Jul-23	98.35
Aug-23	17.88
Sep-23	1,187.47
Oct-23	1,040.93
Nov-23	7,950.97
Dec-23	13,469.79
Jan-24	16,912.79
Feb-24	20,677.32
Mar-24	19,570.65
Apr-24	10,666.55
May-24	1,139.39

Jun-24	514.54
Jul-24	120.33
Aug-24	20.43
Sep-24	1,519.78
Oct-24	1,410.62
Nov-24	11,426.72
Dec-24	17,845.31

Figure 11: Table of the simulated monthly average gas costs in the current situation

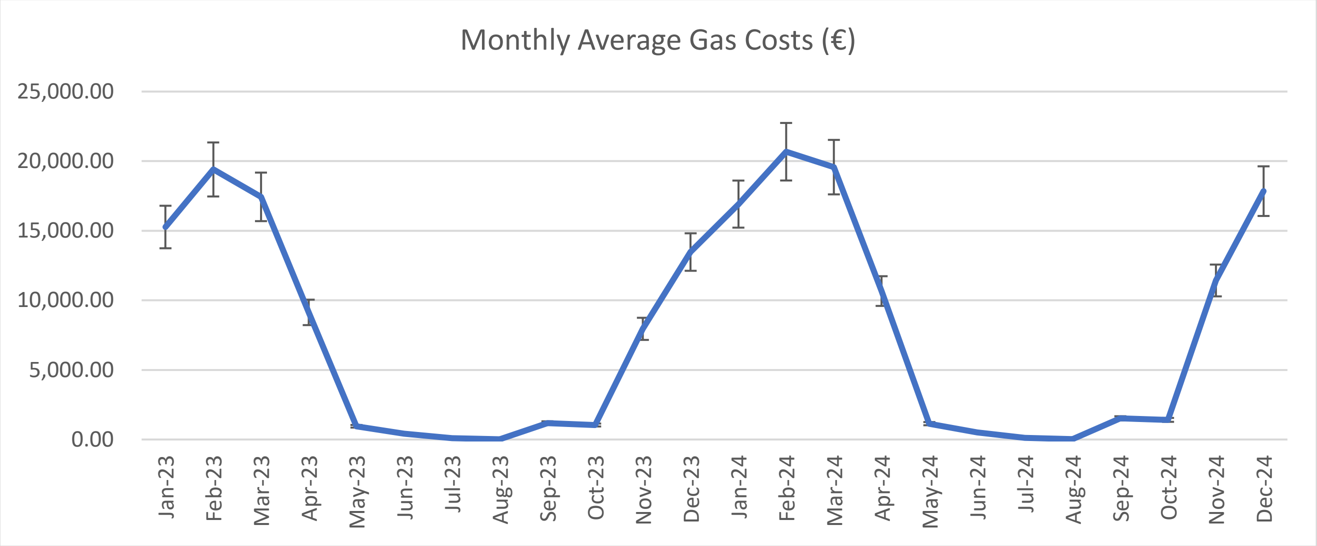


Figure 12: Graph of the simulated monthly average gas costs in the current situation

4.3.2 The Electricity Data

Again, all of the following calculations will be done in the ‘Combining Consumption and Price Data’ file. Following, we have the electricity consumption data sets that the research has also created. These are 2 datasets consisting of 100 trajectories of the electricity consumption per month over the upcoming 2 years. One data set is for the electricity consumption during peak hours and one is for the electricity consumption during base hours. Each set has 100 (trajectories) x 24 (months) = 2400 different datapoints of what the base and peak electricity consumption will be in total per month. This will be in kWh per month. We combine this with the electricity market price datasets that has been created. These 2 datasets consists each of 100 trajectories of what either the base or the peak electricity market prices will do per month over the upcoming 2 years. This also gives us for each set 100 (trajectories) x 24 (months) = 2400 datapoints. This market price is the price in € per kWh.

Qwint charges just like with the gas prices, extra costs afterwards and uses monthly market price averages to base their electricity price on. The overview of these extra costs for electricity are in the figure below:

Extra Costs	Value	Unit
Cost Reduction	0.006	€/kWh
Energy Taxes Bracket 3	0.01189	€/kWh
ODE Taxes Bracket 3	0.0229	€/kWh
Standing Fee	6.99	€/kWh
BTW normally	21%	
BTW between 1 July and 31 december 2022	9%	

Figure 13: Additional electricity costs added by Qwint to the market price

The cost reduction, energy taxes and ODE taxes are again added to the market prices of both the base and peak electricity. Then the new peak electricity price of a particular month is multiplied by the monthly peak electricity consumption of that month and in the same way the new base electricity price is multiplied by the base monthly energy consumption. These two values are added together to get the total electricity costs for that month. On top of these costs the standing fee of €6.99 is added and again the BTW over this summation of costs is calculated and added. This will be the monthly total costs charged at Coes for base and peak electricity. This is done for each month and just like with the gas it is done for the 100 trajectories of electricity consumption (peak and base hours) and for the 100 trajectories of the electricity market price (peak and base). This gives us 2 datasets of 100 x 100 x 24 = 240000 datapoints. The averages are calculated per month just like with the gas and then we have a final 'prediction' of the total electricity costs that Coes will have for the upcoming 2 years.

4.3.3 The Solar Generated Electricity Data

The big difference between the gas costs and the electricity costs, is that Coes itself generates electricity. The electricity that they generate is first used for their own demand and then sent back to Qwint at a lower fee. The money that they make doing this is subtracted from their electricity bill. So we will also try to replicate this process in the simulation. The Smart Trackers that we previously discussed also keep track of the amount of electricity generated by Coes. Besides that they keep track of the amount of electricity Coes sends back to Qwint. This what we will be using. In the file 'Generated Electricity Return Data' we arranged last year's data from the Smart Trackers in a similar fashion to how we arranged the raw electricity and gas consumption data. We decided to use this deterministic data as the electricity that will be send back by Coes to Qwint in the upcoming years. We did this because generated solar energy is very dependent on the weather and predicting the weather would be a very complex task. This means that historical data is directly used as input for the future expected production scenarios.

Now that we know how much electricity we expect to send back in the following years, we can focus on the price for which we sell it back to the energy supplier. Qwint does not have a fixed rate for which generated electricity can be sold back to them. They let the fee depend on the market price of that particular month. Looking at different invoices that Coes received We could estimate that, for both peak and base electricity, the market price was multiplied by 0.6. This was the fee that Coes would receive for the generated electricity. Now that we know how much electricity was sent back each month to Qwint and for how much money per kWh, we know how much money will be subtracted each month from the original total electricity costs. We implemented this in the 'Combining Consumption and Price Data' to get the net total electricity costs per month. The results can be found in the figure below. In this figure the generated solar electricity is already subtracted from the gas costs. Also in this graph, there has been included a 90% confidence band around the average.

Month	Monthly Average Peak Electricity Costs (€)	Monthly Average Base Electricity Costs (€)	Total Average Monthly Electricity Costs (€)
Jan-23	9741.25	1580.84	11329.08
Feb-23	13168.43	2228.72	15404.14
Mar-23	9936.93	2762.55	12706.47
Apr-23	3210.26	2081.38	5298.62
May-23	587.12	1198.02	1792.13
Jun-23	1473.83	1363.62	2844.44
Jul-23	2101.15	1365.78	3473.92
Aug-23	2889.31	1432.60	4328.90
Sep-23	8345.80	1919.00	10271.79
Oct-23	10324.73	2097.17	12428.90
Nov-23	14821.99	2221.56	17050.54
Dec-23	7116.36	1557.53	8680.88
Jan-24	10832.54	1700.43	12539.96
Feb-24	14526.31	2352.86	16886.16

Mar-24	11012.74	2916.43	13936.16
Apr-24	3470.66	2153.26	5630.91
May-24	515.51	1270.51	1793.00
Jun-24	1531.98	1432.58	2971.55
Jul-24	2260.77	1431.90	3699.66
Aug-24	3374.04	1505.38	4886.41
Sep-24	9985.08	2008.78	12000.86
Oct-24	12790.32	2159.40	14956.71
Nov-24	18402.15	2366.91	20776.05
Dec-24	8747.75	1616.31	10371.05

Figure 14: Table of the simulated monthly average electricity costs in the current situation

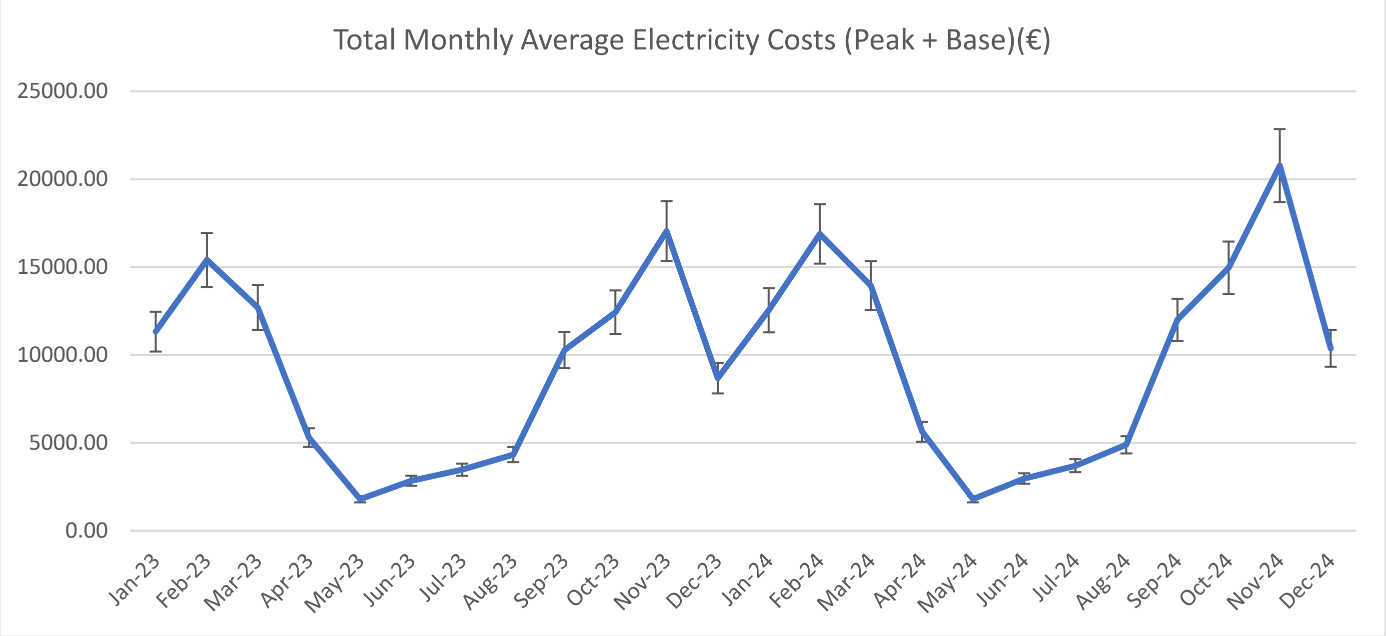


Figure 15: Graph of the simulated monthly average electricity costs in the current situation (peak + base)

5 Implementation of a Battery Energy Storage System

5.1 Introduction

Implementing a Battery Energy Storage System (BESS) is a very expensive investment. So, it would be wise to make a prediction if it would be a viable option for Coes. There are many decisions involved, if Coes wants to implement a battery. Depending on the way they operate it, their energy consumption and thus energy costs will be influenced. For example, when the solar panels generate electricity, you can use it for your own demand, sell it to Qwint, or store it in the battery. Same story with the energy supplier Qwint, Coes can buy electricity from them for their own demand or buy electricity in advance and store it in the battery for later use. These are all decisions or problems that have some form of uncertainty involved. We can define such a decision making problem as a dynamic stochastic optimization problem. An overview of the decisions involved in operating a BESS can be found in the figure below.

