Master's thesis

Development of a software-supported approach to estimate costs of SOFC systems

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Index

List of figures

List of tables

List of abbreviations

APCS	Austrian power cleaning and settlement
AVL	AVL List GmbH
BK	Brennwertkessel
CB	Condensing boiler
CEGB	Central electricity generating board
CHP	Combined heat and power
COICOP	Classification of Individual Consumption by Purpose
DHW	Domestic hot water
E-Control	Energie-Control Austria
EEX	European Energy Exchange AG
EFET	European Federation of Energy Traders
EnEV	Energieeinsparverordnung
EnWG	Energiewirtschaftsgesetz
EXAA	Energy Exchange Austria
MOE	Merit order effect
NPV	Net present value
OTC	Over the counter
SOFC	Solid oxide fuel cell
VBA	Visual Basic for Application
VAT	Value added tax
VDI	Association of German engineering

Variable directory

A	Consistent payment
A_0	Investment amount at the beginning of the observation period
A_1	Present value of the first, second, … n^{th} procured replacement
A_N	Annuity of the capital-related costs
$A_{N,B}$	Operation related costs
A_{NE}	Cash value of the procured replacement
$A_{N,K}$	Annuity of the capital-related costs
$A_{N,S}$	Other costs
$A_{N,V}$	Demand related costs
FV	Future Value
PV	Present Value
R_w	Residual value
T	Observation period in years
T_p	Time of procurement
T_n	Service life (in years) of the installation component
a	Annuity
b	Present-value factor
i	Interest rate or rate of return
n	Number of replacements procured within the observation period
q	Interest factor
r	Price change factor (to be specified beforehand)

Abstract

Die Weiterentwicklung und die dadurch momentan erreichbaren Wirkungsgrade einer Festoxidbrennstoffzelle, im Englischen Solid Oxide Fuel Cell (SOFC), haben das Unternehmen AVL List GmbH (AVL) veranlasst, die SOFC-Anlage mit anderen Kraft-Wärme-Kopplungsanlagen (KWK-Anlagen) zu vergleichen. Diese Arbeit hat die Zielsetzung, eine Kostenabschätzung der SOFC mit einer vorgegebenen Bedarfslinie durchzuführen. Im Zuge dessen soll mit Matlab und Excel ein Programm erstellt werden, welches eine Wirtschaftlichkeitsanalyse ermöglicht. Es wird eine Kostenabschätzung durchgeführt, die auf einer VDI Richtlinie basiert. Diese VDI Richtlinie wird mit notwendigen Funktionen, welche für die AVL als wichtig erachtet werden, ergänzt. Dabei wird auch thematisiert, welche Möglichkeiten bestehen, den produzierten Strom über eine Energiebörse zu handeln. Das Programm für die Simulation von einer SOFC mit Matlab wurde schon im Zuge einer früheren Diplomarbeit entwickelt. Die notwendigen Daten für die Eingabe zur Simulation einer Gastherme und eines Verbrennungsmotors wurden im Vorhinein festgelegt. Zusätzlich werden die Daten zur Simulation der SOFC vom Unternehmen AVL bereitgestellt.

Im Zuge dieser Arbeit wird davon ausgegangen, dass die SOFC-Anlage mit Erdgas betrieben wird. Zu Beginn wird eine kurze Analyse der zu vergleichenden Systeme vorgenommen und nachfolgend wird eruiert, wie viele Haushalte derzeit Zugang zum Erdgasnetz haben. Danach wird nach einer geeigneten VDI Richtlinie gesucht, welche eine Gegenüberstellung gebäudetechnischer Anlagen ermöglicht. Es wird die VDI 2067 gewählt, auf deren Grundlage die Wirtschaftlichkeit mittels Annuitätenmethode beurteilt wird. Der Energiemarkt und die Preisentstehung von Strom und Erdgas werden analysiert und in das Programm zur Kostenabschätzung integriert. Um die Entwicklung der Energiepreise in den letzten Jahren darzustellen, werden die Statistiken von E-Control und Eurostat verwendet. Da das Unternehmen AVL nach einer Möglichkeit suchte, beim Vergleich zweier Systeme den Amortisationszeitpunkt darstellen zu können, wird eine Amortisationsrechnung in die Kostenabschätzung integriert. Zusätzlich können mit einer Sensitivitätsanalyse verschiedene Einstellungen miteinander verglichen werden. Durch die Veränderung verschiedener Einflussfaktoren können die dadurch entstehenden Auswirkungen auf die Amortisationsdauer analysiert werden.

In der Kostenabschätzung für die AVL werden drei verschiedene Systemkombinationen miteinander verglichen. In der ersten Annahme wird eine SOFC in Verbindung mit einem Brennwertkessel simuliert. Die zweite Kombination besteht aus einem Verbrennungsmotor und einem Brennwertkessel. In der dritten Variante wird der Strom ausschließlich aus dem Netz bezogen und der Brennwertkessel soll, wie auch bei den zwei anderen Systemkombinationen, den Wärmebedarf für das Trinkwasser decken. Dabei werden diese Systeme stromgeführt betrieben.

Es werden eine SOFC mit einer Leistung von 4,5 kW und ein Verbrennungsmotor mit einer Leistung von 6 kW simuliert. Für die AVL ist vor allem die Gegenüberstellung der Variante, welche die SOFC beinhaltet mit der Variante, bei welcher der Strom ausschließlich aus dem öffentlichen Netz bezogen wird, von Interesse. Zur Durchführung der Kostenabschätzung werden Einstellun-

gen vorgenommen, die im Zuge von Recherchen als plausibel erachtet wurden. Diese Werte wurden mit den Betreuern der AVL abgestimmt. Es handelt sich dabei um Werte wie den Zinssatz, den Strompreis und den Erdgaspreis, sowie deren jährliche Preisänderungsfaktoren. Die Annuitäten der unterschiedlichen Kosten, die über den Betrachtungszeitraum anfallen, werden in der Kostenanalyse dargestellt.

Abstract

The development and the currently achievable efficiencies of the Solid Oxide Fuel Cell (SOFC) caused the company AVL List GmbH (AVL) to compare SOFC systems with other Combined Heat and Power (CHP) systems in order to find out, which systems are better for specific needs. The aim of this work is to estimate the costs of the SOFC system with a given demand profile. To do so, Matlab and Excel are used to create a program which is then used as a tool to carry out an economic analysis. This cost estimate should be based on a VDI guideline and is supplemented with necessary functions. Furthermore, the opportunities to trade the electricity produced on an energy exchange were investigated. The program for the simulation of a SOFC with Matlab was already developed in the course of another master's thesis. Also, the necessary input data for simulating a gas boiler and a combustion engine was already set in advance. The data to simulate the SOFC was provided by AVL. A user interface for various settings had to be created, because it has not been established so far.

In the course of this thesis it is assumed that the SOFC system is powered by natural gas. The first step is to do a quick analysis of existing systems for comparison and to determine how many households actually have access to the natural gas grid. Thereafter, a suitable VDI guideline was sought in order to be able to contrast building services systems. The VDI 2067 was chosen as a basis to determine the economy by the means of the annuity method. One target of the thesis is to analyse the energy market and price generation of electricity and natural gas and to integrate this data into the cost estimation program. In order to show the evolution of energy prices in the past, statistics from E-control and Eurostat were used. Also, a payback period calculation had to be integrated into the cost estimate, since AVL wanted to compare at least two systems with each other. In addition, a sensitivity analysis was used to compare different settings. This should help to understand what kind of impact the change of various factors has on the payback period.

In the cost estimate for AVL, three different system combinations were compared. First, it is possible to simulate a SOFC in combination with a condensing boiler. The second combination consisted of an internal combustion engine and a condensing boiler. In the third variant, the electricity is solely obtained from the public grid, and a condensing boiler has to cover the heat demand for drinking water, as in the two other system combinations. These systems are operating in an electricity driven way.

The aim is to simulate a SOFC with a power of 4,5 kW and an internal combustion engine with a power of 6 kW. AVL is especially interested in the comparison of the variant number one and three. In order to carry out the cost estimate, settings were made, which were considered plausible in the course of research. These values were discussed and determined with AVL. It concerns values such as the interest rate, the electricity price and the price of natural gas, as well as their respective annual price change factor. The annuities of the different costs incurred over the observation period are presented in the cost analysis.

1 Introduction

This master thesis was developed in cooperation with the company AVL LIST GmbH (AVL). For a better understanding of the topic of the present work, at the beginning of this chapter it will be explained why the company AVL deals with decentralized combined heat and power (CHP) plants. The second subchapter describes the initial situation and the task defined by AVL. Furthermore, the concrete objective for this master's thesis is discussed and finally this introductory chapter explains the used procedure and provides an overview of the content structure of the thesis.

1.1 Decentralized power generation

For the energy supply of our households and plants, the use of fossil fuels is an important component. Therefore, it requires resource-friendly and environmentally-friendly handling of our finite raw materials, and the development of highly efficient power plant technologies and processes for CO_2 reduction. The simultaneous extraction and use of heat and electricity from the energy conversion process by CHP plants is particularly useful. Decentralized supply concepts play a major role, as heat distribution over long distances is not economical. In decentralized energy supply, the system is installed as close to the consumer as possible. This minimizes the losses caused by the transmission of energies between producer and consumer. Currently, CHP plants are still mainly operated with natural gas, but in the long term can be converted to work with biogas or biofuels. These decentralized supply concepts can also help reduce network losses by using as much of the locally generated electricity as possible. To build only decentralized supply systems is neither technically nor economically desirable, since renewable energy sources are discontinuous and not available nationwide. But the further development of such plants will be indispensable in order to cover the constantly increasing global energy demand. (Horenkamp, Hube, & et al., 2007)

These aspects already convinced the company AVL early on and it was recognized that fuel cells have the potential to be a game changing technology for power generation as well as for mobility. Since 2003, AVL has specialized in fuel cell technology, among other things.

For the decentralized energy supply, the company AVL covers the complete development process of SOFC cell combined CHP systems. With an external reformer system, the SOFC can be operated with nearly all conventional fossil fuels or future biofuels. Total efficiencies above 95 % are possible, by usage of the electric energy and the exhaust heat directly for heating. Another aspect is that the SOFC emits very low noise compared to common CHP systems. (AVL, 2018a)

The perceptions vary significantly of what is to be understood by the term decentralized systems. They are ranging from building-related forms of supply to offshore wind energy use. In Figure 1 it is shown which feed-in range decentralized systems predominantly feature. The decentralized supply should be understood as a local, consumption-oriented supply, which complements and sometimes replaces the central supply. (Horenkamp et al., 2007)

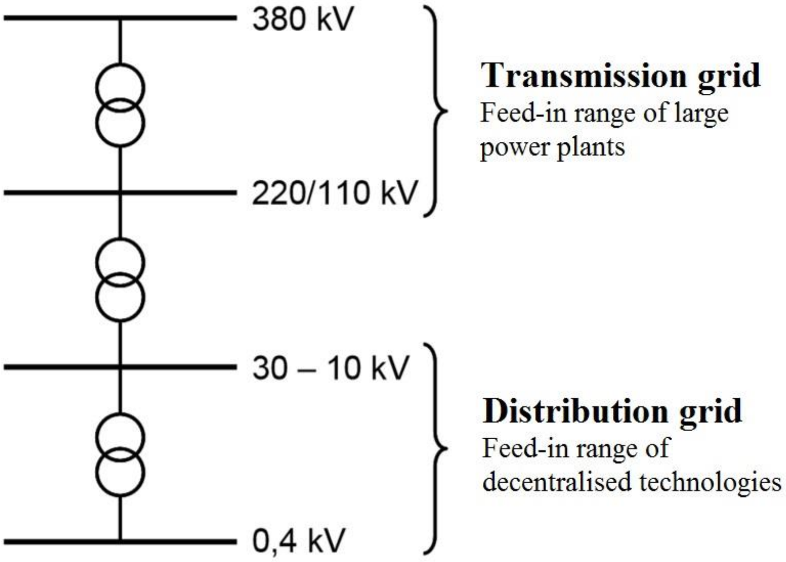

Figure 1: Range of decentralized systems (Horenkamp, Hube, & et al., 2007)

1.2 Task of the master thesis

As a result of the liberalization of the electricity market in 2001, the share of electric energy generation will continue to grow from distributed energy sources in the coming years. In order to get an overview of the competitiveness of the SOFC compared to other CHP plants, it is necessary to carry out a profitability analysis. Building on an existing Matlab-based simulation, a cost estimate will be made. In addition, the ease of use should be given to ensure a comparison of different CHP systems. A simplified and non-standardized profitability analysis has already been done by AVL. In the calculation of AVL many functions were missing, e.g. average values for electricity are assumed and it is not possible to implement the energy prices of the last years as reference. The energy prices are made public via an energy exchange. The energy exchange market in Austria is EXAA. In the profitability analysis, a payback method is to be integrated. In addition, a sensitivity analysis should be integrated. The procedure of the thesis has been structured as explained below.

In the first step, a standardized guideline of the association of german engineering (VDI) is to be found, on which the calculation is based. Various economic aspects such as maintenance costs and electric energy or gas price should be implementable. The inflation and the price change factor of the individual components are considered separately.

As the next step, AVL wants the electric energy price to be calculated on an energy exchange. Further, possibilities to determine the price of electricity, for the feeding as well as the sale of electricity, are to be investigated. Also the natural gas price should be determined. Therefore, it has to be investigated which calculation basis for the natural gas is most suitable.

In order to be able to make various setting options, a user interface was created via Excel for entering various influencing factors. It should also be possible to combine systems, such as SOFC, with an additional gas boiler. This is necessary to cover the lack of heat for hot water production. The missing electrical energy is fed in via the public grid. The amount of heat and electrical energy which has to be covered is determined by demand profiles. The system is operating in an electricity driven way in the simulation. This means that the operation and control of the SOFC depends on the current electric energy demand and not on the heat demand.

The size of a CHP system is crucial, because it not only affects the utilization of a CHP system for a specified demand, but also its economy. In order to determine the dimensioning of the system, Matlab integrates the function of being able to estimate the required performance of the system before the actual simulation. After the simulation, characteristic values such as capacity utilization and produced energy are displayed in an Excel file, for the first overview. In each case, one year is simulated in Matlab and summed up in the cost calculation on the respective observation period.

In the next step, the user interface for the input values is created in Excel. Also, an interface for the output values is created in order to analyse the results of the simulation. The third user interface in Excel has different spreadsheets for the cost estimate. For all this, Excel considerations are made regarding the preservation user-friendliness. An amortization method is implemented to compare different system combinations. The comparison between the ability to obtain the electricity only from the grid with a larger condensing boiler which covers the heat demand, and the combination of an SOFC system with a condensing boiler is very interesting for AVL. This makes it possible to get an overview of whether an installation of such a system is profitable.

In the sensitivity analysis, operator friendliness should be guaranteed. In a few steps it should be possible to get a good overview on what impact various influencing factors such as inflation, electricity price and cost of each component have on the payback period.

1.3 Technology and system boundary

To guarantee a good comparability of the investments, system boundaries must be defined. For the operation of a SOFC system and a gas engine, both are operated with natural gas in the simulation, a gas connection is necessary. In the comparison of the systems it was assumed that there is a gas line and the necessary connection to the system already given. Carbon dioxide emissions and the obligatory purchase of emission certificates are also not taken into account in the cost estimation. Since 2013, the third trading period of the European emission allowance trading has begun. Since then, operators of facilities which produce Carbon dioxide producers have to buy all necessary certificates. Small installations with emissions below certain thresholds can be exempted of emission trading obligations, if an environmental agreement is concluded with these facilities. (BMNT, 2017)

In this master thesis 3 different system combinations will be compared.

- SOFC + condensing boiler + grid connection
- Gas engine + condensing boiler + grid connection
- Condensing boiler + grid connection

If the case of underproduction of domestic hot water occurs and the SOFC or the gas engine system cannot handle it, an additional condensing boiler should cover this peak for these systems. Another boiler for hot water storage in case of overproduction of heat should be also installed. In the simulation, which was done with the software Matlab, all three systems have to cover the same heat and electric energy demand. But it will be also taken into account if there is no CHP system installed and the electric energy is purchased only from the grid. In that case, the condensing boiler has to cover the whole heat demand. Therefore, a condensing boiler with more power than the condensing boiler of the other systems is required.

2 CHP systems

This chapter gives an overview for what CHP systems were designed for and what kinds of CHP systems are existing. Reasons for the purchase of a SOFC system are also briefly discussed.

2.1 Development of CHP systems

Mechanical power was increasingly replaced by electricity, still generated in factories with simultaneous utilizing of waste heat. It didn't take long until factories were suppling nearby apartments with the spare energy generated by CHP plants. (Beith, 2011)

One of the persons who influenced the technology was Oscar Faber. In 1926 he won his first contract as a trained structural engineer with a formed engineering consultancy. Because of the frequent riots in London by unemployed workers, a bank in Threadneedle Street decided to install CHP system to be more independent during these troubled times. To obtain the electric energy exclusively by the national grid was not save anymore for this bank. The target was to integrate a diesel engine part deep inside the building. This was a state-of-the-art engine and Faber, who installed this plant, had to deal with the problem of removing the additional heat during power generation. Ventilating was the standard solution during this time. But he decided to utilize this heat with an installed heating system. To reject the unutilized energy content as heat directly into the atmosphere, he also fastened pipes within the dome of the bank. This is one of the first documented applications of CHP technology in a commercial building, and it inspired other engineers to use and develop this concept further on. (Beith, 2011)

This interestingly shows an advent, were the national grid pushed the development and the way of use of the CHP technology a step further. Nowadays, the national grid allows additional modes of operations of the CHP systems. It is possible to sell the overproduced energy, especially if the retail price is high, which is possible because of the liberalization of the energy market. In addition to this, the use of produced waste heat is an essential reason for making the CHP systems more competitive on the market. In the heat-driven mode of operation of the system makes the produced electric energy to the additional product. This electricity production covers part of the electricity needed to be at least partially independent of the public grid. (Beith, 2011)

2.2 Types of CHP systems

The variety of CHP systems has grown steadily. The combined generation of heat and power can be operated via two methods:

- Extraction of heat produced during electricity generation. This is an electricity demand-oriented cogeneration with the priority target of electric energy.
- Extraction of power, to produce mechanical power or electric energy during the heat generation. This is a heat-demand-oriented cogeneration with the priority target of energy heat. Generation of mechanical energy also includes compressed air generation.

The mechanical work delivered by CHP plants is usually converted directly into electrical energy. For the purpose of this definition, the following energy production plants are assigned to the CHP plants (Beith, 2011):

Table 1: CHP base technologie in 2011 (Beith, 2011)

CHP power generation technology	Power range (applied to CHP)	Power efficiency range (%)	CHP efficiency (peak) %
CCGT*	20 MW to 600 MW	30–55	85
Gas turbine	2 MW to 500 MW	20–45	80
Steam turbine	500 kW to 100 MW	15–40	75
Reciprocating engine	5 kW to 10 MW	25–40	95
Micro-turbine**	30 kW to 250 kW	25–30	75
Fuel cell	5 kW to 1 MW	30–40	75
Stirling engine	1 kW to 50 kW	10–25	80

* Combined cycle gas and steam turbines

** Micro-turbines are small, radial flow gas turbines

Table 1 offers an overview about the different CHP technologies. This data is from 2011, which means that not every value is up to date. For example, the efficiencies of the fuel cells has increased during the last years. Nowadays, an overall efficiency of a fuel cell system around 95 % is possible. (Plansee SE, 2018c).

Further, absorption refrigeration systems have developed, meaning the heating energy is obtained from the waste heat generated during the production of mechanical power and electricity; e.g. stirling engine cogeneration plants, vapor compressor plants, ORC cogeneration plants, gas engine heat pumps and other similar plant systems. It is shown that the optimal application area is given if the simultaneous demand of electric or mechanical energy and heat energy is required. In general, a distinction must be made between controllable and non-controllable energy suppliers. When talking about CHP systems, it's usually about controllable systems. Non-controllable energy suppliers use a physically and meteorologically given, non-materially bound and temporally energetic potential. Although such systems could be controlled, this is at the same time equated with a loss or a targeted reduction of the utilization of this offered energy potential. Usually, only the photovoltaic systems belong to the class of non-controllable producers. (Horenkamp et al., 2007)

2.3 SOFC

With the growing electricity and power demand, fuel cell technology has proved as an alternative source of energy. Aspects like low emission, zero noise pollution and procession at high efficiencies make the fuel cell an increasingly well known technology. Nowadays, the fuel cell technology offers mobile and stationary applications. (AVL, 2018b)

Zero noise pollution is possible because of the absence of vibrations, as it happens for example during the operation of CHP plants like a diesel engine, where it is a common. The SOFC can be used as a CHP system. The fuel cell technology has the great advantage compared to other technologies, that it converts the chemical energy of a fuel through an electrochemical reaction of hydrogen fuel with oxygen to electrical energy.(Töpler & Lehmann, 2017)

Generally, a fuel cell system is divided into stack (the cell stack) and the remaining system components (balance of plant, BoP). An SOFC system is operating at high temperatures between 700 - 850 °C. It converts bioethanol, biogas and natural gas into electrical energy. The electrical efficiency of SOFC systems is between 50 – 60 % and they have an overall efficiency of 90 – 95 %. (Plansee SE, 2018c)

The principle of operation of a fuel cell was already described in 1839 by Sir William Grove. However, the fuel cell technology becomes more important in the second half of the 20th century. An advantage of fuel cells is the flexibility of this technology, because both hydrogen and carbon monoxide can be used as fuels. This process - generating electricity and heat with fuel cell based systems - is also called “cold combustion”. This expression causes confusion because the fuel cell technology itself doesn’t burn anything, and, as mentioned in the previous paragraph, especially the SOFC operates at high temperatures. (Bujalski, 2016)

Summary

The liberalization of the energy market influenced the further development of CHP systems. It allows operators of CHP systems to sell the overproduced energy, especially if the retail price is high. A distinction must be made between controllable and non-controllable energy suppliers. Photovoltaic systems belong to the class of non-controllable systems. SOFC systems are controllable systems which have an overall efficiency until 95 %.

3 Energy sector

In this chapter the energy market in Austria and Germany will be discussed. The distribution grid of electricity and natural gas will be briefly elaborated. How the electricity price is composed and how the energy demand has changed in recent years, will be also addressed. The development of electricity and natural gas prices in recent years and how it will be integrated the energy prices into the calculation, will be explained in more detail in Chapter 7. Furthermore, the various opportunities to participate in the electricity market, will be presented. This is especially important, since the opportunity to trade through the energy market should be investigated. It will be analyzed the different players in the energy market and the energy exchange and their products. At the end of this chapter it will be explained, why the participation in the control energy market is limited and is available for this calculation as an option.

3.1 Specifications of electricity and natural gas grid

To find out how many customers could be interested in calculating the profitability of a gas-fueled SOFC, it was first analyzed how many households and businesses have access to electricity and gas networks at all. If such a system is to be installed, the necessary infrastructure must also be available.

Electricity grid of Austria

Households in Austria have a nationwide electricity connection. Only a few very remote houses or huts provide themselves with electric energy and don't have an electricity connection to the public grid. According to E-Control, it is not possible to show exactly which percentage of Austria's population have an electricity connection as there are only the metering points, which are countable for E-Control. Table 2 lists the number of metering points for each end customer category. (Schörg, 2018)

The industries that sell and purchase electricity need 2 meters. One for the supply of electricity and one to capture the supply of electricity. Since 2001, the number of electricity meters is increasing. The total number of meters in 2014 exceeded the 6 million mark. Due to the growing number of households and the increase in the Austrian population, more and more meters must be installed. But it is not listed, how many people live in such a household. In Table 2 it is distinguished between different customers. Small consumers have an energy amount until 4,0 GWh/a. A medium industry has a consumption of electricity consumption of 4,0 GWh/a to 20,0 GWh/a in this list. Large-scale industry has a consumption of over 20,0 GWh/a. (Schörg, 2018)

Table 2: Metering points for electric energy (Schörg, 2018)

Number of metering points in 1.000						
End customers category	Households	Other small customers	Medium-sized industry	Large-scale industry	Non-households	Total
2001	3.900,0	1.620,8	2,4	0,2	1.623,4	5.523,4
2002	3.919,2	1.622,8	2,5	0,2	1.625,4	5.544,6
2003	3.931,7	1.628,1	2,5	0,2	1.630,8	5.562,5
2004	3.947,6	1.631,1	2,5	0,2	1.633,8	5.581,4
2005	3.983,2	1.639,6	2,6	0,2	1.642,4	5.625,5
2006	4.024,2	1.645,9	2,7	0,2	1.648,8	5.672,9
2007	4.061,2	1.675,8	1,8	0,2	1.677,7	5.738,9
2008	4.092,5	1.666,8	1,9	0,2	1.668,9	5.761,4
2009	4.121,8	1.669,3	1,9	0,2	1.671,3	5.793,2
2010	4.164,2	1.674,4	1,8	0,2	1.676,4	5.840,6
2011	4.208,5	1.665,8	1,8	0,2	1.667,8	5.876,3
2012	4.266,2	1.659,2	1,9	0,2	1.661,2	5.927,4
2013	4.308,6	1.655,7	1,9	0,2	1.657,8	5.966,4
2014	4.356,1	1.650,1	1,9	0,2	1.652,2	6.008,3
2015	4.368,8	1.667,6	2,0	0,2	1.669,8	6.038,7
2016	4.954,9	1.056,0	34,4	31,3	1.121,6	6.076,6
2017	4.980,5	1.073,0	36,0	32,0	1.141,1	6.121,5

Natural gas grid of Austria

The natural gas network has been steadily expanded in recent years. In 1990, the gas network length without transmission lines was 15.000 km. Since 2011, the network length has exceeded the 40.000 km mark and in 2016 it was already 44,000 km. Thus, the length has almost tripled since 1990. (Fachverband der Gas- und Wärmeversorgungsunternehmungen, 2017)

Nevertheless, there are still many households that have no gas connection, as shown in Table 3. Compared to the electricity metering points, the amount of metering points for natural gas is very small. (Schörg, 2018)

Table 3: Metering points for natural gas (Schörg, 2018)

Number of metering points in 1.000						
End customers category	House-holds	Other small customers	Medium-sized industry	Large-scale industry	Non-households	Total
2001	-	-	-	-	-	-
2002	1.230,2	-	-	-	69,4	1.299,6
2003	1.232,3	-	-	-	69,6	1.302,0
2004	1.253,0	-	-	-	71,2	1.324,2
2005	1.264,3	-	-	-	69,9	1.334,3
2006	1.269,0	-	-	-	71,6	1.340,7
2007	1.277,8	-	-	-	73,1	1.350,9
2008	1.278,4	74,3	0,8	0,2	75,3	1.353,7
2009	1.275,4	75,1	0,8	0,2	76,0	1.351,4
2010	1.274,5	76,3	0,9	0,2	77,4	1.351,9
2011	1.273,3	76,4	0,9	0,2	77,5	1.350,8
2012	1.272,5	76,7	0,9	0,2	77,8	1.350,3
2013	1.272,0	77,3	0,9	0,2	78,4	1.350,4
2014	1.270,9	77,0	0,8	0,2	78,0	1.348,9
2015	1.268,5	76,8	0,8	0,2	77,9	1.346,3
2016	1.269,7	75,7	0,9	0,2	76,8	1.346,5
2017	1.245,1	91,9	8,1	2,6	102,6	1.347,7

What’s noteworthy about the listing of Table 3 is that the number of natural gas metering points in the last years has declined. The network was expanded mainly in rural areas. The associated increase of metering points in this area could not compensate the reduction of customers in the urban area. (Schörg, 2018)

Since 2008, a breakdown of natural gas customers has been carried out between small customers and non-houses. Medium sized industry has an annual gas purchase between 2,8 GWh/a and 28 GWh/a. If the purchased amount is smaller, it falls into the category of small customers; with greater purchased amount, it is named a large scale industry. (Schörg, 2018)

3.2 Electric and heat energy composition

The electricity or gas price, which has to be paid for as a customer, consists of three parts. These are the energy price, the network tariff, as well as taxes and duties. The energy price is the part that the supplier receives for his product, thus for the electrical energy or the gas. In the liberalized Austrian market, energy suppliers compete with each other. Each provider sets the prices by itself. The network tariff is given to the network operators. The network tariffs are not set by the companies themselves, but by the regulatory authority Energie-Control Austria (E-Control), the responsible supervisory authority. Taxes and duties build the third share of the electricity price levied by the federal government, the states or the cities and municipalities. Under this point, electricity also includes the green electricity subsidies that every consumer pays to promote renewable energies. Of course, electrical energy, like gas, is also subject to sales tax. (E-Control, 2018)

Data on electricity prices is available from the regulatory authority E-Control and are also collected by Eurostat. The SOFC system should cover only a part and not the whole electric energy demand. In principle, it's possible to cover the whole electric energy demand with an SOFC system, but on the economic side, it's better to install a system not too large and to purchase the underproduced electric energy demand from an official electricity supplier, which will be discussed in more detail in the practical part. In the considerations of this thesis, it will be assumed that a company supplies the electric energy for several households. Because of that, the energy procurement of the industry is consequently focused. But it is also possible to take the household electricity prices for the electricity calculation in account for the further cost estimate.

In the two energy markets for natural gas and electrical energy, domestic consumption increased in 2016. Table 4 shows the energy consumption of different consumption areas. The energy demand of each sector increases every year. The total consumption of electrical energy in Austria in 2016 increased by 1,1 % to 70,7 TWh. Also the delivery to natural gas customers increased by 3,9 % to 87,9 TWh. The consumption amount of individual consumer categories cannot be presented reasonably in the electricity sector for the years 2015 and 2016 as a result of a fundamental change in the allocation. (E-Control, 2017)

Table 4: Energy consumption of Austria (E-Control, 2017)

Sectoral structure of the final energy consumption in TJ						
	Households	Agriculture	Production Area	Services	Traffic	Total
1990	243.488	24.491	213.974	73.137	208.836	763.926
1995	262.861	22.490	220.779	96.395	244.687	847.212
2000	259.565	22.206	249.475	113.156	292.726	937.129
2005	258.260	23.136	296.388	145.076	379.233	1.102.093
2010	264.980	22.408	319.385	141.235	369.297	1.117.306
2013	272.945	23.875	317.913	124.182	370.379	1.109.294
2014	237.527	22.168	309.668	120.180	366.067	1.055.610
2015	255.246	22.995	314.276	116.991	377.555	1.087.062

3.3 Participants on the energy market

On the liberalized energy market, many agents are operating. They can be divided into groups according to German standard definition.

Producer: These are mostly interconnected companies with their own power plant park, independent power producer (“IPP”) and small producers. They produce and supply electric energy to major customers and dealers. (Panos, 2017)

Customer: "Service-oriented customers" are large customers, which often have their own power generator. According to the new energy industry law, in German ‘Energiewirtschaftsgesetz' (EnWG), "basic supply customers" are all household customers and customers with an annual consumption of less than 10.000 kWh/a. The basic supplier is obligated to supply basic supply customers in their network area with electric energy. In accordance with § 36 (2), the universal supplier is the operator, who supplies most households in a network area. (Panos, 2017)

Network operator: Also called “transmission system operator” is the market participant of the energy market, which operates the ultra-high voltage grids with voltages of 380 kV and 220 kV and are interconnected via grid interconnectors to the German grid. “Distribution system operators (VNB)" operate the networks downwards from 110 kV and supply the end customers or redistributors connected to their network with current. (Panos, 2017)

Suppliers: This term includes power plant operators or traders who buy and sell electric energy on their own. Suppliers are accountable for the transmission system operators. This means they must provide their timetable of feed-in and obtaining electric energy all quarter hour metered to their balancing coordinator of the relevant control area. (Panos, 2017)

Energy exchange: Energy exchanges provide a trading platform where market participants bid for the purchase and sale of electric energy or natural gas. Power exchanges organize anonymous markets that are accessible to anyone who meets the access requirements. (Panos, 2017)

3.4 Energy trading

In the liberalized market, electricity and natural gas have become commodities and, like securities and other commodities, are also traded on energy exchanges. The task of the energy exchange is to provide a financially, legally and technically secure marketplace for all admitted trading participants. Energy exchanges organize anonymous markets that are accessible to anyone who meets the access requirements. In Austria, the leading service provider for energy market operations is the Energy Exchange Austria (EXAA). It is a spot market and not a futures market as European Energy Exchange AG (EEX) is based in Leipzig, which is the established energy exchange in Germany. (Panos, 2017)

AVL wants to have the ability to calculate the electric energy price based on the energy exchange prices in the cost estimation too. Due to lack of experience with the energy exchange market, the possibility to trade on the energy market should be analyzed.

