LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
Trilateral Master's Degree Programme in Energy Technology

MASTER'S THESIS

Olcayto Kaya

LEVELISED COST OF ELECTRICITY FOR ELECTRICAL ENERGY FROM RENEWABLE RESOURCES UNDER CONSIDERATION OF CORRESPONDING ENERGY STORAGE

Examiners: Prof. D. Sc. Esa Vakkilainen, M.Sc. Kari Luostarinen

ABSTRACT

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Master's thesis

2020

93 pages, 35 figures, 38 tables

Examiners: Professor Esa Vakkilainen

Keywords: LCOE, energy storage, electricity production costs, load balance

Energy storage is an essential way of balancing load, from that point battery technologies and their price development will build future energy systems. In the given work, development of advanced grid technologies and cost analyses in the field of renewable energy production considering energy storage studied. The target of this research was to determine renewable electricity production costs with related cost components by formulating a calculation model for varying input data. To achieve research target, objectives defined as determination of necessary storage requirements for different renewable energy sources and optimization of energy cost for particular types of consumers. Literature research made based on the review of related energy storage and system concept with extensive operation methods. Calculation input data procured and categorized for every reference problem. Current microgrid applications and their relation with grid stabilization control methods reviewed. Storage technology with renewable adaptation for different type of load profiles and consumer types discussed. As a result, different scenarios including cost optimization components, storage capacities and renewable energy production amounts listed. Mainly small scale applications utilize renewable energy systems with energy storage combination identify the application area of the study. The research and calculation based on cost optimization presented that, energy storage is an essential way to balance load by contributing renewable energy utilization and reducing carbon dioxide emissions.

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Symbols and abbreviations

Latin alphabet

E	Activation energy, J/mol
h	Enthalpy, kJ/kg
k	Reaction rate, s^{-1}
m	Mass flow, kg/s
n	Percentage of energy consumption, %
Q	Net calorific value, kJ/kg
R	Universal gas constant, J/(mol·K)
T	Temperature, K

Greek alphabet

ΔH	Formation enthalpy, kJ/kg
Δh	Flow of energy consumption on a process, kJ/s
η	Percentage of energy use, %; Ratio
τ	Time, s

Dimensionless numbers

A	Pre-exponential factor

Superscripts

$'$	Saturated liquid form
$''$	Saturated vapour form

Subscripts

1	Gaseous product
2	Liquid product
3	Solid product
b	Biomass
bc	Bio-coal
d	Dryer
db	Dry biomass
h	Heater
i	Inlet
m	Moisture
p	Production
t	Torrefaction section
torref	Torrefaction
u	Use

Abbreviations

NCV	Net calorific value
RED	Renewable energy directive
LCOE	Levelized cost of energy

1. INTRODUCTION

1.1 Motivation

The population increase and the developments in the industry sector bring on energy production one of the essential subject matter. To supply the required energy for this increase, conventional methods from Fossil fuels are still form a huge amount of world energy production. Consequently, in some regions, climate change effects started to be observed. Greenhouse gas emissions are remaining considerably high because of high fossil fuel usage. High energy output of the conventional energy production methods enable them dominant against renewable energy plants. Depending on the natural conditions as wind or solar radiation amount, renewable applications requires special design criteria that requires investment cost. But however, governments encourage clean energy usage and utilization. In the last years, consumer's awareness of clean energy, the number of renewable power plants especially for the sources wind and solar applications increased. Even though renewable applications are growing, energy production methods operating with fossil fuel sources are considerably higher. At the same time, carbon dioxide emissions will continue harming the environment if they will not be controlled. Current renewable methods need to be developed and future Technologies should be designed for green electricity production. Electric vehicles are playing also an important role to reduce our carbon footprint. Storing energy was a problematical issue for electric vehicles. However, at present, electric and hybrid cars started to use widely. All of the improvements in modern Technologies allows both consumers in small and large scale to manage energy in their area. Today aside electricity production, electricity management is another important developing subject matter. The management of the renewable applications can be arranged with a battery system by balancing excess energy. Battery usage could grow up also for industrial and private consumers. Every consumer could act as a decentralized microgrid by utilizing renewable sources and energy storage with respective capacity. Energy storage is a beneficial application for balancing the supply and release of the surpluses. Extensive usage of microgrid applications would not only affect the environment positively but also contribute to consumer finance. This could be obtained by a storage system, a solar panel, or a wind turbine depending on the utilizable source. However, system design plays an important role, parameters for designing an energy storage management system needs to be calculated accurately. Lifespan, capacity, equipment cost, and charge-discharge times need to integrate each other, otherwise, the system will not be feasible considering cost optimum. The concept of a smart grid brings another related dimensioning challenge. Photovoltaic technology and its module, power electronics devices as converters, inverters and circuit topologies, battery selection, and energy market regulations for feed-in and purchase from the grid are the main criteria affecting system design.

1.2 Objectives of the Study

Electricity production from renewable energy sources is an efficient way of reducing carbon dioxide and greenhouse gases. In the operation of renewable energy plants depending on the design and demand, surplus energy occurs during the time with low energy demand. Despite this, when renewable energy plants cannot supply the required energy, electrical energy must be obtained from other sources. Electrical energy storage systems are giving opportunity to balance energy by storing or rejecting. The surplus energy mentioned above, could be stored in the battery and in case of low supply that additional energy could be used. Utilization of storage system is not only a solution for balancing but also an effective way of optimization of electricity management. An energy storage system could be designed in many different ways depending on the consumer type, scale, equipment and the budget. Both batteries and photovoltaic panels are relatively developing frequently technologies. System needs to be designed by considering different aspects. To use the energy storage system with a photovoltaic module not only the main equipment but also power electronics getting involved in the process. The objective of the work to determine necessary storage requirements for different renewable energy sources and different types of consumers by dimensioning storage system parameters. The dissertation aims to consider a prototype reference problem and model its properties, creating a formulation of a suitable calculation model, simulating the case with a program environment, researching economic parameters depending on different consumer types and cases and besides, consideration of electricity production costs.

1.3 Reference Problem

Conventional power generation systems remain the strongest stations to supply demand. In some countries renewable power plants started to assist conventional system with a high share. Additionally, storing energy is a considerable topic since years. Advanced energy storage system seems to be an effective solution for modern-day problems by means of their flexibility, optimum renewable utilization and electricity grid reliability. Investments are increasing for battery applications, at the same time cost for storage systems are decreasing. Although they appear to be unproblematic devices, there are still many challenges going on for integration of new technologies to the current system. Storage module combined with a renewable source is beneficial way of reducing carbon emission and at the same time efficient contribution to power generation in frequent number of subsystems. Development and organisation of subsystems also called microgrid concept, could be designed in several methodologies. Thus, construction of a new smart electrical network is a complex process, different fields of engineering such as material science, power electronics, grid operations and utility equipment development should assist the main concept. From that point, mentioned subsystem could be designed depend on different renewable application, storage selection and preferred operating scenario. Techno-economic parameters are decisive on the energy system financing. This dissertation will examine related technologies with electricity production considering energy storage by concentrating on a reference problem solar energy, lithium-ion storage and usage of household consumer.

1.4 Outline of the Dissertation

Chapter 1 summarize the renewable energy progression, country emission reducing policy and first look to photovoltaic and battery utilization trends. Actual numbers of renewable shares and projections. **Chapter 2** gives an introduction about microgrids and their working principle by discussing operation methods. Important controlling options and possible problems. **Chapter 3** presents theoretical information regarding solar energy production with main parameters of design and working principle. **Chapter 4** covers the description of a battery system and comparison between different types. Price overview of lithium-ion batteries. **Chapter 5** reconsider the peak load shaving method by explaining possible scenarios and summarize operation advantages. **Chapter 6** explain an example simulation model based on the study with modelling tools by representing results. **Chapter 7** summarises electricity production costs with analyses of different load data and levelized cost of energy method.

