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AN EXPLORATORY STUDY TO INCREASE THE NET PRESENT VALUE FOR THE HYBRID BOILER

BACHELOR THESIS INDUSTRIAL ENGINEERING & MANAGEMENT

STORK
A Fluor Company

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Preface

I consider myself lucky that I had the privilege of being able to investigate a topic which is in my interest. When students in the Netherlands finish high-school, most of them are obliged to do a research within a subject like mathematics, physics or the Dutch language (profielwerkstuk). It has been more than five years ago since I worked on that project. Even then, green energy and a sustainable environment were already a thing. After struggling to find a topic, I finally came up with an idea that intrigued me. On a basic level, I tried to find out what would happen to the total amount of available energy in the Netherlands if you would invest every euro households spend in PV panels into another sustainable energy source. Now, this topic is still relevant, and this research has some similarities.

First and foremost I want to thank Bart Bramer, my company supervisor. He provided the opportunity to do this study and caused me to refind my interest in the topic. Second, I want to thank Reinoud Joosten and Berend Roorda for their constructive, and academic criticism. Although this report is quite technical, a lot of tips and tricks were helpful and made the report what it is right now.

Enjoy reading!

Gijs Verschuur

Management summary

Context

This study takes place within in Boiler Projects department of Stork Thermeq, Hengelo. This department developed a hybrid boiler which can run on traditional fuels, like coal or gas, but also electricity. Stork is the leading company concerning this technology. The engineers were able to decrease the changeover time to 10 seconds. But until now, sales disappoint.

Problem explanation and goal of the study

The problem cluster provides insight into the causal relations between problems. The general problem is disappointing sales, caused by a low expected savings while using the boiler and an unknown product. The core problem comes up when following the problem cluster. It states: *"Do opportunities exist to get electricity from a quicker market, to increase the NPV?"*. If so, the NPV will increase which may increase the interest of the hybrid boiler.

The goal is to make sure the NPV is positive within four years to make sure the hybrid boiler outperforms a traditional boiler. A sub-goal is to obtain knowledge about the different markets for fuels and about boilers, to combine those in a model to calculate NPVs for the new ways of using the hybrid boiler.

Research design

The main research question, which impacts the design, is: *"Which business case for using the hybrid boiler has the highest NPV when functioning on a different market than the day-ahead market, for the designed powers of 10, 25, and 50 MW?"*. Three of the six sub-questions relate to an exploratory literature study, the others to the results of the hybrid boiler working on a particular market. In the end, a self-constructed model with data from TenneT generates NPVs for each business case. The literature study consists of information from the companies that regulate the markets and some articles.

Results literature study

The literature study exists of two parts. The first part concerns the boiler. A traditional boiler is an industrial instrument with a couple of subparts with the goal of heating water until it becomes steam. The hybrid boiler is a system where a traditional boiler and an electrode boiler are parallelly connected. The electrode boiler provides opportunities like a stand-by function, but also restrictions like the conductivity of the water that goes in the system.

The second part concerns both markets. The gas market is called the TTF, which enables a market participant to buy gas for two years upfront to tomorrow. Per period, different markets exist. The closer to real-time the market is, the more volatile the prices get and the lower the traded volumes are. The two factors that influence the daily gas price are the weather and carbon credit costs.

The electricity market is more complicated than the gas market because of balancing. TenneT has the task of balancing the grid at all times. For this purpose, there are two closer to real-time markets than the intra-day market. Those are the imbalance and the reserve market. Each market has its technical requirements and pricing systems. The final markets used, are the imbalance, FCR and aFRR.

Model

The model uses only three out of the six electricity markets that showed enough potential in their pricing and technical specifications. The data from TenneT show an opportunity to save money on fuel when the boiler switches from gas to electricity at the right time. The model uses different inputs per business case. The five variables are the gas price, electricity price at the imbalance and reserve market, carbon credit price, designed power, CAPEX and OPEX. The model calculates the NPVs per case, per designed power, per scenario. A difference in discount factor causes the need for different scenarios. Some assumptions simplify the model. Although some assumptions had to be made, the sensitivity analysis and a worst case scenario strengthen the results.

Results

Making sure the hybrid boiler functions as an FCR reserve for TenneT gives the highest NPV. The high fee for passively having power available causes the FCR to be significantly the best. The initial investment is earned back within half a year, which results in a met goal. However, the discussion shows some developments which might influence the result in either positive or negative way.

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1. Problem description

This section starts with a little introduction on Stork and the context of the research. Section 1.2 and 1.3 give the context and motivation for the research. Next is Section 1.4, where the core problem is determined. The remaining section gives an overview of how the problem is solved and what the research questions for this research are.

1.1 About Stork

Stork B.V. started 150 years ago as a manufacturer of boilers, pumps, steam and others. They played a big part in the Dutch industrial revolution, as they provided a large number of machines. Over the years, many companies or divisions were bought and sold, but in 2010 the company decided to focus on technical maintenance. Therefore, Stork B.V. changed into Stork Technical Services.

Although the name implies the company only provides services, there is still some production in the company Stork. The division Stork Thermeq, founded in 1997, is a continuation of Stork Ketels. In Hengelo, Stork produces boilers, burners, and deaerators. Stork Thermeq provides different solutions for industrial systems and has customers all over the world. The department that provided this study is the Boiler Project department of Stork Thermeq.

1.2 Research context

The European, so also the Dutch energy market, is changing considerably as a result of a stringent CO_2 policy. Consequently, the share of renewable energy sources is growing significantly, especially of volatile sources such as wind and solar energy. Because of those weather dependent energy sources, the electricity market has become harder to predict. It is technically necessary to keep the input and output close together on the electricity grid, so the need for adjustable power increases as well. Adjustable power is needed to compensate for a surplus of electricity that is in the system. This difference in input and output creates opportunities for companies that already have a kind of energy flexibility. On sunny or windy days, it might be possible that the price for electricity drops below, for example, the price of gas, which makes it more profitable to power a plant with electricity. As a result of the Paris Agreement, industrial users have to invest in new equipment in order to cut CO_2 emissions. Stork Thermeq predicted this need and developed a hybrid boiler, which can be powered by electricity and a traditional energy source, for example, natural gas. The engineers were able to achieve a switchover time between energy sources of ten seconds. As far as they know, they are currently the only one capable of designing such a system, so they got a patent. This technology push is developed in advance of actual demand. So, although the engineers did not have any parties that wanted such an installation, they still developed the product because they thought it would sell eventually. Currently, Stork Thermeq has a couple of projects with different customers. These projects focus on the opportunities for the implementation of the hybrid boiler.

With a somewhat suddenly developed boiler, some unknowns and problems might pop up. Most of the unknowns are about the functionality and the business model of the hybrid boiler. Because it is new to the market, possible customers do not know the risk of their investment. Second, according to research by CE Delft (2015), potential savings are outstripped by investment costs, operating, and maintenance costs. Berenschot (2017) finds that the economic feasibility of electric boilers in the Netherlands is poor. As possible arguments, they come up with grid connection costs, capacity tariffs and the relatively high power prices for most of the year. Their findings make sense when looking at the prices for gas and electricity. For example, two reports from the European Commission showed that at the end of June 2018, 1 MWh electricity is twice as costly as 1 MWh gas. When investigating the data further, the price of electricity is usually higher than the price of gas. Both aspects cause the demand for the hybrid boiler to not be on the level Stork wants it to be. Right now, an industrial user would not switch to a hybrid or utterly electric boiler, because they do not know how they should implement such a machine and because electricity is more costly than traditional fuels.

1.3 Reason for research

However, there is a particular assumption or method those studies used. They all use the data and the prices of the day-ahead market. The day-ahead market is the traditional market for trading electricity. On this market, producers and customers make an estimation per hour how much electricity they will produce or consume the same hour a day later. All estimations together make a nomination. After the market gathers all the nominations, the price is calculated. The following day, not all expectations are correct. Big consumers of producers cannot always be 100% sure what they are going to produce or consume. Any discrepancies can be fixed on some closer to real-time markets, to even out supply and demand. Table 1 gives an overview of the different markets.

Table 1: The time frame of different electricity markets.

Closer to real-time →				
Moment of trade	All other days before	Day before	Delivery day	Real-time
Market	ENDEX	APX Day-ahead	APX Intra-day	Imbalance & reserve

On the intra-day and real-time market, market participants can fix any discrepancies they have after the day-ahead market. As shown in Figure 1, three markets are closer to real-time than the day-ahead market. Those are the intra-day market, the imbalance market and the reserve market. On the intra-day market, market participant trade electricity for the delivery day itself. It enables market participants to correct for shifts in their day-ahead nominations. They often want to do so because the closer to real-time, the more reliable the forecasts get. Because of the short period, intra-day market prices are more volatile than the day-ahead market prices.

Second, the imbalance market is a market which includes two kinds of parties. These are TenneT and balance responsible parties (BRPs). Together they make real-time deals when needed. The volatility is also higher on this market compared to the day-ahead and the intra-day market. Last, the reserve market. TenneT, the Transmission System Operator (TSO) for the Dutch grid, has the responsibility to resolve any power imbalances. The electricity grid needs to be balanced at every point in time because electricity cannot be stored. When a calamity happens, TenneT needs to get or lose electricity as soon as possible. A calamity is, for example, a coal-fired power plant which requires unexpected maintenance. Therefore TenneT has balance service providers (BSPs), market participants who provide balancing services. The first earnings a BSP could get are due to the lower prices compared to the day-ahead market, but a BSP can also earn money by being available to produce or consume electricity. The electricity prices are again more volatile than on the day-ahead market. To make it even more complicated, three different reserve markets, dependent on the time interval a BSP can react after a calamity happened. All with different prices. Section 2.3.4 contains an overview of all the differences.

Overall, the day-ahead market is not the only way to buy electricity. Other markets might provide lower prices for electricity, because of their higher volatility than the day-ahead market. Since the time in which the hybrid boiler can switch between energy source is so fast, Stork Thermeq expects that the hybrid boiler can run electricity from closer to real-time markets. Because of this opportunity, they want to know whether the investment gets better when the hybrid boiler participates on closer to real-time markets. That is the goal of this study.

1.4 Problem statement

Stork Thermeq has a new hybrid boiler, but the traditional way of functioning does not make it an attractive investment. This causes the main problem Stork has right now, namely insufficient demand. A couple of possible causes provoke this problem. Figure 1 gives an overview.

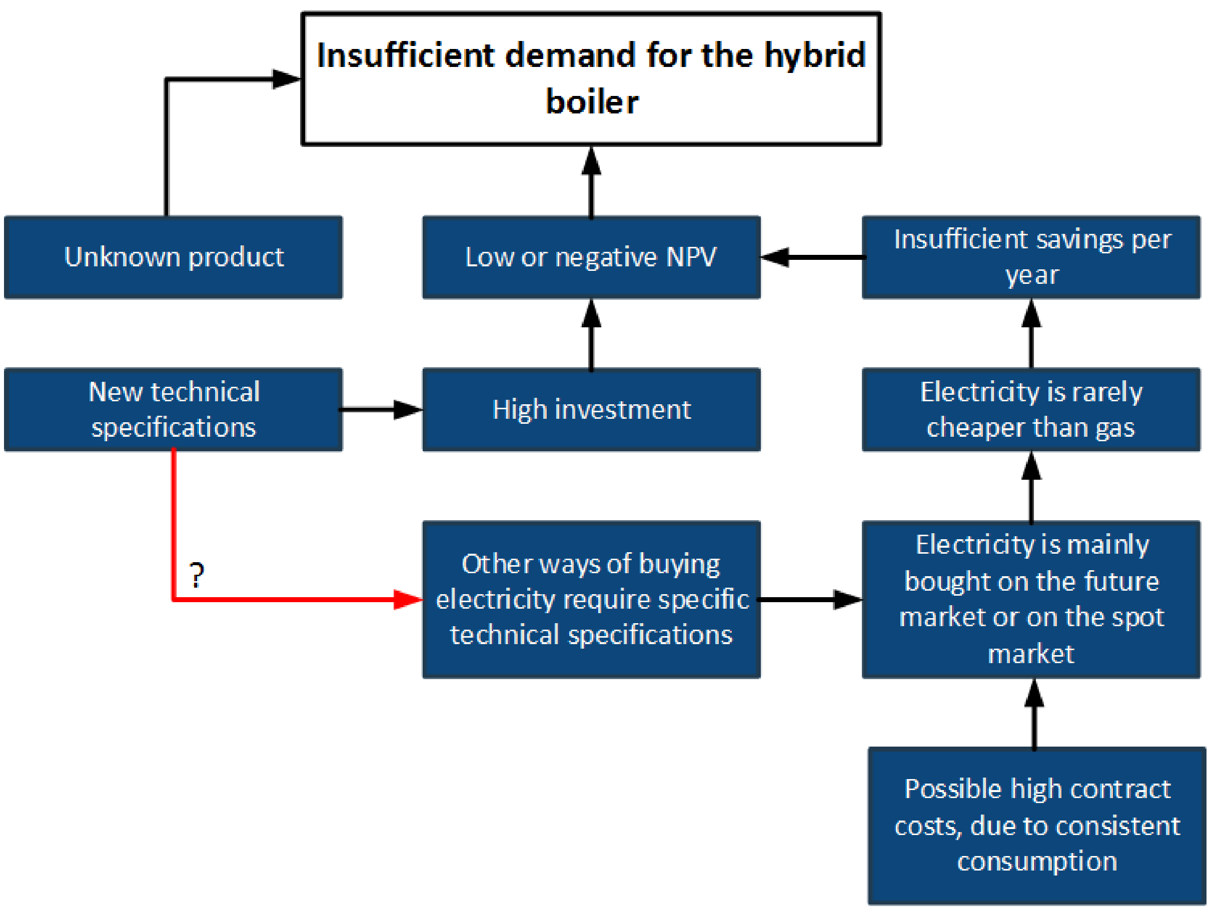


Figure 1: The problem cluster.

Since a boiler is a significant investment, the net present value is quite important. 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. NPV is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project (NPV, Investopedia). So a low or negative NPV is unwanted because it means that the investment is not profitable enough. In this research, two parts influence the NPV, the savings from investment and the cost of investment. To increase the NPV, either the savings have to rise, or the costs have to go down. In the case of the expenses, Stork Thermeq cannot lower any initial investments. Important to note is that the NPV concerns the value of using the boiler. The hybrid boiler should generate value but how much is caused by the way it a plant uses it.

So there have to be improvements on the savings side. The initial idea behind the hybrid boiler is that the e-boiler could take over the traditionally fuelled boiler in case the price of electricity drops under the price of the other fuel. So to get a high NPV, the e-boiler has to be used as often as possible. Regarding the earlier mentioned studies, the price of electricity on the spot markets rarely drops under the price of traditional fuels. That may cause an NPV which is too low. But what will the operating gain be when operating on quicker markets, such as the intra-day, imbalance or reserve market? Operating on quicker markets should be possible since it only takes ten seconds for the boiler to switch energy sources.