3.4.1 Forward market

As mentioned before, it has to be differentiated between spot and forward products. Energy exchange markets are often focused on one of these products such as EEX and EXAA. For better understanding consider Figure 2: Forward market which shows the forward market from the buyer's point of view of energy products. A forward market is a market place on which trades are concluded which have to be fulfilled further in the future, for example one year. For instance, in the case of electricity price, the customer wants to be protected from prices climbing too high, and therefore, various financial products exist. Depending on the situation the buyer has to deal with, a distinction is made between different products. (Panos, 2017)

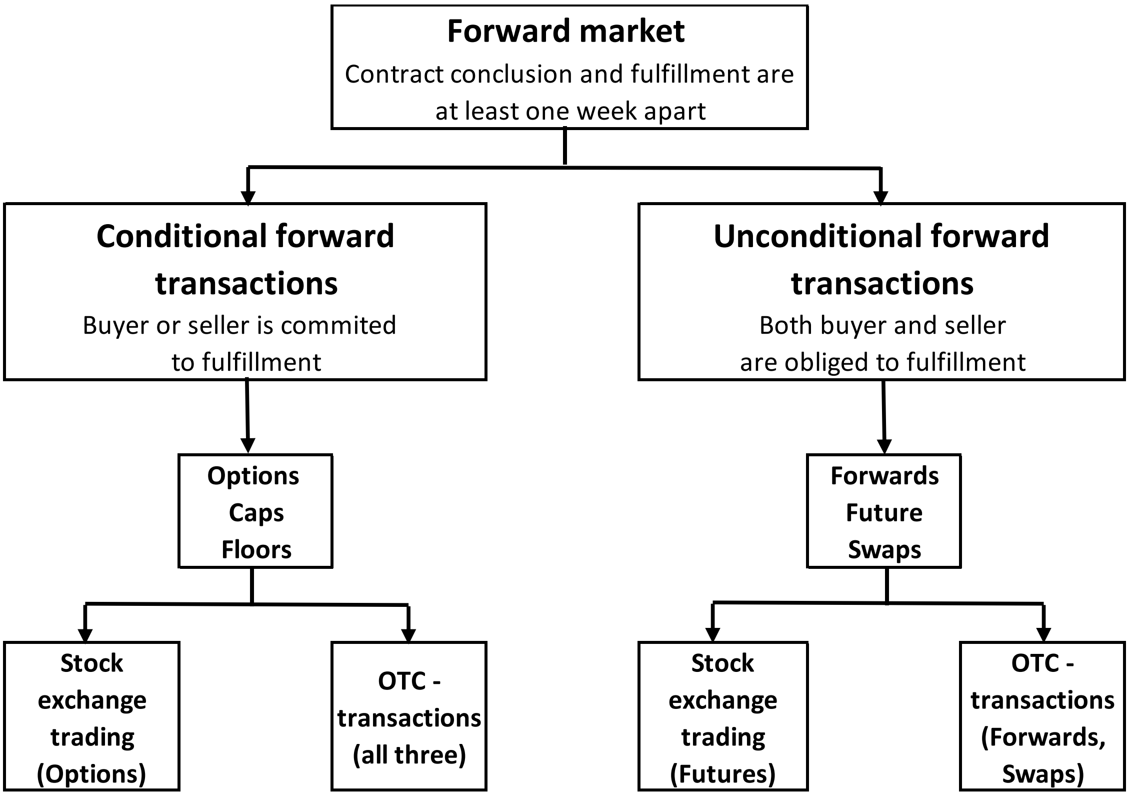

Figure 2: Forward market (Panos, 2017)

The option is a contract that grants the option holder the right, but does not require the obligation, to buy a precisely specified quantity at a predefined price and time in the future. If a company wants to get a contract for a large order, an offer is created in which the company wants to calculate using a fixed electricity price, but it does not want to be committed to purchase an amount of electrical energy and buys a physical call option. Upon conclusion of the contract, a premium (similar to an insurance premium) has to be payed to the trading company. By winning the major contract, the option will be perceived, otherwise it will be dropped completely. (Panos, 2017)

In contrast, future products have the obligation to buy or sell a certain amount of electricity at a price set today at a specific time in the future. If the physical settlement is not done, a cash settlement must be made (depending on the contract specification). This is also known as risk neutralization of both parties. The buyer and seller accept the limited earning potential compared to an option product. On the other hand, no premium payment has to be done. Sometimes the sale of futures contracts is used to hedge against falling electricity prices and the purchase to hedge against rising electricity prices. A future is e.g. sold in anticipation of falling market prices with the intention of realizing a profit through a subsequent buyback at a lower price. (Panos, 2017)

This business cannot only be done with an energy exchange, but also in form of an over the counter transaction. In the second case, the contract will be done with the electric energy supplier directly. The date for the fulfillment of the transactions is in the future. Bilateral transactions are referred to as OTC transactions (OTC = over the counter). Although electricity trading does not trade physically existing goods, the term OTC trading is used here. Thus, if a customer buys goods directly through a supplier, it’s also called direct trade. In contrast to exchange trading, the business partners must know each other, or at least contact via an energy broker, who acts as an intermediary via a platform. A broker negotiates an individual energy price with an energy supplier on behalf of industrial companies or commercial customers. He has the goal to achieve the most favorable price for the customer, and after the negotiation it the energy contract between the actors has to be concluded, whereby the contracting parties remain anonymous until the deal is completed. A broker is often consulted because he brings with him the necessary know-how for the optimal purchasing strategy and, after analysis of the existing contract, can make the selection for suitable energy suppliers. It is assumed that a broker acts independently of energy delivery rates. (Panos, 2017)

3.4.2 Spot market

As shown in Figure 3 energy products can be bought both through the energy exchange and OTC market. The spot market settles short-term deals. The energy exchange trades mainly baseload, peak load and individual hourly contracts. Since 2014, trading of quarter-hour products has also been possible. Spot products are necessary because the over-produced electric energy is difficult to store economically. For baseload products, customers buy a so-called 24-hours block. Electricity is purchased at constant power from 00:00 am to midnight, to cover the base load of one day. At EXAA, the trading unit is 24 MWh, which equates to a constant power of 1 MW over the day. During the day, the consumption of electric energy is higher than at night. To take this into account, peak blocks are bought, which offer electric energy between 8 and 20 o'clock. For peak blocks, the trading unit is 12 MWh and again corresponds to a constant power of 1 MWh. It is also possible to buy off-peak blocks, which are offered outside the peak load time. (EXAA, 2018)

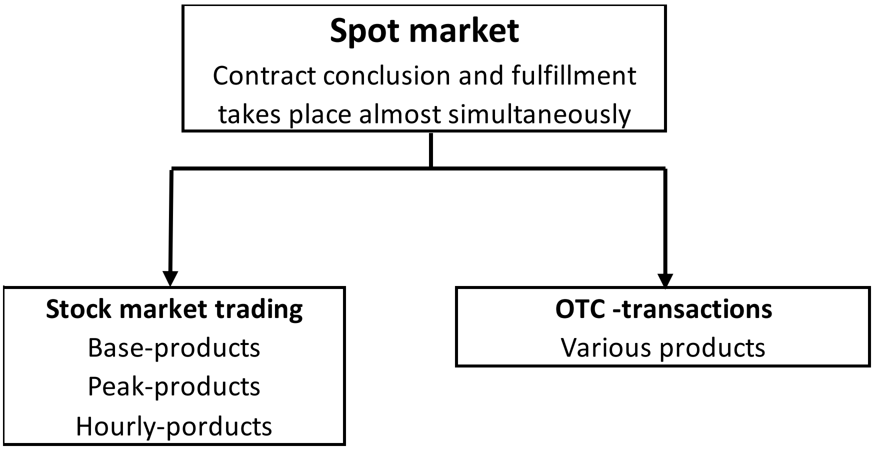

Figure 3: Spot market (Panos, 2017)

On the spot market, it is possible to participate in day-ahead trading and intraday trading. The term day-ahead trading refers to trading electricity for the following day. In places, this trade is also referred to as an auction market, which will be discussed in more detail in Chapter 3.4.5. The second important segment of short-term physical power trading is the intraday market. It starts shortly after completion and publication of the day-ahead trading, whereby the exact starting time varies depending on the energy exchange. In contrast to the day-ahead market, the intraday market primarily exists to close short-term gaps. For example, market participants can use the intraday market to sell or buy differences due to forecast deviations of energy production or to make replacement purchases in the event of unplanned plant outages. Another difference lies in pricing. The trading on the intraday market takes place in real time, and if a trade is made, the price is exactly what is offered. This system is also considered as “pay as bid system”. In this process, the price of the respective bid is raised in continuous trading, whereby, depending on the time of trading, different prices for the same product occur. This pricing is also called bid price procedure and there is no auction in contrast to the day-ahead trading. Rather, the trade runs continuously. This means that a business and thus a price always comes about when a buyer calls the stock market a purchase price that is at least as high as an offer on the stock exchange, or a seller calls the stock market a price that is not higher as a stock purchase offer. The intraday market, however is very illiquid, meaning that during some hours no trading is done. (Süßenbacher, Knaus, & Kabinger, 2015)

Due to the short lead time to physical delivery, intraday trading has a comparatively low trading volume. As a rule, a sufficiently high level is reached only 4 to 5 hours before delivery. As a rule, the prices are more volatile than on the day-ahead market and can reach values of up to ± 9.999,99 €/MWh. There are price-dependent and independent hourly bids. Depending on the stock exchange price, different amounts of electricity are paid out on price-dependent hourly bids. In price-independent hour bids, the exchange participant always receives the same amount of electricity at the market price, regardless of what amount should take the stock market price. Due to the high dynamics and the sometimes extremely attractive price level, intraday trading is extremely interesting, especially for systems with high flexibility. (Süßenbacher et al., 2015)

3.4.3 OTC market vs. Energy exchange

As mentioned before, in contrast to the OTC market in exchange trading, the contracting parties remain anonymous for a transaction. The trading partner in case of a conclusion is always the energy exchange. Another difference between the OTC market and stock market trading is the clearing process. Stock exchanges traditionally have a clearing function. The central task of clearing is the assumption of the counterparty risk and the associated calculation of compensation payments. The term counterparty risk is defined as the risk of financial losses due to the default of a trading partner. If a trading participant fails, the open positions of the insolvent company are closed, which is part of the clearing procedure. In this process, various collateral security instruments are used to offset the financial risks. The most important part of this is the required security services. The amount of the security payment per contract is clearly defined in exchange trading system. This margin is payable before the position is opened, to cover the risk of loss in advance as far as possible. In contrast to the forward products, which are made on the OTC trade, were the payment takes place at the time of delivery, for futures, ongoing payments have to be done: so-called additional margin payments. Variation margin hedges the daily gains and losses of a futures position. (Matzen & Tesch, 2017)

A special form of trading on energy exchanges are exchange trading products which are traded OTC products through brokers that are transferred to the clearing process of the respective exchange after the trade has been concluded. This process is also called OTC Cleared Businesses. The stock exchange offers a substantial advantage by the fact that for the active participation in the trade, only the stock exchange admission must be reached. Numerous contract negotiations, comparable to the OTC market, are completely eliminated. (Matzen & Tesch, 2017)

Another important task of the energy exchange is to ensure that at all times, a seller finds a buyer or a buyer finds a seller at a market price. This is ensured by the so-called "market makers" who can simultaneously discontinue a market-price-oriented offer for sale and purchase at any time. (Matzen & Tesch, 2017)

In the auction process at the stock exchange, price always takes place at the same time. In the run-up to the auction, market participants can submit buy and sell bids. The OTC trading process is not fixed on a specific time. OTC trades are based on freely negotiable contracts. But in OTC trading process standards are also agreed in framework contracts. In Europe, this is typically an EFET framework contract (EFET-European Federation of Energy Traders). (Matzen & Tesch, 2017)

3.4.4 German-Austrian electricity price zone

Since 2002, the German-Austrian-Luxembourg electricity price zone has stood for free, unrestricted and cross-border electricity trading in the middle of Europe. It is the largest contiguous electricity price zone in Europe. But from October 2018, the model of a European internal energy market will be history. The reason for discussions about the allocation of electricity price zones was the regularly insufficient transmission network capacity. This also applies to the case of the German-Austrian electricity price zone. With the energy turnaround[1], a shift in production to the north, where more profitable wind areas are located, has already begun in Germany. As demand does not shift to the north, there is an increasing need for transport, for which the power grids are not designed. In fact, demand from Austria has increased significantly in recent years, aggravating the existing network bottlenecks between Germany and Austria, and especially within Germany. The background is that low electricity prices are often used in times of high wind power generation to fill pumped storage power plants. In consequence, capacity bottlenecks in the German electricity grid and unintentional load flows via the transmission grids of neighboring states during electricity transport within the German-Austrian-Luxembourg price zone regularly occur. In other words, a large proportion of electricity purchased in Austria and imported from Germany is no longer physically transmitted via the German transmission system to Austria, but via the Polish and Czech transmission system. Physical and trade-side electric energy flows diverge due to the limited controllability of electrical energy. These "loop-flows", from the point of view of Eastern European grid operators, endanger the safe operation of the system and require a rest restriction. (IHK, 2017)

The Austrian regulatory authority E-Control, which is responsible for the regulation of the electricity and natural gas industry, wanted to prevent a separation of the electricity price zones and issued a complaint against the decision of the German Agency for the Cooperation of Energy

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[1] Energiewende

Regulators (ACER). Now the E-Control and ACER have agreed on a compromise in bottleneck management. Instead of the previously discussed 2.500 MW, an exchange of 4.900 MW is now possible via cross-border connections between Austria and Germany. (Sperling & Wochnik, 2017)

Bottleneck management can save short term costs in Germany. But this is not a sustainable alternative to grid expansion: The shift of production to the north will continue while large market areas will provide more liquidity. The increase in liquidity helps to offset regional volatility, and thus resulting in cost-efficiency and secured supply. The expansion of cross-border connections between Austria and Germany is in the planning stage, thereby the number of hours in which bottleneck management works, due to exceeding the agreed transferred electric energy amount, will be kept to a minimum. (IHK, 2017)

Due to this current situation and the difficult-to-estimate effects on the Austrian electricity market and its electric energy prices, the decision of the author of this thesis was to stay focused on the prices published by the EXAA spot market. The process of EXAA spot transactions will not change from October 2018, but it should be mentioned that many Austrian companies are also involved in energy exchanges, such as the European Power Exchange (EPEX Spot), which is based in Paris and is a member of the EEX Group.

3.4.5 EXAA Energy Exchange

Liberalization of energy markets was established in almost all European countries’ energy exchanges. One of the main reasons for this is the growing share of volatile generation from renewable energies, which requires ever more flexible marketing, due to rising liquidity, enables ever shorter-term procurement. (Matzen & Tesch, 2017)

The day-ahead market enables the trading of electricity products for the following day. It represents an essential part of stock exchange trading, and at the same time provides an important reference price signal for over-the-counter (OTC) trading. Due to its high cross-border line capacity, the Austrian day-ahead market is closely linked to the German market area and forms a common German-Austrian price zone. As mentioned in Chapter 3.5.4, this common price zone will no longer exist from October 2018 and a so-called bottleneck management will be introduced. On-exchange trading of day-ahead products is common in Austria and Germany via one of two different platforms. On the one hand, this is the European power exchange EPEX Spot, and the Austrian power exchange EXAA, the clearing house for energy products AG. On both platforms, auctions are used to determine the price for delivery on the following day. (Matzen & Tesch, 2017)

EXAA was founded in June 2001, as a commodity exchange, and offers its market participants the opportunity for physical trading of day-ahead products for Germany and Austria since 2002. In December 2012, a special trade for electricity from renewable sources was also introduced. As shown in Figure 4, the EXAA day-ahead market has seen a steady increase in trading volume over the past years to 2012. Since 2013, the energy exchange has recorded constant trading volumes. In relation to the total electricity consumption in Germany and Austria, however, only a small proportion of one to two percent is traded via the EXAA energy exchange.(Süßenbacher et al., 2015)

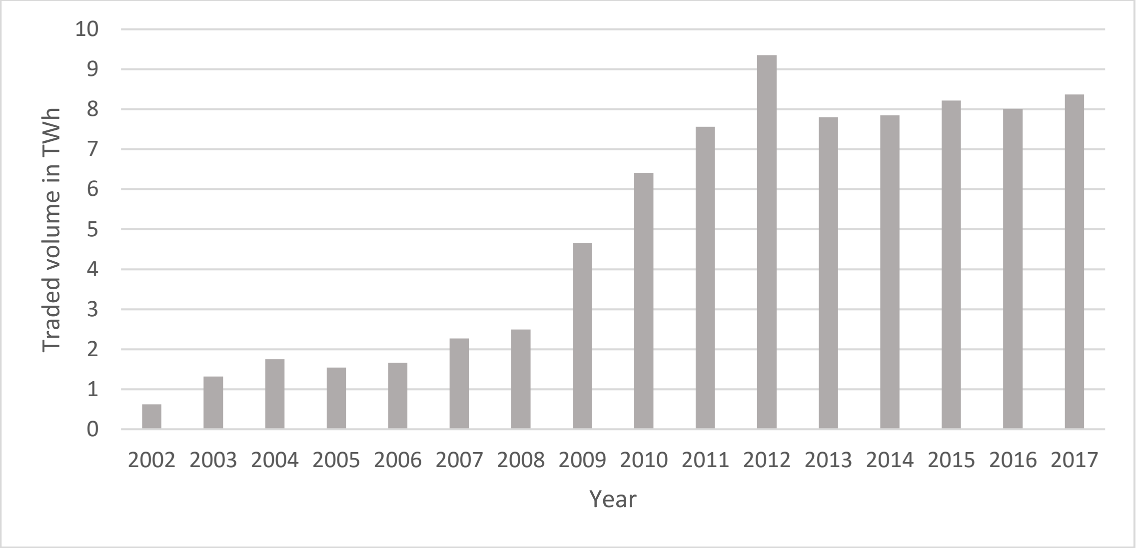

Figure 4: Traded volume of day-ahead EXAA energy exchange products (EXAA, 2018)

Timeline of the day-ahead market

The power exchange EXAA enables its market participants a year-round trading of day-ahead products. Bids for the weekdays Saturday, Sunday and Monday have to be set on Friday already. It is also necessary to submit the bids for all holidays beforehand, including the first day after holidays. The order book will be opened six days before the day-ahead auction. From then on, traders can bid for the auction daily between 12:00 and 16:00. On the day of the auction, it is possible to place bids between 08:00 and 10:12. After closing the order books, the hourly market price is determined using the EXAA matching algorithm. Single-lesson and block bids are auctioned together. At 10:15, the results of the auction, as well as the provisionally awarded bids, will be announced. Thereafter, at 10:16, a three-minute after-auction will start, in which bid overhangs that were not accepted by the matching algorithm or not fully executed can be traded at the established market price. (Süßenbacher et al., 2015)

Merit Order

In the case of the day-ahead market, the selection of fundamentals is based on the merit order. The energy industry describes as merit order the order in which power-producing power plants are installed on a power trading center in order to ensure the economically optimal power supply. In the daily unit price auctions, this determines the market clearing price for the individual hourly products. (Panos, 2017)

In Figure 5 it can be seen that the growing feed-in of renewable energies (photovoltaic, wind energy, biomass) alters the conventional power plant sequence. Fluctuating feed-in photovoltaic and wind power plants with marginal costs close to zero are entering the market and pushing back peak load power plants in the merit order. The energy industry calls this phenomenon the merit order effect (MOE) of renewable energies. The remaining electricity demands that renewable energies cannot cover must still be offset by conventional power plants. (Sensfuß et al., 2018)

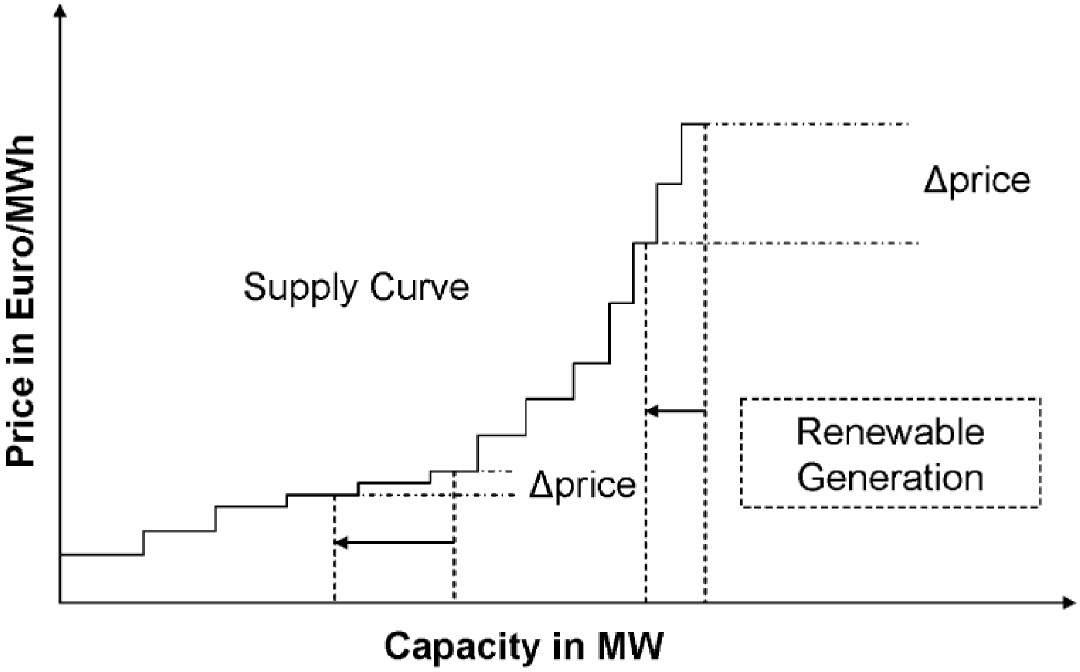

Figure 5: Effect of renewable electricity generation on spot market prices (Sensfuß, Ragwitz, & Genoese)

In theory, the power plant operators charge as much as the variable costs of their power plant for their electricity. Only when the electricity price falls below the variable costs, it makes sense for them to shut down the power plant, although obviously for the producers cannot make a profit if they are only able to cover the variable costs. (Sensfuß et al., 2018)

Negative electric energy prices

Inflexible power sources cannot be shut down and restarted quickly and easily. Renewable energies count as such, because their production depends on external factors (wind and sun). On the electricity market, prices are determined by supply and demand. These in turn depends on several factors, such as the climate, seasons or consumption behavior. This helps to maintain the necessary balance in the power grid. Prices fall with weak demand, which gives the producers the signal to cut their production in order not to overload the power grid. (EPEXSPOT, 2018)

Negative prices are a relatively rare phenomenon as several factors must occur simultaneously. In Germany, where inflexible power generation is increasing as a result of the strong expansion of renewables, negative prices on the German day-ahead market were registered on 24 days in 146 hours in 2017. In the intraday market negative prices were determined in 185 hours over 34 days. If these markets were not coupled, negative prices would occur more frequently, and price peaks would be more severe. In addition, negative prices encourage producers to invest in the development of more flexible power plants that can respond more efficiently to fluctuating energy sources in order to increase security of supply and prevent negative prices. (EPEXSPOT, 2018)

Fees on the EXAA Energy Exchange

The trade is theoretically possible for every energy producer. But the costs or fees incurred in trading are so high, that only very large energy companies have direct access to the trade. How it is possible to carry out the electricity billing on the basis of the prices of the energy exchange will be discussed in Chapter 7.2.1.

The fees of EXAA are levied on the basis of the fee schedule of Wiener Börse AG. EXAA Energy Exchange has commissioned Wiener Börse AG as the clearing house for energy trading. The base fees are collected for: (Wiener Börse AG, 2018)

- Joining the trade market
- Participation in trading
- Transaction fees

In addition, there are still costs to pay as a public exchange trader. These costs can be caused by a electronic random code generator for the trading system process and the establishment of additional trading accounts, which will be not discussed in more detail as they are optional. Table 5 shows the cost overview. It should be noted that the maximum annual business fees are capped at € 15.000. The fee schedule is set up to distinguish between one-time and annual fees. Participants who join EXAA's cash market solely to participate in the trading of cash products of Electric Power named Green Power will not be required to pay any entry fee for one year from commencement of trading in Cash Products Electric Power. (Wiener Börse AG, 2018)

Table 5: Fees at EXAA Energy Exchange (Wiener Börse AG, 2018)

Participation in the EXAA market for electric power products			
As a	Membership fees	Business fees	
		Basis	maximum
Standard Member, Non-clearing Member	10.000 EUR	25 EUR / GWh	
		10.000 EUR	15.000 EUR

In addition to the above-mentioned business fee, a contribution must be paid for each MWh traded on the stock exchange. These transaction fees amount to 0,075 EUR / MWh, which is the same for both buyer and seller. (Wiener Börse AG, 2018)

3.4.6 Control energy

The expansion of renewable energies naturally leads to higher fluctuations in the electricity grid, because the wind strength and the sun intensity are not always the same. Nevertheless, the power supply in Austria almost never fails. This is possible because on the one hand electricity producers are obliged to give the most accurate forecasts regarding delivery volumes in order to optimally plan the feed-in to the power grid and to keep the standard frequency in the power grid at 50 hertz. On the other hand, control energy is very important. If power consumption surprisingly changes because of the failure of a power plant, the control energy should bridge the gap of the predicted amount of energy. This is necessary to prevent the collapse of the power grid. But it is also possible a surplus of electric energy is produced or the demand is lower than what was forecast. Then, a power producer must throttle the electricity production. Balancing increased supply of electric energy or sudden weak demand is called "negative control energy". The control energy is a reserve to compensate the fluctuations in the power grid. For technical and economic reasons, three types of control are distinguished: primary control, secondary control and tertiary control. (Panos, 2017)

The costs for control energy represent an essential component of the grid costs for the extra-high voltage grid, with approx. 40 %. The prices for minute reserves, which are advertised daily for the next day, fluctuate very strongly and have reached values of up to 700 Euro/MWh in the past.

In order for the primary control reserve to be fully available again quickly after an intervention, it is automatically replaced by the secondary control within 30 seconds. Within 15 minutes of the occurrence of the fault, the frequency and the transfer performance must be brought to their target value. The secondary control reserve is provided by the power plants belonging to the respective control area operating at partial load. The tertiary control or minute reserve should have replaced the secondary reserve at 15 minutes the latest after a performance change has occurred. It is manually activated and deployed through the use of storage, pumped storage and gas turbine power plants. (Panos, 2017)

The main hurdle for participation in the control energy market is the minimum power of 1 MW for the minute reserve and primary reserve. For the secondary reserve, the minimum capacity of 5 MW is required. (APG, 2018)

At the moment, AVL does not focus on SOFC systems capable of producing 1 MW. In addition, it still has to be analyzed how quickly such a system has to meet the required performance in order to be able to participate in the market for primary reserves. Due to this fact, this work will not deal with the control energy market.

Summary

This chapter gives an overview of different options to participate in the energy exchange market. The forward market long term market. Trades are concluded which have to be fulfilled further in the future. In contrast, spot market is a short term where deals are done with a short delivery time. For both variants a distinction can be made between OTC market and s stock exchange. In contrast to the OTC market in exchange trading, the contracting parties remain anonymous for a transaction.

4 Economic analysis

This chapter discusses the standardized guideline of the Association of German engineering (VDI), which was used for the SOFC analysis. In order to get an overview of how this VDI is structured, various steps will be briefly described, and the used methods theoretically examined. Especially t AVL wants to have the amortization method in the program for the cost estimate integrated. This method is important because the costs should be graphed over the observation period.

4.1 VDI

The association VDI was founded in 1856, boasting the objective: „all intellectual forces of technology to work together“ and is today of one of the most important technical and scientific associations in Europe with approximately 155.000 members. The VDI bundles the skills and Know-how of engineers and natural scientists. Its responsibilities include: (Bach, 2017)

- Creation and provision of competent contacts for questions of land policy in the fields of engineering and technology
- Advice to the government, the ministries and the parliament by competent technical partners
- Cooperation with other technical-scientific associations and chambers
- Preparing opinions and contributing to the resolution of national economic, environmental, transport, research and education tasks
- Promoting intensive cooperation between schools, universities and industry

The VDI finances itself through donations by the members and the sale of various VDI guidelines.