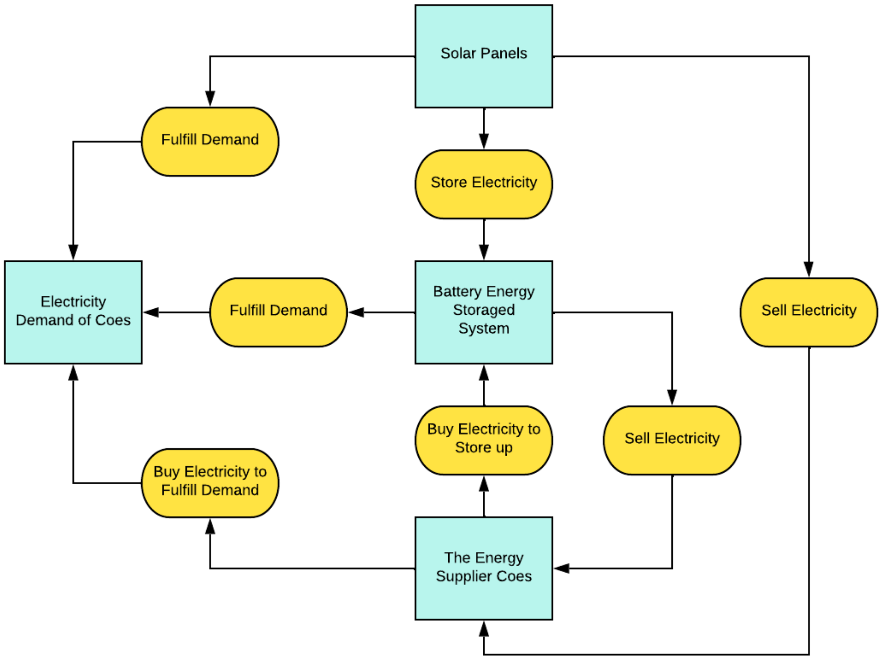


Figure 16: Depiction of the decisions involved in operating a BESS

5.2 Markov Decision Process

5.2.1 Definition

We will describe our dynamic stochastic optimization problem as a Markov Decision Process. A Markov decision process (MDP) is a mathematical framework for modeling decision making in situations where outcomes are partly random (exogenous) and partly under the control of a decision maker (endogenous) (Jagtap, R. 2022) and where you have to make sequential decisions over time. In the case of Coes, we have control over how to operate the storage and on when to buy and sell electricity from the market. So we have influence on the storage level of the battery. The outcomes that we cannot control is the price for which we buy and sell the electricity. MDPs are useful for studying optimization problems solved via dynamic programming. In an MDP, a decision maker interacts with an environment that is modeled as a Markov process. The decision maker receives rewards according to a reward function that depends on the current state and action taken. As mentioned before, the goal of the decision maker is to find a policy that maximizes the expected sum of rewards over time. In the case of Coes, we will try to minimize the total amount of energy costs that they have.

5.2.2 Description of the Markov Decision Process of Coes

The MDP consists of different stages. These are points in time when the environment is in a particular state and the decision maker can make decisions based on this. These states can be divided into two categories: the endogenous and exogenous states. The exogenous states are the states, which are random and cannot be influenced by the decision maker. The endogenous states are (partly) under the control of the decision maker and can be influenced. The MDP finds itself in different (endo- and exogenous) states dependent on the stage and the decisions made at the previous stage. Based on the states and stages, decisions are made. In the end these decisions made and the uncertainty in the MDP, determine what the states will be in the next stage of the MDP. We used 'Operations Research' (Wayne L. Winston, 2003) to describe the MDP of Coes, which can be found below:

Stages: $i \in I = \{0, 1, \ldots, I-1, I\}$
Every stage is 1 hour, with horizon I

States:
Endogenous state component: $s_i \in S_i$

- Where s_i is the storage level of the battery: $s_i \in [0, S]$
- S is the maximum capacity of the battery

Exogenous state component: $w_i \in W_i$

- Where w_i is the electricity price divided into 2 separate components:
  - PP_i is the price for which electricity can be bought from the energy supplier at peak hours
  - PB_i is the price for which electricity can be bought from the energy supplier at base hours
  - QP_i is the price for which electricity can be sold back to the energy supplier at peak hours
  - QB_i is the price for which electricity can be sold back to the energy supplier at base hours

Full MDP state: $(s_i, w_i) \in S_i$ x W_i = $(S_i, PP_i, PB_i, QP_i, QB_i)$

Actions: $a_i \in A_i(S_i)$

- Either:
  - Charge battery: buy electricity from the energy supplier
  - Charge battery: store electricity generated by the solar panels
  - Discharge battery: sell electricity back to energy supplier
  - Discharge battery: in order to fulfill the demand

$a_i \in A_i(S_i) = [SR^c, PR^c, SR^D, DR^D]$

- SR^c = Amount of electricity to charge the battery with from the supplier
- PR^c = Amount of electricity to charge the battery with from solar panels
  - $SR^c \in [0, S - s_i]$
  - $PR^c \in [0, S - s_i]$
- SR^D = Amount of electricity to discharge the battery with to the supplier
- DR^D = Amount of electricity to discharge the battery with to meet demand
  - $SR^D \in [0, s_i]$
  - $DR^D \in [0, s_i]$
- η^R = the round-trip efficiency of the battery

Discount factor = δ , where $0 < \delta \leq 1$

Reward: for taking action a_i at stage i

R(s_i, w_i, a_i) $= (PP_i * SR^c - PB_i * SR^c)/\eta^R + (QP_i * SR^D - QB_i * SR^D) * \eta^R$ (Also called the immediate reward)

At a given stage and state (i, s_i, w_i) ∈ I x S_i x W_i we take an action $a_i \in A_i (S_i)$

This gives us:

- A transition to the new state $s_{i+1} = f_i(s_i, a_i) \in S_{i+1}$

Where $f_i(s_i, a_i) = s_i + a_i * \eta^R$

Policy = π = a collection of actions to take, dependent on the states of the system

$\pi = \{Z_i(.,.) : S_i \text{ x } W_i \rightarrow A_i, i \in I\} \in \Pi$

- Where Π is a set of possible policies

The goal is to find the policy that maximizes the expected discounted cumulative reward:

$$\max_{\pi \in \Pi} E[\sum_{i \in I} \delta^i \, r_i\big(s_i^\pi, w_i, z_i^\pi(s_i^\pi, w_i)\big) + \delta^I \, r_I(s_I^\pi, w_I) \ |(s_0, w_0)]$$

5.2.3 Assumptions in the MDP

We will make a couple of assumptions to make the model less complex:

- All of the solar generated electricity is first used to satisfy the demand of Coes, after that it is stored in the battery. If demand is fulfilled and the battery is full, the electricity is sold back to Qwint.
- The electricity demand of Coes will always first be supplied by the solar panels. If they cannot provide the needed electricity, the battery will provide it. Only if the battery is empty, electricity will be bought from the supplier.
- To make the problem a little less complex, We assume that the battery, regardless of its capacity, can be filled up within an hour. This will make the simulation also less realistic, because in real life dependent on the capacity, it will take 3-4 hours to fill the battery.

There are also a couple of unknown values in the MDP that we can now assign a value to. In a phone conversation with Big Ass Battery (BAB), a company that supplies and installs battery systems of different formats a lot of battery related parameters were filled in. We will use the values of their battery system in this research.

- The cycle efficiency of the battery (charging and discharging efficiency together) is between the 90% and 95%. We will use a value of 92.5% in the MDP and simulation.
- The daily electricity loss of the battery is around 6 kWh per day.
- The standard battery that they install has a capacity of 400 kWh, for a price of €466.666,-
- The battery capacity can be upscaled and downscaled by 200 kWh per step up to 800 kWh. An upscale of 200 kWh costs an additional €100.000,-. This means automatically that a downscale of 200 kWh costs €100.000,- less.

5.2.4 Solution to the MDP

A dynamic stochastic optimization problem could be solved using dynamic programming. But in the case of a Markov Decision Process, we have to deal with a continuous exogenous state. This makes it intractable to solve it that way. We chose to not find a policy using this method, because it would make the implementation of the policy harder. Besides that it would make operating the battery also more complex for Coes. What we will be doing is finding simple heuristics that can be used to easily operate the battery storage. A heuristic can be seen as a simple rule-of-thumb strategy that helps improving the operationalization of an optimization problem. As we mentioned before, a battery gives us the flexibility to choose when to buy or to sell electricity. We know that electricity is more expensive during peak hours, for both selling and buying electricity. So we will make use of that. We will try to buy electricity during base hours, so we can use it during peak hours. The heuristic that we will implement is as follows:

"We will fill the battery up to the maximum capacity during base hours at 6:00 in the morning each day."

From the historical electricity data we can derive that each morning there is a peak in electricity demand, to startup all of the machines. If we fill the battery up in advance during base hours, all of the electricity needed can be provided at a base electricity price instead of at the peak price. This is because the peak hours of Qwint start at 7:00 in the morning. The battery will only be used to fulfill the demand of Coes. This means that the battery will not always be emptied during the day. So the battery will not be used for trading electricity. Electricity is only sold back to the supplier if the battery has reached its maximum capacity.

5.3 Simulating the BESS and Heuristic

5.3.1 Simulating the New Energy Costs

If we want to discover the effects of a battery system on the electricity costs, we first have to find out what this implementation does to the electricity behavior. The fundamental calculations, of turning the monthly energy profiles into trajectories for the energy consumption, stay the same. So, we only have to implement the parameters of the battery storage and the heuristic. In accordance to the MDP we implemented the logic, the parameters and all of the assumptions that we made in the previous paragraph. For each hour of the day the battery storage level is checked, demand is subtracted from this level and generated solar energy is added to the storage level. The first battery capacity that we will be using is 400 kWh. In the figure below, a graph can be found, which describes the behavior of the battery by showing the storage level during an average day in March. It can be seen that ,for example, at 6 o'clock in the morning the battery is filled till the max capacity, but that the demand during that hour is also already subtracted from it.