In Figure 1, the red arrow stands for this opportunity. Do the new technical specifications enable different buying strategies and how does it influence the savings? When this opportunity exists, it creates a win-win scenario in the current electricity supply chain. A hybrid system should be able to cope with the electricity peaks PV parks or wind turbines cause. That is a win for TenneT because they obtain more partners that help in balancing input and output. The second win is for the plant owners since they get the opportunity to buy electricity for a lower price. The opportunity leads to the core problem.

Two problems in the problem cluster are not addressed yet. First is the problem of the unknown product. This problem has to do with the knowledge of possible customers that Stork has developed such a system. To be able to solve this problem, the sales or marketing method should be the topic. Subjects like marketing and sales are outside the scope of this research.

The second problem is the contract costs. Now, a plant pays a certain tariff for consuming electricity, and the more consistent the consumption is, the lower the contract costs are. When a plant has a predictable need, the contract costs less than when a plant has a variable need. With the implementation of a hybrid boiler, the consumption becomes inconsistent due to a changing use of fuel. Throughout this research, this problem is kept in mind but not researched. The reason not to is due to the specific cases per plant and the bureaucratic atmosphere. To be able to change that situation, discussions have to take place with big players such as TenneT, Eneco, Nuon, et cetera.

1.4.1 The core problem

The core problem of this research is: “Do opportunities exist to get electricity from a quicker market, to increase the NPV?”. Stork Thermeq emphasises this core problem. They conducted a study and found that it would take over 150 years to get an NPV of zero when a plant gets its electricity from the day-ahead market. So it would take 150 years to earn back the investment entirely, without making any money until that moment. For a boiler running on traditional fuel, the NPV should be around zero in four years. For the hybrid boiler, it means that the NPV has to be 0 or higher within four years to be a more attractive investment than a traditional one. The expected savings have to increase to higher the NPV. In this research, the goal is to increase the savings by analysing the intra-day market, imbalance, and reserve market, together with what technical specifications they require from a hybrid boiler.

The low savings are the core problem, because of the opportunities stated earlier when different markets get analysed. Furthermore, the other ends of the problem cluster, which contains subjects like b2b marketing and the development of a boiler, are less in my field of research.

1.5 Research design

The research design exists out of four parts. The first part explains the way of solving the problem. Followed by the restrictions since there are a lot of opportunities to expand this research to an unworkable size. Then, the method of gathering information is determined. Last, this part ends with the research questions.

To compare the savings, the choice for the second fuel is natural gas. This decision makes natural gas the benchmark. Natural gas is one of the less polluting fuels based on CO_2 emissions compared to other traditional fuels. Companies that want to invest in durability, therefore, want their second energy source to be natural gas. From now on, every time the term gas gets used, it refers to the fuel natural gas.

1.5.1 Set up of the research

The most important part is to find out whether the hybrid boiler can participate in another market than the day-ahead market. Therefore the technical specifications of the hybrid boiler must be known, together with the knowledge of the different electricity markets. If any opportunities occur, business cases should differ in ways of buying electricity. Participating in different markets causes a difference in NPV. The solution with the highest NPV is, most likely, found in a business case where the electrical part of the boiler takes over the gas part for the largest proportion of time. Appendix B contains the formula for the NPV. The primary method of how the savings get determined causes this expectation. The main savings consists of the amount of time the e-boiler runs, multiplied by the price difference between electricity and gas. To be able to calculate the main savings, the time that the e-boiler takes over, and the price differences need to be known.

Per business case, the moment that the price of electricity drops under the price of gas and the moment the e-boiler takes over differs. This difference is essential to keep in mind since it influences the possible expected savings. To determine the differences in the business cases, the model uses the same input for every business case.

A property of a boiler to take care of is the designed power of the boiler. It influences two main things, namely the consumptions and the costs. The higher the designed power, the more electricity or gas the hybrid boiler will use. Second, a higher designed power might require extra materials which is needed to build the installation. Generally, boilers Stork designs vary between 10 MW and 50 MW. Since every potential customer of Stork wants a plant-specific solution, the hybrid boiler is not just a product with a predetermined power. Stork can design various iterations of hybrid boilers, including a different power.

The power influences the possible savings. In the model, the calculation for the NPV includes three different powers. Those are 10, 25 and 50 MW.

1.5.2 Restrictions

One of the possible restrictions is that some parts of the information might be too technical. Gaining in-depth knowledge about boilers takes a lot of time. A boiler has too many different researchable topics, such as thermodynamics, which causes a need for pre-knowledge. The gas and electricity markets also exist out of many topics. Since those topics are quite large, this research included only the most significant parameters. Right now, the parameters are the technical aspects of the markets and their pricing.

The second restriction has to do with the savings. Technically, the system can run on both energy sources. This research excludes the use of a combination since it makes the calculation harder to do. It means that if the boiler is running, it runs either on gas or electricity.

1.5.3 Information sources

Most of the information regarding the electricity and gas markets is available in the literature, while the basic knowledge of boilers is within Stork Thermeq. Regarding the requirement of information within Stork Thermeq, there is no particular strategy. My company supervisor provides a lot of information. In case information is needed from someone else, it is no problem because of the open work environment and flat hierarchical structure. The exploratory nature of this study causes the need for literature. Besides the basic knowledge about the boiler and the different markets, the model needs data as input. TenneT provides the required data.

1.5.4 Research questions

The core problem and the scope of the research lead to the main research question. Different sub-questions split the main research question into different parts. The order of the sub-questions follows out of the need for specific information. General information about the boiler is the first step of the learning process. The second step is to understand the gas and electricity markets. If everything goes as expected, a business case pops up. The choice of electricity market provides different business cases. Then, a model calculates the NPV. Therefore, after the gathering of information, the next sub-question is about the model. The finished model gives insight into how the possible savings change. The conclusion focuses on the end value and on the technical implications per business model. A recommendation finishes the research. All the different sub-questions support the main research question, which is:

Which business case for using the hybrid boiler has the highest NPV when functioning on a different market than the day-ahead market, for the designed powers of 10, 25, and 50 MW?

The sub-questions are:

1. How does the hybrid boiler work?
2. How do the gas markets work?
3. How do the electricity markets work, in terms of requirements for functioning and the prices?
   a. How does the intra-day market work?
   b. How does the imbalance market work?
   c. How do the reserve markets work?
   d. What are the technical differences between markets?
4. On which markets is the hybrid boiler able to function?
   a. What are the opportunities per market?
   b. What are the restraints per market?
   c. What are suitable markets to be included in the business case?
5. What are the possible business cases?
   a. What is the definition of the business case?
   b. What does the model look like and what are the input variables?
6. What is the best business case per 10, 25 and 50 MW?
   a. What are the expected savings per business case?
   b. What are the constraints per business case?
   c. What are the recommendations?

1.5.5 Stakeholders

The only real stakeholder in my research is Stork because it is the company that requested the study. They ultimately want to sell more hybrid boilers and want more insights on how to do so. During the research, my company supervisor made it possible to get data from the other departments when needed.

Next, some less important stakeholders exist. Those are possible customers and TenneT. Potential customers are stakeholders because customers think that the hybrid boiler is not a good financial investment to make, although it helps them reduce their CO_2 emissions. This is obviously a sales problem. They are more willing to invest in durable options, but as stated in the problem identification, customers are held back in investing in the hybrid boiler by the prices of electricity on the day-ahead market. That might be solved by operating on a different electricity market, but the customer then has to obtain electricity differently. This change is not an easy one, it requires time and more study. The findings will perhaps be used to convince a customer. That makes them a stakeholder.

Second, TenneT is a stakeholder because, when hypothetically more plants are going to use a hybrid boiler, the supply and demand on the national high voltage grid change. The change is caused by more industrial partners that can use electricity as input for their plant. So more plants will connect to the electricity grid and because they do not always know their exact consumption, add volatility in the output of electricity. Although the change of volatility in output will not be that big, it might be of a considerable size that it will influence choices that TenneT will make while balancing the grid. TenneT might even desire the increased volatility in the output because it can be used to even out the volatility in the input, caused by PV parks or wind turbines. So a couple of stakeholders exist but only Stork is a stakeholder throughout the research. The reasoning behind it is that Stork is the only problem owner and there is no contact with the other two parties.

1.6 Conclusion

The behaviour of the industry regarding the use of energy is changing. Stork wanted to make use of this change and developed a hybrid boiler. Electricity and a second fuel can power the hybrid boiler. This study uses natural gas as the benchmark. Although there was no actual demand yet, Stork still developed the boiler. The development is a risk since you put money in a technology of which you do not know whether it is profitable. The first studies on the NPV of the hybrid boiler were not as positive as Stork thought. However, all studies use the electricity prices of the day-ahead market to calculate the NPV. The day-ahead market is usually the market of choice, but also different markets on which electricity can get bought exists. As can be seen in the problem cluster, there is insufficient knowledge within Stork to determine whether the NPV is higher when electricity is obtained from another market.

Are there opportunities to get electricity from a closer to real-time market to increase the NPV? Opportunities should occur by analysing the technical specifications of the hybrid boiler, the gas market, and the electricity market. The business case uses knowledge on those subjects to in the end calculate an NPV. The corresponding model is going to provide information on which use of the boiler on which market has the most impact on the NPV. The model answers the main research question of the research:

"*Which business case for using the hybrid boiler has the highest NPV when functioning on a different market than the day-ahead market, for the designed powers of 10, 25, and 50 MW?"*

2. Literature study

The theoretical part of the research answers Sub-questions 1 till 3d. The order is in line with the research design. The working of the hybrid boiler is the first part, followed by the gas market and the electricity market. Each of these three sections ends with a conclusion.

2.1 The working of the hybrid boiler

In this part, the working of the hybrid boiler is worked out. To learn about every part of a boiler is quite much since boilers are complex systems. That is why the explanation of the functioning of a boiler is quite general. In the end, the focus lies on the technical aspects of the hybrid boiler regarding its functioning on the different electricity and gas markets. The hybrid boiler is a system in which a classic boiler and an electrode boiler are integrated into one system. So, the first needed knowledge is about a traditional boiler. The second part, the electrode boiler, gives the main differences in comparison to the traditional boiler. The collected information on both boilers enables the explanation of the working of a hybrid system. This section finished with a discussion on the technical requirements and the opportunities.

2.1.1 The conventional boiler

By burning fuel, heat or energy gets released. A boiler uses energy to heat water until it becomes steam. Steam then is used to convert the energy once more in for example electric, kinetic or other forms of energy. Steam is also used to kill the weed in horticulture, or in the wood industry to dry the wood. One of the properties of steam is that it can be overheated, to reach higher temperatures. When heating water in a closed system, energy is put in the system while no energy can escape. The surplus of energy causes water to evaporate. When all the water has evaporated, it does not stay at a temperature of 100 °C. Steam can reach higher temperatures and also higher pressures. This overheated steam can be used for example to generate electricity. Pipes guide the stream to a turbine, which rotates due to the pressure difference. By doing so, it uses the energy in the steam to move. After cooling down, water flows back into the boiler to be heated again. Figure 2 gives an overview of how water flows in a complete system.

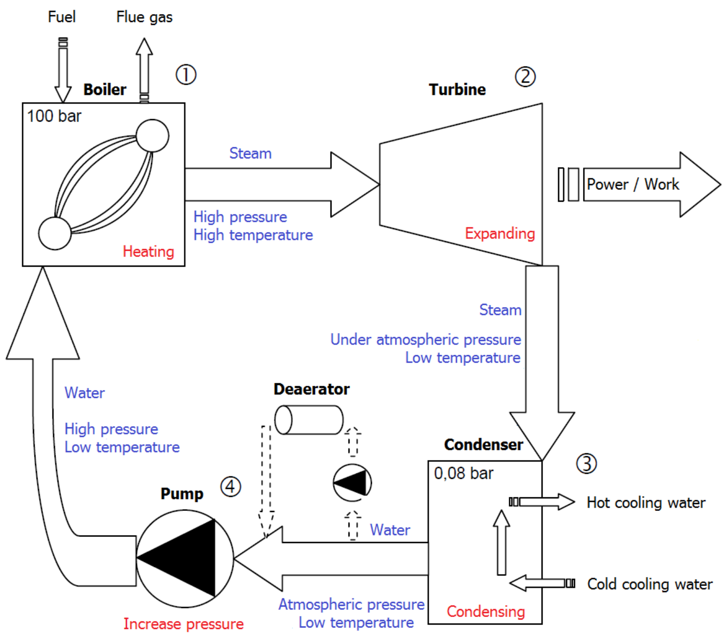


Figure 2: The scheme of the water flow in a power plant

As can be seen, water goes in at a low temperature and steam leaves at a high temperature. Figure 2 suggests that it is only the boiler that is increasing the temperature. However Figure 2 does not include a couple of standard parts the boiler consists of. Commonly, those are the economizer, the steam drum, the evaporator and the superheater. Figure 3 shows the working of a boiler. All the different parts have their role in increasing the temperature. Next paragraph contains a more specific explanation per piece.

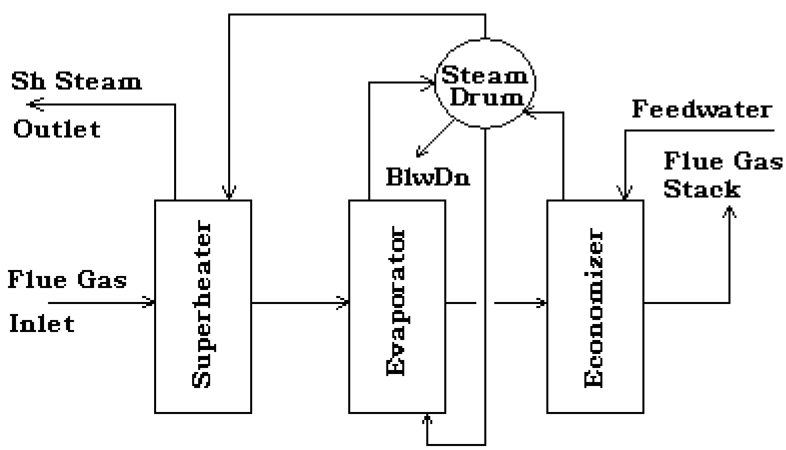


Figure 3: Flows and parts inside a boiler.