Purpose of the standard guide VDI 2067

The VDI 2067 series of guidelines deals with the calculation of the profitability of building service systems. This last version of VDI 2067 Part 1 was integrated into the VDI directive in September 2000. However, changes or further developments were continuously carried out. The VDI applies to all types of buildings, and with that, it enables to calculate the energy requirements step by step. In this thesis, the demand profiles already exist. But if this is not the case, this VDI guideline allows the calculation of the energy requirement. For 25 years, a large group of volunteer engineers in the VDI has been trying to solve the problem of evaluating technical building equipment in an energetic and economic way, so that clear and verifiable statements can be delivered. The purpose of the guideline is to evaluate buildings and their technical equipment economically. In this VDI guideline, a financial expense is to be understood only as a valuation variable in the comparison of plant variants. In an economical evaluation of power plants, it is always asked if alternatives are more economical. For object analysis, the individual amounts that occur in calculating the cost of an asset for the various components as well as expenditures and operations can be evaluated in relative size to determine the economic relevance of improvement measures. (Bach, 2017)

The cost of investing in the initial purchase and replacement, the cost of energy, maintenance and service, etc. are stated and calculated as annuities, reflecting the full-time course of costs during a given period of time. The financial expenditures do not allow a direct valuation, but only the comparison of plant variants. (Bach, 2017)

It is important to decide here on the financial consequences of investments, which have a varying impact not only in the year of investment, but throughout the entire life cycle of the following years. The dynamically developing cash flows, disbursements and deposits, are represented mathematically by number series (numerical series). This refers to payments that change the cash on hand or current account during the term. (Bach, 2017)

It should be emphasized that the cost development must be specified in concrete terms. This means that a scenario of interest rate as well as price changes for the period have to be defined. A speculative view should therefore be excluded. (Bach, 2017)

4.2 Annuity Method

For calculating the profitability of an investment, there are various methods, based for example on the capital value, the internal interest rate, the annuity and the amortization. The guideline VDI 2067 uses the annuity method on the basis of present values. (VDI, 2012)

The annuity method is based on the net present value method. But the annuity method has another target size, the annuity. An annuity is a result of equal payments that accrue in each period of the observation period. In contrast, the result of the net present value method is the sum of all payments which occur during the observation period. (Götze, 2008)

Present value

In order to understand the approach of the annuity method, I will go into specific details such as present value and net present value. In order to be able to compare different investments, the individual returns have to be related to a specific time, so that these amounts can be compared with each other. The present value method is used for this. The formula for the cash value is: (Panos, 2017)

$$PV = \frac{FV}{(1+i)^{T_p}} \tag{4.1}$$

PV: Present Value [€]
FV: Future Value [€]
i: Interest rate or rate of return [%]
T_p: Time of procurement

The present value is calculated per discounting of expenses or revenues which were made in the future. That procedure has to be done to make all cashflows, which usually do take place at different times in the future, comparable. (Panos, 2017)

Net present value

The basis of all dynamic procedures for profitability calculations is the net present value method. NPV (Net Present Value) is the difference between the total present value of all receipts and the sum of the present value of all expenses within the operating life (or service life) of an investment, like an electric power system. The mathematical formulation is as below. (Panos, 2017)

$$NPV = -I_0 + \sum_{Tn=1}^{Tn=x} \frac{FV}{(1+i)^{T_n}} \tag{4.2}$$

I_0: Investment at the beginning of the observation period

For a better understanding of the capital value, which is better known as net present value, Figure 6 shows the influencing factors and helps to distinguish between the present value and net present value. The present value is the sum of each discounted cash value of for example the next 6 years as shown in Figure 6. The present value minus the investment is the net present value. It should be mentioned that the example shows only positive present values. However, it is possible that in one year the expenses are higher than the revenues. (Panos, 2017)

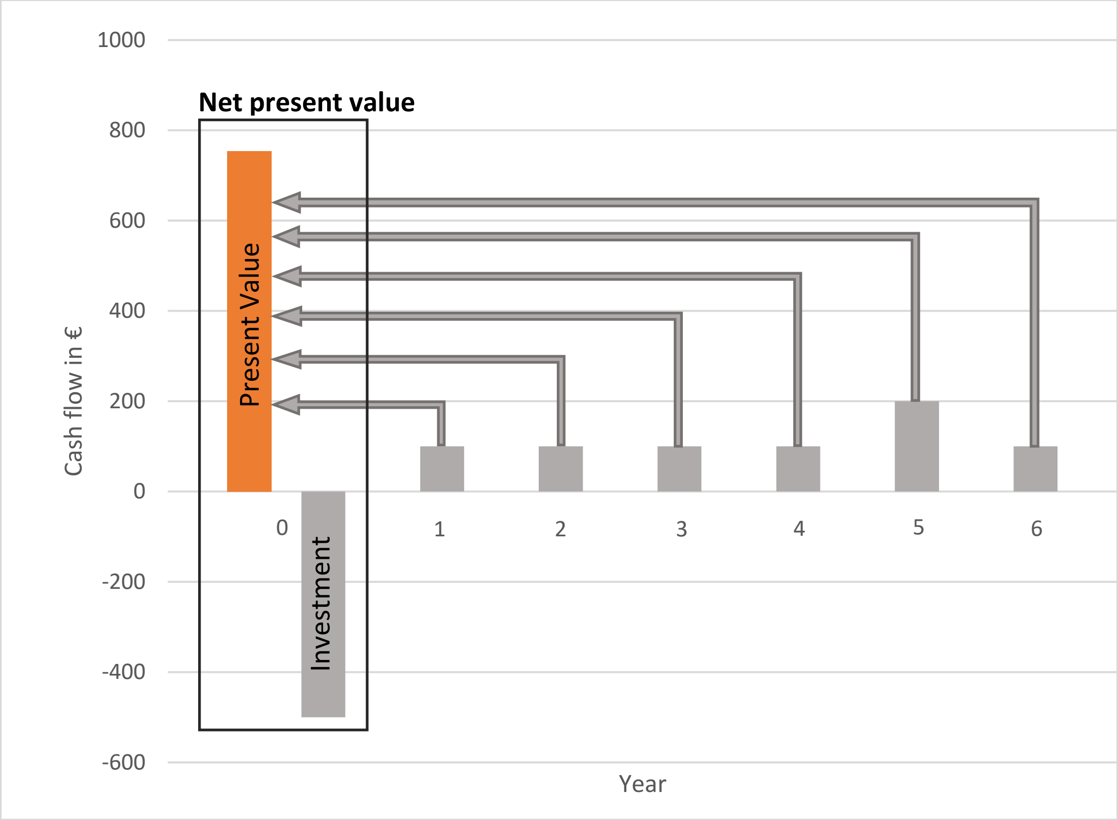

Figure 6: Net present Value (Own representation based on Panos, 2017)

The reference time chosen for the present value is usually the commissioning time of the new system. All payments made earlier, which take place before the system runs, for example capital expenditures, are compounded. Acquisition costs incurred in later periods are discounted like revenues and operating expenses. The compounding and discounting interests have to be defined previously. The interest rate used in the calculation stands for the possible investment on the capital market as investing in an investment. Another example would be if the procurement of a replacement has to be made later, and the money is already invested at the beginning of the observation period, the interest accumulating until it has to be bought. To simplify the calculation, it is assumed that all payments during the period of operation are taken into account at the end of the year. The profitability criterion is the net present value. If the capital value is positive, this means that the investment is economical (absolute economy). Between alternative investments, the one with the highest capital value is the most economic one. An important fact is that the present values of investment options are comparable only if their imputed lifetime is the same. (Panos, 2017)

With VDI 2067, the future value must first be determined when calculating the present value. This is done by multiplying the amount that is to be used for the investment at the start of the commissioning of the investment by the price change factor. This price change factor results from the price change, which can be different for each component. The present value of a replacement purchase that must be made in a certain year, is calculated as follows using the designations used in VDI 2067. (Bach, 2017)

$$A_1 = A_0 * \frac{r^{T_n}}{q^{Tn}} \tag{4.3}$$

A_0: Investment amount in €
A_1: Present value of the first, second …,n^{th} procured replacement
r: Price change factor (to be specified beforehand)
q: Interest factor
T_n: Service life (in years) of the installation component

If the cash value of annual costs incurred during the period under consideration is to be calculated, the annual costs remain the same over the entire running time in the first step, e.g. taking the consumption related costs in the first year of operation, then applying the formula. (Bach, 2017)

$$A_0 = A * \frac{q^T - 1}{(q-1) * q^T} \tag{4.4}$$

A: Consistent payment
T: Observation period in years

When using this VDI guideline, it is also possible to take into account the residual value of each component and to include it in the calculation. If the residual value has been estimated by straight line depreciation of an investment at the end of the observation period and the discounting to the beginning of the period the formula for the residual value is: (VDI, 2012)

$$R_w = A_0 * r^{(n*T_n)} * \frac{(n+1) * T_n - T}{T_n} * \frac{1}{q^T} \tag{4.5}$$

R_w: Residual value in €
n: Number of replacements procured within the observation period

For each type of installation component, a specific service life has to be indicated. If the service life of a component is shorter than the observation period of the whole system, instead of the initial amount of money of the investment of a component, the discounted amount of money for the replacement investment has to be paid. (VDI, 2012)

Since the energy-related assessment of building services equipment according to VDI 2067 generally uses annual energy expenditure as criteria, it makes sense to translate the cash values into constant annual amounts, so-called annuities, and to use these as benchmarks for the sake of clarity. The general annuity factor is by definition. (Bach, 2017)

$$a = \frac{q^T - (q-1)}{q^T - 1} = \frac{q-1}{1-q^{-T}} \tag{4.6}$$

The annuity factor is the reciprocal of the discounted sum factor. With an annuity method investment, variants with different lifetimes can be compared. Lifespan does not matter when comparing annuities. Capital values, on the other hand, are, as already mentioned, comparable only for investment variants with the same service life. If price changes of the individual components can occur during the period under consideration, these costs should first be multiplied by the price-dynamic present value factor and then by the annuity factor. (Bach, 2017)

$$b = \frac{1-\left(\frac{r}{q}\right)^T}{q-r} \tag{4.7}$$

4.2.1 Different kind of costs

To perform the annuity method, different cost factors have to be considered. The price change factor is not equal for each kind of cash flow. The guideline VDI 2067 distinguishes between

- Capital-related costs
- Demand-related costs
- Operation-related costs
- Proceeds
- Other Costs

The total annuity of each variant should be considered. Especially the capital related costs are not the same every year. The individual replacement procurements must be added. The residual value is also taken into account in the VDI guideline. As shown, the sum is multiplied with the annuity factor and the result is the annuity of the capital-related costs. (VDI, 2012)

$$A_{N,K} = (A_0 + A_1 + A_2 \dots A_n - R_w) * a \tag{4.8}$$

$A_{N,K}$:	Annuity of the capital-related costs
$A_1 \dots A_n$:	Cash value of the procured replacement
A_0:	Beginning procurement

The demand and operation related costs, other costs and proceeds have to be multiplied with a specific present value because for each cost term, the price change factor is usually not the same. Other costs include expanses, for example for insurances, contributions and duties. (Bach, 2017)

Finally, the annuity of total annual payments has to be summed. The proceeds are positive, and the costs are negative. (Bach, 2017)

$$A_N = A_{NE} - \left(A_{N,K} + A_{N,V} + A_{N,B} + A_{N,S}\right) \tag{4.9}$$

A_N: Annuity of the capital-related costs
A_{NE}: Cash value of the procured replacement
$A_{N,V}$: Demand related costs
$A_{N,B}$: Operation related costs
$A_{N,S}$: Other costs

If the proceeds are greater than the sum of the costs $A_N > 0$, profit can be generated. Otherwise, $A_N < 0$, by the investment no money can be earned. But at least two different initial situations must be distinguished from each other. The first case would be if an investment is made to turn a profit. This is true e.g. when a system operates only to feed the produced electric energy into the grid to earn money. In this approach, an investment should only be made if the annuity is greater than zero. In the second case, there are various relevant investments which can be chosen, and by comparison, the economic viability should be analyzed. Therefore, the annuities of the investments must be compared with each other. This case occurs if e.g. a system operates to cover its own electric and heat energy demand to a part. The system costs more than it can generate by feeding electric energy and the resulting revenues. Thus, the annuity of the investments to be compared is negative. The system whose annuity amount is less negative, is the one that should be favored. (Bach, 2017)

4.3 Amortization method

With the amortization method, a payback period is calculated as a measure for leaving economically unappreciable variants. This method is used above all for cost-effectiveness issues, namely to offset increased investments in energy efficiency with the savings in initial costs due to lower energy consumption. The aim of the amortization method is to determine simply and clearly what is worth considering. In the commentary to VDI 2067, written by Heinz Bach, the static amortization method is described and applied. The influence of changes in interest rates and prices is waived. However, based on VDI 2067, it is possible to record the dynamic development of costs, and thus carry out the dynamic amortization method. The static amortization period is mainly about finding out whether it is worth looking at a plant in more detail. This finding is preceded by a sensation, namely the feeling of an interest in an object, e.g. on a system concept or on a technology, which is advertised, and then further the feeling of a reasonable limit of financial capacity. (Bach, 2017)

The payback period calculated for static conditions therefore indicates whether it is above or below a reasonable limit. It is by definition: (Bach, 2017)

$$t_A = \frac{Investment\ difference}{Savings\ in\ each\ year} \tag{4.10}$$

In the equation the numerator shows the difference between the investment amounts as annual savings in running costs, in the denominator, and not only the consumed portion, but also the savings in the operating share. (Bach, 2017)

The amortization time calculation determines the number of years it takes to recoup the capital employed for a measure by cutting costs. For this, the term payback time has been established. The method is usually applied statically. (Panos, 2017)

Payback periods can also be applied dynamically. When determining the dynamic payback period, the annual savings are discounted and deducted from the investment expense. The difference is the capital value. As soon as this becomes positive, the payback period is reached. Dynamic calculations lead to significantly longer payback times, especially at high interest rates, if a profit is to be generated by this investment. This is due to the fact that the returns are discounted to the start of the study period. In general, the calculated payback time must be shorter than the required one. The useful life of the measure must be longer than the payback time. The required payback time for measures to reduce operating costs, is different for the different branches of industry, but typically short, and ranges usually between 3 to a maximum of 5 years, depending on the industry. It is about whether the amortization time is within reasonable limits. This means that the payback time is based on the feeling of a limit of reasonableness and one can not decree one's feeling. The measures identified in the context of energy audits are listed in a ranking list after their evaluation. A distinction is made between no-cost, low-cost and high-cost measures. In the ranking, all "no cost" measures have top priority. In particular, the high-cost measure requires other criteria besides the payback time, e.g. the amount of the investment and the expected useful life of the individual measures. (Panos, 2017)

In the cost estimation and evaluation of how economical the SOFC system is compared to other systems, the VDI 2067 was supplemented with a dynamic payback calculation. As already mentioned, the static amortization period is often used, but AVL would like to add the influence of the interest factor.

The following example shows the cash flows to be considered. With the static pay back method, the average cash flow is used for the calculation. In the dynamic investment calculation, the individual cash flows of each year must be calculated. Especially the influence of interest requires a consideration of the individual returns of each year. To approximate the actual dynamic payback period, the following linear interpolation formula can be used. Here, variable t* indicates the period of the last cumulated negative net present value: (Götze, Northcott, & Schuster, 2015)

$$Dynamic\ payback\ period\ \approx\ t^{*}\ \frac{Net\ present\ value_{t^{*}}}{Net\ present\ value\ _{t^{*}} -\ Net\ present\ value\ _{t^{*}+1}} \tag{4.11}$$

The approach to interpolate between the negative present value and the first positive present is possible by assuming that the individual cash flows occur in a linear fashion. If there is an amortization point, a distinction is made between two results. In the first case the investment project’s payback period is shorter than the target length of time, which is usually expressed in years. By reaching this target, the investment is defined as absolutely profitable. If the investment has a shorter payback period than the alternative investment project it is defined as relatively profitable. (Götze, Northcott, & Schuster, 2015)

According to the list of the yearly discounted cashflow in Table 6, payback calculation is done were an investment pays off. This situation is achieved when the revenue exceeds the initial investment made. The calculation used for this master thesis requires a comparison between two investments. It may also be that an investment is not intended to generate income. It should only cover the need for electricity or heat through production of said energy. Therefore, different plants should be compared to determine which is less costly and therefore more economical to buy. (Götze, Northcott, & Schuster, 2015)

Table 6: Cashflow example (Götze et al., 2015)

Point in time	Net cash flow (€)	Present values of discounted net cash flows (€)	Cumulative net present values (€)
t	NCF_t	NCF_t*q^{-t}	NCF_t*q^{-t}
0	-100.000	-100.000	-100.000
1	28.000	25.926	-74.074
2	30.000	25.720	-48.354
3	35.000	27.784	-20.570
4	32.000	23.521	2.951

Main advantages

- The cash flow is taken into account in absolute terms
- Different levels of risk of different projects and activities
- Determining the time when the case arrives that the accumulated present values have reached the amount of the taken investment

Main disadvantage

- It does not measure the total cash flow over the entire project period

In comparison to the static amortization calculation, the dynamic approach offers a greater relevance to reality and is preferable to the static method, in case of doubt. The time to amortization primarily quantifies the risk that arises from the fixed capital bond into an investment object. The amortization period should always be flanked by a supplementary method of cost-effectiveness, which outweighs the economic advantage or disadvantage of the project for the period beyond the payback period. These include the mentioned annuity method and net present value method. (Geilhausen, Bränzel, Engelmann, & Schulze, 2015)

4.4 Interest, Inflation

For someone who wants to invest his money, it is important to know, what is the real interest income of a financial investment. The real interest rate is an important variable, which describes the change in value of an asset taking inflation into account. In order to analyze the composition of the real interest rate and its evolution, each value will be defined separately.

Interest

The interest rate is the price of borrowed or invested capital. It is given as a percentage per period. The interest rates shown in Table 7 are the nominal interest rates. These data are published by the Austrian National Bank. (Turner, Winkler, & Pfeiffe, 2018)

Table 7: Deposits of private households (Turner, Winkler, & Pfeiffe, 2018)

Year Duration	2015	2016	2017	2018*
Until 1 year	0,38 %	0,31 %	0,24 %	0,20 %
1 to 2 years	0,44 %	0,38 %	0,35 %	0,33 %
Over 2 years	0,86 %	0,77 %	0,84 %	0.57 %

*May 2018

Unfortunately, there is not enough data available to detect a trend in how interest rates could develop over the next few years. Because of this reason, a fixed-rate investment opportunity was sought to be found. A fixed interest rate is necessary, especially for the observation period of the cost estimate which has to be done. By a fixed-term comparison for long-term investment, which is carried out by the comparison portal with the name Interest Rate Comparison, Kommunalkredit Austria AG offers the highest interest rate for longer-term deposits. (Turner, Winkler, & Pfeiffe, 2018)

This form of investment is to be favored if it is not necessary to access the money for several months or years. The longer money is invested, the better the guaranteed fixed interest rate on fixed assets is becoming, as shown in Table 8. Nevertheless, the money can be accessed if required at any time. If this occurs, the bank will deduct interest, as a result of the not-fulfilled investment period. The calculation takes 25 % capital gains tax into account. (Kommunalkredit Austria AG, 2018)

Table 8: KOMMUNALKREDIT INVEST deposit account (Kommunalkredit Austria AG, 2018)

Duration	<10.000€	≥10.000€
6 months	0,30 %	0,55 %
12 months	0,55 %	0,90 %
18 months	0,57 %	0,92 %
24 months	0,60 %	0,95 %
36 months	0,76 %	1,11 %
60 months	0,85 %	1,20 %
96 months	1,15 %	1,50 %
120 months	1,30 %	2,00 %

Inflation

Inflation is defined as the general increase in prices of goods and services, combined with a loss of purchasing power. The price increase within a certain period, usually one year, is called the inflation rate. The inflation rate does not refer to a single good, but to the weighted prices of a defined group of goods and services contained in the basket of goods. (Panos, 2017)

Table 9 gives an overview on which goods for example can be summarized in such consumer groups. Goods that affect the general population are often summarized in such baskets, from which the inflation index is calculated. Each product is weighted differently, depending on how often this item is bought. (Statistik Austria, 2018)

Table 9: Consumer groups (Statistik Austria, 2018)

Consumer groups	%
Apartment, water, energy	2,07
Household and ongoing maintenance of the house	1,77
Various goods and services	1,08

Table 10 shows how inflation forecasting has been published by various institutions. They are not equivalent, but they are 0,4 % apart at the most. The times given next to the various names of the institutions, is the time this forecast was made. The percentages for each year which are listed are always refer to the previous year. Most developed economies have been aiming for an inflation rate of 2 % per annum since the early 1990s. (Statista, 2018)

Table 10: Forecasts of inflation in Austria (Statista, 2018)

Institution	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Bank Austria (July 2018)	2,2 %	2,0 %	-	-	-	-
EU commission (July 2018)	2,2 %	1,9 %	-	-	-	-
WIFO: Austrian Institute for Economic Research (June 2018)	2,0 %	2,0 %	-	-	-	-
IHS: Institute of Advanced Studies (June 2018)	2,1 %	2,1 %	-	-	-	-
OeNB: National Bank of Austria (June 2018)	2,2 %	2,0 %	1,9 %	-	-	-
OECD: Organisation für wirtschaftliche Zusammenarbeit und Entwicklung (Mai 2018)	2,1 %	2,3 %	-	-	-	-
IWF: Internationaler Währungsfonds (April 2018)	2,2 %	2,2 %	2,2 %	2,2 %	2,1 %	2,1 %
BMF: Bundesministerium für Finanzen (April 2018)	1,9 %	1,9 %	1,9 %	1,9 %	1,9 %	-

Price change factor

The price increase of a single good is called the escalation rate. It can be higher or lower than the inflation rate. We distinguish between nominal and real escalation rates. In the first one the inflation is included, in the second one not (inflation adjusted). The price changes of the goods and services of a market basket within a period are displayed in a price index (plural price indices), weighted and expressed in percentage points relative to the price level of a reference year whose price level is set at 100 percent. Collecting, analyzing and publishing prices is one of the main tasks of the National Statistical Institutes. In Germany, the Federal Statistical Office is responsible for this, in Austria it is Statistics Austria and in Switzerland the Federal Statistical Office. (Panos, 2017)

Summary

The cost estimate is based on the VDI guideline 2067. The annuity method and the amortization method are used to compare the SOFC systems with a reference system. For long-term deposits KOMMUNALKREDIT INVEST offers a maximum fixed interest rate of 2 %. For each single good another escalation rate exists. It is distinguished between nominal and real escalation rates. In the first one the inflation is included, in the second one not.

5 Selection of the system

5.1 Initial situation

As mentioned in the introduction, different system combinations can be chosen to cover the electric and heat energy demand in the Matlab simulation. The demand profiles over the year depend on the specific requirement area. This thesis is focused on a demand profile provided by AVL, to determine the economic profitability of an SOFC system compared to a gas engine and the pure purchase of electric energy from an electric energy supplier. Each of these three system alternatives are operating with an additional condensing boiler. This is necessary to support the SOFC or the gas engine to produce enough heat energy. If no system is installed for the production of electric energy, the heat demand should be covered by a condensing boiler, whose size should be larger than the installed ones in the other two system combinations.

The simulation of an SOFC and large engine system was done by Dominik Königshofer with the thesis ‘Simulation of load profiles for the application of a SOFC CHP power plant as controllable power plant of the future’. (Königshofer, 2018) The input of various values, which are necessary for the calculation, was done with various Matlab and Excel scripts as well as Excel files for each system.

Different system combinations should be comparable and AVL wants to be able to simulate other simplified referential systems. Therefore, it is necessary to create an input file via Excel which contains all relevant parameters concerning the three systems.

The electric energy price is an important topic for AVL and the competitiveness of the SOFC on the energy market. If the operator of a CHP system wants to earn money with the overproduced electric energy and he gets too little money for the electricity sold, to install a system becomes increasingly unattractive. For further simulations of the SOFC, the electric energy price calculation should be non-dependend on the specific size of a system. The demand can range from a combination of a few households to a big industry plant. Therefore, a study of the energy market, their prices and the reliance on the electric energy demand is needed. The pure purchase of electric energy doesn’t have to be analyzed in detail, but the function, to consider large sales quantity and large feed in volumes of electric energy, has to be implemented in the cost estimation. The purchase and sale on the basis of the electric energy trade market should be analyzed, as well as determining which amount is needed to make it at all possible.

A simple cost estimation disregarding any interest as well as lists of components with different life services was already completed by AVL. However, up to now the price change factor was missing, which is important for AVL. If the components have to be changed during the observation time of the SOFC system, AVL wants to take increasing or decreasing prices into account. The stack is one of the components of the SOFC, which usually have to be changed during the observation time. In the coming years, a decrease in stack prices for the SOFC is expected. To take that into account, a price change factor to implement that effect needs to be considered. The main task is that in the end, an amortization method and a sensitivity analysis should be implemented in the cost evaluation tool.

5.2 Input field of the simulation

To simplify the input process and to get a better overview of the different values which were defined and set, an Excel-file with structured spreadsheets has to be made. All system installations which were chosen to cover the energy demand have to be integrated. The name of the file is ‘Input Matlab for TCO’. Following input parameter have to be defined.

- Power of the system in W
- Starting part load point
- Minimal part load point
- Maximum part load point
- Downtime (first hour)
- Downtime (last hour)

These values have to be set for each system for the SOFC, combustion engine, and three times for the condensing boiler of each system combination. If the comparison of only two system combinations is required, changes must be made in the Matlab code. These changes can be made in the M-file with the name ‘ALL_Systems_SOFC_LE_GH’, where all combinations which have to be simulated are listed. A change would be necessary, for example, if the simulation of the combustion engine is not needed. In that case, the command to simulate the combustion engine can be deleted.

The next step is that in the value setting process, the operating temperatures have to be defined, regarding the minimum and the maximum temperature and at which temperature which load point can be reached. Also, the self-adjusted temperature must be defined, if the load is kept at a certain level. This means a constant temperature will be set if the load does not change during operation. These settings can be changed for all systems which have to be simulated. In the example shown in Figure 7, the partial load point of 50 % can be reached at a temperature of 720 °C and full load operation is possible at 810 °C. The straight lines which are shown in the diagram only connect the specified values. It is important that the value is indicated at 0 degrees and a load of 0. This is necessary, for example, if a downtime during operation of the system occurs, e.g. due to a planned maintenance work.

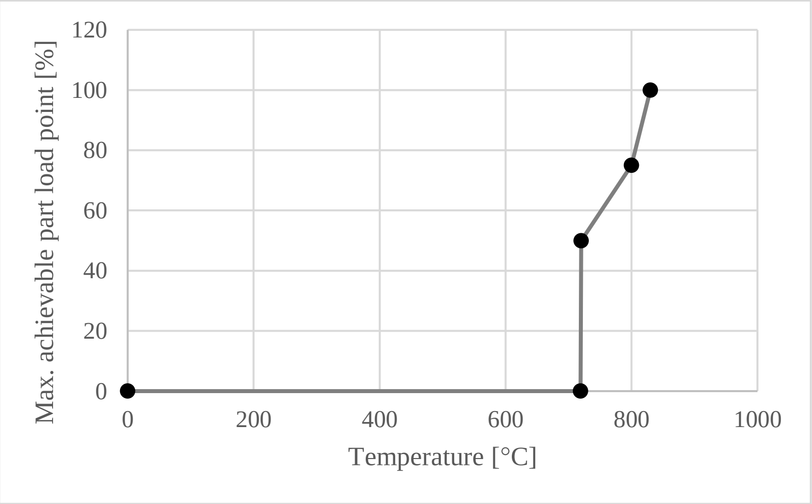

Figure 7: Max. achievabale part load point of an SOFC system (Own representation)

For the gas heater, large engine and condensing boiler, all parameters for the simulation have been specified by AVL.

Also, for the change in operating temperature during load change an input field exists. This value is needed to be able to simulate the impact of many load changes during operation on the cost estimate. At each load point other efficiencies are possible. That means, for example, if the load point of the SOFC system changes from 50 % to 75 %, at a specific initial temperature the system temperature changes 2 degree per minute. It takes time for the system to warm up to the maximum temperature if the load of the SOFC increase.

The net efficiencies can be defined in relation to the load point. The stated efficiencies in this thesis are always net efficiencies. The load level is numbered in decimal steps and for each load point the efficiency can be entered. For the simulation, it is not necessary to define the efficiency of each load point. In order to get the simulation working, the efficiency at 0 and 100 percent load must be indicated. If values are missing between two load points, for example 10 and 50, the values for 20, 30 and 40 are interpolated. The electrical efficiencies and the thermal efficiencies must be specified for each simulation. In Table 11, Table 12 and Table 13 the efficiencies to be achieved in dependence upon the load for each system, which can be simulated, are listed. The total efficiency is also displayed beside the electrical and thermal one. Efficiency is denoted by the Greek letter eta (η).

Table 11: Efficiencies of the SOFC system (Own representation)

SOFC			
Load	η_{el} [%]	η_{th} [%]	η_{total} [%]
0	0	90	90
10	8	82	90
50	60	30	90
100	50	41	90

Table 12: Efficiencies of the condensing boiler (Own representation)

Condensing boiler[1]			
Load	η_{el} [%]	η_{th} [%]	η_{total} [%]
0	0	98	98
50	0	98	98
100	0	98	98

Viessmann Vitodens 300-W B3HB[1]

Table 13: Efficiencies of the combustion engine (Own representation)

Combustion engine[2]			
Load	η_{el} [%]	η_{th} [%]	η_{total} [%]
0	0	75	75
50	20	66	86
80	24	66	90
100	27	67	94

Viessmann Vitobloc 200 EM-6/15[2]

Finally, the ramp rate must be defined for each system. The power ramp-up rate of SOFC systems primarily depends upon the temperature of the stack. Table 13 shows the efficiencies of the combustion engine Vitobloc 200 EM-6/15 from Viessmann (which is a leading manufacturer of heating, industrial and cooling systems in Germany). The additional condensing boiler is also from Viessman. These systems were also used for the cost estimate in Chapter 9.

5.3 Demand profiles

As is apparent from the input values in Table 11 and Table 13, which are provided by AVL and reflect the current technical feasibility of the SOFC, the SOFC system has a higher electrical efficiency than an internal combustion engine. But this does not mean that the SOFC can automatically be displayed as a better system. At first, the selected demand profile has to be analysed. The dimensioning of the plant and determining how big the system should be is necessary in order to operate the plant economically. Without this procedure, the correct size of the plant would have to be iteratively determined, which would require many simulations.

The demand profile used, which is analysed in Figure 8, consists of 2 houses with 9 apartments each. 25 people live in each house. The houses are located in the urban area and are multi-family houses. The cost estimates in this thesis are to be made with at least one demand profile.

There is a demand profiles for the electricity and the heat demand. In order to be able to estimate in advance how big the system needs to be, an M-file which plots the respective need for electricity and heat and the necessary power over time is available. Two diagrams were created for the analysis of demand profiles. The first diagram is shown in Figure 8. The diagram shows how many hours the system must be operated at what electrical power output to meet the demand. Here, the capacity utilization can be estimated for a specific capacity of the system. Or it can be estimated, how much power the plant needs when purchasing a system that should be operated in full-load operations mostly.

For the demand profile in Figure 8, with the agreement of AVL, a power of approximately 5 kW was defined as adequate. With this power it is ensured that the plant is largely operated at full load. If the system is operated at full load it produces the maximum amount of electric energy that would otherwise has to be purchased from an electric energy supplier. This has a favorable effect on the cost estimate because it reduces annual costs of purchased electricity. An internal combustion engine with an electric power of 6 kW and an SOFC system with an average electric power of 4,5 kW were assumed. The AVL wanted to simulate a SOFC system with an installed electric capacity of 4,5 kW. It is required to find a gas combustion engine which has approximately the same electrical power and if it is possible it should come from the company Viessmann. At Viessman there are currently no new gas combustion engines with an electrical capacity under 6 kW available. That is why the gas combustion engine named Viessmann Vitobloc 200 EM-6/15 was chosen as the reference system. The combustion engine has a thermal output of 14,9 kW.

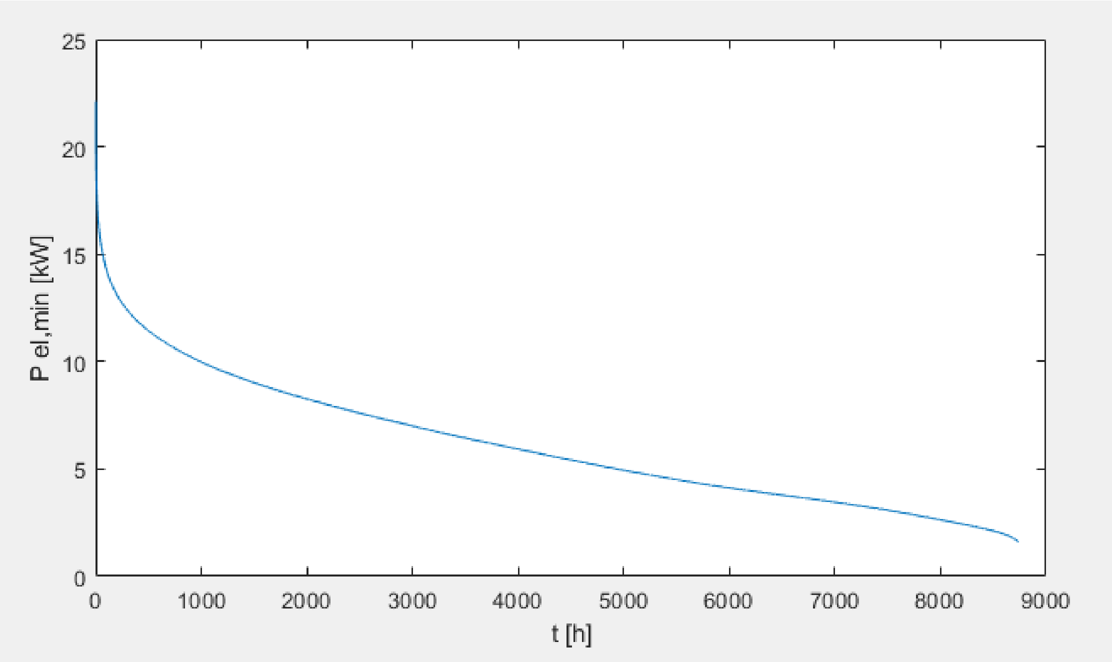

Figure 8: Analysis of the demand profile in Matlab (Own representation)

In order to be able to carry out this estimation in another way, there is also a second diagram. A bar diagram which can be seen in Figure 9. For example, in this illustration it is shown, that an electric power of 7,2 kW would be needed for about 70 % of the year and 2,4 to 4,8 kW would be needed during 35 % of the operating time.