2. ENERGY OUTLOOK GERMANY

Similar to the other countries Germany share of energy generation from fossil fuels is still compose higher rate than renewables. However, the number of investments and installed renewable applications are increasing including wind, solar and bioenergy. Because the country has very low oil and natural gas production, these sources dependent on external purchase. This situation develops renewable energy policies and investments. The share of renewables in electricity consumption has steadily grown over the last few years – from around 6% in 2000 to almost 38% in 2018. By 2025, at least 40-45% of electricity consumed in Germany is targeted to come from renewables. The progress of renewables in Germany showed in the Figure 1.

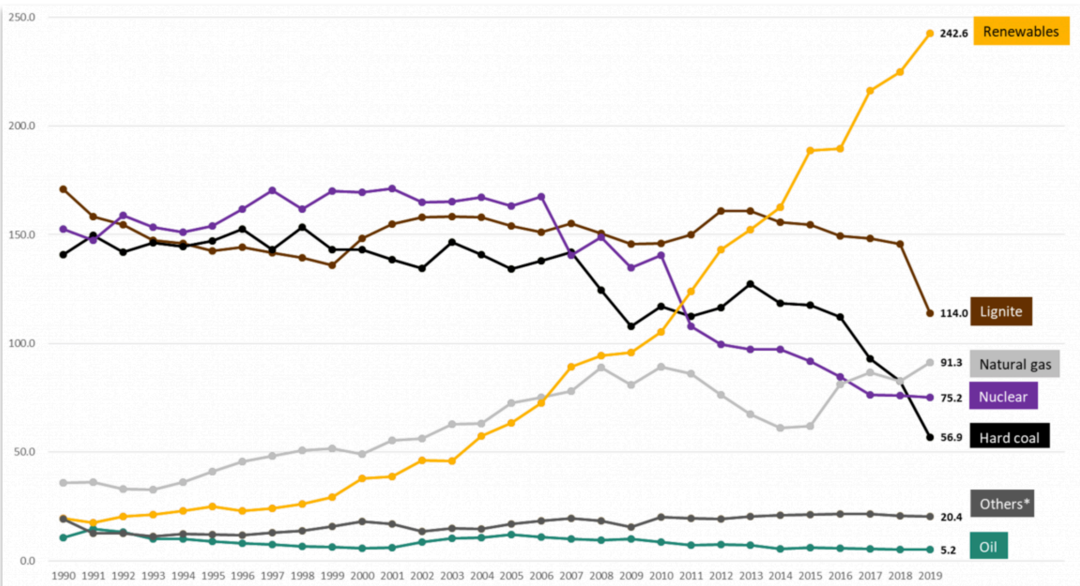

Figure 1. Power generation in Germany 1990-2019 by source in TWh [1]

Germany is a leader country in encouraging clean energy usage, additionally invest green technologies. All the improvements in policies, developing technologies and electric vehicle usage in transportation sector resulted lower carbon dioxide emissions. Energy-related CO_2 emissions have fallen over the last decades. Power and heat generation is the largest source of energy-related CO_2 emissions in Germany. In 2017, the sector accounted for 42% of total emissions, followed by transport (22%), industry (12%), residential (12%), commercial (6%) and other energy industries (3%).In 2017, emissions were 719 $MtCO_2$, 9% below the 2005 value and 24% below 1990. [2]. According to all improved numbers, country has ensured high energy efficiency, managed energy demand and sustained economic growth. Further projects such as storage systems combined with renewables proceed to contribute energy challenges of the country. Production of energy is increasing respective to the high demand, therefore electricity generation models developing rapidly. For this reason, energy market is developing parallel to production. Germany has one the unique and liberal energy market in Europe. Encouragement of government for market adaption for the last consumer with small scale, brings forward electricity wholesale companies to develop advanced tariffs. The common use of application photovoltaics combined with battery system in small scale applications could be named as PV-battery home energy system. For good measure, electric vehicles and their charging stations also rationalize creating flexible sub-systems than to supply demand with regular tariff. With decreasing costs of battery and photovoltaic panels, usage of home energy systems increased. By the end of 2018, some 120,000 households and commercial operations had already invested in PV battery systems [13]. The price review comparison for PV, battery and household electricity price in the last decade showed in the Figure 2.

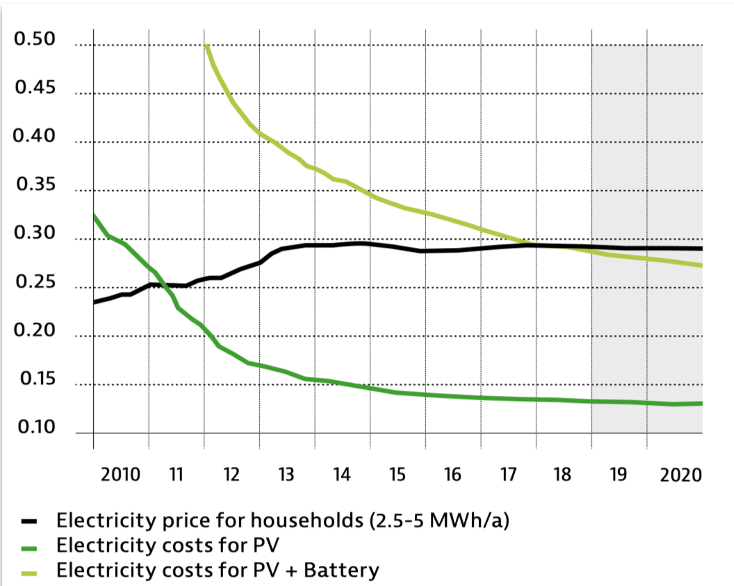

Figure 2. Comparison of PV, PV+Battery and households prices in Germany [3]

Combined storage and renewable systems are not only reducing emissions and managing energy optimally, but also compensating the fluctuations in real time. Another way to create a natural battery is pumped storage hydro-electricity but geographical condition of Germany restricting developing this model. As a result, home energy system and smart grid adaption is one of the key points for the country. Today household consumer considers these technologies as high investment cost, in the next decade with fallen prices, it would be possible to see more solar panels on rooftop and a storage to create individual load shaving. Organisation of small, large and power-to-heat applications will effect smart grid adaptation directly by considering not only solar but also wind onshore, offshore.

3. MICROGRID

3.1. System Concept

High electricity demand contributes to the concept of smart technologies and new operation scenarios. As per usual, electricity production relies on conventional non-renewable sources mainly coal and natural gas. Increase in the harmful emissions made new clean energy supply methods necessary. Currently high output power gained from mostly from conventional sources is distributed to the area or last consumer by high voltage lines. Utilization of a storage system assisted by a renewable energy source could contribute to reduce emissions and additionaly could create an independent energy distribution system. From this perspective, the concept of the microgrid brings forward the idea of a decentralized network, which could be defined as the operation of a power network subsystem [4]. The system can work in two different main modes, grid connected or islanding mode. Simple scheme of the microgrid showed below.

