MSc Program
Renewable Energy in Central and Eastern Europe

TU WIEN CONTINUING EDUCATION CENTER

Evaluation of regional promotion strategies for Virtual Power Plants using 100% renewables

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Master Thesis
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Renewable Energy in Central & Eastern Europe

Affidavit

I, **Christian Anwander**, hereby declare

1. that I am the sole author of the present Master Thesis, *Evaluation of regional promotion strategies for Virtual Power Plants using 100% renewables*, 102 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Date Signature

Abstract

The goal of this Master Thesis is to simulate the possibility of fulfilling the electricity supply of the community Ellzee out of their own local resources by using a Virtual Power Plant and combining existing generation capacities with new storage facilities.

The main part of the paper assesses the economic effect for the different power plant owners participating in the Virtual Power Plant. The economic assessment with regards to different promotion strategies will be done on the basis of energyPRO simulations for the Virtual Power Plant in combination with a Vanadium Redox-Flow-battery. The battery will be defined according to the technical requirements for the different promotion strategies especially for participating on the balancing market for offering Tertiary Control Reserve.

The findings show that participation on the balancing market for trading Tertiary Control Reserve for the Virtual Power Plant isn't economic viable so far due to high costs of storage systems and the relatively low revenues on the balancing energy market. Also the necessary cost reductions will be defined for the Redox-Flow battery according to the Net present value calculation over the life time. In addition estimations for the participation on other parts of the balancing market will be given.

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Abbreviations

BiomasseV	Ordinance on the Generation of Electricity from Biomass
BMUB	Ministry of environment, nature conservation and nuclear
CHP	Combined Heat and Power Plant
EEG	Renewable Energy Source Act (Erneuerbare-Energien-Gesetz)
EEWärmeG	Renewable Energies in the Heat Sector Promotion Act
EnEV	Energy Savings Ordinance
EnWG	Energy Act (Energiewirtschaftsgesetz)
FIT	Feed-in-Tariff
kW	Kilowatt
kWh	Kilowatt hour
KWKG	Combined Heat and Power Act
MaPrV	Ordinance on the Management Premium for Electricity from Wind Power Plants and Solar Power Plants
MW	Megawatt
MWh	Megawatt hour
PCR	Primary Control Reserve
SCR	Secondary Control Reserve
TCR	Tertiary Control Reserve
VPP	Virtual Power Plant
PV	Photovoltaic
SDLWindV	Ordinance on System Services by Wind Energy Plants (Systemdienstleistungsverordnung)
SHP	Small Hydro Power Plant
TSO	Transmission System Operator

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1 Introduction

The German national goals for climate protection are the reduction of greenhouse gas by 40% and at the same time to achieve 18% renewables in final energy consumption by 2020. The 2010 announced Energy Concept sets the strategic targets for these goals. It is the first long-term timetable for climate protection and the transformation of the energy supply. After Fukushima the Energy Concept was amended by the decision to gradually phase-out of nuclear power by 2022.

Renewable energies can make a growing contribution to the security of supply, therefore the German Ministry for the Environment, nature conversation and nuclear safety initiated different programs to achieve the above mentioned targets. One of them is to bring renewable electricity production more in line with demand by speeding up grid expansion, improving market and system integration and increasing the use of storage facilities.

Transferring these goals on a regional and community level it is also necessary to work on new methods to assist the transformation of the energy system. Questions of energy supply and their environmental impact become more and more key factors for site decisions not only for companies but also for private individuals. Up to now this field was mostly affected by single arrangements, but there are an increasing number of regional energy concepts.

In 2007 an initiative by the Ministry of environment, nature conservation and nuclear safety was founded to support regional climate and energy concepts to accommodate the growing numbers of regions or municipalities which initiate their own transformation process of the energy system in a regional context. The initiative "100%-EE-Regionen" helps regions to convert their energy supply fully to renewable by financing part of the costs.

1.1 Motivation and objective of this work

The core object of this Master Thesis is to simulate on the basis of a regional energy concept the possibility of fulfilling the electricity supply of the community Ellzee out of their own local resources by using a Virtual Power Plant and combining existing generation capacities with new storage facilities. Additionally the economic effects for the region as well as for the power plant owners will be assessed.

The municipality 'Ellzee' is situated in the southwestern part of Bavaria in the administrative region Swabia in the district of Guenzburg. The municipality is willing to change to 100% renewable and already initiated the development of an energy concept by evaluating the actual demand and supply in the area. In Ellzee already exist several renewable power plants for producing electricity and heat:

- three biogas plants
- one 400 Kilowatt ground mounted photovoltaic installation and several roof top installations
- one run-of-river hydro power plant with 600 kilowatt

There are also plans to install further facilities like a 7.2 megawatt wind farm within the next year and additionally a local heating system in one of the municipalities in this area.

The thesis shall be written in cooperation with the company *Active energy systems GmbH* (ACTENSYS) which is located in the respective area and also is trying to generate a business model out of the master thesis. The availability of the above mentioned data is given by ACTENSYS.

The goal of this Master Thesis is to simulate if the energy supply of the region can be switched to 100% renewable by using a *Virtual Power Plant* (sometimes also known as Combined Power Plant).
In order to achieve the mentioned goal the following core objectives have to be addressed:

- Evaluate if local electricity demand can be provided by the Virtual Power Plant by combining the given renewable generation in the region
- Assess the economic feasibility by evaluating possible and future promotion strategies for the Virtual Power Plant

According to the above mentioned core objectives the following major scientific questions have to be answered:

- Is it possible to combine regional produced electricity to fully meet the regional demand in this area
- What are the technical parameters in terms of storage facilities to achieve a stable energy supply
- What are the economic parameters of the regional Virtual Power Plant in accordance to the actual promotion system

1.2 Methodology and structure of work

The applied method in this Master Thesis can be described in the following steps:

1. Definition of the energy demand and supply for the community Ellzee in 2012
2. Simulation of the energy demand and supply over 2012 within the simulation software EnergyPRO from EMD
3. Assessment of the possibility of fully meet the electricity demand by renewables in the area by combining the generation capacities to a Virtual Power Plant
4. Calculation and evaluation of the storage capacity needed for this purpose
5. Assessment of the economic feasibility of the Virtual Power Plant by
    - analyzing the possible compensation system for the different power plants in 2012 under the Renewable energy legislation (EEG)
    - and compare with the actual and future promotion strategies for Virtual Power Plants
    - assessment of the prerequisites for the different promotion markets

First of all the basic data for the simulation have to be collected. This will be done by using existing contacts of ACTENSYS which is located in the area but mostly by using data from an ongoing project which has the goal to examine an energy concept for the community Ellzee.
Based on these data simulations of the yearly energy demand and supply will be done. For that purpose the program EnergyPRO from EMD will be used.

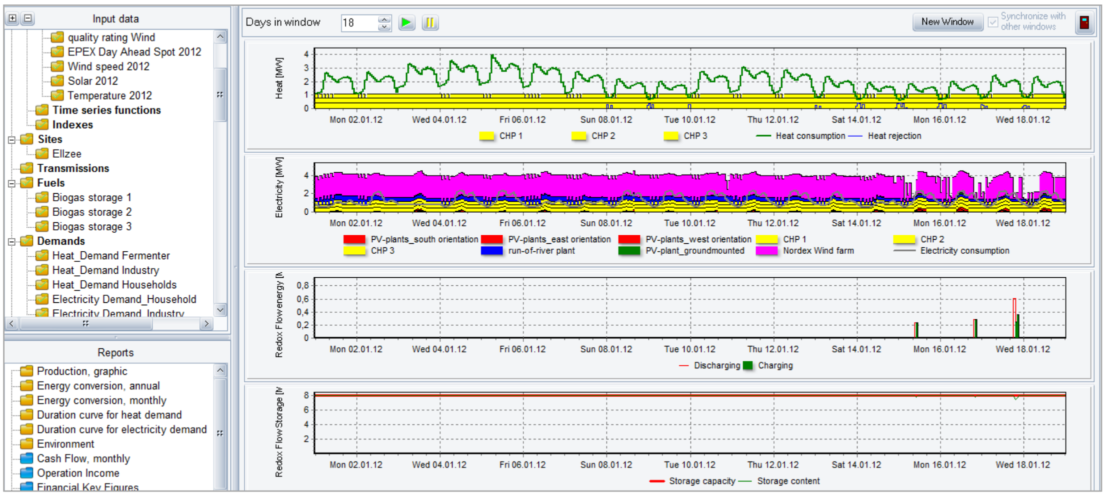

Figure 1: time series simulated in energyPRO (own calculation 2014)

The company EMD is supplying countries worldwide with software and consultancy services within the field of project design, planning and documentation of environmental friendly energy projects, particularly wind energy projects. EMD is well known in the wind energy business due to their world's most comprehensive software package for design and planning of wind farm projects - Wind PRO. 'energyPRO is a Windows-based modeling software package for combined techno-economic analysis and optimization of both cogeneration and trigeneration projects as well as other types of complex energy projects with a combined supply of electricity and thermal energy (steam, hot water or cooling) from multiple different energy producing units'.[1] For this simulation the existing renewable power plants will be combined to a Virtual Power Plant.

[1] (EMD International, 2014)

2 Background

2.1 Promotion possibilities for RE

‘German energy law covers a variety of energy related subjects and legal areas. There is no single codification of German energy law. Instead, German energy law can be found in various statutes, ordinances and other provisions. Many areas of German energy law are heavily influenced by European energy law.’[2]

2.1.1 Feed-in-Tariffs

The main German legal framework regarding the energy market is the German Energy Act from 7th of July 2005 (Gesetz über die Elektrizitäts- und Gasversorgung – Energiewirtschaftsgesetz – EnWG). The main objectives according to §1 EnWG are to ensure a safe, cost-effective, consumer-friendly, efficient and environmentally-friendly power and gas supply served by an increasing share of renewable energy as well as efficient and unrestricted competition and safeguarding of an effective and reliable operation of power grids.

Beside EnWG there are various other statutes and ordinances in the German energy legislation. One of the most known and effective acts for promotion of renewable energy is the “Renewable Energy Sources Act” (Gesetz für den Vorrang Erneuerbarer Energien – Erneuerbare-Energien-Gesetz – EEG 2012). The last amendment was on 1st of April 2012. The purpose of this Act is to facilitate a sustainable development of energy supply. To achieve this purpose the Act aims to increase the share of renewable energy sources in electricity supply up to 80 percent by 2050. In the Energy Source Act the technical and economic parameters for the connection of the different renewable energies are defined and therefore accomplished by different Ordinances. The following list entitles only the ordinances which are important for this work:

- Ordinance on System Services by Wind Energy Plants (Verordnung zu Systemdienstleistungen durch Windenergieanlagen – Systemdienstleistungsverordnung – SDLWindV) to help to secure the network security due to increasing wind capacity in the grid

- Ordinance on the Generation of Electricity from Biomass (Verordnung über die Erzeugung von Strom aus Biomasse – Biomasseverordnung –

[2] (Lang)

BiomasseV) stipulates which substances are recognized as biomass under the tarifff provisions of the Renewable Energy Sources Act

- Ordinance on the Management Premium for Electricity from Wind Power Plants and Solar Power Plants (Verordnung über die Höhe der Managementprämie für Strom aus Windenergie und solarer Strahlungsenergie – Managementprämienverordnung – MaPrV)

Beside the Renewable Energy Source Act further acts are to consider regarding the transformation of the energy system. The following list is subtotal and also entitles only the act from importance to this work:

- Renewable Energies in the Heat Sector Promotion Act (Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich – Erneuerbare-Energien-Wärmegesetz – EEWärmeG),established in 2009 and is aiming to increase the share of renewable on the heat production to 14% in 2020

- Combined Heat and Power Act (Gesetz für die Erhaltung, die Modernisierung und den Ausbau der Kraft-Wärme-Kopplung - Kraft-Wärme-Kopplungsgesetz – KWKG 2002) since 2009 aiming to provide 25% of the gross electricity generation by CHPs by 2020

- Energy Savings Ordinance (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden – Energieeinsparverordnung – EnEV)) since 2009

In the following the regulations[3] for the Feed-In-Tariff for the different renewable energy sources will be explained.

[3] Most references according to (RES-legal)

2.1.1.1 Feed-In-Tariffs for Biomass

For biomass the structure of the feed-in tariff is shown in the following figure:

	tariff for					
	biogas (excl. biowaste fermentation and small manure installations) and solid fuel installations				biowaste fermentation installations [5] (Section 27a)	Small manure installa-tions (Section 27b)
rated average annual capacity	basic tariff	substance tariff class I [2]	substance tariff class II [3]	gas processing bonus (Section 27c(2))		
[kW_{el}]	[ct/kWh]					
≤ 75 [4]						25 [6]
≤ 150	14.3			≤ 700 standard cubic metre (scm)/h: 3		
≤ 500	12.3	6	8		16	
≤ 750	11	5		≤ 1,000 scm/h: 2		
≤ 5,000	11	4	8 / 6 [4]	≤ 1,400 scm/h: 1		
≤ 20,000	6	-		-	14	

2) Over 500 kW and up to 5,000 kW only 2.5 ct/kWh for electricity from bark or forest waste wood.
3) Only for selected, ecologically desirable substances.
4) Over 500 kW and up to 5,000 kW only 6 ct/kWh for electricity from manure (only nos. 3, 9, 11 to 15 of Annex 3 of the Biomass Ordinance (BiomasseV)).
5) Applies exclusively to biogas installations which ferment certain types of biowaste (pursuant to Section 27a (1)) and which are directly connected to a facility for post-rotting the solid fermentation residues. The post-rotted fermentation residues must be recycled. The tariff may only be combined with the gas processing bonus.
6) Special category for biogas installations utilising manure of up to 75 kW installed capacity at the site of the biogas generation plant; may not be combined (i.e. no additional basic tariff, substance tariff or gas processing bonus).

Figure 2: tariff structure for electricity from biomass[4]

- €ct 6 – 14.3 per kWh (according to system size)
- plus (if applicable) bonus of €ct 2.5 – 8 per kWh for use of special substances (§ 27 par. 1, 2 EEG in conjunction with BiomasseV)

Further points to consider are:

- digression rate is 2% (§ 20 par. 2 no. 5 EEG)
- New systems will receive the tariff level applicable on the day they are put into operation

This tariff level will apply for the entire payment period, i.e. for 20 years (§ 20 EEG).

[4] (Bundesministerium für Wirtschaft und Energie)

2.1.1.2 Feed-In-Tarifs for Solar

For Photovoltaic the feed-in tariff has changed dramatically within the last years and month. An overview is shown in the following figure:

Prerequisites:

- Electricity from a ground-mounted system is eligible only if the system was erected within the territorial application of a formal development plan (e.g. a local development plan) and is situated on a transitional area like former military zone or next to highways and railway tracks (distance up to 110m)
- Where a solar energy system is installed on a building, this building shall meet certain statutory requirements (§ 32 par. 1, par. 2 EEG)
- For systems between 10kW and 1000kW (installed on a building) only 90% of the produced energy are eligible for the FIT; the 10% have to be used by the operator itself or have to be sold on the market

Year	Month	Degression	Rooftop mounted				Ground mounted
			up to 10 kW_p	up to 40 kW_p	up to 1 MW_p	up to 10 MW_p	up to 10 MW_p
2012	April	-	19.50	18.50	16.50	13.50	13.50
	May	1.0%	19.31	18.32	16.34	13.37	13.37
	June		19.11	18.13	16.17	13.23	13.23
	July		18.92	17.95	16.01	13.10	13.10
	August		18.73	17.77	15.85	12.97	12.97
	September		18.54	17.59	15.69	12.84	12.84
	October		18.36	17.42	15.53	12.71	12.71
	November	2.5%	17.90	16.98	15.15	12.39	12.39
	December		17.45	16.56	14.77	12.08	12.08
2013	January		17.02	16.14	14.40	11.78	11.78
	February	2.2%	16.64	15.79	14.08	11.52	11.52
	March		16.28	15.44	13.77	11.27	11.27
	April		15.92	15.10	13.47	11.02	11.02
	May	1.8%	15.63	14.83	13.23	10.82	10.82
	June		15.35	14.56	12.99	10.63	10.63
	July		15.07	14.30	12.75	10.44	10.44
Maximum remuneration part[73]			100%	90%	90%	100%	100%

Figure 3: tariff structure for photovoltaic[5]

Tariffs:

- €ct 13.50 – 19,50 per kWh (depending on energy source and system size, minus the respective degression rate of 1% (see below)
- > 10MW there is no FIT

[5] (Wikipdia)

The degression rate is set by law and applies to a statutorily defined additional capacity ("regular degression"). When the total additional capacity installed exceeds or falls below a certain amount, the degression percentage increases or decreases by a statutorily fixed number of percentage points ("flexible cap"). Depending on market developments, this percentage may increase or decrease.[6]

2.1.1.3 Feed-In-Tariff for Wind Energy

For Wind Energy the feed-in tariff is:

Prerequisites:

- Fulfilment of technical requirements. System operators shall make sure that the requirements stipulated in the Ordinance on System Services by Wind Energy Plants are met (§ 6 par. 5 EEG; SDLWindV).

year of commissioning	basic tariff in ct/kWh	initial tariff in ct/kW[9)]	system services bonus[10)]	Repowering bonus [11)]	small-scale wind up to 50 kW in ct/kWh
2012	**4.87**	**8.93**	**0.48**	**0.5**	**8.93**
2013	4.80	8.80	0.47	0.49	8.80
2014	4.72	8.66	0.47	0.49	8.66
2015	4.65	8.53	0.46	0.48	8.53
2016	4.58	8.41	-	0.47	8.41
2017	4.52	8.28	-	0.46	8.28
2018	4.45	8.16	-	0.46	8.16
2019	4.38	8.03	-	0.45	8.03
2020	4.32	7.91	-	0.44	7.91
2021	4.25	7.79	-	0.44	7.79

[9)] The higher initial tariff is paid for five years. This is extended pursuant to Section 29(2) by two months for each 0.75 percent of the reference yield by which the installation yield falls short of 150 percent of the reference yield. See also 6.2 below.
[10)] Pursuant to Section 29(2), the system services bonus for new installations is paid for the same period as the higher initial tariff, provided these installations are commissioned prior to 31 December 2015. The requirements under Section 6(5) EEG must be verifiably met.
[11)] The repowering bonus pursuant to Section 30 for the replacement of existing wind energy installations on the same or on an adjacent site is paid for the same period as the higher initial tariff, provided the replaced installations were commissioned prior to 1 January 2002.
[12)] Pursuant to Section 29(3), the reference yield calculation does not apply to small-scale wind installations of no more than 50 MW. For these installations a reference yield of 60 percent is assumed. This means that they are eligible for the initial tariff for the entire tariff payment period.

Figure 4: tariff structure for wind energy onshore[7]

Tariffs:

- €ct 4.87 – 8.93 per kWh (according to duration of payment) + repowering bonus of €ct 0.5 per kWh and system service bonus of €ct 0.48 per kWh (§ 29 par 1-2; § 30 EEG)

[6] (RES-legal)

[7] (Bundesministerium für Wirtschaft und Energie)

– degression rate of 1.5% for other systems (§ 20 par. 2 no. 7b EEG)

2.1.1.4 Feed-In-Tariff for hydro power

Year of commissioning	up to 500 kW in ct/kWh	up to 2 MW in ct/kWh	up to 5 MW in ct/kWh	up to 10 MW in ct/kWh	up to 20 MW in ct/kWh	up to 50 MW in ct/kWh	over 50 MW in ct/kWh
2012	**12.70**	**8.30**	**6.30**	**5.50**	**5.30**	**4.20**	**3.40**
2013	12.57	8.22	6.24	5.45	5.25	4.16	3.37
2014	12.45	8.13	6.17	5,39	5.19	4.12	3.33
2015	12,32	8.05	6.11	5.34	5.14	4.08	3.30
2016	12.20	7.97	6.05	5.28	5.09	4.03	3.27
2017	12.08	7.89	5.99	5.23	5.04	3.99	3.23
2018	11.96	7.81	5.93	5.18	4.99	3.95	3.20
2019	11.84	7.74	5.87	5.13	4.94	3.91	3.17
2020	11.72	7.66	5.81	5.08	4.89	3.88	3.14
2021	11.60	7.58	5.76	5.02	4.84	3.84	3.11

Installations are only entitled to tariff payments if hdyropower use meets the requirements of Sections 33 to 35 and Section 6(1) sentences 1 nos. 1 and 2 of the Federal Water Act. Existing installations which were commissioned before 1 January 2009 are eligible for the new tariffs if the rated average annual capacity or the installed capacity was increased after 31 December 2011, or the installation was retrofitted for the first time with a remote reduction of the feed-in capacity pursuant to Section 6(1). Entitlement to the tariff payment applies from completion of the measure for the duration of 20 years plus the remaining part of the year in which the measure was completed. Further details are regulated under Section 23(2) EEG. Due to the comprehensive changes in the hydropower sector transitional provisions apply pursuant to Section 66(5) and (14).

Storage power stations can receive tariff payments pursuant to Section 23(6) if these are constructed on existing storage facilities or are extensions to existing storage power stations. This only applies to storage facilities which are fed from natural tributaries. Electricity from pumped-storage plants is not entitled to the tariff payment, except in the case laid down in Section 16(2).

Figure 5: tariff categories for hydro power[8]

Average tariff rates in ct/kWh
for electricity generation from run-of-river power plants
For comparability, year of commissioning 2012 is assumed in each case.

	EEG 2009 Duration of tariff payment • for installations ≤ 5 MW: 20 years plus year of commissioning • for installations> 5 MW: 15 years plus year of commissioning			**EEG 2012** Duration of tariff payment for all installations: • 20 years plus year of commissioning	
Install-ation capacity (full load hours [h/a])	**up to and including 5 MW**		**over 5 MW**	**up to and including 5 MW**	**over 5 MW**
	new build	**modernisation**	**new build, extension**	**new build, modernisation**	**new build, extension**
500 kW (4,500)	12.67	11.67	7.08	12.70	12.70
2 MW (4,800)	10.48	10.03	6.57	10.31	10.31
5 MW (5,000)	9.06	9.18	6.30	8.47	8.47
20 MW (5,500)			6.07		6.27
50 MW (5,500)			5.29		5.29

Figure 6: comparison EEG 2009 and 2012 for hydro power[9]

[8] (Bundesministerium für Wirtschaft und Energie)

2.1.2 Direct power marketing

Renewables must also be able to compete with fossil energy sources with regard to commercial aspects in addition to ecological aspects if the integration in the free power market shall be successful. This attempt was first introduced at 1st of January 2012 with the EEG 2012. Since then power plant operators have the possibility of offering and selling their energy quantities directly on the free power market.

The market premium model intends to motivate generators of renewable power volumes to operate their systems in a market-oriented manner by increasing feeding-in of green power at those times at which the demand and prices on the exchange are particularly high.

Power generators become power traders and market their energy directly via the power exchange on the free energy market. They generate the regular, fluctuating market price for their power. This revenue is usually lower than the feed-in-tariff under EEG. The price difference between the feed-in-tariff and the market price achieved is offset with the help of the market premium. This so-called market premium is a financial bonus for the operators of all systems for the generation of energy from renewable sources that move from the fixed feed-in-tariffs to direct marketing of their power on the power exchange. The law has offered this premium as an incentive in order to cushion risks in direct power marketing. This means the generator achieves at least the same profit for the power generated that it would have generated under the old EEG model. [10]

‘Even though direct marketing of green power entails higher risk due to the price fluctuations on the power exchange, the market premium offsets the trading risk for plant operators. Direct marketing even offers plant operators the opportunity of generating additional revenue. If a generator sells its green power above the monthly average price, the generator still receives the full amount of the market premium. In this way, the power producer can achieve profits that are even higher than those obtainable under the current EEG feed-in remuneration.’[11]

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[9] (Bundesministerium für Wirtschaft und Energie)

[10] (energy2market, 2014)

[11] (energy2market, 2014)

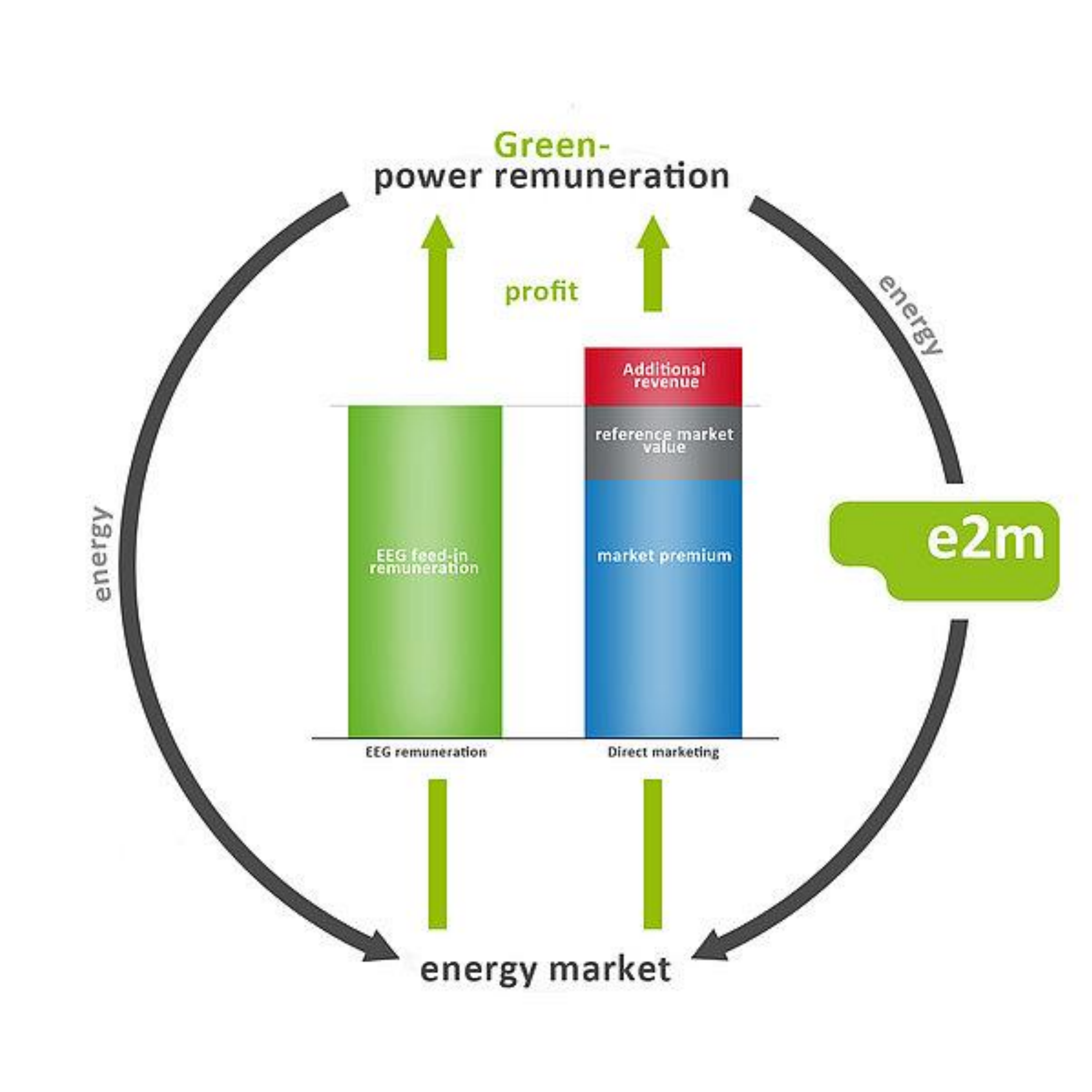

Figure 7: direct power marketing[12]

Since November 2012 the Ordinance for Management premium (MaPrV) was additionally introduced for the fluctuating renewables solar and wind power. The management premium is part of the market premium model and was situated to avoid an increase of promotion costs. It will decrease the premium on a yearly basis and will only be paid if the power plants are operating with remote control.

The above mentioned direct marketing on the basis of the market premium possible constitutes the precursor of the future marketing requirement.

Especially for biogas power plants with a capacity more than 750 kW the direct marketing is mandatory from 2014 onwards. There is than no fixed feed-in-tariff for biomass. Only the management premium is paid for the additional promotion costs,

[12] (energy2market)

in 2012 the premium was 0,3 ct/kWh and will decrease until 2015 to 0,225 ct/kWh. The aim of the direct marketing model is to promote a market oriented production of energy by CHPs to support fluctuating energies like wind and solar to compete with fossil energy sources.

This needed flexibility of CHPs is only achievable by providing additional production capacity (further storage tanks, additional engine). To cover the costs for the additional installations a flexibility premium was introduced.

The following figure shows the success of the direct marketing since the introduction in 2012, the biggest share in the direct marketing is covered by wind onshore.

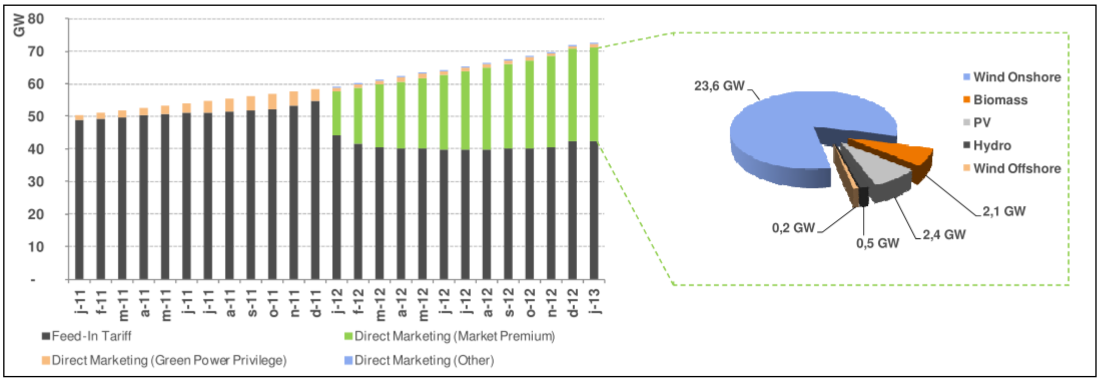

Figure 8: market development Direct Marketing[13]

13 (energy2market)

2.1.3 Balancing Energy Market

A further promotion possibility is to provide balancing energy to the energy balancing market. The German power grid is naturally subject to fluctuations. In Germany there are 7.000 MW of positive balancing power for supply bottlenecks and 5.500 MW of negative balancing power for over productions on standby[14].