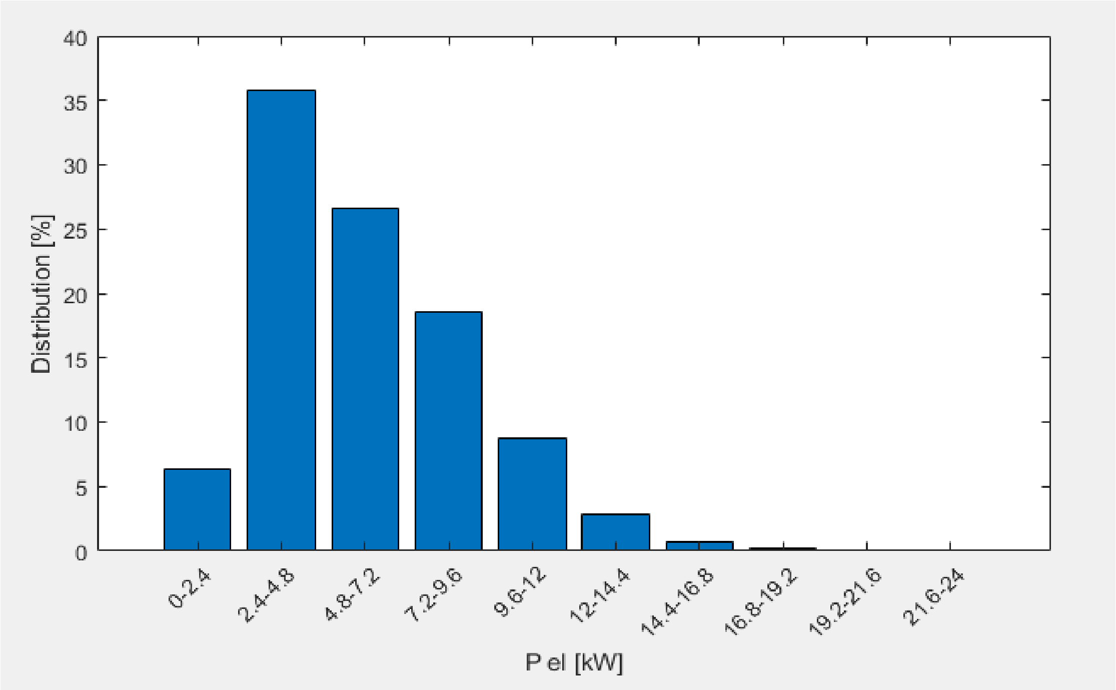

Figure 9: Electric power distribution during one year (Own representation)

These diagrams are also available for the heat needed. However, the system is operated in a electricity driven simulation mode. As a result, only the electrical power is looked at. It is important to ensure that the system can store the heat produced, if it exceeds the heat demand. This aspect will be discussed in more detail in the Chapter 6.2.

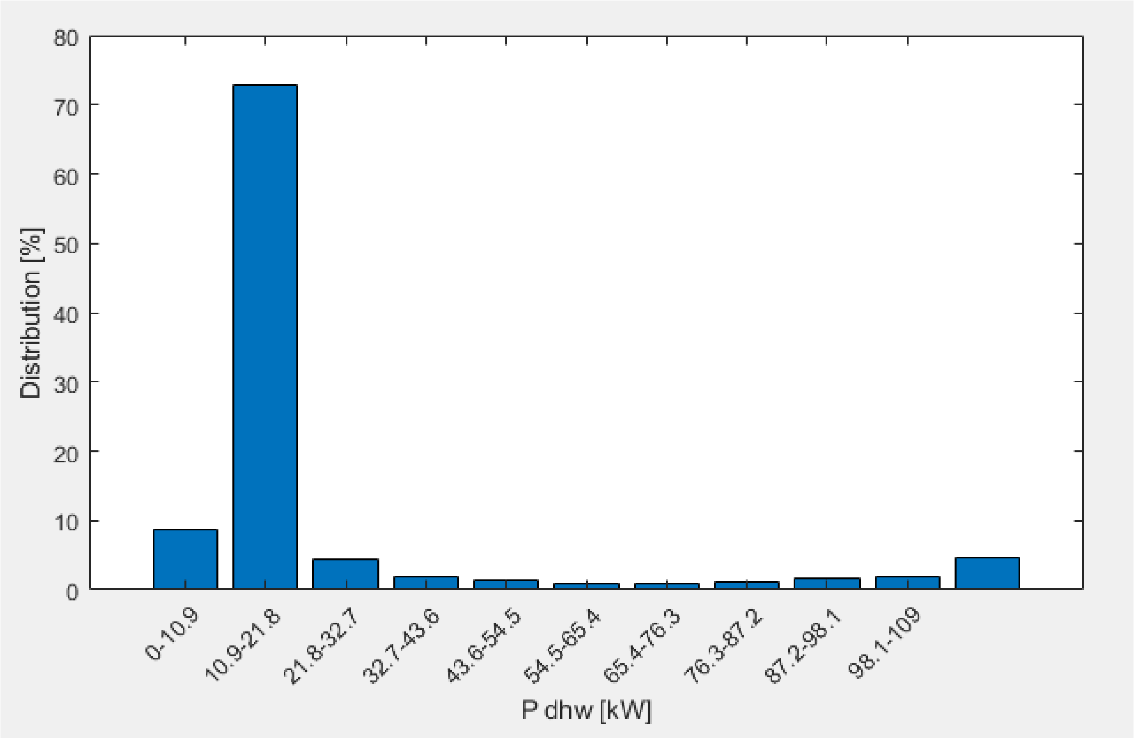

Figure 10: Heat power distribution during one year (Own representation)

Summary

This thesis is focused on a demand profile of 2 houses with 9 apartments, to determine the economic profita-bility of a SOFC system compared to a gas engine and the pure purchase of electric energy from an electric energy supplier. All these three systems have an additional condensing boiler to cover the total heat demand. The input process of all necessary input values like the power and efficiencies of different load points of the systems is done by an Excel-file with structured spreadsheets. The stated efficiencies are always net efficiencies. The demand profiles can be analysed via two diagrams which are created via Matalb. One diagram shows how many hours the system must be operated with which electrical power to meet the demand. The second one is a bar diagram which shows the power distribution of the demand profile to be analysed in another way.

6 Simulation in MATLAB

This chapter shows the input and output procedure of the simulation. It should give an overview of all values which are calculated by the simulation. Therefore, the programs which are used are Excel and Matlab.

6.1 Path of the value transfer

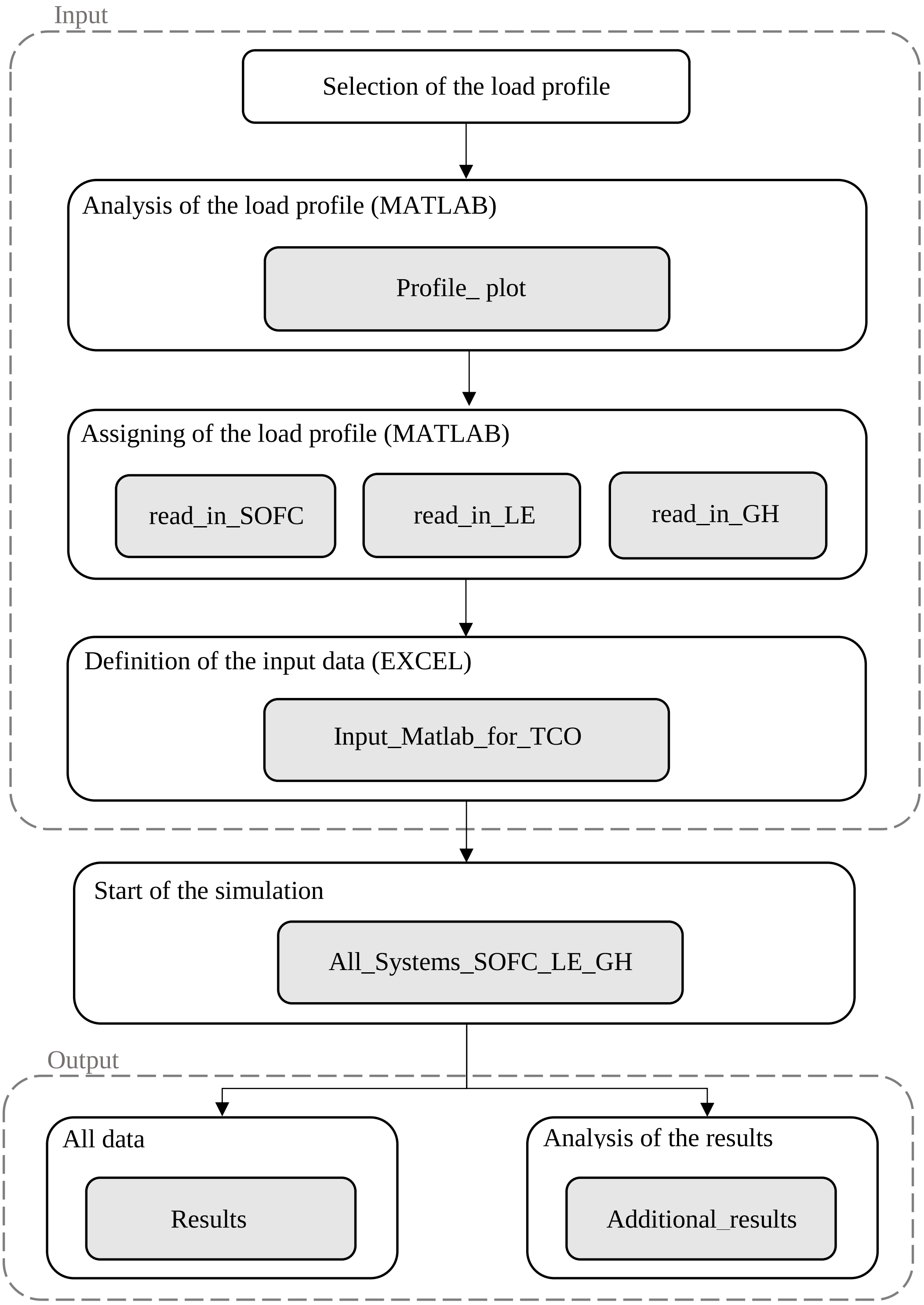

Figure 11: Path of the Matlab simulation (Own representation)

The path in Figure 11 gives an overview on the simulation procedure. AVL has access to different demand profiles, and their respective load profiles. As a first step, it must be defined which one has to be simulated.

If a comparison is to be made between SOFC with gas boiler, combustion engine with gas boiler and electricity supply from the grid with gas boiler, the simulation takes about 20 hours on a computer with a main memory of 16 gigabytes and an Intel processor named intel i7 CoreTM 7th generation. The heat demand that cannot be covered by the SOFC should be covered by the following simulation of the gas boiler. The same procedure takes place in the simulation of the internal combustion engine. As already mentioned in the previous chapter, for the supply of the electricity from the grid, only one heat source is simulated which should cover the heat spring.

The read-in M-file with the abbreviation LE stands for a reference system, which can be compared with the SOFC system. The designation LE stands for large engine. But it can also be simulated just as a small engine with condensing boiler. Subsequently it is necessary to set the correct parameters in the Excel-file 'Input_Matlab_for_TCO'.

The command to execute the simulation of the chosen systems that should be simulated and compared contains the M-file with the name 'All_Systems_SOFC_LE_GH'. If a system like the combustion engine should not be simulated can be deleted from this M-file. The two files named 'Additional results' and 'Results' show the summarized results of the simulation.

6.2 Output of the simulation

After the simulation ends, data is transferred into two different Excel-sheets. The Excel file named 'Results' shows the necessary results for the further cost estimation, especially for the calculation of the electricity price. The following values are displayed.

- Amount of gas used
- Produced electric energy
- Produced heat energy
- Overproduction of electric energy
- Underproduction of electric energy
- Underproduction of heat energy

The values are listed for one year and are calculated in kWh/s. The electricity price is published on the energy exchange market EXAA every 15 minutes. At the moment, electricity is traded on the energy exchange in no smaller time unit. Therefore, the minute values are summed up in 15-minute periods. The prices of electric energy of the last year are available on the EXAA homepage. The sum of proceeds and expenses through underproduction and overproduction is given to the cost estimation.

The second Excel-sheet with the name 'Additional_results' was created to get an overview of the utilization of the systems. This particular presentation of the most meaningful values should guarantee a structured comparability of the systems. How this table is shown in Chapter 9 by giving an example.

The following values are used to analyze whether the system is correctly dimensioned and whether an additional condensing boiler is necessary.

- Power of the system
- Availability
- Utilization
- Demand electric energy
- Produced electric energy
- Demand heat energy
- Produced heat energy
- Total produced heat energy
- Coverage electric energy demand
- Coverage heat demand
- Maximum heat storage
- Minimum boiler size

All these values are displayed separately in specifically named spreadsheets for each system. The load distribution is shown as a percentage, and in the form of a bar chart. A spreadsheet with the name ‘overview’ shows all systems and their results for easier comparability.

The availability changes because of the different downtimes of each system. Downtime is needed for component exchanges because of the different life cycles of each component. The SOFC must cool down until the replacement process of the components can begin.

The utilization rate of electric energy production of a system shows whether the size of the system was selected correctly. The formula for the utilization of the production of goods consists of the quantity produced and by the maximum amount that can be produced by the system (Beer, 2014)

$$\text{Utilization} = \frac{\text{Throughput}}{\text{Production Capacity}} \tag{6.1}$$

In this calculation, the throughput is equal to the electricity produced, and the production capacity corresponds to the maximum amount of energy that can be produced with the system.

Both the amount of energy consumed and the amount of electric energy sold through overproduction, is reflected in the term produced electric energy. The demand of electric and heat energy shows which energy requirements the buildings in need of supply have. Total produced heat energy is composed for example of the produced heat by the SOFC and the additional condensing boiler.

Coverage rate of electric and heat energy shows the relationship between the needs that can be met by the plant and the need to buy from outside. This value can be very high, especially with the combustion engine. Due to the current-controlled operation of the plant, the additional amount of heat produced exceeds the need for heat. This allows two measures to be taken. Either the system is equipped with a boiler that temporarily stores the over-produced energy quantity, or the heat-generating system must be shut down. The function that throttles the system if too much heat production occurs, is not yet implemented in the simulation and will presumably be supplemented by AVL. In this type of operation, the overproduced electricity is sold or temporarily stored. In order to calculate the boiler size, the temperature must be known with which the boiler should store the heat energy through the medium of water.

Summary

The input M-file with the name ‘All_Systems_SOFC_LE_GH’ contains all functions, which have to be simulated. If this file is executed the simulation of the chosen systems starts. A After the simulation has finished, the values necessary for the analysis of the system are displayed in the Excel file named ‘Additional results’. In the Excel file named ‘Results’ the sum of proceeds and expenses through underproduction and overproduction of electric energy is calculated and given to the cost estimate. These files contain the energy prices published by energy exchange EXAA.

7 Development and calculation of the energy price

In this chapter, the values of spending and revenue by buying and selling electric energy which are used in the cost estimate, are discussed. Especially, price trends seen in the energy market in recent years will be shown and discussed.

7.1 Electric energy price trends

The statistics for electricity prices are provided by E-Control and Eurostat. Usually it is distinguished between households or a medium manufacturing industry on the energy market. The percentage distribution of electricity costs is shown in Figure 12. (E-Control, 2018)

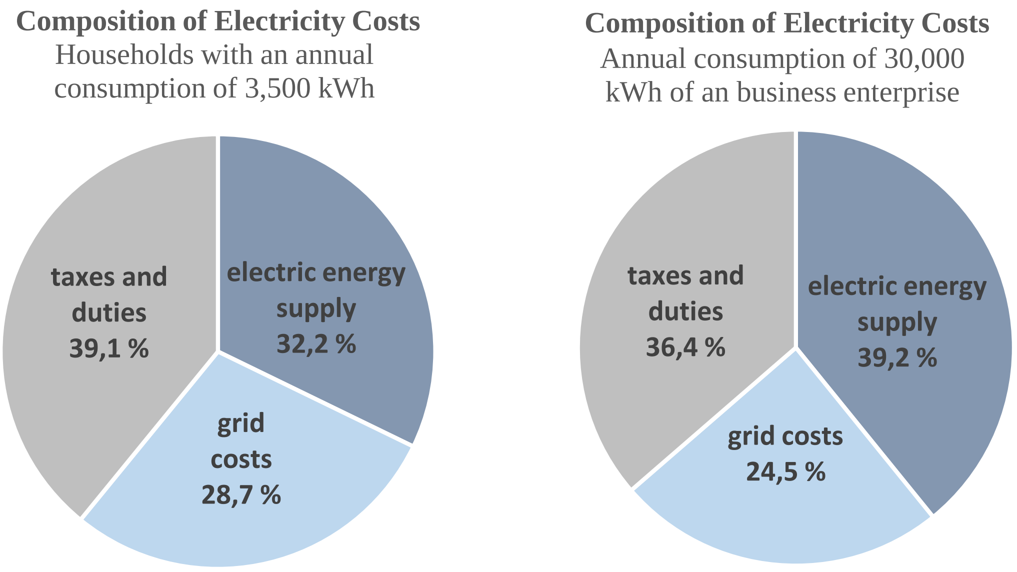

Figure 12: Composition of annual electric costs (E-Control, 2018)

The electric energy amount of an Austrian household with 2 persons and an electric water heater is between 3.800 – 4.200 kWh/year. The average electricity costs of such a household is about 0,1978 €/kWh. A small industry plant which needs less than 20 MWh must pay 0,16 €/kWh. This gap increases when it comes to consumer groups with a higher consumption like the consumer group IE, which only pay 0,0492 €/kWh. Table 14 lists the different consumer groups and their consumptions. The pie chart in Figure 12 shows only a small difference between households and large customers. The reason is that the cost reduction of all 3 parts, which are energy, grid costs, taxes and duties, of the electricity costs reduces the electricity price. Especially the percentage of grid cost for business enterprises compared to households reduces the most. The percentage of grid costs of big pantographs, which have an energy demand of up to 70.000 MWh, reduces up to 24 %.

For the AVL it would be too imprecise to make only the distinction between household customers and commercial customers, which are named as business enterprises in Figure 12, when forming the basis for the electricity price compilation. For example, the prices for commercial customers vary between 16 Cent / kWh and 4 Cent / kWh. Thus, the difference between the various consumer groups has been analyzed. In further analysis, the focus has been on companies, as the demand profiles available given by AVL do not represent the needs of a single household. If the energy demand of several households has to be covered via communal facility like a CHP system, the energy costs are calculated on the basis of the electricity costs for companies. But it is also possible to integrate the prices for households in the calculation. In the Excel-spreadsheet for the cost estimate, it is possible to select whether electricity costs should be calculated on the basis of electricity prices for companies or households.

In order to be able to recognize a trend for the electricity price, the values of E-Control and Eurostat will be compared. The composition of the three cost components and the total costs are shown in Table 14.

Table 14: Comparison Eurostat and E-Control (Own representation)

Consumer group	Group IA: Consumption < 20 MWh	Group IB: 20 MWh – 500 MWh	Group IC: 500 MWh – 2 000 MWh	Group ID: 2 000 MWh - 20 000 MWh	Group IE: 20 000 MWh- 70 000 MWh
Eurostat*	Cent/kWh				
Energy	5,67	4,66	4,12	3,35	1,40
Grid costs	5,90	4,09	2,73	2,05	1,40
Taxes and duties	4,49	3,35	3,19	2,55	2,12
Total	16,06	12,30	10,04	7,95	4,92
E-Control**	Cent/kWh				
Energy	6,30	4,93	4,20	-	-
Grid costs	5,84	4,32	2,98	-	-
Taxes and duties	7,68	6,07	5,44	-	-
Total	19,82	15,32	12,62	-	-

* (Eurostat, 2018)
** (E-Control, 2018)

As mentioned in Chapter 3, the electricity prices are composed of the three components energy costs, network costs as well as taxes and duties. In addition, the E-Control statistics also take into account different consumer groups. It can be seen clearly, that the price of electricity drops, as the consumption of the related consumption group increases. Table 14 shows that the total price of Eurostat and E-Control does not match. E-Control confirmed that Eurostat does not include the value added tax (VAT). (Steiner, 2018)

This statement by E-Control is underscored by the fact that, considering the three individual cost factors, the biggest difference is the cost factor "taxes and duties". But the other costs of Eurostat and E-Control do not match 100 %, which could be due to different statistical data collections. The E-Control electricity price allocation was used for the calculation. (Steiner, 2018)

In order to see a trend in electricity price development, the total costs of the last 8 years have been analyzed first. Figure 13 shows the volatility of electricity prices. But from 2013 on it can be seen that they have steadily declined. In 2008, a new calculation method for the electricity price was introduced, and due to this fact only the period from 2008 to 2016 is considered. 2017 statistics are not yet available at Eurostat.

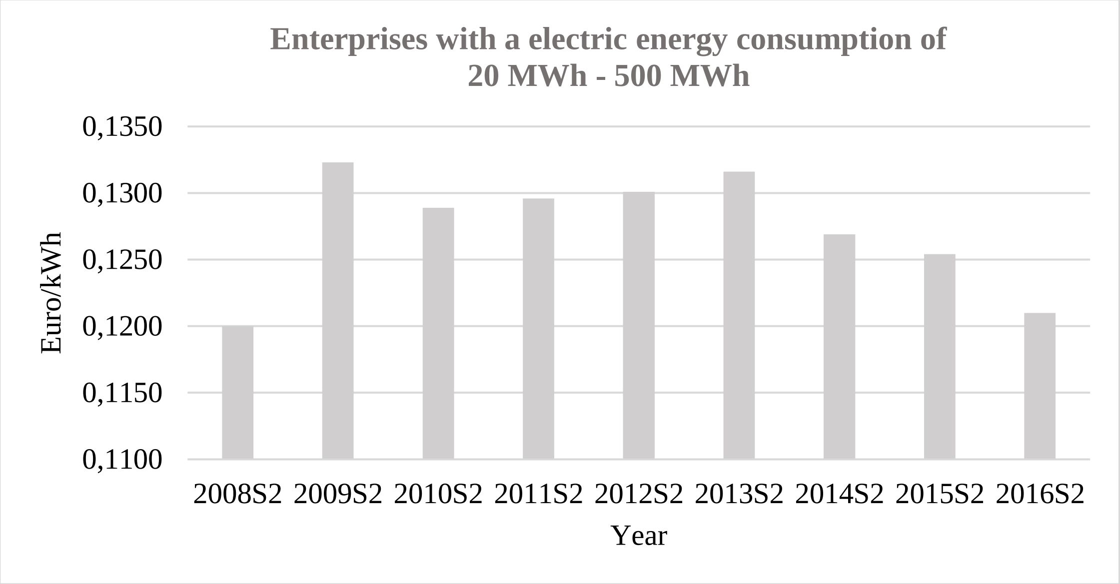

Figure 13: Total annual electric energy costs of the consumer Group IB (Eurostat, 2018)

To get an approximation of the trend in electricity prices, individual cost factors were investigated separately, as shown in Figure 14. The individual cost factors presented are derived from consumer group IB, which have a consumption between 20 MWh and 500 MWh per year. (Eurostat, 2018) With this bar graph, energy costs, taxes and duties show a clear direction. The energy costs have steadily decreased. The grid costs remained constant between 3 and 4 Cent per kWh. Taxes and duties, on the other hand, rose steadily. (Eurostat, 2018)

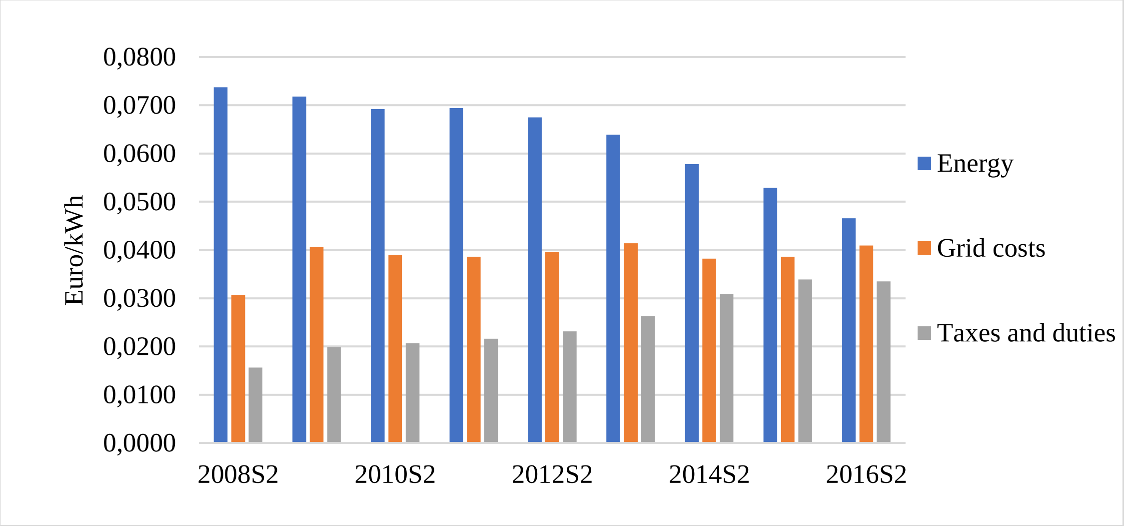

Figure 14: Annual composition of electric energy costs of the consumer Group IB (Eurostat, 2018)

According to a statement in January 2017 by Dr. Wolfgang Urbantisch, CEO of E-Control Austria, household electricity prices came to a low in 2016. Above all, competition in the energy market was responsible for the price spiral. Over the next few years, the price of electricity should rise or at least remain the same. This statement was confirmed by rising electricity prices in 2017. It is assumed that electricity prices will continue to increase. (selectra, 2017)

Based on this statement and the upcoming German-Austrian electricity price zone separation and the resulting congestion management described in Chapter 3.4.4, this thesis assumes that electricity prices will increase.

7.2 Energy price evaluation

One of AVL's questions is whether it is even possible to calculate the electricity supply and electricity feed-in amount based on the EXAA energy prices, and if so, how it can be done. As already mentioned in Chapter 3, the direct settlement via EXAA is theoretically possible, but only done by large energy producers like Verbund Trading GmbH. The first idea was to find a smaller energy producer, to determine whether it is possible or not and if so what is needed to trade through the energy exchange. The energy producer, who meets these requirements is described in Chapter 7.2.1.1.

In the course of the cost estimate, it will be distinguished between two energy purchasing options. The first option is to carry out the calculation via an intermediary such as Verbund, based on the EXAA electricity prices. If the first option is not desired or not possible, the electricity prices of E-Control are used in their entirety as the basis for calculation. How these two possibilities work in detail will be described in the following two subchapters.

7.2.1 Purchase and sale of electric energy on the basis of a power exchange via Verbund

Through an electricity supplier such as Verbund, from a trading volume of 1 GWh per year, the energy billing can be based on the energy prices published by an energy exchange. The electricity provider requires a surcharge per MWh to cover the resulting effort and profit. In Table 15, the sum of 2 €/MWh is the surcharge, which is required by the electricity provider Verbund. Additionally, balancing costs will be charged, if the agreed amount of electrical power that is to be delivered cannot be met. These costs will be charged by the Balance Group Coordinator. In Austria, the name of this coordinator is Austrian Power Cleaning and Settlement (APCS). (Gassner, 2018)

For the calculation of the revenues, to be generated by the sale of electrical energy, costs for remuneration for measurement services and a system service fee still have to be taken into account. These costs can be found in the Federal Law Gazette for the Republic of Austria in the system utilization fee regulation 2018 (Systemnutzungsentgelte-Verordnung 2018). The Remuneration for measurement service varies between 2,4 to 75 € per month. This depends on which meter has to be used. Meters are needed to measure the electricity consumption or the amount of electricity fed into the grid. To find out which meter to use, the network operator must be contacted. Which meter have to be used depends on the energy consumption and the energy amount fed into the grid. In a spreadsheet in Excel, the calculation of the electricity prices is done. This Excel spreadsheet lists also the different meters which can be chosen. In this list, the correct electricity meter only needs to be selected. The system service fee, according to section 10 in the system utilization fee regulation 2018, is only payable for connection services of more than 5 MW.

In addition, 20 % VAT will be charged, reducing the proceeds. Thus, revenues are calculated based on the energy prices available from the energy exchanges EXAA and EEX in recent years, minus the taxes and duties just mentioned. (Wiener Börse AG, 2018)

The capacity of the plant in Table 15 is less than 5 MW. That's why there are no additional expenses in this cell.

Table 15: List of possible electric energy feed-in costs (Gassner, 2018)

1) Surcharge for trading via intermediaries	[€/MWh]
	2
2) Remuneration for measurement services	[€/month]
Three phase Energy meter	2,4
3) System Service Fee	[€/kWh]
Installed load > 5MW	0,098
Installed load < 5MW	0

Table 16: Calculated electric energy feed-in costs (Own representation)

	Excl. Sales tax [€/year]	Incl. Sales tax [€/year]
1) Surcharge for trading via intermediaries	0,50	0,60
2) Remuneration for measurement services	28,8	34,56
3) Installed power > 5MW	0	0
Total earnings	970,70	764,84

In order to calculate the costs by purchasing electric energy, the network costs and taxes have to be calculated, in addition to the EXAA energy costs. The data used is from the E-Control Austria.

7.2.1.1 SAPPI Austria Produktions-GmbH & Co.KG

In search of a suitable company, the factory named SAPPI Austria Produktions-GmbH & Co.KG was chosen, which operates a plant for the production of paper at the location Bruckner Straße 21, 8101 Gratkorn, which is approved under material law. This factory is a customer of Verbund and therefore represents a suitable example to understand the practicalities of sale and purchase of electric energy. Electric energy production by SAPPI amounts to approx. 615 GWh/a. What is decisive for the calculation is the amount of energy sold and purchased. The company SAPPI buys 110 GWh/a of electricity and sells 40 GWh/a. (Reimelt, 2014)

The current data from SAPPI (as of 2012) are given as follows:

- Electric energy production (CHP, hydropower) approx. 615 GWh/a
- Purchased electric energy amount approx. 110 GWh/a
- Electric energy sales approx. 40 GWh/a

SAPPI Austria Produktions-GmbH & Co. KG purchases electrical energy from the public grid via the 110-kV grid of Energie Steiermark. This power requirement increases by an average of about 85 MW per year. Covering the increasing demand of each year, it is possible on the one hand by an increase in self-generation, which results from the more high-pressure steam from the CHP boiler systems, on the other hand from an increase of full-load operation hours of the gas turbine with waste heat boiler, and if required by reference from the public grid. (Reimelt, 2014)

The paper mill SAPPI in Gratkorn has several possibilities to cover the heat demand for paper production. According to Utilities Manager DI Hubert Hopf, a liquor boiler is operated at full load. Furthermore, it is possible to use a gas turbine, a coal boiler and a condensing boiler to cover the additional heat demand. These two systems and their maximum electric energy generation are listed below. For instance, the gas turbine has a higher electric efficiency compared to the coal fired boiler but the thermal efficiency is smaller. (Hopf, 2018)

- Gas turbine, 45 % electric energy generation
- Coal-fired boiler, 19 % electric energy generation
- Condensing boiler, 10 % electric energy generation

The gas turbine has a rated output of 46 MW. Depending on the electricity price, a combination of the systems is made. But there is also the case, were the electric energy price is very high, and the gas turbine is operated at full load and the additional heat produced covers the heat demand. If this situation occurs, the coal boiler and condensing boiler are not operated. The price difference between coal and gas should also be considered. If the electric energy price is too low, or (in exceptional cases) a negative electricity price occurs, the gas turbine is switched off and the coal boiler and the condensing boiler are operated. (Hopf, 2018)

The company SAPPI has a contract with the experts at Verbund and does not trade directly through the energy exchange. A timetable must be submitted on the day before until 10 o’clock. This timetable is created based on an already existing forecast. Care is taken to ensure that it is lucrative to operate the gas turbine, in order to produce surplus electricity. The forecast is produced every day by Verbund for the next 3 days and sent to SAPPI. The forecast for the next day is the most accurate. On Friday, the timetable for the next 2 days must be submitted, because the energy exchange must publish the price of electricity for Sunday. Mostly, the gas turbine operates in full load during the early afternoon (peak load) from Monday to Friday. But the fact that many quick load changes will result in higher maintenance costs has to be considered as well. (Hopf, 2018)

Direct trading on the spot market EXAA or EPEX involves high fees. In addition, it is also associated with an additional effort to be able to estimate the approximate course of electricity prices for the next few days. Electricity providers like Verbund have this confidence and are already trading on a power exchange. For many electricity producers, this makes it possible to gain access to the electricity exchange through a contractual partner such as Verbund. From a trading volume of 500 GWh, direct trading via the power exchange is considered (Gassner, 2018)

Verbund trades on the spot market EPEX Spot, which belongs to the EEX Group. As already mentioned in Chapter 3.4.4, in October 2018 the common electricity market between Austria and Germany will be regulated. As it cannot be estimated how this will affect the electricity market and whether the electricity providers will continue to trade on the EEX electricity exchange, it will be focused on the values of 2012 of the Austrian electricity exchange EXAA for the calculation of electricity prices as a reference. (Gassner, 2018)

7.2.2 Purchase and sale of electric energy through an electricity supplier

If the sum of sales and purchases of electricity is less than one GWh, the costs will be calculated on the basis of the statistics, provided by E-Control. The consumer groups are shown in Table 9. The consumer group specified for consumption is automatically selected in Excel and considered for further calculation.