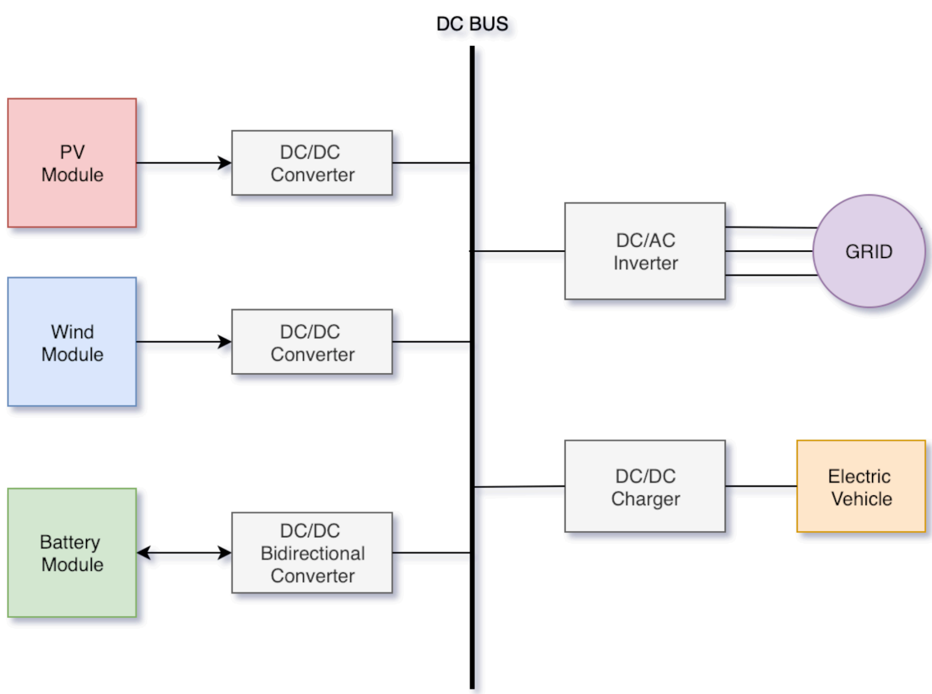

Figure 3. Simplified microgrid scheme

The subsystem could contain both renewable systems and conventional systems. In any type of the energy production, output power should be transmitted in the grid by balancing the load. This could be obtained by also with several subsystems. The main advantages of dividing the main grid into essential number of subsystems are, controlling the load and sustaining an uninterrupted power supply. Because of their concept and operation methodologies, microgrids are smart grids based on a working scenario. Comparison between conventional and smart grid listed below in Table 1.

Table 1. Comparison between conventional and smart grid [5]

Conventional Grid	**Smart Grid**
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed Generation
Less sensors	All over Sensors
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and Islanding
Limited Control	Distributive control

Smart microgrids usually work on a small scale in the target area or facility, where a variety of loads with different profiles could be supplied through a controlled distribution system integrated with various power generation sources [6]. In this dissertation renewable power generation sources will be reviewed. Nowadays smart microgrids are used in small scale application, but in the future entire electricity grid will be formed by pretty high number of smart grids that can keep working by flexible functionality for load balancing. Depending on the design, different types of the power generation methods could be used by meeting the requirements of the storage system and economical parameters. Photovoltaic panels are the widely used devices but also wind on-shore and off-shore can be used in a microgrid system. The operational model of a microgrid depends on the application and area, the system could be disconnected from the main network or can operate connected to the main grid. However, system should operate efficiently when voltage fluctuations and in case of black outs at any time occurs. Control and operational strategies play an important role in the microgrid concept, in that grid needs to balance power between production and consumption. The excess capacity in stand-by mode, could be reduced if the peak consumption is shifted or utility grid which can assist power balancing and avoid undesired injection and can perform peak load shaving during peak hours [7].

3.2 Control and Operation

Controlling a microgrid consist of several energy conversion points, thus the micro sources operates in the system connected to power electronics converter or inverter. Devices of power electronics gives the flexibility to microgrid, every micro source operates with planned control algorithm and new micro sources could be added to subsystem. Power electronics controllers provide control and operation duties for reliable grid activity listed below [24];

- Micro sources should work conveniently in the defined operating points with respective limitations.
- active and reactive powers are transferred according to necessity of the microgrids and/or the distribution system.
- Disconnecting and connecting operations managed with success.
- market participation is optimized by optimizing production of local microsources and power exchanges with the utility.
- Heat control needs to be optimized.
- Uninterrupted load supply should be provided.
- In case of general failure, the microgrid is able to operate through black-start.
- Energy storage needs to be capable of supporting system, contribute to the efficiency and reliability of the system.

Microgrid control and operation is regulation of power and voltage, when there is a change in reference load or any fault, operation mode must be adapted by monitoring voltage and load instability and change to islanding or grid-connected mode.

As showed in the microgrid scheme (Figure 3.), even in a simple system there could be AC and DC micro sources operating. AC sources needs to be rectified and DC source needs to be inverted. The voltage source inverter controls both the magnitude and phase of its output voltage. The vector relationship between the inverter voltage, V, and the local Microgrid voltage, E, along with the inductor's reactance, X, the power angle, δp determines the flow of real and reactive power (P &Q) from the micro source to the microgrid. Voltage, phase relation with P & Q magnitudes is given below [8].

$$P = \frac{3}{2}\frac{VE}{X}\sin\delta_p \qquad (2.1)$$

$$Q = \frac{3}{2}\frac{V}{X}(V - \mathrm{E}\cos\delta_p) \qquad (2.2)$$

$$\delta_p = \delta_V - \delta_E \qquad (2.3)$$

During the day depending on special cases that effects electricity grid as power disturbance, at that point island mode can be switched. Issueless transition between islanded and grid-connected mode is should be the main key point because frequency could be changed. When the microgrid switched to islanding and isolated completely from main grid, each micro source needs to modify their voltage. This could be obtained by controlling voltage droop. Voltage droop controlling graphs given below.

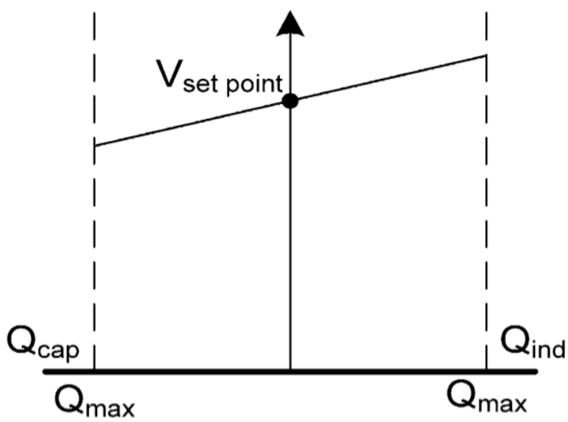

Figure 4. Voltage droop set point [9]

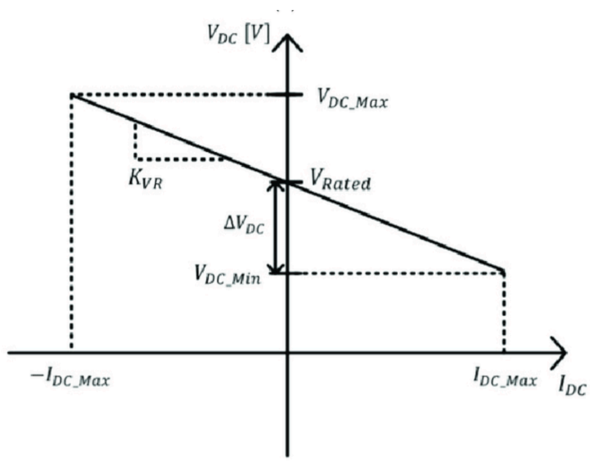

Figure 5. Droop control example [10]

3.3. Components

As mentioned before a microgrid could be modified according to the aimed application and requirements. Frequently used main components are the photovoltaic panels, wind energy, fuel cells and micro-turbines. Electricity generation systems can change regarding economic parameters, however two main module plays an important role, power electronics components and energy storage. Mainly system operate with one or more energy producer and produced energy required to be converted from DC to AC and regarding to the storage capacity, output should be adjusted with boost or buck converter. A microgrid concept concentrate on the low voltage network, that gives advantage of low investment cost and also reliable working efficiency. There could be both controlled and non-controlled loads in the management system. Power electronics switching devices could work as mode selection by controlling battery charge and discharge and PV or wind power generation. Switches can be controlled with PWM generators that operated with PI controllers. An example of basic components and control devices showed in the Figure 6.