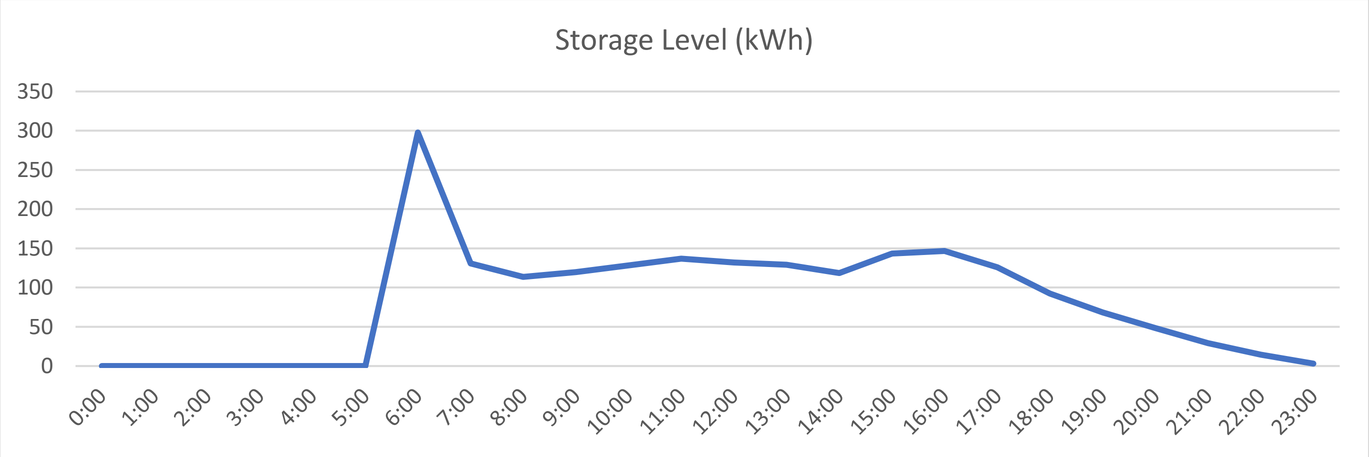


Figure 17: Graph of the storage level during an average day in march in kWh

We also installed trackers, that will keep track of how much energy still needs to be bought at what time of the day (electricity is bought when storage level is 0), how much solar energy is returned to Qwint (electricity is sold when the maximum capacity has been reached) and of course how much electricity is bought at the beginning of each day (the implemented heuristic). This is then formatted in the same way as in the original file. So we get a table with 100 trajectories of the peak electricity consumption, the base electricity consumption and the solar electricity generated.

We inserted this data in the ‘Combining Consumption and Price Data after Implementation’ file. This file uses the exact same logic as the original ‘Combining Consumption and Price Data’ file, only now it calculates the energy costs for the new situation. The results can be found in the figure below. The graph also contains the trend line of total electricity costs of the old situation for comparison. Both lines also have a 90% confidence band around the average.

Month	Monthly Average Peak Electricity Costs (€)	Monthly Average Base Electricity Costs (€)	Total Average Monthly Electricity Costs (€)
Jan-23	8777.72	3243.71	12028.41
Feb-23	10415.31	4414.97	14837.26
Mar-23	6210.67	4614.47	10832.13
Apr-23	825.76	3642.30	4475.05
May-23	-1201.12	1841.35	647.22
Jun-23	1238.35	2785.43	4030.77
Jul-23	938.91	3016.52	3962.42
Aug-23	1131.30	3067.34	4205.63
Sep-23	5716.07	3784.59	9507.65
Oct-23	8369.44	4247.62	12624.05
Nov-23	14078.75	4301.20	18386.93
Dec-23	5371.94	3175.62	8554.55

Figure 18: Table of the simulated monthly average electricity costs when a BESS with a capacity of 400 kWh is implemented

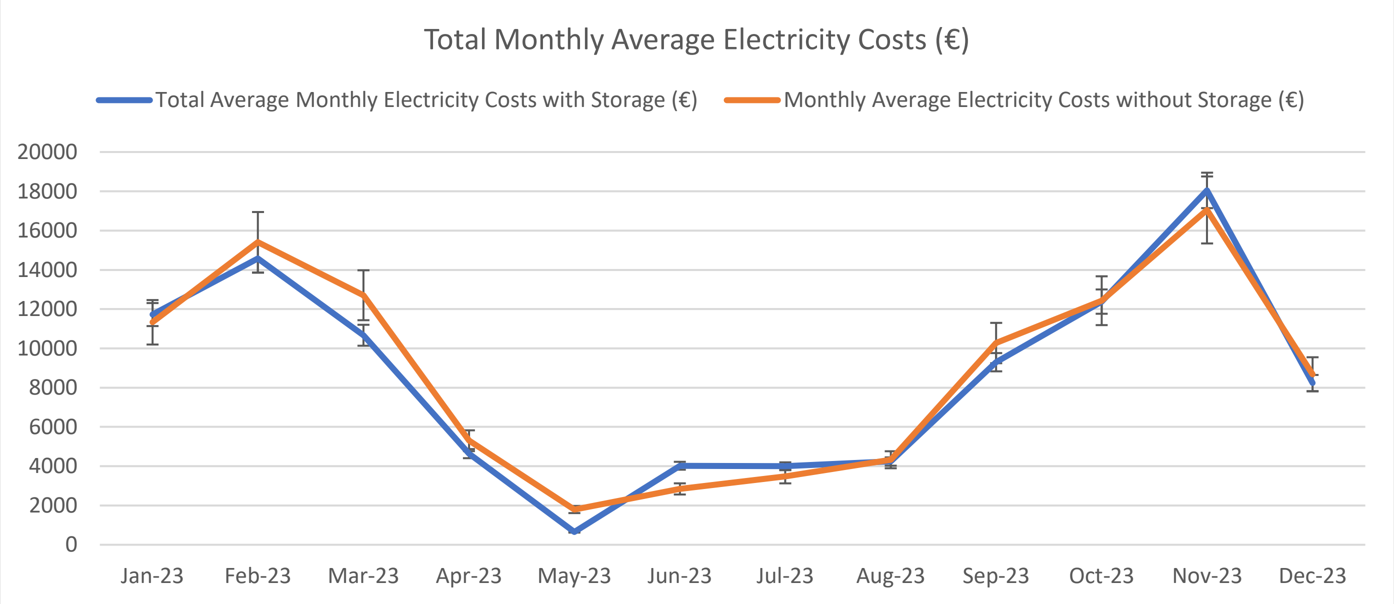


Figure 19: Graph of the simulated monthly average electricity costs when a BESS with a capacity of 400 kWh is implemented compared to no implementation

5.3.2 Comparing the new situation with the current Situation

Now we will start looking for differences between the old situation and the simulated new simulation. This way we try to find out how the battery storage system and the heuristic affect the energy behavior of Coes. We can also analyze if it gets us the intended results. First off all, we take a look at the 2 tables below. Here we have depicted the monthly peak and base electricity consumption for the current situation, against the consumption of the new situation (using a battery with a capacity of 400 kWh). Due to our policy, Coes will fill up the battery with electricity, every morning during base hours. This causes the total amount of electricity bought during base hours to increase significantly, as can be seen in the second table. We can confirm that in this case the policy gets us the desired result, because the total amount of monthly peak electricity bought by Coes decreases significantly, as can be seen in the first table.

Month	Peak Electricity bought without Storage (kWh)	Peak Electricity bought with Storage (kWh)
Jan-23	43606.31	27607.54
Feb-23	60701.07	33564.12
Mar-23	58745.64	30190.98
Apr-23	31998.54	8759.65
May-23	20812.09	4288.33
Jun-23	24050.62	13721.63
Jul-23	27411.55	11824.96
Aug-23	21080.70	5224.49
Sep-23	39609.79	14001.48
Oct-23	44359.99	22239.17
Nov-23	60744.73	44787.57
Dec-23	29527.84	12527.19

Figure 20: Table of the total monthly peak electricity consumption in the new (400 kWh battery) and current situation

Month	Base Electricity bought without Storage (kWh)	Base Electricity bought with Storage (kWh)
Jan-23	7623.24	25547.80
Feb-23	10589.30	32189.23
Mar-23	13273.40	21873.28
Apr-23	10454.36	21189.31
May-23	6563.43	9683.19
Jun-23	6896.63	14238.86
Jul-23	6587.72	15890.03
Aug-23	6729.24	18124.68
Sep-23	8892.29	27965.52
Oct-23	9456.27	31585.56
Nov-23	10166.14	31984.94
Dec-23	6994.86	23636.36

Figure 21: Table of the total monthly base electricity consumption in the new (400 kWh battery) and current situation

Moving on, one of Coes their biggest struggles was, that they would generate electricity without being able to use it themselves. This meant that they had to send it back to the supplier against a lower fee. This was one of the main reasons, we suggested to invest in a battery system. In the table below we find the total amount of electricity returned to the electricity supplier in the current situation, against the new situation (with a 400 kWh battery). The less electricity we send back to the supplier, the better. As can be seen in the table, the amount of electricity returned in the new situation (with a battery), is significantly less than in the current situation. This means that the storage system affects this type of behavior in a very positive way. During the spring and summer months, there is still a large amount of electricity returned. But the situation has improved, which is the most important takeaway.

Month	Electricity returned to supplier without storage (kWh)	Electricity returned to supplier with storage (kWh)
Jan-23	3718.65	0
Feb-23	10809	328.11
Mar-23	41606	8942.3
Apr-23	48275	19835
May-23	49155	24748
Jun-23	46720	23387
Jul-23	47626	22574
Aug-23	22358	7927.4
Sep-23	11264	910.44
Oct-23	3871.4	0
Nov-23	1703.5	328.11
Dec-23	2869.1	538.71

Figure 22: Table of the monthly amount of electricity returned to Qwint in the new (400 kWh battery) and current situation

In the figure below the monthly amount of money saved when a battery with a capacity of 400 kWh is implemented, can be found.

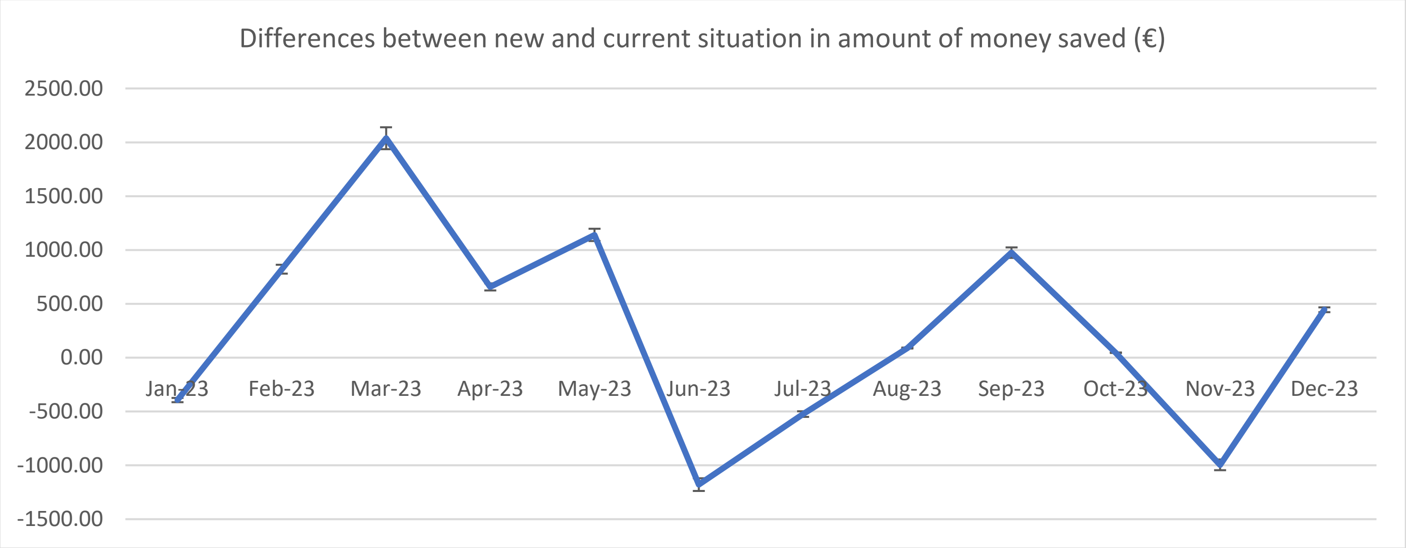


Figure 23: Graph of the simulated monthly average electricity costs saved when a BESS with a capacity of 400 kWh is implemented

In the months January, June, July and November Coes is expected to pay more money for electricity then is expected, when no battery is installed. In the other months, Coes will save money compared to the current situation. This is an unexpected trend, which contradicts the goal of the implementation.