For the sale of electric energy from a non-renewable energy source, no data is published, unfortunately. According to Verbund, it is difficult to find an electricity supplier that will take away this electricity from a non-renewable source of energy. For this, an intensive research would have to be done, to find out if it is even possible. For the sale of electricity, an Excel-spreadsheet contains a table where the revenue per kWh can be entered. (Gassner, 2018)

7.3 Natural gas price trends

As natural gas is primarily considered as a substitute for petroleum, the development of the price of natural gas depends on international petroleum indicators. These therefore influence the price of natural gas with a certain delay of about 3 to 6 months. (E-Control, 2018)

In order to recognize the price differences between the different trading participants, a distinction is made between households and industry, as is the case with electricity prices. As can be seen from the electricity prices in the Chapter 7.1 before, the network costs for business enterprises decrease the most compared to the other costs, as is also shown in Figure 12. The costs of natural gas supply are also reduced, but they make up a larger part of the costs compared to household customers. The composition of the natural gas price for households and business enterprises is shown in Figure 15. (E-Control, 2018)

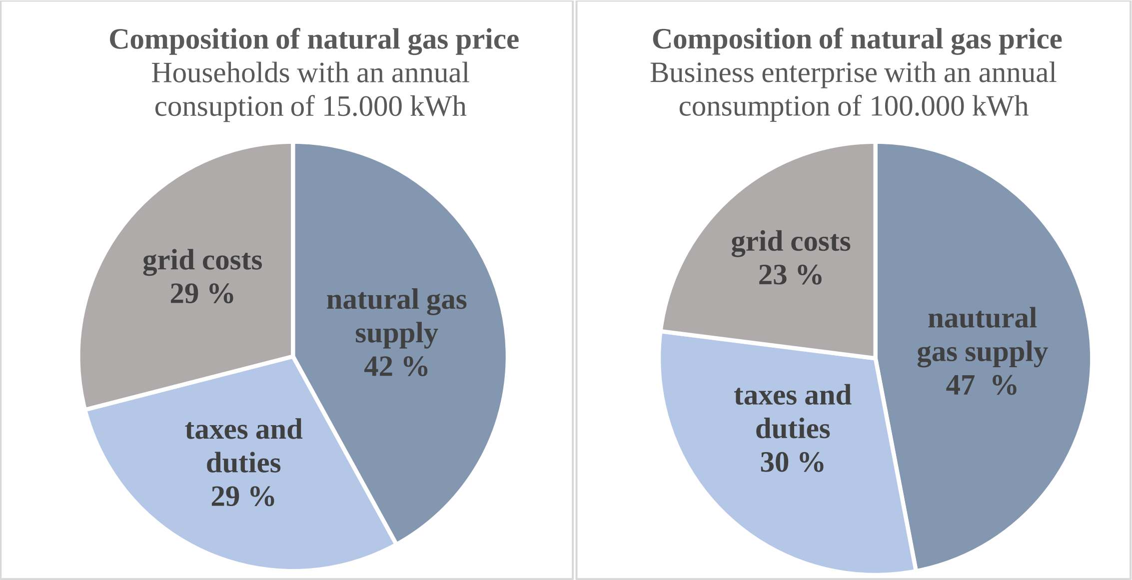

Figure 15: Composition of annual natural gas costs (E-Control, 2018)

As the energy prices between the supplier and the customer are in most cases individually negotiated in the commercial and industrial sector from 400.000 kWh annual consumption onwards, the price development on the stock exchange is important information for negotiations in the event of a supplier change. Nevertheless, values that reflect the approximate costs of natural gas have to be investigated. E-Control publishes statistics for each year from natural gas trading. In Table 17 the values of business operations are listed and it can be seen, that the price of natural gas between consumption of less than 278 MWh and consumption of 27,8 GWh to 277,8 GWh is almost halved. Therefore, it is very important to distinguish between the amounts of energy that are needed, as is the same with electricity prices. (E-Control, 2018)

Table 17: Natural gas price of 2017 (E-Control, 2018)

Consumption	Until 278 MWh	278 MWh - 400 MWh	400 MWh – 2,8 GWh	2,8 GWh – 5,6 GWh	5,6 GWh – 27,8 GWh	27,8 GWh – 277,8 GWh
Unit	Cent/kWh					
Energy	2,785	2,494	2,277	2,113	1,950	1,877
Grid costs	1,693	1,405	1,088	0,983	0,621	0,325
Taxes and duties	1,703	1,577	1,443	1,374	1,240	1,104
Total	6,181	5,476	4,808	4,469	3,811	3,306

E-Control has no historical values listed on its homepage. In order to be able to analyze the natural gas price trend of recent years, Eurostat's figures have been taken into account. Figure 16 shows the course from the second half of 2012 onwards. The statistics of previous years are not listed by Eurostat, because neither the statistics nor the calculation of the average cost of natural gas was calculated using the same methodology. (Eurostat, 2018)

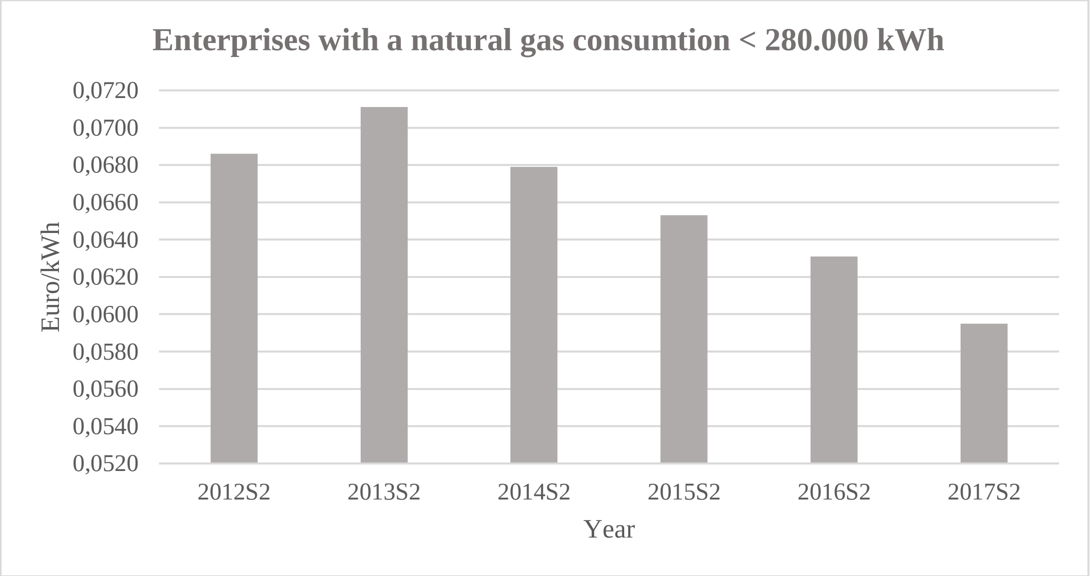

Figure 16: Total annual natural energy costs (Eurostat, 2018)

Similar to electricity prices, the price of natural gas fell from 2013 onwards. But if the Austrian gas price index is considered, the pure energy costs increase since 2017. Due to the reduction in network costs, a sinking gas price will still be presented in 2017 compared to the previous year. (Stromliste, 2017)

It is likely that the price of gas will continue to decline due to dwindling oil reserves. How long the underground stocks will last is still unclear. Gas prices have been heavily tied to oil prices for many years. In the past, the present price of oil was used to estimate the future development of gas prices. If the latter rose, gas prices also went up with a six-month delay. But in the meantime, there is a trend reversal. The increasing relevance of short-term futures and spot markets is influencing prices more strongly by supply and demand. Thus, according to some experts, the gas price is at least partially decoupled from the price of oil. Due to this fact, and the higher prices on the future market in 2017, compared to previous years, rising natural gas prices are expected. (Stromliste, 2017)

Based on these statements and in view of the fact that oil costs have continued to rise in 2018, rising natural gas prices will be assumed, just as with electricity prices.

Summary

The electric energy price and the natural gas price strongly depends on the customer group. The grid cost of electricity reduces the most with increasing electric energy consumption. For both, electric energy and natural gas rising prices are assumed. It is very expensive to trade electric energy directly via an energy exchange. Because of this reason the company SAPPI has a contract with the experts at Verbund and does not trade directly through the energy exchange. Verbund acts as intermediary and requires a surcharge of 2 €/MWh for trading.

8 Cost evaluation program

In order to assess the economic viability of capital goods and technical equipment, different criteria and thus different calculation methods must be applied. The task given by AVL is that an payback method should be carried out, as they want to know when an SOFC plant pays off against a reference system. The resulting payback periods due to changes of costs and service life's of several components, which are needed to operate a SOFC, should be analysed. The component groups, which are used are shown in Chapter 9.3.1 in Table 37.

AVL already has a TCO calculation tool that was based on the VDI guideline 2884. A total-cost-of-ownership tool was developed for industrial powertrains in AVL. However, since this calculation is strongly tailored for the automotive sector and the disposal costs and the transaction costs for the SOFC are not available at AVL, which is needed for a TCO calculation, another VDI guideline was sought. It should purely deal with building services engineering. This aspect is particularly important, because the operation of the calculation program should be as simple as possible. Also the interfaces between the two software-tools, which are Excel and Matlab, should be made comprehensible. After the VDI 2067 which carries the title "Economic efficiency of building installations" was identified, an analysis of this VDI took place. In consultation with AVL, it was decided to take this VDI as calculation basis for this master's thesis.

In order to be able to create the amortization method, various input data are required. The lower list below shows the values that were taken into account by the VDI guideline.

- Investment
- Service life
- Factor of maintenance
- Effort for operation
- Price change factor
- Accrual factor

All these listed values above, with the exception of the price change and accrual factor, must be entered for each component. How this list of components looks like is shown in Chapter 9.3.1. The guideline VDI 2067 only provides an input field for a price change factor like for the demand costs, and not for each component of the plant. Which kind of costs are provided with a price change factor is listed in Chapter 4.2.1. First, the observation period must be set. This is not the lifetime of the entire system. The observation period is an assumption or a wish of the operator, how long a specific demand of heat or electricity should be covered by a CHP system, regardless of how long the service life of the system is. Not every component of a CHP system has the same service life, which is shown in Chapter 9.3.1. To be able to cope with this condition of different service life's, a decision has to be made, if the residual value should also be included in the calculation or not. With considered residual value in the cost estimate it is assumed that the CHP system can be sold after the observation period ends. This reduces the total cost of the plant during the observation period and has a positive effect on the cost estimate for this plant. All components, which are installed in this plant, are to be reflected in the calculation. It is possible to represent different components in a component group. For each component, a service life has to be specified, to determine the number of replacement purchases that will be needed. The period of observation, divided by the service life of a component, gives the number of replacement purchases. But if the period of observation is 20 years and the service life is 5 years, care must be taken in order to ensure that a component is not replaced again at the end of 20 years and that the component is replaced only twice. The factors of maintenance, service and inspection include all technical and administrative measures, necessary to maintain the functionality of the components. These are summarized and expressed as a percentage of the initial investment. In addition, the effort of the operation must be specified. This amount is expressed in Euro per year, along with the average cost for one hour and the number of hours, which are needed to do this operation.

Factors such as the accrual factor are assumed to be constant over the period considered. This is necessary to be able to discount replacement purchases that take place at different times. Costs, such as the capital costs, result from the nominal price increase.

8.1 Additions to the VDI guideline

To estimate speculative risks, an amortization calculation and a sensitivity analysis are added. These methods are commonly understood as methods for risk assessment. These calculations are not listed in VDI 2067 Part 1. Nevertheless, they are well in accordance with the valuation principles of VDI 2067 applicable. In the German book ‘Energie und Geld für Gebäude und Technik’ which means ‘Energy and Money for Buildings and Technology’, which is also disseminated as a commentary on the VDI 2067, the static payback period calculation, which can be based on the VDI 2067, takes up the topic and provides the necessary calculation method. (Bach, 2017) AVL would like to have the opportunity to be able to represent the influence of a price reduction or price increase of different components. At the same time inflation should be considered. The Association of German Engineers has thus created a guideline, which makes it possible to compare different system concepts with the annuity method. In this VDI, no experience and calculative values such as cost of inspection, maintenance and service for the SOFC are included. Calculative values are the result of the joint work by the parties involved in authoring the guideline. For over systems e.g. solar collectors these calculative values are specified in the guideline VDI 2067 but none of the listed systems in the guideline are used in this thesis. (VDI, 2012) Thus, assumptions of the calculative values must be made for the SOFC system. Above all, the stack modules should be cheaper due to further developments and increased production figures. More details will be described in the Chapter 9. As explained theoretically in Chapter 4.2, the VDI guideline deals with the investment difference of the plants and the savings during the year, compared to the reference system.

8.1.1 Real interest rate

The Guideline VDI 2067 has only one input for the interest, which determines the accrual factor. It is not specified whether the interest is inflation-adjusted or not. In order to eliminate misunderstandings that may occur in the entry of interest, it was decided in consultation with AVL to make a distinction between the inflation and the nominal interest rate shown in Table 18. Two input fields have been created for which inflation and real interest are to be entered in percent. All cells for which manual entries have to be made are marked in blue.

The Classification of Individual Consumption by Purpose (COICOP) is an international classification that divides household consumption into twelve main groups. Three of these main groups are listed in Chapter 4.4 in Table 9. (Statistik Austria, 2018)

The calculation can be performed by a general inflation factor entered in Table 18, provided the price change factors of each component group of the system needed for the simulation are not available. This entered inflation rate influences all components, the natural gas and the electric energy amount which have to be purchased. Inflation varies between the various consumer groups, so it is advisable to enter the individual price change factors of each component exactly. If the price change factors are present, the inflation, which affects all costs, should be set to zero. These price change factors are also named as inflation adjusted escalation rate. (Panos, 2017)

Table 18: Input field of interest and inflation (Own representation)

			(i+1)
Interest in %	1,20	Nominal interest rate	1,03
Inflation in %	2,00	Inflation rate	1,02
		Real interest rate	1,01

8.1.2 Amortization time calculation based on VDI 2067

For the calculation of the dynamic payback period, an additional spreadsheet was created in Excel. Because of different individual price change factors of e.g. operation, consumption, and different component groups, a list of the various costs is created which includes e.g. the operation-related costs or consumption-related costs. Then, the amount of the payments will be calculated at the time of entry. The price change factor always refers to one year and therefore the time when these costs are incurred has to be taken into account.

As shown in the formula, the present value is composed of the amount at the beginning of the observation of the accrued interest and the price change factor: (Bach, 2017)

$$A_1 = A_0 \frac{r^t}{q^t} \tag{8.1}$$

A_0: Cashflow in €
A_1: Present value of the first, second …,n^{th} procured replacement
r: Price change factor (to be specified beforehand)
q: Interest factor
t: Time of cashflow

This procedure has to be done with every accrued expense and revenue. Thereafter, the amounts are added up for each individual year to receive the entire cash flow. In the Table 19, the abbreviation of each cost and proceeds is listed.

The costs of investment are not listed in Table 19, because in this example the investment of the plant takes place at the beginning of the observation period. Therefore, the investment spending in the year zero is currently not influenced by interest or price change factors. However, if the investment is to be made in the future, it is necessary to consider these influences. Only cost groups which are influenced by interest and price change factors are listed int the table below.

Table 19: Cost groups (Own representation)

SOFC	Time	1	2	3	4	5
Demand-(consumption-)related costs	Av1(€)	5475,9	5370,6	5267,3	5166,0	5066,6
Operation-related costs	Ab1(€)	0	0	0	0	0
Maintenance costs	Ain 1	990,6	971,5	952,8	934,5	916,5
Other costs	As1(€)	0	0	0	0	0
Additional purchase	Ac1(€)	3690,0	3619,1	3549,5	3481,2	3414,3
	Ah1(€)	854,7	838,3	822,2	806,3	790,8
Proceeds	E1(€)	8,65	8,49	8,32	8,16	8,01
Disc. Cashflow of each year (SOFC)	(€)	11002,5	10790,9	10583,4	10379,9	10180,3

For all three combinations of systems which are performed, this calculation is implemented. After the calculation, the values for each year are added. As shown in Table 20, the expenditures in year zero represents the investment for the plant. The accumulated discounted cash flows are listed below for each year.

Subsequently, it has to be analyzed if there is an intersection point between the two cash flows. If the accumulated cashflows are higher in one year, but lower in the next compared to the reference system, the payback period must be between the two years. What can be said for sure, is that in this case, the SOFC system is cheaper than the reference system, if the system has to run this 10-year observation period. To determine the intersection by interpolation, the following formula is used. By interpolating two straight lines, the intersection point is determined, which in the example of Table 20 is 4,32 years.

This interpolation process is programed in the Visual Basic for Application (VBA) program in Excel. Thus, the payback period is automatically displayed, whenever there is a change in a value required for the payback calculation.

Table 20: Accumulated discounted Cashflows (Own representation)

Year	SOFC_GH	Year	RefSys_GH
0	-14826,2	0	-8184,0
1	-24485,8	1	-19329,9
2	-34353,1	2	-30712,1
3	-44434,2	3	-42337,7
4	-54735,6	4	-54214,1
5	-65263,9	5	-66348,7
6	-76025,9	6	-78749,4
7	-87028,5	7	-91424,09
8	-98279,1	8	-104380,9
9	-109785,1	9	-117628,4
10	-121554,1	10	-131175,4

8.1.3 Sensitivity analysis

The sensitivity analysis is an expanded cost evaluation, at the dependence of the chosen profitability criterion on alternative assumptions to the prescribed, or in the first step scheduled, parameters, e.g. the interest rate or price change factor is shown.

The AVL demanded to carry out the sensitivity analysis in Excel. Especially the clarity and a quick service are again one of the most important aspects. If values are changed in this program, the user has to press the button with the name ‘Calculation of residual values purchases’. This will recalculate the payback period and it has to be considered whether this change is worth presenting in the sensitivity analysis. If this is the case, the button ’Sensitivity analysis’ must be pressed second. This copies all values in another spreadsheet named ‘Sensitivity analysis’ to a new line. Thus, all significant changes can be listed among each other. All values that can be changed, are always displayed in one line. When this button is pressed, the operator automatically jumps to the sensitivity analysis. This is important, because in addition to the newly created line with the changed values, a column is marked in which the change made is to be described, or at least named. All that is written in this column serves as a name for the individual curves and the intersections. If this designation is not carried out, it is difficult to analyze in retrospect which change has generated which amortization point. Two of these sensitivity analyses are selectable. One for each comparison:

- SOFC compared with a reference system
- SOFC compared with the pure electricity purchase from the public power grid

The present settings are also displayed in both spreadsheets. How the diagram, in which the various curves and their intersection points are displayed, looks, is shown in Chapter 9.4.

It would have been possible to perform these calculations in Matlab and to pass the results to Excel. But in order to make it possible to perform a cost estimate without Matlab, these functions for the sensitivity analyses are implemented in Excel using Visual Basic Application (VBA). To perform this calculation independently, values such as natural gas consumption and the amount of electric energy sold in case of overproduction, must be entered manually.

Summary

In order to be able to carry out a cost estimate in accordance with AVL specifications, various changes and additions to the VDI 2067 had to be made. For example, an amortization method was added to compare two systems. The VDI guideline was also supplemented with price change factors for each component group. This is to be able to represent separately price changes, for example, from the stack of SOFC. For the risk assessment, a sensitivity analysis was added.

9 Cost estimate of a SOFC system

This chapter presents the whole procedure, from setting the input values for the simulation to the results of the payback time calculation and the sensitivity analysis. The chosen settings were discussed and selected by the company AVL.

9.1 Input values of the simulation

For the cost estimation of SOFC system two different cases are considered. First, a SOFC system is simulated with input values considered feasible for AVL at that time. In the second simulation, target values are entered which the SOFC is expected to achieve in the near future, such as improved efficiency. These are assumptions and not fixed values and might therefore well be exceeded.

The two values displayed for electrical efficiency in Table 21 are the efficiencies at full load of the SOFC system at the beginning of operation, called the Beginning of Life (BOL), and at the end of the operation, named End of Life (EOL). BOL and EOL are related to the service life of the stack. The stack is a component in the SOFC system, which usually has to be frequently changed. The service life of the stack is shorter compared to the system service time, which is shown in Table 21. Matlab simulates the operation of the systems e.g. a SOFC system and a combustion engine for one year, and not for every single year of the observation period. This means that a possibility must be identified that the reduction of the electrical efficiency can still be considered in the simulation.

In this thesis it is distinguished between two cases of SOFC systems. The differences between these two cases are listed in Table 21. Case two has an electric efficiency between 60 and 48. Therefore the efficiency is estimated at 54. In this calculation, it will be assumed that the life of the last stack used ends at the end of the observation period. The observation period can also be over before the stack’s life ends. This means that the electric efficiency at the end of the operation of the last stack is higher than the specified electric efficiency at the end of the service live of the stack, which is shown in Table 21. For the sake of simplicity, this increase in efficiency because of a residual service life of the last stack used is not taken into account. This means that the average value between EOL and BOL will be used in this calculation. One of AVL’s next projects will be to take this increase in efficiency into account.

Table 21: Analysed cases (Own representation)

	Unit	CASE One	CASE Two
El. efficiency BOL/EOL	%	55/44.1	60/48
Total efficiency	%	90/90	95/95
Power	kW	4,5	4,5
System service time	h	80.000	130.000
Stack service life	h	30.000	80.000

As described in the introduction in Chapter 1, a SOFC system is simulated in combination with a condensing boiler. As a referential system, an internal combustion engine with a condensing boiler is simulated. In addition, the operation of a condensation boiler is simulated in the case of a pure electric energy supply from the grid.

The condensing boiler used for the simulation in combination with the SOFC system or the combustion engine is named Viessmann Vitodens 300-W B3HB with a nominal heating capacity of 1,9 to 11,0 kWh. The combustion engine is named Viessmann Vitobloc 200 EM-6/15. If the electric energy is only purchased from an energy supplier, the utilized condensing boiler is also the Vitodens 300-W B3HB by Viessman, but here with a nominal heating capacity of maximally 24 kWh. For the two condensing boilers the same efficiencies and system properties are defined (compare Table 22).

For all simulated systems, the minimum partial load point was set to 0 % and the maximum partial load point to 100 % for all systems. This was intended to answer the question of whether the SOFC system is still profitable if operated at very low partial load ranges. The downtime required by the SOFC system is assumed to be one 1 % of the operating time. For the combustion engine, a downtime of twenty hours was assumed. For the calculation of condensing boilers, a downtime can’t be set yet. To do this further improvement are necessary.

All systems start at full load. At the moment the simulation is only possible for one year because it is assumed that the consumption will be similar in the following years. This time period of just one year has been decided by the AVL. This saves time in the simulation, because not every year has to be simulated separately.

As shown in Table 22 and Table 23 the specified electric efficiency values for each load are not similar. The SOFC system has the highest electric efficiency at load point of 50 %. The blower for ventilation of the system must operate at a higher power at full load than in partial load. The higher power consumption of the blower causes higher energy consumption of the SOFC system itself and thus a higher consumption of natural gas. In the second case, the plant not only has a higher electrical efficiency but also a higher thermal efficiency, which results in a higher overall efficiency. For the simulation of the SOFC system and the combustion engine only the electrical efficiency and the overall efficiency are required and transferred to the simulation in Matlab. The thermal efficiency is the difference between the overall efficiency and electrical efficiency and is calculated in Matlab. For the second case, the efficiencies are changed only for the SOFC system whereas the annual demand level stays the same (compare Table 22 and 23).

In the input field in Excel, different input parameters of the simulated systems of the cases one and two have been entered only for the efficiencies depending on the partial load points (compare Table 22 and 23). Otherwise, in the two simulated cases, no different values were entered for the operation. According to AVL it is assumed that the system characteristics are the same. The other input parameters for the simulation like the power of the systems, which are described in chapter 5.2, will be the same for both cases, except the mentioned efficiencies. Also, the values entered for the combustion engine and the condensing boiler are the same in both cases. The condensing boiler for drawing electricity only from the grid has more power in comparison to the other system combinations but the system-defining input parameters, e.g. the efficiencies, are the same. Which power the simulated systems have, is also shown in Table 27, Table 28 and Table 29.

Table 22: Efficiencies CASE 1 (Own representation)

SOFC			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	90	90
10	8	90	82
50	60*	90	30
100	49,5*	90	40,5
Combustion engine			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	75	75
50	20,3	85,32	65,5
80	24,44	90,32	65,88
100	27	94	67
Condensing boiler			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	98	98
100	0	98	98

*Average el. efficiency between BOL and EOL

Table 23: Efficiencies CASE 2 (Own representation)

SOFC			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	95	95
10	8	95	87
50	65,5*	95	29,55
100	54*	95	41
Combustion engine			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	75	75
50	20,3	85,32	65,5
80	24,44	90,32	65,88
100	27	94	67
Condensing boiler			
Load	η_{el} [%]	η_{total} [%]	η_{th} [%]
0	0	98	98
100	0	98	98

*Average el. efficiency between BOL and EOL

The operating temperature has a great influence on the maximum achievable part load point of the SOFC system. This is why it is necessary to consider the influence of the operating temperature in the simulation. In Table 24, the operating temperature and the maximum partial load points to be achieved are entered. The resulting percentages, which refer to the maximum temperature to be reached, are calculated and used in the simulation. The lower row of Table 24 shows which temperature is set automatically when the system is operated for a longer period of time. This automatic setting of a consistent operating temperature at a constantly operated load point happens in reality because the temperature depends on the amount of energy consumed in form of natural gas.

For reasons of simplification, the maximum achievable part load point for the combustion engine and the condensing boiler is set at 100 percent, which means that the load points are achievable at any temperature and, conversely, the self-achievable temperature is the maximum temperature at any part load point. These settings must be made so that a temperature dependence in the simulation of a combustion engine and condensing boiler can be excluded.

Table 24: Operating temperature at specific load points (Own representation)

Temperature [°C]	Temperature [%]	Max. achievable part load point [%]
0	0	0
719	86,63	0
720	86,75	50
800	96,39	75
830	100	100
Self-adjusting Temperature [°C]	Self-adjusting Temperature [%]	Part load point [%]
720	86,75	0
760	91,57	5
780	93,9	50
830	100	100

As mentioned in Chapter 5.2 explaining the input options, the change in operating temperature during load change must be set for all three systems. For the combustion engine and the condensing boiler, these input values have no effect on the calculation because the data is transferred to the simulation without interdependency of temperature and part load point. This means the operating temperature is at the maximum level at any part load point. The two examples in Table 25 show the impact of the change in load point on the temperature of the SOFC system. Load increase from 50 % to 70 % at an actual operating temperature of 720 °C causes a temperature change of two degrees per minute. In the case of decrease of the load point, the operating temperature decreases by two degrees per minute.

Table 25: Change in operating temperature over time (Own representation)

Example One		Example Two	
x= 0.5 → 0,75		x= 0,75 → 0,5	
Temperature [°C]	dT [°C/min]	Temperature [°C]	dT [°C/min]
720	2	720	-2
800	2	800	-2
830	0	830	-2

9.2 Results of the Matlab simulation

This subchapter provides tables explaining the results of the Matlab simulation of Case 1 and Case 2. For each system combination, the results are displayed in an Excel sheet. The results for the combination combustion engine with condensing boiler and the operation of a condensing boiler, which is responsible for covering the entire heat demand, are the same for both cases, since no system changes were made. Only the SOFC system will be analyzed again for Case 2 because the efficiencies and the service life of the stack are not the same for both cases (compare Table 21).

CASE 1

As explained in more detail in Chapter 5.3, a demand profile was used in the simulation, which corresponds to the demand by two houses with nine apartments each. The gray-labeled cells of Table 26 contain the values that were passed to the simulation. All other values displayed in Table 26 were calculated during the simulation in Matlab. The 99 % availability corresponds to the specified downtime. The condensing boiler is only operated with a utilization rate of 10 %. But since the condensing boiler should cover the peak heat demand, the sizing is still desired. The condensing boiler has to be large enough to cover these peaks. In addition, no smaller condensing boiler was found at Viessmann. However, it is desired by AVL that the condensing boiler and combustion engine used as reference system, should be from the same manufacturer. Thus, Viessmann was chosen as the manufacturer. Unfortunately, a deficit in the hot water supply of 14,4 % can be seen. Since the available boiler is filled with a maximum hot water volume of 139 liters, it must be considered that the condensing boiler produces the required hot water quantity in advance and fills the tank, which in our estimation has a maximum water volume of 1500 liters. In existing systems, the tank is filled until it is full, so that no bottlenecks can arise. This mode of operation is not available in the current simulation. The reason for that is the objective of the simulation which only required the system to meet the current needs. The handling of the additional energy requirement will be explained at the end of this chapter.

Table 26: Simulation results of the SOFC of CASE 1 (Own representation)

SOFC & Condensing boiler				
	Unit	SOFC	Condensing boiler	Delta*
Power of the system	kW	4,5	11	-
Availability	%	99,0	100	-
Utilization	%	88,86	10,97	-
Demand of electric energy	kWh	53305,0		
Produced electric energy	kWh	34931,4	-	18373,6
Demand of heat energy	kWh	43994,1		
Produced heat energy	kWh	27104,6	10543,9	6345,7
Total produced heat energy	kWh	37648,5		-
Coverage electric energy demand	%	65,1	-	34,9
Coverage heat demand	%	61,6	23,97	14,4
Max. heat storage	kWh	6,5	-	-
Min boiler size (SOFC)	l	139	-	-

*Difference between demand and produced amount of energy in kWh or %

For the simulation, an internal combustion engine with a higher performance than the comparative SOFC system was used, which is shown in Table 27. Unfortunately, no internal combustion engine with a power of 4,5 kW was available at Viessmann for which there is a data sheet. The downtime at the internal combustion engine was set to 20 h. Since the combustion engine as well as the SOFC system are operated in an electricity driven manner, too much heat is generated. This surplus of hot water is stored in the tank. The amount of hot water which have to be contained in the boiler is way too large. The bigger the boiler, the more expensive it gets. It also produces 160 %

more heat energy than is actually needed. Thus, energy is wasted senselessly. In addition, a boiler with 1600 liters would require a lot of space, which can cause problems in housing this boiler. It is therefore advised to operate the system heat-managed during further simulations to avoid that the internal combustion engine is throttled upon excess heat production. This change will be made as AVL makes further improvements but is not yet considered in the cost estimate. However, the condensing boiler is not taken into account because this system only produces 2,5 kWh of energy. This heat energy amount of 2,5 kWh which the condensing boiler must additionally produce is produced at the beginning of the simulated year. In the simulation of the system, there is no hot water in the tank at this time, which covers the heat demand. However, it is assumed that the tank is full at the beginning of the year and can cover this energy requirement of 2,5 kWh. Also, this aspect will be taken into account in further projects by AVL to improve the simulation.