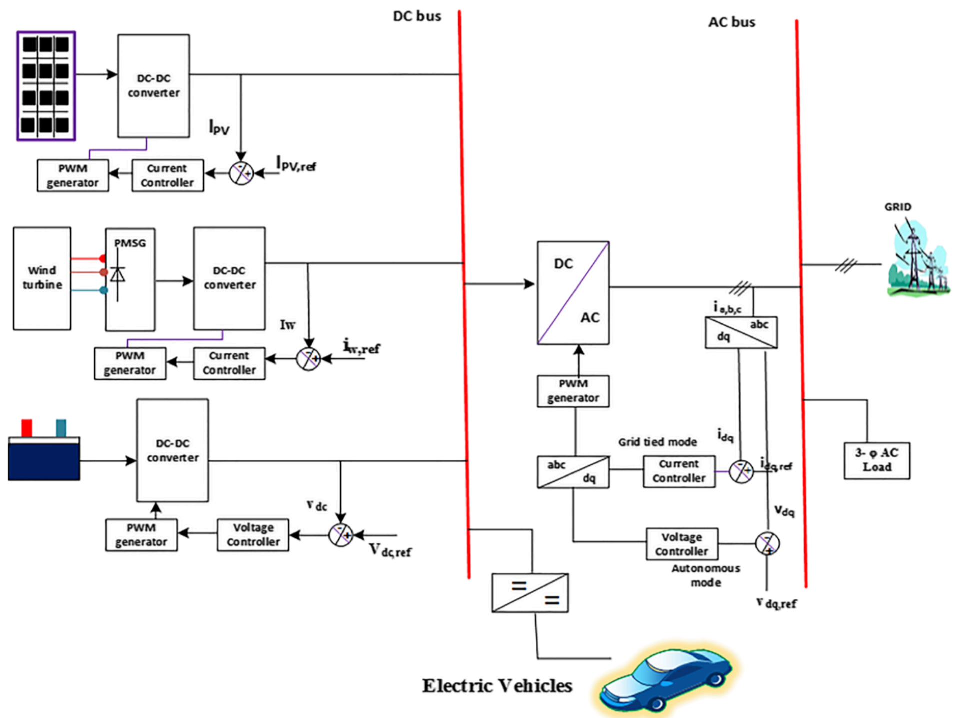

Figure 6. Detailed microgrid control scheme [11]

4. SOLAR ENERGY SYSTEM

4.1. Photovoltaic Cell

A solar cell or also widely used with the name photovoltaic cell defined as an electronic device that can produce electrical energy by using sun irradiation. Similar to the battery a solar cell has positive and negative output that creates potential difference when sunlight falls on the cell. Different than the batteries and other energy production devices, chemical reaction or a movement does not occur in a solar cell. When solar irradiation reflects the solar cells, current and voltage start to rise, therefore electrical power is generated. A solar cell could produce maximum 0,5 V to 0,6 V. Silicon is used as the main material for solar cells by reason of it is a favourable semi-conductor that can absorb photons.

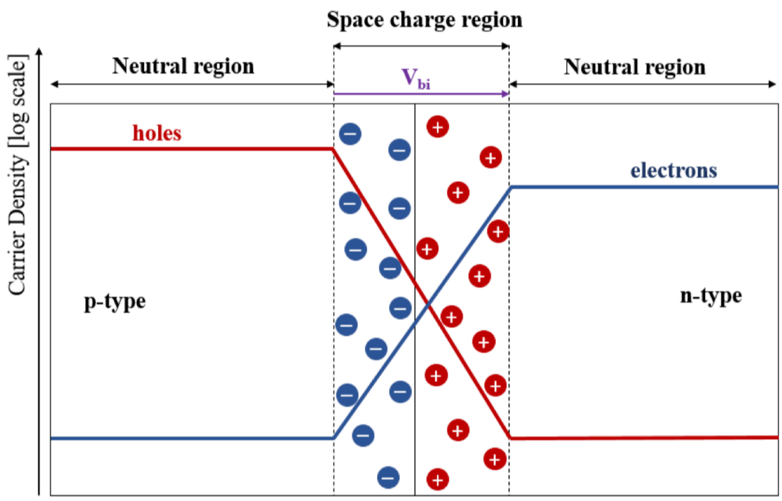

Figure 7. Example of a solar cell p-n junction [12]

As shown above, solar cell working principle based on the p-n junction. For electricity generation, electric field needs to be created, using the semi-conductor layers with p-type and n-type. When both layers joint together and solar irradiation be reflected, positively charged free holes move from p-type side to the n-type side, in a similar way same movement happens for the negatively charged free electrons from n-type side to the p-type side. This movement in the junction result of current rise named diffusion current and electric field in the junction region which is called space charge region. This application works similar as diode which activated by the photons of solar irradiation. Because photovoltaics working principle related directly with solar irradiation, the current produced in the cell depends also angle of the solar panel and intensity of the sunlight, cloudy weathers and night times are the times system could not operate. Increasing the area of the cells by panels covers more sunlight and gives better efficiency, however module should be designed respective to techno-economic parameters.

4.2. Characteristics of a Solar Cell

Characteristics of a solar cell models are valid for the relation between current and voltage for different values of solar irradiance and temperatures. The characteristic graph could show variations regarding manufacture parameters, but the characteristic would be similar if the solar cell concept is not using a different technology. Current-voltage and power-voltage graphs with temperature and irradiance for 1 kW solar cell showed in the Figure 8 and Figure 9.

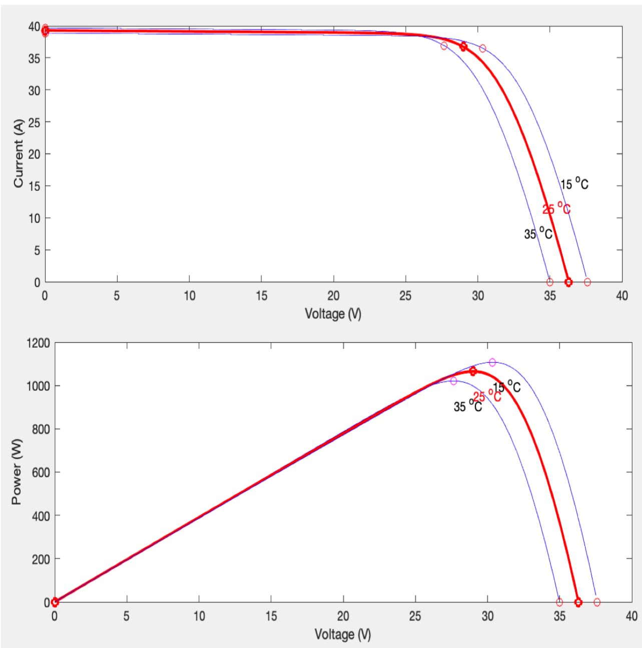

Figure 8. Characteristic curve of a solar cell with temperature

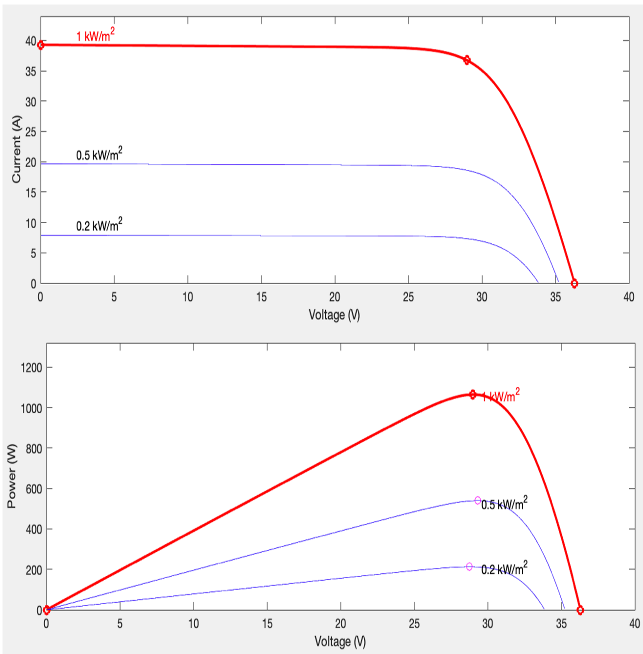

Figure 9.Characteristic curve of a solar cell with irradiance

Starting point of the current represents the short circuit current which is the maximum current that related solar cell can reach when the voltage is zero and in the same logic, when voltage reaches its maximum value while current is zero it is named as open circuit voltage. It could be also explained as the load connected to the solar device is in its maximum value. In the graphs marked points identify the maximum power point for the cell, which gives the point that can solar cell works in its highest efficiency. During the day when solar irradiation changes by time, efficiency could be increased by tracking maximum power point.