- **Economizer**: This part is used to preheat the water before it enters the evaporator. It withdraws heat from the gasses that a burning fuel releases. When for example while burning fossil fuels, flue gasses gets released. The burning takes place in a firebox which is excluded in Figure 3. The firebox would be positioned before in inlet of flue gas. Flue gas is the gas exiting a plant through a flue, which is the space inside a chimney. Flue gas is mostly a combination of nitrogen, carbon dioxide (CO_2), water vapour, any oxygen which is not used during the combustion and some different pollutants. Flue gas has a high temperature. To enlarge the efficiency of the boiler, water that is cooled down after it came out of the turbine gets guided through these waste gasses to warm up again. Thereby the waste gasses lose some temperature. Lowering the temperature of the waste gasses is not all about efficiency; legal purposes require this as well.
- **Steam drum**: Typically, water does not just consist of water molecules. It contains various other materials, which might influence the pipe system. A drum makes sure that the steam that comes out of the boiler is 100% evaporated water, so with no liquid water particles left. The drum works on the difference in density, so water and steam can be separated. The common term for steam which contains no liquid water particles is dry steam.
- **Evaporator:** This is often referred of as the boiler itself. In the evaporator, water gets heated to 100 °C by the heat of the burned fuel. After water leaves the drum, it gets guided through pipes closer to the heat source and back to the drum.
- **Superheater:** There is not one standard temperature of steam which industrial processes use. Every plant needs its own temperatures to run as efficiently as possible. A superheater helps to produce overheated steam. Pipes guide steam close to the combustion. The maximum temperature lies around 700 °C. The superheater is closer to the firebox than the evaporator to ensure the highest temperature.

The four parts together give a simplified explanation of the working of the boiler. The study could be expanded, but it is not necessary for this research. There is one technical remark, the explanation is about a water tube boiler. Other types are available in the industry, but this is the type Stork works with the most.

2.1.2 The electrode boiler

This section explains the differences between the classic boiler and the electrode boiler. In terms of what they do, the two are similar. Still, water gets heated until it becomes saturated steam. The main difference is in the way water gets heated. The evaporator is the part that differs. When the term electrode boiler gets used, it means that it is a classic boiler with an electrode evaporator instead of a normal one. A property of water causes the way an electrode boiler works, namely conducting electricity. Conducting electricity, more specific alternating current or AC, through water heats the water. It is possible to reach such temperatures that water becomes steam. The active surface of the electrodes and the conductivity of the water influence the amount of power an electrode boiler has.

Right now, Stork plans to work with an electrode boiler developed by a company in Sweden, named Zeta. The relevant specifications of this steam boiler type are as follows. It can have powers from 3 to 70 MW, running on a minimum voltage of 6 kV while working under the pressure of 10 to 55 bar. The power and pressure fit the requirements of Stork. The range of these variables creates a lot of opportunities for designing plant-specific solutions.

Unfortunately, the voltage is a restriction. The unique connection which is needed to connect the boiler to the electricity grid is not nationwide available. In the designs of Stork, it would be a 10 kV connection which is required. The need for such a connection might influence the initial investment since a 10 kV connection needs to be bought. Another restriction which is not in the specifications, but required for a working system, is the water which goes in the system. It needs to be of a certain quality, and it must have a specific conductivity. The restrictions bring a couple of technical challenges which might add extra costs to it - more on this in Section 3. The price of the electrode evaporator is around €750.000,- and €800.000,-.

2.1.3 The hybrid boiler

The hybrid boiler consists of earlier mentioned systems. The newness is caused by the way the system is engineered and designed, not by a new machine or a new part that Stork developed. In current designs and plans, the connection of the electrode boiler and the traditional boiler is in parallel. The fact that the connection is parallel means that there is an option to rebuild current traditional boilers into hybrid boilers, by implementing an electrode boiler in the system. Therefore, at least an electrode boiler and some piping are needed. The boiler and the piping cause the minimum of material costs. Optional costs for a system Stork can build also include pumps and nozzles.

The fact that the invention is a system of how to implement an electrode boiler, makes the hybrid boiler as developed by Stork, an invention with multiple usages. It can be paired up with all kinds of different boilers which all use different fuels, for example, coal, natural gas, biogas and biomass. So when hypothetically the Netherlands would get rid of natural gas, the product will not become worthless. For now, as also stated in the research design, only a gas-powered evaporator is used as the counterpart of the electrode boiler in the hybrid boiler.

A couple of other specifications or technical requirements are worth mentioning. One is the standby function and its ability to switch from energy source quickly. When the boiler runs on gas, the electrode evaporator can go on standby to react as soon as possible when needed. The system is in standby when the water level is under the electrodes while keeping the water warm with a metal spiral. When required, the water level raises to the normal level, which immediately will cause the production of steam. The second technical influence is the required maintenance per year. It does not cost that much, but it influences the cost per year. It comes down to renewing some insulators once per year.

2.1.4 Conclusion

The answer to Sub-question 1 is that the hybrid boiler is a system that consists of a traditional boiler and an electrode boiler. After installing an electrode boiler parallel to the traditional boiler, a hybrid boiler runs on two energy sources. With the implementation of the electrode evaporator, some restrictions pop up which do not exist for a classic boiler. Examples are water conductivity, the need for a particular grid connection, and yearly maintenance costs. On the other side, it creates opportunities with the standby function, which enables a quick switch between the energy source.

2.2 Gas market

This section answers Sub-question 2. Since the layout of the Dutch gas market changed a lot throughout time, the next paragraph contains a short overview. Section 2.2.2 explains the current state of the gas market. The end of this section is an overview of the prices of the last years and concludes this section with the main findings to use in the business case.

2.2.1 Brief introduction and history

Since natural gas was found in Groningen in 1959, the Netherlands became Western Europe's leading gas supplier. The discovery created a new situation. An excess of gas caused the Netherlands to focus on export. At its top, 80 billion m^3 was produced per year. Around 75% got exported to other countries (Schipperus & Mulder, 2015). But the reserves are depleting and the number of earthquakes per year increased. The KNMI registered 124 earthquakes in 2017, compared to 7 in 2002 (Interactieve kaart, NAM). Both aspects did influence the gas market in the Netherlands. Formerly, the focus was exporting gas but after the governmental restrictions the focus became trading. To enhance trading, the Dutch government came up with policy measures which made it possible for the market to become a virtual gas hub. The virtual hub is represented as a virtual trading point neglecting all the physical characteristics of the network (del Valle et al, 2017). A gas hub is the heart, or a roundabout of a gas network, consisting of pipes and liquefied gas terminals. The hub is used as a central pricing point for the network's natural gas. It caused the gas market to be more liquid and more transparent since more parties are involved in trading.

2.2.2 Current system

The name of the Dutch gas hub is the Title Transfer Facility (TTF), set up in 2003. Gasunie Transport Services (GTS) manages the TTF. They are responsible for the systems and the parties that trade on it. The TTF is a virtual marketplace, where participants get the opportunity to trade gas which is already present in the system. The availability of gas in the system is called entry-paid gas. Using the TFF, gas can switch from its owner before it leaves the grid. With the help of a gas exchange, traders can sell or buy gas on the TTF. Right now, the ICE ENDEX and Powernext are the two power exchanges. A trade gets registered in the form of a nomination. A nomination is an electronic notification stating the volume of gas transferred, the period and the buying and selling parties (TTF, GTS).

In 2011 the most recent market model got introduced. The TFF has become the central trading point for all natural gas in the Dutch transmission system, and a new balancing regime has been introduced (Mirrelo & Polo, 2015). Every market party is responsible for keeping its portfolio balanced through buying and selling gas on the TTF. Every market party determines their entries, exits, and trading plans for the day-ahead. GTS then publishes the Program Imbalance Signal (PIS) which is the accumulated balancing position of every participant. All the PISs summed up result in a System Balance Signal (SBS). When the SBS is not equal to zero, a system imbalance occurs. It becomes then the task of GTS to make sure the market gets corrected. A Bid Price Ladder (BPL) helps to fix the market. A BPL is a system that is the last opportunity for participants to sell or buy gas from GTS. The participants that help to solve the imbalance will earn money, the participants who cause it have to pay a fee, based on the costs involved during that particular imbalance situation. Figure 4 shows the schematic working of the TTF.

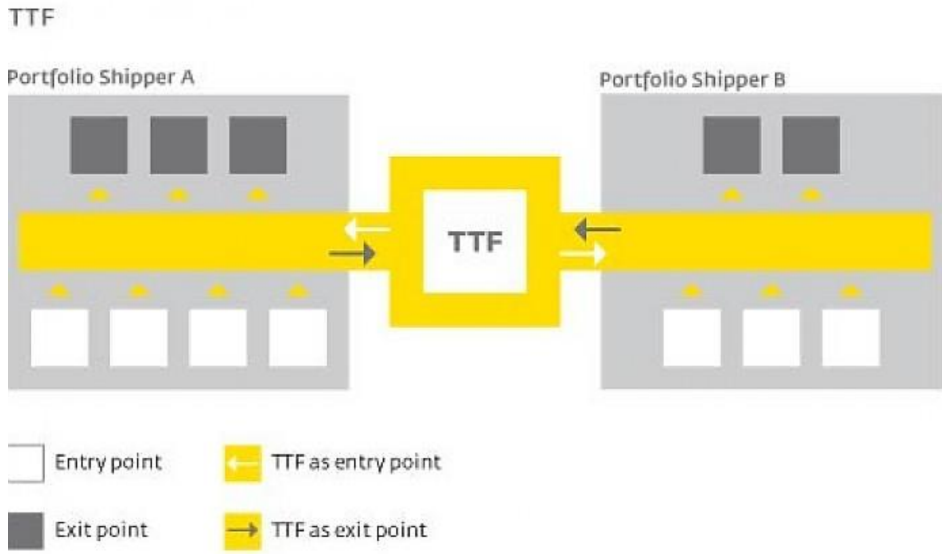


Figure 4: Schematic working of the TTF. (Retrieved January 18, 2019, from https://www.gasunietransportservices.nl/shippers/producten-en-diensten/ttf)

When all deals are closed, gas is transported to the end consumer. From the market participants, gas can go to an end consumer, but this is not always the case. Suppliers who do not trade on the TTF can buy their gas from another market participant to sell it to an end consumer.

2.2.3 Markets

The duration of the contract and the traded volume cause a difference in the products traded in different markets. Therefore two different markets exist, the spot market and the forward market. On the spot market, products are traded that provide gas directly or up to 30 days later. The day-ahead and within-day are both submarkets of the spot market. The difference between those markets is the moment on which the market functions. The day-ahead market is used for trading volumes that are used the day after. A gas day starts at 06:00 am and ends 24 hours later. So when contracts are traded on Tuesday, the Wednesday after delivery will happen. The within-day market is the last moment to buy or sell gas, to fix any deviations in the portfolio of the market participants. For this market, the tradeable delivery period is calculated from the time of the beginning of delivery (the next full hour after the conclusion of the trade plus three full hours preliminary lead time) and the end of delivery at 06:00 of the following calendar day. For example, if you want to fix any deviations at 11:30 and instantly close a trade, the gas will be delivered from 15:00 to 6:00.

Every market participant trades on different markets or with other participants to create a portfolio. This portfolio is used to buy or sell gas, depending on what the focus of the company is. Examples of market participants are Eneco, De Nederlandse Energie Maatschappij, and Gazprom.

2.2.4 Prices

The leading gas price is TTF price, the price on the day-ahead market. The TTF price is dependent on a couple of factors. The prices at hubs can be viewed as prices resulting from gas-to-gas competition (Hulshof et al, 2015). Fundamental factors affecting demand or supply in the gas market have significant effects on the movements in the day-ahead price. Those factors can be variables like temperature. The colder it gets, the more gas is wanted to heat for example households.

A second factor that has some influence on the price of gas is the price for carbon credit. Since the European Union decided that the CO_2 emissions had to go down, big plants are now required to get certificates per tonne CO_2 they want to produce. These certificates are traded on a market called the EU ETS.

Last, the amount of gas needed also influences the price, since bulk discounts play a role in the gas market. The required input of gas is also related to the designed power of the hybrid boiler. The higher the designed power, the more gas it uses per hour. The higher consumption of gas influences the bulk discounts. The set up for the model in Section 4.3.1 gives more information about bulk discounts.

Future of the price

The prediction for 2019 is that the gas price increases, due to a converting policy of the EU ETS. The policy states that there will be 40% less carbon credit available to be traded (MarktRapport week 51 2018, Nuon). The price in 2017 has increased by 30%. Figure 5 shows this. Since it is usual to buy gas a couple of years upfront, most charts regarding the gas prices include the gas prices for multiple years. The years in the chart stand for the price for gas if you buy it now for that particular year.

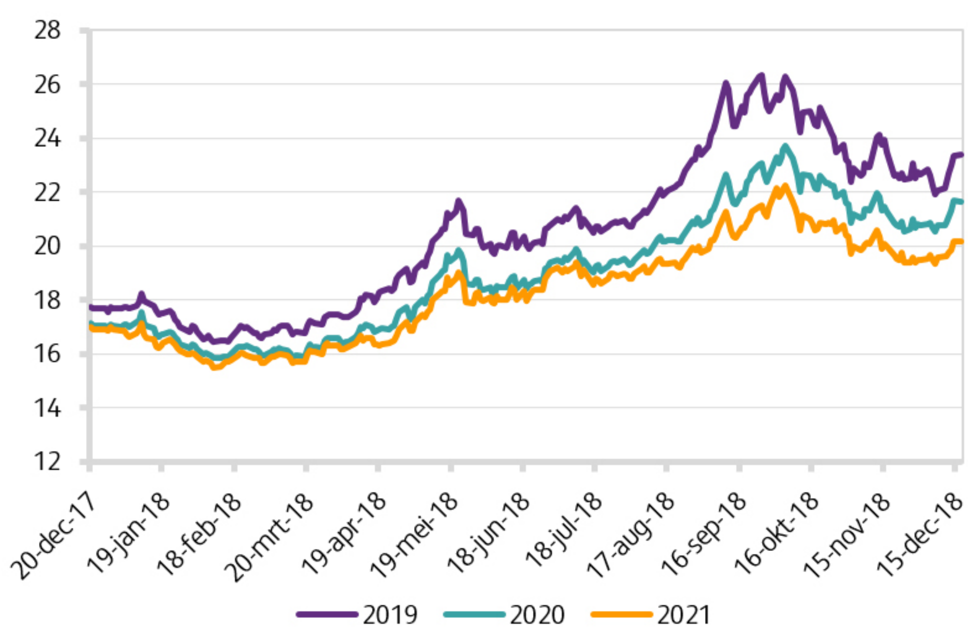


Figure 5: Behaviour of the gas price over 2018. (Retrieved January 1,2019 from https://www.nuon.nl/grootzakelijk/energiekenners/business-bibliotheek/marktrapport-2018-51/)

The gas price as input for the business case

To be able to compare the prices of electricity and gas, historical data from 2015 to 2018 are used. The used price is the TTF price. This choice is due to the availability of data and the volumes that are traded on the different markets. The TTF price in the last years is available, as well as the influence of the total consumption on the bulk discount. The input is the average prices per MWh per year, as published by the CBS. Figure 9 shows these discounts, in Section 4.3.1.

2.2.5 Conclusion

An overview of the findings summarises the answer of sub-question 2. First, the TTF is the Dutch gas hub which makes it possible to trade gas daily. Market participants do so to be able to deliver gas to their customers, since not every plant is trading gas for themselves. A couple of different markets provide the purchase of gas, the day-ahead, the within-day and imbalance market. The markets differentiate by the moment the gas is traded. The closer to real-time the market is, the more volatile the prices get and the lower the traded volumes are. Per supplier and end consumer, the prices are different. The two factors that influence the gas price are the weather and carbon credit costs. The business cases use an average gas price per MWh per year.