Table 27: Simulation results of the combustion engine (Own representation)

Combustion engine & Condensing boiler				
	Unit	CHP	Condensing boiler	Delta*
Power of the system	kW	6	11	-
Availability	%	99,7	100	-
Utilization	%	80,8	0,003	-
Demand of electric energy	kWh	53304,9		
Produced electric energy	kWh	42351,5	-	10953,4
Demand of heat energy	kWh	43994,1		
Produced heat energy	kWh	114560,4	2,5	-70568,9
Total produced heat energy	kWh	114563,0		
Coverage electric energy demand	%	78,51	-	21,5
Coverage heat demand	%	260,4	0,01	-160,4
Max. heat storage	kWh	1540,2	-	-
Min boiler size (SOFC)	l	33004	-	-

*Difference between demand and produced amount of energy in kWh or %

It is simplifyingly assumed that the boiler has the necessary size to save this amount of hot water. The demand for electrical energy is covered up to 21,5 %, i.e. by 13,4 % better than the SOFC system.

Figure 17 shows the differences in load between SOFC and the combustion engine. The combustion engine has more electrical power than the SOFC system. Therefore, the combustion engine more often operates in the partial load area in comparison to the SOFC system.

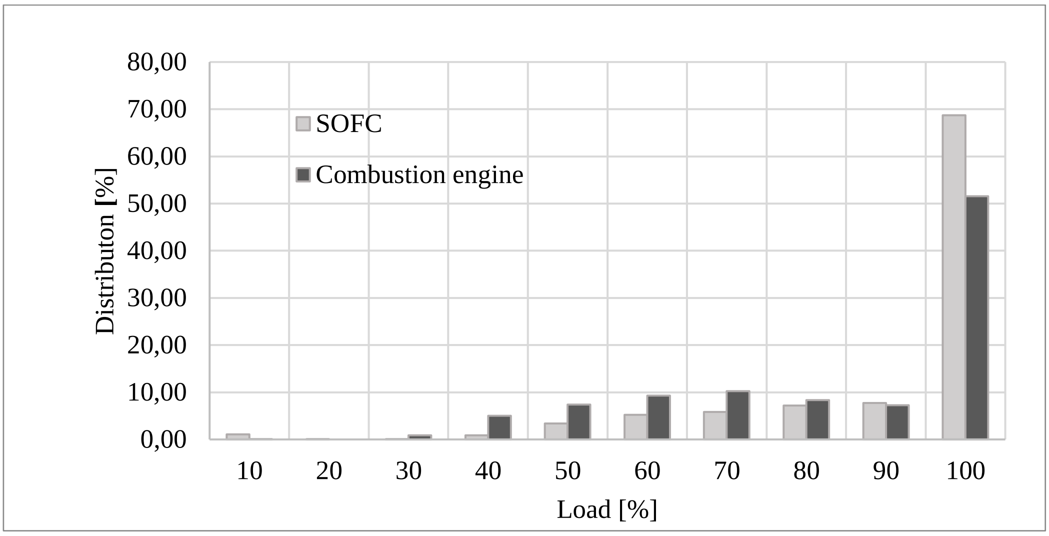

Figure 17: Load Distribution (Own representation)

For pure electric energy purchase from an energy supply over the public grid the condensing boiler should cover the entire heat requirement (compare Table 28). Again, there is a 4,49 %. deviation from the actually required amount of heat. And again, the reason for this is that the condensing boiler always follows the current electrical demand and thus never fills the tank to be covered for peak heat demand. The required calculation of the maximum tank volume is missing. It is assumed that the boiler should have the same size as for the SOFC system.

Table 28: Simulation results of the condensing boiler (Own representation)

Condensing boiler			
	Unit	Condensing boiler	Delta
Power of the system	kW	26	-
Availability	%	99,8	-
Utilization	%	18,5	-
Demand of electric energy	kWh	53304,9	
Produced electric energy	kWh	-	-
Demand of heat energy	kWh	43994,1	
Produced heat energy	kWh	42017,5	1976,6
Total produced heat energy	kWh	42017,5	-
Coverage electric energy demand	%	-	-
Coverage heat demand	%	95,51	4,5
Max. heat storage	kWh	-	-
Min. boiler size (SOFC)	l	-	-

*Difference between demand and produced amount of energy in kWh or %

The differences in the operation of the respective condensing boiler of each system, and the different partial load profiles, are shown in Figure 18. The condensing boilers from the SOFC and the combustion engine have the same power of 11 kW. The condensing boiler, which must cover the entire heat requirement, has a capacity of 26 kW. In this representation, the additional amount of heat which the condensing boiler produces in advance is not included.

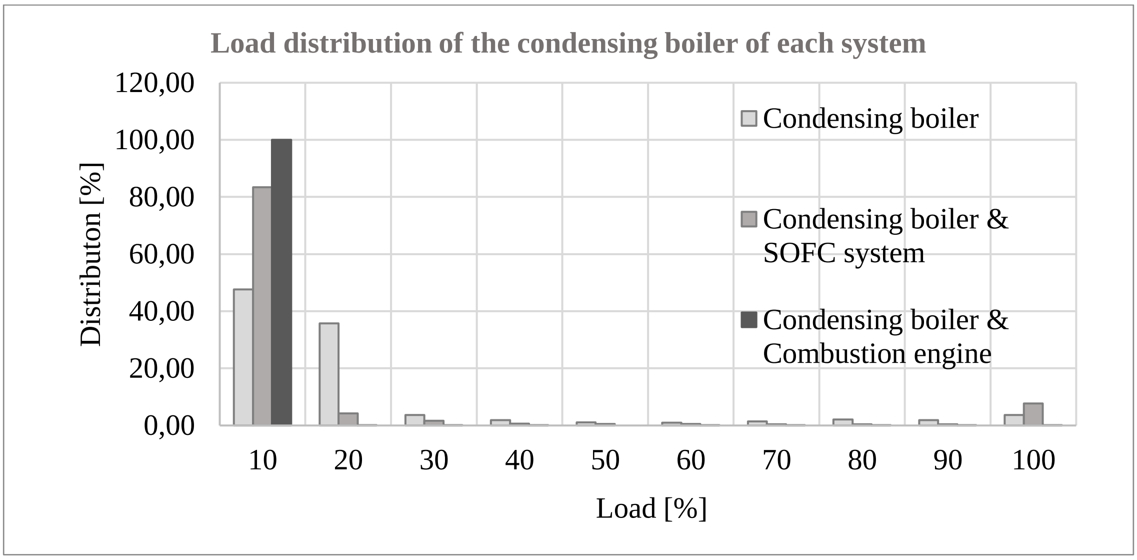

Figure 18: Comparison condensing boiler (Own representation)

CASE 2

As already mentioned, only the SOFC in the simulation for Case 2 has been provided with different input values. Due to the same electrical power of the SOFC systems, they both produce the same amount of energy in Case 1 and Case 2. Considering that the condensing boiler will pre-produce the lack of heat, this system will often operate at higher loads than shown in the simulation.

In Case 2, the electrical and overall efficiency is increased compared to Case 1 (compare Table 29). As a result of the reduced natural gas consumption, less heat energy is generated at a similar thermal efficiency. This can be explained by the fact that less energy in the form of natural gas has to be supplied to the system. The thermal efficiency in Case 2 is by 0,5 % higher but cannot compensate for the proportion of the smaller amount of natural gas. The condensing boiler of Case 2 tries to compensate the smaller heat energy production of the SOFC plant. At the end of the year, the heat demand is covered by up to 16 %.

Table 29: Simulation results of the SOFC of Case 2 (Own representation)

SOFC & Condensing boiler				
	Unit	SOFC	Condensing boiler	Delta*
Power of the system	kW	4,5	11	-
Availability	%	99,0	100	-
Utilization	%	88,9	12,3	-
Demand electric energy	kWh	53305,0		
Produced electric energy	kWh	34931,4	-	18373,6
Demand heat energy	kWh	43994,1		
Produced heat energy	kWh	25097,6	11841,9	7054,7
Total produced heat energy	kWh	36939,4		-
Coverage electric energy demand	%	65,1	-	34,9
Coverage heat demand	%	57,0	26,92	16,0
Max. heat storage	kWh	4,4	-	-
Min boiler size (SOFC)	l	95	-	-

*Difference between demand and produced amount of energy in kWh or %

In order to incorporate the influence of additionally required energy into the calculation, the amount of natural gas needed by the condensing boiler to produce this heat in advance must be calculated. For the sake of simplification, it will be assumed that the condensing boiler with 95 % efficiency cushions the extra heat in times when demand is lower, as shown in Table 30. This amount of energy is required to be included in the calculation of the further cost estimate. For every system manifesting an underproduction of heat energy after the simulation, the necessary additional natural gas consumption is listed in Table 30. The simulation of the combustion engine does not show any shortage of heat energy; on the contrary, too much heat is available. Therefore, the condensing boiler connected with the SOFC is shown in the Table 30 for both cases. It also shows the bigger condensing boiler with a heating power of 26 kW, which is used if the electric energy is only purchased. The additional consumption of natural gas of the 26 kW condensing boiler is the same for both cases because the settings are the same. As already mentioned, only the SOFC settings are different for cases 1 and 2.

Table 30: Additional natural gas energy amount (Own representation)

Case 1 Condensing boiler (11kW)	kWh/a
Natural gas consumption of the SOFC system (Result of the simulation)	68928,7
Natural gas consumption of the condensing boiler (Result of the simulation)	10758,8
Additional consumption of natural gas of the condensing boiler	6679,6
Total amount of natural gas per year	86367,3
Case 2 Condensing boiler (11kW)	kWh/a
Natural gas consumption of the SOFC system (Result of the simulation)	63188,2
Natural gas consumption of the condensing boiler (Result of the simulation)	12083,3
Additional consumption of natural gas of the condensing boiler	7426,0
Total amount of natural gas per year	82697,6
Case 1/2 Condensing boiler (26kW)	kWh/a
Natural gas consumption of the condensing boiler (Result of the simulation)	42875,0
Additional consumption of natural gas of the condensing boiler	2080,6
Total amount of natural gas per year	44955,7

After the analysis of the simulation results of each system which are listed for example in Table 29, it should be decided whether the size of the system was chosen correctly. A cost estimate is performed with these simulation results. The high unused amount of heat produced by the internal combustion engine significantly increases fuel consumption. According to AVL, the SOFC system will perform better compared to the combustion engine due to the low power of the systems, which are simulated. The initial investment costs, which are listed in Table 32 and Table 33, of the simulated combustion engine are higher compared to the SOFC system. Also the following annual costs during the operation of the combustion engine are higher. This is why it is especially important to establish a comparison between the pure electricity supply from the public grid and the SOFC system.

9.3 Cost evaluation of investigated Cases

The life period of the components of each system like the SOFC system and especially of the more expensive components is one of the main influencing factors, i.e. the observation period plays a major role for the result of the payback period. In this calculation, the period under consideration is set on 15 years.

Before the 2 different cases can be compared, values must be defined which must be the same for both cases. This includes values such as inflation, price change factor of the individual components and means, such as natural gas, which are necessary for the operation of the plant. Table 31 lists the price change factors of the costs incurred each year. Furthermore, the cash value factors calculated for these costs which are necessary for the profitability calculation are listed. Cash value factors are stated for the costs incurred each year.

Table 31: Price change and cash value factor (Own representation)

Types of costs	Price change factor		Cash value factor	
Demand - (consumption-)related costs	rv	1,02	bv	14,7
Operation-related costs	rb	1,01	bb	13,7
Other costs	rs	1,01	bs	13,7
Maintenance /operation costs	ri	1,01	bi	13,7
Proceeds	re	1,02	be	13,7
Current related costs	rc	1,02	bc	14,7

These values were entered into the calculation tool with the agreement of the AVL for the comparison of the cases. However, as in the previous chapter, it should be mentioned that these are pure assumptions. The values of the last few years were used as a reference and it was estimated which assumptions could be considered plausible. In a further sensitivity analysis, the different influences will be illustrated by changing these values.

As described in Chapter 2.3 a fuel cell system is divided into stack (the cell stack) and the remaining system components (balance of plant, BoP). According to AVL, it is expected that the fuel cell system will become cheaper in the next few years. Especially the price of the stack should fall – by how much cannot be predicted but we cautiously assumed a mere 2 percent reduction over the next few years. The BoP components are prudently assumed to be only 1 percent. For the remaining components of the SOFC system, the condensing boiler and the combustion engine, a price change of 1 % is assumed. This is because these systems no longer expect the big development spurt. Taking this price change factor into consideration, the non-inflation-adjusted price changes will be addressed. The value of inflation was zeroed, because the price change factor was set separately for each component. As mentioned earlier, the inflation factor refers to all components and expenses.

The interest for invested money is estimated at 1,2 %. This percentage usually increases depending on how long the money is guaranteed to be in the bank. If less than 10,000 Euro are invested with a guaranteed investment period of 5 years at Kommunalkredit Austria Bank, (see Chapter 10), a fixed interest rate of 0,85 % is guaranteed. For an investment of more than 10.000 Euro, it is 1,20 %. For a time period of 10 years and an investment of less than 10.000 Euro, the percentage is 1,15 and for an investment of 10.000 Euro for a period of over 10 years, the interest rate is 1,5 %. Because money is not invested separately for every component, an interest of 1,20 % is assumed in this calculation.

9.3.1 CASE 1

First of all, the required components and the components' related values, such as the investment costs, are listed in a table in Excel. The values of this table which are important for the cost estimate are listed in Table 30. The lifetime in the comparison of the 2 cases in Table 19 are given in hours. Table 30 shows the lifetime converted into years. The replacement frequency is then displayed automatically. The installation costs also include the operating costs, but it is also possible to enter these separately. For this, there are additional cells next to each component into which the service hours required and their hourly rate per annum can be entered.

Table 32: SOFC system & condensing boiler, Case 1 (Own representation)

Service life, in years	Factor for maintenance, in %	Frequency of replacement	Designation of component	Investment, in €	Price change factor
Tn	fk	n		Ao	rk
3,47	0	4	Stack	5000	0,98
9,25	6,78	1	BoP	11800	0,99
15,00	0	0	Additional components	3000	1,01
15,00	1,2	0	Installation costs	5000	1,01
5,78	3,95	2	Condensing boiler	3800	1,01
15,00	0	0	Installation costs	900	1,01
				29500	

The additional component costs are related to the tank with a volume of 1500 liters. The same tank is installed for the over-systems. In Table 32 and Table 33 the factor for maintenance of the SOFC and the combustion engine is different. The difference in percentage is due to the different investment costs of the two systems. Maintenance costs for both systems are estimated to be 800 Euro, referring to the first year. Therefore, the percentage for maintenance is not the same of both systems.

Table 33: Combustion engine, Case 1&2 (Own representation)

Service life, in years	Factor for maintenance, in %	Frequency of replacement	Designation of component	Investment, in €	Price change factor
Tn	fk	n		Ao	rk
5,55	3,14	2	Combustion engine	25500	1,01
15,00	0	0	Additional components	3000	1,01
15,00	0	0	Installation costs	5000	1,01
				33500	

As already mentioned in the previous chapter, no condensing boiler is installed in addition to the combustion, since too much heat was already produced by the engine. The 5,55 years of service life is equal to 48.000 hours.

Table 34: Grid & condensing boiler, Case 1&2 (Own representation)

Service life, in years	Factor for maintenance, in %	Frequency of replacement	Designation of component	Investment, in €	Price change factor
Tn	fk	n		Ao	rk
5,78	3,95	2	Condensing boiler	4227,6	1,01
15,00	0	0	Additional components	3000	1,01
15,00	0	0	Installation costs	900	1,01
				8127,6	

How much natural energy is needed, be it for heat or electricity production, and the associated costs, are shown in Table 35. The revenue generated from the selling of electricity is also presented. These values all refer to the first year. Due to these price change factors, the expenses for the next few years can increase or decrease. The row for other costs is only used if additional costs are incurred and should not be added to any of the other costs. This is not the case with this calculation and therefore the annual costs are zero. The revenue generated by the sale of over-powered electricity is very low, both in the SOFC system and in the internal combustion engine. Due to the fact that the systems are powered by electricity, this is not surprising. But if the plant is operated so as to generate more revenue, a combination of different systems has to be considered, as is the case with the company SAPPI. This calculation is only intended to ensure that the unused electricity does not have to be cached and fed into the public electricity grid. But it would also be possible to install a battery that stores the over-produced electricity.

Table 35: Energy amount of Case 1 (Own representation)

CASE 1		SOFC	GRID	REF_SYS
Purchased natural gas	KWh/a	68928,8	42875	171946,7
	€/kWh	0,061	0,061	0,061
	€/a	4260,5	2778,7	10628
Sold electricity	KWh/a	252,1	-	499,7
	€/kWh	0,03	-	0,03
	€/a	8,8	-	17,5
Purchased electricity	KWh/a	18625,7	53304,9	11453,1
	€/kWh	0,1982	0,15316	0,198
	€/a	3762,4	10767,6	2313,5
Purchased natural gas (Additional condensing boiler)	KWh/a	17438,6	53304,9	-
	€/kWh	0,061	0,061	-
	€/a	1490,7	-	-
Total amount of natural gas purchased				
	€/a	5253,1	10767,6	2313,6
Other costs				
	€/a	0	0	0

Total annuity

All annuities are listed Table 36. The annuities of capital-related costs of small combustion engines are higher in comparison with a SOFC system. The investment costs are higher and the service life is shorter than with a SOFC system. If the plants were to be sold, the more decisive would be the difference between the capital costs in favor of the combustion engine. But the simulation of the large engine would also have to be overhauled because, as shown in the previous chapter, far too much heat is produced and a heat-driven simulation should be carried out.

Due to these facts, the focus should be on the comparison between the SOFC & Condensing boiler (CB) system and the Grid CB system. The winner in this comparison is the SOFC & CB system due to lower total annuity costs.

Table 36: Total annuity of Case 1 (Own representation)

Annuity	SOFC & CB	Combustion engine	Grid & CB
	Euro	Euro	Euro
Capital-related costs	4534,8	6128,2	1204,1
Consumption-related costs	6601,4	12199,1	3189,5
Operation-related costs	1017,2	856,6	178,7
Other costs	0,0	0,0	0,0
Electric energy costs	4318,6	2655,5	12359,3
Annuity of proceeds	10,1	20,1	0,0
Total annuity	-16461,9	-21819,6	-16931,6

Payback period Case 1

In order to be able to estimate when the payback period will occur, the investments and their discounted cash flows incurred over the years are compared. This comparison is presented in Figure 19. In this case, no uniform line can be seen, since the assumed life of the internal combustion engine is too short, not to be replaced over the entire period of observation. The strong increases in discounted cash flows in years 6 and 12 reflect these expenditures for replacement purchases. The stack of the SOFC has to be replaced 4 times during this period and the BoP system once. However, these costs are not as high as the individual replacement procurements for internal combustion engines. Therefore, only a slightly fluctuation can be seen in the discounted cash flows. The costs of the combustion engine were shown in Table 33. The biggest fluctuation of the discounted cashflows of the SOFC can be seen from year 9 to 10 due to the purchase and replacement of the BoP system. There is no intersection of the two systems in this comparison, since the investment costs of the combustion engines at the beginning of the observation period are already higher than those of the SOFC & CB system.

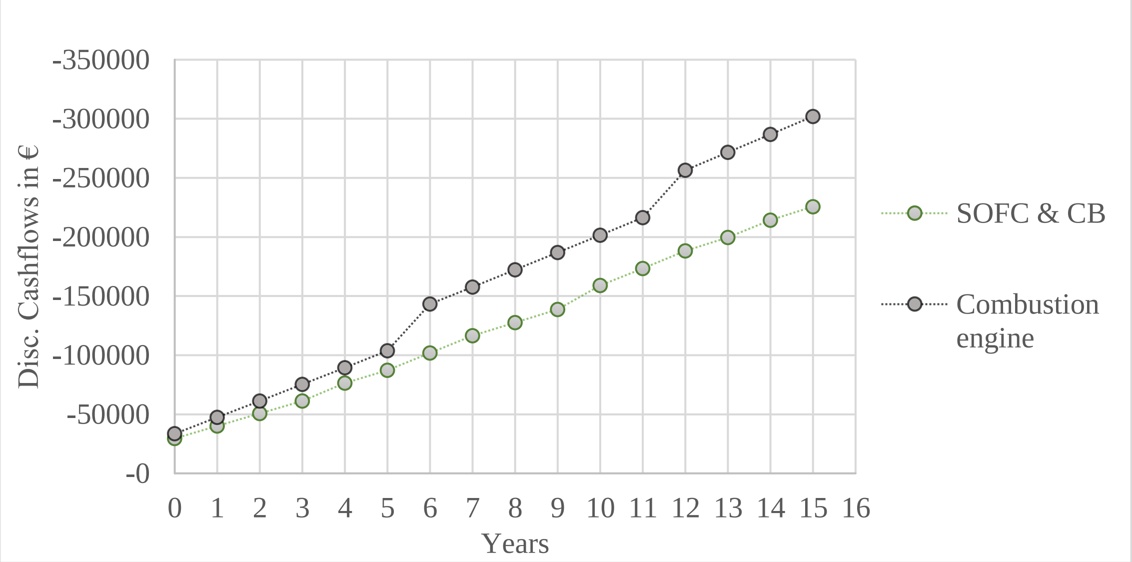

Figure 19: Payback period SOFC& CB vs combustion engine, Case 1 (Own representation)

In the comparison between the SOFC & CB system there is an intersection point as shown in Figure 20. This point in time is the payback period of the SOFC & CB system. After 8,76 years, the SOFC & CB system is amortized, but the further course of costs is very similar to the one of the Grid & CB system. This, again, is reflected in the total annuity presented in Table 36. To what extent this payback period is shortened by employing an advanced SOFC system is shown in Case 2.

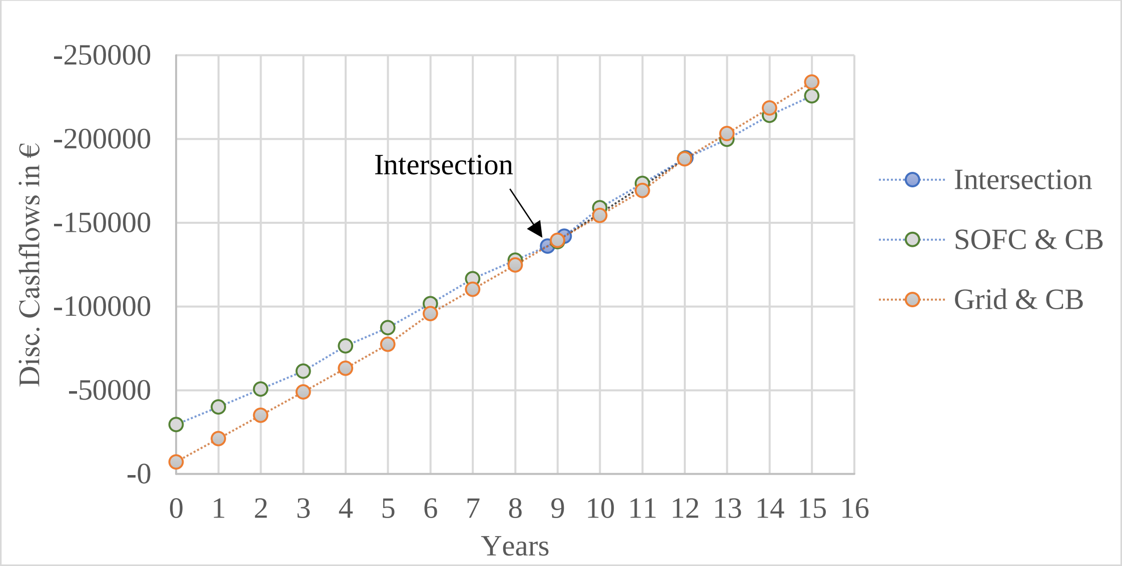

Figure 20: Payback period SOFC & CB vs Grid & CB, Case 1 (Own representation)

9.3.2 CASE 2

As already shown in Table 21, firstly the simulation of the second case with a better efficiency of the SOFC system is performed and secondly the service life of the BoP system and the stack is extended. The individual components are shown in Table 37.

Table 37: SOFC system Case 2 (Own representation)

Service life, in years	Factor for maintenance, in %	Frequency of replacement	Designation of component	Investment, in €	Price change factor
Tn	fk	n		Ao	rk
9,25	0	1	Stack	5000	0,98
15,03	6,78	0	BoP	11800	0,99
15,00	0	0	Additional components	3000	1,01
15,00	0	0	Installation costs	5000	1,01
5,78	3,95	2	Condensing boiler	3800	1,01
15,00	0	0	Installation costs	900	1,01
				29500	

Due to this advanced SOFC system, fewer replacements are needed. The stack only needs to be replaced once during the 15-year observation period, and the BoP system will not be changed once. The price change factors, the investment and maintenance costs, have remained unchanged compared to Case 2.

Total annuity

Table 38 shows the reduced capital and consumption-related costs. The former has a lower annuity due to the fewer replacement purchases required. The consumption-related costs have been reduced through the improved efficiency of the SOFC. All other annuities have the same value as in Case 1. Overall, this results in a reduced total annuity, which divides the costs evenly over the number of observation years. These costs are 1711 Euro lower than in Case 1. Also in Case 2 the combination SOFC & CB is the system with the lowest total annuity. As shown in Table 38 the total annuity of the combination SOFC & CB is 2231 Euro lower than the combination Grid & CB.

Table 38: Total annuity of Case 2 (Own representation)

Annuity	SOFC & CB	Combustion engine	Grid & CB
	Euro	Euro	Euro
Capital-related costs	2981,0	6128,2	1204,1
Consumption-related costs	6394,0	12199,1	3189,5
Operation-related costs	1017,2	856,6	178,7
Other costs	0,0	0,0	0,0
Electric energy costs	4318,6	2655,5	12359,3
Annuity of proceeds	10,1	20,1	0,0
Total annuity	-14700,6	-21819,6	-16931,6

Payback period Case 2

As with Case 2, there is no point in comparing the SOFC & CB combination and the combustion engine. Not only are the consumption-related costs higher than the SOFC & CB combination, also the investment costs of the combustion engine are higher. The discounted cashflows of the individual years of the SOFC & CB combination have declined, as shown in Figure 21.

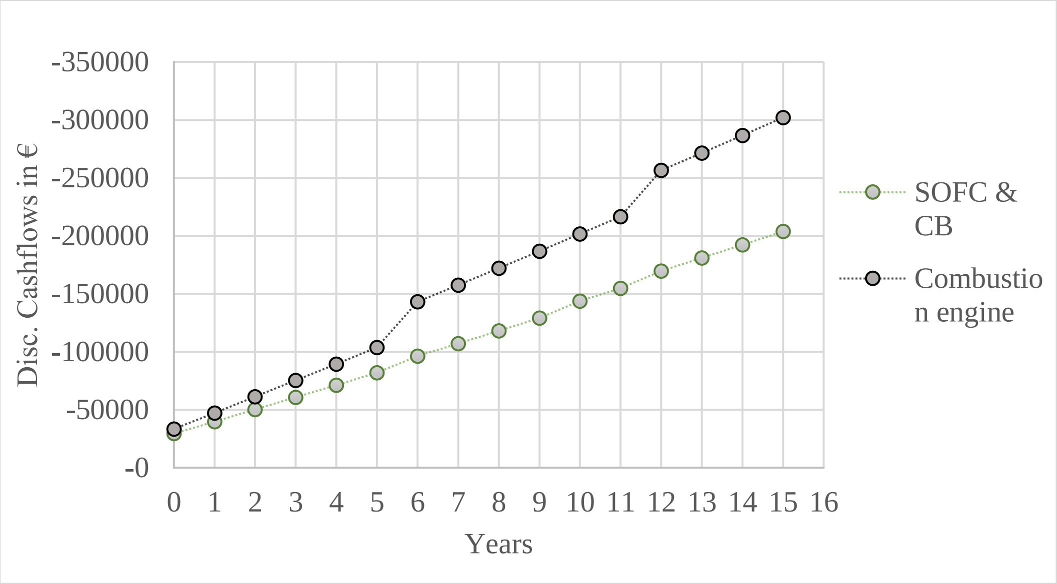

Figure 21: Payback period SOFC& CB vs combustion engine, Case 2 (Own representation)

The time until the combination SOFC & CB compared to the pure electricity purchase amortizes has dropped to 6,1 years (compare Figure 22). Thus, the payback period has decreased by 2,6 years compared to Case 2. The accumulated discounted cash flows are not as similar after the amortization period as in Case 2, which is also confirmed by the greater difference in the total annuity of the two systems. To what extent changes such as a higher accrual factor affect this amortization time will be examined by means of a sensitivity analysis.

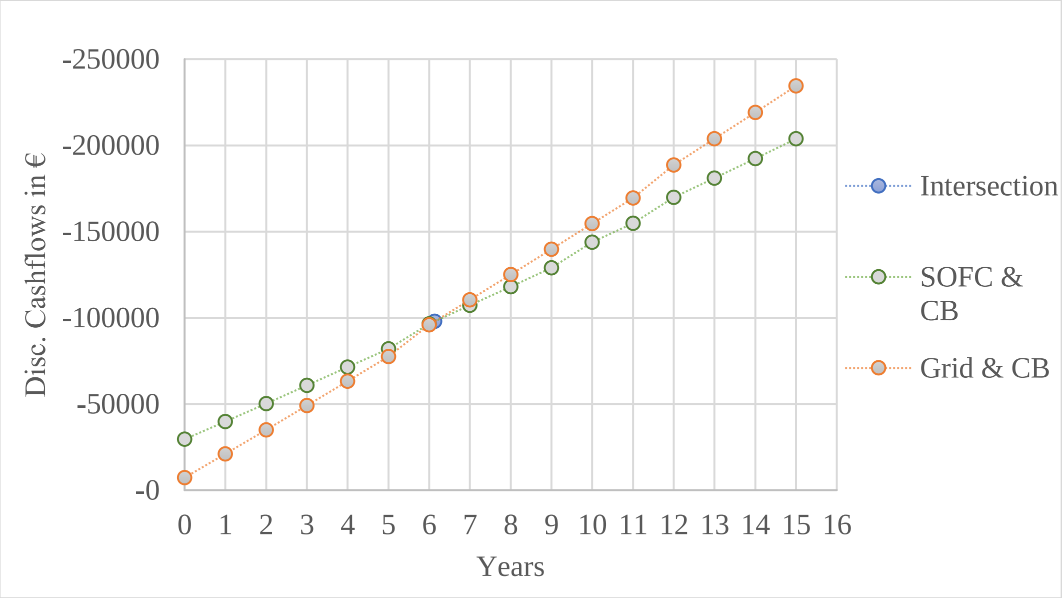

Figure 22: Payback period SOFC & CB vs Grid & CB, Case 2 (Own representation)

9.4 Sensitivity analysis of Case 2

The sensitivity analysis of the combination SOFC & CB compared to combination Grid & CB determines the effects of different influencing factors more precisely. The focus will be on Case 2. By changing the settings made for Case 2, it can be shown how much the payback period changes. In particular, the influence of the accrual factor and the price change factors of electricity and natural gas is analyzed. These influencing factors are difficult to predict, which makes a sensitivity analysis indispensable.

There are 3 factors which require accurate analysis and whose future course is particularly difficult to predict. In Table 39, Table 40 and Table 41 the different possible percentages of these three factors, namely the consumption-related costs, in this case natural gas costs, current related costs and accrued interest, are listed. These factors are responsible for the largest impact on the resulting costs during the period under consideration. The fact that influencing factors, such as the price change factor for electric energy for the next year, cannot be predicted accurately makes this observation necessary. The electricity price changes between -2 % and 10 % are and those impact on the payback time shows Table 39. Especially the impact of a rising electricity price has to be evaluated. The question why positive rather than even more negative percentages or resulting price change factors were considered was discussed in Chapters 7.1 and 7.3.