In order to ensure the reliable and failsafe operation of the power grid, a balance has to be established between the energy fed in and the consumption of energy.

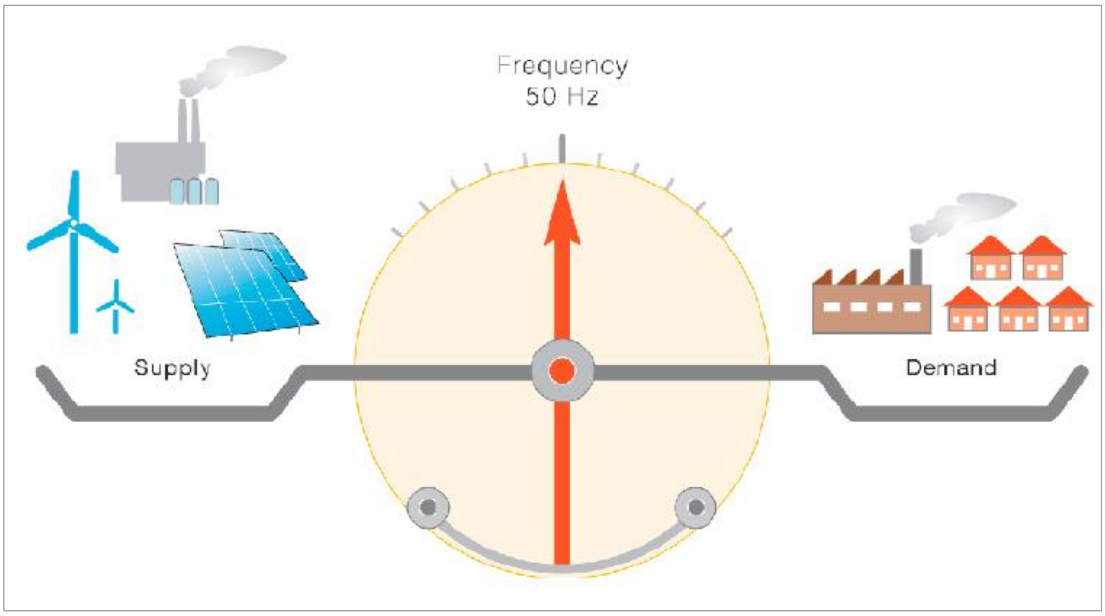

Figure 9: balancing power[15]

In order to keep the frequency constant there are three levels of balancing:

- Primary control reserve (PCR)
- Secondary control reserve (SCR)
- Minute reserve / Tertiary control reserve (TCR)

'Short imbalances in power frequency are compensated by primary balancing. If the imbalance continues, primary balancing is replaced by the secondary reserve. Both stages of balancing are activated fully automatically and can only be provided by power plants with particularly short response times. If the fluctuations in the power

[14] (Statkraft)

[15] (Focus)

frequency last longer than 15 minutes which is catered for by secondary balancing, the next balancing stage, the minute reserve, cuts in.'[16] This stage is switched on manually on request of the transmission system operator. The minute reserve is to differentiate in positive and negative reserve. Positive reserve is needed when the electricity production exceeds the consumption and the negative reserve if more electricity energy is fed in the grid than used.

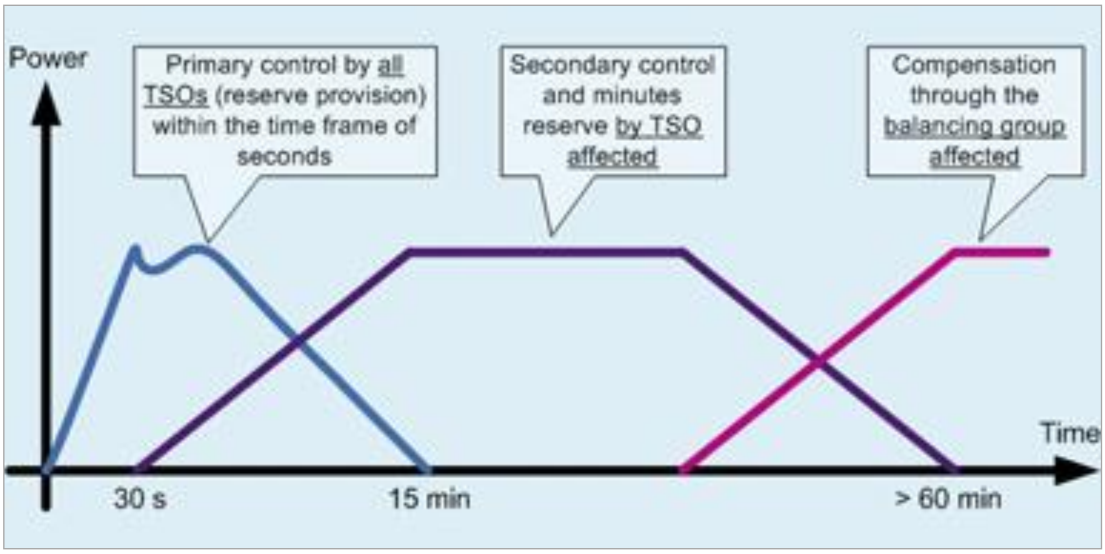

Figure 10: sequence of activation[17]

Control reserve is tendered on the internet platform www.regelleistung.net which is commonly operated by the four German TSOs. Power plant operators can participate on this market under certain circumstances. The tendering process for the control reserve differs in some points, the auction for the minute reserve are procured on a daily basis and for the primary and secondary reserve on a weekly basis. SCR and TCR tender positive and negative products separately.

The acceptance of the bid follows the principal of the merit-order of the electricity power prices. The energy price is only relevant if the power prices are the same. The accepted bids achieve their payment according the offered power prices (pay-as-bid).

[16] (energy2market)

[17] (Amprion)

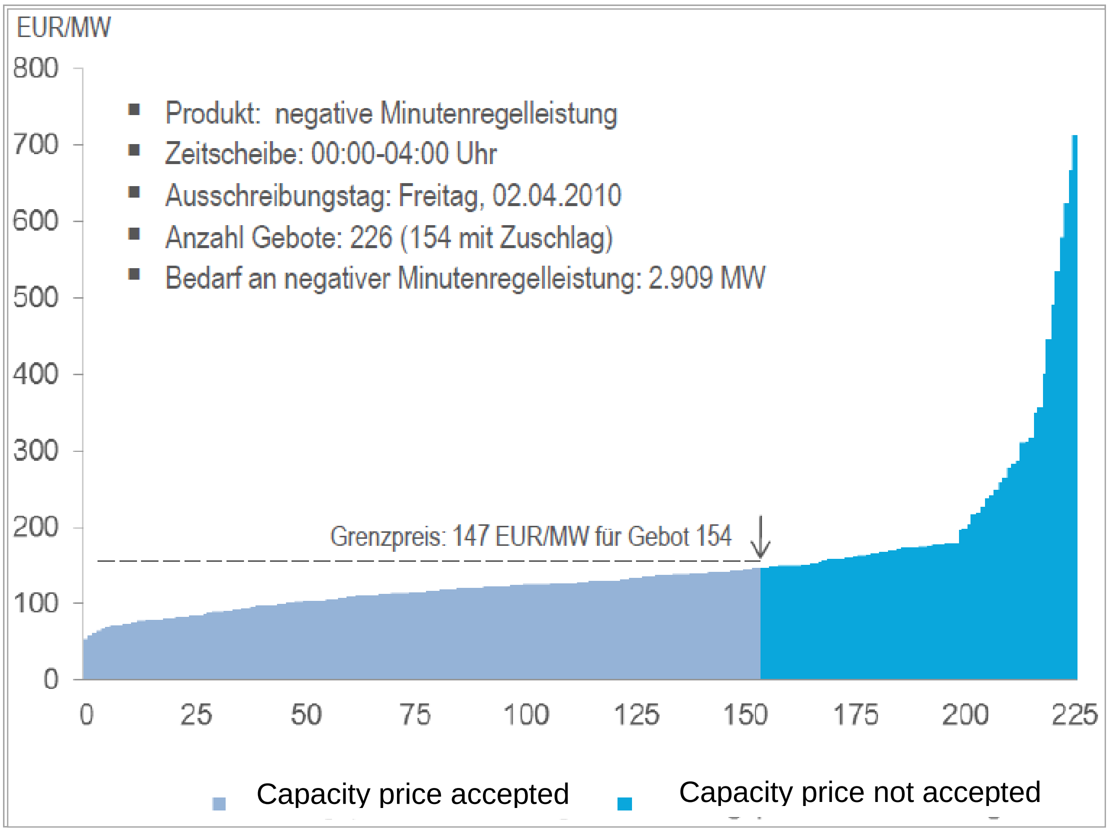

Figure 11: tender for tertiary reserve[18]

Successful offers have to be able to guarantee a provision over a certain time; primary reserve for a week, secondary reserve is divided into two time-slices (peak and off-peak) and minute reserve even into 6 times 4 hours slices. The minimum bid for primary reserve is 1 megawatt, for secondary and tertiary reserve 5 megawatt. The bid of each supplier for SCR and TCR has to specify a power price bid for provided reserves (paying the provision) as well as an energy price bid for deployed reserves (paying a possible activation). In the case of activation both are paid, for Primary reserve only the provision is paid. The bidders are selected then in accordance with the merit order of capacity prices. Figure 13 shows the main product characteristics of the control reserve.

[18] (Clean Energy Sourcing, 2013)

	PCR	SCR	TCR
tender period	weekly	weekly	daily
tender time	as a rule on Tuesdays (W-1)	as a rule on Wednesdays (W-1)	as a rule Mo-Fri, 10 a.m.
product time-slice	none (total week)	peak: Mo-Fri, 8 a.m. to 8 p.m., without public holiday off-peak: residual period	6 x 4 blocks of hour
product differentiation	none (symmetric product)	positive / negative SCRL	positive / negative TCR
minimum bid amount	1 MW	5 MW	5 MW (submission of bid for a block of max. 25 MW possible)
increment of bid	1 MW	1 MW	1 MW
call for tender	capacity price merit-order	energy price merit-order	energy price merit-order
remuneration	pay-as-bid (capacity price)	pay-as-bid (capacity price and energy price)	pay-as-bid (capacity price and energy price)

Figure 12: overview tendering process[19]

In 2012 were tendered in average 2.130 megawatt of negative and 2.091 megawatt of positive secondary reserve per week, for Peak and off-peak times in equal measure. For the minute or tertiary reserve a daily amount of around 2.000 megawatt positive and 2.400 Megawatt negative powers is traded.[20]

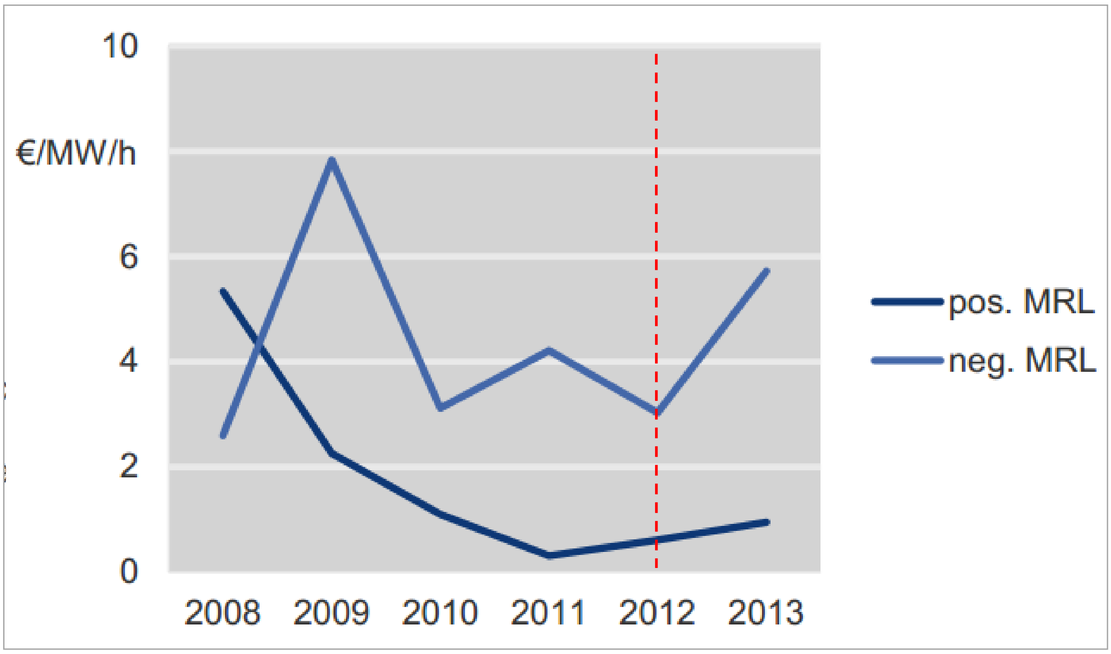

Figure 13: development of the power price for Tertiary/Minute Control Reserve[21]

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[19] (Consentec GmbH, 2014 S. 21)

[20] (Balance Power GmbH, 2012)

[21] (Consentec GmbH, 2014 S. 25)

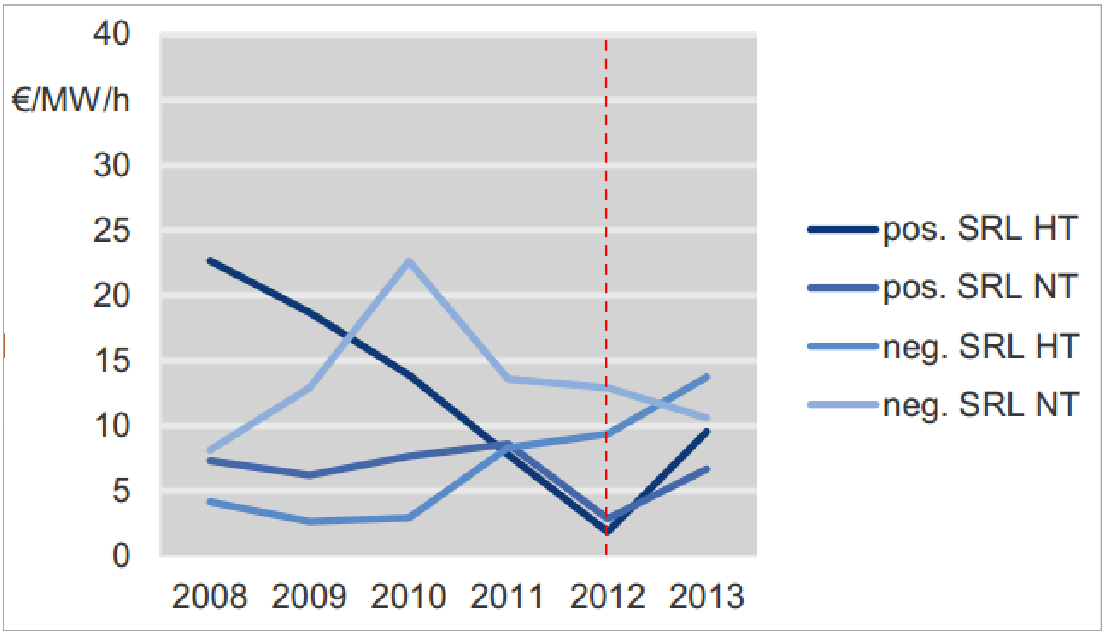

Figure 14: development of the power price for Secondary Control Reserve[22]

According to the study 'Regelleistungskonzepte/-markt'[23] the power prices for secondary and tertiary control reserve are highly fluctuating but also have a tendency to decrease. The latter can be explained mainly with the increasing intensity of competitive rivalry and decreasing spot prices. What also can be seen from the assessment before is that negative balancing power is compensated higher than positive power.

Corresponding to the above shown graphs the following figure presents the different values for the 4 hour time slice for negative and positive tertiary control reserve.

[22] (Consentec GmbH, 2014 S. 25)

[23] (Consentec GmbH, 2014 S. 25-26)

Zeitscheibe	2010	2011	2012
0 - 4 Uhr	12.179	13.860	8.417
4 - 8 Uhr	12.007	13.948	8.518
8 - 12 Uhr	790	1.787	2.333
12 - 16 Uhr	823	2.159	2.525
16 - 20 Uhr	779	2.140	2.360
20 - 24 Uhr	1.267	3.698	2.230
Summe	27.845	37.592	26.384

Figure 15: sum of mean power prices of negative TCR (€/MW)[24]

Zeitscheibe	2010	2011	2012
0 - 4 Uhr	182	118	122
4 - 8 Uhr	766	390	506
8 - 12 Uhr	3.340	631	1.156
12 - 16 Uhr	2.046	562	995
16 - 20 Uhr	2.510	518	1.845
20 - 24 Uhr	919	411	757
Summe	9.763	2.631	5.381

Figure 16: sum of mean power prices of positive TCR (€/MW)[25]

The numbers show for the negative TCR the highest profit potential especially for the two time slices from 00 a.m. to 08 .a.m. in the morning.

Additionally to the discussed power price, profit can be realized by the energy price if the offered energy is called up by the energy provider. The following graphs shows the period (hours in 2012), the occurrence of call ups and the profit per megawatt (MW) in dependency of the offered energy prices for tertiary control reserve in 2012 (positive and negative).

[24] (Clean Energy Sourcing, 2013)

[25] (Clean Energy Sourcing, 2013)

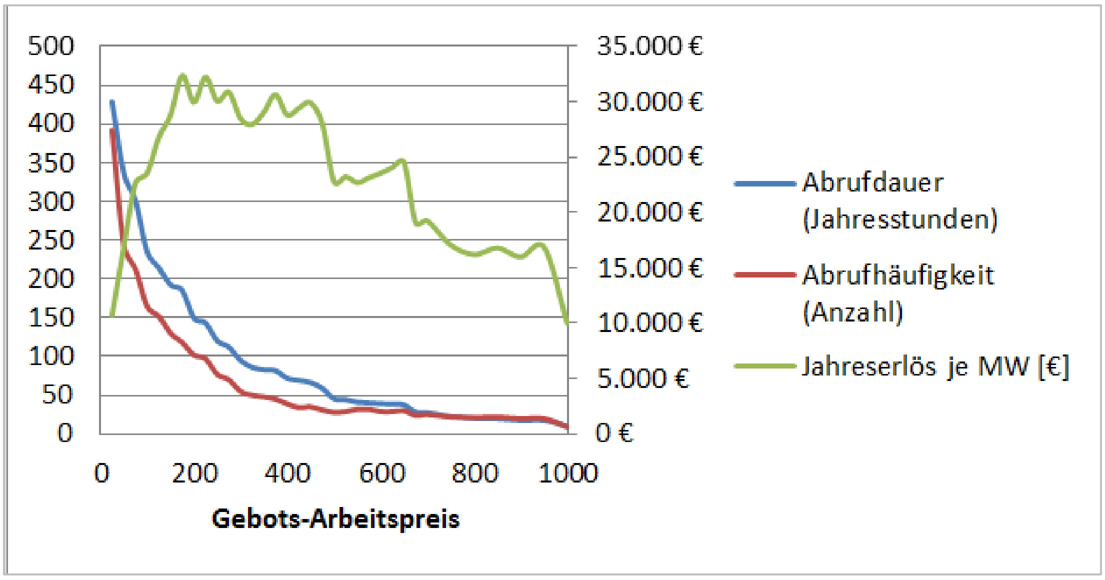

Figure 17: mean values for negative TCR energy prices (data from EMD)

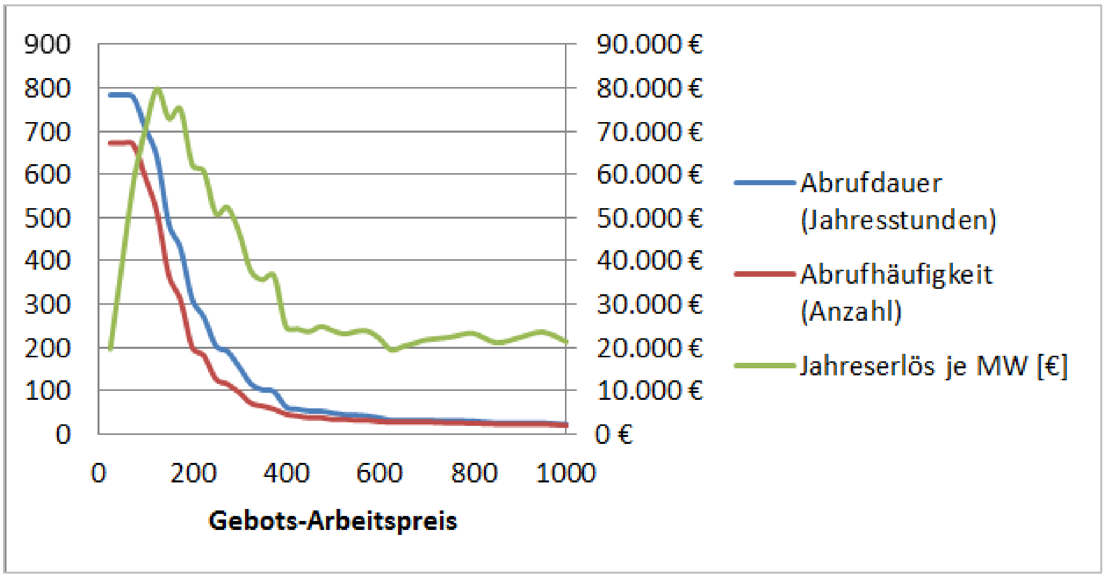

Figure 18: mean values for positive TCR energy prices (data from EMD)

Noticeable is the higher profit for positive TCR which is contrary to the analysis of the power prices. But also for both negative and positive TCR that lower offered energy prices are called up more frequent and longer than higher prices. Both can be explained by the merit-order effect.

Figure 19 and Figure 20 gives corresponding to Figure 14 an overview about the sum values for the SCR.

Zeitscheibe	2010	2011	2012
HT	42.308	23.094	5.360
NT	42.566	47.810	16.394
Summe	84.874	70.904	21.754

Figure 19: sum of mean power prices of positive SCR (€/MW)[26]

Zeitscheibe	2010	2011	2012
HT	9.063	23.850	23.821
NT	127.545	71.871	68.897
Summe	136.608	95.721	92.718

Figure 20: sum of mean power prices of negative SCR (€/MW)[27]

Individual power plants operators especially of fluctuating renewables like wind and solar usually lack the mentioned necessary prerequisites in Figure 12. This is the reason why only fossil power plants were able to participate on the balancing market in former times. To market the renewable energy as balancing energy the generation facilities can be pooled within a Virtual Power Plant to fulfill the preconditions.

Depending on the structure of the Virtual Power Plant they can provide only the minute reserve or even all reserves from minute to primary. In the meantime most of the providers working with renewable energies deliver minute and secondary reserve power. For example on of the first companies who was handling all three power reserves was Energy2Market, as can be seen in the following figure. For 2014 there are 14 companies prequalified for delivering primary reserve, 20 for the secondary reserve and 36 for minute reserve[28] (full list see annex 4).

[26] (Clean Energy Sourcing, 2013)

[27] (Clean Energy Sourcing, 2013)

[28] (Consentec GmbH, 2014)

Präqualifizierte Anbieter je Regelenergieart

Anbieter	PRL	SRL	MRL
Alpiq AG	●		
ArcelorMittal Eisenhüttenstadt GmbH			●
Axpo AG	●		
Axpo Deutschland GmbH		●	●
Axpo Trading AG	●		
BalancePower GmbH			●
BKW FMB Energie AG	●		
BS Energy Braunschweiger Versorgungs-AG & Co.KG			●
Centralschweizerische Kraftwerke AG	●		
citiworks AG			●
Clean Energy Sourcing GmbH		●	●
CURRENTA GmbH & Co. OHG			●
DELTA Energy B.V.	●		
E.ON Global Commodities SE	●	●	●
EnBW Erneuerbare und Konventionelle Erzeugung AG	●	●	●
Energieservice Westfalen Weser GmbH		●	●
Energieversorgung Schwerin GmbH & Co. Erzeugung KG		●	
Energy2market GmbH	●	●	●

Figure 21: abstract of the prequalified providers of balancing power[29]

Due to the even more strict preconditions of the primary reserve only the two stages secondary and minute reserve will be assessed further within this thesis.

29 (Regelleistung.net, 2014)

2.2 Energy storage technologies

There are different kinds of storage facilities on the market available. To get an overview some of the different technologies will be explained shortly in the following. The storage technologies are roughly distinguished between short- and long-term facilities where short term means less than 24 hours storage possibility and long-term longer than 24 hours.

Long-term storage

– **Pumped storage hydropower (PSH)**

Typical systems employ off-peak electricity to pump water from a lower-elevation reservoir to a higher-elevation reservoir, and then release water from the upper reservoir when electricity is needed. As this happens, the water flows through a turbine that generates electricity.[30] In general, pumped hydro systems can start operation and reach full power in a few minutes. They can be used as a capacity reserve, as well as for grid frequency, voltage stabilization and even provide reactive power to the grid. The efficiency of the pumped hydro systems is between 70% and 80%.[31]

In Germany there are 30 Pumped Hydro Power Plants with a capacity of 6,3 GW and 40GWh storage capacity installed. According to different prognosis the capacity can be increased to 10,6 GW (64GWh) by 2025 and 14,6 GW (87GWh) by 2040

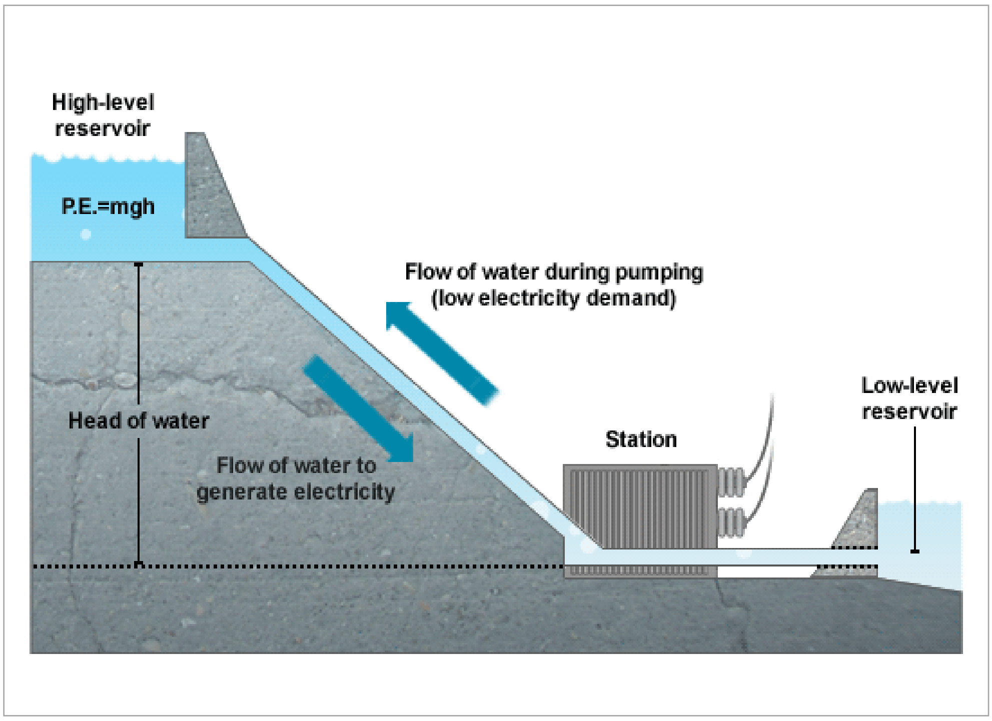

Figure 22: Pumped Storage Hydropower[32]

[30] (Eesi, 2013)

[31] (IRENA, 2012)

[32] (BBC)

- **Compressed Air Energy Storage (CAES)**

  Electricity is used to compress air with 40-120 bars which is than stored underground in caverns. For the energy recovery compressed air is directed through a turbine to generate electricity.

  There are only two systems operating so far, in Alabama and Germany. The efficiency is indicated with 50 – 70%. Designs for second-generation systems are currently underway, with plans for lower costs, higher efficiencies and faster construction times. One such project, known as the Bethel Energy Center, is being developed in Tennessee Colony, Texas, and is expected to reach 317 MW[33].