2.3 Electricity market

This section contains a couple of sub-questions. Section 2.3.1 gives a brief overview of the current system, with a focus on the balancing activities the transmission system operator (TSO) does. Section 2.3.3 explains the difference in markets by evaluating the price and some technical requirements. The last section contains the most important conclusions. The business case and model use those conclusions to get to an optimal case ultimately.

2.3.1 Current system

In the current Dutch system, six different players are somehow involved in the movement of electricity. This section gives a summary of the six players. To start, Figure 6 provides an overview of the players.

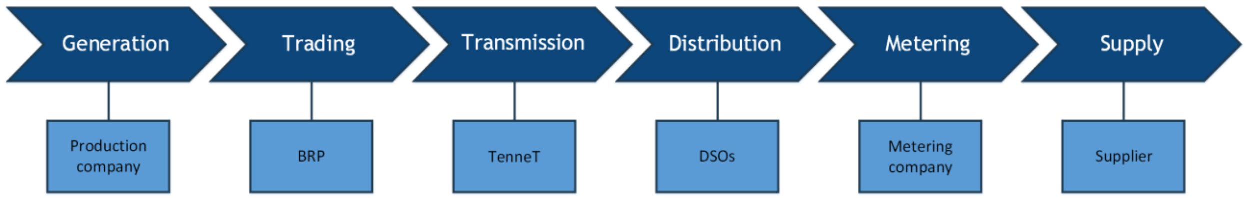


Figure 6: Schematic view of the electricity supply chain.

Generation

It starts with the generation of electricity. A couple of options of how electricity is generated are standard in the Netherlands, namely:

- Fossil fuel powered plants.
- Onshore and offshore wind turbine parks.
- PV fields and privately held PV systems.
- Nuclear plant.
- Hydropower plants.
- Biomass plants.
- Plants which implemented a combined heat and power installation.

In 2017, around 70% of the Dutch gross electricity production came from fossil fuels (TenneT, 2017).

Trading

Big plants want to trade the generated electricity. The abbreviation BRP in Figure 6 stands for balance responsible party. A BRP is a private legal entity that monitors the balance of one or multiple access points to the electricity grid. Every generator and consumer in the grid is obliged to have a contract with a BRP, or alternatively be their own balance responsible party (Market review 2017, TenneT). In general, BRPs have an extensive portfolio where they have contracts with many generators or consumers. BRPs are players that trade on centralised and international markets. Examples of BRPs are Eneco, Stedin, and Nuon.

Transmission

The third player is the TSO, TenneT. TenneT is a company 100% owned by the Dutch government, which has the responsibility to control the high-voltage grid. High voltages are voltages from 110 kV and higher. For the lower voltages, DSOs are responsible. Managing the grid means keeping the in- and outputs the same. The frequency of the AC is the difference between the input and output. TenneT is obligated to keep the frequency in the grid between 49,8 and 50,2 Hz. A stable frequency is necessary because electricity cannot be stored, which is caused by the physical properties of electricity. Since TenneT is only a facilitator for the transport of electricity, it is dependent on the behaviour of BRPs. That is why every BRP has to inform TenneT daily what their transactions are going to be. Per imbalance settlement period (ISP), which is 15 minutes, TenneT measures whether any deviations in the portfolio of the BRPs exist. When these deviations occur, BRPs can trade with TenneT to equalise their portfolio.

The way TenneT can fix any leftover deviations is by using balancing reserves. Parties that generate or consume electricity when TenneT asks them to have a contract with TenneT mostly. By law, TenneT is obliged to contract a minimum capacity of different reserves to assure sufficient reserves can be activated to fulfil their local demand (Market review 2017, TenneT). More on this in Section 2.3.2.

Distribution

When the electricity leaves the high voltage grid, the distribution system operators (DSOs) manages it. DSOs are responsible for the construction, maintenance, management and development of the transportation and distribution networks for electricity between the high voltage grid and the customers (Tanrisever, 2015). In total, the country has eight DSOs spread over the country.

Metering

A metering company registers the actual amounts of electricity which get generated or used. Under the Dutch Electricity Metering Code, based on the Electricity Act of 1998, metering activities may only be outsourced to parties that have been authorised by TenneT to perform such operations. They check whether the delivered power is according to the agreements (Metering responsibility, TenneT).

Supply

Last, the supplier is the party responsible for the end delivery from households to businesses. A DSO can be a supplier as well, but this is not always the case. The supplier makes money by selling it to the end consumer with a little margin.

2.3.2 Balancing

As stated earlier, TenneT is responsible for keeping the high voltage grid stable. Stabilising the grid is called balancing and can be seen as real-time buying or selling electricity by a TSO (Market review 2017, TenneT). It might happen that BRPs do not meet their promises, but the consequences differ. When you generate more or consume less than scheduled, then there is a certain surplus of electricity. This surplus can be sold for the imbalance price. But when you use more or generate less than scheduled, there is an imbalance shortage. Shortfalls like this can be fixed by paying the imbalance price for the deficit. The imbalance price is dependent on the reserves used. Therefore an understanding of the reserves is needed.

Balancing service providers (BSPs) manage the three different reserves. Those are parties that somehow can generate or consume electricity, and have a contract with TenneT how to do so. The reserves are the frequency containment reserve (FCR), the automatic frequency restoration reserve (aFRR) and the manual frequency restoration reserve (mFRR) (Ancillary services, TenneT). The last market, the mFRR, has two submarkets, the mFRRsa and the mFRRda. The difference between those is the way the reserve gets activated, scheduled activation (sa) or direct activation (da).

Working as a FCR reserve

The FCR is the reserve power that is activated under the control of the primary regulation. The primary control is a locally designed automatic device, which ensures a constant ratio between frequency change and installation or power change within a maximum of 30 seconds (site TenneT). The primary goal of the FCR is to stabilise frequency disturbances in the entire grid. The activation of the reserve goes entirely automated by orders TenneT gives to the contracted systems.

Working as an aFRR reserve

The second reserve is the aFRR. TenneT mainly uses bids offered by BSPs. They determine how much they can deliver and for which prices. TenneT enters into capacity contracts with BSPs to make sure BSPs place enough bids. More on this on the market explanation of the aFRR. A technical specification of the aFRR is that when your bid is accept, your system has to react within 30 seconds, and needs to have a ramp rate of at least 7%.

Working as a mFRRda reserve

The mFRRda or incident reserve is used for maintaining the balance in case of incidents and substantial, long-lasting power deviations. A BSP which functions as a mFRRda reserve has an obligation to be able to draw or supply the power agreed from the Dutch grid when TenneT says so.

Working as a mFRRsa reserve

Last, the mFRRsa looks a lot like the aFRR, but the main difference is the call time. A mFRRsa has to be activated after 15 minutes and indicates what it generates or draws per 15 minutes. This period of 15 minutes is also called a price time unite (PTU). Since this reserve mainly concerns the more significant installations. The lack of no contracted bids is another difference.

The reason TenneT has multiple reserves is due to their working and timing. When the FCR needs to run for an hour, it cannot fix any deviations for that next hour. When new deficits occur while all FCR powers are running, the system reacts more slowly. So the reserves gradually take over each other. If the FCR cannot fix the differences, the additional reserves take over. Around 80% of the leftover imbalance after the FCR, is taken over by the aFRR (Lampropoulos, 2018). Figure 7 gives an overview of the different reserves and their call time.

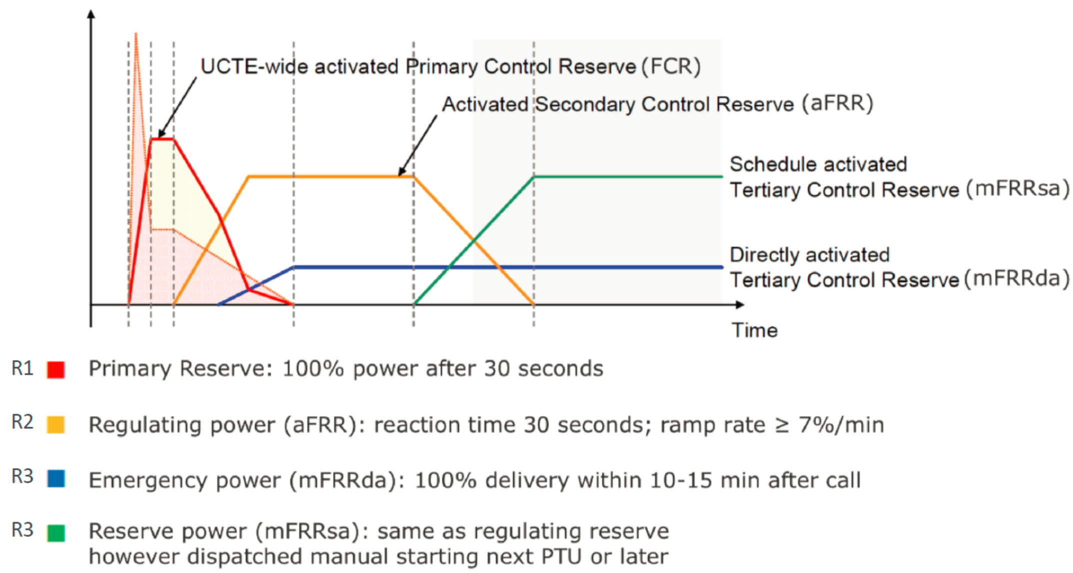


Figure 7: Short term balancing requirements in the electricity grid (Source: internal presentation Stork).

2.3.3 Spot markets and imbalance market

Plants have various ways to obtain electricity. As stated in Section 1.3, the current studies use the prices distracted from the day-ahead market. The order of the discussed markets is their moment in time. This section starts with the day-ahead market and ends with the mFRRsa. The way a BSP or BRP sells or buys electricity defines the working of the market. This research excludes any further from real-time markets than the day-ahead market.

Day-ahead market

Both the day-ahead and intra-day market are spot markets, regulated by APX. The definition Investopedia (Spot market, Investopedia) gives of a spot market is: “The spot market is where financial instruments, such as commodities and securities, are traded for immediate delivery.” The difference between the two, as their names suggest, is the period in which the market is open. The day-ahead market opens at 00:00 on the day before delivery. From that point, orders may be placed. At 11:00, TenneT releases an available transmission capacity, which will tell the BRPs how much capacity will available be per hour. Last, at 12:00 the auction closes, and the APX software calculates the corresponding prices. They publish the prices at 12:55 and the prices are binding. The format the market uses is a two-sided, double-blind auction. It means that both sellers and buyers may place anonymous orders, with different prices and quantities on an hourly basis. The total sum of those orders results in demand and supply curves for each hour of the next day.

Intra-day market

Contrary to the day-ahead market, the intra-day market starts at 15:00 the day before delivery. Trading on the intra-day market is the last opportunity for spot market-based transactions before submitted schedules become financially binding. A BRP can trade up to five minutes before delivery. The format of the intra-day market is continuous trading. Continuous trading means that BRPs submit supply and demand bids to a central platform, and matching bids are continuously cleared on an individual basis (Brijs, 2017). The continuous trading order book is visible to all BRPs, and contain all submitted bids that have not cleared yet. BRPs can cancel bids at any given time. This format makes it possible that each trade uses different prices. The price on the intra-day market is more volatile than on the day-ahead market, which means that the price of electricity on the intra-day market does drop under the price of gas more often than the price on the day-ahead market.

Imbalance market

As said in Section 2.3.2, TenneT is responsible for balancing the grid. After the intra-day market closes, unforeseen differences between the scheduled generation and consumption and the actual values can occur. Brijs et al. gave five possible reasons why namely:

- Unexpected renewable energy source generations variations.
- Unexpected consumption variations.
- Unplanned outages of generations and consumption capacity, and grid elements.
- Discrepancies between the durations of day-ahead or intra-day market periods and real-time settlements periods.
- The discretisation of continuous time in discrete market periods.

When a BRP deviates from their schedules volumes, TenneT acts as an artificial market participant that trades with a BRP for a certain price. This price is known before the trade happens and is highly volatile. The imbalance bidladder constructs the price. All bids per ISP combined give an overview which tells how much it costs to generate or consume a certain amount of power. Figure 8 shows an example.

The bidladder works as follows. Say TenneT calculates that there is a shortage during one ISP. Then the profits position becomes long, which means BRPs that can generate more electricity than they first predicted. They can get up to the maximum price on the y-axis for selling electricity to TenneT. Using electricity from the grid while the ISP in this position becomes quite expensive since rejecting electricity costs the same as generating.

On the other hand, there can be an excess of electricity. An excess means that BSPs that can consume more than they first planned to can get their electricity for a lower price. The situation can be that TenneT has such a significant excess, that prices become negative, so TenneT pays a BSP to use electricity. In this situation, generating electricity will result in lower marginal profits, and if the line of the bidladder is under 0, you have to pay to inject electricity into the grid.

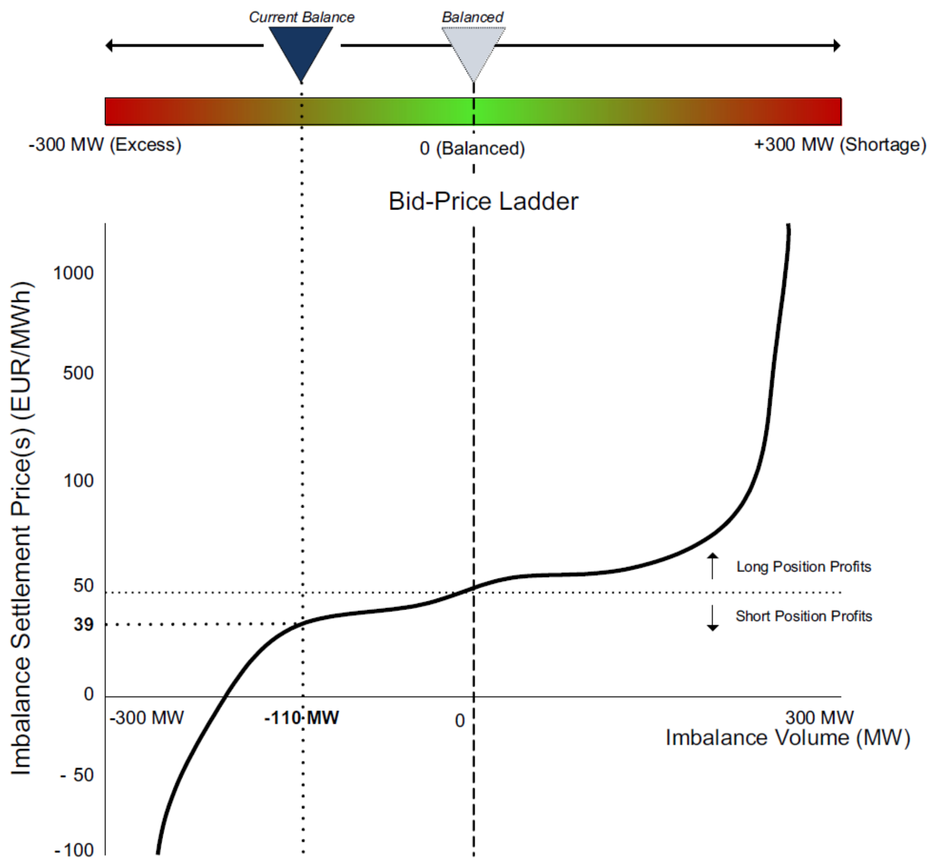


Figure 8: Example of the imbalance bidladder (Lampropoulos, 2018).