Table 39: Payback time as a function of the electricity price change (Own representation)

Price change of electricity	Expenses until amortization point	Payback period
%	€	Years
-2	161833,6	12,4
-1	114820,4	8,1
0	106887,2	7,2
1	101393,6	6,6
2	97226,0	6,1
3	93372,1	5,7
4	89969,0	5,5
5	87058,0	5,2
6	84553,1	5,0
7	82665,8	4,8
8	81027,6	4,6
9	79582,5	4,4
10	78302,2	4,3

The payback period for the SOFC decreases with increasing electricity prices. If the combination SOFC & CB is used less electric energy has to be purchased compared to the pure electric energy supply from the public grid.

By contrast, with increasing prices of natural gas the payback period of the combination SOFC & CB decreases. Also, the combination Grid & CB needs natural gas for the operation of the condensing boiler, but the consumption is much less. The total amount of natural gas per year of case 2 of the combination SOFC & CB is 82697,61 kWh/a. The condensing boiler of the combination Grid & CB has a natural gas consumption of 44955,67 kWh/a. The composition of this required amount of natural gas is listed in Table 30.

Table 40: Payback period as a function of the gas price (Own representation)

Price change of natural gas	Expenses until amortization point	Payback period
%	€	Years
-2	86870,2	5,6
-1	89179,2	5,7
0	91718,4	5,8
1	94343,7	5,9
2	97212,4	6,1
3	100528,4	6,3
4	104418,9	6,5
5	109065,0	6,7
6	114998,2	7,0
7	122832,8	7,4
8	134714,6	8,0
9	0,0	0,0
10	0,0	0,0

The accrual factor can also be guaranteed due to a fixed interest rate for each year during a specific period of time. Fixed interests minimize the risk and results in a more accurate cost estimate. How it comes to a fixed interest rate is explained in Chapter 4.4. Although it is assumed that to invest money with a fixed interest rate will be done anyway. If no fixed interest rate is assumed, the influence of different accrued interests should be analysed. It is assumed that the accrued interest will be at least positive in this cost estimate, since the money would not be deposited to a bank account if the minimum accrued interest was assumed to be zero. This is not the case for the two other influencing factors, such as gas and electricity, and therefore negative percentages of up to minus two percent are assumed.

Table 41: Payback period as a function of the accrued interest (Own representation)

Accrued interest change	Expenses until amortization point	Payback period
%	€	Years
0	97712,8	5,9
1	97844,8	6,1
2	97686,7	6,3
3	97538,4	6,6
4	97399,2	6,8
5	97266,1	7,1
6	97136,3	7,4
7	97014,4	7,8
8	96896,8	8,2
9	96781,5	8,6
10	103392,4	10,2

For a better overview of the discussed values, Figure 23 shows all three influencing factors. Each of the individual points in the figure represents a payback period. The lowest and highest percentages, which are considered to be important for the sensitivity analysis, are indicated in the illustration. The individual payback periods in between the lowest and highest percentages (marked in the same color) represent the intermediate percentages. Upon entering these percentages, the price change factor (natural gas, electricity) and the accrual factor is calculated, and the result is the payback period represented as a point in Figure 23. The expenses in € are the discounted cashflows

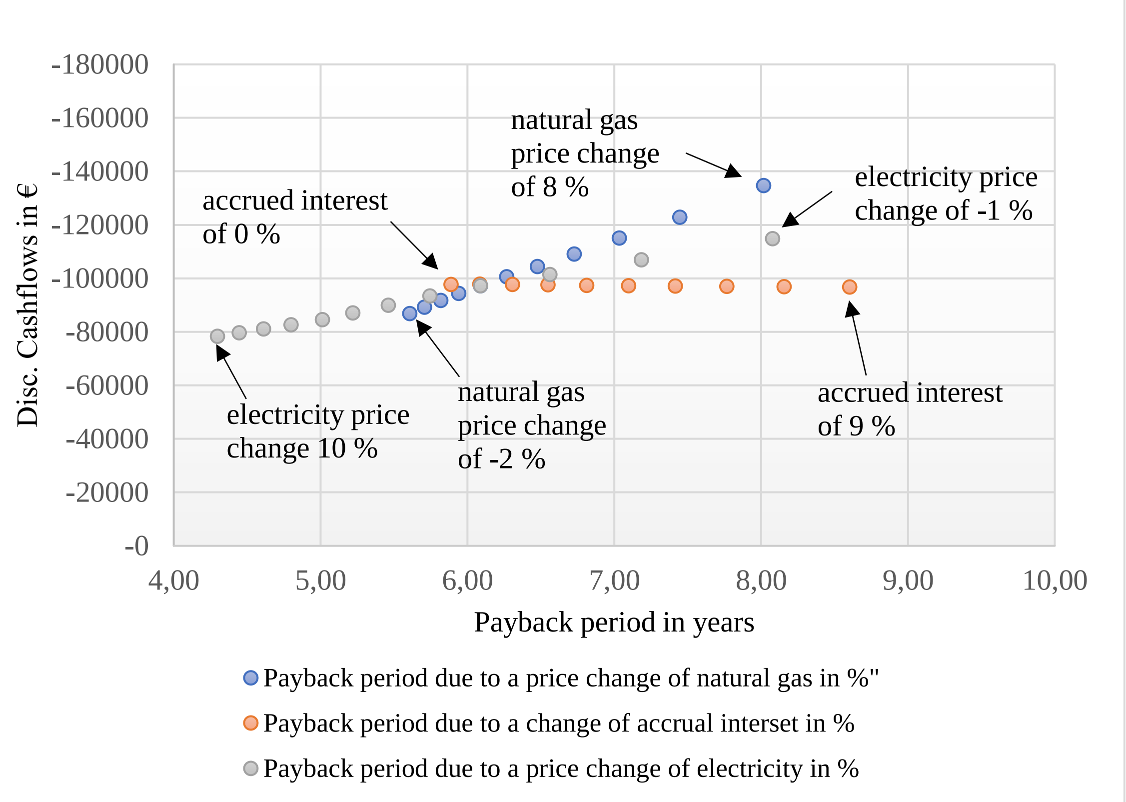

Figure 23: Sensitivity analysis of hard-to-predict factors (Own representation)

If these amortization points are connected by a line, the intersection of these lines represents the payback time that has already been calculated for Case 2. This intersection represents a payback period of 6,13 years, which was discussed in Chapter 9.3.2. Only one influencing factor has been changed, and the others were kept constant. What stands out as interesting in this representation is how much an increasing price change factor of electricity reduces the payback period for the system combination SOFC & CB. It makes clear that the electricity price has a substantial impact on the payback period.

The two lines represent the different cost curves of the discounted cashflows at different interest rates, in the illustration of Figure 24. Since the sum of annual costs of the combination Grid & CB are higher than that of the combination SOFC & CB, a positive accrual factor has a greater impact on the first mentioned combination. Therefore, the payback period of the SOFC system increases with a rising accrual factor.

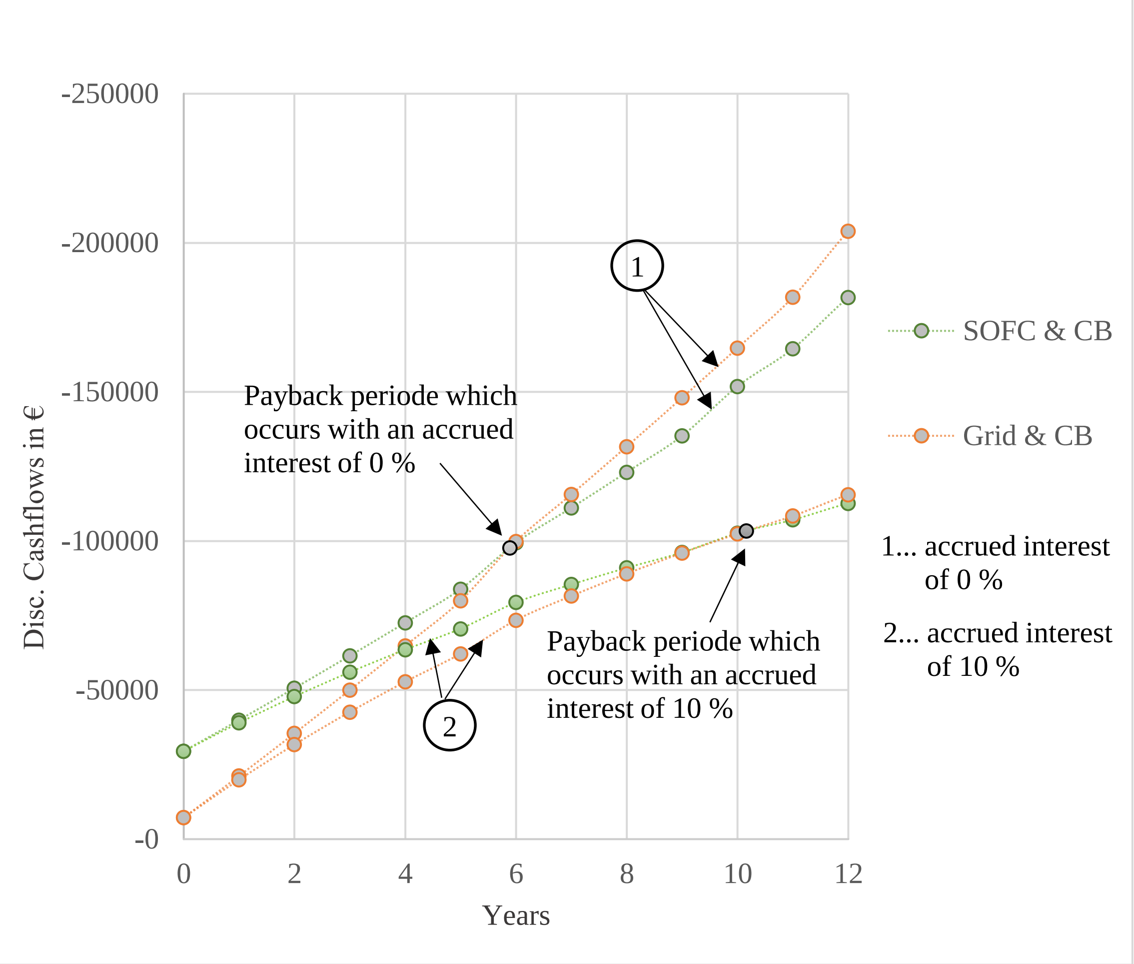

Figure 24: Change in payback period due to a different accrued interest (Own representation)

Due to the fact that replacements, such as stack, have to be bought in the 10th year, their purchase has no influence on the payback period. But the net present value at the end of the observation period is already affected. This is again a reason for always considering the annuities or the net present value if investments have to be made or compared. At the beginning of the observation time the stack price is 5000 Euros. Due to the basic settings that have been made for Case 2, the price for the second stack, which has to be replaced after 9,25 years, is 3466,3 Euros. If the total NPV of the period under consideration were calculated, and no additional stack was needed, the payback period would not change, but the NPV would decrease by 1723,9 Euros. In this comparison between two systems, this would mean a lower total expenditure.

As already mentioned, the replacement must be made after 9,25 years. This discounted cashflow is not shown exactly at the time when the procurement takes place in Figure 25. This is because the total costs incurred in the respective year are always are added together and transferred as an amount to the calculation. That is why the sudden increase in costs is shown in the 10th year. The second line below shows the cash flows without replacement, in order to determine what impact this payment has on the continuation of the further accumulated discounted cash flows.

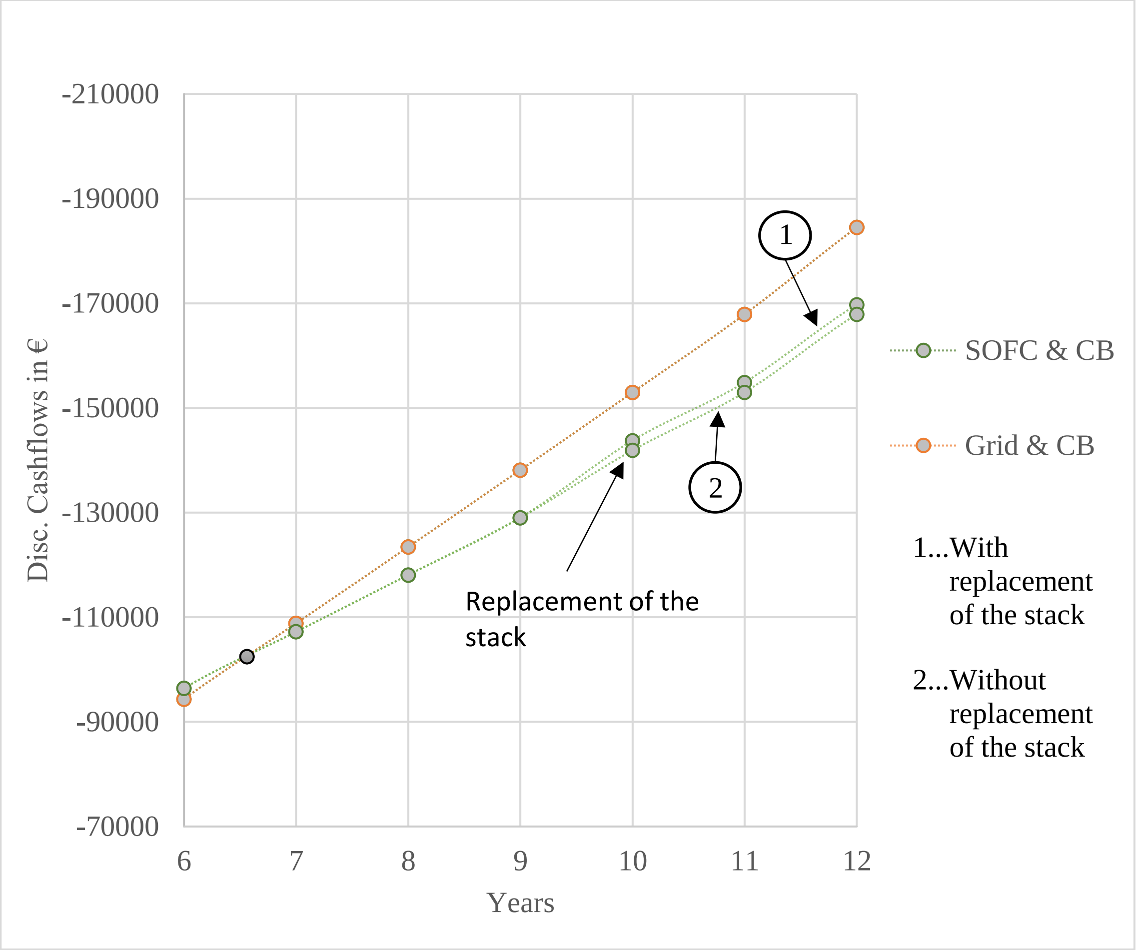

Figure 25: Influence of replacement purchases (Own representation)

Summary

For the cost estimate, two cases of s SOFC were considered. The SOFC is simulated with different efficiencies and service life's. Especially the comparison of the SOFC versus the pure purchase of electricity by a electricity supplier is considered as important by the AVL. This serves to see if it is profitable to purchase a SOFC system. In this comparison, a payback time of 6,13 years was calculated for the case with the higher efficiencies and longer service life's.

10 Conclusion

A cost estimate and its results from a SOFC plant in conjunction with a condensing boiler strongly depends on the demand profile to be covered. This work addressed the coverage of an electrical demand and heat demand for DHW heating of 2 houses with 9 apartments each. 25 people live in each house. The operation of an internal combustion engine with a power of 6 kW is possible to simulate by using Matlab. But due to the electricity driven simulation and the lack of throttling of the combustion engine upon excess heat production, it is not possible to represent the economic viability of the engine compared to the SOFC at any demand profile. The only exception are cases where the heat demand is so high that no problem with the wasted heat arises or cases where the plant is so small that it has to cover only a small part of the overall electrical needs. But what certainly speaks for the SOFC is that the electricity demand in Austria compared to the heat demand will continue to grow in the coming years. Past data shows that the electricity consumption of households doubled from 8,3 to 17,1 TWh between 1985 and 2010. Because of this development, the SOFC, which has higher electrical efficiency compared to the internal combustion engine, is often the better investment. Before, however, the need for heat and power of each building must be evaluated to determine which system – like for example, a SOFC without or with condensing boiler or just an internal combustion engine – is most economical. This demand profile analysis can be done with a program which was created with the software Matlab. The developed calculation tool can, after simulating larger plants, provide information about how the size and the associated different amounts of electrical energy that are produced influence the profitability of a SOFC plant compared to other systems. By generating power starting from 1 MW, it is possible to settle the electricity costs and the revenues based on the energy prices of an energy exchange such as EXAA.

In this work, two different cases of a SOFC were simulated, first with Matlab, and then compared to other system combinations in a largely automated cost estimation. Above all, the focus of this thesis was on the comparison of SOFC & CB and Grid & CB. In the second case of the SOFC, higher efficiencies and lifetimes of the BOP system and the stacks were assumed. The SOFC has an average electrical power of 4,5 kW in this simulation.

Over the 15-year review period of the SOFC in Case 2, the SOFC & CB combination in comparison with the Grid & CB combination had a payback period of 6,1 years. If the payback period is within reasonable limits depends on the feeling of the investor and feelings can not be decreed. In this thesis, it was all about the question of whether or not it would be profitable to operate such a system. If the 15-year observation period must be met and the SOFC meets these input levels, such as an electrical efficiency of up to 60 % at the beginning of the operation and a 48 % at the end of the operation, then the clear answer is: yes, it pays off to install such a system for the given energy demand. Even at high natural gas prices, which may arise over the next few years, the SOFC at the end of this period is a better choice than just sourcing electricity from an electric energy supplier. The influence of an annual 8 % increase in natural gas prices was also shown in the calculation, and even in this case, the payback period is 8,2 years. What needs to be taken into account is that not only the price of natural gas, but also many other factors, such as electricity and its price change factor over the period of application, have a great influence on the amortization period. These factors and the risk of them having a major impact on the calculation were presented in a sensitivity analysis. However, the SOFC can also be understood as an additional security device that can cover a part or all of the energy demand, if desired, in the event of a power failure.

The simulation in Matlab and the subsequent cost estimation based on the VDI guideline 2067 works, but a few improvements should be made so that the comparison between a combustion engine and a SOFC system can be performed. First, the heat-controlled operation of the internal combustion engine should be simulated. Second, throttling of a CHP system should be possible if the heat production is too high with an electricity driven simulation of the internal combustion engine.

The cost estimate tool can be used to calculate the total annuities, the NPV and the required dynamic amortization period. Programming in VBA was necessary to enable an easier operation and, above all, a fast comparison of different systems in Excel. Last but not least, the sensitivity analyses were facilitated in so far as only one button has to be pressed upon changing a value to display the influence on different diagrams.

In conclusion, the SOFC system is a good alternative to existing systems and a good way to reduce the consumption of our finite natural resources, such as natural gas. If, in the future, operation with hydrogen, which is likely to become producible by using renewable energy, should be possible, fuel cells would also offer this possibility.

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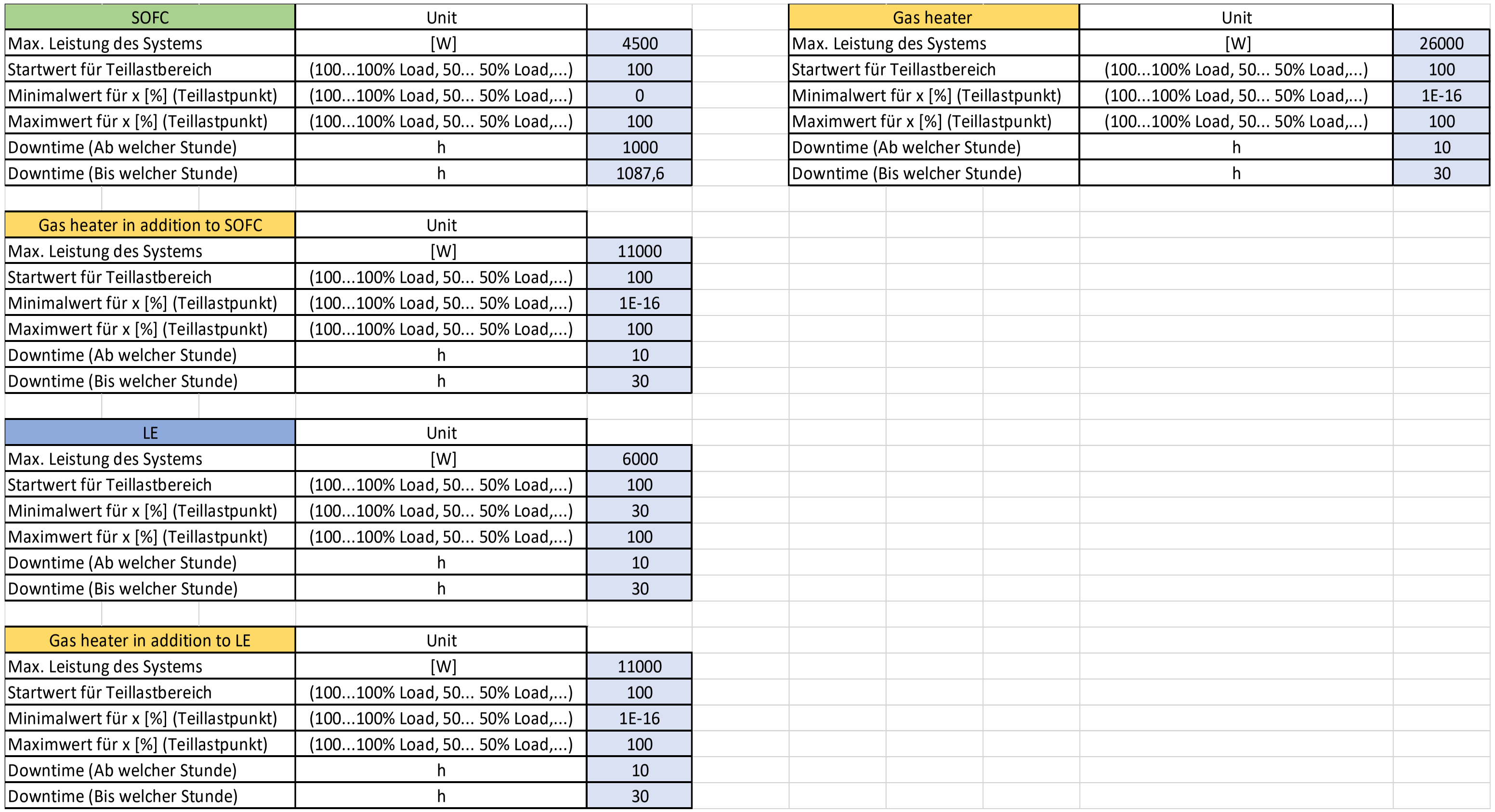
Appendix

Example of input values for the simulation



SOFC	Unit	
Max. Leistung des Systems	[W]	4500
Startwert für Teillastbereich	(100...100% Load, 50... 50% Load,...)	100
Minimalwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	0
Maximwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	100
Downtime (Ab welcher Stunde)	h	1000
Downtime (Bis welcher Stunde)	h	1087,6

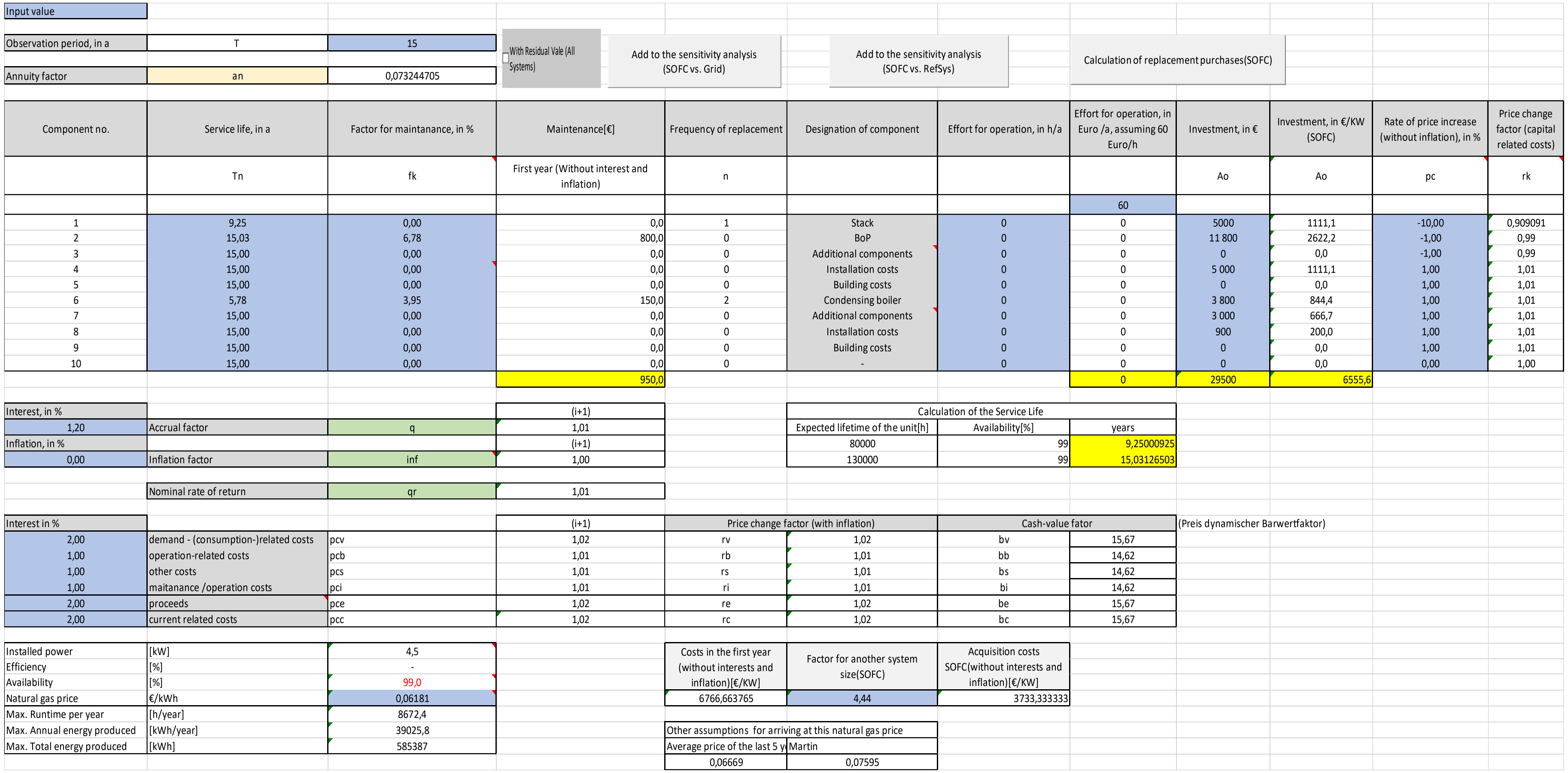
Gas heater	Unit	
Max. Leistung des Systems	[W]	26000
Startwert für Teillastbereich	(100...100% Load, 50... 50% Load,...)	100
Minimalwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	1E-16
Maximwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	100
Downtime (Ab welcher Stunde)	h	10
Downtime (Bis welcher Stunde)	h	30

Gas heater in addition to SOFC	Unit	
Max. Leistung des Systems	[W]	11000
Startwert für Teillastbereich	(100...100% Load, 50... 50% Load,...)	100
Minimalwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	1E-16
Maximwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	100
Downtime (Ab welcher Stunde)	h	10
Downtime (Bis welcher Stunde)	h	30

LE	Unit	
Max. Leistung des Systems	[W]	6000
Startwert für Teillastbereich	(100...100% Load, 50... 50% Load,...)	100
Minimalwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	30
Maximwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	100
Downtime (Ab welcher Stunde)	h	10
Downtime (Bis welcher Stunde)	h	30

Gas heater in addition to LE	Unit	
Max. Leistung des Systems	[W]	11000
Startwert für Teillastbereich	(100...100% Load, 50... 50% Load,...)	100
Minimalwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	1E-16
Maximwert für x [%] (Teillastpunkt)	(100...100% Load, 50... 50% Load,...)	100
Downtime (Ab welcher Stunde)	h	10
Downtime (Bis welcher Stunde)	h	30

Input values for the cost estimate and the button which can be clicked



Input value

Observation period, in a	T	15
Annuity factor	an	0,073244705

Component no.	Service life, in a	Factor for maintanance, in %	Maintenance[€]	Frequency of replacement	Designation of component	Effort for operation, in h/a	Effort for operation, in Euro /a, assuming 60 Euro/h	Investment, in €	Investment, in €/KW (SOFC)	Rate of price increase (without inflation), in %	Price change factor (capital related costs)
	Tn	fk	First year (Without interest and inflation)	n				Ao	Ao	pc	rk
							60				
1	9,25	0,00	0,0	1	Stack	0	0	5000	1111,1	-10,00	0,909091
2	15,03	6,78	800,0	0	BoP	0	0	11 800	2622,2	-1,00	0,99
3	15,00	0,00	0,0	0	Additional components	0	0	0	0,0	-1,00	0,99
4	15,00	0,00	0,0	0	Installation costs	0	0	5 000	1111,1	1,00	1,01
5	15,00	0,00	0,0	0	Building costs	0	0	0	0,0	1,00	1,01
6	5,78	3,95	150,0	2	Condensing boiler	0	0	3 800	844,4	1,00	1,01
7	15,00	0,00	0,0	0	Additional components	0	0	3 000	666,7	1,00	1,01
8	15,00	0,00	0,0	0	Installation costs	0	0	900	200,0	1,00	1,01
9	15,00	0,00	0,0	0	Building costs	0	0	0	0,0	1,00	1,01
10	15,00	0,00	0,0	0	-	0	0	0	0,0	0,00	1,00
			950,0				0	29500	6555,6		

Interest, in %			(i+1)
1,20	Accrual factor	q	1,01
Inflation, in %			(i+1)
0,00	Inflation factor	inf	1,00
	Nominal rate of return	qr	1,01

Calculation of the Service Life		
Expected lifetime of the unit[h]	Availability[%]	years
80000	99	9,25000925
130000	99	15,03126503

Interest in %			(i+1)	Price change factor (with inflation)		Cash-value fator	
2,00	demand - (consumption-)related costs	pcv	1,02	rv	1,02	bv	15,67
1,00	operation-related costs	pcb	1,01	rb	1,01	bb	14,62
1,00	other costs	pcs	1,01	rs	1,01	bs	14,62
1,00	maitanance /operation costs	pci	1,01	ri	1,01	bi	14,62
2,00	proceeds	pce	1,02	re	1,02	be	15,67
2,00	current related costs	pcc	1,02	rc	1,02	bc	15,67

(Preis dynamischer Barwertfaktor)

Installed power	[kW]	4,5
Efficiency	[%]	-
Availability	[%]	99,0
Natural gas price	€/kWh	0,06181
Max. Runtime per year	[h/year]	8672,4
Max. Annual energy produced	[kWh/year]	39025,8
Max. Total energy produced	[kWh]	585387

Costs in the first year (without interests and inflation)[€/KW]	Factor for another system size(SOFC)	Acquisition costs SOFC(without interests and inflation)[€/KW]
6766,663765	4,44	3733,333333

Other assumptions for arriving at this natural gas price	
Average price of the last 5 y	Martin
0,06669	0,07595