If we sum up the electricity costs of each month, we get the total electricity costs that Coes will have to pay next year if a battery is implemented. If we compare those costs with the total electricity cost next year without any implementations, we get the following result:

Total Electricity Costs of 1 Year without battery (€):	105609.81
Total Electricity Costs of 1 Year with battery (€):	104092.07
Total amount of money saved in 1 year (€):	1517.74
Improvement percentage compared to current situation:	1.44%

Figure 24: Amount and percentage of money saved when we implement a battery with 400 kWh capacity

Now, it is important for Coes to know if implementing a battery system is financially viable. The best way to do this, is to look into the break-even point. This is the point in time, when the total amount of saved money is equal to the initial investment costs. We will calculate this using the Discounted Cash-Flow Analysis that we described earlier. We implemented in the 'Combining Consumption and Price Data after Implementation' file the formula of the Net Present Value, which can be found in section 3.2.2.

We will use a discount rate of 1.2% like we explained. The initial investment costs of a battery with a capacity of 400 kWh were €466.000,-. The cashflow in the first year will be the €1517,74 (1.44% of the initial investment) that we will save in the first year. The cash-flow will also remain constant for each year. This is because we assume that the amount of money saved, will stay relatively the same throughout the years. Our goal is to calculate the point in time t for which the NPV > the initial investment costs. At this point in time the initial investment will be earned back. The results can be found in the table below:

Years	Present Value of the Cash Flow per Year	Net Present Value per Year
0	1517.74	1517.74
1	1499.74	3017.47
2	1481.96	4499.43
3	1464.38	5963.81
4	1447.02	7410.83
5	1429.86	8840.69
6	1412.91	10253.60
7	1396.15	11649.75
8	1379.60	13029.35
9	1363.24	14392.58
10	1347.07	15739.66
…	…	…
20	1195.60	28362.38

Figure 25: NPV calculated over the life time span of a battery with 400 kWh capacity

In the information that we received from 'Big Ass Battery' it was stated that the life time of the battery is 15 to 20 years. We can conclude from the table that after 20 years we have only saved €28.362,38, which is by far not enough to break-even. This means that the investment will not pay itself back if we invest in a battery with a capacity of 400 kWh.

5.3.3 Implementing a Battery with a Capacity of 200 kWh

The results of implementing a battery with a capacity of 200 kWh can be found in appendix A. All of the input values stay the same, except the implementation costs. The initial investment becomes €366.000,-. Figure 36 depicts the electricity costs and also contains the trend line of the total electricity costs of the old situation for comparison. Both lines also have a 90% confidence band around the average. In figure 37 the monthly savings can be found. Just like with the 400 kWh battery in January, June, July and November the savings are negative, which means that the electricity costs have gone up compared to the old situation.

We can conclude from figure 39 that after 20 years we have only saved €9.176,54, which is by far not enough to break-even. This means that the investment will not pay itself back if we invest in a battery with a capacity of 200 kWh. Compared to the investment in a 400 kWh battery, the improvement percentage compared to the current situation has gone down to 0.46%. This means that in the first year only 0.46% of the initial investment is earned back.

5.3.4 Implementing a Battery with a Capacity of 600 kWh

The results of implementing a battery with a capacity of 600 kWh can be found in appendix. Again, all of the input values stay the same, except the implementation costs. The initial investment becomes €566.000,- in this case. In figure 42 the monthly savings can be found. Just like with the 200 kWh and the 400 kWh batteries, in January, June, July and November the savings are negative, which means that the electricity costs have gone up compared to the old situation.

We can conclude from figure 44 that after 20 years we have only saved €47.904,09, which is also by far not enough to break-even. This means that the investment will not pay itself back if we invest in a battery with a capacity of 600 kWh. Compared to the investment in a 400 kWh battery, the improvement percentage compared to the current situation has gone up to 2.43%. This is the best improvement percentage thus far.

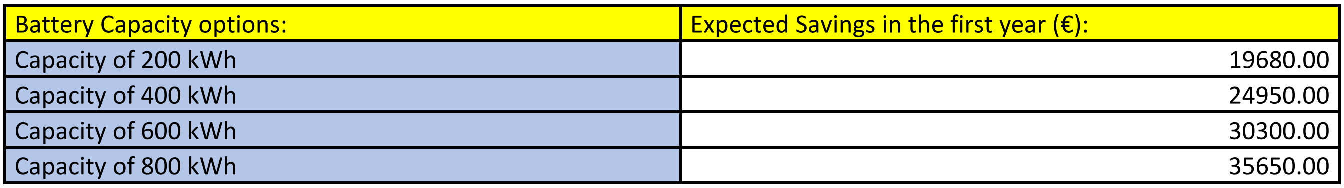
5.3.5 Implementing a Battery with a Capacity of 800 kWh

Lastly, the results of implementing a battery with a capacity of 800 kWh can be found in appendix C. Again, all of the input values stay the same, except the implementation costs. The initial investment becomes €666.000,- in this case. In figure 47 the monthly savings can be found. Just like with the 200, 400 and 600 kWh batteries, in January, June, July and November the savings are negative, which means that the electricity costs have gone up compared to the old situation.

Again we can conclude from figure 49 that after 20 years we have only saved €58.296,00, which is sadly, also by far not enough to break-even. This means that the investment will not pay itself back if we invest in a battery with a capacity of 800 kWh. Compared to the investments in other battery capacities, the improvement percentage compared to the current situation has gone up to 2.95%. This means that it seems that the improvement percentage goes up if the battery capacity is increased. But this is still not enough to get to a break-even point. Besides that the initial investment also becomes a lot bigger, meaning that Coes needs a lot more capital to buy such a battery.

5.3.6 Break-even of the Implementation

We determined that with all of the available capacity options, the battery will not pay itself back. So we will try to find out how we can break-even. In order to break even the Net Present Value must become larger than the initial investment. This will have to happen within 20 years, because that is the life span of the battery. This means that a battery with a capacity of 200 kWh has to save €366.000 within in 20 years. A battery with 400 kWh capacity has to save €466.000 within 20 years and so forth. Using this information we determined the cash flows that each capacity must have within the first year, so that the investment can pay itself back:



Battery Capacity options:	Expected Savings in the first year (€):
Capacity of 200 kWh	19680.00
Capacity of 400 kWh	24950.00
Capacity of 600 kWh	30300.00
Capacity of 800 kWh	35650.00

Figure 26: Battery capacities and the needed cash-flows in order to break-even

As can be seen, with increasing battery capacity, the needed cash flow in the first year increases. This is logical because the initial investment also becomes larger. But as we have already determined, with a bigger battery capacity, more money is saved per year. All of these cash-flows are a lot bigger than the expected cash flows that we simulated. Although the implemented policy is not effective, these needed cash-flows are too large and it will be very hard to save this amount of money in the first year after implementation. So we will take a look at how much the initial implementation costs must go down to be able to break-even within 20 years after the investment (using the implemented policy). As can be seen in the table below, the cost reduction for al capacities must go down by more than 90%. The larger the capacity of the battery is, the less the battery costs must be reduced. But the percentual cost reduction between the 600 and 800 kWh batteries is almost insignificant.

Battery Capacity options:	Percentage of Battery costs reduction to make investment profitable (%)
Capacity of 200 kWh	97.49
Capacity of 400 kWh	93.91
Capacity of 600 kWh	91.53
Capacity of 800 kWh	91.24

Figure 27: Battery capacities and the needed maximum initial investment in order to break-even

6 Implementation of a Thermal Wheel

6.1 Introduction

We already explained the function of a thermal wheel and how it could help decrease the gas consumption, thus the gas cost of Coes. We gathered information on the implementation of thermal wheels with the help of ‘Energie Partners’ a Dutch company that collaborates with companies and advises them on how to save energy. The information that they provided helped me in setting up a simulation that could make trajectories for the gas costs if Coes would implement thermal wheels. Beforehand, they already told me that the investment would be very costly and that it would be very hard to earn back. They also confirmed that the gas heaters are already quite old and would not last long enough to make the implementation worth it. We will still simulate how the thermal wheels would change the gas consumption and gas costs. If the conclusion of ‘Energie Partners’ is confirmed, we will still be able to explain why this is the case. If the simulation indicates otherwise, we can try to find out why there are opposing results and if it could still be profitable to install a thermal wheel.

6.2 Simulating the Implementation of a Thermal Wheel

6.2.1 Simulating the New Gas Costs

Our goal is to find out if implementing a thermal wheel would be financially viable for Coes. The thermal wheel will be used in the gas heaters, so the implementation will affect the gas usage and gas costs. That is why we will reuse the ‘PredictGasConsumption’ file and turn it into the ThermalWheelSimulation’ file. We will make use of the same logic used to simulate trajectories of the future gas behavior.

The gas heaters are not turned on all the time. They are not used in the summer and they are also turned off for the larger part of spring and autumn. Coes told me that the heaters are only used from October until April. Looking at the historical gas data we confirmed this but also established that they are also turned off during October. The gas heaters are also not in use for a big part of the day. They are turned on around 4 o’clock in the afternoon and are turned off around 4 o’clock in the morning. So their running time on average is 12 hours per day. The gas usage of the 3 heaters is respectively: 15.1, 13.0 and 22.1 M^3/hour for units 1, 2 and 3. So, their gas usage in total would be 50.2 M^3/hour. Now we have to divide 50.2 by 3. The reason for this was explained to me by the Energie Partners. They said that only 1 of the 3 heaters is used at a time. So for the gas consumption of the heaters we take the average gas consumption per heater, which is 50.2 divided by 3. This is 16.73 M^3/hour.

To calculate the amount of gas that we can save per month, we first calculate the total gas consumption of the heaters per month. The amount of gas that we can save is a certain percentage of the gas consumption of the heaters. First off, we multiply the amount of days in a particular month with the 12 hours that the heaters are turned on. Then we multiply this with the average gas usage of the heaters. This is the total gas consumption of the 3 gas heaters during that month. Like we mentioned the amount of gas saved is a percentage of the gas consumption. This percentage is highly dependent on the outside circumstances, mainly the temperature. The graph that can be found in the picture below (Herath, H.M.D.P. et al. 2019) represents the percentage of energy saved, based on the outside temperature. It assumes that the thermal wheel has an efficiency of 55%, which is quite low. It also assumes a relative humidity of fresh air of 80%.