A rule about the prices is that the price of additional electricity increases exponentially as the total shortage increases. On the other hand, the price received for electricity decreases as total surplus increases; it can even become negative (Lampropoulos, 2018). Bids can be placed six quarters before the current quarter.

2.3.4 Reserve markets

In case the sum of the BRPs last adjustments cannot make up for the differences, TenneT needs to have something to trade at the imbalance market. Therefore, TenneT has different reserves which can fill the gap. Per reserve, TenneT made up various constraints on how they want to buy or sell electricity. For example, TenneT has a different procurement process and reward system per reserve.

Market for FCR generated power

TenneT organises two weekly auctions to purchase FCR volumes. A national and an international auction for other TSOs. The collection of those TSOs are all member of the Union for the Coordination of the Transmission of Electricity (UCTE). The agreement means that a total of 24 countries can help each other by providing FCR. The price per MWh is dependent on imbalance bidladder prices. Next, a weekly fee for passively having power available is paid when in contract with TenneT. The average payment per MW is €2.450 in 2017.

Market for aFRR generated power

To get contracts with potential aFRR reserves, TenneT organises a weekly and monthly tender. To tender is to invite bids for a project or accept a formal offer such as a takeover bid (Tender, Investopedia). Tender usually refers to the process whereby governments and financial institutions invite bids for large projects that must be submitted in a finite deadline. For TenneT, there must be a minimum quantity of aFRR available, so they always have to have ongoing contracts with suppliers. A contract means that suppliers have thereby committed themselves to bid at least the contracted quantity. Other parties that do not have contracts are also allowed to bid their available capacity. This way, the price of the electricity out of the aFRR is determined on bid price only, and not just on the behaviour of the partners TenneT has. All bids together make a reserve bidladder, which is a different bidladder than the imbalance bidladder.

The merit order system determined the acceptance of a bid. A merit order is an order method based on the marginal price. So the cheapest bid for delivering electricity gets bought first, then the second cheapest and so on. TenneT keeps buying or selling until they reach the required in- or output. When in contract with TenneT, the fee for passively having power available is somewhere around €87.500 per MW per year in 2017.

Market for mFRRda generated power

TenneT has a contract with suppliers who have mFRRda available. No non-contracted partnerships exist. The incident reserve supplier has the obligation, over the entire contract period, to be able to draw or supply the power agreed from the Dutch grid on call from TenneT. Again, the merit order system determined which party has to generate or use. TenneT purchases their mFRRda reserve quarterly and monthly (Website TenneT). The mFRRda also gets rewarded for the fact that it is passively available, and usually an MWh price around €200,- is paid.

Market for mFRRsa generated power

For this reserve are no contracts. The marginal price of the highest bid called determines the price. Since this reserve will be scheduled for the next quarter, the market is less hectic, and the amount of mFRRda cause a lower amount of traded volumes.

The monthly fees are from the market review TenneT did in 2017. For the model, the chart provides an estimation for the yearly or weekly fee. This chart only gives the fees for FCR and aFRR, but not for the mFRRda.

2.3.5 Differences between the reserve markets

The main differences between the reserves exist out of two parts: technical differences and the way TenneT buys excess electricity. The technical differences are different when the moment of activation differs, as Figure 7 shows. If a plant wants function as a reserve, their installations have to be designed in such a way that they reach the contracted call times. Running at full power within 30 seconds is not something all systems are able to - the same counts for the minimum ramp-up rate of 7% for the aFRR. Also, the amount of contracted power differs between the reserve markets.

Secondly is the pricing. Pricing differs between contracted and non-contracted reserves, as well as the earnings per MWh and being passively available. Each reserve has different values. Appendix A gives the overview Lampropoulos (2018) made. Their table provides a complete summary of the differences.

2.3.6 Conclusion

This conclusion contains the answers on Sub-questions 3 till 3d. The overview below gives a summary about the technical requirements, and the working of the different markets. Because this part contained multiple sub-questions, the sub-questions are answered individually.

3: How does the electricity market work, in terms of technical specifications and the prices?

The electricity market is built around the supply chain. Every generator or consumer is linked to a BRP, which is responsible for its portfolio. In this portfolio, the total input or output is given per 15 minutes. The BRPs have the responsibility to fulfil their promises, which can be hard to do. This is caused by the predictions that have to be made, which could differ from the exact portfolio of the BRP at real-time. To make sure the BRPs are able to keep their promises, electricity is traded in different manners and on different markets.

3a: How does the intra-day market work?

The intra-day market is quite similar to the day-ahead market. The market is operated by APX, and electricity can be traded until five minutes before delivery.

3b: How does the imbalance market work?

The imbalance market is the last opportunity for BRPs to adjust their portfolio. Electricity is traded with TenneT, based on an imbalance bidladder. This bidladder is constructed per 15 minutes. The prices are more volatile than on the intra-day market and are more often lower than zero. This is favourable since a negative price means that TenneT pays the BRP to consume electricity.

3c: How do the reserve markets work?

The reserve markets are managed by TenneT, to have something to trade with BRPs when they cannot fix the deviations in the grid themselves. TenneT uses four different types of reserves. These are the FCR, the aFRR, the mFRRda, and the mFRRsa. Per reserve, there is a different procurement process to contract power. BSPs go in a contract with TenneT to make sure there is power available to fix any discrepancies when needed. Per reserve, the fees for passively having power available and the price per MWh differ.

3d: What are the technical differences between the markets?

The main technical differences can be found between the reserve markets. The intra-day and imbalance market are within the normal way of buying electricity and do not require any technical specification compared to the day-ahead market. Electricity gets bought and is delivered at the desired moment. The technical differences for the reserve markets are the amount of power, ramp rate, reaction time, and time span.

3. Functioning of the hybrid boiler on different electricity markets

To determine whether the NPV of the hybrid boiler increases when it operates on another electricity source than the day-ahead market, we combine the working of the different markets and the hybrid boiler. Each electricity market has different opportunities and requirements regarding the hybrid boiler. Section 3.1 until 3.5 give information on these properties.

However, a concern about the inflow of gas exists. In the most extreme case, the hybrid boiler can switch between electricity and gas per quarter. That is no problem for the imbalance market and reserve market for electricity, but gas is traded in hourly products. So to be able to use the e-boiler as many quarters as possible, the inflow of gas needs to be flexible as well. When constructing the business cases, the assumption is made that it will be possible. Chapter 6 gives more information on the assumption.

3.1 Intra-day

The intra-day market looks a lot like the day-ahead market. When looking at the prices of electricity, they do differ a bit in comparison to the day-ahead market. Unfortunately, not enough for the NPV to increase significantly to reach an NPV of 0 in four years. That is why the intra-day market is from now on excluded from the research. The expected possible savings are not high enough.

3.2 Imbalance

The way the hybrid boiler can function on the imbalance market is as follows. Last moment adjustments in generating or consuming electricity cause an imbalance and make the market. The hybrid boiler can adjust close to real-time because of the turn rate. To increase the savings of the hybrid boiler, a plant first communicates that it will not use any electricity and will run solely on gas. But when TenneT has an excess, you can place a bid to consume electricity and switch your system to electricity. That causes a change in the BRPs portfolio, which can be used to solve the imbalance.

A question that pops up is how and who is going to determine the bids and whether the boiler has to switch. It needs to be done in a short amount of time. Therefore, Stork partnered with a company that has built software which can be connected to the boiler. This software can place bids and can turn on the electric part of the boiler. With this technology, the hybrid boiler is perfectly able to function on the imbalance market.

3.3 FCR

The FCR is technically the most challenging one. The system has to work on full base load within 30 seconds when TenneT says so, since a plant agreed on it. Therefore, using the hybrid boiler as FCR comes with three considerations.

The first consideration is the ramp up situation. To reach full power within 30 seconds, the system has to run on gas so that it can switch. This strategy is similar to the imbalance market. Since TenneT gives the order, there is no information when your particular system is going to change fuel. Although the switch is quick, it might cause a little loss of energy which goes into the plant, also on the way back. The moment the system switches back is unknown as well. The moments that the electrode boiler runs are less predictable than on the imbalance market, due to the bidding system. This is done by software but can be regulated by an operator who has then more insights into what the system is going to do.

The second consideration is somewhat technical. To run on full power, the electrodes need to be covered in water. The standby function now keeps the water warm under the electrodes, so to set them under water again, water has to be pumped up. To be able to run at full power within 30 seconds, there is a chance per installation that the CAPEX increases because of extra pump power.

The third consideration is the fact that the system works with contracts. Since a weekly auction determines which plant they contract for the passive power, it might happen that TenneT excludes your bid for that week. Also, the FCR power procurement system is dependent on demand and supply. So it is possible to be contracted for all the weeks, but that will influence the agreed fee you will get for having the power available.

3.4 aFRR

The aFRR consists out of contracted and non-contracted reserves. Both contracted, and non-contracted reserves have to bid a minimum of 4 MW and have to be able to ramp up, or down, with at least 7% of the traded volume per minute. By activation, the minimum value is 1 MW. Since the minimum power used in this research is 10 MW, those requirements are no problem. Also, the ramp rate of 7% is no problem. Contrary to the FCR, no extra pump power is needed, because of the ramp rate.

The next consideration is whether being contracted is a profitable option. Being contracted has the advantage that money is earned for the not working e-boiler. So although the system runs on gas, the fact that power is available for TenneT provides some income. The only disadvantage is the fact that a plant is obligated to make a bid when TenneT says so. Non-contracted systems have more flexibility in deciding what energy source to use at a particular moment since they have no obligation to bid when TenneT asks them so.

However, there is a concern. Although the switching speed of the boiler is suitable for the quickest reserves, the first concern holds for all contracted reserves. When having a contract with TenneT, they expect you to be able to generate and consume electricity. Therefore, a plant needs a partner which can compensate for the fact that the plant is only consuming electricity. An example of such a party is an aggregator. An aggregator is an instance which brings both producers and consumers together. The combination of multiple plants, wind turbines or PV parks makes it possible to reach an equal amount of power, on the generation and consuming side. That is why the assumption is made that no problem occurs when a plant only wants to buy electricity from the reserve markets. However, the fact you need a “buddy” causes the yearly fee to half, since the two of you together work as one reserve. The shared fee is not the case for the FCR.

3.5 mFRR

Both mFRR reserves seem less potent for the hybrid boiler than the FCR and the aFRR. The lack in potential is due to their timing, powers and for specifically the mFRRda the lower yearly fee. The time in which the hybrid boiler can switch is less relevant for this reserve. Also, the required powers are in 5 or 20 MW. Since the minimum power of the hybrid boiler is 10 MW, this reserve is not compatible with all powers. Last, the difference in yearly fee can be made up with the price per MWh. But in order for the mFRRda to be more profitable than the aFRR, at least 500 MWh per year has to be generated serving as mFRRda. This is not guaranteed. To conclude, the business case exclude the mFRR.

3.6 Conclusion

This section gave an answer on Sub-questions 4a and 4b, mainly focussed on the differences per market. The main conclusion of this chapter is Sub-question 4c, namely which markets are suitable to be included in the business cases. After considering the five different markets, the business case uses only three of them. They seem optimal, there are no technical difficulties, and the possible savings are expected to increase sufficiently to get the wanted NPV.

4. Design of the business cases

In this chapter, we construct the business cases. We start by defining the general business case. Section 4.2 explains the choices for the differences per the business cases. Then, different business cases require different calculations. Section 4.3.3 gives an insight into how the calculations work and what the corresponding assumptions are. The last section enumerates the differences per business case.

4.1 Definition of the business cases

The definition of the business cases consists out of two parts. First what the expected savings are in a year, comparing the differences in the electricity and gas prices. For this purpose, the idea of how much could be saved if the plant had used a hybrid boiler instead of a traditional boiler in a year is crucial. The hybrid boiler creates the opportunity to save money by requiring the electricity from one of the three chosen markets. Filling in the variables in the model gives an overview of the possible savings, which then provides the input for the cash flows.

Second are the cash flows which result in the NPV, which is the most important value, as stated in the core problem. Cash flows up to four years are calculated and discounted, to obtain the NPV of the investment.

4.2 Possible business cases

The goal of the business cases is to give more insight into what the cash flows and NPV are of the hybrid boiler. With the current three chosen electricity markets, four business cases are constructed. These are:

1. Getting electricity from the imbalance market.
2. Getting electricity as FCR reserve.
3. Getting electricity as contracted aFRR reserve.
4. Getting electricity as non-contracted aFRR reserve.

The aFRR is part of two business cases because of the flexibility it gives to be non-contracted. Since the entire research is built around the flexibility which the hybrid boiler can provide to a plant, it is interesting to know what extra flexibility might cost.

4.3 The model

First, all the input variables are determined, followed by the restrictions and the calculation. Last, the choice for the output variables is explained.

4.3.1 Input

For the business cases, five variables are used. Those are the gas price, electricity price at the imbalance and reserve market, carbon credit price, designed power, CAPEX and OPEX. Together they make it possible to calculate the savings that the hybrid boiler would have provided in a certain reference year. The reason of choice per variable is given below.

Gas price

The gas price is a quite generic number. No clear data per month are available since there are no connections to suppliers in my research. Suppliers could provide in-depth data about the gas price. The site of the CBS provided the most specific, available data. They have a review of the gas price per specific power for a plant, per year. Figure 9 shows this.

Prijscomponenten	Transactieprijs									Leveringsprijs								
Belastingen	Inclusief btw en belastingen			Exclusief btw en inclusief belastingen			Exclusief btw en belastingen			Inclusief btw en belastingen			Exclusief btw en inclusief belastingen			Exclusief btw en belastingen		
Onderwerpen	Aardgasprijs			Aardgasprijs			Aardgasprijs			Aardgasprijs			Aardgasprijs			Aardgasprijs		
	Verbruiksklassen niet-huishoudens			Verbruiksklassen niet-huishoudens			Verbruiksklassen niet-huishoudens			Verbruiksklassen niet-huishoudens			Verbruiksklassen niet-huishoudens			Verbruiksklassen niet-huishoudens		
	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer	10 tot 100 TJ	100 tot 1 000 TJ	1 000 TJ en meer
Perioden	*euro per GJ*																	
2015	12,247	9,638	8,026	10,122	7,965	6,633	7,400	6,939	6,228	11,892	9,272	7,670	9,828	7,662	6,339	7,107	6,636	5,934
2016	11,599	8,387	6,170	9,586	6,932	5,099	6,309	5,836	4,672	11,216	7,985	5,764	9,269	6,599	4,764	5,992	5,503	4,336
2017	10,843	8,130	6,873	8,961	6,719	5,680	5,906	5,620	5,252	10,414	7,679	6,423	8,607	6,346	5,308	5,552	5,247	4,880

Figure 9: Screenshot data CBS.
(Retrieved January 18, 2019 from https://statline.cbs.nl/Statweb/search/?Q=aardgas&LA=NL)

The numbers in the columns are transaction prices, excluding VAT and including other taxes. The VAT is excluded because the electricity price is also without VAT. (A Dutch company does almost always calculate their yearly numbers without the VAT.) To be able to use these numbers, the total power of a plant must be known, to determine which scale the plant ends up. Stork expects to sell the hybrid boiler to big plants and agreed with the assumption that they hypothetically sell a hybrid boiler to a plant with a total consumption of more than 1000 TJ. Table 2 shows the converted gas prices from €/GJ to €/MW.