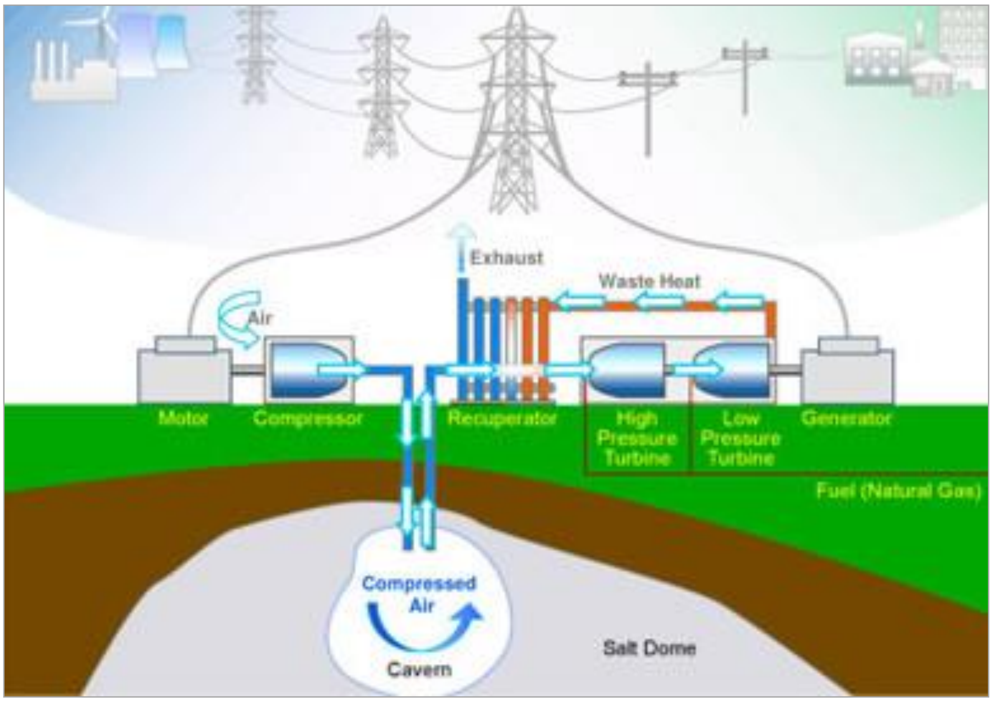

Figure 23: Compressed Air Energy Storage[34]

[33] (Eesi, 2013)

[34] (Storeelectric)

- **Power-to-Gas (PtG)**

  The Power-to-Gas technology uses hydrogen as an energy carrier to store electricity through electrolysis. The energy carrier hydrogen can than directly or after further processing to SNG (substitute natural gas) be stored into the gas grid or stored stationary.

  Up to now the efficiency of the complete process chain including electrolysis and methanation is between 30-40%[35].

  These storage technologies have significant potential due to their high energy density, quick response times, and potential for use in large-scale energy storage applications. In case of the methanation and the use of the existing gas grid the capacity will reach around 200TWh which would be sufficient for several months.

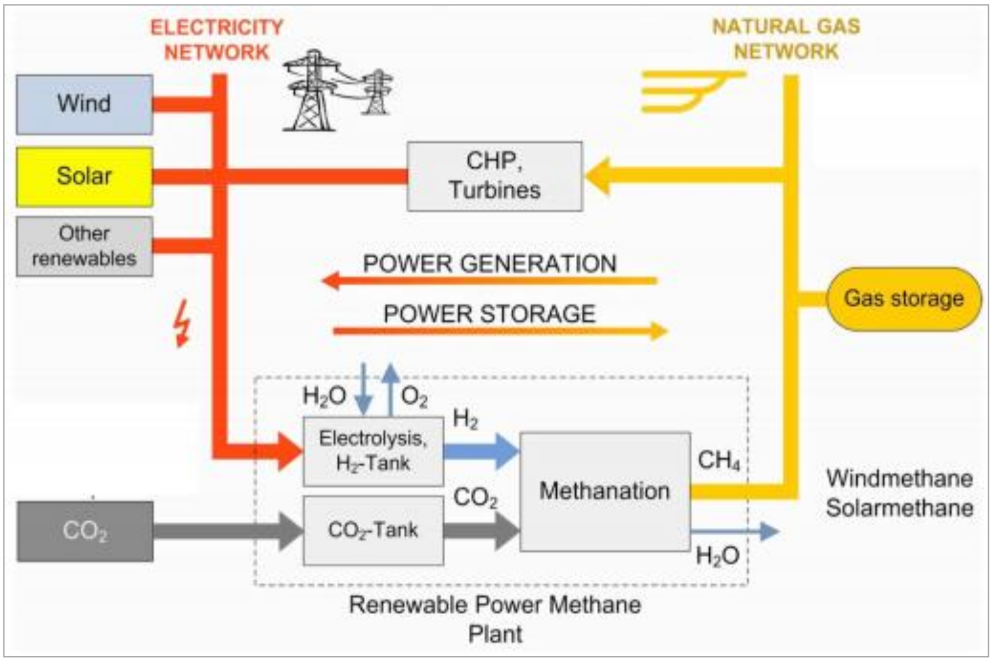

Figure 24: renewable power to methane/SNG[36]

[35] (mgm consulting partners GmbH)

[36] (Sterner, 2013)

Short-term storage

- **Batteries**

  Batteries are electrochemical storage technologies which store electricity via electrochemical processes into chemical energy and vice versa. With relatively high efficiencies between 75 – 95%[37] and also high costs per kW they will mainly be used for home photovoltaic installations and in electric vehicles. But there are also projects ongoing where batteries are used for grid stabilization on a bigger scale. In the following figure the Vanadium Redox-Flow battery will be explained more in detail.

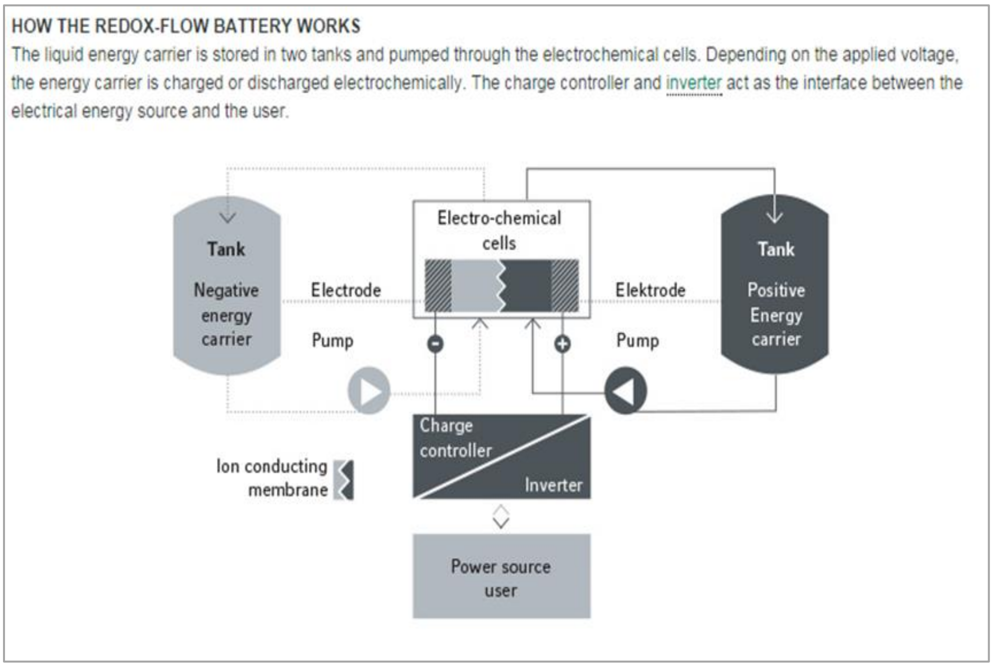

Figure 25: Vanadium Redox Flow Battery[38]

According to the IEA Energy Storage Roadmap the costs for the different technologies are:

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[37] (mgm consulting partners GmbH)

[38] (Gildemeister)

Technology	Location*	Output	Efficiency (%)	Initial investment cost (USD/kW)	Primary application	Example projects
PSH	Supply	Electricity	50 - 85	500 - 4 600	Long-term storage	Goldisthal Project (Germany), Okinawa Yanbaru Seawater PSH Facility (Japan), Pedreira PSH Station (Brazil)
UTES	Supply	Thermal	50 - 90	3 400 - 4 500	Long-term storage	Drake Landing Solar Community (Canada), Akershus University Hospital and Nydalen Industrial Park (Norway)
CAES	Supply	Electricity	27 - 70	500 - 1 500	Long-term storage, arbitrage	McIntosh (Alabama, United States), Huntorf (Germany)
Pit storage	Supply	Thermal	50 - 90	100 - 300	Medium temperature applications	Marstal district heating system (Denmark)
Molten salts	Supply	Thermal	40 - 93	400 - 700	High-temperature applications	Gemasolar CSP Plant (Spain)
Batteries	Supply, demand	Electricity	75 - 95	300 - 3 500	Distributed/ off-grid storage, short-term storage	NaS batteries (Presidio, Texas, United States and Rokkasho Futamata Project, Japan), Vanadium redox flow (Sumimtomo's Densetsu Office, Japan), Lead-acid (Notrees Wind Storage Demonstration Project, United States), Li-ion (AES Laurel Mountain, United States), Lithium Polymer (Autolib, France)
Thermochemical	Supply, demand	Thermal	80 - 99	1 000 - 3 000	Low, medium, and high-temperature applications	TCS for Concentrated Solar Power Plants (R&D)
Chemical-hydrogen storage	Supply, demand	Electrical	22 - 50	500 - 750	Long-term storage	Utsira Hydrogen Project (Norway), Energy Complementary Systems H2Herten (Germany)

Figure 26: Overview of Energy storage technologies: current status and costs[39]

[39] (IEA, 2014)

The storage technologies exist on many levels of development from the early research and development to mature and deployed level.

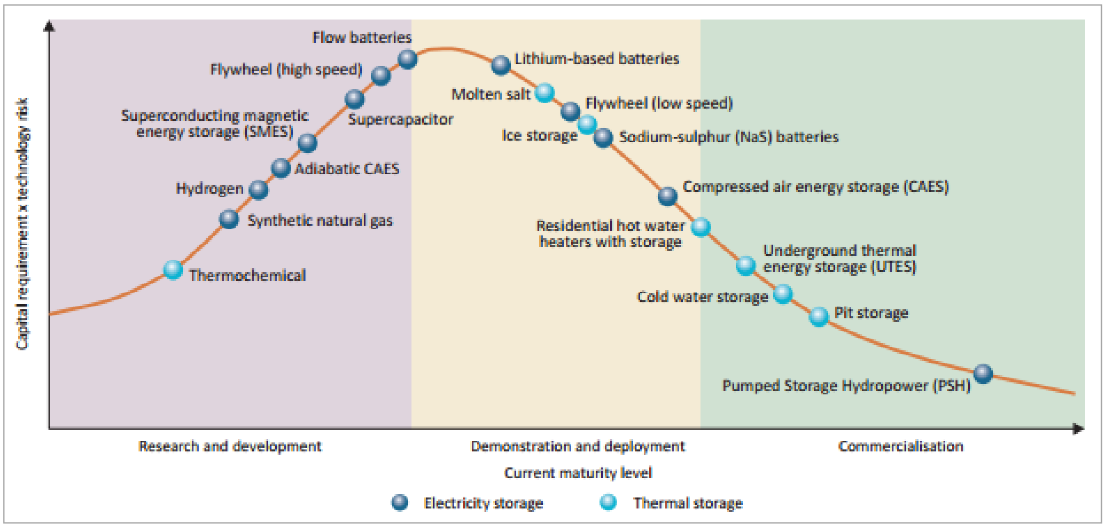

Figure 27: Maturity of energy storage technologies[40]

As can be seen in the figure before the only technology of the above mentioned which is commercially viable is Pumped Storage Hydropower. But the usability is limited due to the needed natural circumstances of two reservoirs on different height levels. Hydrogen and SNG currently stands on R&D level but have a high potential as long term storage technology due to the use of the existing gas pipelines as storage medium.

[40] (IEA, 2014)

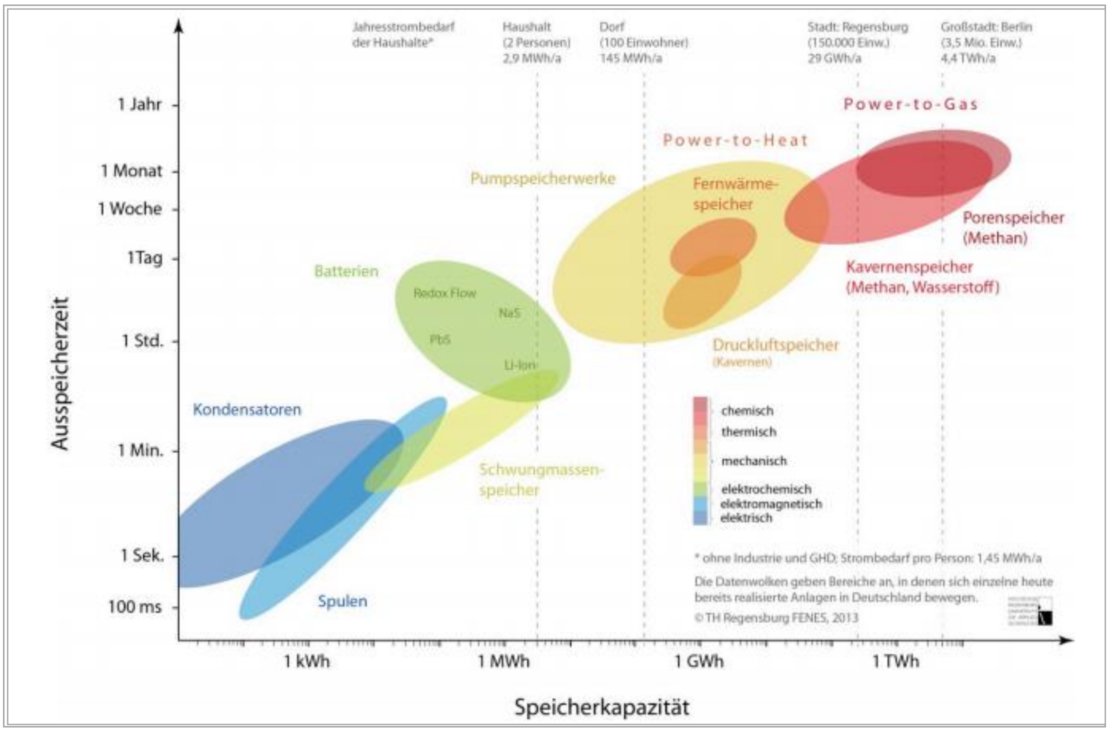

Figure 28: overview of storage technologies in terms of capacity versus storage time[41]

[41] (Sterner, 2013)

3 Database

3.1 Community of Ellzee

The community 'Ellzee' is situated in the district of Guenzburg which is located in the southwestern part of Bavaria in the administrative region of Swabia.

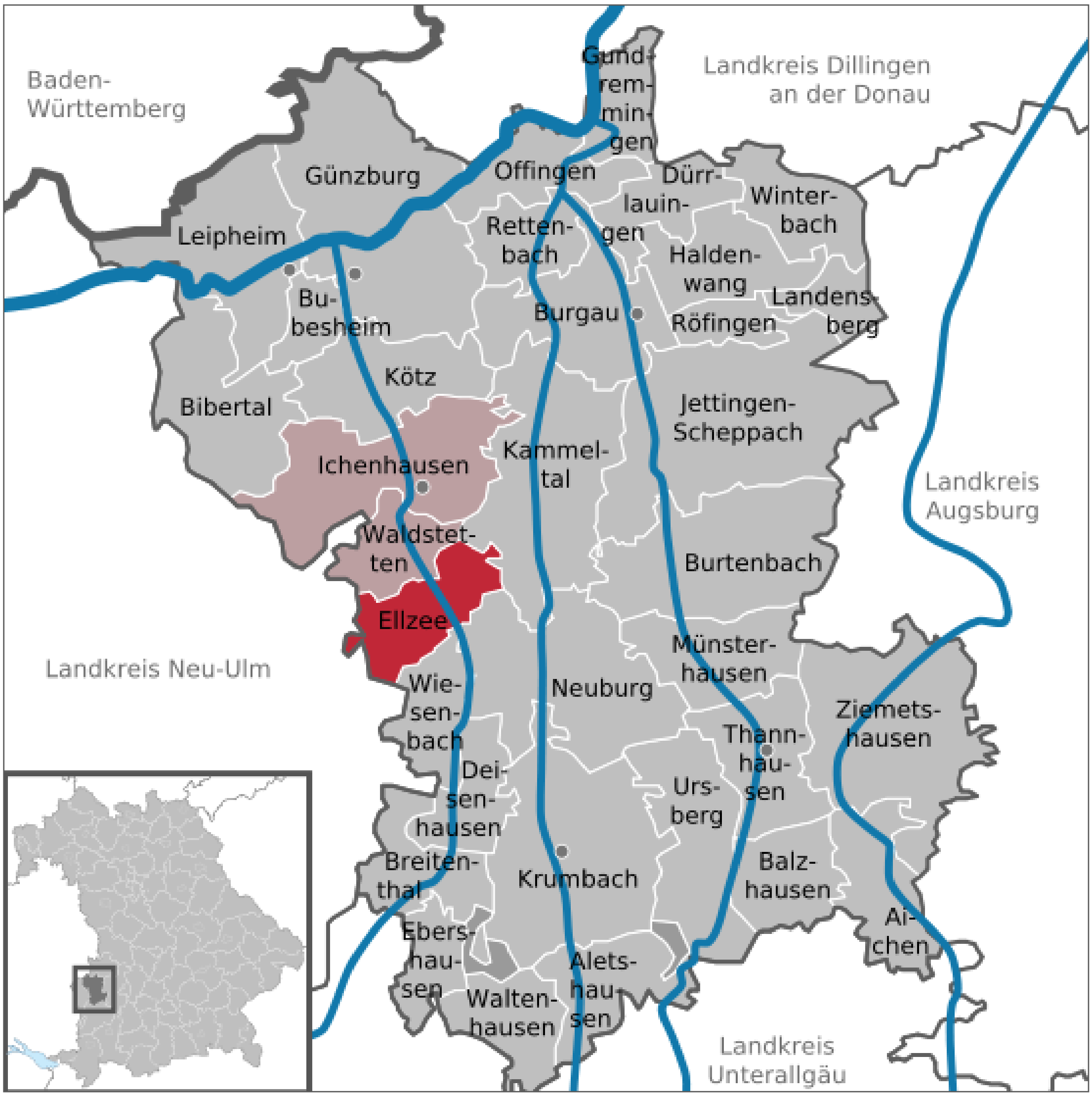

Figure 29: Location of Ellzee within Bavaria and the district Guenzburg[42]

Ellzee lies 485 meters above sea level and covers an area of 14.77 square kilometers and has a population density of 78 inhabitants per square kilometer. Per

[42] (Wik14)

2011 the residential population was 1.141 inhabitants and the households come up with a total number of 487 with an average size of 117 square meter[43].

The community of Ellzee with the 2 villages, Hausen and Stoffenried, belongs together with the community of Waldstetten to the administrative partnership of Ichenhausen.

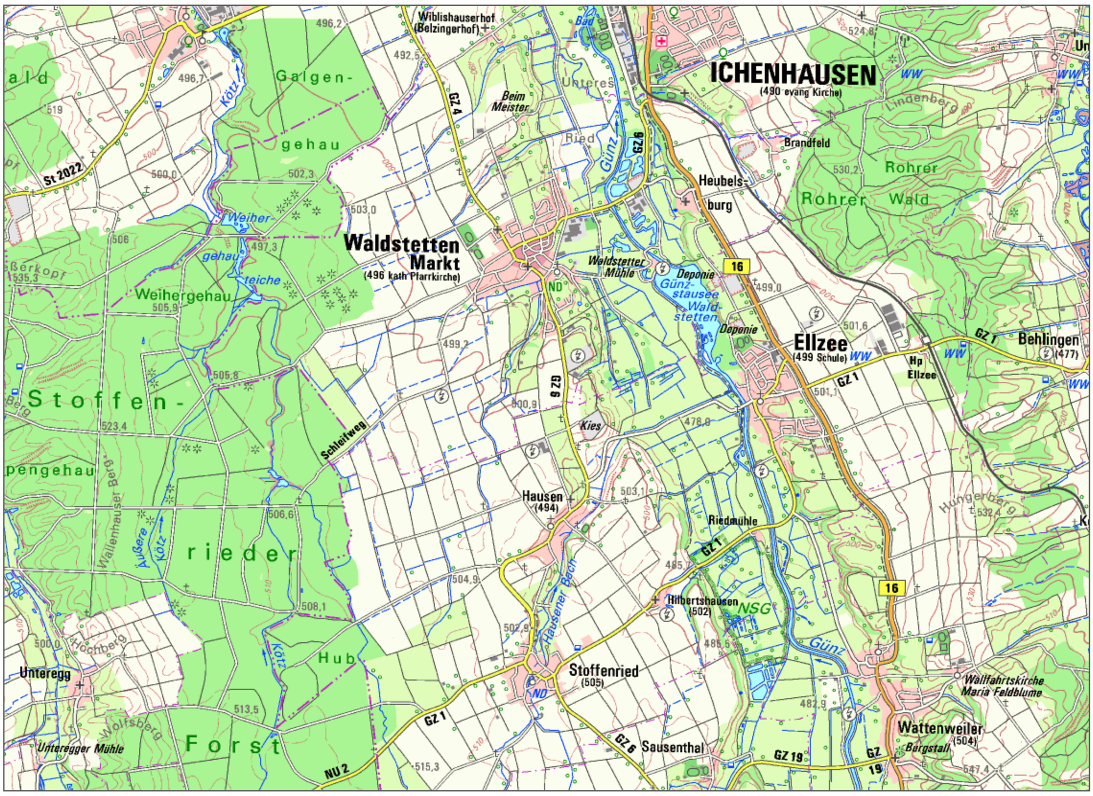

Figure 30: overview of the community Ellzee[44]

In total 414 buildings are in the community, in average since 2007 two residential buildings are constructed per year. This results in a slow renewing.

The demand and supply for the community of Ellzee will be assessed by using data from a local energy concept on the one hand and own interpretations of available online data on the other hand. The energy concept was done by the company renergie Allgäu e.V. in cooperation with the community Ellzee. The concept was subsidized by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) under the project '100%-Erneuerbare-Energie-

[43] (Bayerisches Landesamt für Statistik und Datenverarbeitung, 2013)

[44] (Landesamt für Digitalisierung)

Regionen' (100% renewable regions) and therefore was underlying certain criteria's for the evaluation of data.

3.2 Energy Demand in 2012

The annual electricity consumption for the community Ellzee comes up to 11.162 megawatt hours according to the above mentioned energy concept. Most of the electricity is used by the industry followed by households and agriculture. The heating demand in 2012 summarizes to 10.569 megawatt hours where households are responsible for at least 82 percent. The following figure gives an overview about the collected data:

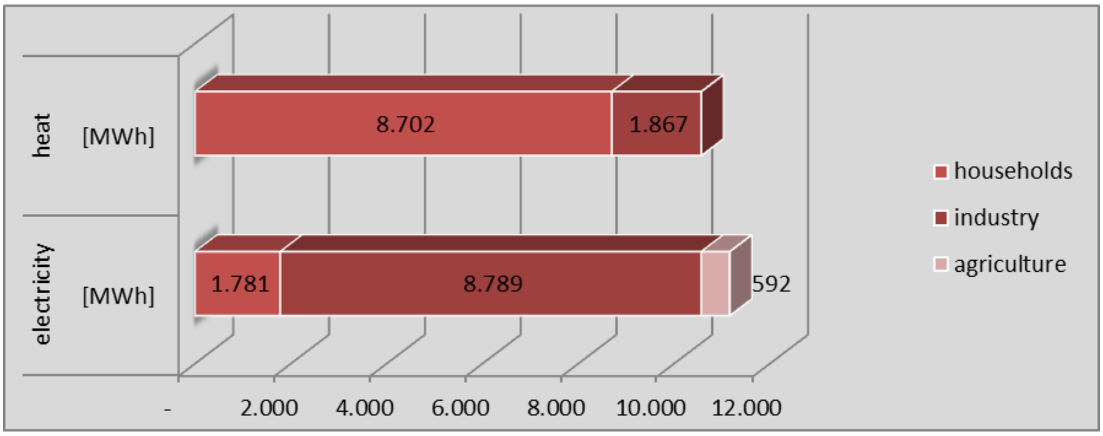

Figure 31: Ellzee, heat and electricity demand 2012 (own calculation 2014)

For the simulation standardized demand curves in combination with the actual demand will be used to get the precise demand curves for the different users. The following figures showing an abstract of these electricity demand curves for households and industry. The curve for households shows high demands during noon and evening and the industry curve has constant peaks during daytime and low demands at the weekends.

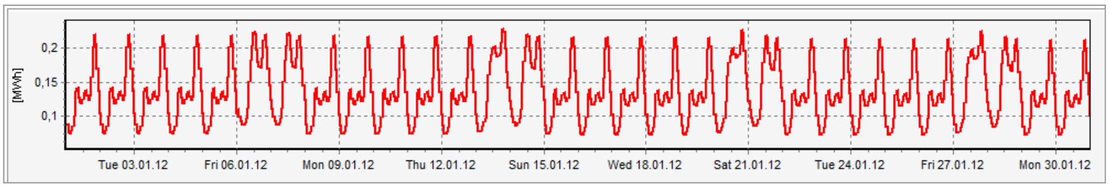

Figure 32: abstract of the electricity demand households (own calculation 2014)

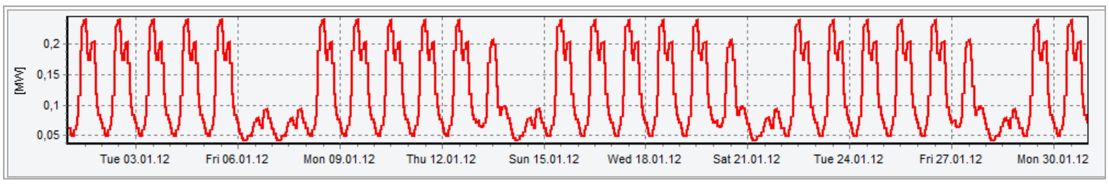

Figure 33: abstract of the electricity demand industry (own calculation 2014)

3.3 Renewable Energy Supply in 2012

3.3.1 Solar

According to the '*Energie Atlas Bayern*'[45] there are 92 photovoltaic-installations[46] in the community of Ellzee with a power of 1.210 kilowatts and an electricity production of around 1.250 megawatt hours. This corresponds with the data from the energy concept. All of the plants are rooftop mounted. The first photovoltaic plant was installed in 2002.

Figure 34: photovoltaic installations according to the 'Energie Atlas Bayern'

3.3.2 Biogas

There are three biomass plants in the community of Ellzee installed. The total power is 1.184 kilowatt and the size of the plants is between 370 and 430 kilowatts. The total annual electricity energy production of the three plants is around 9.700 megawatt hours.

[45] (Bayerisches Staatsministerium für Wirtschaft und Medien)

[46] See Annex 1: Photovoltaic installations

Figure 35: biogas installations according to the 'Energie Atlas Bayern'[47]

Figure 36 shows the main characteristics of the installed CHPs.

name	power [kW]	annual electricity production [kWh]	FLH	commissioning	KWK bonus	immission bonus
Biomass 1	430	3.521.485	8.190	2006	yes	no
Biomass 2	374	2.932.019	7.840	2006	yes	yes
Biomass 3	380	3.270.583	8.607	2005	yes	yes
sum	**1.184**	**9.724.087**				

Figure 36: Ellzee, overview of the biomass plants[48]

[47] (Bayerisches Staatsministerium für Wirtschaft und Medien)

[48] (Bayerisches Staatsministerium für Wirtschaft und Medien)

3.3.3 Hydro

In the community of Ellzee only one hydro power plant is installed. The run-of-river plant is build alongside the river Guenz and has a power capacity of 600 kilowatt. The plant was built in 1955 and is run by Bayerische Elektrizitätswerke GmbH.

Figure 37: Ellzee, run-of-river plant[49]

The total annual electricity production of the plant is specified with around 1.800 megawatt hours according to the Bayerische Elektrizitätswerke. Figure 38 shows the annual production curve for the hydro power plant as it will be simulated within energyPRO.

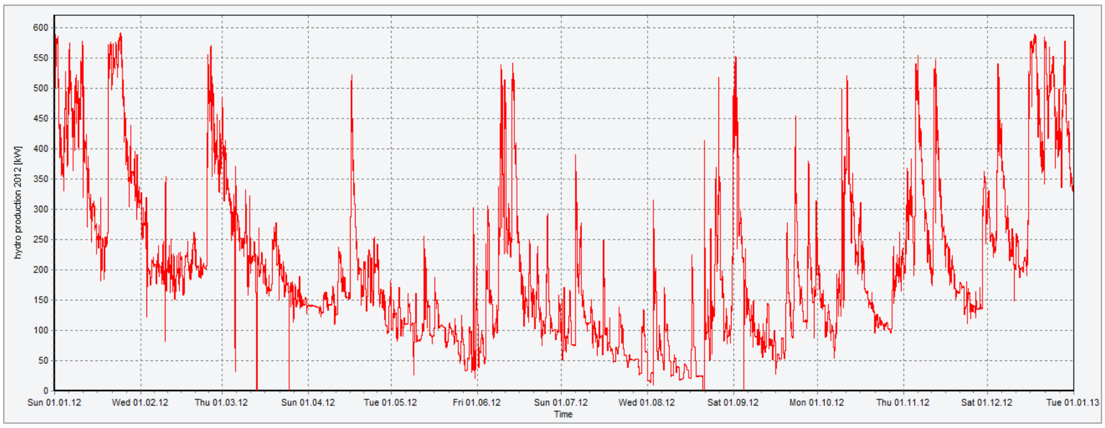

Figure 38: electricity production hydro power plant (own calculation 2014)

3.3.4 Summary

For 2012 the generation portfolio for the different renewables consists of photovoltaic, biogas and hydro power plants. The production data for electricity and heat are mentioned in the following figure.