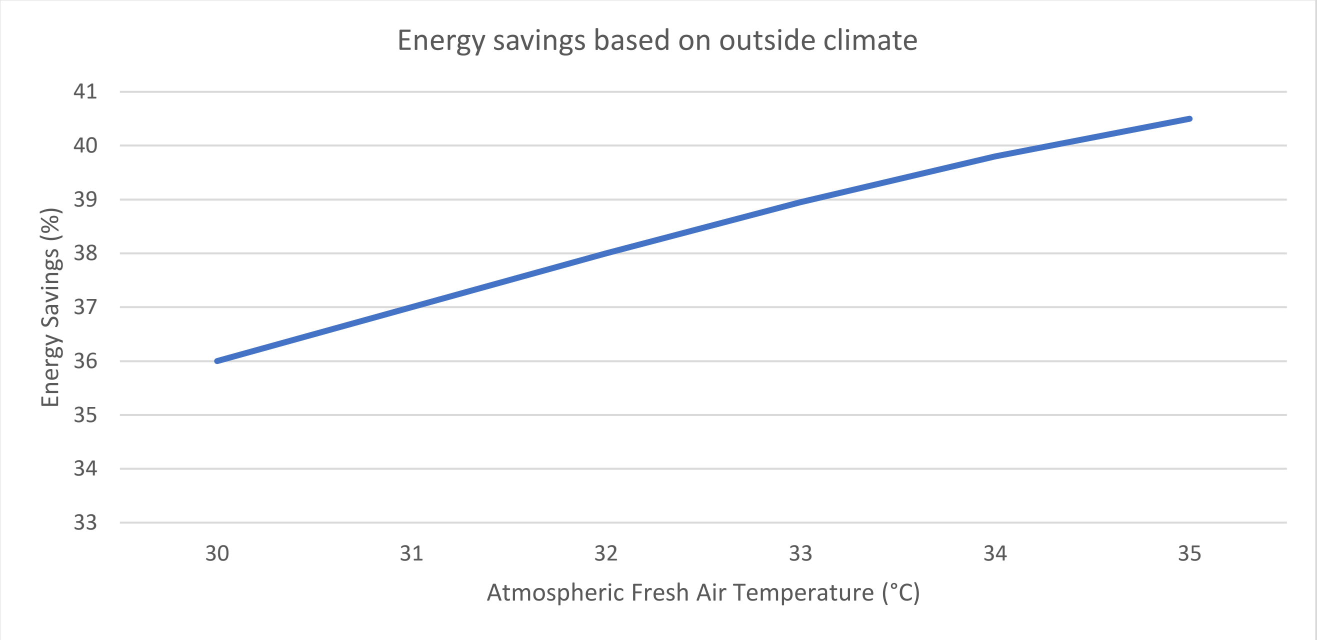


Figure 28: Graph that depicts the energy saving percentage based on outside climate

Based on the graph, we made very rough estimations of the percentage of gas saved per month in the Netherlands. The results can be found in the table below. The temperatures were based on the average monthly temperatures of last year in the Netherlands..

Month:	Percentage
Januray	11%
February	13%
March	13%
April	15%
November	15%
December	10%

Figure 29: Estimated energy saving percentage per month in the Netherlands

Now that we know the percentages, the percentage of the right month is multiplied with the gas consumption of that month. This will be the amount of gas saved during that month. If we subtract this from the total gas consumption of that month we get a scenario for the total gas consumption of that month after implementing a thermal wheel. We make this change only in the relevant months, which we previously discussed (November until April).

Our results will be the input for the 'Combining Consumption and Price Data after Implementation' file that we already used for the battery and electricity costs. Here we will calculate in a similar manner the gas costs of the new thermal wheel situation. The results can be found in the figure below. The graph also contains the trend line of gas costs of the old situation for comparison. Both lines also have a 90% confidence band around the average.

Month	Monthly Average Gas Costs with Thermal Wheel (€)	Monthly Average Gas Costs Saved (€)
Jan-23	14659.64	608.81
Feb-23	18526.89	876.52
Mar-23	16470.29	963.84

Apr-23	8061.07	1,072.45
May-23	951.29	0.00
Jun-23	414.52	0.00
Jul-23	98.35	0.00
Aug-23	17.88	0.00
Sep-23	1187.47	0.00
Oct-23	1040.93	0.00
Nov-23	6849.58	1,101.40
Dec-23	12919.08	550.71

Figure 30: Table of the simulated monthly average gas costs +monthly average savings when a thermal wheel is implemented

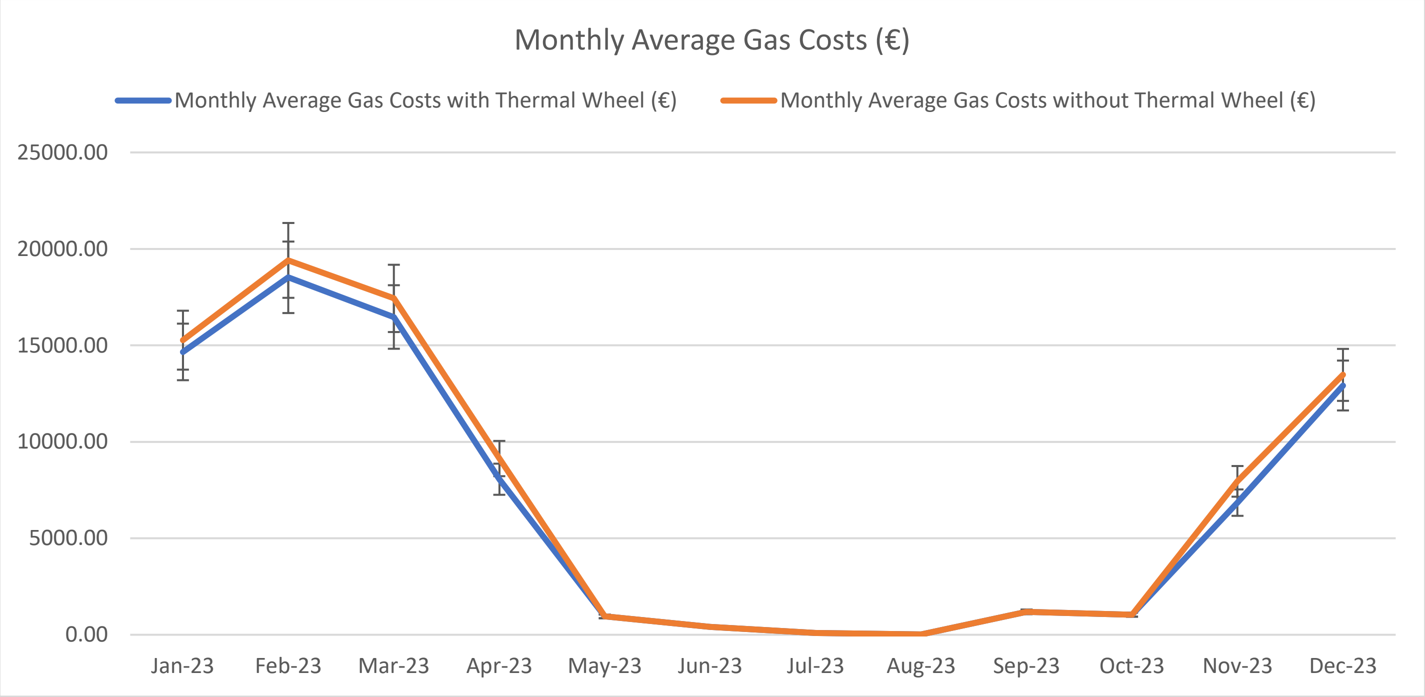


Figure 31: Graph of the simulated monthly average gas costs when a thermal wheel is implemented compared to no implementation

In the figure below the saved costs per month can be found, when a thermal wheel is installed. As can be derived from the graph, Coes wil save the most money during the winter months. This is very logical because the heaters are in use from October until April. When the heaters are turned off, they consume no gas, which means that no gas and thus no money can be saved. The amount of saved money in a certain month may not seem equal to 10-15% of the gas consumption in that month, as indicated in figure 26. This is because the thermal wheel only improves the efficiency of the 3 gas heaters in the left production hall. The efficiency of ,for example, the infrared heaters and the central boilers are not improved. This means that the total gas usage efficiency does not improve with 10-15%.

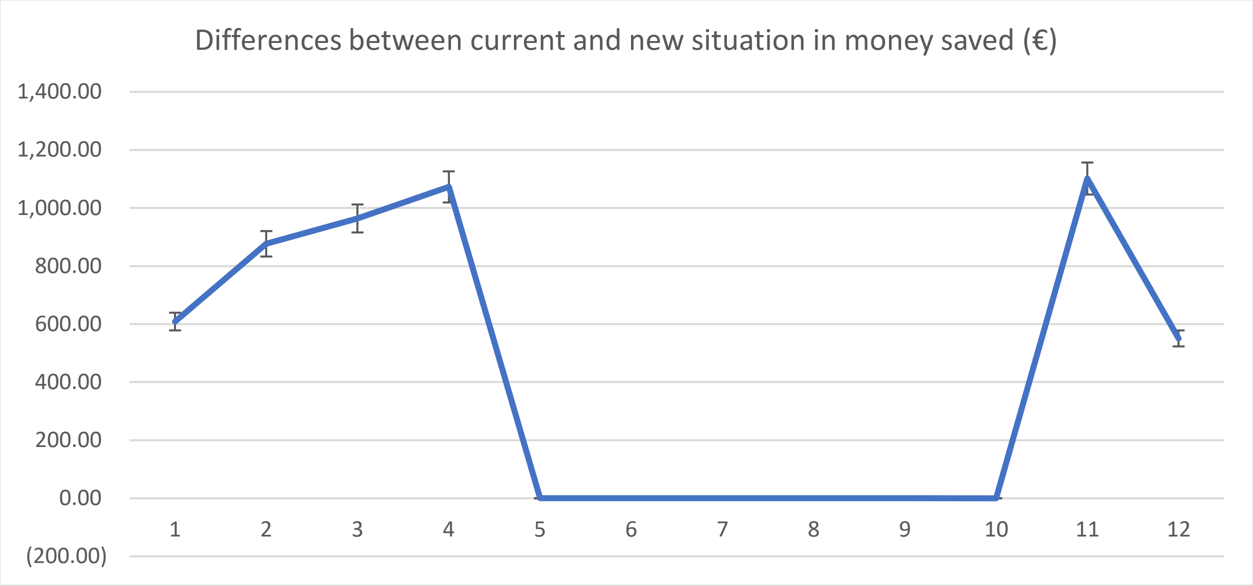


Figure 32: Graph of the simulated monthly average gas costs saved when a thermal wheel is implemented

6.2.2 Comparing the new situation with the current situation

Now that we have the results, we can start comparing the new situation to the old situation. Just like with the implementation of the battery system, we will sum up the costs over a time period of a year and then compare the costs with and without a thermal wheel implemented. The result can be found in the figure underneath.