At the moment of this research, the gas prices for the last quarter of 2018 is missing. Therefore an estimation is made for the price in Q4. Since the gas price is dependent on the season, the ratio of Q4 in comparison to the other three quarters is determined and averaged over the three years. This value, together with the gas prices of the other three quarters gives the average price of 2018.

Table 2: Average price per MWh gas per year.

Year	2015	2016	2017	2018
Average gas price per MWh	€23,88	€18,36	€20,45	€23,75

Electricity price

Since TenneT is a government-owned company, they have to be transparent in the things they do. So from their website, lots of data can be downloaded by everyone who wants to. The relevant data are available at their website (Export data, TenneT). The tool on their site allows the download of yearly data. The "Imbalanceprice" sheet shows the imbalance and reserve price for rejecting and injecting electricity per quarter. This is the price in the merit order on which TenneT stopped trading because they reached their desired amount of electricity. The data give an overview on how many quarters a year electricity could have been acquired for a lower price than gas. So the total savings is the sum of the difference in price summed over all quarters. Table 3 shows the results.

Table 3: The results after analysing both bidladders from 2015 until 2018.

Year	Bidladder	Total savings per MWh	Number of hours	Average savings per MWh
2015	Imbalance	€ 309.813,81	1421,25	€ 54,50
	Reserve	€ 417.108,89	1893,5	€ 55,07
2016	Imbalance	€ 169.467,16	1421	€ 29,81
	Reserve	€ 202.199,22	1695	€ 29,82
2017	Imbalance	€ 139.364,38	1201,25	€ 29,00
	Reserve	€ 177.826,76	1495,25	€ 29,73
2018	Imbalance	€ 160.929,11	913	€ 44,07
	Reserve	€ 198.589,89	1099,5	€ 45,15

Carbon credit price

With the hybrid system, gas consumption will go down, which means the produced amount of CO_2 is also lower. Since big plants have to buy carbon credit per tonne CO_2, this will add up in the savings because less money has to be spent on carbon credits when the electrode boiler is running. Table 4 gives the average prices per year per tonne CO_2. The website of Sandbag (EUA price, Sandbag) provided the data.

Table 4: Average price per carbon credit per year.

Year	2015	2016	2017	2018
Average price	€7,69	€5,35	€5,83	€15,92

Designed power

The designed power influences the yearly consumption of fuel. The losses in the system are negligible. For example, an installation of 10 MW, consumes 10 MWh per hour. The hybrid boiler engineer of Stork supports this assumption. With this assumption, the amount of saved money per year is linear to the designed power. So an installation with twice the power saves twice as much money on the differences in the prices of electricity and gas.

CAPEX

Studies Stork does at a plant determine the CAPEX. When Stork knows the situation and the requirements of a potential customer, they make a quotation which states the initial investment. As explained in Section 2.1.2, a couple of technologies and choices of materials influence the CAPEX.

OPEX

After meetings with the company supervisor, we agreed that the OPEX is a percentage of the CAPEX, namely 5%. The experience within Stork bases this number and is logical in a way that a larger installation needs more maintenance.

4.3.2 Desired output

The output consists of two parts. The first part is the savings per year, dependent on the input and business case. Next section stated the exact calculation. These numbers indicate what the savings are, having a hybrid boiler instead of a traditional boiler.

The second output is the cash flow sheet. This sheet determines the NPV of the investment. The sheet implements the predicted savings per year to give an overview of how they behaved over the last four years.

Then, the model requires a choice of one of the three scenarios. The difference in the scenarios is the rate of the growth of the cash flow. The reason to work with scenarios is due to the difficulty to predict the savings. Therefore, three different growth rates of the cash flows give three different scenarios. As Figure 10 shows, a little increase in the possible savings, around 12 to 15%, happened from 2017 to 2018. The higher average savings per MWh cause this. Multiplying the number of hours and the average savings per MWh comes up the possible savings.

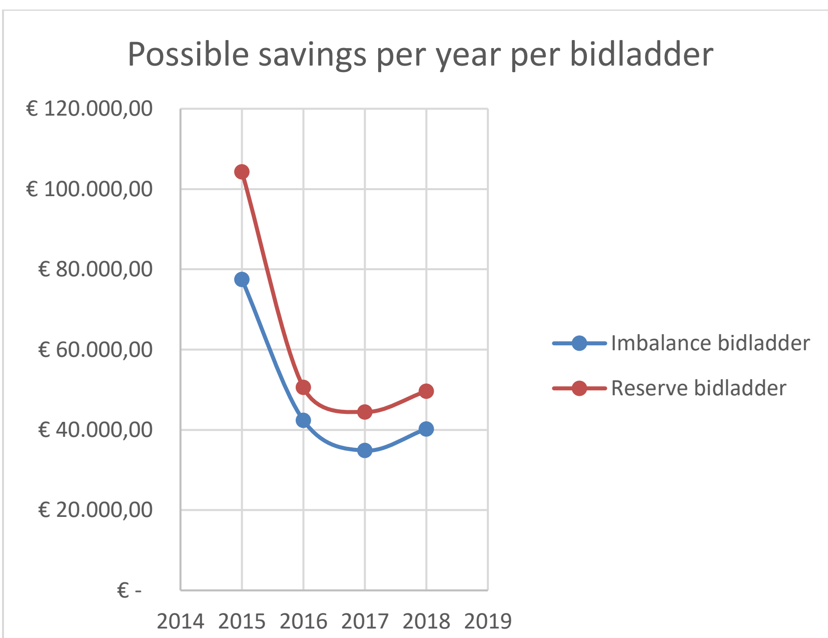


Figure 10: Possible savings per bidladder per year.

The growth rates for the four years of the scenarios are respectively 0, 8, and 15%. The growth from 2017 to 2018 and knowledge about the gas and electricity markets imply these numbers. In 2018 the carbon credit prices influenced the gas price heavily. The expectation is that the possible savings for 2019 will not increase the same as 2018, but increase more slowly. The impact of an increase in generators of electricity, such as households with PV systems causes this expectation. On the consumer side, electric vehicles also influence input and output in the grid. Therefore, Scenario 2 uses 8%. Scenario 1 is a conservative assumption that the possible savings will not grow over four years. Scenario 3 involves a growth which can be compared with the growth of the possible imbalance bidladder savings between 2017 and 2018. With those numbers, the savings get projected from 2019 to 2022. The savings, together with the CAPEX, the OPEX, and the discount factor result in the NPV and functions as the main output of this research.

The discount factor is the last input variable. In the model, the discount factor is a variable which changes per potential customer. The variance per customer is taken into account because the discount factor can be connected to the weighted average cost of capital, or the WACC, of a company. A definition of the WACC is: *"WACC, or Weighted Average Cost of Capital, is a financial metric used to measure the cost of capital to a firm. The two main sources a company has to raise money are equity and debt. WACC is the average of the costs of these two sources of finance, and gives each one the appropriate weighting"* (Wall Stress Oasis, 2019). Since no data from customers are available, this study excludes the calculation of the WACC. When a potential customer finds a partner in Stork,

A discount factor of 8% gives general results while analysing the data. This choice is based on the WACC of customers Stork works with. The percentages vary between 5% and 10%, so the model uses a rounded average of 8% to calculate the NPV.

4.3.3 Calculations and assumptions

The basic model consists of three parts. The model needs the possible savings for a reference year, and the corresponding cash flows to get output. To start, the model goes through each quarter, determining whether the price for 1 MWh electricity on one of the bidladders is lower than the gas price. If so, the difference between the gas and electricity price is determined and the quarter counter will go up. The number of quarters in which electricity was cheaper, as well as the total difference over all quarters are results after going through one year. Dividing this gives an average amount of euros that could have been saved per quarter per MWh if a plant used a hybrid system. This amount is then multiplied by the power and divided by four, to come up with the possible yearly savings for a hybrid boiler. Appendix B gives the formula, to clarify the text.

The second part of the basic model considers the savings of the amount of non-emitted tonnes of CO_2. This amount is lower because a part of the time the e-boiler took over the gas boiler. Therefore, the amount of non-used gas in MWh, in that year, gets converted to tonne CO_2 and is multiplied by the price of that year. This calculation results in the carbon credit a plant does not have to pay in one year, which is a form of saving.

The third part of the savings is crucial for two of the four business cases. When being in contract with TenneT, plant owners get compensation for passively having power available. This third way of saving adds up in the total savings in that particular business case. All the calculations are done in Excel, both in the worksheet and with the use of VBA. Appendix D shows the most important lines of code.

Merit order restriction

Last, the merit order system influences the possible earnings for having passively having power available. The merit order system gets used in two different ways. The first way determines the bids that TenneT accepts on the imbalance bidladder. The second way constructs the reserve bidladder and determines the accepted aFRR bids. The usage causes an adjustment in the savings in the model. A merit order implies that when you place a bid, it does not mean your bid gets accepted. Without this restriction, the total savings would consist of the maximum or minimum price TenneT paid in that quarter. A plant does only get this amount if it is the perfect bid where you are the last one accepted by TenneT. Making this assumption will, therefore, give a distorted image of what the expected savings are in the reference years. Thus, the model cuts a percentage of the savings due to merit order systems.

In consultation with Stork and Recoy, a partner of Stork which has done similar research at a location of Air Liquide and the partner that develops the software for the boiler, this percentage comes down to 40%. This decision means you earn only 40% in comparison with the perfect way of placing bids. Reaching 40% can be done in a couple of ways, but this research excluded the exact bid strategy, because of the restriction of time and knowledge. The discussion gives more in-depth reasoning behind this assumption.

List of assumptions

A couple of assumptions influence the calculation of the business case. They are a combination of already stated assumptions and new subjects. Table 5 lists the assumptions.

Table 5: List of assumptions.

Assumption	Reason
Boiler is running 24/7.	If the boiler is always running, the system is able to get a contract with TenneT to serve as a reserve. Next, if the boiler is running 24/7, savings can be made in all quarters.
Gas price is based on a total consumption of over 1000 TJ per year.	Stork expects to sell the hybrid boiler to big plants and agreed with the assumption that a hybrid boiler would only end up in a plant with a total consumption of more than 1000 TJ.
The gas that is used is high caloric.	Since two different types of gas exist, the amount of tonne CO_2 produced per MWh is different. Since earlier assumptions stated that the plant is running 24/7 and at least uses 1000 TJ per year, the target customer is a big consumer of gas. Almost all plants of this size run on high caloric gas, so that is the standard for this research. This is used in order to calculate the tonnes CO_2 per MWh.
Gas consumption is as flexible as the electricity consumption.	Stated in Chapter 3, the assumption is made that how flexible the use of electricity is going to be, gas will match the flexibility. This gives the opportunity to compare the gas and electricity prices per quarter, without having to do extra calculations or checks on possibilities.
OPEX is 5% of the CAPEX.	Decision made in consultation with Stork since it is the rule of thumb they use.
CAPEX and designed power are related.	A second rule of thumb Stork uses. The increase of designed power and the increase of CAPEX are correlated, since a higher designed power requires a more work. The starting point is based on a CAPEX of €1.500.000,- for a hybrid boiler with a designed power of 25 MW. This means that the CAPEX for a 10 and 50 MW boiler are €785.000 and €2.450.000 respectively.
The electrode boiler has its own connection with the grid.	This assumption is based on the contracts. This enables to look solely at the opportunities of the hybrid boiler, without considering the other electricity needs of a plant.
If you want to be a FCR or aFRR reserve 24/7, you are able to do so.	FCR and aFRR reserves get their contracts through auctions or tenders. The assumption that you are always one of the BSPs makes it easier to calculate to total earnings of the third savings in Business Cases 2 and 3.

4.4 Differences between the business cases in the model

A couple of differences between the business cases influence the savings and the NPV. Table 6 compares the differences.

Table 6: Differences per business case.

Business case	1	2	3	4
Which bidladder	Imbalance	Imbalance	Reserve	Reserve
Earnings passive power	No	Yes, €2.450,- per MW per week	Yes, €87.500 per MW per year	No
Influenced by the merit order restriction	Yes	No	Yes	Yes

To see the differences per business case, the corresponding savings per case are calculated at the same time. In the cash flow worksheet, four similar dashboards show the expected savings per year and the final NPV. Figure 11 shows the dashboard.

Business case 1: Imbalance

	2015	2016	2017	2018
Savings				

	2019	2020	2021	2022
Expected savings	€ -	€ -	€ -	€ -
OPEX	€ -	€ -	€ -	€ -
CAPEX	€ -			
Cashflows	€ -	€ -	€ -	€ -
Discount factor	8%			
Discounted value	€ -	€ -	€ -	€ -
NPV	€ -			

Business case 2: FCR

	2015	2016	2017	2018
Savings				

	2019	2020	2021	2022
Expected savings	€ -	€ -	€ -	€ -
OPEX	€ -	€ -	€ -	€ -
CAPEX	€ -			
Cashflows	€ -	€ -	€ -	€ -
Discount factor	8%			
Discounted value	€ -	€ -	€ -	€ -
NPV	€ -			

Business case 3: Contracted aFRR

	2015	2016	2017	2018
Savings				

	2019	2020	2021	2022
Expected savings	€ -	€ -	€ -	€ -
OPEX	€ -	€ -	€ -	€ -
CAPEX	€ -			
Cashflows	€ -	€ -	€ -	€ -
Discount factor	8%			
Discounted value	€ -	€ -	€ -	€ -
NPV	€ -			

Business case 4: Non-contracted aFRR

	2015	2016	2017	2018
Savings				

	2019	2020	2021	2022
Expected savings	€ -	€ -	€ -	€ -
OPEX	€ -	€ -	€ -	€ -
CAPEX	€ -			
Cashflows	€ -	€ -	€ -	€ -
Discount factor	8%			
Discounted value	€ -	€ -	€ -	€ -
NPV	€ -			

Figure 11: The cash flow dashboard.

5. Results of the business cases

This section treats the results per power per business case. Filling in the variables as stated in the last section provides a corresponding NPV. A table presents the results of the model for each different power.