4.3. Single-Diode Model

Single-diode model is not a complex and hence the most used model for PV-cell. Model consist of five main parameters. Current generated from the solar irradiation (I_{ph}), diode current (I_D) , Shunt resistance (R_P) , series resistance (R_S) , output current of the cell (I_{PV}). Listed parameters shown below.

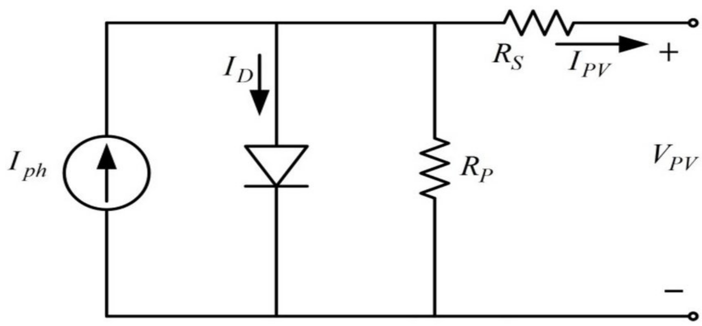

Figure 10. Equivalent Circuit of One-Diode Model

By applying fundamental rule of the electric circuit Kirchhoff's Current Law [13];

$$I_{PV} = I_{ph} - I_D - I_P \tag{4.1}$$

The equation of the Photovoltaic cell based on the Shockley diode equation [14];

$$I_D = I_0 \left[\exp\left(\frac{e(V_p + R_S I)}{n k_B T} \right) - 1 \right] \tag{4.2}$$

Updating the diode current and the diode reverse current in the Kirchhoff's Current Law equation proceed for the output current equation of the solar cell;

$$I_{PV} = \left[I_{ph} - I_0\left[\exp\left(\frac{e(V_p+R_sI)}{nk_BT}\right) - 1\right] - \frac{V_p+R_sI}{R_p}\right] \quad (4.3)$$

4.4. Photovoltaics Configuration

Physical configuration of the solar system directly effective with the output power and solar coverage. Especially for the simulation progress, designing solar structure with checking their manufacture values is highly significant. The power obtained from one cell is very low and the number of cell needs to be increased. This application will give better results in efficiency by lowering Physical configuration of the solar device showed in Figure 11. When many cells (a) connected in series it creates the string (b), by connecting the strings in parallel form the solar module (c) and the number of connected models create the array (d).

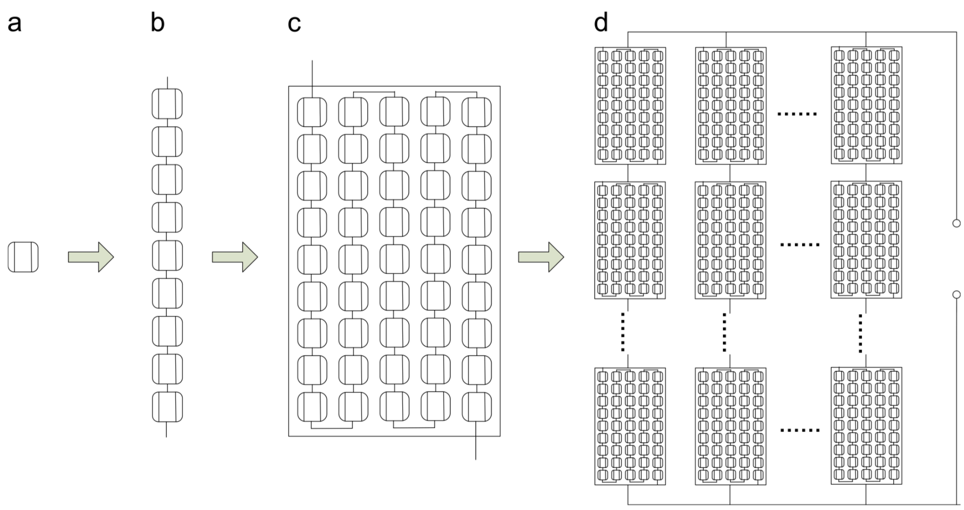

Figure 11. Photovoltaics physical configuration [15]

4.5. Maximum Power Point Tracking (MPPT)

MPPT is an essential power extracting technique for solar panels and wind turbines. As specified in its name, the MPPT algorithm allows to achieve maximum available power from the used energy application. Especially in the applications combined with photovoltaics and battery, power tracking plays meaningful role. MPPT controller is a high frequency DC-DC converter, it converts DC output voltage to the high frequency AC voltage and again converts to other DC voltage that matches exactly for the battery. PV-module operates at the most possible maximum voltage by comparing solar panel output voltage with the battery voltage. When the voltages are not in the efficient case, algorithm fixes the voltage to the reference maximum voltage. This method also increases the power extraction in unsteady conditions for energy generation from PV as cloudy days or weak solar irradiation levels. Sample MPPT algorithm sketch showed in the Figure 12.

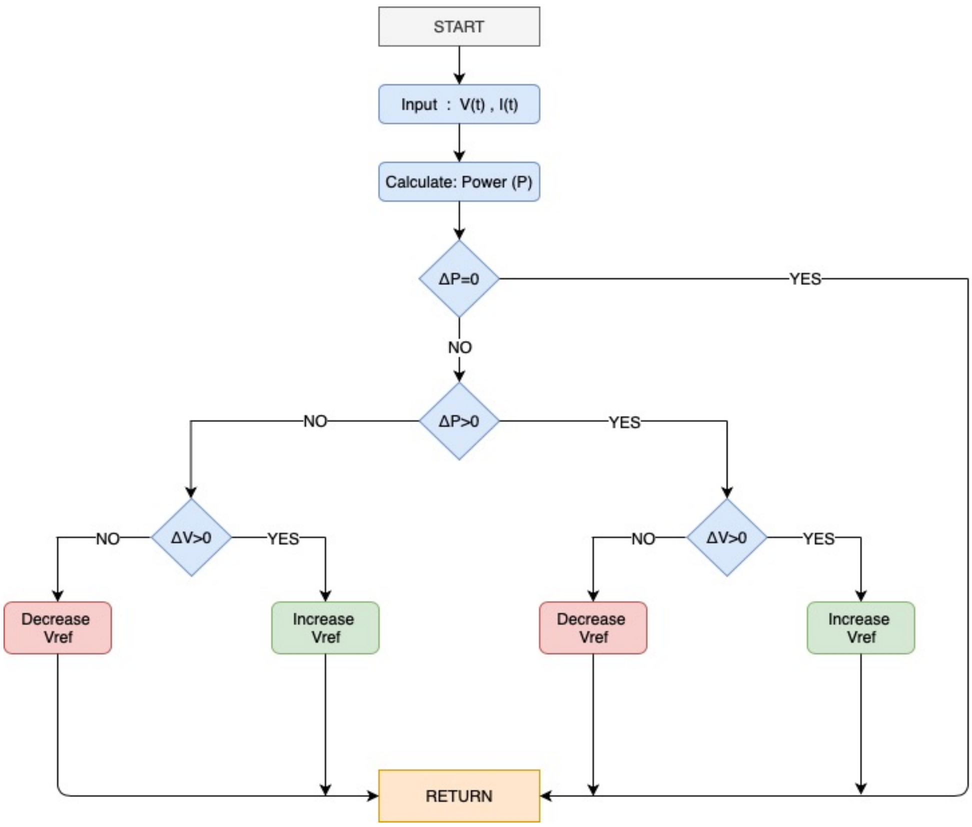

Figure 12. MPPT algorithm example [16]

MPPT algoritm is not a complex but effective for utilizing solar energy with a maximum power extraction. It is based on checking voltage and current values regularly. With respective values power calculated, if there is no change in the power, system will not do any voltage adjustment. In other cases, depending on solar irradiances, generated power in the cells are also changing and it results as power fluctuation. In case of power change monitored, reference voltage restored. This operation also known as perturb and observe (P&O).