[49] (Bayerische Elektrizitätswerke)

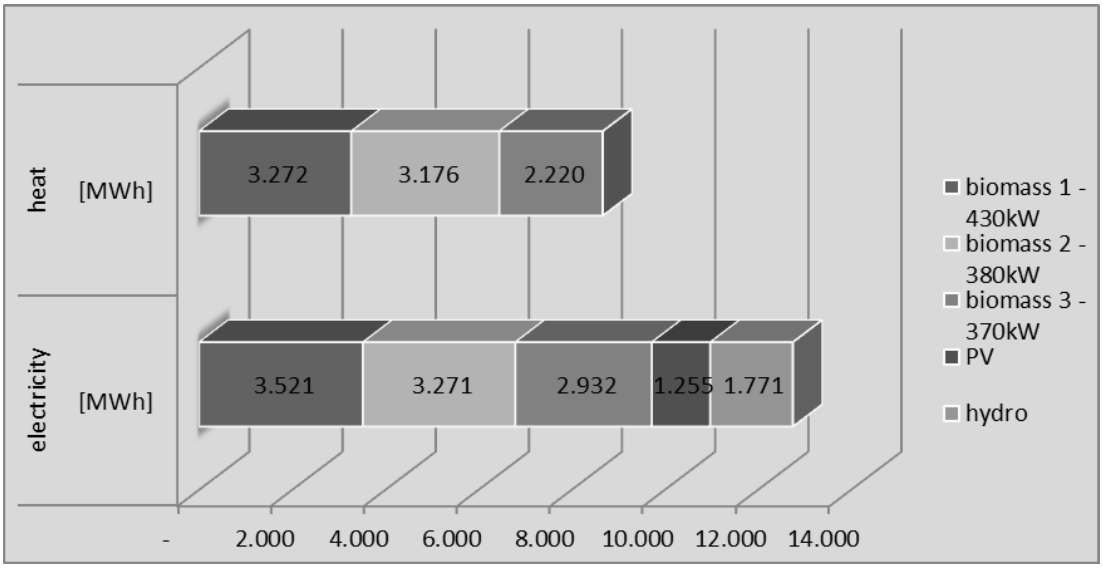

Figure 39: Ellzee, heat and electricity production by renewables in 2012 (own calculation 2014)

3.4 Generation potential of Renewable Energies

The potentials of the different renewables will be assessed in the following chapters.

3.4.1 Wind

The power of wind can be described as kinetic energy of the air of mass m passing through the area A over a given time:

$$\mathbf{P_{Wind} = 0{,}5 * m * v^2 = 0{,}5 * \rho * A * v^3}$$

m: mass flow, with $\rho * A * dx/dt = \rho * A * v$

ρ air density [kg/m³]

A: Rotor area, with $r^2 * \pi$ [m²]

R: rotor diameter [m]

v: wind speed [m/s]

1926 Betz discovered that there is a maximum power which can be extracted by a wind turbine. This maximum is defined as power coefficient $c_{p,\ Betz} = 16/27 = 0{,}59$ and results in:

$$\mathbf{P_{Betz} = 0{,}5 * m * v^2 = 0{,}5 * \rho * A * v^3 * c_{p,\ Betz}}$$

Finally the theoretical maximum power extraction is 59 percent. Modern wind turbines have already values above 50%.

As from the formula before can be seen the single most important question is, how much wind can be expected at hub height.

The assessment of the measured or collected wind data normally is done by statistical calculations (frequency distribution per wind speed interval) and ends up in the mathematical function of a Weibull-distribution (shown below).

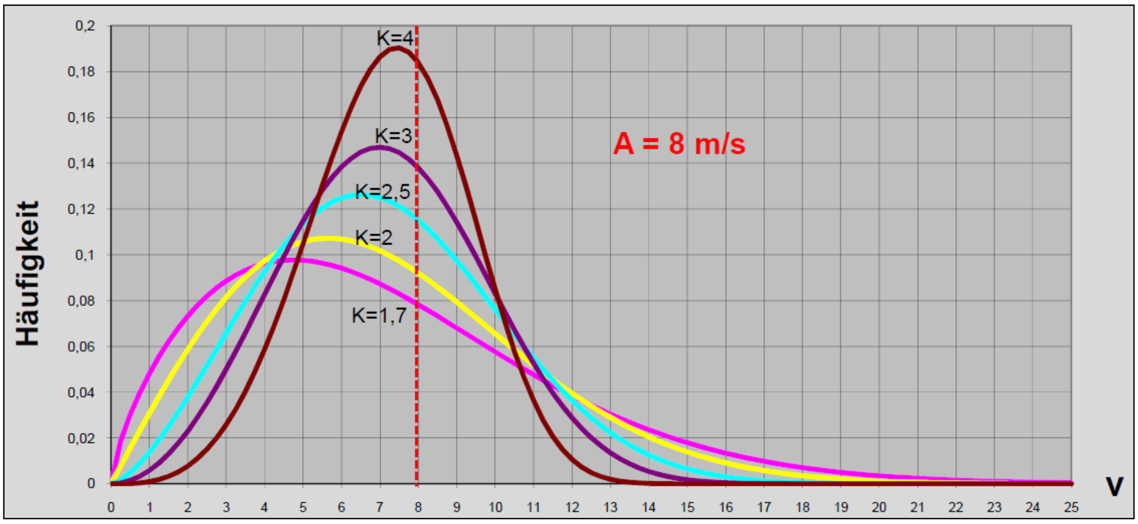

Figure 40: Weibull-distribution with different k-factors[50]

Figure 40 shows the Weibull-distribution with different k-factors. The scale parameter A gives an idea of the maximum of the curve, the higher the value the higher the mean wind speed.

The shape factor „k“ is an inverse measure of the variations of the wind velocity with respect on the mean. If the wind often flows at the same speed the value of k will be comparatively large. Unsteady conditions results in low k-values.

Typical parameters are:

A = 4 (inland) – 7 (coast)

k = 1,6 (inland) – 2,5 (coast)

The Rayleigh distribution corresponds to a value of k=2. The yield calculation in information brochures of wind turbine generator manufacturers is usually based on the Rayleigh distribution.

The local wind situation in the area of Ellzee is mostly influenced by the north to south oriented mountain ridges between the valleys of the rivers Guenz, Kammel and Iller.

50 (EMD Deutschland, 2014)

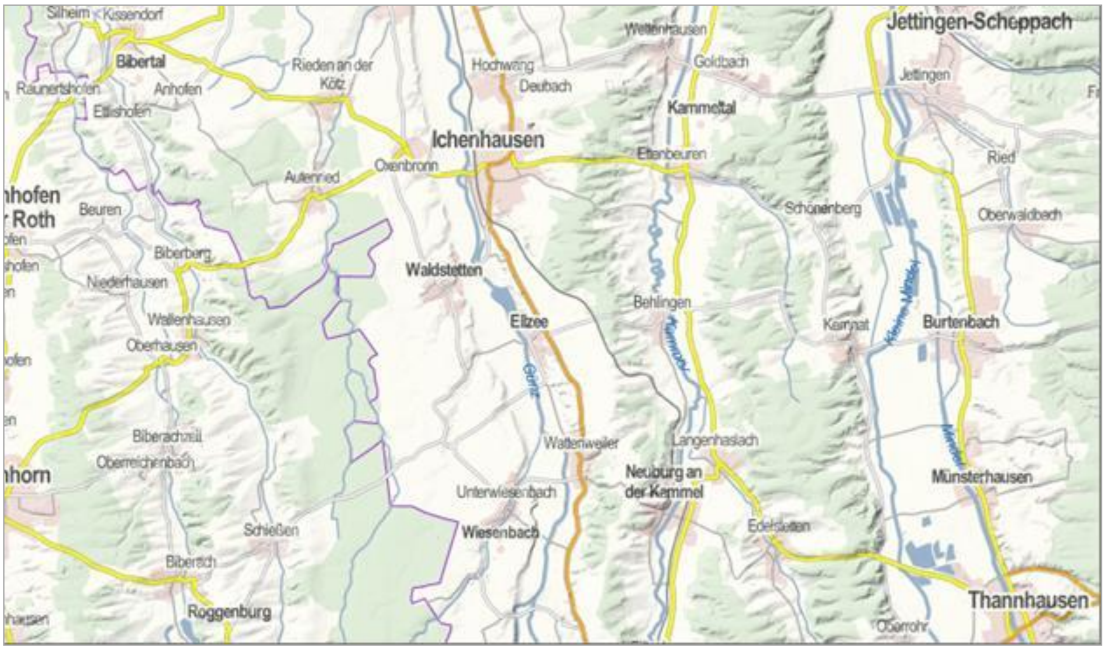

Figure 41: topographical map of the area Ellzee[51]

The ridges originate from the outlets of the Alps glaciers. The total heights of the ridges in this region are around 540 to 560 meters above sea level.

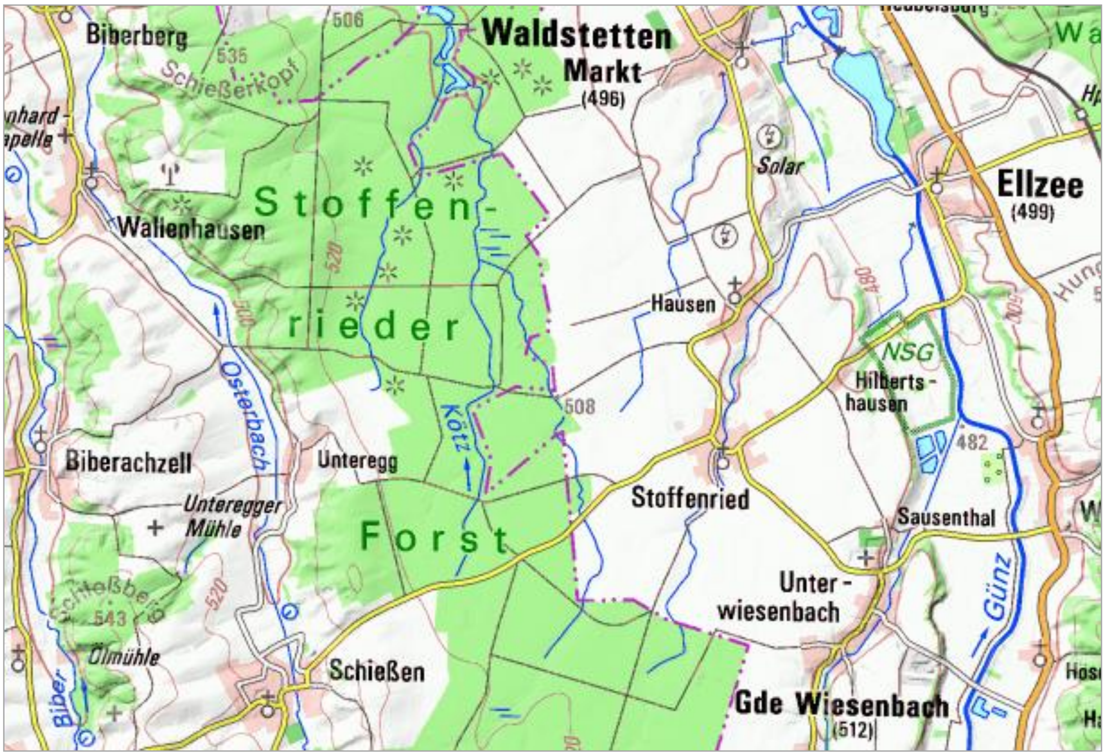

Figure 42: official map of the area Ellzee[52]

[51] (Landesamt für Digitalisierung)

[52] (Landesamt für Digitalisierung)

The complex terrain with smaller valleys in combination with a lot of forest leads to a high roughness which has a massive influence of the wind situation. The roughness will decrease with the height over ground and the laminar wind streams will take over. This effect has a direct influence on the wind speeds at hub height as can be seen in the following graph.

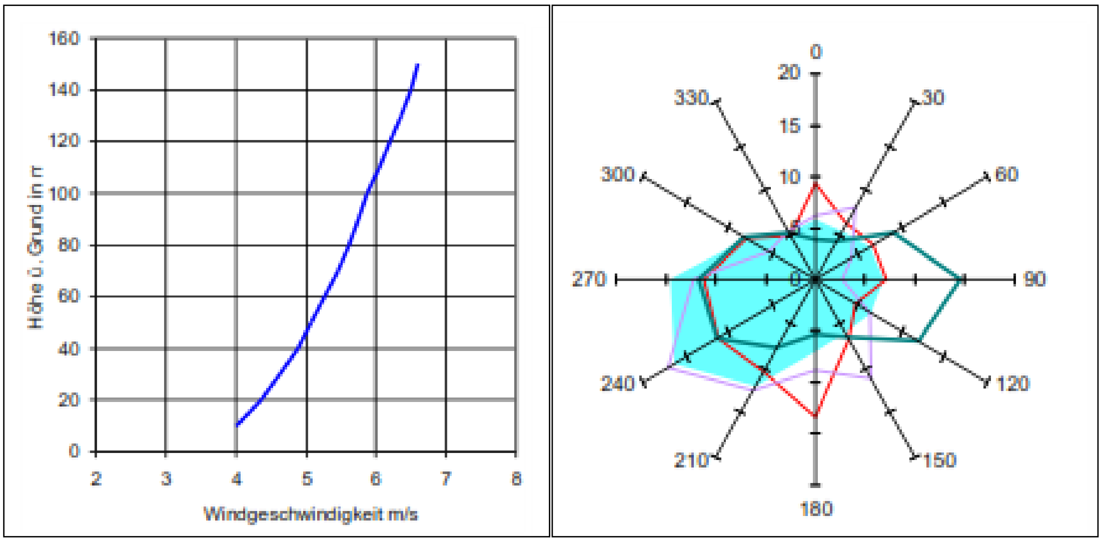

Figure 43: wind rose and increase of wind speed with height[53]

Corresponding to that effect the use of wind power in the southern part of Germany was becoming interesting with 'low-wind-speed turbines', which means hub heights higher than 120 meters and rotor diameters with more than 100 meters as well as a good ratio between generator size and swept area of the rotor.

[53] (Voltgrün, 2012)

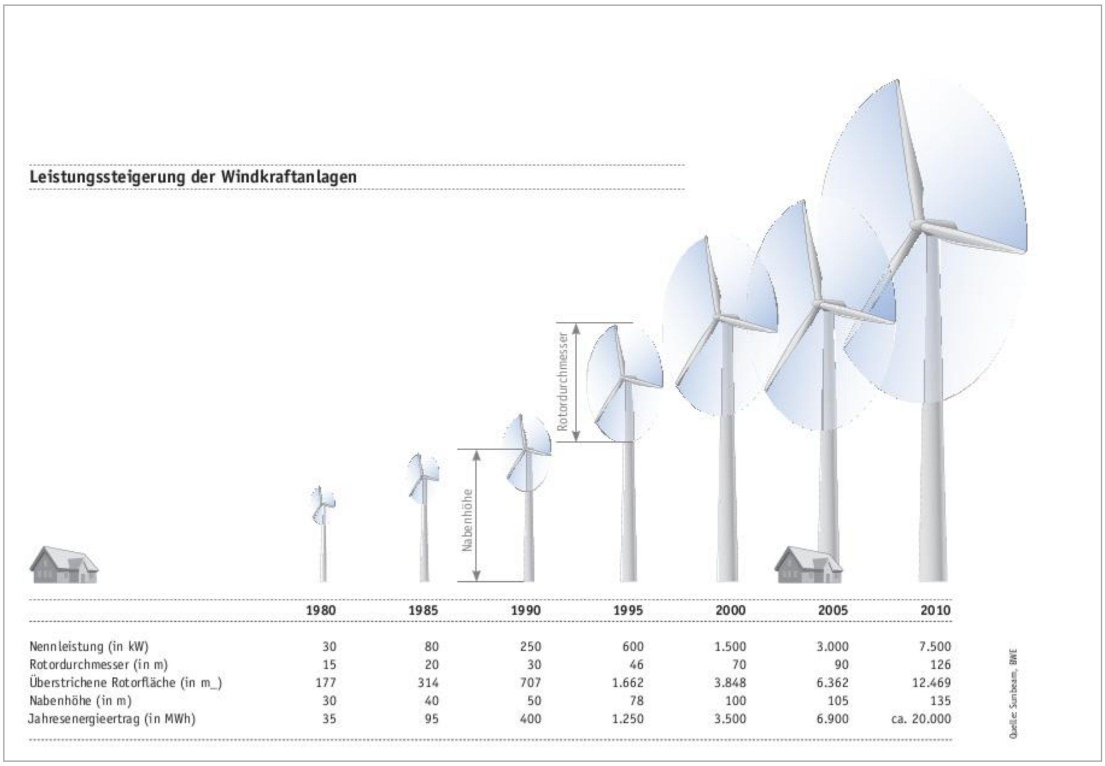

Figure 44: development of wind turbine generators[54]

There are different manufacturers for WTG on the market which would be suitable for southern Germany. **Fehler! Verweisquelle konnte nicht gefunden werden.** gives an overview about the actual available turbine types.

Table 1: overview of actual wind turbine generators for low wind speed sites[55]

manufacturer	turbine	Pel [MW]	rotor diameter [m]	hub height [m]
ENERCON	E82	2,300	82	138
	E92	2,300	92	138
	E101	3,050	101	135
				149
NORDEX	N117	2,400	117	141
VESTAS	V112	3,075	112	140
	V126	3,000	126	140

[54] (BWE, German Wind Energy Association, 2012)

[55] own calculation 2014

According to the regional planning committee there is one preferred area for the erection of wind turbines issued in the community of Ellzee. For these areas certain criteria's already were evaluated like distances to houses, landscape protection areas and others. Wind turbine development isn't allowed in areas outlying of preferred areas. This regional planning instrument gives communities the possibility to rule the use of wind energy in their area to a certain point.

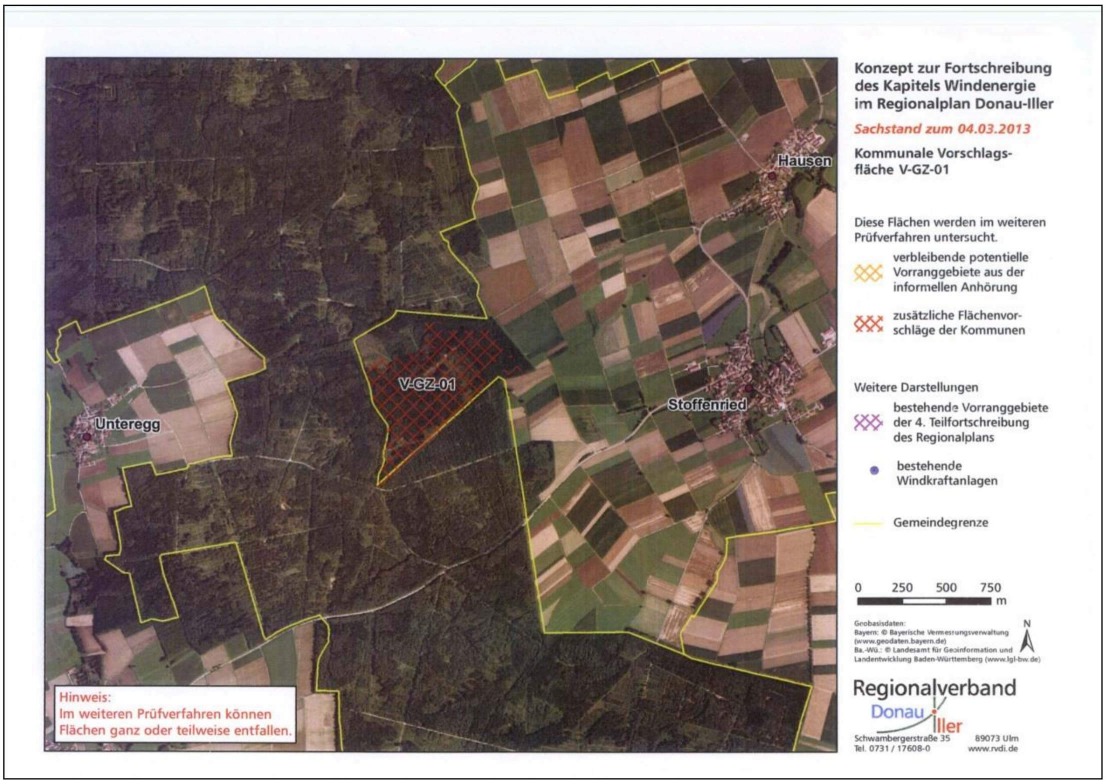

Figure 45: preferred area for the use of wind energy in the community Ellzee[56]

The 'Energie-Atlas-Bayern' shows for the mentioned area wind speeds at 140m height within a range of 5 to 6 m/s. To assess if the site is economically useable further facts have to be evaluated.

[56] (Regionalverband Donau Iller, 2014)

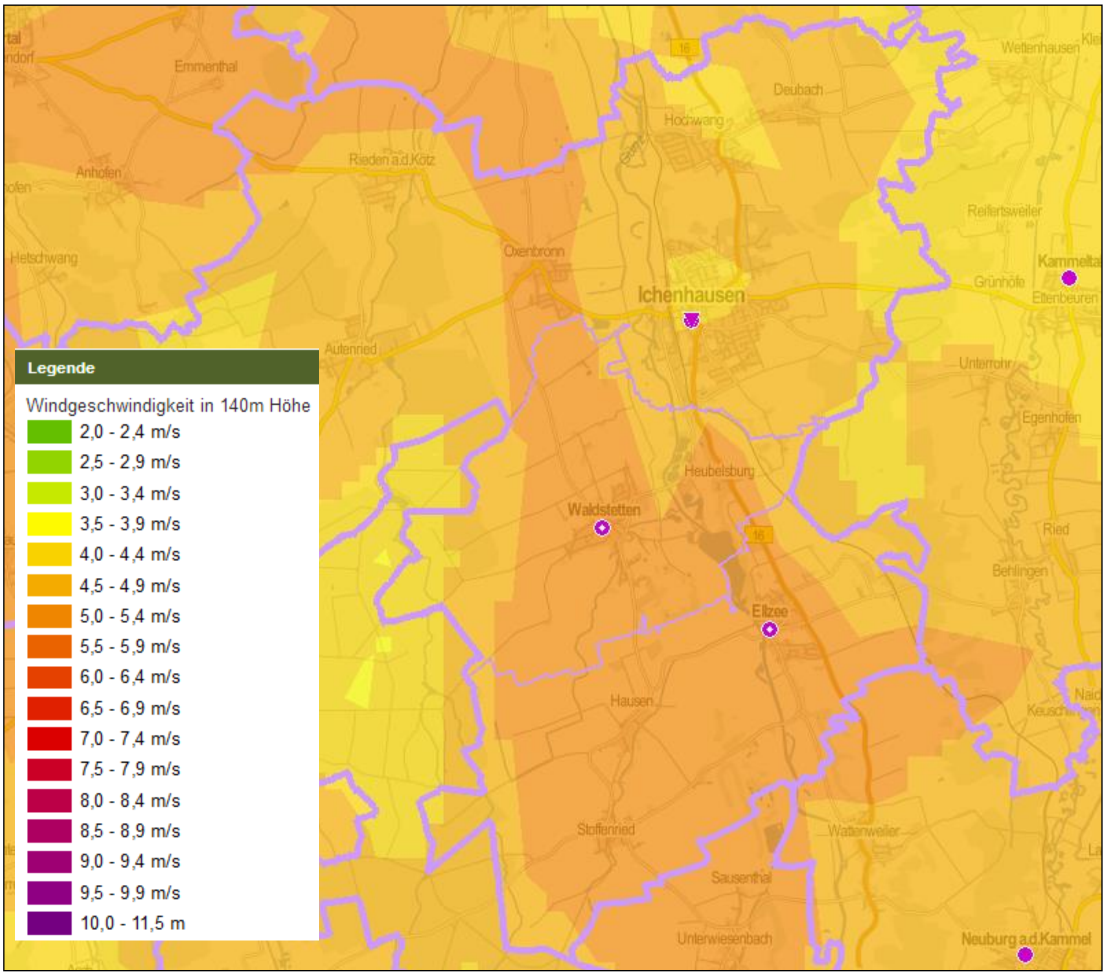

Figure 46: wind speeds at 140m hub height[57]

For around 60 to 70 percent of the overall costs the wind turbine generator is responsible, followed by costs for infrastructure, where the costs for the grid connection mostly take the highest share.

With the turbine NORDEX N117 the area is suitable for 3 turbines due to the fact that turbines have to keep distances in between of about 5 times rotor-diameter not to affect the energy production by them. Otherwise the created turbulences (after the rotor) will affect the next turbine and the energy yield of the wind farm will decrease.

[57] (Bayerisches Staatsministerium für Wirtschaft und Medien)

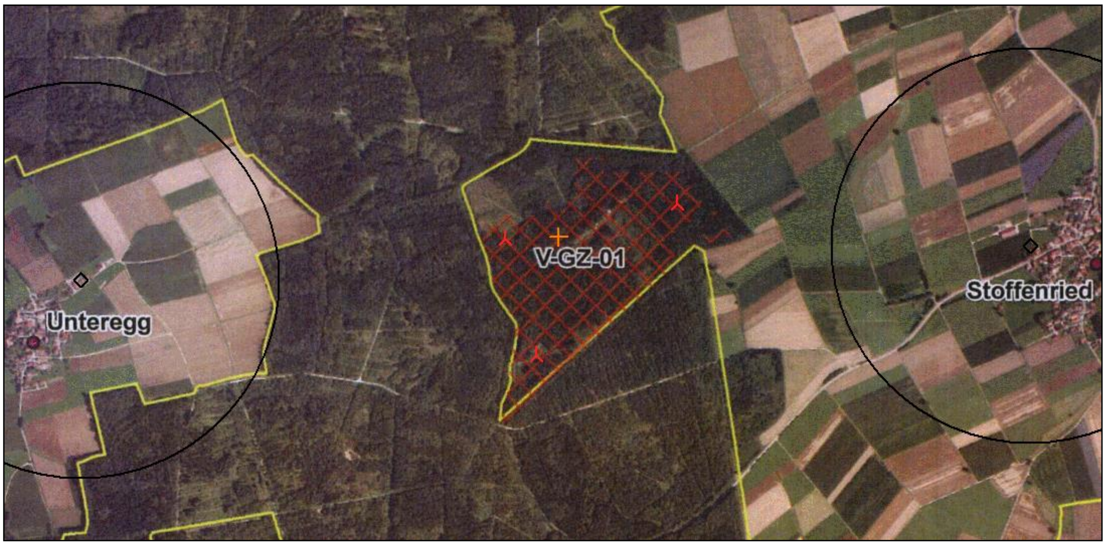

Figure 47: site specification wind farm (3 x N117)[58]

To assess the energy potential of the site accredited wind consultants have to digitalize the area to simulate the roughness and calculate the energy yield by using the following power curve for the Nordex N117-2.4.

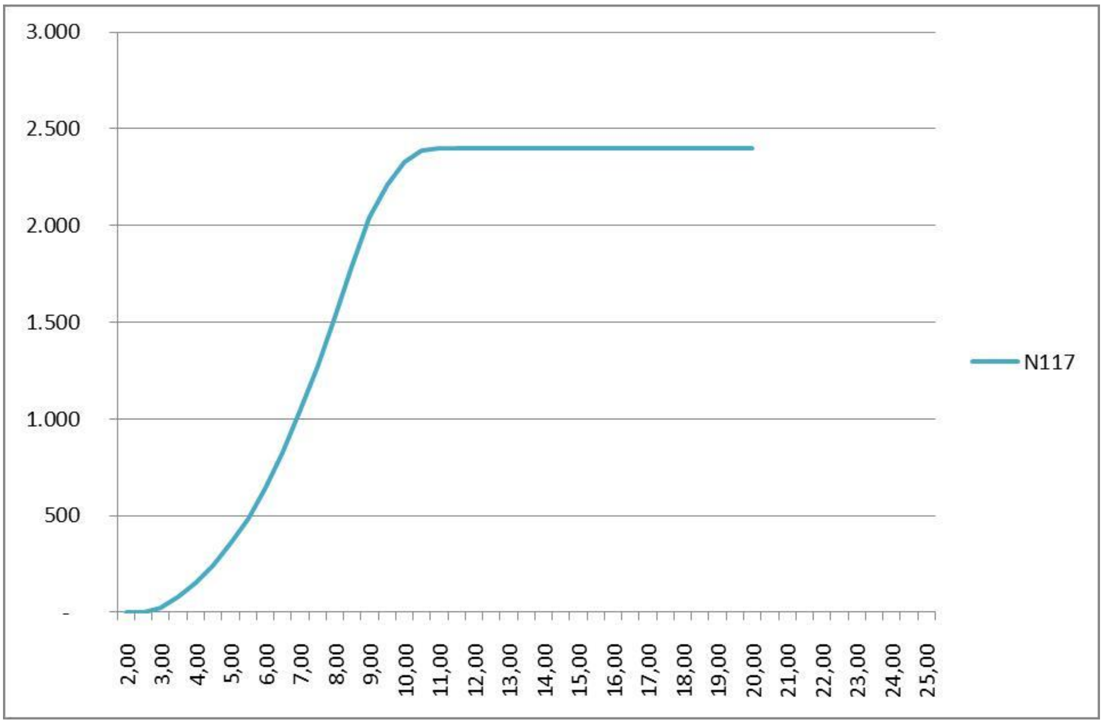

Figure 48: N117-2.4 power curve (wind speed/ kW)[59]

[58] (Voltgrün, 2012)

[59] own calculation

The forecast of the annual energy yield for the three Nordex turbines is 17.7 Terawatt hours. It is planned to install the turbines in 2013.

3.4.2 Solar

Photovoltaic systems can be separated into systems installed on the roof of buildings or ground mounted on the field. As a rule of sump for one kilowatt electricity power 6 to 8 square meters of roof area are needed and around 10 square meters for ground mounted photovoltaic-systems. They consist of the following main parts:

- modules/panels
- mounting
- inverters

The Modules are the main part of a photovoltaic-system, because they convert the sunlight into electricity. The capacity of modules is in the range of 100 to 300 kilowatt peak. Solar cells are also usually connected in series in modules, creating an additive voltage. All cells have at least two layers of semiconductors differently charged. By light shining on the semiconductors an electrical field between the junctions is build and causes electricity flow. The higher the intensity of the incoming light is the higher the electrical flow. There are different types of solar cells or modules on the market. Most common are the mono-crystalline, poly-crystalline and the thin-film photovoltaic modules.
The energy production can be calculated by defining the irradiation and the system parameters and the following formulas:

Energy generation **= A**rea *** η * R**adiation *** P**erformance **R**atio

Energy:	produced energy by the solar installation [kWh]
Area:	Total solar panel Area in square meter [m²]
Radiation:	Annual average irradiation on tilted panels (shadings not included), the amount of solar power striking a given area and a measure of the intensity of the sunshine [kWh/m²]
η	yield of the solar panel given by the ratio electrical power of one solar panel divided by the area of one panel [%]

Performance Ratio: efficiency of the photovoltaic system; ration between actual and ideal energy production; values should be higher than 70 percent [kWh/kWp]

The irradiation in the area is according the 'Energie-Atlas Bayern' around 1200 kilowatt hours per square meters.