5.1 The expected savings and NPV per business case per power

Since the model shows all four business cases at once, the model ran nine times for each different business case with the designed powers of 10, 25 and 50 MW and the different scenarios. Appendix C shows the values of all 36 iterations. Appendix C shows all the value of the business cases. This sections focusses on the worst and best business case regarding Scenario 1, the most conservative one. Figure 7 gives the highest and lowest values that came up after running the model.

Table 7: Differences between Business Cases 1 and 2.

Scenario 1	10 MW	25 MW	50 MW
Business case 1	€ -312.306,-	€ -236.421,-	€ 176.953,-
Business case 2	€ 4.244.915,-	€ 11.156.632,-	€ 22.963.061,-

The first thing that pops up is the NPV of Business Case 2 together with the significant difference in comparison with the other cases. An NPV of almost 35 million euros in Scenario 3 for 50 MW is around 14 times the CAPEX of a 50 MW hybrid boiler. The third savings, the fee for passive power, cause this. The third savings is almost 6,5 million euros in that scenario. Section 5.5 discusses the realistic nature of this value.

The second noticeable result is the linearity of the NPVs. This connection is logical since all the formulas connect linearly. It also means that higher designed powers always increase the NPV to an even higher amount.

5.1.1 The worst case scenario concerning the gas price

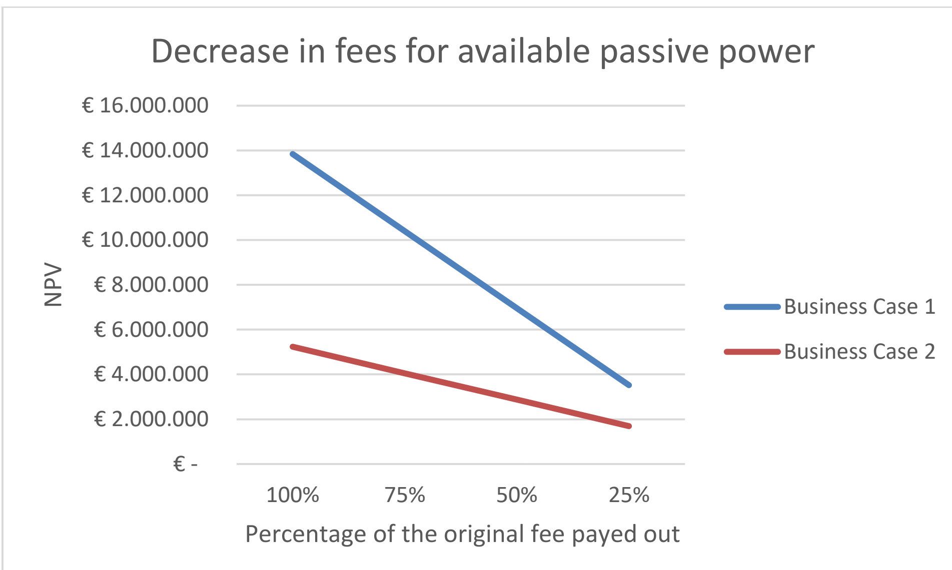
The worst case scenario has to do with the fact that the model uses the lowest gas prices as input. The model bases the savings on the difference in the costs regarding gas and electricity. This difference increases when either the gas price goes up or the electricity price goes down. The second assumption in Table 5 states that the used gas price is the lowest value out of the data from the CBS. To recall, the existence of bulk discounts causes a lower price when a plant uses more gas. When the model uses one of the other gas prices, the possible savings increase, since the difference became bigger. The increase in possible savings implies that smaller plants benefit in some way from their lower gas use, while bigger plants keep profiting from the fact that their demand is high. So the model already has a built-in worst case scenario, which strengthens the results of this research overall.

5.2 Sensitivity analysis

Since the model depends on a couple of important parameters, the influence of a decrease or increase f those parameters could harm the result. Therefore, the sensitivity analysis tests three different parameters. Those are the fees for passively having power, the average amount of time the e-boiler is running and the WACC. This study excludes the gas price since it is already a worst case scenario. The second excluded parameter is the carbon credit price because of the low impact on the total NPV. The analysis uses a 25 MW boiler in Scenario 1 to test the differences.

5.2.1 Fees for passively having power

The main reason why Business Cases 2 and 3 are better than the other two is due to the fees. The prices you can get per MW are relatively high, compared to the savings on gas and carbon credit. But what happens when the fees drop, for example, 25, 50 or 75%? A decrease possibly occurs when more and more plants are willing to serve as a BSP, so TenneT gets more plants or companies to choose. A 100% decrease results in copies of Business Cases 1 and 4, so the maximum decrease is 75%. Figure 12 shows the results.

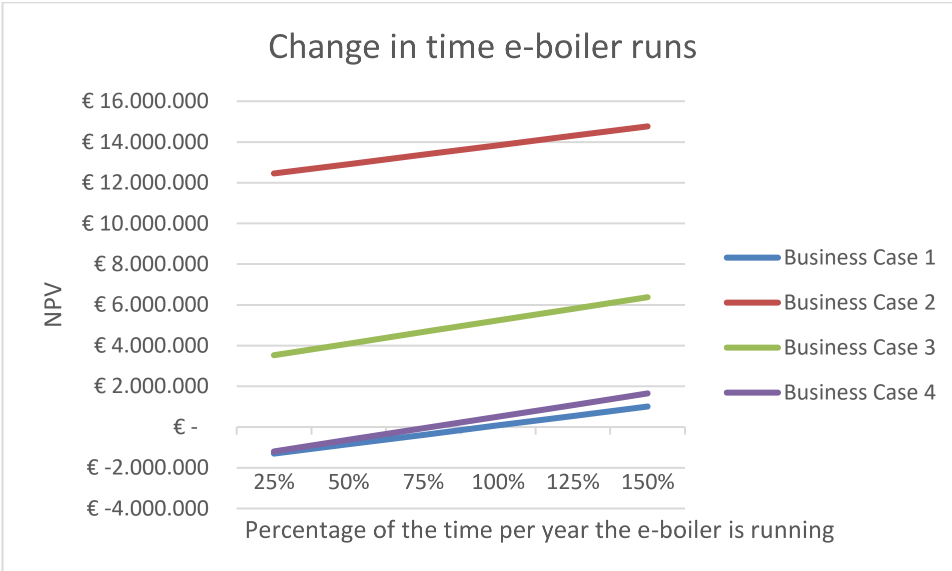


As expected, the NPV decreases linearly. This results in two main conclusions. First, the lower the fees are, the closer the business cases come together. Since both business cases have unique conditions, those will play a more significant role in the decision which case to use when the fees drop down. The second conclusion is that the NPV does not drop under zero. That implies that a major cut in the savings is not enough to make the project unprofitable.

A wrong assumption is to compare the decrease in fee as a decrease in the percentage of time per year that a plant functions as a contracted reserve. The model uses the assumption that a plant is always in contract with TenneT. So instead of a decrease of the fee, a reaction could be that it is the same as a reduction of the time having a contract. This idea is wrong since that would also impact the other savings.

5.2.2 Amount of time the e-boiler is running

In a similar fashion as the last section, the amount of time the e-boiler runs could also drop a certain percentage. But the current developments in the energy market might also cause an increase in time. This sensitivity analysis looks into the percentages of 25%, 50%, 75%, 125% and 150%.

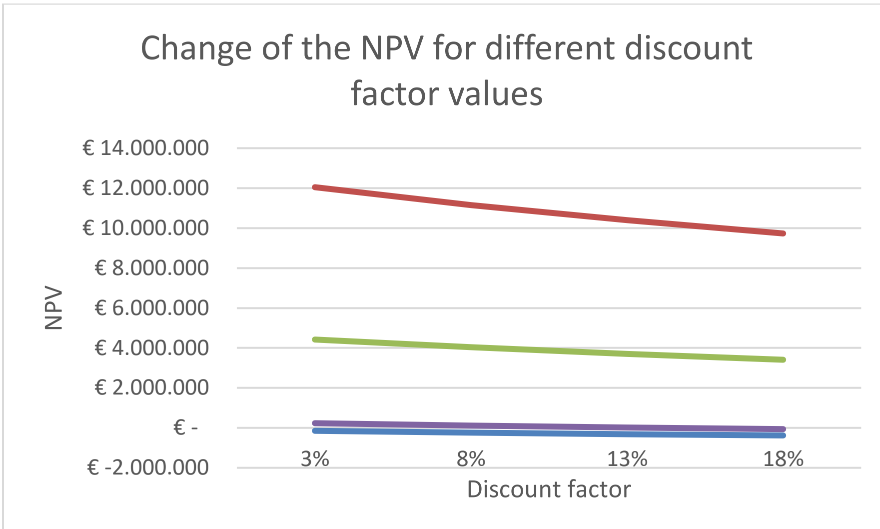


To determine these NPVs, the first and second savings are adjusted with the corresponding percentage. The reasoning behind this decision is because when the e-boiler runs for example less, there is less money saved on the price difference between gas and electricity. Besides this first loss, a plant produces more CO_2 because the plant uses more gas to power itself. The conclusion is that the difference between the 25% and 150% NPVs is three million euros maximum. For Business Cases 1 and 4 it is the difference between a good or bad investment, while for the other two business cases it does not matter that much. It is essential when choosing Business Cases 1 and 4 that the time does not decrease since both NPVs become negative at 75%.

Although the first two savings are low in comparison to the third savings, you could argue that they keep each other in balance. Namely, when the amount of time the e-boiler runs decreases, the potential savings will decrease. This decrease in possible savings discourages plants or companies to serve as a reserve, so with the basic rule of supply and demand in mind, this causes the passive fee to go up to make it more attractive. It also works the other way around. This development makes this research even stronger since bad scenarios even out in some way.

5.2.3 Impact in the difference of the discount factor

One of the fixed parameters in the model is the discount factor, which is a quite general percentage. Depending on the financial state of a company or plant, the discount factor differs. Therefore, the discount factor is the last variable included in this sensitivity analysis. The analysis tests a discount factor of 3, 8, 13 and 18%. With 3% for a very financially healthy company to 18% for a not so healthy company. Figure 14 shows the NPV for different discount factor values.



The differences are not that high because the period of time the model runs. When for example the NPV existed out of ten years, the discount factor plays are more significant role. The impact for Business Case 2 is bigger for the other scenarios, since those contain higher cash flows. For all discount factors higher than eight, the investment becomes worse. For Business Case 4 the NPV even becomes negative when the discount factor is 18%.

5.2.4 Conclusion of the sensitivity analysis

While changing the variables, it does have a significant impact on the profitability of the investment but not enough to make it a bad one. The worst case would be when the fees would decrease and even then the NPV is higher than the initial investment of €1.500.000,-. Most plants or companies consider this as a good investment to make. So, although the model and the research use a couple of assumptions, worst case scenario's do not influence the general output of the model.

6. Conclusions

The first part consist of the conclusions per business case, while the second part presents the main conclusion. The last part is a recommendation to Stork, regarding the best way to sell the hybrid boiler to potential customers.

6.1 Conclusions per business case

Generally, the NPVs show that the hybrid boiler is a profitable investment, although not every business case or scenario ends up with a positive NPV. This section gives a conclusion business case, to construct a general conclusion in the end.

6.1.1 Imbalance

The imbalance business case shows negative values four out of nine times. Three of those four times occur when the designed power is 10 MW. The other value is in Scenario 1, the 0% cash flow growth, for the 25 MW boiler. Running the model a couple of times gives the information that a designed power of at least 41 MW solely gives positive NPVs. Although some negative values occur, that does not make the imbalance market a bad business case. The advantage of this business case is the freedom of placing bids. So although the NPV is lower than in Cases 2 and 3, it gives freedom of choice when to switch.

6.1.2 FCR

The FCR business case gives the highest NPVs out of the four business cases. The incredible high third savings, the fee for passive power, cause this. The fee of €2450,- per MW per week sums to a yearly bonus of €6.370.000,- for a 50 MW hybrid boiler. This amount is already twice as high as the CAPEX. If TenneT pays the fees weekly, the payback period of a 50 MW boiler is 19 weeks in Scenario 1. The number of weeks to reach zero is higher for lower powers, but the numbers still imply an incredibly profitable investment.

6.1.3 Contracted aFRR

The second highest NPVs are in this business case. The difference with the FCR comes down to the first and second savings. Those savings are higher, but the third savings are lower. Because of the fee, no negative NPVs occur. This business case has an advantage over Business Cases 1 and 2 regarding the outlet of CO_2 because of the use of the reserve bidladder. So when a plant focuses on reducing its yearly production of CO_2, this case might be more attractive.

6.1.4 Non-contracted aFRR

The non-contracted aFRR business case is after the imbalance business case the least profitable one. Two out of the nine NPVs are negative and also less negative compared to the negative values of the imbalance business case. The only advantage is the same as the third business case, less CO_2 production than in Business Case 1 and 2.

6.2 General conclusion

The differences between business cases and designed powers are significant. The fee for passive powers which provides enormous possible savings for high powers cause this big difference since TenneT pays per MW. An equal comparison of the NPVs of the four business cases is not doable. The differences are too big. Therefore, Business cases 1 and 4, and 2 and 3 are split. This way, a comparison between the contracted and non-contracted business cases provide an even view. The differences are not only caused by the existence of the fees, but also in the usage of the boiler. Non-contracted means there is more flexibility in when to buy electricity.

When looking at Business Cases 2 and 3, the higher yearly fees of Business Case 2 makes it more profitable. The difference between the cases is around two and a half times. Looking at Business Cases 1 and 4 shows that the latter is more profitable, but the difference is not so big as for Cases 2 and 3, but still significant enough to choose 4 over 1. In the end, Business Case 2 is by far the best option, but some external effects or priorities might favour one of the other business cases.

Answer of the main research question

The main research question, as stated in Section 1.5.4 is: "*Which business case for using the hybrid boiler has the highest NPV when functioning on a different market than the day-ahead market, for the designed powers of 10, 25, and 50 MW?*". The answer to this question is Business Case 2, buying electricity as FCR reserve. From an operational perspective, it is not the only profitable business case. The other business cases might come in handy for specific plants or usage strategies. One thing that has become clear during this research is that every plant, system, customer or hybrid boiler is different and has other, particular needs. All business cases contribute to the saleability of the hybrid boiler.

The result is that plants can reduce their CO_2 emissions, while still saving money making an investment. The first part plays a role because when a slightly negative NPV occurs, plant owners likely reconsider the investment. The environment in the Dutch industry is changing, and the hybrid boiler provides a profitable way to cut the number of tonnes CO_2 produced.

6.3 Recommendations

Although a lot of different subjects are discussed, the hybrid boiler still seems a good investment to make. Especially Business Case 2 stood above the pack. The prices TenneT pays for their reserves are so high that even a 50% cut in the savings of Business Cases 2 and 3 still result in a profitable investment. Successive to this research, research could be done on the contracts, because they influence the system. It could be possible, since the supply chain would end up with more winners. TenneT and potential plants should be able to work together, so for example, excess electricity is used the most efficient way possible. The country profits from such improvements in the big industries. To conclude, the hybrid boiler influences a quadruple win situation, where the producer, the customer, the electricity provider, and the environment benefits from this product.