5. BATTERY ENERGY STORAGE SYSTEM (BESS)

5.1. Battery Types

Battery is the essential device to store energy, it contains electro chemical compounds with cell layout. Chemical energy stored in a cell or cells for advanced batteries converted to electrical energy. Electrochemical cells can be classified as flow batteries, primary batteries and secondary batteries. Flow batteries work on a simple basis, anode and cathode electrolytes stored in different containers and in the middle ion-separated membrane takes place. When the electrolytes flow they meet in the electrochemical cell and electricity produced. They named also as redox flow batteries. Decisive parameter for a storage application is the capacity and amount of stored energy in the battery. Capacity is given mostly in ampere-hours(Ah) and stored energy in watt-hours(Wh). Energy density of a battery related with the electrolyte amount, because the production happens with ion exchange, generated power related with chemical reactions. Primary batteries are the most used storages in daily life. They can work very efficient in the devices that requires lower energies. Disadvantage of them is they could not recharge and rechargeable ones are not optimally cheap for their energy amount. Secondary batteries are seen as the future of many technologies, because they could be recharged with high number of cycles. That function makes them valuable for electric vehicles, electronic devices and especially photovoltaic energy systems. Secondary batteries could be considered as high technology products; thus they could be examined in several different parameters. Important parameters for the secondary batteries listed in Table 2.

Table 2. Parameters related with secondary batteries

Parameter	**Explanation**
Investment Cost	All costs including equipment pro kWh
Response Time	The time current step applied in discharge or charge mode
Specific Power	The power amount pro weight of the battery (W/kg)
Specific Energy	The energy amount pro weight of the battery (Wh/kg)
Number of Cycles	The maximum number of cycles
O&M Cost	Operation and Maintenance costs
Cycle Efficiency	Ratio of discharge energy to charge energy amount
Lifespan	Depends of the shelf life
Self-Discharge	Losses in the cells because of the chemical reactions
Temperature	Optimal operating temperature ,effects efficiency

Another important parameter is to examine remained energy in the battery, which is called state of charge (SOC). As every device batteries are getting damaged after specific time, condition of the battery can be identified with the parameter state of health(SOH). Different parameters as lifespan, thermal effects and electrical specifications define the current challenges for various type of the battery models. Considering battery in a renewable microgrid concept compose the important part, after the electricity generation, battery controls the balancing by storing required amount of energy. Some battery types comparison listed by different parameters in Table 3.

Table 3. Comparison of different battery types [17]

Energy Storage	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Specific Power (Wh/kg)	Life Cycle	Efficieny (%)	Cost ($/kWh)
Lead acid	35	100	180	1000	>80	60
Valve regulated	50	–	150+	700+	–	150
Metal foil	30	–	900	500+	–	–
Nickel–iron	50–60	60	100–150	2000	75	150–200
Nickel–zinc	75	140	170–260	300	76	100–200
Nickel–cadmium	50–80	300	200	2000	75	250–300
Lithium–iron sulphide	150	–	300	1000+	80	110
Lithium-ion polymer	130–225	200–250	260–450	1200	–	150
Lithium-ion	118–250	200–400	200–430	2000	>95	150
Electric double-layer capacitor	5–7	–	1–2M	40 years	>95	–
Hybrid capacitors	10–15	–	1–2M	40 years	>95	–
Flywheel	10–150	–	2-10k	15 years	80	–

Battery technologies assist many new technologies nowadays. In the perspective of designing a renewable system, batteries enable quite much flexibility and independence because of their improved capacities. This technological possibility brings forward important aspects for field of batteries Every battery application has different strength in a specific parameter, however lithium-ion batteries are widely used in renewable combined storage systems. Lead acid batteries have the most advantage in economical perspective, on the other hand energy related values are considerably lower. As mentioned above, storage system has a duty for compensating or rejecting the respective energy. Depending on the daily position, battery will be actualizing charge and discharge operations which will be effecting life cycle. As listed in Table 2. Lithium-ion batteries have high energy density, relatively lower cost and high number of life cycle together comparing with other chemical pairs.

5.2. Electrical Model

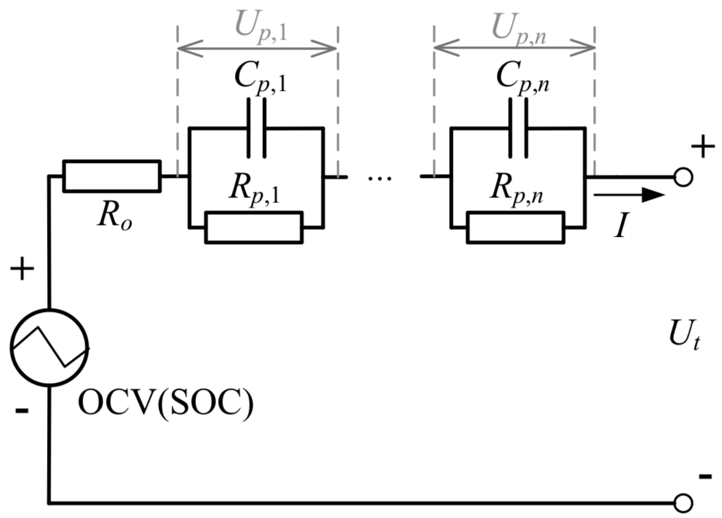

Figure 13. Electrical equivalent circuit of a battery [18]

Equations to calculate state of charge, battery voltage and open-circuit voltage listed below [19];

$$SOC(t) = SOC_{init} - \int_0^t \frac{I_{bat}(t)}{C_{bat}} \qquad (5.1)$$

$$V_{bat} = V_{oc} - I_{bat}Z_{eq} \qquad (5.2)$$

$$V_{oc} = A_0 + A_1 * SOC + A_0 + A_2 * SOC^2 + \ldots\ldots + A_n * SOC^n \qquad (5.3)$$

V_{bat}	Battery voltage (V)
I_{bat}	Battery current (A)
V_{oc}	Open-circuit voltage (V)
Z_{eq}	Equivalent parasitic impedance (Ω)
SOC	State of charge (%)
SOC_{init}	Initial state of charge (%)
C_{bat}	Battery capacity (Ah)

5.3. Battery Management System (BMS)

A microgrid or for small scale home energy system, it is stated the system contains different modules that works with a relation each other. If operation defined as sections for production, storing and transmission, battery management system is the section that creates system concept. Basically, a battery or battery pack is called module, comes with a covering outside and auxiliaries related with power electronics. From that point it is a plug-and-play device. However, as mentioned in the previous sections, a battery operates with certain parameters effecting their operation efficiency and lifespan. Especially for an application requires load balancing, there could be several numbers of charging or discharging operations that will not happen always in the same conditions and scenario. Therefore, battery management system needs to be integrated for the storage system. Main obligation of BMS is to protect battery, decrease ageing rate and stabilize required current extraction. Essential parameters could be monitored in a BMS listed below;

- State of charge estimation
- State of health estimation
- Monitoring current and voltage
- Temperature
- Charge-discharge control
- Power limitations

By controlling these parameters, harmful faults as over-heating and over-charging could be avoided, damages could be decreased to minimum. Charge and discharge could be made by defining state of charge limits, this limitation enables to stop charging after desired amount reached. Battery could contain parallel and in series connections to obtain higher capacities. It is important to have limitations due to different cell identification, to avoid imbalance in the cells and high(undesired) current applied, operation could work in a specified range. This operation called as cell balancing.