Amortisation spreadsheet in Excel

Dynamic amortization period

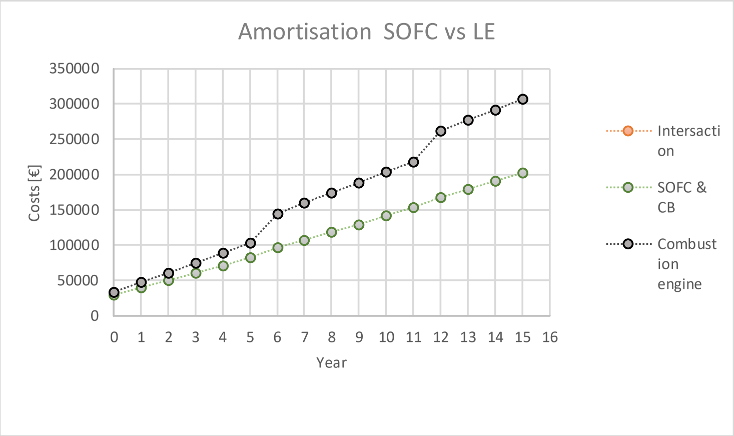
Accrual interest [%]	1,20	Accrual factor	1,01
Infaltion [%]	0,00		

Observation period, in a	T	15

SOFC vs. LE	Unit	SOFC_GH	LE_GH
CAPEX	€	38825,14	33500,00
Average of OPEX	€	11492,88	18255,02

Amortisation period	0,00

Expenses until amortization point	
	0



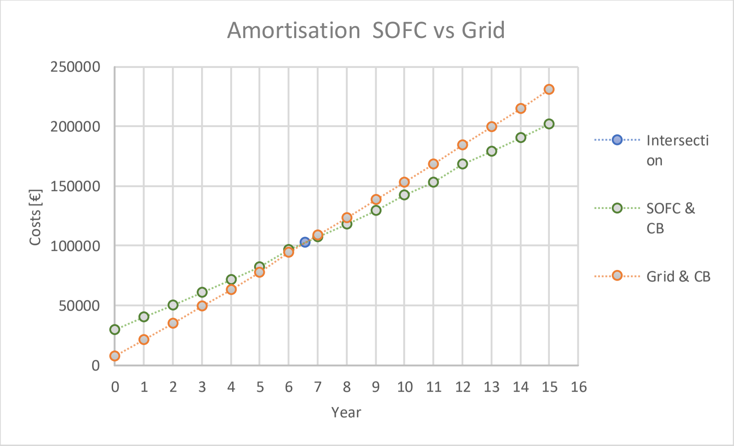
	Net Present Value
SOFC	260199,68
Ref_Sys	385650,91
Grid	309235,02

SOFC vs Ref_Sys	125451,23

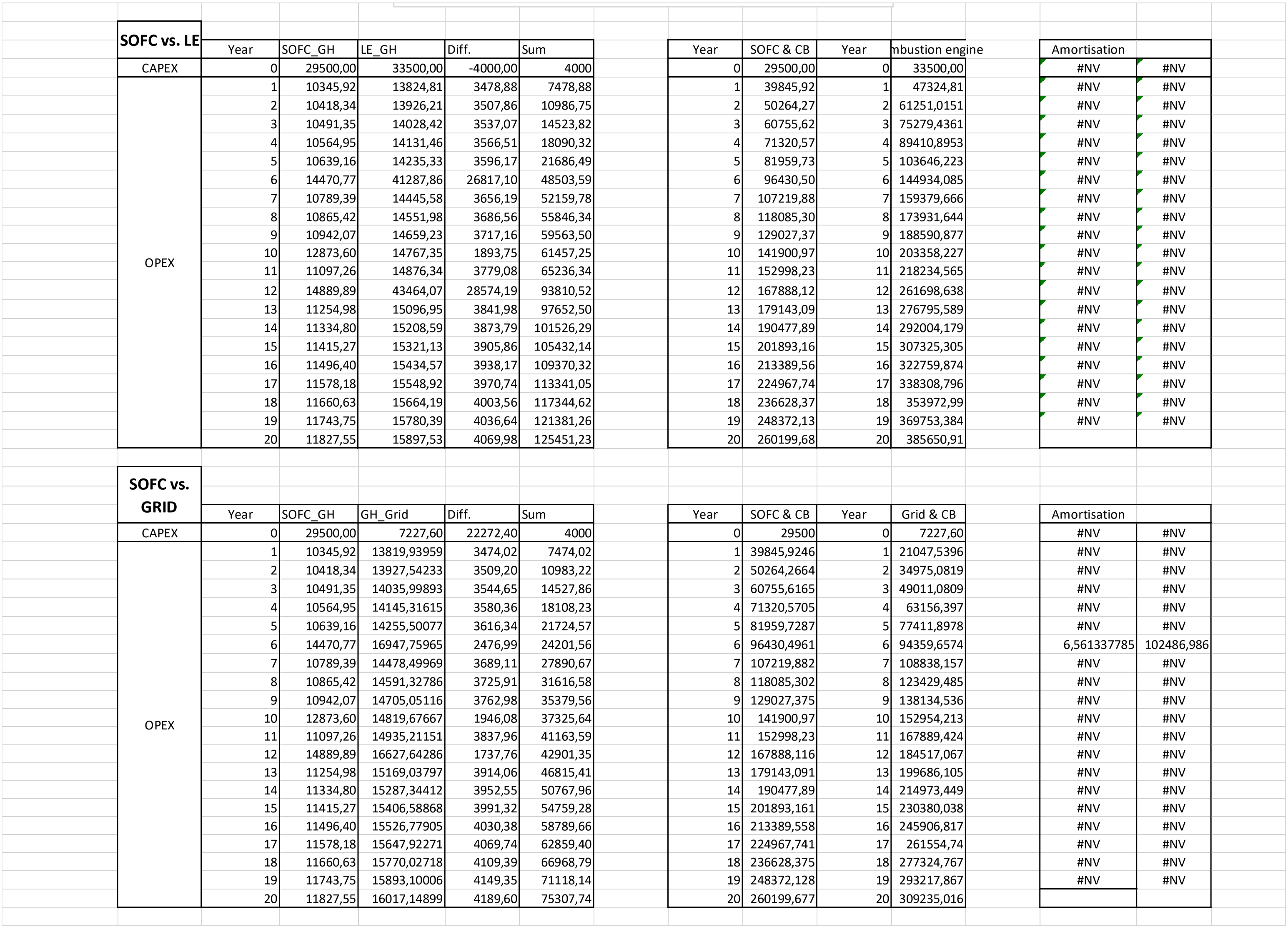
SOFC vs. GRID	Unit	SOFC_GH	GH_Grid
CAPEX	€	29500,00	7227,60
Average of OPEX	€	11492,88	14876,83

Amortisation period	6,56

Expenses until amortization point	
	102486,986



Calculation oft he payback period in Excel



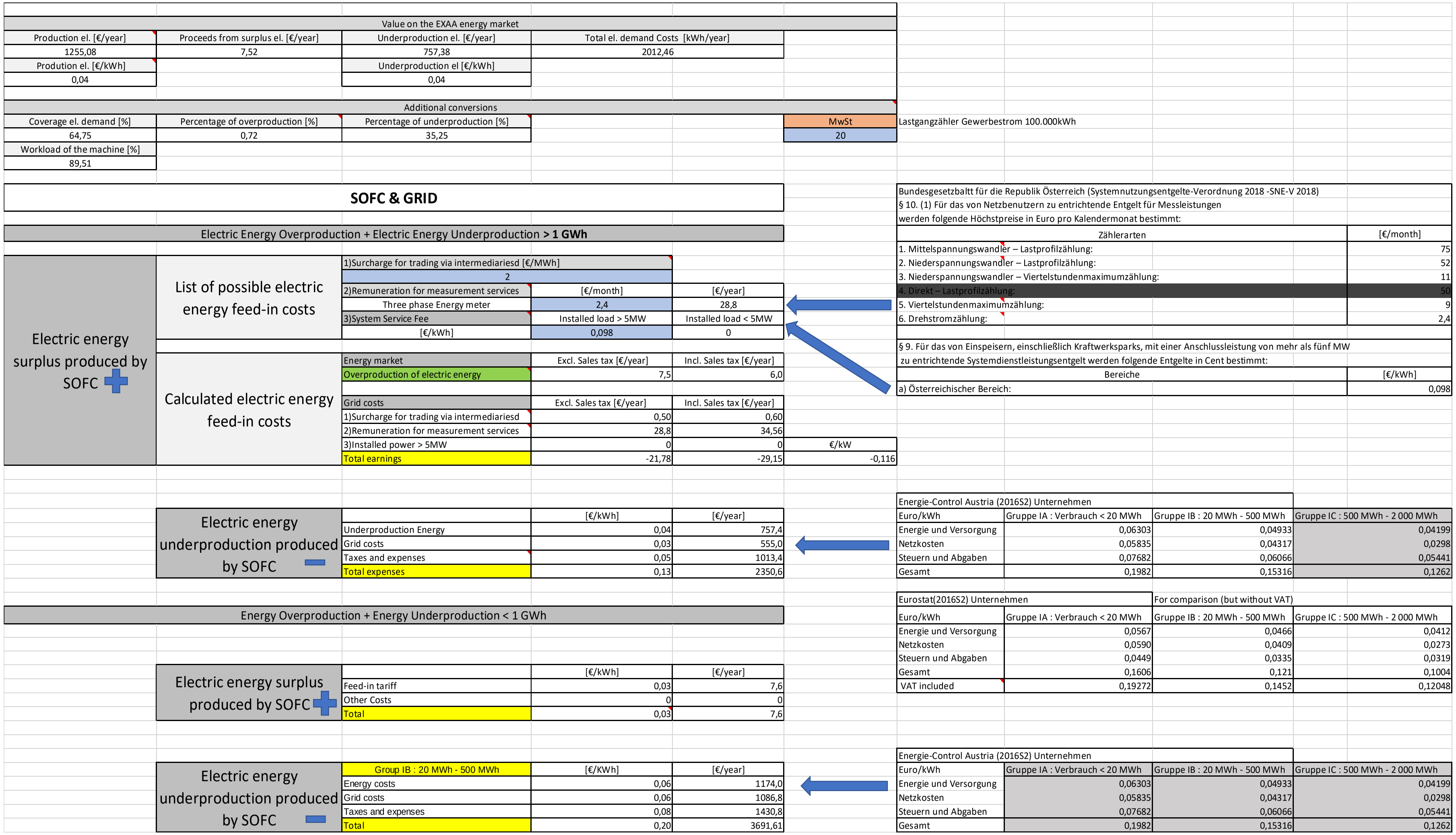
SOFC vs. LE	Year	SOFC_GH	LE_GH	Diff.	Sum	Year	SOFC & CB	Year	mbustion engine	Amortisation	
CAPEX	0	29500,00	33500,00	-4000,00	4000	0	29500,00	0	33500,00	#NV	#NV
OPEX	1	10345,92	13824,81	3478,88	7478,88	1	39845,92	1	47324,81	#NV	#NV
	2	10418,34	13926,21	3507,86	10986,75	2	50264,27	2	61251,0151	#NV	#NV
	3	10491,35	14028,42	3537,07	14523,82	3	60755,62	3	75279,4361	#NV	#NV
	4	10564,95	14131,46	3566,51	18090,32	4	71320,57	4	89410,8953	#NV	#NV
	5	10639,16	14235,33	3596,17	21686,49	5	81959,73	5	103646,223	#NV	#NV
	6	14470,77	41287,86	26817,10	48503,59	6	96430,50	6	144934,085	#NV	#NV
	7	10789,39	14445,58	3656,19	52159,78	7	107219,88	7	159379,666	#NV	#NV
	8	10865,42	14551,98	3686,56	55846,34	8	118085,30	8	173931,644	#NV	#NV
	9	10942,07	14659,23	3717,16	59563,50	9	129027,37	9	188590,877	#NV	#NV
	10	12873,60	14767,35	1893,75	61457,25	10	141900,97	10	203358,227	#NV	#NV
	11	11097,26	14876,34	3779,08	65236,34	11	152998,23	11	218234,565	#NV	#NV
	12	14889,89	43464,07	28574,19	93810,52	12	167888,12	12	261698,638	#NV	#NV
	13	11254,98	15096,95	3841,98	97652,50	13	179143,09	13	276795,589	#NV	#NV
	14	11334,80	15208,59	3873,79	101526,29	14	190477,89	14	292004,179	#NV	#NV
	15	11415,27	15321,13	3905,86	105432,14	15	201893,16	15	307325,305	#NV	#NV
	16	11496,40	15434,57	3938,17	109370,32	16	213389,56	16	322759,874	#NV	#NV
	17	11578,18	15548,92	3970,74	113341,05	17	224967,74	17	338308,796	#NV	#NV
	18	11660,63	15664,19	4003,56	117344,62	18	236628,37	18	353972,99	#NV	#NV
	19	11743,75	15780,39	4036,64	121381,26	19	248372,13	19	369753,384	#NV	#NV
	20	11827,55	15897,53	4069,98	125451,23	20	260199,68	20	385650,91		

SOFC vs. GRID	Year	SOFC_GH	GH_Grid	Diff.	Sum	Year	SOFC & CB	Year	Grid & CB	Amortisation	
CAPEX	0	29500,00	7227,60	22272,40	4000	0	29500	0	7227,60	#NV	#NV
OPEX	1	10345,92	13819,93959	3474,02	7474,02	1	39845,9246	1	21047,5396	#NV	#NV
	2	10418,34	13927,54233	3509,20	10983,22	2	50264,2664	2	34975,0819	#NV	#NV
	3	10491,35	14035,99893	3544,65	14527,86	3	60755,6165	3	49011,0809	#NV	#NV
	4	10564,95	14145,31615	3580,36	18108,23	4	71320,5705	4	63156,397	#NV	#NV
	5	10639,16	14255,50077	3616,34	21724,57	5	81959,7287	5	77411,8978	#NV	#NV
	6	14470,77	16947,75965	2476,99	24201,56	6	96430,4961	6	94359,6574	6,561337785	102486,986
	7	10789,39	14478,49969	3689,11	27890,67	7	107219,882	7	108838,157	#NV	#NV
	8	10865,42	14591,32786	3725,91	31616,58	8	118085,302	8	123429,485	#NV	#NV
	9	10942,07	14705,05116	3762,98	35379,56	9	129027,375	9	138134,536	#NV	#NV
	10	12873,60	14819,67667	1946,08	37325,64	10	141900,97	10	152954,213	#NV	#NV
	11	11097,26	14935,21151	3837,96	41163,59	11	152998,23	11	167889,424	#NV	#NV
	12	14889,89	16627,64286	1737,76	42901,35	12	167888,116	12	184517,067	#NV	#NV
	13	11254,98	15169,03797	3914,06	46815,41	13	179143,091	13	199686,105	#NV	#NV
	14	11334,80	15287,34412	3952,55	50767,96	14	190477,89	14	214973,449	#NV	#NV
	15	11415,27	15406,58868	3991,32	54759,28	15	201893,161	15	230380,038	#NV	#NV
	16	11496,40	15526,77905	4030,38	58789,66	16	213389,558	16	245906,817	#NV	#NV
	17	11578,18	15647,92271	4069,74	62859,40	17	224967,741	17	261554,74	#NV	#NV
	18	11660,63	15770,02718	4109,39	66968,79	18	236628,375	18	277324,767	#NV	#NV
	19	11743,75	15893,10006	4149,35	71118,14	19	248372,128	19	293217,867	#NV	#NV
	20	11827,55	16017,14899	4189,60	75307,74	20	260199,677	20	309235,016		

Calculation the total dicounted cashfows of each year

SOFC		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand-(consumption-)related costs																					
Av1(€)	3905,7	3936,5	3967,7	3999,0	4030,6	4062,5	4094,6158	4126,984304	4159,60869	4192,49097	4225,63319	4259,037404	4292,70568	4326,64012	4360,8428	4395,31587	4430,06145	4465,0817	4500,37879	4535,9549	4571,81226
Opertaion-related costs																					
Ab1(€)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintanance costs																					
Ain 1	950,0	948,1	946,2	944,4	942,5	940,6	938,7777837	936,9224917	935,070866	933,2229	931,378586	929,5379169	927,700885	925,867484	924,037707	922,211545	920,388993	918,570042	916,754686	914,942918	913,134731
Other costs																					
As1(€)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Additional purchase																					
Ac1(€)	3762,4	3792,1	3822,1	3852,3	3882,8	3913,5	3944,405609	3975,586681	4007,01424	4038,69025	4070,61665	4102,795439	4135,2286	4167,91816	4200,86613	4234,07456	4267,5455	4301,28104	4335,28326	4369,55427	4404,09621
Ah1(€)	1664,9	1678,0	1691,3	1704,7	1718,1	1731,7	1745,417849	1759,215618	1773,12246	1787,13924	1801,26682	1815,506086	1829,85791	1844,32319	1858,90282	1873,59771	1888,40876	1903,33689	1918,38303	1933,54811	1948,83308
Proceeds																					
E1(€)	8,82	8,89	8,96	9,03	9,11	9,18	9,249644682	9,322764403	9,39646215	9,47074248	9,54561001	9,621069376	9,69712526	9,77378238	9,85104548	9,92891936	10,0074088	10,0865188	10,1662541	10,2466198	10,3276207
Replacements	0	0	0	0	0	0	3756,8	0	0	0	1854,25	0	3714,09	0	0	0	0	0	0	0	0
Sum of OPEX each year (SOFC)		10345,9	10418,3	10491,4	10565,0	10639,2	14470,8	10789,4	10865,4	10942,1	12873,6	11097,3	14889,9	11255,0	11334,8	11415,3	11496,4	11578,2	11660,6	11743,8	11827,5
Summe (first year)																					

Calculation of expenses and revenues due to electric energy



Value on the EXAA energy market

Production el. [€/year]	Proceeds from surplus el. [€/year]	Underproduction el. [€/year]	Total el. demand Costs [kWh/year]
1255,08	7,52	757,38	2012,46
Prodution el. [€/kWh]		Underproduction el [€/kWh]	
0,04		0,04	

Additional conversions

Coverage el. demand [%]	Percentage of overproduction [%]	Percentage of underproduction [%]	MwSt
64,75	0,72	35,25	20
Workload of the machine [%]			
89,51			

Lastgangzähler Gewerbestrom 100.000kWh

SOFC & GRID

Electric Energy Overproduction + Electric Energy Underproduction **> 1 GWh**

Electric energy surplus produced by SOFC ➕

List of possible electric energy feed-in costs

1)Surcharge for trading via intermediariesd [€/MWh]		
2		
2)Remuneration for measurement services	[€/month]	[€/year]
Three phase Energy meter	2,4	28,8
3)System Service Fee	Installed load > 5MW	Installed load < 5MW
[€/kWh]	0,098	0

Calculated electric energy feed-in costs

Energy market	Excl. Sales tax [€/year]	Incl. Sales tax [€/year]	
Overproduction of electric energy	7,5	6,0	
Grid costs	Excl. Sales tax [€/year]	Incl. Sales tax [€/year]	
1)Surcharge for trading via intermediariesd	0,50	0,60	
2)Remuneration for measurement services	28,8	34,56	
3)Installed power > 5MW	0	0	€/kW
Total earnings	-21,78	-29,15	-0,116

Bundesgesetzbaltt für die Republik Österreich (Systemnutzungsentgelte-Verordnung 2018 -SNE-V 2018)
§ 10. (1) Für das von Netzbenutzern zu entrichtende Entgelt für Messleistungen
werden folgende Höchstpreise in Euro pro Kalendermonat bestimmt:

Zählerarten	[€/month]
1. Mittelspannungswandler – Lastprofilzählung:	75
2. Niederspannungswandler – Lastprofilzählung:	52
3. Niederspannungswandler – Viertelstundenmaximumzählung:	11
4. Direkt – Lastprofilzählung:	50
5. Viertelstundenmaximumzählung:	9
6. Drehstromzählung:	2,4

§ 9. Für das von Einspeisern, einschließlich Kraftwerksparks, mit einer Anschlussleistung von mehr als fünf MW
zu entrichtende Systemdienstleistungsentgelt werden folgende Entgelte in Cent bestimmt:

Bereiche	[€/kWh]
a) Österreichischer Bereich:	0,098

Electric energy underproduction produced by SOFC ➖

	[€/kWh]	[€/year]
Underproduction Energy	0,04	757,4
Grid costs	0,03	555,0
Taxes and expenses	0,05	1013,4
Total expenses	0,13	2350,6

Energie-Control Austria (2016S2) Unternehmen

Euro/kWh	Gruppe IA : Verbrauch < 20 MWh	Gruppe IB : 20 MWh - 500 MWh	Gruppe IC : 500 MWh - 2 000 MWh
Energie und Versorgung	0,06303	0,04933	0,04199
Netzkosten	0,05835	0,04317	0,0298
Steuern und Abgaben	0,07682	0,06066	0,05441
Gesamt	0,1982	0,15316	0,1262

Eurostat(2016S2) Unternehmen — For comparison (but without VAT)

Euro/kWh	Gruppe IA : Verbrauch < 20 MWh	Gruppe IB : 20 MWh - 500 MWh	Gruppe IC : 500 MWh - 2 000 MWh
Energie und Versorgung	0,0567	0,0466	0,0412
Netzkosten	0,0590	0,0409	0,0273
Steuern und Abgaben	0,0449	0,0335	0,0319
Gesamt	0,1606	0,121	0,1004
VAT included	0,19272	0,1452	0,12048

Energy Overproduction + Energy Underproduction < 1 GWh

Electric energy surplus produced by SOFC ➕

	[€/kWh]	[€/year]
Feed-in tariff	0,03	7,6
Other Costs	0	0
Total	0,03	7,6

Electric energy underproduction produced by SOFC ➖

Group IB : 20 MWh - 500 MWh	[€/KWh]	[€/year]
Energy costs	0,06	1174,0
Grid costs	0,06	1086,8
Taxes and expenses	0,08	1430,8
Total	0,20	3691,61

Energie-Control Austria (2016S2) Unternehmen

Euro/kWh	Gruppe IA : Verbrauch < 20 MWh	Gruppe IB : 20 MWh - 500 MWh	Gruppe IC : 500 MWh - 2 000 MWh
Energie und Versorgung	0,06303	0,04933	0,04199
Netzkosten	0,05835	0,04317	0,0298
Steuern und Abgaben	0,07682	0,06066	0,05441
Gesamt	0,1982	0,15316	0,1262

Overview of input values in Excel

Observation period, in a	15
Accrual factor	1,01
Inflation factor	1,00

SOFC	Investment	Investment	Maintanance	Effort for operation	Service life	Frequency of replacement	Rate of price increase (without inflation), in %
	€	€/kW	€/a	€/a	a	-	%
Stack	5000	1111,111111	0	0	9,25	1	0
BoP	11800	2622,222222	800,000942	0	15,03	0	-10,0
Additional components	0	0	0	0	15,00	0	-1,0
Installation costs	5000	1111,111111	0	0	15,00	0	-1,0
Building costs	0	0	0	0	15,00	0	1,0
Summe	29500	6555,555556	949,986942	0			

Natural gas price	€/kWh	0,0618
Proceeds (Feed current into the grid)	€/kWh	0,030
Expenses (Purchase of current)	€/kWh	0,198
Additional Heat (gas heater)	€/kWh	0,062

LE	Investment	Investment	Maintanance	Effort for operation	Service life	Frequency of replacement	Rate of price increase (without inflation), in %
	€	€/kW	€/a	€/a	a	-	%
-	0	0	0	0	15,00	0	0,0
LE	25500	4250	800	0	5,55	2	0,0
Additional components	3000	500	0	0	15,00	0	1,0
Installation costs	5000	833,3333333	0	0	15,00	0	1,0
Boiler	0	0	0	0	15,00	0	1,0
Summe	33500	5583,333333	800	0			

	€/kWh
Natural gas price	0,0618
Proceeds (Feed current into the grid)	0,030
Expenses (Purchase of current)	0,198
Additional heat (gas heater)	0,062

Grid	Investment	Investment	Maintanance	Effort for operation	Service life	Frequency of replacement	Rate of price increase (without inflation), in %
	€	€/kW	€/a	€/a	a	-	%
Gas Heater	4227,6	162,6	166,9	0	5,78	2	1,0
Boiler	0	0,0	0,0	0	15,00	0	1,0
Summe	7227,6	278,0	166,9	0			

	€/kWh
Natural gas price	0,062
Proceeds (Feed current into the grid)	-
Expenses (Purchase of current)	0,15

E-Mail-communication with Frau Mag. Esther Steiner

Von: Werner Hader <w.hader@student.tugraz.at>
An: Esther Steiner <Esther.Steiner@e-control.at>
Datum: 29.03.2018 16:42
Betreff: Re: Antwort: WG: Kundenanfrage

Sehr geehrte Frau Mag. Esther Steiner

ich habe bei dem Vergleich nur die Werte von 2016 verwenden können, da
es bei Eurostat keine Auflistung mit (Energie, Netzkosten, Steuern und
Abgaben) für 2017 gegeben hat.
Es gibt nur die Auflistung vom 2 Semester 2016.
1)Eurostat: 'Elektrizitätspreiskomponenten für Nichthaushaltskunde, ab
2007 - jährliche Daten [nrg_pc_205_c]'
2)E-Control: 'MStOeN-2017_PreiseNHH'
Ich schicke ihnen den Screenshot beider Berechnungen. Es kann
natürlich sein, dass sie die MwSt auch bei der Kategorie Steuern und
Abgaben weggelassen haben aber das steht leider nicht dabei.

Mit freundlichen Grüßen
Hader Werner

Von: Esther Steiner <Esther.Steiner@e-control.at>
An: Werner Hader <w.hader@student.tugraz.at>
Datum: 29.03.2018 17:05
Betreff: Re: Antwort: WG: Kundenanfrage

Sehr geehrter Herr Hader,

ich habe mir jetzt die jährlichen und die halbjährlichen Daten angesehen.

Es ist definitiv so, dass die MWSt in der Komponentenaufteilung nicht enthalten ist.

Hier die Gegenüberstellung:

Warum dies so ist, kann ich Ihnen leider nicht sagen.

Mit freundlichen Grüßen

Esther Steiner

Mag. Esther Steiner

Volkswirtschaft / Statistik

E-Mail-communication with Franz Schörg

Von: Franz Schoerg/Volkswirtschaft/Wien/e-control/at
An: werner.hader@outlook.de
Datum: 14.08.2018 14:23
Betreff: Kontaktformular ausgefuellt

Sehr geehrter Herr Hader
Anbei die Jahresreihen der erhobenen Zählpunkte für Strom und Gas.

Number of metering points in 1.000						
End customers category	Households	Other small customers	Medium-sized industry	Large-scale industry	Non-households	Total
2001	3.900,0	1.620,8	2,4	0,2	1.623,4	5.523,4
2002	3.919,2	1.622,8	2,5	0,2	1.625,4	5.544,6
2003	3.931,7	1.628,1	2,5	0,2	1.630,8	5.562,5
2004	3.947,6	1.631,1	2,5	0,2	1.633,8	5.581,4
2005	3.983,2	1.639,6	2,6	0,2	1.642,4	5.625,5
2006	4.024,2	1.645,9	2,7	0,2	1.648,8	5.672,9
2007	4.061,2	1.675,8	1,8	0,2	1.677,7	5.738,9
2008	4.092,5	1.666,8	1,9	0,2	1.668,9	5.761,4
2009	4.121,8	1.669,3	1,9	0,2	1.671,3	5.793,2
2010	4.164,2	1.674,4	1,8	0,2	1.676,4	5.840,6
2011	4.208,5	1.665,8	1,8	0,2	1.667,8	5.876,3
2012	4.266,2	1.659,2	1,9	0,2	1.661,2	5.927,4
2013	4.308,6	1.655,7	1,9	0,2	1.657,8	5.966,4
2014	4.356,1	1.650,1	1,9	0,2	1.652,2	6.008,3
2015	4.368,8	1.667,6	2,0	0,2	1.669,8	6.038,7
2016	4.954,9	1.056,0	34,4	31,3	1.121,6	6.076,6
2017	4.980,5	1.073,0	36,0	32,0	1.141,1	6.121,5

Number of metering points in 1.000						
End customers category	Households	Other small customers	Medium-sized industry	Large-scale industry	Non-households	Total
2001	-	-	-	-	-	-
2002	1.230,2	-	-	-	69,4	1.299,6
2003	1.232,3	-	-	-	69,6	1.302,0
2004	1.253,0	-	-	-	71,2	1.324,2
2005	1.264,3	-	-	-	69,9	1.334,3
2006	1.269,0	-	-	-	71,6	1.340,7
2007	1.277,8	-	-	-	73,1	1.350,9
2008	1.278,4	74,3	0,8	0,2	75,3	1.353,7
2009	1.275,4	75,1	0,8	0,2	76,0	1.351,4
2010	1.274,5	76,3	0,9	0,2	77,4	1.351,9
2011	1.273,3	76,4	0,9	0,2	77,5	1.350,8
2012	1.272,5	76,7	0,9	0,2	77,8	1.350,3
2013	1.272,0	77,3	0,9	0,2	78,4	1.350,4
2014	1.270,9	77,0	0,8	0,2	78,0	1.348,9
2015	1.268,5	76,8	0,8	0,2	77,9	1.346,3
2016	1.269,7	75,7	0,9	0,2	76,8	1.346,5
2017	1.245,1	91,9	8,1	2,6	102,6	1.347,7

Report from memory

DI Hubert Hopf
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The paper mill SAPPI in Gratkorn has several possibilities to cover the heat demand for paper production. According to Utilities Manager DI Hubert Hopf, a liquor boiler is operated at full load. Furthermore, it is possible to use a gas turbine, a coal boiler and a condensing boiler to cover the additional heat demand. These two systems and their maximum electric energy generation are listed below. For instance, the gas turbine has a higher electric efficieny compared to the coal fired boiler but the thermal efficiency is smaller.

- Gas turbine, 45 % electric energy generation
- Coal-fired boiler, 19 % electric energy generation
- Condensing boiler, 10 % electric energy generation

The gas turbine has a rated output of 46 MW. Depending on the electricity price, a combination of the systems is made. But there is also the case, were the electric energy price is very high, and the gas turbine is operated at full load and the additional heat produced covers the heat demand. If this situation occurs, the coal boiler and condensing boiler are not operated. The price difference between coal and gas should also be considered. If the electric energy price is too low, or (in exceptional cases) a negative electricity price occurs, the gas turbine is switched off and the coal boiler and the condensing boiler are operated. The company SAPPI has a contract with the experts at Verbund and does not trade directly through the energy exchange. A timetable must be submitted on the day before until 10 o'clock. This timetable is created based on an already existing forecast. Care is taken to ensure that it is lucrative to operate the gas turbine, in order to produce surplus electricity. The forecast is produced every day by Verbund for the next 3 days and sent to SAPPI. The forecast for the next day is the most accurate. On Friday, the timetable for the next 2 days must be submitted, because the energy exchange must publish the price of electricity for Sunday. Mostly, the gas turbine operates in full load during the early afternoon (peak load) from Monday to Friday. But the fact that many quick load changes will result in higher maintenance costs has to be considered as well.

Report from memory

DI Ferdinand Gassner

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Direct trading on the spot market EXAA or EPEX involves high fees. In addition, it is also associated with an additional effort to be able to estimate the approximate course of electricity prices for the next few days. Electricity providers like Verbund have this confidence and are already trading on a power exchange. For many electricity producers, this makes it possible to gain access to the electricity exchange through a contractual partner such as Verbund. From a trading volume of 500 GWh, direct trading via the power exchange is considered. Verbund trades on the spot market EPEX Spot, which belongs to the EEX Group. As already mentioned in Chapter 3.4.4, in October 2018 the common electricity market between Austria and Germany will be regulated. As it cannot be estimated how this will affect the electricity market and whether the electricity providers will continue to trade on the EEX electricity exchange, it will be focused on the values of 2012 of the Austrian electricity exchange EXAA for the calculation of electricity prices as a reference. For the sale of electric energy from a non-renewable energy source, no data is published, unfortunately. According to Verbund, it is difficult to find an electricity supplier that will take away this electricity from a non-renewable source of energy. For this, an intensive research would have to be done, to find out if it is even possible. For the sale of electricity, an Excel-spreadsheet contains a table where the revenue per kWh can be entered