Total Gas Costs of 1 Year without Thermal Wheel (€):	86370.71
Total Gas Costs of 1 Year with Thermal Wheel (€):	81196.99
Total amount of money saved in 1 year (€):	5173.73
Improvement percentage compared to current situation:	5.99%

Figure 33: Amount and percentage of money saved when we implement a thermal wheel

In the first year we will save €5173.73 with a thermal wheel implemented. We will use the Discounted Cash-Flow Analysis like we did in with the battery implementation, to find out if the investment is worth it. The discount rate used will be 1.2% again. In the conversation with the Energie Partners they explained that it was really hard to determine the initial investment costs. Implementing a thermal wheel in 1 gas heaters would costs approximately €70.000,-, so €210.000,- in total. In addition Coes would need to install a new ventilation shaft network. We made an estimated that this would cost an additional €90.000. So in total an investment of €300.000 would be need. Using the same method as with the battery implementation we got the following results;

Years	Present Value of the Cash Flow per Year (€):	Net Present Value per Year (€):
0	5173.73	5173.73
1	5112.38	10286.10
2	5051.76	15337.86
3	4991.85	20329.71
4	4932.66	25262.38
5	4874.17	30136.55
6	4816.38	34952.92
7	4759.26	39712.19

8	4702.83	44415.02
9	4647.07	49062.08
10	4591.96	53654.04
…	…	…
97	1626.65	300763.51

Figure 34: NPV calculated for a thermal wheel

The installation of thermal wheels would have earned itself back after 97 years. This takes way too much time. As mentioned before the gas heaters themselves are already quite old and obsolete. They would not last long enough for the implemented thermal wheels to earn themselves back. So this implementation option is not financially viable.

7 Conclusion and Recommendations

7.1 Conclusion

In this section we will be discussing the results that we retrieved from the simulation and how it can help to answer our research questions. When we started this research, the first thing we did was look into the problems that Coes had. We determined the main problem, which is the lack of efficient and environmentally friendly heat and power systems, and the action problem, which is to define an investment strategy to upgrade the heating and power systems. By solving the action problem We hoped to improve the situation at Coes. In order to become more familiar with the company and the processes within the company, we interviewed the director of Coes and came up with a depiction of the supply chain. In the supply chain we linked the processes to the source of energy they use, so that we could better understand where the energy consumption came from. We then established 2 concrete problems that could be solved by investing in 2 particular implementations. The first problem was the lack of flexibility that Coes had regarding the electricity that they generated with their solar panels. Implementing a battery system could help in increasing this flexibility. The second problem was the obsolete and old gas heaters that Coes still used. We intended to lower the gas consumption by increasing the efficiency of these heaters, by implementing a thermal wheel.

7.1.1 Implementing a BESS

First of all, the implementation of the battery system. Implementing a BESS could give Coes more flexibility, because they would be able to store the electricity generated by the solar panels. This would give them more control over when to satisfy demand and by which means (generated- or bought electricity). We simulated the implementation of a BESS with 4 different capacity options. 200, 400, 600 and 800 kWh would have implementation costs of €366.000,-, €466.000,-, €566.000,- and €666.000,- respectively. We simulated how much money would be saved in comparison to the original situation and used this as the expected cashflows in the upcoming years. We concluded that none of the capacities would be able to break-even within 20 years (the lifespan of the battery). The cashflows are by far too low to even be able to come close to the break-even point. When we look at the tables and graphs of the newly simulated electricity costs, we can conclude that for every capacity the amount of saved money is too low in every month.

When we compare the different battery capacities with each other, of course the implementation costs stand out. They are very high. Also an additional €100.000,- for every 200 kWh added to the capacity is quite expensive. It makes sense when we focus on the savings per capacity. With increasing capacity we save more money per year. We can conclude this from the improvement percentage compared to the original situation. This percentage shows the savings compared to the electricity costs of the old situation, and it increases if the battery capacity increases. Still this is not enough to come close to breaking even. This is why we looked into, when the investment would be able to break-even. We calculated what the cashflow every year must be, to be able to break-even over 20 years. The results can be found in figure 26. The resulting cashflows are all way too high too realistically save per year. This is why we also looked into, how much the initial investment costs must go down to be able to break-even with the currently expected cashflows. These results can be found in figure 27. If we compare these initial investment costs with the costs that were presented by ‘Big Ass Battery’, we can conclude that, even though the costs will probably go down over the next few years, it will not go down that much. This makes the implementation of a BESS for Coes not a viable option.

When we look back at the graphs which indicate the savings made per month, we have one constant trend. In January, June, July and November the savings are negative, which means that the storage system costs Coes more money than before. The negative savings in January are very low and may be caused by the holiday in the beginning of January. The negative savings in November can be explained, due to the fact that November has the highest electricity consumption of all months, there is little to no generated electricity and we still buy electricity during base hours. From figure 20 and 21 we can derive that the peak electricity costs go down and the base electricity costs go up, but not by the same amount. The base costs go up by a larger amount. This means that Coes has to buy more electricity in total due to the operating policy. In the end this causes the savings to become negative. The negative savings in June and July are quite big, but there is also a logical explanation for this. During these months the generated solar energy is at its highest, meaning that we need to buy less electricity to meet our demand. But we still fill up the battery at the beginning of each day, even though it may not be necessary. This causes Coes to send back relatively more electricity during these months, as can be seen in figure 22. Which counteracts the goal, of using as much generated electricity as possible for themselves. To improve the policy, a seasonal policy must be made. We already know that Coes their demand and thus consumption is highly dependent on the season. Besides that the electricity that they generate depends on the weather, so also on the season. By making a seasonal policy, Coes can better operate their storage system dependent on these factors. This will not instantly make the investment worth it, but by improving the policy in this way we could increase the monthly savings and decrease the return-on-investment time.

7.1.2 Implementing a Thermal Wheel

Now we will discuss the implementation of a thermal wheel. We already explained how it would help improve the efficiency of the gas heaters currently in use. When we look at the results of the simulation, we can derive that in every month, money will be saved and that the amount of saved money per year seems higher than the amount of money we save with implementing a BESS. This is confirmed when we see the improvement percentage compared to the original situation, which is 5.99%. This is a lot higher than the best improvement percentages that we got from the BESS. Still we concluded from figure 6F that the break-even point would be reached after 97 years, Which takes way too long. Of course we can look into the cashflows and how much these would have to go up in order to breakeven faster. Or how much the implementation costs would have to go down in order to make the investment profitable. This is not necessary. As mentioned before the ‘Energie Partners’ of Coes also calculated if this investment would be worth it. They mentioned that the current gas heaters are over 20 years old, and desperately need to be replaced within the next few years. They concluded that upgrading the (efficiency of the) heaters would never be able to break-even because the heaters themselves would not last long enough to make it profitable. This makes the implementation of thermal wheels also not viable for Coes. We can state that the high gas consumption of Coes is caused by the obsolete and inefficient heat systems. Instead of trying to upgrade these systems, I would suggest replacing them. This may be a larger investment, but it will also last longer, giving it more time to get to a breakeven point. It may also be possible to install a thermal wheel in this heater, making it even more efficient. Another option may be to switch to electrical heating in the left side of the building. Coes is already an very electrical oriented company. So switching more systems to this form of energy may be a very viable option. It will also reduce CO2 emissions.

7.2 Limitations of this research

Now that we have stated the conclusions of the research, we can focus on the limitations.

- In the research we use the historical data for generated solar energy as the input for the simulation. This data is deterministic and assumed to be true for the following years. Of course this is unrealistic, because expected generated solar energy is dependent on the weather. The weather is quite hard to predict, so we can say with certainty that there will be differences between the expected generated solar energy that we use and the actual generated solar energy of next year. This can go both ways, either more electricity will be produced next year, or less. A possible solution would be to use a lot of days, which results possible errors canceling out.
- In order to simulate trajectories of the gas and electricity market prices, we used the historical market price data of last year. Last year was an unusual year regarding energy prices. The war between Ukraine and Russia played a big role in the extreme fluctuations in the gas and electricity

prices. But like we said, we did base my future predictions on these historical prices. If we look at the gas and electricity prices right now, they have dropped significantly compared to when we started this research. So the predicted trajectories might be higher than the actual market prices this year.

- The costs of the implementation of the thermal wheels is an estimation. we were told by the 'Energie Partners' that implementing 1 thermal wheel, would cost an estimated €70.000,-. This would mean that implementing 3 wheels would cost €210.000,-. The remaining €90.000,- is an estimation of what buying and implementing a new (required) ventilation network would cost.

7.3 Recommendations and Future Research

Now, taking into account the conclusions that we made, based on the research performed, we can recommend a few things to Coes. These will also be interesting or notable findings in this research that could lead to future research subjects. First of all, we recommend Coes to still keep an eye on the possibility of implementing a battery system. As we mentioned. We predict that the cash flows will not be large enough to break-even within 20 years. Besides that the implementation costs will no go down fast enough that we can break even with the simulated expected cashflows. But if, due to development of BESS technology, the implementation costs go down or the lifespan of the batteries increases. It could still be a very interesting option for Coes. Also by implementing a more effective policy, more money can be saved per year, meaning that the expected cashflows will also increase. This is why we recommend to focus on a seasonal policy. Like we already mentioned Coes their demand is highly dependent on the season and temperature. Besides that their generated electricity is dependent on the weather. By adjusting the policy to these factors, we can turn the negative savings into positive savings. This will increase the yearly cash-flow, the return on investment and will make the break-even point shorter. This is why I recommend Coes to still keep the option of implementing a battery open, even though it may not be viable at this moment. This is because the electricity flexibility problem that Coes has, will remain.

Regarding the gas costs we have sadly concluded that implementing a thermal wheel will also not be viable. We already mentioned that the gas heaters are too old to try to implement upgrades, like a thermal wheel. We recommend Coes to replace the 3 gas heaters with a new heating system, either gas or electric. The 'Energie Partners' recommend to place 1 heater, that can handle the supply and exhaust of air for the whole facility. This means that there is no need for 3 separate heaters, in every production hall 1. Implementing a thermal wheel in this solo heater will probably be profitable. This is first of all, because Coes only needs to implement 1 thermal wheel instead of 3, significantly decreasing the implementation costs. The lifespan of the heater is also much longer, giving the thermal wheel more time to break-even, compared to the current situation. Lastly with only 1 unit, instead of 3, the yearly maintenance costs of the fans, the engines and the gas burners, will also decrease. This would be a very interesting research subject for a follow-up study. To calculate if it would be a financially viable option to replace the 3 gas heaters with 1 new model. And additionally if it would be profitable to install a thermal wheel in it. Another possible follow-up research would be to analyze if it would be profitable to switch the gas heaters to electrical heaters. As we have already stated, Coes is already very invested in electrical machinery and equipment. Adding the heating systems to this grid could be a very profitable option. This is certainly a recommendations that should be looked into.