5.4. Lithium-ion Battery Technology

Identically, lithium-ion batteries sustain electrical energy by using electrode principle similar to other type of batteries. Charge operation take place as a result of ion movement from cathode to anode and discharge operation happens with reverse direction anode to cathode. Lithium-ion battery set up with multiple cells in parallel or series to increase voltage and current. Cell contains electrodes and electrolyte with lithium ions. Electrodes separated with each other with a separator sheet. Simplified cell construction showed in Figure 14.

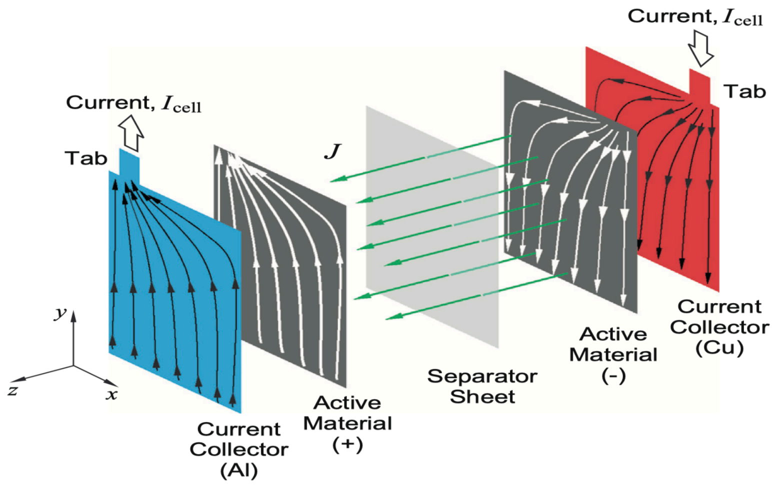

Figure 14. Simplified cell construction [20]

Separator sheet selected as polymer membrane that lets ion exchange by blocking electron flow. Cathode side of the battery because the source of lithium compounds defines the capacity therefore average voltage and anode side releases lithium ions and creates an external circuit by allowing current movement along. As chemical compound of lithium-ion battery mainly LiCoO2 and graphite used. Anode and cathode side reactions are given below [21];

Anode Side: $$LiXC_6 \leftrightarrow xLi^+ + xe^- + Li_{1-x}C_6 \quad (5.4)$$

Cathode Side: $$LiCoO_2 \leftrightarrow xLi^+ + xe^- + Li_{1-x}CoO_2 \quad (5.5)$$

5.5. Lithium-ion Battery Price Overview

Lithium ion batteries used in electronic and mobility devices almost since 30 years. The projection for the electric vehicle usage expected to rise next decade. Lithium ion battery technology offers high energy density and number of cycle that makes them quite appropriate device for transportation applications dependent on an electrical storage. With an increase of number in home storage systems and grid applications their cost will be lowered. From that point , not only industrial applications but also household implementation will contribute pricing of lithium-ion batteries with the improvements in the power output and energy density. Price development over worldwide listed in the Figure 15.

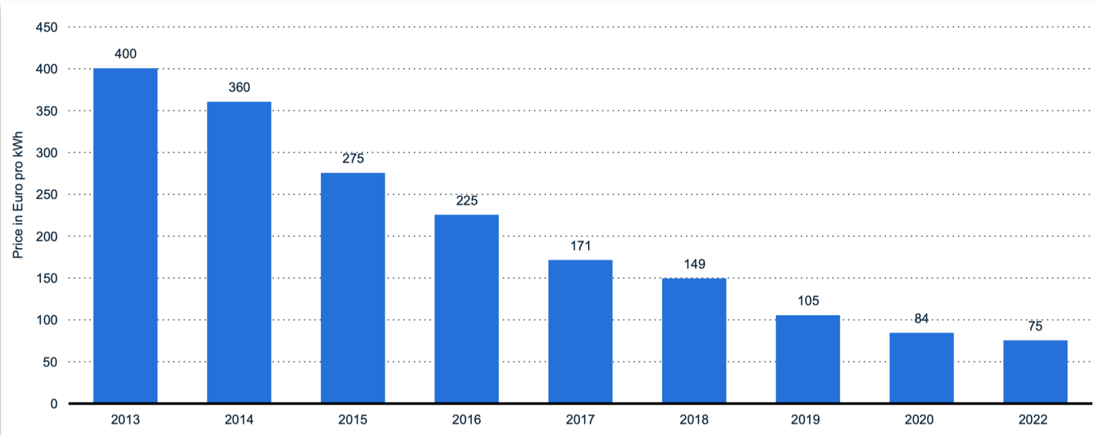

Figure 15. Worldwide price development for Lithium-ion batteries [22]

By 2010, their total market volume increased one order of magnitude (from about 2 to 20 GWh), reaching a total annual market value of about 6.5 bn € largely owing to portable electronics. From 2010 onwards Li-ion batteries have been growing annually at 26 % in terms of production output and 20 % in terms of value (5). In 2017, the total market size of Li-ion batteries was about 120 GWh (24 bn €) [23]. According to the current market values compared to last years, it is possible to see prices are falling with a huge measure. On the other hand, a battery contains a chemical compound and price will be dependent on the lithium reserve when projected market shares be realised. Competitiveness of battery manufacturers and the demand for lithium-ion batteries will define the market share.

6. PEAK LOAD SHAVING

During the day depending on location and daily conditions, electricity demand changes. Managing peak and off-peak hour loads is important to operate grid optimally with safety. Electricity network expand extensive areas day by day due to new living arrangements respective to the increase in end user number. For an interrupted electricity supply power plants needs to respond momentarily electricity demand increase. Continuous growth in peak load raises the possibility of power failure and raises the marginal cost of supply. Therefore, supply and demand (consumption balancing or meeting peak load has become a major concern of utilities [24]. To meet the peak loads, small scale power plants that could start to operate fast relative to huge power plants, but they are mostly plants working with natural gas or in power systems diesel generators. This scenario result with again higher costs in operation and maintenance. Additionally, after all improvement in reducing emissions and renewable energy applications, engaging the whole power system for non-renewable sources is completely not meeting the present-day energy targets. To add another economical point, during peak hours electricity price rises to high values and opposite to that during base hours because of low demand prices see the radically low values and this creates fluctuation in the market. Although storage technologies are developing, challenges with storing energy still remains unsolved. Excess power generated by power plants are not stored, in other word it is wasted. However, the prices for per unit electricity increasing according to that. Undoubtedly, electricity network design to meet the maximum load and developed parallel to further usage. Next decade, electricity demand will increase more with electric vehicle adaption to the grid and increased production in the industrial field. Management of peak load needs to planned, energy storage system in small scale for the household could be a modern solution for stabilizing grid, reducing electricity prices and high operation costs of power plants. Methods of peak load shaving combined with operation and control strategies of energy storage systems provide an opportunity for actual issues. Electricity prices changes during the day parallel to the demand and available energy produced. Peak load shaving works in a basic principle, storing the energy in battery when the prices behold low and releasing the stored energy in peak hours. The graph showing peak load shaving showed in Figure 16.