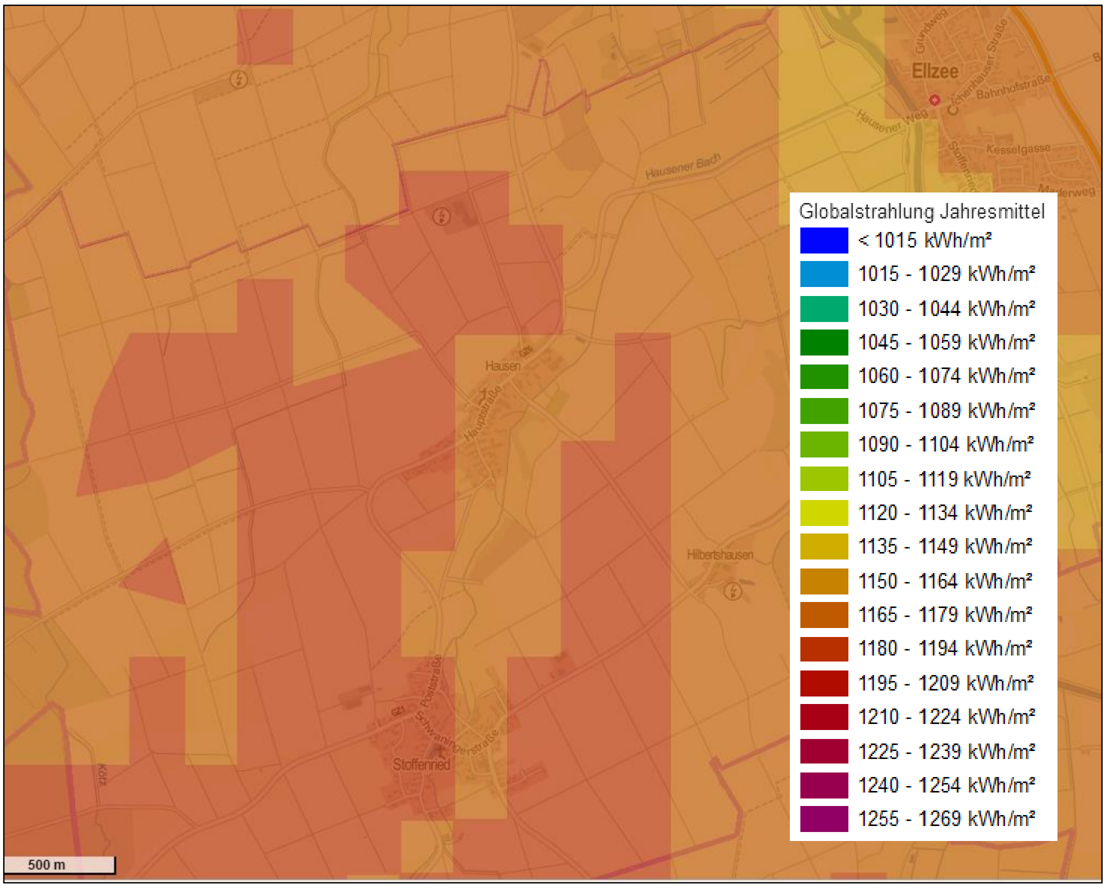

Figure 49: global irradiation for the community of Ellzee[60]

According to the energy concept the community Ellzee has a theoretical potential of 8.195 megawatt hours for photovoltaic. In the theoretical potential 100 percent of the possible areas are used by photovoltaic installations. With an irradiation of 1.200 kilowatt hours per square meters this corresponds to 6.800 square meters which is 7 times the area which is used in 2012 by photovoltaic installations.

[60] (Bayerisches Staatsministerium für Wirtschaft und Medien)

3.4.3 Hydro

Due to the intense use of river Guenz for Small Hydro Plants (SHP) there is no reasonable potential for SHPs in the community.

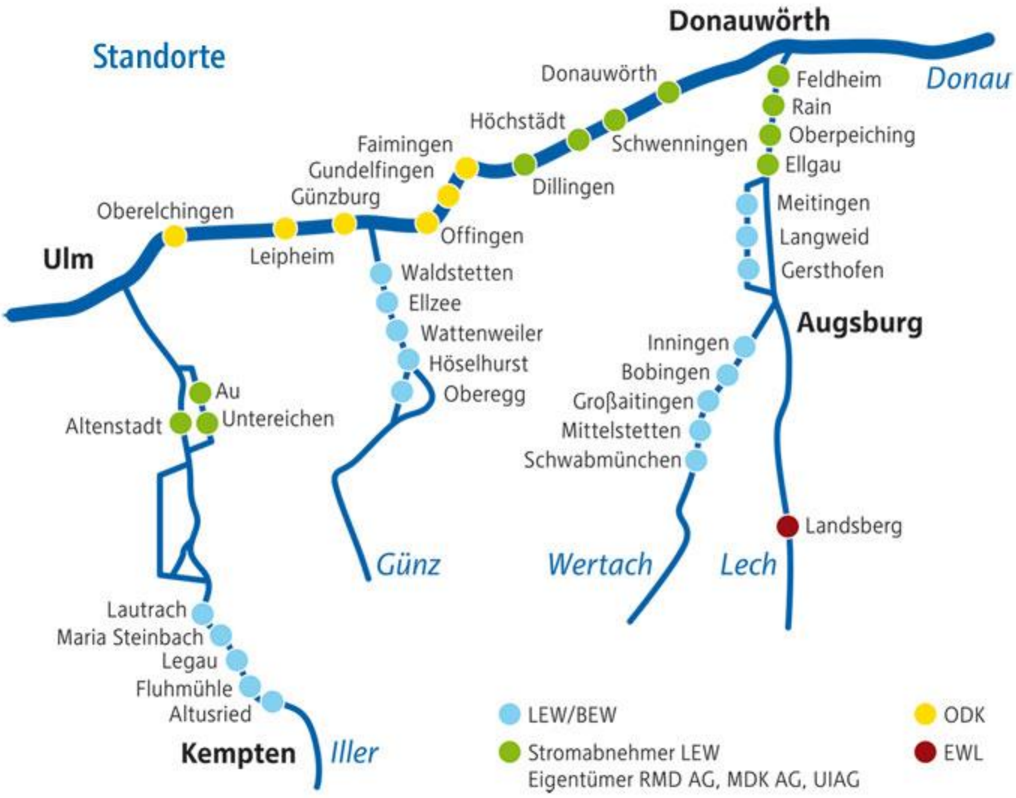

Figure 50: BEW, hydro power plants[61]

All water rights for the river Guenz are reserved by BEW and the complete head of water is used by the 5 SHPs around the river. According to the owner the technical standard of the SHPs is state of the art. All in all there is no further potential for hydro power.

[61] (Bayerische Elektrizitätswerke)

3.4.4 Biomass

There are different conversion processes for biomass; Figure 51 gives an overview about the different possible technologies.

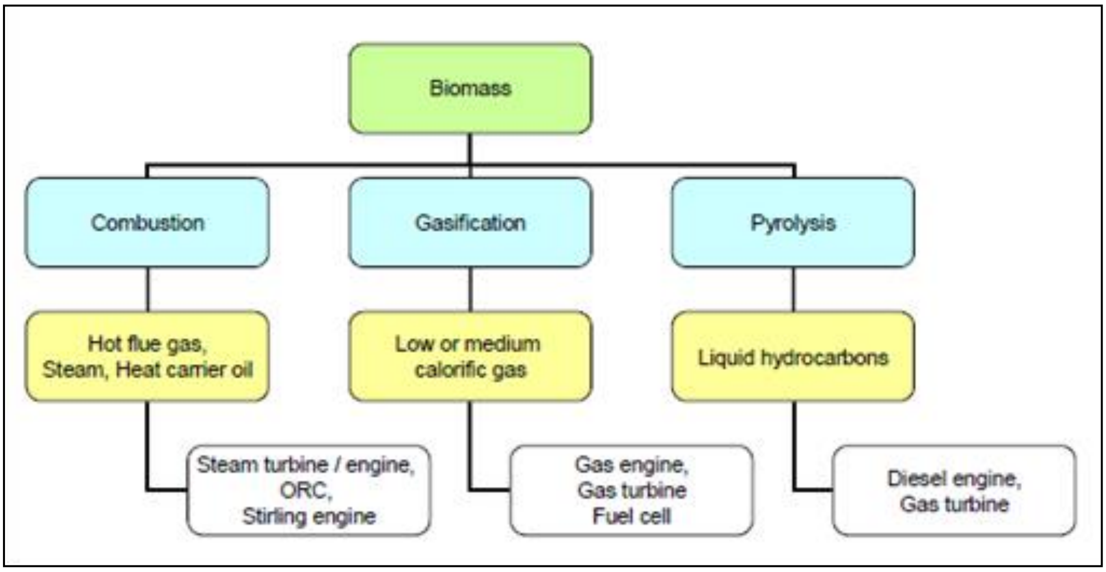

Figure 51: conversion processes for biomass[62]

On rural areas the most common process is gasification with biogas plants using substrates from the farm and producing electricity in a combined heat and power plant (CHP). The existing biomass plants in the community of Ellzee are such types of plants and consist of a liquid manure store, a feed-in unit for solid substances, a digester where the actual fermentation takes place and a digestate storage tank for the fermented biomass.

With conventional technology up to 45 percent of the energy contained in biogas can be converted into electricity. When the resulting surplus heat is also used, the overall efficiency can be raised to about 85%. The surplus heat can be used to heat residential houses, schools or as process heat and even replace fossil fuel.

According to the energy concept the theoretical production potential for electricity is 826 Megawatt hours and for heat 1.500 Megawatt hours.

[62] (Quaschning, 2013)

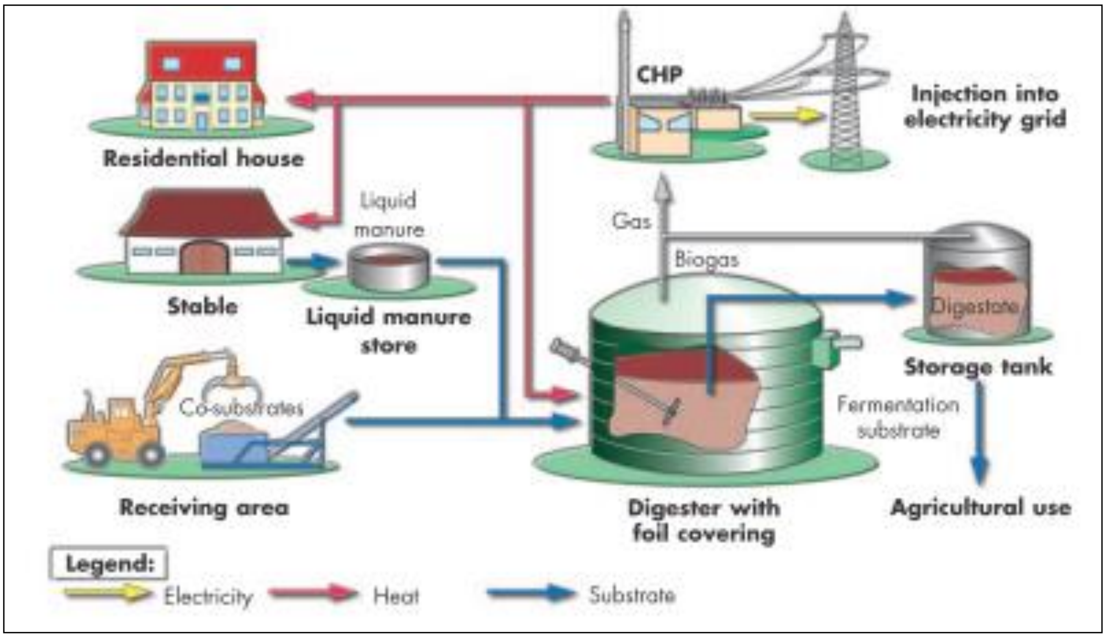

Figure 52: scheme of processes in a farm-based biogas plant[63]

The demand for land feeding one person in Germany is 1.870 m². Therefore 215 hectare would be theoretically necessary for the 1.149 inhabitants. Figure 53 shows the different kinds of land use in the community.

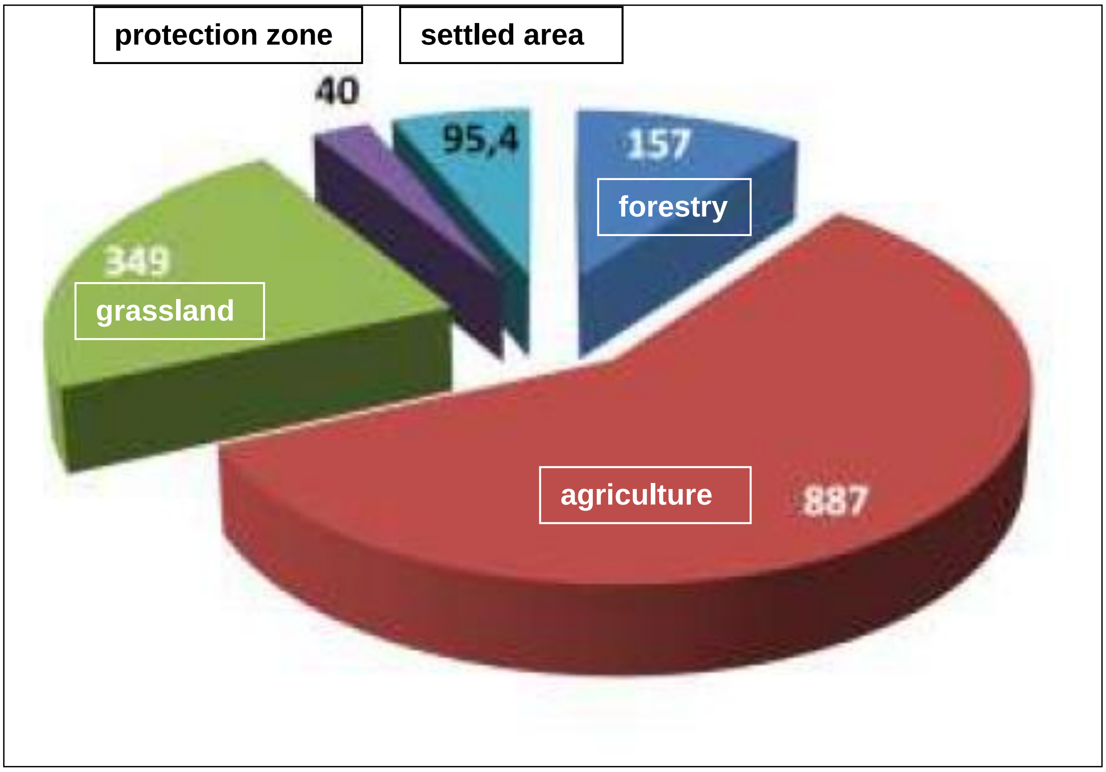

Figure 53: different kinds of land use in the community of Ellzee [hectare][64]

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[63] (Agency for Renewable Resources, 2013)

Agriculture - and grassland uses the two biggest areas with together 1.236 hectare, followed by forestry area. The already existing biogas plants are using around 430 hectares of land which leaves a theoretical potential for energetic use of around 591 hectares.

According to the energy concept only 10% of the area which is already used for biomass production shall be declared as potential for the use of biogas. The relevant 43 hectares stand for to the already mentioned 826 MWh electrical and 1.500 heat potential. In summary the community of Ellzee has a high potential of renewables sources in the future.

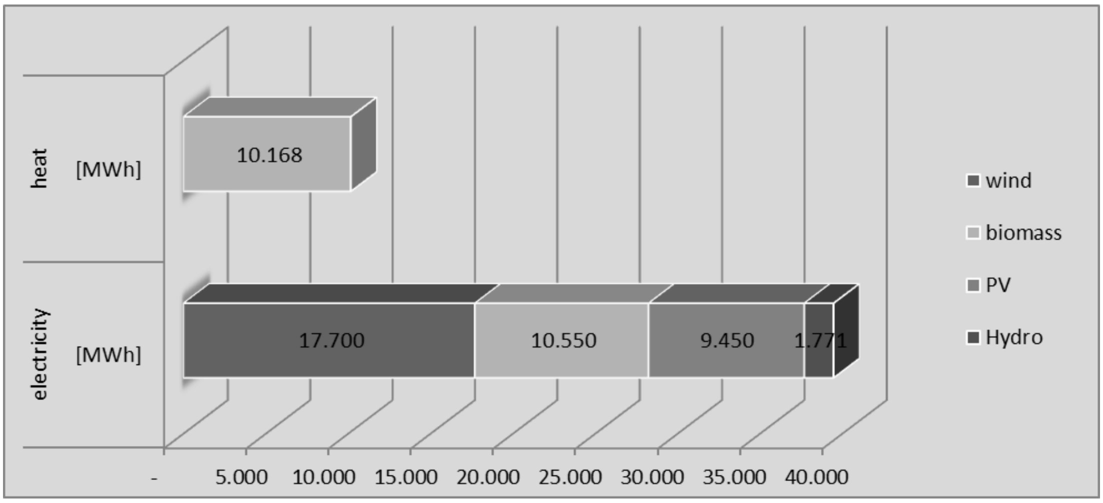

Figure 54: Theoretical potential of energy production by renewables (own calculation 2014)

[64] (renergie Allgäu, 2013)

3.5 Summary demand and supply in 2012

For the later simulation and economic assessment the generation portfolio has to be defined. The generation portfolio for the simulation consists of the power plants mentioned in 3.2. plus the wind power plant with commissioning date in 2012. The simulation will assess mainly the electricity production. In the case of the CHPs the heat production will be simulated only not to affect the electricity production of the CHP. The portfolio for the simulation shows the following figure, differentiated into installed capacity and produced electricity:

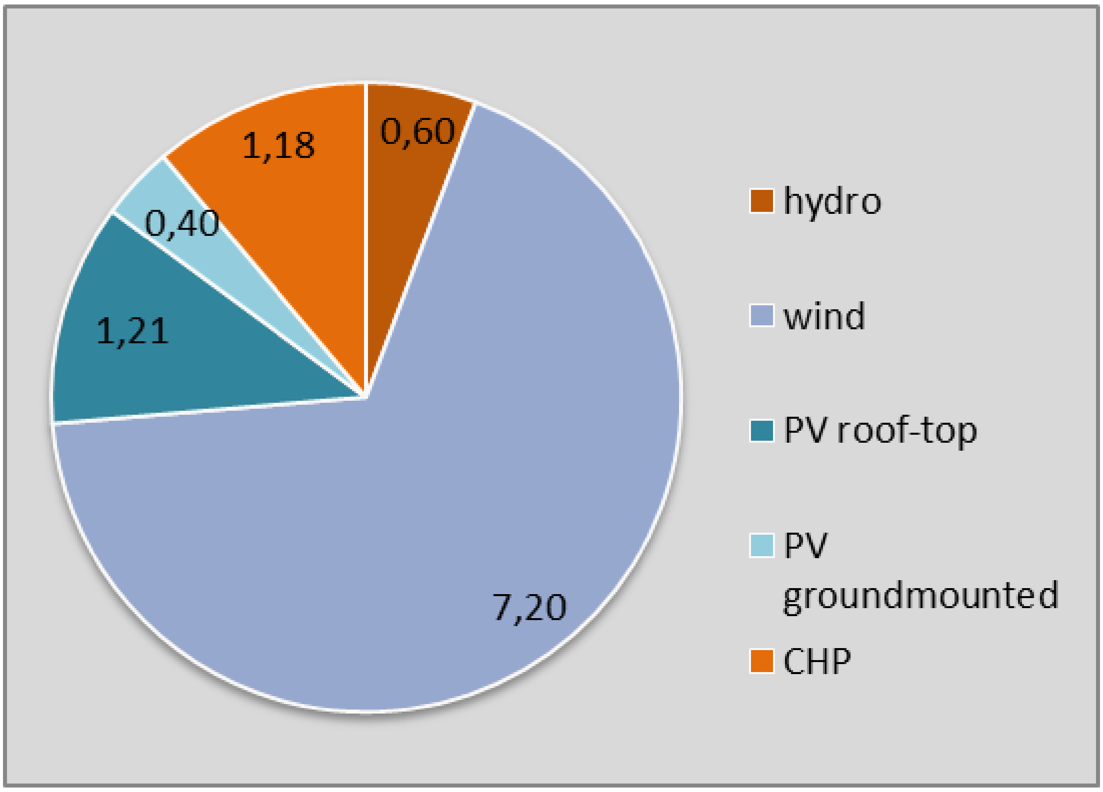

Figure 55: installed power generation portfolio 2012 [MW] (own calculation 2014)

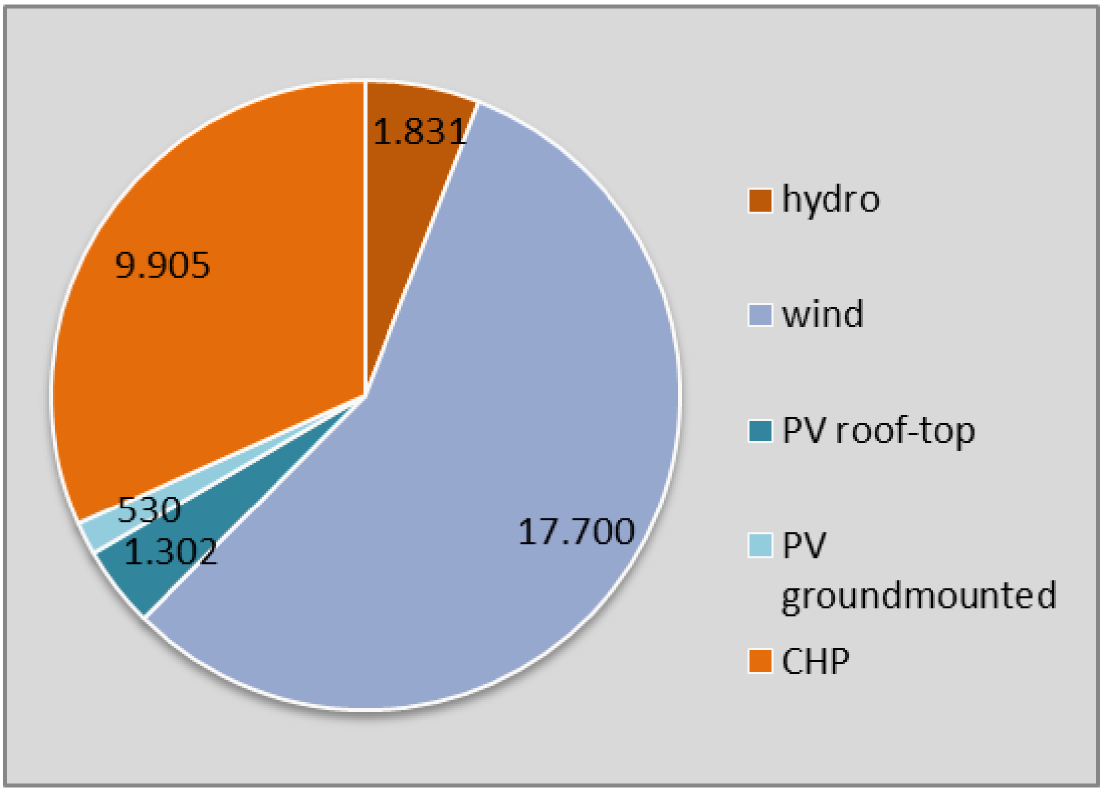

Figure 56: electricity production in 2012 [MWh] (own calculation 2014)

For a better understanding of the difficulty of the combination of volatile renewables like wind and photovoltaic the monthly electricity production is shown in the next figure.

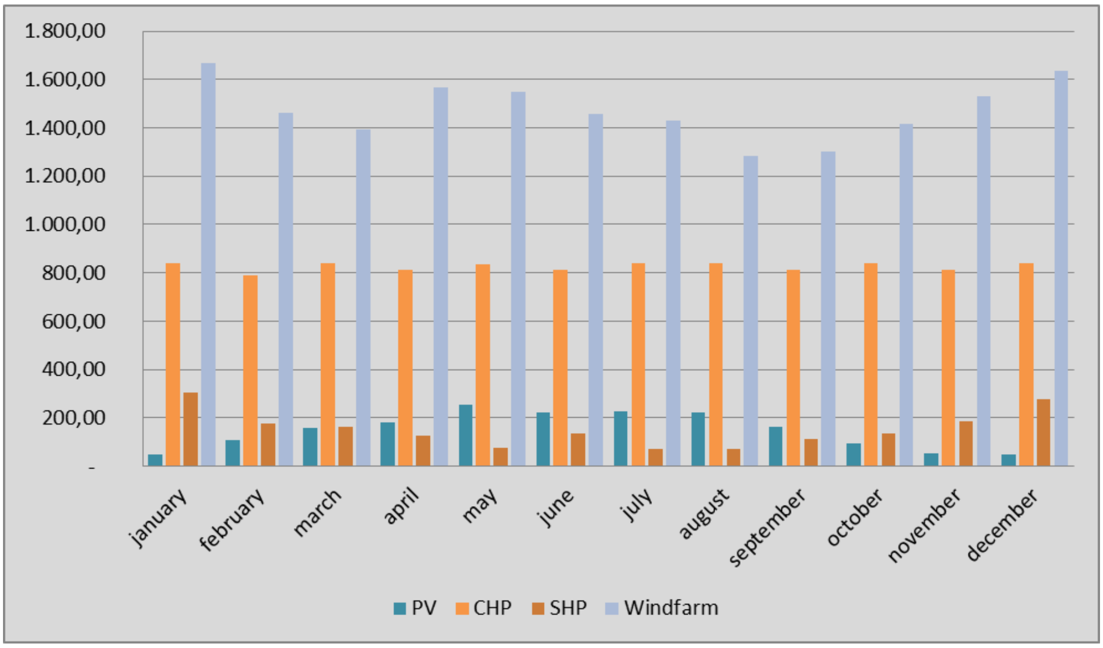

Figure 57: monthly distribution of the electricity production (own calculation 2014)

4 Simulation of the Virtual Power Plant

4.1 Software EnergyPRO

‘EMD is a Danish software and consultancy company supplying countries worldwide with software and consultancy services within the field of project design, planning and documentation of environmental friendly energy projects, particularly wind energy projects.’[65]

EMD has developed the two programs WindPRO and EnergyPRO. The latest will be used in this Master Thesis. EnergyPRO is a techno-economic simulation program for analyzing and optimizing of energy projects. In the following graph the different modules can be seen. In this context the modules design, operation and finance will be mainly used.

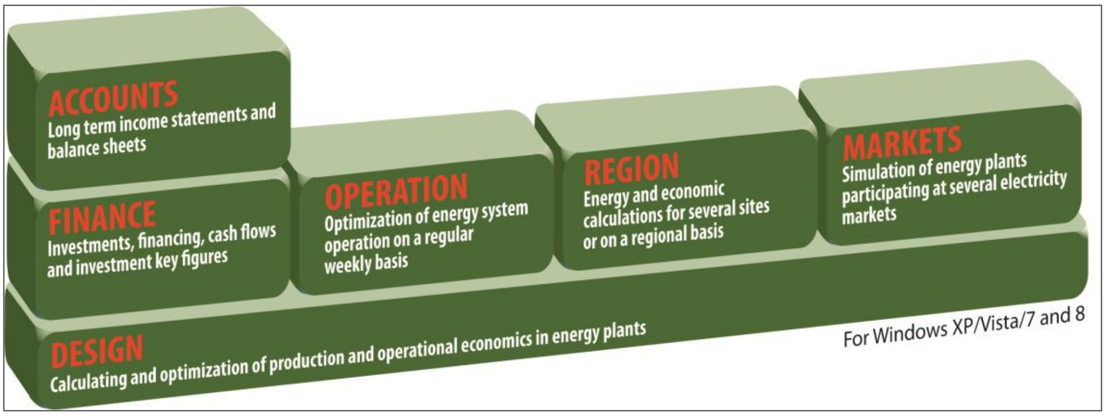

Figure 58: overview energyPRO modules[66]

4.2 Assumptions

For the simulation model with energyPRO different assumptions have to be defined, the technical assumptions are:

- Due to the fact that the orientation of the different photovoltaic roof-top installations are not known the installations will be combined to 3 modules

[65] (EMD International)

[66] (EMD International)

with east, west and south orientation to meet the given yearly electricity production
- To calculate the daily production of photovoltaic the yearly energy production will be distributed according to the local irradiation values
- Technical requirements for the internal communication won't be addressed
- Charging/discharging cycles are not evaluated further

For the economic calculation the following assumptions were implied:
- Energy compensation are based on the EEG 2012
- the Electric Energy and power prices are based on data from www.regelleistung.net
- no additional energy from the free market is needed for charging the storage system

4.3 Simulation of the supply and demand in 2012

In order to proceed to obtain the first core objectives - whether the local electricity demand can be provided locally - the collected data of the actual demand and supply have to be assessed with the EMD model energyPRO. Consistent with the energy concept the electricity as well as the heat demand and supply side will be assessed in this chapter. Nevertheless the focus of this work is the electricity demand and supply of the community and the adjacent economical assessment will be based on that.

Therefore the demand is divided into
- Electricity demand households
- Electricity demand industry
- Heat demand industry
- Heat demand households

And will be faced to the production data of the single renewable power plants like
- Run-of-river plant
- photovoltaic-plants with different orientations
- Ground mounted photovoltaic
- Wind farm
- CHP-plants

Figure 59 gives an overview about the different parts and gives also a first idea of the Virtual Power Plant which will be discussed in the further chapters.