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Appendices

Appendix A: Battery with capacity of 200 kWh

Month	Monthly Average Peak Electricity Costs (€)	Monthly Average Base Electricity Costs (€)	Total Average Monthly Electricity Costs (€)
Jan-23	9839.25	2381.16	12227.41
Feb-23	11720.97	3237.19	14965.15
Mar-23	7446.88	3423.24	10877.11
Apr-23	1704.82	2783.36	4495.17
May-23	-964.73	1665.09	707.35
Jun-23	1640.22	2275.85	3923.07
Jul-23	1380.86	2436.73	3824.58
Aug-23	2168.78	2157.95	4333.73
Sep-23	7080.85	2581.68	9669.52
Oct-23	9864.70	2874.39	12746.08
Nov-23	15609.27	2942.56	18558.82
Dec-23	6525.16	2258.62	8790.77

Figure 35: Table of the simulated monthly average electricity costs when a BESS with a capacity of 200 kWh is implemented

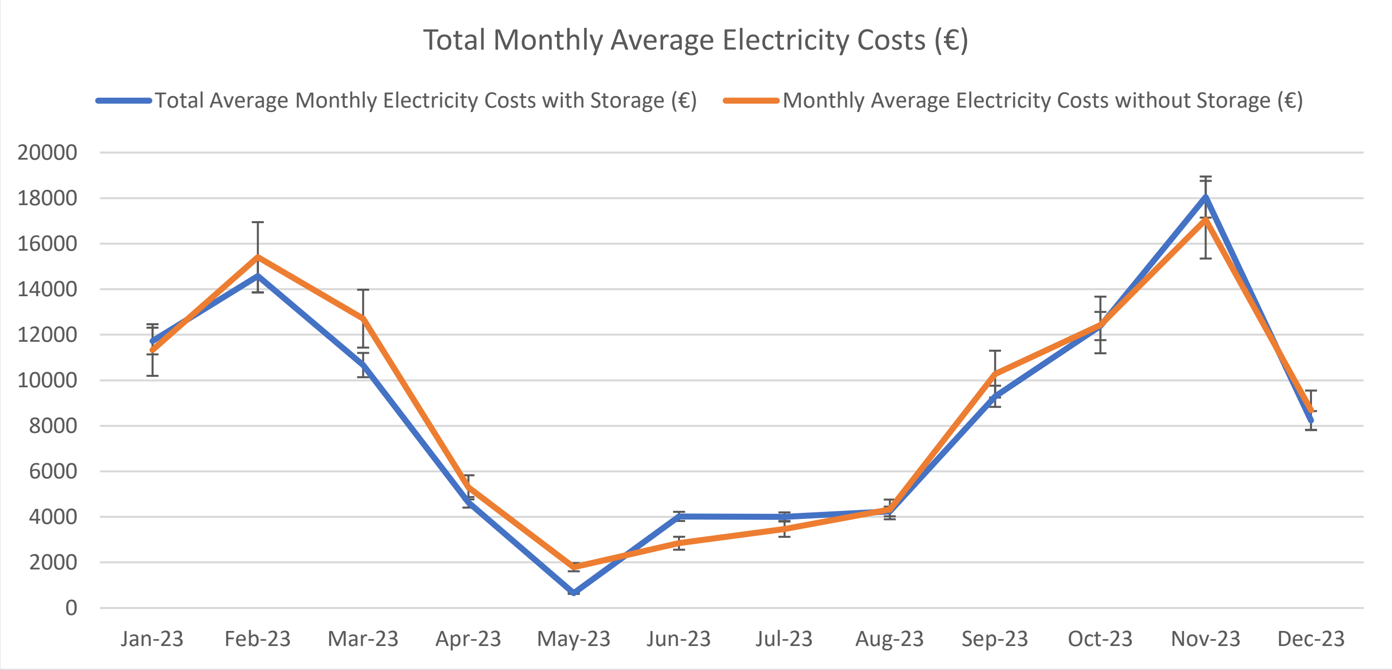

Figure 36: Graph of the simulated monthly average electricity costs when a BESS with a capacity of 200 kWh is implemented compared to no implementation

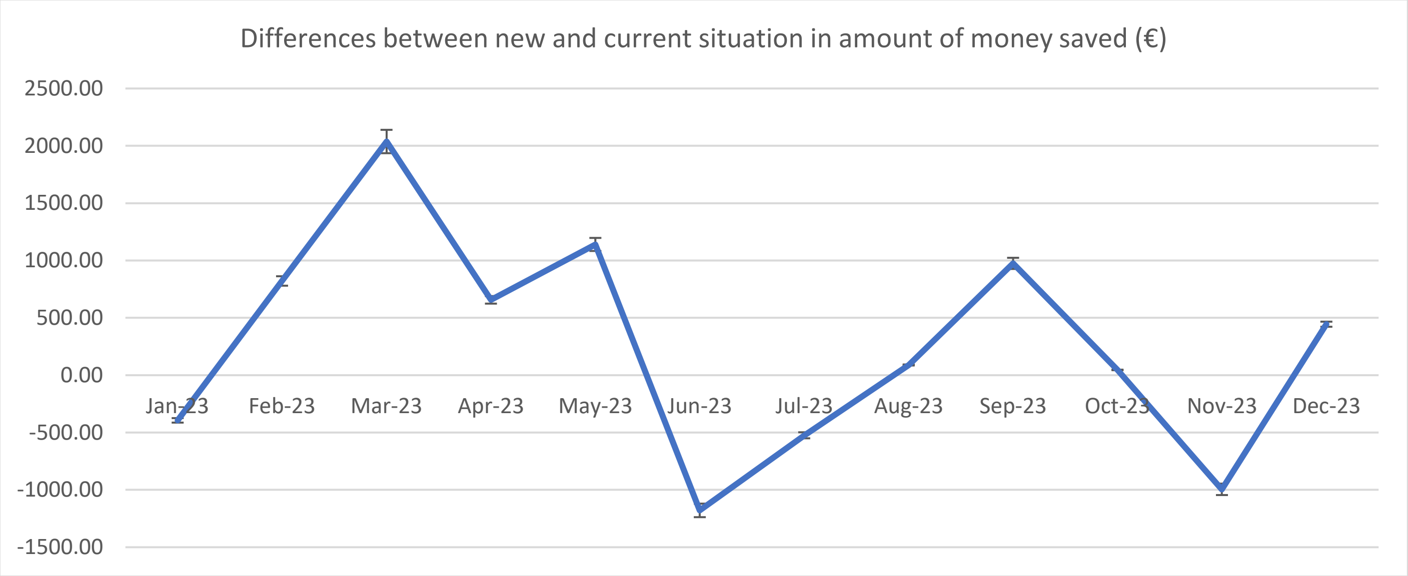

Figure 37: Graph of the simulated monthly average electricity costs saved when a BESS with a capacity of 200 kWh is implemented

Total Electricity Costs of 1 Year without battery (€):	105609.81
Total Electricity Costs of 1 Year with battery (€):	105118.75
Total amount of money saved in 1 year (€):	491.06
Improvement percentage compared to current situation:	0.46%

Figure 38: Amount and percentage of money saved when we implement a battery with 200 kWh capacity

Years	Present Value of the Cash Flow per Year	Net Present Value per Year
0	491.06	491.06
1	485.23	976.29
2	479.48	1455.77
3	473.80	1929.57
4	468.18	2397.75
5	462.63	2860.37
6	457.14	3317.51
7	451.72	3769.23
8	446.36	4215.59
9	441.07	4656.66
10	435.84	5092.51
…	…	…
20	386.83	9176.54

Figure 39: NPV calculated over the life time span of a battery with 200 kWh capacity

Appendix B: Battery with capacity of 600 kWh

Month	Monthly Average Peak Electricity Costs (€)	Monthly Average Base Electricity Costs (€)	Total Average Monthly Electricity Costs (€)
Jan-23	7713.60	4154.43	11875.02
Feb-23	9110.14	5593.22	14710.35
Mar-23	5187.74	5558.15	10752.88

Apr-23	342.03	4141.20	4490.22
May-23	-1261.50	1901.96	647.45
Jun-23	1109.37	2912.09	4028.45
Jul-23	1380.86	2436.73	3824.58
Aug-23	596.73	3609.49	4213.21
Sep-23	4459.83	4934.14	9400.96
Oct-23	6872.79	5621.78	12501.56
Nov-23	12548.48	5660.64	18216.12
Dec-23	4219.36	4159.22	8385.57

Figure 40: Table of the simulated monthly average electricity costs when a BESS with a capacity of 600 kWh is implemented

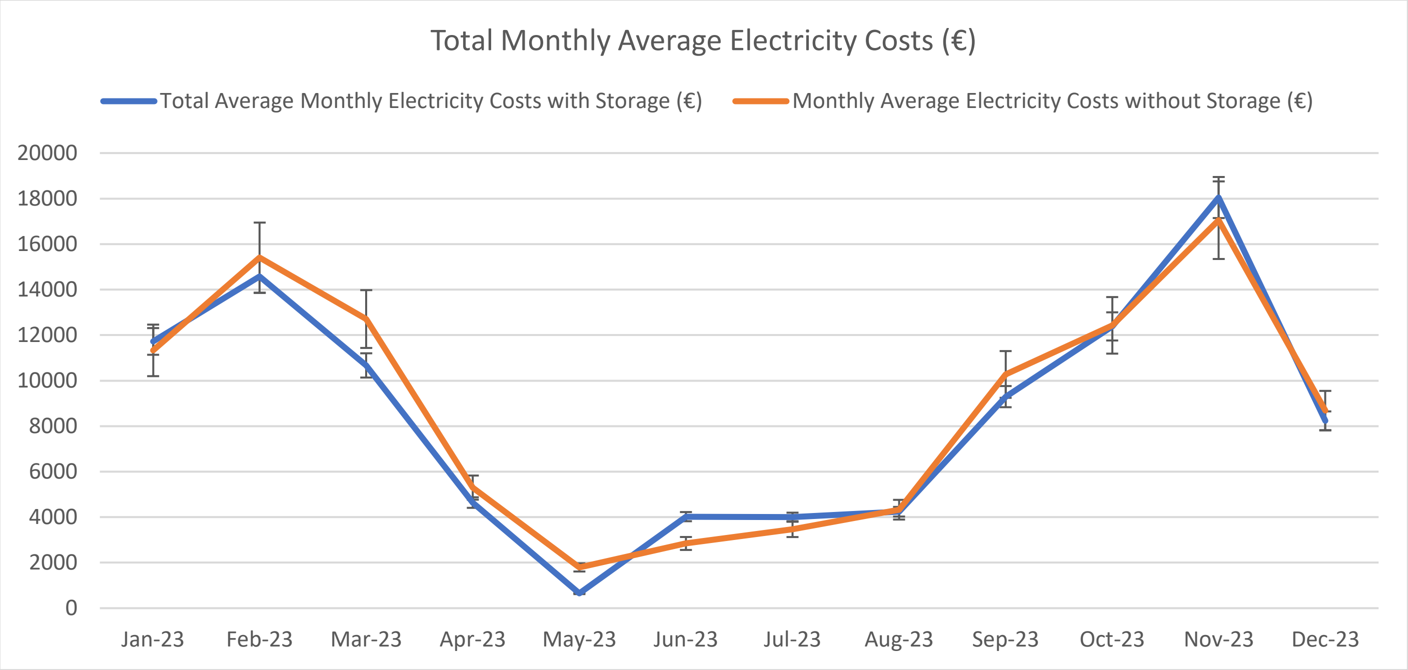

Figure 41: Graph of the simulated monthly average electricity costs when a BESS with a capacity of 600 kWh is implemented compared to no implementation