7. Discussion

The first remarks to make are the limitations of this research. Framing is necessary to conduct research. The theme of this research is a specific product with almost endless possibilities. Therefore, the discussion includes seven subjects. The seven issues are the most relevant because they all influence the NPV in some way or have to do with current changes in the different markets or systems. The topics are:

- the contracts and assumptions about the gas price.
- the merit order percentage.
- the future of gas prices and carbon credit.
- the future of the smart grid.
- the future of the hybrid boiler.
- the use of the data from 2015 until 2018.
- the possible results combining business cases.

The contracts and assumptions about the gas price

Two types of costs which are not involved in this research are costs regarding the contract you have with the supplier. First, the fact that the use of gas can be as flexible as the use of electricity. This would decrease the bulk discount and increase the contract costs for gas. Next the assumption that the hybrid boiler has its own connection to the grid, which influences the contracts for electricity. Both those contracts will go up in costs with the implementation of a hybrid boiler. How much is not known, but the difference is significant. Another remark is a possible breakdown. The chance exists but what would happen with the contracts and mainly how much does it costs you. Also maintenance should be planned as precise as possible to increase the profit out of the contracts. To improve the model, research should be done on what the best strategy is.

The contracts also cause the outputs to be embellished. Business cases in scenarios which end up close to zero may seem more profitable than a gas boiler, but because of the contracts, they are not. Therefore, as stated in the conclusion, only cases with an NPV above a million are considered as good enough.

The merit order percentage

The most important comment about the merit order percentage is about validity. The 40% that is used in our research is not guaranteed to happen. It is dependent on a lot of different variables such as the number of parties that place a bid, the supply and demand curve, and the software which is bound to the boiler. Because the savings are halved by this percentage, any changes in the percentage could influence the NPV a lot. For example, the NPV in Business Case 1, Scenario 2 for a 50 MW boiler increases with 227 % if the merit order percentage increases to 60%. This is makes operating on the imbalance market more attractive. Therefore good software which can determine the best bid strategy is valuable. Especially for high power boilers, since they benefit the most from a good price per MWh. With the savings made by a 20% increase, if the software cost half a million, it would still be a needed investment to make. The merit order percentage is that important.

The future of gas prices and carbon credit

Two of the three parts of the savings concern the gas price and the carbon credit prices. Since those two are connected, they influence the NPV together. With the Paris Agreement, the European Union agreed with the plans to lower the amount of carbon credit available that can be sold throughout the next 30 years. A first real decrease happened for the year 2019, which was noticeable in the market during the end of 2018. The prices went up almost three times. So when a next big decrease in tradable carbon credit occurs, the price might go up even more.

Seasonality is a factor which always influences the gas price since it is linked to the basic principles of supply and demand. But when the carbon credit prices increased in 2018 it was noticeable in the gas price as well. This was always a bit correlated, but not as close as at the end of 2018. If this stays the case, the possible savings might grow exponentially, since per MWh the difference between the electricity and the gas price increase, as well as the amount of money that has to be spent on carbon credit. This obviously leads to an increase of the NPV, no matter the business case.

There is also a trend in the Netherlands which involves getting rid of gas. Already, districts of some city are trying to warm their houses and cook without the use of gas. When gas becomes less and less popular, the price of gas will most likely decrease. This likelihood is due to the gas production in other countries and the current European gas connections. A declining gas price influences the NPV in a bad way. To keep the system profitable enough, other options should be studied. More on this on the future of the hybrid boiler.

The future of a smart grid

The conventional electricity grid has its limitation. That is why various companies and instances conduct research on a smart grid. This kind of grid is an electricity system where a lot more data get shared. From input or output per point or real-time analysis about the balancing, a smart system would provide fewer problems regarding the volatility of input and output. For example, even projects exists to research if it possible to implement a blockchain system in a households fuse box. When household have such a system, they can buy or sell their electricity to the person or instance they want. With a smart grid, the market and corresponding contracts will behave differently. When the time is there, research could be done on how the hybrid boiler should be implemented in such a system.

The future of the hybrid boiler

After the conclusion, the future of the hybrid boiler is expected to be sufficient enough to generate demand. But the business case is built around partnering an electrode boiler with a gas boiler. Stork I busy with a lot of possible opportunities and systems. To get to the NPV of those systems, a completely different model has to be built. For example, when the counterpart is a boiler fuelled with biomass, the carbon credit needed on a yearly basis drops drastically.

Nevertheless, since the system provides flexibility and makes it possible to switch from energy source, there will always be an opportunity to save money. Maybe the NPV will not be the same as in this research, but the technology to combine two types of evaporators is valuable. As stated before, it is also dependent on the markets on which different fuels are traded.

The use of the data from 2015 until 2018

The predicted cash flows are based on old data. This is a discussion point since the market is quickly changing. I noticed it when reading different articles about the gas and electricity market. For example, articles from 2013 where rarely usable because of how quick everything changes. With this idea in mind, only articles from 2015 until now were used. But that does not guarantee a solid basis to make a prediction on. Therefore every year the analysis of the last year should be included in the model when hypothetically the model is used for more than one year.

The possible results when combining business cases

Right now, the business cases are straightforward. It is a certain way of procuring electricity calculated with the relevant variables. But, Recoy did a research on this. Opportunities to combine the first three business cases do occur, or even include the mFRR to increase the possible savings per year. This way, extra savings could be generated. For example, you could combine Business Cases 1 and 4. As can be seen in the data, the prices on the imbalance and aFRR bidladder differ, so to be able to make use of the lowest of the two per quarter, should increase the savings. However, this business does require even more technical specifications. Second, also the contracts might influence this kind of business case even more.

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9. Appendices

Appendix A: Comparison of the reserves TenneT has from Lampropoulos *et al*.

Table B.1

Main characteristics of the operating reserves for balancing that are currently traded in the Netherlands.

Network Code on Load Frequency Control & Reserves (NC LFCR)	Frequency Containment Reserves (FCR)	automatic Frequency Restoration Reserves (aFRR)[a]		manual Frequency Restoration Reserve (mFRR)			
Former name	Primary reserves	Secondary reserves		(Directly activated) Tertiary reserves		(Schedule activated) Tertiary reserves	N/A
Name (Name in Dutch)	Primary reserve (Primaire reservevermogen)	Regulating power/aFRR directly activated (Regelvermogen)		Incident Reserve/Emergency power/ mFRR directly activated (Noodvermogen)	TSO – TSO mFRR direct activated	Reserve power/mFRR schedule activated (Reservevermogen Balanshandhaven)[b]	Passive contribution (Passieve Bijdrage)
Type (Contracted/Non-contracted)[c]	Contracted	Contracted[d]	Non-contracted	Contracted[e]	Contracted	Non-contracted	N/A
Contracted capacity (MW)	102 MW (up/down)[f]	340 MW (up/down)[g]	N/A	350 MW (up)/200 MW (down)[h]	350 MW (up/ down)	N/A	N/A
Capacity - Symmetrical product	Yes	Yes	N/A	No	Yes	N/A	N/A
Capacity settlement rule	Pay as bid	Pay as bid	N/A	Pay as bid	–	N/A	N/A
Capacity payment (fee for contracted capacity)	€/MW/week[i]	€/MW/annum	N/A	€/MW/annum	–	N/A	N/A
Indicative capacity fees	350–400 k€/week in 2015 (96 MW up/down)	35.9 M€/annum in 2015 (300 MW up/ down)	N/A	6.7 M€ in 2015 (350 MW up). The corresponding price for 2016 for upwards capacity is 11250 €/MW/ annum[j]	N/A	N/A	N/A
Energy - Symmetrical product	N/A	No	No	No	No	No	N/A
Energy payments (compensation for activated energy)	N/A	Marginal price: Based on the marginal price of the highest bid called		Equal to the product of volume and price per ISP: The price is defined in the contract (TenneT TSO B.V., 2016a): the marginal bid price + 10%, or the EPEX DAM price + 200 €/MWh or at least 200 €/MWh (when the EPEX DAM price < 0).	Price-based[k]	Marginal price: Based on the marginal price of the highest bid called	Imbalance price: Note that the energy payments are subject to the system state
Prequalification	Yes	Compliance check of systems on paper only		–	–	–	N/A
Lead time	N/A	One full clock hour (4–7 ISPs)		N/A	N/A	One full clock hour (4–7 ISPs)	N/A
Activation method	Automatic	Automatic, based on a merit order	Automatic, based on a merit order	Manual[l]	Manual[l]	Manual, based on a merit order	Market response, not activated by TenneT
Deactivation method	N/A	N/A	N/A	Manually at the end of the ISP	Based on human operator decision	Implicit	N/A
Min. bid size	1 MW	4 MW	4 MW	4 MW (in the merit order) 20 MW (in the tender phase) Note: In 2016 there were about 17 contracts between 20 and 140 MW		4 MW	
Activation ramp rate		≥ 7%/min.	≥ 7%/min.	≥ 100%/ISP	–	≥ 100%/ISP	N/A
Full Activation Time	30 s	15 min	15 min	10–15 min	15 min	15 min	N/A
Activation minimum step	N/A	1 MW	1 MW	Mostly full contracts but it can also be less (partial activation with a min. of 20 MW and steps of 5 MW but in general the requirements are for a total of 200–300 MW)	–	4 MW	N/A
Activation duration	Continuous	≥ 4 (s)	≥ 4 (s)	≥ 15 (min)	–	≥ 15 (min)	N/A
Verification method	Ex-post check (Monitoring of plant performance carried out after the event)	Ex-post		Ex-post	–	–	N/A
Settlement method for activated energy	N/A	Based on requested energy (according to the TSO's activation LFC signal)		Based on 5 min periods, the metered value is deducted from the reference value	–	Imbalance settlement system	Imbalance settlement system
Share (%) of aFRR in total activated FRR/RR energy[m]	N/A	> 80%		< 20%			N/A

[a] There are two types of aFRR, one contracted and one non-contracted but the merit order lists are merged.

[b] Mandatory for units > 60 MW in accordance with the Network Code.

[c] Tenders are published on the website of TenneT (http://www.tennet.eu) and TenderNed (www.tenderned.nl).

[d] Tender for regulating power (2016): 50% annual contracts, and 50% quarterly contracts. Contracts for 100% availability. Mandatory for units > 60 MW in accordance with the Network Code.

[e] Call for emergency power (mFFRda) is announced by TenneT.

[f] The total volume is determined on a yearly basis by ENTSO-E regional group Continental Europe (CE). At least 30% must be delivered within the Netherlands whereas the remaining capacity can be delivered through a common auction: https://www.regelleistung.net.

[g] In accordance with ENTSO-E directive: 340 MW for the year 2016.

[h] Largest possible incident minus already existing reserves (2016): 700 MW (upward regulation), whereas 350 MW are available through TSO – TSO cooperation (DE & BE). Contract for 97% minimum availability per year or quarter. Tender for downward regulation capacity (200 MW) has been announced but not yet released. Emission standards for combustion plants result into less availability for directly activated mFRR.

[i] Purchase through weekly auctions on: https://www.regelleistung.net. Contracts for 100% availability.

[j] ENTSO-E transparency platform: https://transparency.entsoe.eu/.

[k] The prices that are paid to the balancing service providers do not influence the marginal price of TenneT's normal internal operations.

[l] Manual deployment 24/7 by telephone call.

[m] Based on data for February and June 2015 from the ENTSO-E Transparency platform and information provided directly by TSOs (ENTSO-E, 2016).

Appendix B: Formulas

Formula NPV

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

$With$:
$R_t = net\ cashflow\ during\ year\ t$
$i = discount\ rate$
$t = numer\ of\ years$

Formula expected savings imbalance and reserve market

$$Total\ savings\ \text{in year}\ j = \sum_{n=1}^{30540} \Delta P_{n,j} * Q_{n,j}$$

$$Amount\ of\ quarters\ electrode\ boiler\ is\ running\ in\ year\ j = \sum_{n=1}^{30540} Q_{n,j}$$

$With$:

$\Delta P_{n,j} = price\ of\ 1\ \text{MWh}\ gas\ in\ quarter\ n\ in\ year\ j - price\ of\ 1\ MWh\ electricity\ in\ quarter\ n\ in\ year\ j$

$$Q_{n,j} = \begin{cases} 0, & if\ \Delta P_{n,j} < 0 \\ 1, & if\ \Delta P_{n,j} \geq 0 \end{cases}$$

Appendix C: All NPVs for the three designed powers

Table 8: Net present values of a 10 MW hybrid boiler.

10 MW	Scenario 1	Scenario 2	Scenario 3
Business case 1	€ - 312.306,-	€ - 185.050,-	€ - 57.115,-
Business case 2	€ 4.244.915,-	€ 5.318.630,-	€ 6.398.064,-
Business case 3	€ 1.394.965,-	€ 1.876.794,-	€ 2.361.188,-
Business case 4	€ - 170.015,-	€ - 13.206,-	€ 144.437,-

Table 9: Net present values of a 25 MW hybrid boiler.

25 MW	Scenario 1	Scenario 2	Scenario 3
Business case 1	€ - 236.421,-	€ 81.720,-	€ 401.557,-
Business case 2	€ 11.156.632,-	€ 13.840.920,-	€ 16.539.505,-
Business case 3	€ 4.031.758,-	€ 5.236.329,-	€ 6.447.315,-
Business case 4	€ 119.308,-	€ 511.329,-	€ 905.437,-

Table 10: Net present values of a 50 MW hybrid boiler.

50 MW	Scenario 1	Scenario 2	Scenario 3
Business case 1	€ 176.953,-	€ 813.237,-	€ 1.452.909,-
Business case 2	€ 22.963.061,-	€ 28.331.637,-	€ 33.728.806,-
Business case 3	€ 8.713.312,-	€ 11.122.453,-	€ 13.544.427,-
Business case 4	€ 888.412,-	€ 1.672.453,-	€ 2.460.671,-

Appendix D: List of abbreviations

Abbreviation	Meaning
aFRR	automated Frequency Restoration Reserve
APX	Amsterdam Power Exchange
BPL	Bid Price Ladder
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CAPEX	Capital Expenditures
CBS	Centraal bureau voor de statistiek
DSO	Distribution system operator
ENDEX	European Energy Derivatives Exchange
EU ETS	European Union Emission Trading Scheme
FCR	Frequency Containment Reserve
GTS	Gasunie Transport Services
ISP	Imbalance Settlement Period
kV	kilo Volt
mFRR	manual Frequency Restoration Reserve
MW	Mega Watt
MWh	Mega Watt per hour
NAM	Nederlandse Aardgas Maatschappij
NPV	Net Present Value
OPEX	Operational Expenditures
PIS	Program Imbalance Signal
PTU	Price Time Unit
PV	Photovoltaics
SBS	System Balance Signal
TSO	Transmission system operator
TTF	Title Transfer Facility
UCTE	Union for the Coordination of the Transmission of Electricity
VAT	Value Added Taxes
WACC	Weighted Average Cost of Capital.