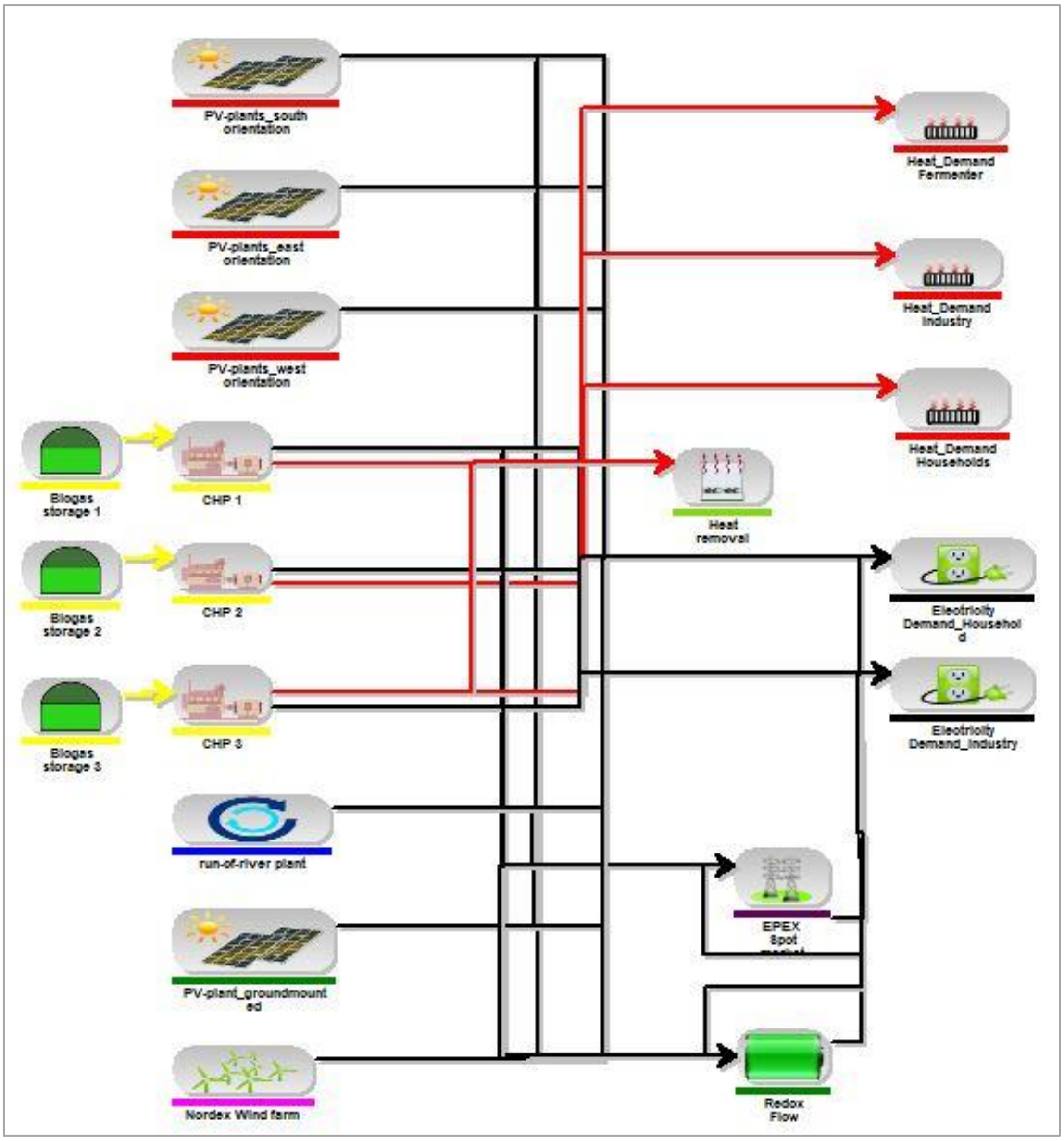

Figure 59: overview of the Virtual Power Plant within energyPRO (own calculation 2014)

The EMD model works not only with absolute data per annum it even more uses or can provide energy flows to simulate the energy demand and supply for a year or longer. Therefore the collected data from chapter 3.5 have to be rolled out over 2012 by using predefined time series and functions.

The demand site was simulated by using standardized load profiles for households and industry which were then rolled out by energyPRO over 2012 by combining the yearly consumption with the load profiles.

The supply site was simulated by using different approaches, for the run-of-river plant the production data was provided by the owner of the plant, for the photovoltaic-plants as well as the CHPs and the wind farm implemented calculation tools were used to rebuild the energy flows over 2012.

In some cases it was not possible to reconstruct the exact yearly production data by the simulation program EnergyPRO due to influences in between the plants and the distribution grid. The failure for the electricity supply between simulation and yearly given production data from the energy concept were around 2 percent. Figure 60 shows the data for the annual energy conversion of all installations.

The annual data show that the heat demand of 11.1 gigawatt hours can only be fulfilled by around 65 percent but for electricity the community of Ellzee can be seen as self-sufficient. The electricity demand of 10.6 gigawatt hours has on the counterpart a renewable electricity production of around 31.3 gigawatt hours. To assess if the demand is met by the production on every time in 2012 the operation strategy of the simulation has to be defined.

Calculatedperiod: 01.2012 - 12.2012

Heat demands:

Heat_Demand Fermenter	519,6 MWh
Heat_Demand Industry	1.867,0 MWh
Heat_Demand Households	8.731,5 MWh
Total	11.118,1 MWh
Max heat demand	4,3 MW

Heatproductions:

PV-plants_south orientation	0,0 MWh/year	0,0 %
PV-plants_east orientation	0,0 MWh/year	0,0 %
PV-plants_west orientation	0,0 MWh/year	0,0 %
CHP 1	3.513,6 MWh/year	39,6 %
CHP 2	3.250,1 MWh/year	36,6 %
CHP 3	2.111,1 MWh/year	23,8 %
run-of-riverplant	0,0 MWh/year	0,0 %
PV-plant_groundmounted	0,0 MWh/year	0,0 %
Nordex Wind farm	0,0 MWh/year	0,0 %
Total	8.874,8 MWh/year	100,0 %

Electricity demands (not including electricity consumed by energy units):

Electricity Demand_Household	1.789,2 MWh
ElectricityDemand_Industry	8.811,8 MWh
Total	10.601,0 MWh
Max electricity demand	2,5 MW

Electricity produced by energy units:
EPEX Spot market:

	All periods [MWh/year]	Of annual production
PV-plants_south orientation	265,3	0,8%
PV-plants_east orientation	592,8	1,9%
PV-plants_west orientation	443,9	1,4%
CHP 1	3.777,1	12,1%
CHP 2	3.337,9	10,7%
CHP 3	2.789,7	8,9%
run-of-riverplant	1.831,2	5,9%
PV-plant_groundmounted	529,9	1,7%
Nordex Wind farm	17.700,0	56,6%
Total	31.267,7	100,0%
Of annual production	100,0%	

Figure 60: overview about energy production in 2012 ((own calculation 2014))

EnergyPRO gives the possibility to simulate different ways of operation strategies. For example it is possible to combine the power plants with the different grid levels by underlying these with their operation data or to simulate the power plants in an island operation with or without connection to the electricity grid.

To obtain the first core object - to assess if it is possible to supply the local energy demand by the renewable power plants in the region - the later operation strategy will be the better choice. The operation strategy of an island system gives the possibility to assess the preferred self-sufficiency, because energyPRO tries to simulate first of all to fulfill the given electricity demand. There are two ways of simulation in the island operation strategy, with or without exchange with the electricity market.

For this simulation the exchange was allowed due to the fact that without exchange the fulfillment of the electricity demand goes at the expense of the heat production and therefore the given data cannot be simulated correctly.

As a result of the simulation in energyPRO the Figure 61 and Figure 62 show the duration curves for electricity and heat demand. Additionally to the mentioned self-sufficiency based on the absolute data the duration curve for electricity shows that the demand is met all the time by the production.

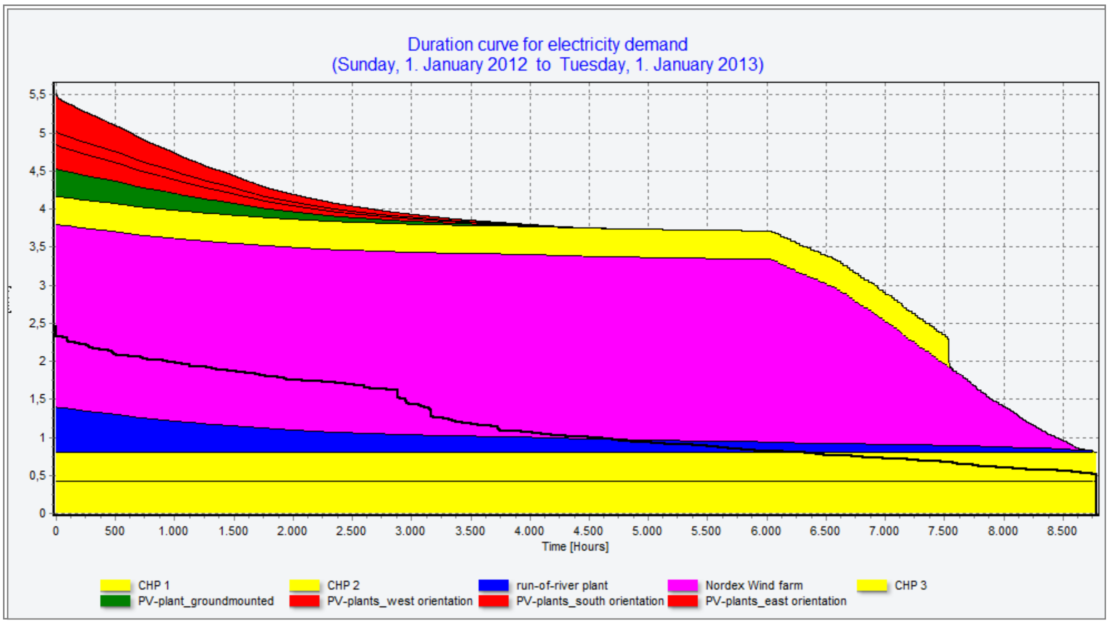

Figure 61: duration curve for electricity demand 2012 (operation time order)[67]

For heat there can be seen that the demand is not met by the production.

[67] own calculation 2014

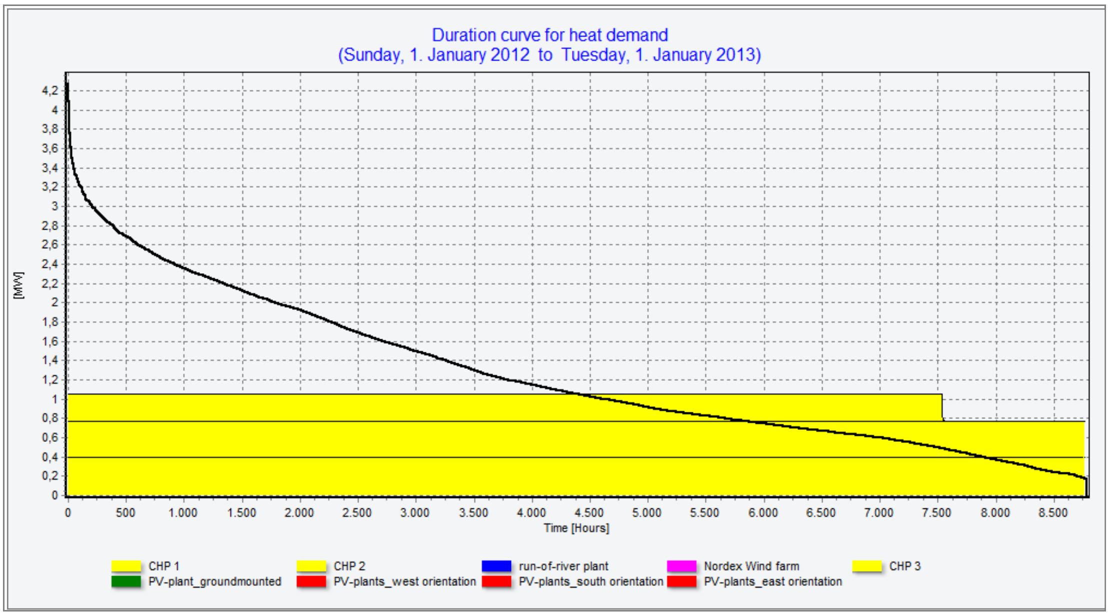

Figure 62: duration curve for heat demand 2012 (own calculation 2014)

To analyze these further four different time slots (each 7 days) in winter and summer as well as in spring and autumn were picked out and the graphs from energyPRO were compared to each other.

In January the high heat demand is significant, as well as high wind and hydro production. Electricity from photovoltaic is only available in small amounts. Heat and electricity production from biogas is nearly constant over the year.

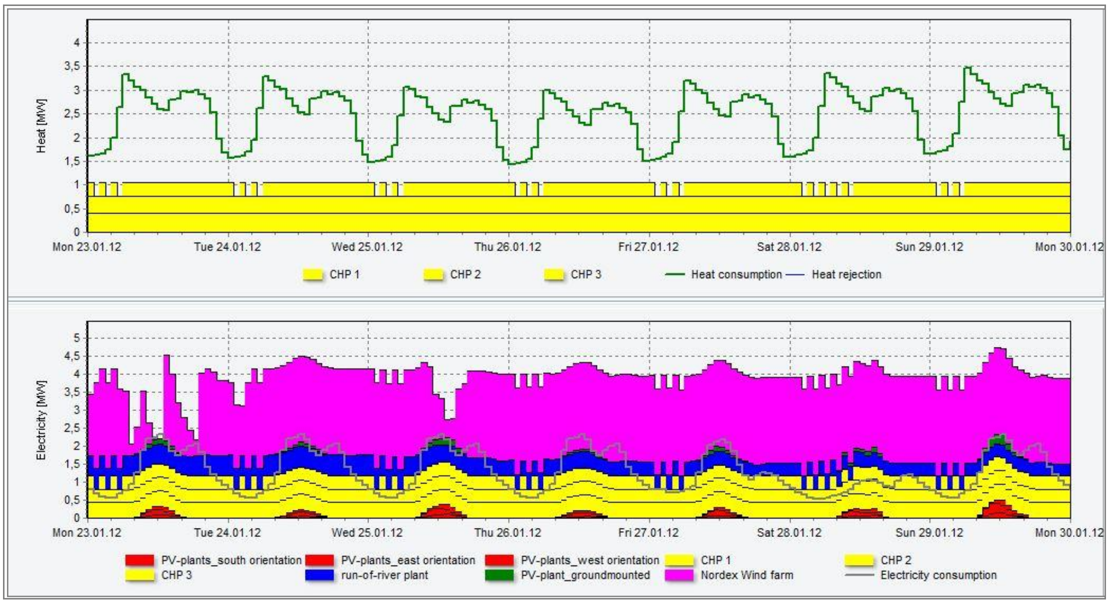

Figure 63: production graph for heat and electricity over 7 days (January 2012)[68]

[68] own calculation 2014

Due to the lowered heat demand in April the demand can nearly met by the biogas heat production. On the electricity simulation the production figures from wind become more and more unsteady, the hydro production decline but on the other side photovoltaic production increases.

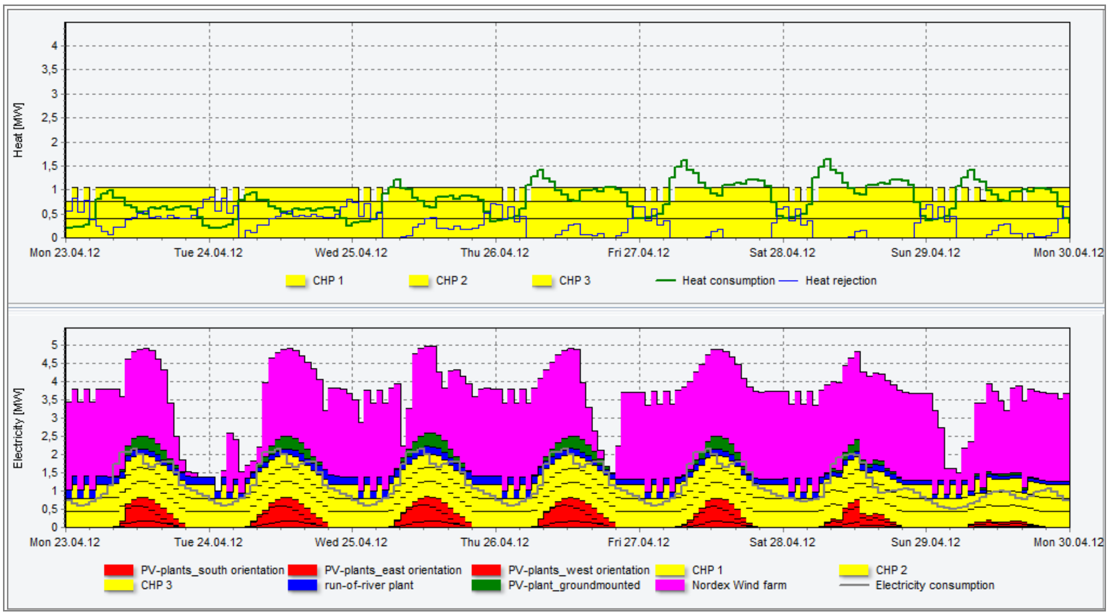

Figure 64: production graph for heat and electricity over 7 days (April 2012)[69]

During the summer months the renewable production units continue the picture shown in April, photovoltaic produces peaks during the day, hydro produces only on a minimum level and wind becomes more and more unsteady.

[69] own calculation 2014

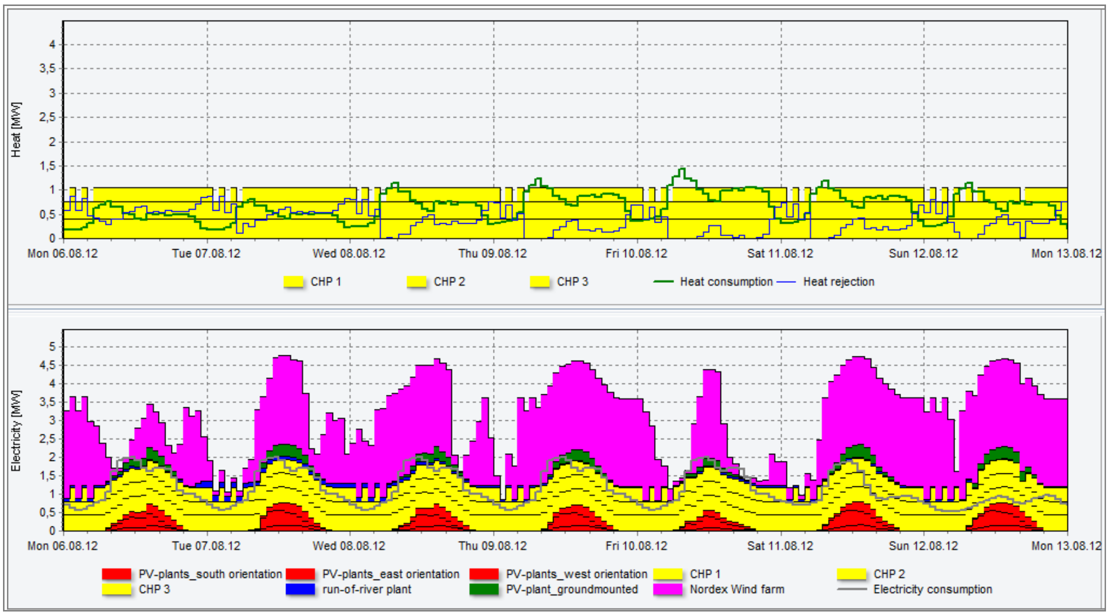

Figure 65: production graph for heat and electricity over 7 days (August 2012)[70]

During summer to autumn and further to winter the production of the different renewable units switches back to the first mentioned characteristic production behavior, higher wind and hydro production figures with corresponded lower photovoltaic supply.

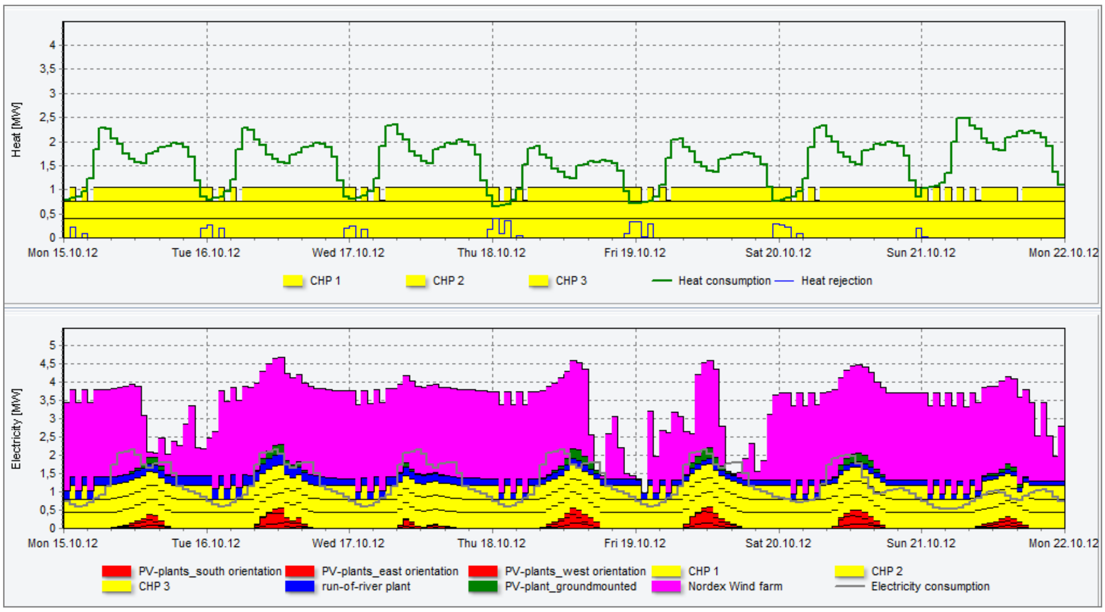

Figure 66: production graph for heat and electricity for 7 days (October 2012)[71]

[70] own calculation 2014

[71] own calculation 2014

In summary the typical production characteristics for the different renewable units were identified over the year. As well as the most important critical point of self-sufficiency by renewables - the unsteady production and therefore the missing base –load capability!

To summarize this chapter the residual load curve for electricity gives a good impression about the self-sufficiency of the whole system. It is defined in this thesis as the difference between electricity production of all power plants and the electricity demand in the area. By analyzing the residual load curve for electricity the periods of negative values can be identified. Negative values mean the demand exceeds the production. The highest shortage of electricity with 681 kilowatt occurred on the 6th of February 2012 between 6 and 7 pm (see Annex). In sum around 9 megawatt electricity was not met by the production in 2012. The longest shortage took place on the 1st of October from 4pm to 7 pm. The following figure shows an abstract of the residual load curve where the shortages with negative values can be seen.

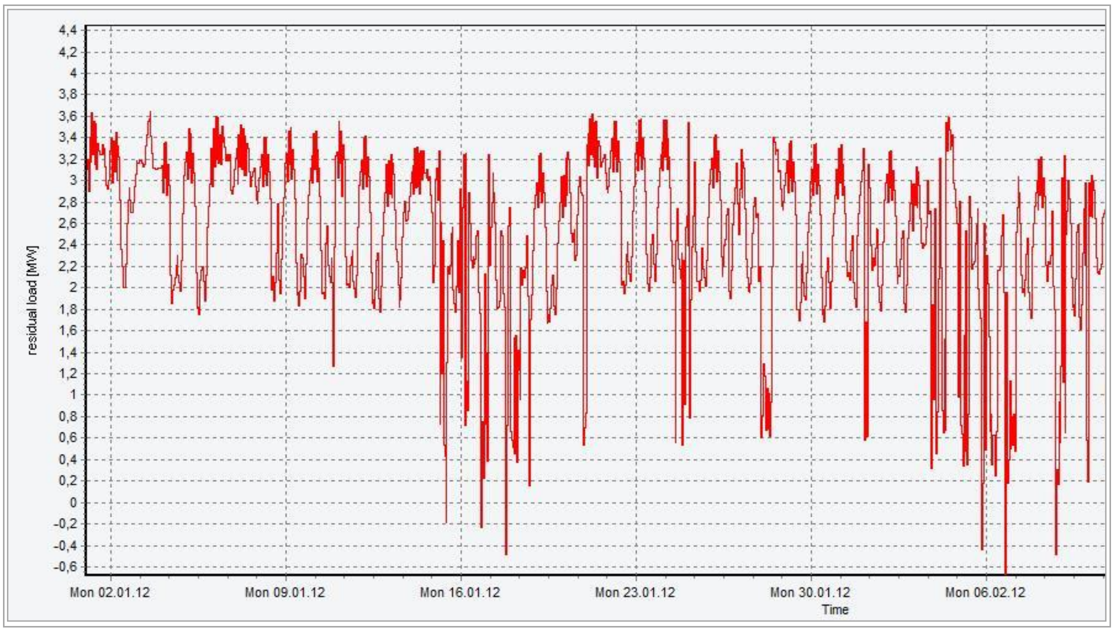

Figure 67: residual load curve (production minus demand)[72]

Nevertheless the community Ellzee could be self-sufficient by renewables energy in terms of capacity with the current installed units. The self-sufficiency in terms of energy will be discussed further under the assessment of the needed storage capacity.

[72] own calculation 2014

4.4 Assessment of the storage system

As mentioned above the community of Ellzee would be self-sufficient by renewables in terms of electricity production in 2012. But what about the other years, when the wind and photovoltaic conditions are worse? Therefore the status of electricity self-sufficiency can only be a snap-shot for 2012.

The more renewables will be integrated into the system in the next years the more the security of the system will be threatened due to the fact of the unsteady energy production of renewables. Storage technologies will help to compete with that problem. According to the efzn[73] study on the suitability of storage technologies for system security around 35 gigawatt installed power of short-term storage facilities like pumped hydro storage or batteries with an energy capacity of 188 gigawatt hours and 36 gigawatt long-term storage facilities means chemical storage as methane or hydrogen with an energy capacity of 8.000 gigawatt hours will be needed until 2050 to integrate 80% renewables according to the energy concept 2010[74]. According to the costs and the current status of development only PtG and batteries can be seen as useful for the application in Virtual Power Plants. Batteries shall be used for the latter calculation because the needed connection for the gas-storage isn't available in the community Ellzee so far. Batteries can be installed everywhere without prerequisites.

According to the later economic assessment the storage system will be determined for three different scenarios. In a first step the storage system will be used to fulfill 100 percent self-sufficiency of the community. On a second step the different prerequisites for the participation on the balancing market (SCR and TCR) will be transferred to the storage system.

4.4.1 Storage system 1MW$_{el}$ / 2MWh

As mentioned in the simulation section only a few times the demand of the community exceeds the electricity production. For the determination of the storage system - to reach energy self-sufficiency for the community Ellzee - the values from the residual load curve assessment will be used. The longest and the highest shortage shall be used to determine the storage system. The longest shortage was

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[73] (efzn, 2013)

[74] (mgm consulting partners GmbH)

given with 3 hours and around one megawatt and the maximum shortage per hour with 680 kilowatt electricity power.

For the further simulation we will use due to the relatively short storage times the Vanadium Redox Flow battery from Gildemeister which can be scaled up into the megawatt-range through parallel connection of multiple batteries (CellCubes).
According to the Gildemeister configuration platform the following combination of 5 CellCubes FB 200 – 400 should be plausible.

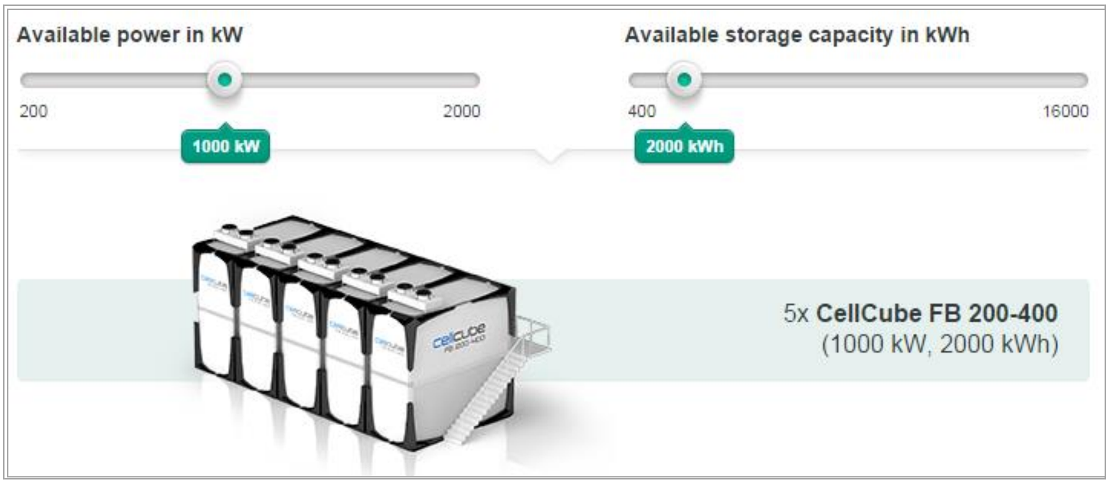

Figure 68: Gildemeister[75]

Figure 69 shows the simulation results in energyPRO for the period with the highest shortage (06.02.2012). Figure 70 shows the second determination criteria, the longest shortage on the 1st of October 2012. As can be seen the residual load curve now shows in combination with the storage system positive values for this period, which means the demand is always met by the electricity production. For that time the complete electricity power of the storage system is used.