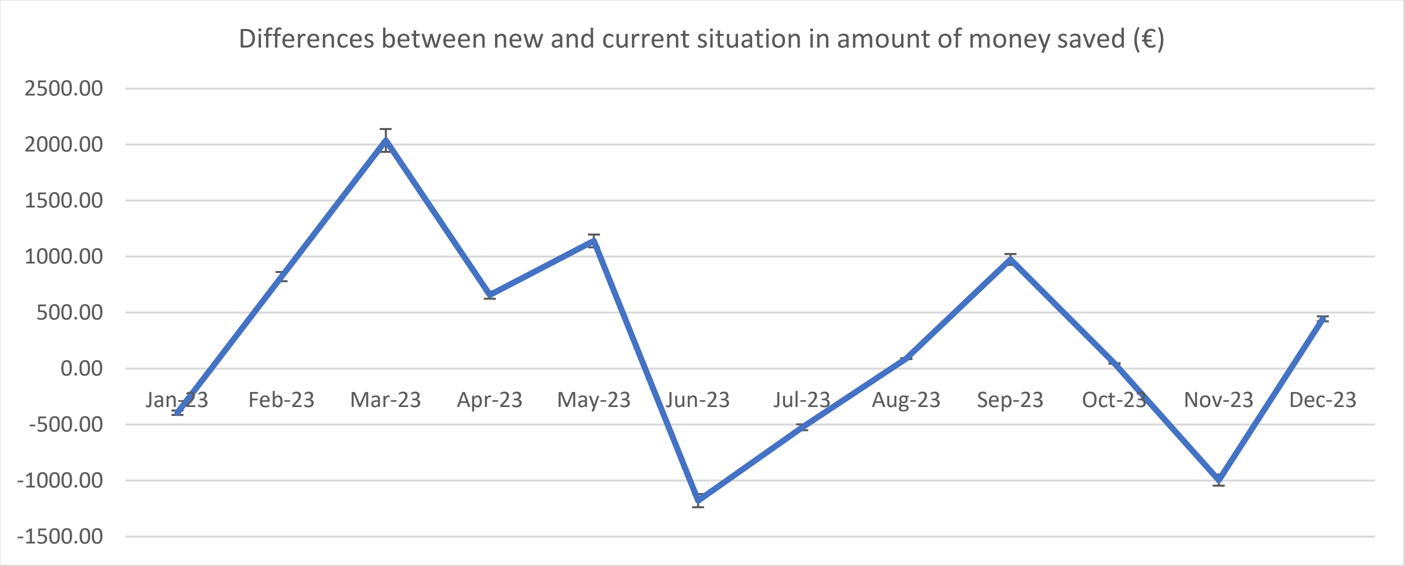

Figure 42: Graph of the simulated monthly average electricity costs saved when a BESS with a capacity of 600 kWh is implemented

Total Electricity Costs of 1 Year without battery (€):	105609.81
Total Electricity Costs of 1 Year with battery (€):	103046.35
Total amount of money saved in 1 year (€):	2563.46
Improvement percentage compared to current situation:	2.43%

Figure 43: Amount and percentage of money saved when we implement a battery with 600 kWh capacity

Years	Present Value of the Cash Flow per Year	Net Present Value per Year
0	2533.06	5096.52
1	2503.02	7599.54
2	2473.34	10072.89
3	2444.02	12516.90
4	2415.04	14931.94
5	2386.40	17318.34
6	2358.10	19676.44
7	2330.14	22006.58
8	2302.51	24309.09
9	2275.21	26584.29
10	2248.23	28832.52
…	…	…
20	2019.37	47904.09

Figure 44: NPV calculated over the life time span of a battery with 600 kWh capacity

Appendix C: Battery with capacity of 800 kWh

Month	Monthly Average Peak Electricity Costs (€)	Monthly Average Base Electricity Costs (€)	Total Average Monthly Electricity Costs (€)
Jan-23	6652.02	5063.85	11722.87
Feb-23	7804.96	6770.55	14582.50
Mar-23	4207.54	6454.17	10668.70
Apr-23	237.25	4397.33	4641.57
May-23	-1281.39	1926.33	651.92
Jun-23	1064.39	2952.01	4023.39
Jul-23	698.79	3292.08	3997.86
Aug-23	495.53	3737.20	4239.72
Sep-23	3250.06	6039.64	9296.69
Oct-23	5380.45	6995.61	12383.05
Nov-23	11020.20	7018.65	18045.83
Dec-23	3086.17	5143.01	8236.17

Figure 45: Table of the simulated monthly average electricity costs when a BESS with a capacity of 800 kWh is implemented

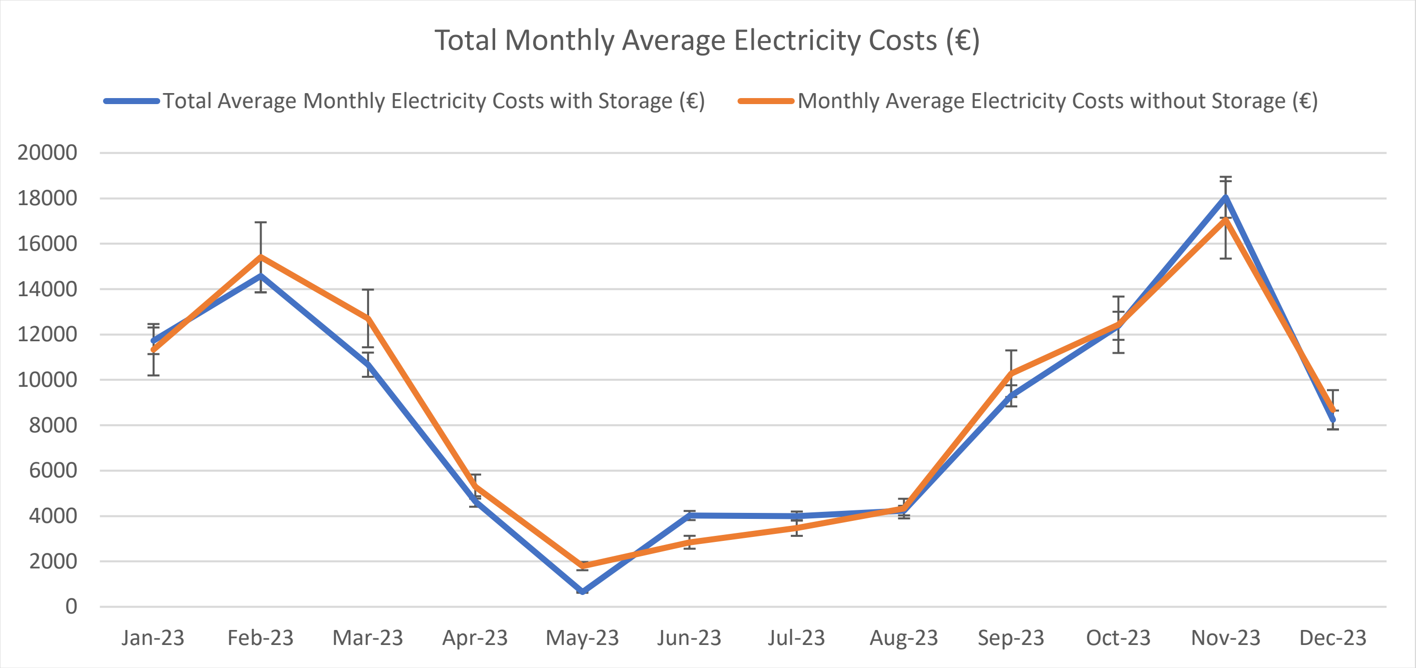

Figure 46: Graph of the simulated monthly average electricity costs when a BESS with a capacity of 800 kWh is implemented compared to no implementation

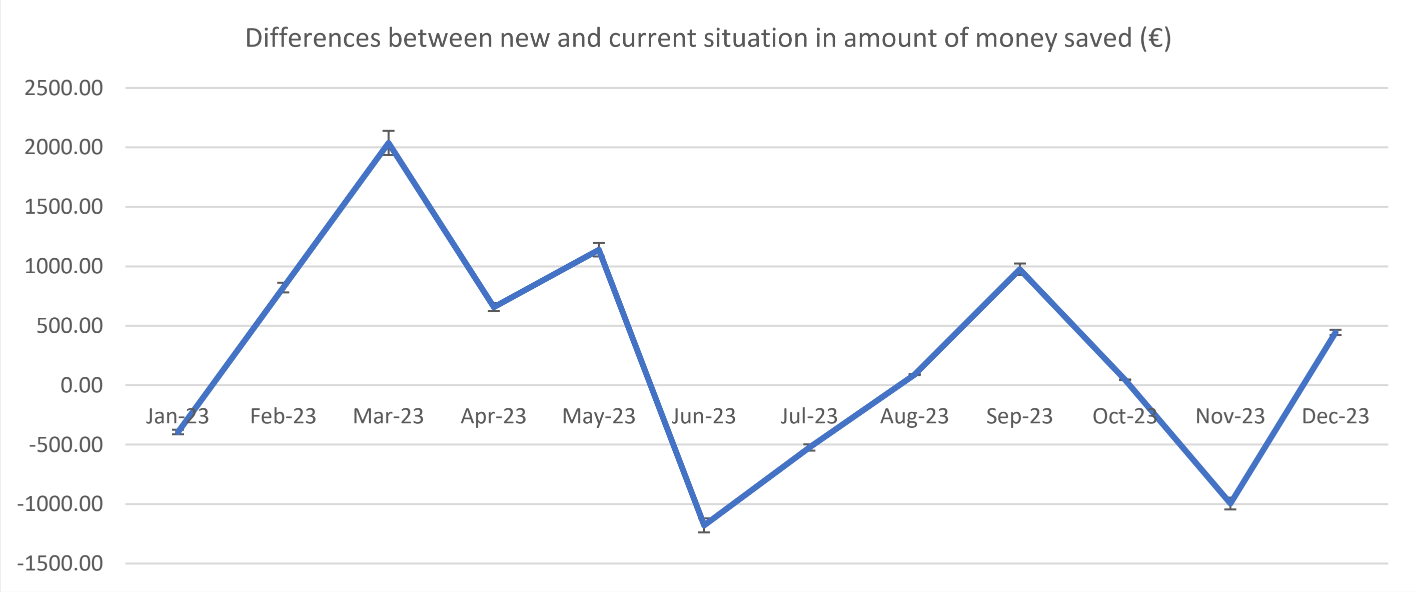

Figure 47: Graph of the simulated monthly average electricity costs saved when a BESS with a capacity of 800 kWh is implemented

Total Electricity Costs of 1 Year without battery (€):	105609.81
Total Electricity Costs of 1 Year with battery (€):	102490.26
Total amount of money saved in 1 year (€):	3119.55
Improvement percentage compared to current situation:	2.95%

Figure 48: Amount and percentage of money saved when we implement a battery with 800 kWh capacity

Years	Present Value of the Cash Flow per Year	Net Present Value per Year
0	3119.55	3119.55

1	3082.56	6202.11
2	3046.01	9248.12
3	3009.89	12258.01
4	2974.20	15232.21
5	2938.93	18171.15
6	2904.08	21075.23
7	2869.65	23944.88
8	2835.62	26780.50
9	2802.00	29582.50
10	2768.77	32351.27
…	…	…
20	2457.43	58296.00

Figure 49: NPV calculated over the life time span of a battery with 800 kWh capacity