[75] (Gildemeister)

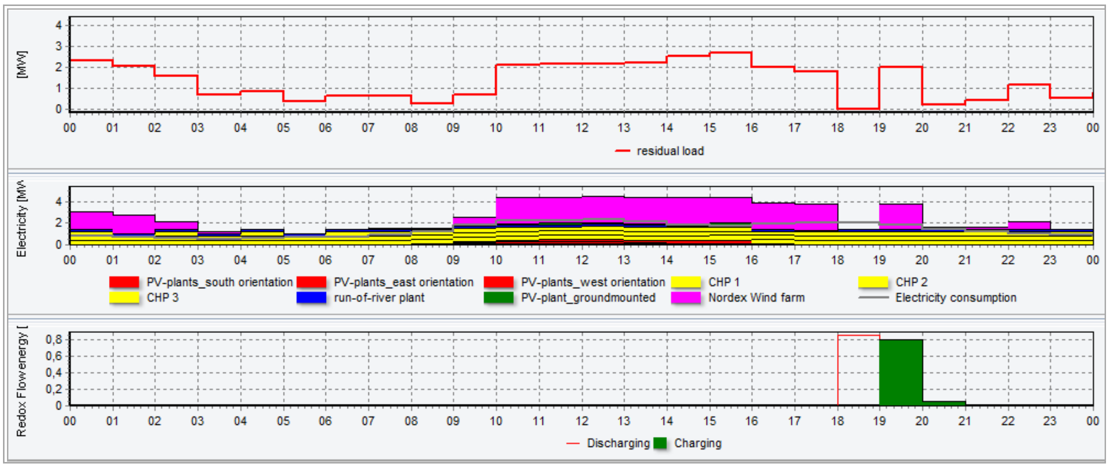

Figure 69: energyPRO simulation (06.02.2014)[76]

Figure 70 shows the graph for the residual load, the actual energy production of the different power plants, the charging/discharging of the storage and additional the content of the storage system. With that storage system the community of Ellzee would be completely self-sufficient in terms of electricity for the year 2012.

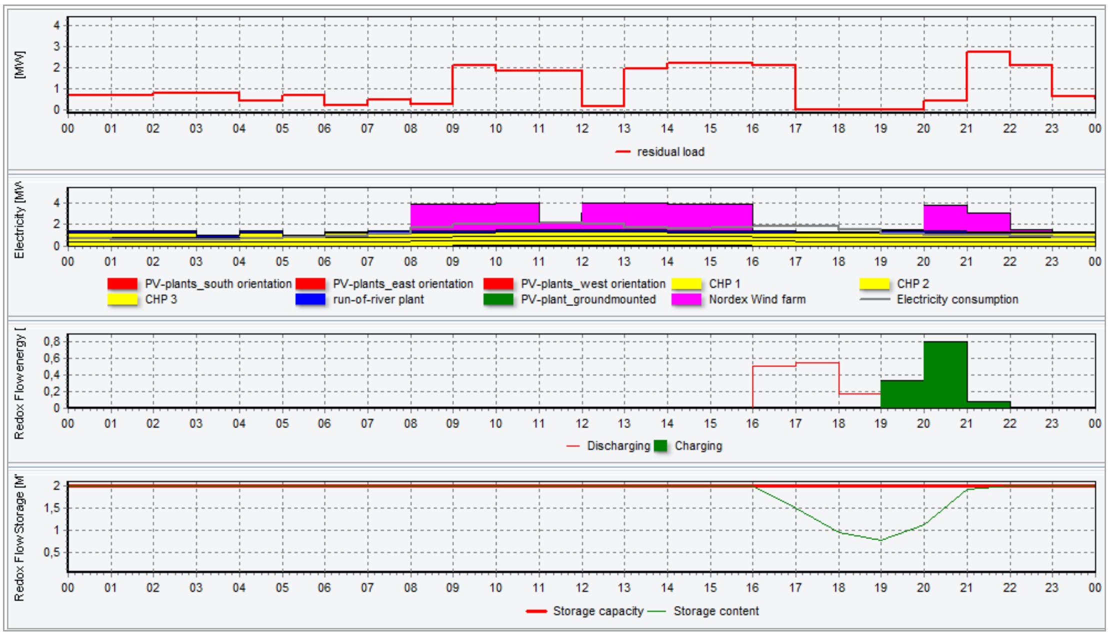

Figure 70: energyPRO simulation (01.10.2012)[77]

The costs for the battery storage systems are relatively high and differ with the used system. According to the above mentioned EIA study the costs for batteries are between 300 and 3.500 /kW. Another study shows prices in the range of 1.200 to

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[76] own calculation 2014

[77] own calculation 2014

1.500 euros per kilowatt[78]. The used storage system from Gildemeister costs around 4.000 €/kW which is in the upper region of the mentioned ranges.

For the later economic assessment the basic parameters for the above discussed system from Gildemeister are the following.

	1MW$_{el}$/2MWh
Investment costs:	4 Mio. Euros
WACC	6,40%
Depreciation period:	20 years
O&M costs:	0,5% of the investment

4.4.2 Storage system for the balancing market (5MW$_{el}$ / 20 MWh)

Due to the fact that one of the major questions is the economic assessment of the Virtual Power Plant and therefore the different promotion strategies have to be evaluated, the storage system has to be defined for the participation on the balancing market. To fulfill the requirements for the balancing market the storage system has to be adjusted on the necessary electric power and energy demands. The above defined storage system was calculated with the claim to meet 100 percent electricity supply for the community Ellzee. Additionally to that now the storage system has to be determined to participate on the minute and the secondary reserve market. According to the balancing energy market, which is handled about the online-platform www.regelleistung.de, for the secondary reserve it will be distinguished between two tariff-times, peak (8 am – 8 pm) and off-peak (residual time) from Monday to Friday. At least an electricity power of 5 megawatt has to be available during this time.

For the tertiary or minute reserve one day is divided into 6 intervals each 4 hours long. Within these intervals the minimum bid amount is also 5 megawatt. With a minimum of 5 megawatt, the storage system has to have an energy capacity of minimum 20 megawatt hours for the tertiary reserve and even 60 megawatt hours for the secondary reserve.

The storage system from Gildemeister was sufficient for the first objective to reach 100 percent energy autarky. For the further assessment the system has to be scaled

[78] (mgm consulting partners GmbH)

up. On the basis of the needed storage power capacity and the needed long-term storage ability (12 hours) for the secondary reserve the maximum of the storage system can be defined for the simulation. This can be stated with the mentioned 5 Megawatt electricity power and 60 megawatt hours. According to Gildemeister the maximum for the storage system is currently a storage time of up to 10 hours with 5 Megawatt and 40 Megawatt hours (with costs of around 45 million euros).

For the later economic assessment the basic parameters for the above discussed systems from Gildemeister are the following.

	$5MW_{el}$/*20MWh*	$5MW_{el}$/*60MWh*
Investment costs:	33 Mio. Euros	45 Mio. Euros
WACC	6,40%	
Depreciation period:	20 years	
O&M costs:	0,5% of the investment	

5 Results

In order to answer the second objective of the thesis - the economic feasibility of a Virtual Power Plant - two types of compensation systems will be compared. In a first step the economic situation of the different production units will be analyzed by underlying that all units are compensated with the fixed Feed-in-tariffs under the EEG 2012. There will be no direct marketing allowed, only for the hydro plant because it was installed more than 20 years ago and therefore no FIT is eligible.

In a second step the economics of the Virtual Power Plant will be assessed for direct marketing and additional in combination with the possibilities on the balancing market.

5.1 Economic appraisal for Feed-In-Tariffs (EEG 2012)

As a first step the renewable power mix of the community Ellzee will be calculated only with the requirement of using the under point 2.1 mentioned feed-in-tariffs within the EEG 2012. For the calculation of the total revenues first of all the tariffs for the different renewables have to be defined. The calculation of the total revenues is based on the start of commissioning, the installed capacity as well as the produced energy within 2012. According to the start of commissioning and the degression rate under the EEG the feed-in-tariff can be determined for every single power plant. Due to the manageable amount of power plants most of them can be calculated separately in EnergyPRO. There are two exceptions; the run of river plant is calculated with direct marketing over the intra-day market, because the plant is too old to define a feed-in-tariff under the EEG. The second exception is for the 92 roof-top photovoltaic-installations when the average feed in tariff was calculate according to the annex 2. The orientation of the different photovoltaic installations was not known and therefore the total amount was pooled into three different plants with west, south and east orientation. All three plants will be calculated with the average value of 380.8 € per Megawatt hour[79].

In summary the total revenues of all renewable power plants in the community Ellzee is around 4.0 million Euros. The following figure gives an overview of the different revenues and the feed-in tariffs used.

[79] See also Annex 3

Revenues								
run-of-riverplant	:	1.831,2	at	41,495*	=	75.984		
PV_south	:	220,5 MWh	at	380,8	=	83.964		
PV_west	:	581,5 MWh	at	380,8	=	221.446		
PV_east	:	537,6 MWh	at	380,8	=	204.731		
wind farm	:	17.700,0 MWh	at	95,1	=	1.683.272		
CHP 1								
NaWaRo	:	3.777,1 MWh	at	60,0	=	226.627		
basictariff	:	3.777,1 MWh	at	101,5	=	383.378		
CHP 1 Total							**610.005**	
CHP 2								
NaWaRo	:	3.337,9 MWh	at	60,0	=	200.275		
basictariff	:	3.337,9 MWh	at	103,7	=	346.142		
CHP 2 Total							**546.417**	
CHP 3								
NaWaRo	:	2.789,7 MWh	at	60,0	=	167.381		
basictariff	:	2.789,7 MWh	at	102,3	=	285.385		
CHP 3 Total							**452.766**	
PV_groundmounted	:	435,9 MWh	at	211,1	=	92.013		
Total Revenues								**3.970.599**
Total Operating Expenditures								**0**
Operation Income								**3.970.599**

* Average price

Figure 71: Operation income 2012 (based on FIT under EEG 2012) by energyPRO[80]

The revenues for the CHPs are based on two different components. The total tariff consists of the capacity related basic tariff and the bonus for the use of renewable primary products (NaWaRo).

In comparison hydro power has the lowest average compensation with 4 ct/kWh. The average compensation for electricity from renewables is 17,3 ct/kWh. Concluding Table 2 shows the economic and physical results in 2012.

Table 2: Economic results under the Feed-In-Tariff[81]

Renewable source	installed capacity [MW]	percentage P_{total}	energy produced [MWh]	percentage E_{total}	revenues [€]	percentage $revenues_{total}$	average compensation [€/kWh]
hydro	0,60	5,67%	1.831	5,86%	75.984	1,91%	0,041
wind	7,20	67,99%	17.700	56,61%	1.683.272	42,39%	0,095
PV roof-top	1,21	11,43%	1.302	4,16%	510.141	12,85%	0,392
PV groundmounted	0,40	3,78%	530	1,70%	92.013	2,32%	0,174
CHP	1,18	11,14%	9.905	31,68%	1.609.188	40,53%	0,162
Total	**10,59**	**100%**	**31.268**	**100%**	**3.970.598**	**100%**	**0,173**

[80] own calculation 2014

[81] own calculation 2014

5.2 Economic appraisal for market premium model

The legal and economic framework for direct power marketing is pretty complex for single power producers. As an alternative, plant operators have the option of participating in a Virtual Power Plant. In this case also the operation expenditures like trading fees for the EPEX, dealer fees and the costs for generation of production prognosis will be shared by all participants of the Virtual Power Plant.

In the following the different possibilities of direct power marketing will be discussed. First of all the revenues will be assessed by using the market premium model. The following simulation includes the revenues according to the energy production and the prices on the stock exchange EPEX. To calculate the average costs it will be supposed that the production prognosis meats the real feed-in of energy and therefore no balancing costs (for not meeting the prognosis) will accrue.
Figure 72 shows the result of the simulation for the operation income under the market premium model. For every single power plant the market premium and the management premium were calculated. Additionally all the produced electricity will be market on the stock exchange EPEX. The total revenues are around 3.7 million euros, which is 240.000 € less than the revenues according to the FIT calculation (see 5.1). The additional operation expenditures are also listed and decrease the revenues further. The before mentioned assumption no balancing costs accrue (the production prognosis meats the real feed-in) brings an additional financial risk for the power plant owner but won’t be determined further in this thesis.

Revenues								
CHP 1								
market premium	:				=	245.149		
Management Premium	:	3.777,1 MWh	at	3,0	=	11.331		
EPEX	:	3.777,1	at	42,596*	=	160.891		
CHP 1 Total							**417.372**	
CHP 2								
market premium	:				=	223.987		
Management Premium	:	3.337,9 MWh	at	3,0	=	10.014		
EPEX	:	3.337,9	at	42,596*	=	142.183		
CHP 2 Total							**376.184**	
CHP 3								
market premium	:				=	183.252		
Management Premium	:	2.789,7 MWh	at	3,0	=	8.369		
EPEX	:	2.789,7	at	44,755*	=	124.852		
CHP 3 Total							**316.473**	
Hydropower								
EPEX	:	1.831,2 MWh	at	41,495*	=	75.984		
Hydro power Total							**75.984**	
Wind								
market premium	:				=	941.795		
Management Premium	:	17.700,0 MWh	at	12,0	=	212.400		
EPEX	:	17.700,0	at	43,022*	=	761.482		
Wind Total							**1.915.677**	
PV_groundmounted								
Management Premium	:	435,9 MWh	at	12,0	=	5.230		
market premium	:				=	73.468		
EPEX	:	435,9 MWh	at	45,034*	=	19.629		
PV_groundmountedTotal							**98.328**	
PV_south								
market premium	:				=	74.577		
Management Premium	:	220,5 MWh	at	12,0	=	2.646		
EPEX	:	220,5	at	45,122*	=	9.949		
PV_south Total							**87.172**	
PV_east								
market premium	:				=	182.003		
Management Premium	:	537,6 MWh	at	12,0	=	6.452		
EPEX	:	537,6	at	45,992*	=	24.727		
PV_east Total							**213.181**	
PV_west								
market premium	:				=	196.747		
Management Premium	:	581,5 MWh	at	12,0	=	6.978		
EPEX	:	581,5	at	43,927*	=	25.545		
PV_west Total							**229.270**	
Total Revenues								**3.729.641**
OperatingExpenditures								
EPEX basis sum	:				=	25.000		
EPEX annual fee	:				=	10.000		
EPEX trading fee	:	20.619,6 MWh	at	0,04	=	825		
prognoses	:				=	0		
Dealer fee	:	20.619,6 MWh	at	1,5	=	30.929		
electricityimport	:				=	704		
Total Operating Expenditures								**67.458**
Operation Income								**3.662.182**

Figure 72: Operation income 2012 (based on market premium model under EEG 2012)[82]

Table 3 gives an overview about the economic situation and compared to the economics in the chapter before the average compensation per kWh decreased slightly. What also can be seen is that the market premium model only makes sense for the wind power and photovoltaic plant owners. Every other energy source will be compensated with a lower rate compared to the FIT-model.

[82] own calculation 2014

Table 3: Economic results (market premium model)[83]

Renewable source	installed capacity [MW]	percentage P_{total}	energy produced [MWh]	percentage E_{total}	revenues [€]	percentage $revenues_{total}$	average compensation [€/kWh]
hydro	0,60	5,67%	1.831	5,86%	75.984	2,04%	0,041
wind	7,20	67,99%	17.700	56,61%	1.915.677	51,36%	0,108
PV roof-top	1,21	11,43%	1.302	4,16%	529.623	14,20%	0,407
PV groundmounted	0,40	3,78%	530	1,70%	98.328	2,64%	0,186
CHP	1,18	11,14%	9.905	31,68%	1.110.029	29,76%	0,112
Total	**10,59**	**100%**	**31.268**	**100%**	**3.729.641**	**100%**	**0,171**

5.3 Economic appraisal for balancing market

The second option for a Virtual Power Plant in terms of direct marketing is to participate on the balancing market.

By participation on the balancing market not all of the available energy from a Virtual Power Plant has to be traded on the balancing market, beside that the remaining energy can be traded under the market premium model. As mentioned before there are three kinds of control reserve which are traded on the balancing market.

Due to the fact that *primary control reserve* has to be available within 15 seconds the communication infrastructure of the Virtual Power Plant especially in between the single producers has to be appropriate designed. This means a massive investment for a Virtual Power Plant because normally all the single power producers are wide spread. As most of the already realized Virtual Power Plants in Figure 21 the focus in this thesis will be on the two options secondary and minute control reserve.
Secondary control reserve (SCR) is tendered once per week for peak (8 a.m. – 8 p.m. without public holidays) and off-peak times (residual time). *Minute or tertiary control reserve* (TCR) will be traded on a daily basis. For both control reserves the minimum capacity for the bid has to be 5 Megawatt. Negative and positive reserve will be handled separately. The offer has to imply the power price to hold the power available and the energy price for the actual delivery. The acceptance of bids will occur according the merit order of the power prices. The accepted bids will then be ordered starting with the lowest energy price.

[83] own calculation 2014

The simulation of the balancing market in EnergyPRO with secondary and tertiary power reserve including the compensation scheme for power and energy prices is pretty complex and currently not available for energyPRO. With the next software update the simulation of the balancing market will be possible.

To assess the economic situation of the VPP in combination with the balancing market the costs of the storage system will be faced the possible incomes of the different control reserves.

As mentioned under 4.4 participating on the balancing market needs a minimum power capacity of 5 megawatt. Due to the small amount of controllable energy (hydro and CHP) the requirements for the balancing market shall be fulfilled completely by the storage system. On the other side the currently maximum available system from Gildemeister consists of 25 Cellcubes FB 200-1600 (5 MW-40 MWh) with investment costs of around 45 million, which wouldn't met the requirements for secondary control reserve market. Taking part only on the tertiary power reserve market would result in downsizing the storage system to 25 Cellcubes FB 200-800 (5 MW-20 MWh). Out of the basic parameters under point 4.4 the costs of the different storage systems can be calculated, see Table 4.

Table 4: Costs of the Vanadium-Redox-Flow storage system[84]

Vanadium Redow Flow

electric power	*kW*	*1.000*	*5.000*
storage capacity	*kWh*	*2.000*	*20.000*
Battery	€	4.250.000	33.125.000
Planing	€	425.000	3.312.500
Investment	**€**	**4.675.000**	**36.437.500**
O & M	**€/a**	**23.375**	**182.188**

For the calculation of the possible incomes of the balancing market the power capacity prices as well as the energy prices have to be evaluated. As mentioned in

[84] Own calculation 2014 on the basis of data from Gildemeister

Figure 14 and Figure 13 the tendency of the achievable power capacity prices is decreasing, for positive power reserve even more than for negative reserve. According to these figures in conjunction with Figure 15 and Figure 16 the following power capacity prices in 2012 will be used for the later calculation.

Table 5: average power prices for TCR and SCR (2012)[85]

data 2012		average power price [€/MWh]	average power price [€/MW]
pos. TCR		0,60	5.381
neg. TCR		3,00	26.384
pos. SCR	peak	2,50	5.360
	off-peak	3,50	16.394
neg. SCR	peak	9,00	23.821
	off-peak	13,00	68.897

The evaluation of the energy prices for the different kinds of Tertiary and Secondary Control Reserve is more difficult due to the lack of sufficient data. Adequate data is only available for the Tertiary Control Reserve (see Figure 17 and Figure 18). On the basis of the before mentioned facts and the limitation of the storage system to a maximum storage capacity of 40 megawatt hours[86] the further calculation will be done only for Tertiary Control Reserve.

The possible income for the actually delivered energy is mainly depending on the offered energy price per megawatt hour. Therefore the offered energy price has to be defined. Figure 15 and Figure 16 shows the dependency of the possible incomes, the probability of accepting offered bids and the delivery time to the offered energy price. For the calculation of the income 200 euros per megawatt hour will be

[85] own calculation 2014

[86] Trading TCR would need at least 60 megawatt hours storage capacity under the given circumstances; up to date the maximum scalability of the Gildemeister FB CellCubes is 40 MWh

fixed as offered energy price, because that price generates the highest incomes according to the mentioned graphs in 2012. The energy price of 200 €/MWh represents a lower price and therefore results - according to the merit order effect - in a higher acceptance probability.

Table 6: average energy capacity prices for TCR (2012)[87]

data 2012	offered energy price	energy price	rate for accepting bid	total energy price
	[€/MWh]	[€/MW]	[%]	[€/5MW]
pos. TCR	200	75.000	80%	**300.000**
neg. TCR	200	32.000	80%	**128.000**

For calculating the possible total incomes of the Virtual Power Plant by trading tertiary control reserve on the balancing market the following assumptions will be taken as basis:

- Gildemeister storage system with 5 MW electric power and 20 MWh energy storage capacity
- storage system delivers all time-slices for negative and positive TCR (6 x 4 hours)
- the charging energy for the storage system will be taken to 100 percent by the renewables from the VPP; therefore no additional energy delivery costs will be considered
- 80 percent of the time the offered energy prices will be accepted

[87] own calculation 2014

Table 7: total income by trading negative/positive TCR (2012)[88]

data 2012	average power price [€/MW]	total power price [€/5MW]	offered energy price [€/MWh]	total energy price [€/5MW]	total income [€/5MW]
pos. TCR	5.381	**26.905**	200	**300.000**	**326.905**
neg. TCR	26.384	**131.920**	200	**128.000**	**259.920**

For the economic feasibility of the storage system the above evaluated costs of the storage system and the generated incomes of trading the electricity as Tertiary Control Reserve will be finally assessed by using the Net-Present-Value (NPV) method. 'NPV is a central tool in discounted cash flow (DCF) analysis and is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting and widely used throughout economics, finance, and accounting, it measures the excess or shortfall of cash flows, in present value terms, above the cost of funds… NPV is an indicator of how much value an investment or project adds to the firm.' (2014)

According annex 5 the NPV is negative and therefore the investment for the storage system (5 MW_{el}/20 MWh) is not economical viable. This was the expected result for the time being.
To get an idea of the economics of the storage system sensitivity analyses of the NPV will be done by reducing the investment cost. This shows a break-even point at around 90 percent cost reduction.

[88] own calculation 2014

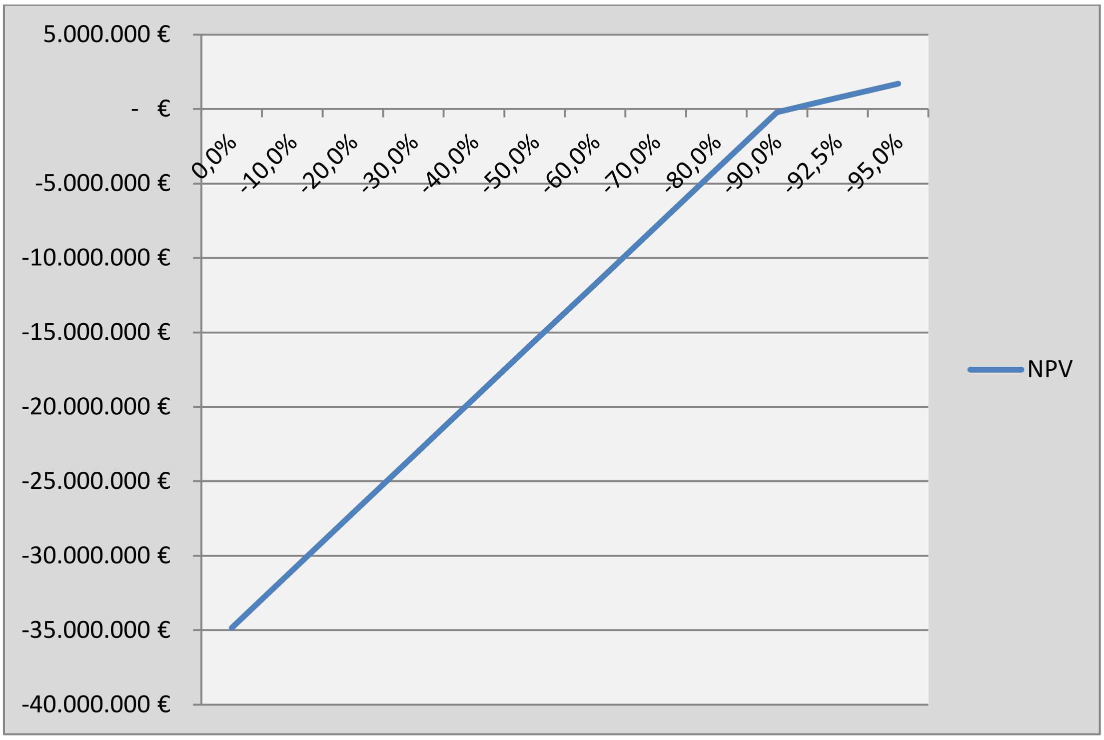

Figure 73: Net Present Value in dependency of the investment cost reduction[89]

Further calculations with different income scenarios like negative TCR would not result in better values due to the fact that with the positive TCR (positive TCR, see Table 7) the best available income scenario was chosen. In further studies there could be assessed the results of trading negative Secondary control reserve. According Table 5 there could be some potential for higher yields, because already the power prices are at a high level.

Additionally has to be mentioned that delivering energy to the balancing market will reduce the amount of energy which can be sold via the premium model. Under the assumption that all time-slices will be delivered with a capacity of 5 megawatt the specific income for offering and delivering positive TCR are 7,46 euros per megawatt hour.

[89] own calculation 2014

Table 8: specific income by trading negative/positive TCR (2012)[90]

data 2012	offered energy price	total energy price	total income	specific income
	[€/MWh]	[€/5MW]	[€/5MW]	[€/MWh]
pos. TCR	200	**300.000**	**326.905**	**7,46**
neg. TCR	200	**128.000**	**259.920**	**5,93**

Comparing the specific income (see 5.3) from participating on the balancing market for positive TCR with the market premium income values under 5.2 the relatively high negative value for the NVP is understandable. With the market premium model the power plant operators reach average compensations around 170 euros per megawatt hour, without taking the massive investment costs for the storage system. For the time being participation on the balancing market isn't economical for the different power plant owners with small VPP as in the case of the community Ellzee.

[90] own calculation 2014

6 Conclusion

The German electricity production is subject to increasing modifications. Renewable energies do have a growing influence to the grid with all its positive and negative consequences. The superior goal is to bring renewable electricity production more in line with demand by speeding up grid expansion, improving market and system integration and to increase the use of storage facilities.

The projects[91] 'Kombikraftwerk 1 und 2' from the German Ministry for the Environment, nature conversation and nuclear safety in conjunction with private partners has shown that the supply with 100% renewables is possible (Kombikraftwerk 1) and the system security (Kombikraftwerk 2) can also be provided under these circumstances.

The goal of this thesis was to combine renewables on regional level and to assess the economic possibilities of the Virtual Power Plant by using different promotion possibility under the German EEG.

Based on the data of a conducted energy concept for the community Ellzee first of all the energy supply and demand in the region was calculated for 2012. The annual electricity consumption is 11.162 megawatt hours compared to around 30.000 megawatt hours electricity production. The heating demand summarizes to 10.569 megawatt hours and the supply to nearly 8.000 megawatt hours. The data were simulated within the program energyPRO which enrolls the given data (heat and electricity) over the whole year by using predefined time series or profiles. It is also possible to deposit certain promotion strategies to assess the economic situation as well as combining different generation units with storage capacities.

In a second step the possibility of electric self-sufficiency of the community Ellzee from renewables was to assess. Therefore the residual load curve which is defined within the thesis as the difference between electricity generation and demand was to calculate. Although the above mentioned electricity production is three times higher than the demand shows the residual load curve times where the demand is not met by the generation (negative residual load). These times were shown as visual illustration in energy PRO.

After the evaluation of the different times where the demand was not met by the production the necessary storage system was to define. Therefore the battery

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[91] http://www.kombikraftwerk.de/

technology Redox-Flow was chosen due to the fact that the technology has according to Figure 28 the needed requirements (capacity, storage time, scalability). The definition of the storage system was based on the times with the highest (capacity) and the longest shortage in terms of electric energy. For the calculated data the storage system had to be of a capacity of 1MWel and 2MWh. The costs for the Vanadium-Redox-Flow battery from the supplier Gildermeister are around 4,25 million euros. Within this configuration the first main question of the master thesis was answered, the self-sufficiency for the region in terms of electricity supply by renewables is possible for 2012. To which extend this statement can be transferred to other years and what would be the economic parameters for the supply with 100% renewables for the power plant owners as well as the consumers could be part of further assessments.

In the second part of the master thesis the economic assessment was done underlying different promotion possibilities for the Virtual Power Plant. There were three different ways of promotion under the EEG to compare. Selling the produced electricity to fixed prices defined as Feed-In-Tariffs, where every kind of renewable production has its own tariff which is granted for 20 years. For the different renewable energy generation units the compensation per kWh can be seen in Table 2 where the average compensation value is calculated with 173 Euros per MWh.
The second way of promoting the electricity is selling it on the stock exchange within the market premium model. This model shall introduce the renewable generation to the free electricity market via the stock exchange EPEX in Leipzig. The model is based on the fact that the generators are selling their electricity on the EPEX but at least get the same payment per kWh as under the Feed-In-Tariff. They even can generate more income, because this premium will be offered as an incentive in order to cushion risks in direct power marketing. According to Table 3 the average compensation with 171 euros per MWh is slightly under the value for FIT compensation. Remarkable is there that the market premium model only makes sense for the wind power and photovoltaic plant owners. Every other energy source will be compensated with a lower rate compared to the FIT-model.

For CHP plants there would be the further assessment possible underlying the promotion scheme for flexible CHPs where the units get incentives for adding an additional CHP in order to produce more flexible base load.

The third promotion strategy deserved upgrading the single generation units to a Virtual Power Plant where all generation units are combined. The Virtual Power Plant gives further possibilities to market the generated energy by adding storage capacity to the system. Part or all of the energy can be traded on the balancing market via Primary, Secondary and Tertiary Control Reserve to balance fluctuations in the power grid. The different kinds of balancing power differ in terms of duration of the imbalance. For the assessment of the economics the storage system had to be defined. Due to the high shares (more than 60%) of volatile generations like wind and photovoltaic and the along going unpredictability of feeding in electricity the needed energy for the balancing market had to be delivered by the storage system. For the calculation the Tertiary Control Reserve market was chosen as basis, because of the availability of market data and the limitation of the storage system from Gildemeister to 40 megawatt hours of energy storage capacity.

To fulfill the requirements of the Tertiary Control Reserve a Vanadium-Redox-Flow system with a capacity of 5MW and 20MWh had to be implemented. The costs for the system are according to Table 4 with 33,12 million euros very high. For the assessment of the economics of the battery the Net Present Value method was used. In combination with the possible income for trading positive Tertiary Control Reserve (Table 7) and the high investment cost the NPV was negative and therefore the investment under the given conditions not economic viable. The sensitivity analyses showed that a cost reduction of around 90% would be needed to be economical with the Redox-Flow battery.

Compared to the income potential of the two other strategies the balancing market for Tertiary Control Reserve offers very low rates (between 5,9 and 7,4 €/MWh) according to Table 8. Therefore the direct marketing within the market premium model is the promotion strategy with the highest income potential.

There is further potential to assess different control reserves, for example offering negative SCR. The calculated incomes for the capacity price in Table 5 do have potential. In combination with shorter time –slices (<12 hours) and daily tender times the high storage costs could be reduced and be economic viable for even smaller Virtual Power Plants. The extra costs for these shorter tendering times shall be also evaluated in further assessments.

Summarizing is to say; ‘to justify long-term expansion and the sustainable integration of renewable energies in the free power market, power from renewable resources must also be able to compete with fossil energy sources with regard to the commercial aspects - in addition to ecological aspects. However, individual plants are frequently too small to efficiently and directly market the energy generated. Moreover, many plant operators do not have any experience on the trading floor of the energy exchange' (energy2market, 2014). Here the model of regional Virtual Power Plants acting on the different energy markets is in my point of view the best way. As a result, renewable energies can compete in the near future with electricity generated from nuclear power and fossil energy sources under market conditions.

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8 Annex

Annex 1: Photovoltaic installations[92]

Nan	Geometrie (EWKT)	Leistung (kW	Stromproduktion 2012 (kW	Volllaststunden (berechne	Inbetriebnahn	Freiflächenanlag
Ellzee	SRID=31468;POINT (4375854 5356623)	5	3.553,00	710,60	2004	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	29	25.743,00	887,69	2004	nein
Ellzee	SRID=31468;POINT (4373656 5355603)	16	18.376,00	1.148,50	2004	nein
Ellzee	SRID=31468;POINT (4373833 5355570)	9	9.796,00	1.088,44	2003	nein
Ellzee	SRID=31468;POINT (4373786 5355552)	9	9.477,00	1.053,00	2004	nein
Ellzee	SRID=31468;POINT (4373791 5355524)	7	6.559,00	937,00	2002	nein
Ellzee	SRID=31468;POINT (4373791 5355524)	9	9.709,00	1.078,78	2003	nein
Ellzee	SRID=31468;POINT (4373752 5355493)	6	6.233,00	1.038,83	2002	nein
Ellzee	SRID=31468;POINT (4375528 5356726)	12	13.213,00	1.101,08	2005	nein
Ellzee	SRID=31468;POINT (4373025 5356357)	30	33.633,00	1.121,10	2004	nein
Ellzee	SRID=31468;POINT (4373847 5354730)	12	12.418,00	1.034,83	2008	nein
Ellzee	SRID=31468;POINT (4374010 5355983)	22	23.782,00	1.081,00	2009	nein
Ellzee	SRID=31468;POINT (4373594 5354835)	9	7.977,00	886,33	2006	nein
Ellzee	SRID=31468;POINT (4373457 5354436)	15	15.184,00	1.012,27	2006	nein
Ellzee	SRID=31468;POINT (4373530 5354721)	9	8.957,00	995,22	2009	nein
Ellzee	SRID=31468;POINT (4374010 5355983)	31	33.684,00	1.086,58	2007	nein
Ellzee	SRID=31468;POINT (4375477 5356885)	5	4.989,00	997,80	2008	nein
Ellzee	SRID=31468;POINT (4375528 5356726)	10	9.957,00	995,70	2009	nein
Ellzee	SRID=31468;POINT (4375725 5357179)	2	2.555,00	1.277,50	2008	nein
Ellzee	SRID=31468;POINT (4373580 5354674)	13	12.157,00	935,15	2003	nein
Ellzee	SRID=31468;POINT (4373818 5354510)	6	7.010,00	1.168,33	2004	nein
Ellzee	SRID=31468;POINT (4373595 5354594)	19	17.921,00	943,21	2004	nein
Ellzee	SRID=31468;POINT (4373442 5354626)	8	8.953,00	1.119,13	2005	nein
Ellzee	SRID=31468;POINT (4373540 5354664)	11	12.627,00	1.147,91	2007	nein
Ellzee	SRID=31468;POINT (4375602 5356546)	9	9.147,00	1.016,33	2006	nein
Ellzee	SRID=31468;POINT (4373729 5354433)	26	31.155,00	1.198,27	2007	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	22	24.232,00	1.101,45	2009	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	22	24.127,00	1.096,68	2009	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	22	24.260,00	1.102,73	2009	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	11	12.059,00	1.096,27	2009	nein
Ellzee	SRID=31468;POINT (4375504 5357062)	5	5.697,00	1.139,40	2009	nein
Ellzee	SRID=31468;POINT (4373791 5355524)	8	8.501,00	1.062,63	2009	nein
Ellzee	SRID=31468;POINT (4375537 5357506)	45	48.163,00	1.070,29	2009	nein
Ellzee	SRID=31468;POINT (4375783 5356992)	26	27.730,00	1.066,54	2008	nein
Ellzee	SRID=31468;POINT (4373552 5354425)	16	18.009,00	1.125,56	2009	nein
Ellzee	SRID=31468;POINT (4373740 5354604)	22	24.358,00	1.107,18	2009	nein
Ellzee	SRID=31468;POINT (4375525 5357332)	5	4.873,00	974,60	2009	nein
Ellzee	SRID=31468;POINT (4373833 5355570)	20	19.509,00	975,45	2009	nein
Ellzee	SRID=31468;POINT (4376559 5357292)	21	22.378,00	1.065,62	2010	nein
Ellzee	SRID=31468;POINT (4375519 5357183)	10	10.926,00	1.092,60	2010	nein
Ellzee	SRID=31468;POINT (4375676 5356726)	8	9.023,00	1.127,88	2010	nein
Ellzee	SRID=31468;POINT (4373580 5354674)	8	7.661,00	957,63	2010	nein
Ellzee	SRID=31468;POINT (4375638 5356923)	14	16.708,00	1.193,43	2010	nein
Ellzee	SRID=31468;POINT (4373545 5354604)	21	24.195,00	1.152,14	2010	nein
Ellzee	SRID=31468;POINT (4373401 5354584)	34	35.772,00	1.052,12	2010	nein
Ellzee	SRID=31468;POINT (4375670 5356716)	32	37.130,00	1.160,31	2010	nein
Ellzee	SRID=31468;POINT (4373540 5354664)	13	14.146,00	1.088,15	2010	nein
Ellzee	SRID=31468;POINT (4373785 5355735)	9	9.520,00	1.057,78	2010	nein
Ellzee	SRID=31468;POINT (4373530 5354721)	6	6.157,00	1.026,17	2009	nein
Ellzee	SRID=31468;POINT (4373740 5354604)	11	12.178,00	1.107,09	2009	nein
Ellzee	SRID=31468;POINT (4375676 5356726)	17	20.780,00	1.222,35	2010	nein
Ellzee	SRID=31468;POINT (4373552 5354425)	3	1.940,00	646,67	2010	nein
Ellzee	SRID=31468;POINT (4375860 5356740)	9	9.708,00	1.078,67	2010	nein
Ellzee	SRID=31468;POINT (4375860 5356740)	2	2.427,00	1.213,50	2010	nein
Ellzee	SRID=31468;POINT (4373530 5354721)	8	9.341,00	1.167,63	2010	nein
Ellzee	SRID=31468;POINT (4375602 5356546)	6	4.906,00	817,67	2010	nein
Ellzee	SRID=31468;POINT (4376559 5357292)	11	11.675,00	1.061,36	2010	nein
Ellzee	SRID=31468;POINT (4375597 5356572)	21	23.397,00	1.114,14	2010	nein
Ellzee	SRID=31468;POINT (4375676 5357017)	4	2.721,00	680,25	2010	nein
Ellzee	SRID=31468;POINT (4375676 5357017)	5	4.082,00	816,40	2010	nein
Ellzee	SRID=31468;POINT (4375504 5357062)	4	2.214,00	553,50	2011	nein
Ellzee	SRID=31468;POINT (4373962 5355949)	12	8.030,00	669,17	2011	nein
Ellzee	SRID=31468;POINT (4375503 5357144)	8	8.128,00	1.016,00	2011	nein
Ellzee	SRID=31468;POINT (4374582 5356970)	28	30.830,00	1.101,07	2010	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	19	20.932,00	1.101,68	2010	nein
Ellzee	SRID=31468;POINT (4373663 5356457)	19	21.294,00	1.120,74	2010	nein
Ellzee	SRID=31468;POINT (4373572 5354526)	10	11.021,00	1.102,10	2011	nein
Ellzee	SRID=31468;POINT (4375514 5357124)	4	3.627,00	906,75	2011	nein
Ellzee	SRID=31468;POINT (4375958 5356608)	5	3.456,00	691,20	2011	nein
Ellzee	SRID=31468;POINT (4375419 5357213)	14	14.583,00	1.041,64	2011	nein
Ellzee	SRID=31468;POINT (4375958 5356608)	13	10.188,00	783,69	2011	nein
Ellzee	SRID=31468;POINT (4373546 5355558)	8	9.568,00	1.196,00	2011	nein
Ellzee	SRID=31468;POINT (4375846 5356976)	4	3.515,00	878,75	2011	nein
Ellzee	SRID=31468;POINT (4375338 5357288)	17	13.469,00	792,29	2011	nein
Ellzee	SRID=31468;POINT (4373915 5354388)	10	6.497,00	649,70	2011	nein
Ellzee	SRID=31468;POINT (4375415 5356952)	30	28.278,00	942,60	2011	nein
Ellzee	SRID=31468;POINT (4373915 5354388)	2	1.249,00	624,50	2011	nein
Ellzee	SRID=31468;POINT (4375708 5357201)	7	6.939,00	991,29	2011	nein
Ellzee	SRID=31468;POINT (4375708 5357201)	13	13.420,00	1.032,31	2011	nein
Ellzee	SRID=31468;POINT (4375524 5357024)	8	6.292,00	786,50	2011	nein
Ellzee	SRID=31468;POINT (4375608 5357229)	15	12.181,00	812,07	2011	nein
Ellzee	SRID=31468;POINT (4375557 5357115)	5	3.500,00	700,00	2011	nein
Ellzee	SRID=31468;POINT (4375618 5357037)	8	6.762,00	845,25	2011	nein
Ellzee	SRID=31468;POINT (4375618 5357037)	9	7.607,00	845,22	2011	nein
Ellzee	SRID=31468;POINT (4375460 5357333)	12	9.273,00	772,75	2012	nein
Ellzee	SRID=31468;POINT (4375514 5357124)	6	5.213,00	868,83	2011	nein
Ellzee	SRID=31468;POINT (4373401 5354584)	32	21.013,00	656,66	2011	nein
Ellzee	SRID=31468;POINT (4375846 5356976)	8	6.552,00	819,00	2011	nein
Ellzee	SRID=31468;POINT (4373616 5355638)	14	14.583,00	1.041,64	2012	nein
Ellzee	SRID=31468;POINT (4373832 5354459)	9	9.796,00	1.088,44	2013	nein
Ellzee	SRID=31468;POINT (4373540 5354664)	16	18.009,00	1.125,56	2012	nein
Ellzee	SRID=31468;POINT (4373733 5355662)	5	3.500,00	700,00	2012	nein
		1.210	**1.234.573**			

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Annex 2: Calculation of average FIT for PV[93]

location	power [MW]	electricity production	FLH	commissioning	ct/kWh	€/a
SRID=31468;POINT (4373915 5354388)	2	1.249,00	624,50	2011	28,74 €	358,96 €
SRID=31468;POINT (4373552 5354425)	3	1.940,00	646,67	2010	35,40 €	686,76 €
SRID=31468;POINT (4375504 5357062)	4	2.214,00	553,50	2011	28,74 €	636,30 €
SRID=31468;POINT (4375860 5356740)	2	2.427,00	1.213,50	2010	35,40 €	859,16 €
SRID=31468;POINT (4375725 5357179)	2	2.555,00	1.277,50	2008	46,75 €	1.194,46 €
SRID=31468;POINT (4375676 5357017)	4	2.721,00	680,25	2010	35,40 €	963,23 €
SRID=31468;POINT (4375958 5356608)	5	3.456,00	691,20	2011	28,74 €	993,25 €
SRID=31468;POINT (4375557 5357115)	5	3.500,00	700,00	2011	28,74 €	1.005,90 €
SRID=31468;POINT (4373733 5355662)	5	3.500,00	700,00	2012	18,65 €	652,75 €
SRID=31468;POINT (4375846 5356976)	4	3.515,00	878,75	2011	28,74 €	1.010,21 €
SRID=31468;POINT (4375854 5356623)	5	3.553,00	710,60	2004	57,40 €	2.039,42 €
SRID=31468;POINT (4375514 5357124)	4	3.627,00	906,75	2011	28,74 €	1.042,40 €
SRID=31468;POINT (4375676 5357017)	5	4.082,00	816,40	2010	35,40 €	1.445,03 €
SRID=31468;POINT (4375525 5357332)	5	4.873,00	974,60	2009	43,01 €	2.095,88 €
SRID=31468;POINT (4375602 5356546)	6	4.906,00	817,67	2010	35,40 €	1.736,72 €
SRID=31468;POINT (4375477 5356885)	5	4.989,00	997,80	2008	46,75 €	2.332,36 €
SRID=31468;POINT (4375514 5357124)	6	5.213,00	868,83	2011	28,74 €	1.498,22 €
SRID=31468;POINT (4375504 5357062)	5	5.697,00	1.139,40	2009	43,01 €	2.450,28 €
SRID=31468;POINT (4373530 5354721)	6	6.157,00	1.026,17	2009	43,01 €	2.648,13 €
SRID=31468;POINT (4373752 5355493)	6	6.233,00	1.038,83	2002	48,10 €	2.998,07 €
SRID=31468;POINT (4375524 5357024)	8	6.292,00	786,50	2011	28,74 €	1.808,32 €
SRID=31468;POINT (4373915 5354388)	10	6.497,00	649,70	2011	28,74 €	1.867,24 €
SRID=31468;POINT (4375846 5356976)	8	6.552,00	819,00	2011	28,74 €	1.883,04 €
SRID=31468;POINT (4373791 5355524)	7	6.559,00	937,00	2002	48,10 €	3.154,88 €
SRID=31468;POINT (4375618 5357037)	8	6.762,00	845,25	2011	28,74 €	1.943,40 €
SRID=31468;POINT (4375708 5357201)	7	6.939,00	991,29	2011	28,74 €	1.994,27 €
SRID=31468;POINT (4373818 5354510)	6	7.010,00	1.168,33	2004	57,40 €	4.023,74 €
SRID=31468;POINT (4375618 5357037)	9	7.607,00	845,22	2011	28,74 €	2.186,25 €
SRID=31468;POINT (4373580 5354674)	8	7.661,00	957,63	2010	35,40 €	2.711,99 €
SRID=31468;POINT (4373594 5354835)	9	7.977,00	886,33	2006	51,80 €	4.132,09 €
SRID=31468;POINT (4373962 5355949)	12	8.030,00	669,17	2011	28,74 €	2.307,82 €
SRID=31468;POINT (4375503 5357144)	8	8.128,00	1.016,00	2011	28,74 €	2.335,99 €
SRID=31468;POINT (4373791 5355524)	8	8.501,00	1.062,63	2009	43,01 €	3.656,28 €
SRID=31468;POINT (4373442 5354626)	8	8.953,00	1.119,13	2005	54,53 €	4.882,07 €
SRID=31468;POINT (4373530 5354721)	9	8.957,00	995,22	2009	43,01 €	3.852,41 €
SRID=31468;POINT (4375676 5356726)	8	9.023,00	1.127,88	2010	35,40 €	3.194,14 €
SRID=31468;POINT (4375602 5356546)	9	9.147,00	1.016,33	2006	51,80 €	4.738,15 €
SRID=31468;POINT (4375460 5357333)	12	9.273,00	772,75	2012	17,67 €	1.638,54 €
SRID=31468;POINT (4373530 5354721)	8	9.341,00	1.167,63	2010	35,40 €	3.306,71 €
SRID=31468;POINT (4373786 5355552)	9	9.477,00	1.053,00	2004	57,40 €	5.439,80 €
SRID=31468;POINT (4373785 5355735)	9	9.520,00	1.057,78	2010	35,40 €	3.370,08 €
SRID=31468;POINT (4373546 5355558)	8	9.568,00	1.196,00	2011	28,74 €	2.749,84 €
SRID=31468;POINT (4375860 5356740)	9	9.708,00	1.078,67	2010	35,40 €	3.436,63 €
SRID=31468;POINT (4373791 5355524)	9	9.709,00	1.078,78	2003	45,70 €	4.437,01 €
SRID=31468;POINT (4373833 5355570)	9	9.796,00	1.088,44	2003	45,70 €	4.476,77 €
SRID=31468;POINT (4373832 5354459)	9	9.796,00	1.088,44	2013	15,29 €	1.497,81 €
SRID=31468;POINT (4375528 5356726)	10	9.957,00	995,70	2009	43,01 €	4.282,51 €
SRID=31468;POINT (4375958 5356608)	13	10.188,00	783,69	2011	28,74 €	2.928,03 €
SRID=31468;POINT (4375519 5357183)	10	10.926,00	1.092,60	2010	35,40 €	3.867,80 €
SRID=31468;POINT (4373572 5354526)	10	11.021,00	1.102,10	2011	28,74 €	3.167,44 €
SRID=31468;POINT (4376559 5357292)	11	11.675,00	1.061,36	2010	35,40 €	4.132,95 €
SRID=31468;POINT (4373663 5356457)	11	12.059,00	1.096,27	2009	43,01 €	5.186,58 €
SRID=31468;POINT (4373580 5354674)	13	12.157,00	935,15	2003	45,70 €	5.555,75 €
SRID=31468;POINT (4373740 5354604)	11	12.178,00	1.107,09	2009	43,01 €	5.237,76 €
SRID=31468;POINT (4375608 5357229)	15	12.181,00	812,07	2011	28,74 €	3.500,82 €
SRID=31468;POINT (4373847 5354730)	12	12.418,00	1.034,83	2008	46,75 €	5.805,42 €
SRID=31468;POINT (4373540 5354664)	11	12.627,00	1.147,91	2007	49,12 €	6.202,38 €
SRID=31468;POINT (4375528 5356726)	12	13.213,00	1.101,08	2005	54,53 €	7.205,05 €
SRID=31468;POINT (4375708 5357201)	13	13.420,00	1.032,31	2011	28,74 €	3.856,91 €
SRID=31468;POINT (4375338 5357288)	17	13.469,00	792,29	2011	28,74 €	3.870,99 €
SRID=31468;POINT (4373540 5354664)	13	14.146,00	1.088,15	2010	35,40 €	5.007,68 €
SRID=31468;POINT (4375419 5357213)	14	14.583,00	1.041,64	2011	28,74 €	4.191,15 €
SRID=31468;POINT (4373616 5355638)	14	14.583,00	1.041,64	2012	17,67 €	2.576,82 €
SRID=31468;POINT (4373457 5354436)	15	15.184,00	1.012,27	2006	51,80 €	7.865,31 €
SRID=31468;POINT (4375638 5356923)	14	16.708,00	1.193,43	2010	35,40 €	5.914,63 €
SRID=31468;POINT (4373595 5354594)	19	17.921,00	943,21	2004	57,40 €	10.286,65 €
SRID=31468;POINT (4373552 5354425)	16	18.009,00	1.125,56	2009	43,01 €	7.745,67 €
SRID=31468;POINT (4373540 5354664)	16	18.009,00	1.125,56	2012	17,67 €	3.182,19 €
SRID=31468;POINT (4373656 5355603)	16	18.376,00	1.148,50	2004	57,40 €	10.547,82 €
SRID=31468;POINT (4373833 5355570)	20	19.509,00	975,45	2009	43,01 €	8.390,82 €
SRID=31468;POINT (4375676 5356726)	17	20.780,00	1.222,35	2010	35,40 €	7.356,12 €
SRID=31468;POINT (4373663 5356457)	19	20.932,00	1.101,68	2010	35,40 €	7.409,93 €
SRID=31468;POINT (4373401 5354584)	32	21.013,00	656,66	2011	27,33 €	5.742,85 €
SRID=31468;POINT (4373663 5356457)	19	21.294,00	1.120,74	2010	35,40 €	7.538,08 €
SRID=31468;POINT (4376559 5357292)	21	22.378,00	1.065,62	2010	35,40 €	7.921,81 €
SRID=31468;POINT (4375597 5356572)	21	23.397,00	1.114,14	2010	35,40 €	8.282,54 €
SRID=31468;POINT (4374010 5355983)	22	23.782,00	1.081,00	2009	43,01 €	10.228,64 €
SRID=31468;POINT (4373663 5356457)	22	24.127,00	1.096,68	2009	43,01 €	10.377,02 €
SRID=31468;POINT (4373545 5354604)	21	24.195,00	1.152,14	2010	35,40 €	8.565,03 €
SRID=31468;POINT (4373663 5356457)	22	24.232,00	1.101,45	2009	43,01 €	10.422,18 €
SRID=31468;POINT (4373663 5356457)	22	24.260,00	1.102,73	2009	43,01 €	10.434,23 €
SRID=31468;POINT (4373740 5354604)	22	24.358,00	1.107,18	2009	43,01 €	10.476,38 €
SRID=31468;POINT (4373663 5356457)	29	25.743,00	887,69	2004	57,40 €	14.776,48 €
SRID=31468;POINT (4375783 5356992)	26	27.730,00	1.066,54	2008	46,75 €	12.963,78 €
SRID=31468;POINT (4375415 5356952)	30	28.278,00	942,60	2011	28,74 €	8.127,10 €
SRID=31468;POINT (4374582 5356970)	28	30.830,00	1.101,07	2010	35,40 €	10.913,82 €
SRID=31468;POINT (4373729 5354433)	26	31.155,00	1.198,27	2007	49,12 €	15.303,34 €
SRID=31468;POINT (4373025 5356357)	30	33.633,00	1.121,10	2004	57,40 €	19.305,34 €
SRID=31468;POINT (4374010 5355983)	31	33.684,00	1.086,58	2007	46,28 €	15.588,96 €
SRID=31468;POINT (4373401 5354584)	34	35.772,00	1.052,12	2010	33,68 €	12.048,01 €
SRID=31468;POINT (4375670 5356716)	32	37.130,00	1.160,31	2010	33,68 €	12.505,38 €
SRID=31468;POINT (4375537 5357506)	45	48.163,00	1.070,29	2009	40,91 €	19.703,48 €
	1.210	**1.234.573**			**38,08 €**	**486.172,39 €**

[93] own calculation 2014

Annex 3: negative residual load values[94]

Timestamp	Residual load	
	Production ./. Demand	
	[MW]	
15.01.2012 09:00	-	0,18618
16.01.2012 19:00	-	0,22892
17.01.2012 18:00	-	0,48502
05.02.2012 19:00	-	0,43705
06.02.2012 18:00	-	0,68100
08.02.2012 18:00	-	0,48222
12.02.2012 09:00	-	0,07632
12.02.2012 19:00	-	0,43545
21.02.2012 19:00	-	0,44732
06.03.2012 18:00	-	0,39624
14.03.2012 19:00	-	0,42645
15.03.2012 19:00	-	0,25635
20.03.2012 18:00	-	0,44193
20.03.2012 19:00	-	0,21816
20.07.2012 18:00	-	0,08605
30.08.2012 08:00	-	0,04438
22.09.2012 08:00	-	0,17547
01.10.2012 16:00	-	0,40558
01.10.2012 17:00	-	0,43313
01.10.2012 18:00	-	0,13867
08.10.2012 08:00	-	0,17451
17.10.2012 18:00	-	0,11543
18.10.2012 18:00	-	0,16530
20.10.2012 08:00	-	0,05576
24.10.2012 18:00	-	0,22742
25.10.2012 18:00	-	0,03578
23.11.2012 16:00	-	0,36209
26.11.2012 15:00	-	0,09887
12.12.2012 19:00	-	0,26208
18.12.2012 17:00	-	0,31759
18.12.2012 19:00	-	0,16372
19.12.2012 12:00	-	0,36590
29.12.2012 10:00	-	0,00463
29.12.2012 12:00	-	0,23138
sum	**-**	**9,06237**
max.	-	0,00463
min.	-	0,68100

[94] own calculation 2014

Annex 4: prequalified providers of balancing power[95]

Präqualifizierte Anbieter je Regelenergieart

Anbieter	PRL	SRL	MRL
Alpiq AG	●		
ArcelorMittal Eisenhüttenstadt GmbH			●
Axpo AG	●		
Axpo Deutschland GmbH		●	●
Axpo Trading AG	●		
BalancePower GmbH			●
BKW FMB Energie AG	●		
BS Energy Braunschweiger Versorgungs-AG & Co.KG			●
Centralschweizerische Kraftwerke AG	●		
citiworks AG			●
Clean Energy Sourcing GmbH		●	●
CURRENTA GmbH & Co. OHG			●
DELTA Energy B.V.	●		
E.ON Global Commodities SE	●	●	●
EnBW Erneuerbare und Konventionelle Erzeugung AG	●	●	●
Energieservice Westfalen Weser GmbH		●	●
Energieversorgung Schwerin GmbH & Co. Erzeugung KG		●	
Energy2market GmbH	●	●	●
Entelios AG		●	
envia Mitteldeutsche Energie AG		●	●
Evonik Power Saar GmbH	●	●	
GDF SUEZ Energie Deutschland	●	●	●
GDF SUEZ Portfolio Management B.V.	●		
GETEC Energie AG			●
Hamburg Energie GmbH			●
Heizkraftwerk Würzburg GmbH		●	
Infracor GmbH			●
Infraserv GmbH & Co. Höchst KG		●	
Kraftwerke Mainz-Wiesbaden AG		●	●
Lechwerke AG		●	●
Mark-E AG		●	●
MVV Energie AG			●
N-ERGIE Kraftwerke GmbH			●
Next Kraftwerke GmbH		●	●
Nordenhamer Zinkhütte GmbH		●	
RWE Supply & Trading GmbH	●	●	●
RWE Vertrieb AG			●

95 (Regelleistung.net, 2014)

Präqualifizierte Anbieter je Regelenergieart

Anbieter	PRL	SRL	MRL
Stadtwerke Düsseldorf AG			●
Stadtwerke Hannover AG (enercity)	●	●	●
Stadtwerke München GmbH	●	●	●
Stadtwerke Rosenheim			●
Stadtwerke Tübingen GmbH		●	
Statkraft Markets GmbH	●	●	●
Steag GmbH	●	●	●
Südvolt GmbH			●
swb Erzeugung GmbH & Co. KG			●
ThyssenKrupp Steel Europe AG			●
TIWAG - Tiroler Wasserkraft AG		●	●
Trianel GmbH		●	●
Trimet Aluminium SE	●		
Vattenfall Energy Trading Netherlands N.V.	●		
Vattenfall Europe Generation AG	●	●	●
VSE AG			●
VW Kraftwerk GmbH			●

Präqualifizierte Anbieter sind alle Anbieter, die einen gültigen Rahmenvertrag zur Regelleistungserbringung mit mindestens einem Anschluss-ÜNB abgeschlossen haben und gleichzeitig präqualifizierte Leistungen von mindestens der Mindestangebotsgröße aufzuweisen haben.

Annex 5: Net Present Value calculation[96]

Financial Parameters:

Investment Horizon			**20**	**year**
WACC / risk adj. disc. rate			**6,40%**	
Investment Costs		5MW	**36.437.500**	**€**
O&M Costs			**182.188**	**€/yr**
Income	*pos. TCR*		**326.905**	**€**

Year	Discounted CF	Nominal CF	O&M	Investment/ Replacement	Electricity sale
0	- 36.437.500 €	- 36.437.500 €	- €	- 36.437.500 €	- €
1	136.013 €	144.718 €	- 182.188 €	- €	326.905 €
2	127.831 €	144.718 €	- 182.188 €	- €	326.905 €
3	120.142 €	144.718 €	- 182.188 €	- €	326.905 €
4	112.916 €	144.718 €	- 182.188 €	- €	326.905 €
5	106.124 €	144.718 €	- 182.188 €	- €	326.905 €
6	99.740 €	144.718 €	- 182.188 €	- €	326.905 €
7	93.741 €	144.718 €	- 182.188 €	- €	326.905 €
8	88.102 €	144.718 €	- 182.188 €	- €	326.905 €
9	82.803 €	144.718 €	- 182.188 €	- €	326.905 €
10	77.822 €	144.718 €	- 182.188 €	- €	326.905 €
11	73.141 €	144.718 €	- 182.188 €	- €	326.905 €
12	68.742 €	144.718 €	- 182.188 €	- €	326.905 €
13	64.607 €	144.718 €	- 182.188 €	- €	326.905 €
14	60.721 €	144.718 €	- 182.188 €	- €	326.905 €
15	57.069 €	144.718 €	- 182.188 €	- €	326.905 €
16	53.636 €	144.718 €	- 182.188 €	- €	326.905 €
17	50.410 €	144.718 €	- 182.188 €	- €	326.905 €
18	47.377 €	144.718 €	- 182.188 €	- €	326.905 €
19	44.528 €	144.718 €	- 182.188 €	- €	326.905 €
20	41.849 €	144.718 €	- 182.188 €	- €	326.905 €

NPV **- 34.830.185 €**

[96] own calculation 2014