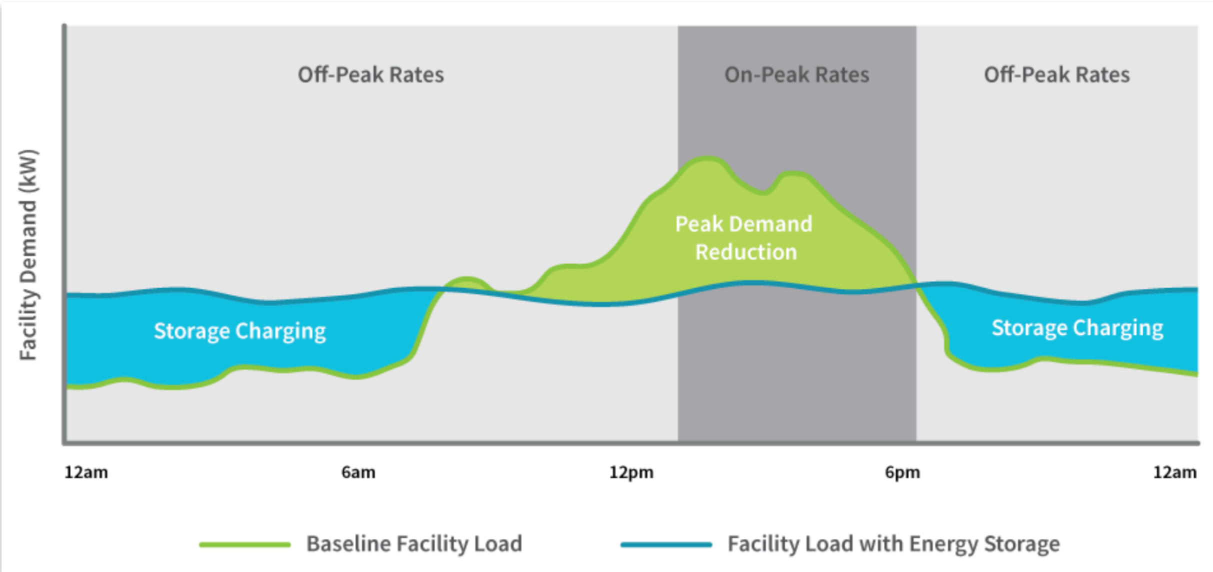

Figure 16. Peak load shaving [25]

Energy storage systems have several benefits for both consumer and grid operator. Surplus energy occurred in the day can be stored in battery and could be used in household necessity or to charge electric car. From this point consumer can decide operating scenario by avoiding paying high electric bills. Likewise, by avoiding peak loads grid operator can stabilize grid. Combine operation of grid and storage is an effective way to apply peak load shaving. Peak load shaving depends on an algorithm that stabilize power by increasing or decreasing with a specified state of charge percentage. To set the values would be working in load shaving strategy, demand needs to be specified. Example algorithm for controlling peak load shaving showed in Figure 17. Working principle of the algorithm based on decision of charging, discharging or working idle. If the grid power without battery remains between lower and upper threshold power limit, system continue to work idle. Charging mode will be active in case of grid power follow up less than lower threshold power limit. Discharge will be made only if battery state of charge is more than 50%. In that case, difference between power demand and upper power threshold will be checked.

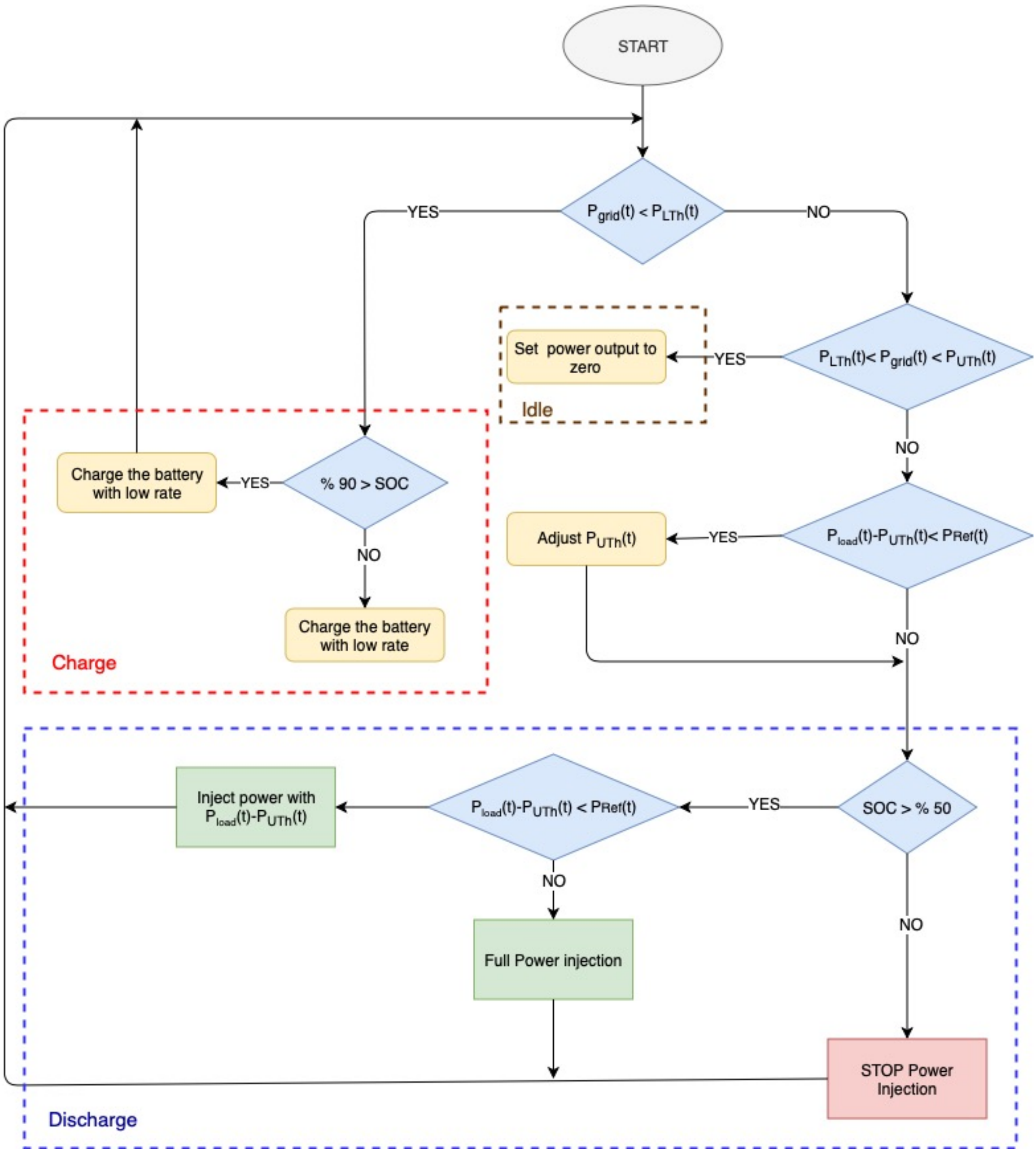

Figure 17. Control algorithm for peak load shaving [26]

$P_{grid}(t)$ Grid power

$P_{load}(t)$ Power demand

$P_{Ref}(t)$ Reference power

$P_{LTh}(t)$ Lower power threshold limit

$P_{UTh}(t)$ Upper power threshold limit

7. SIMULINK SIMULATION

7.1 Simulation Properties

Brief information with photovoltaics combined with a battery explained in the previous chapters. The stand-alone PV with charging and discharging could be simulated with constructing system scheme and power electronics equipment in MATLAB Simulink. Simulink blocks allow to combine system components by adjusting parameters. In the simulation, solar module with total 1 kW power output combined with a lithium-ion battery with 24V, 50 Ah capacity used. Energy storage system tested with constant temperature with respective increasing irradiation and with a temperature, irradiance profile that differs. Battery charging and discharging response during power from solar observed. Battery and PV properties used in the simulation listed in Table 4. Simulink blocks used in the simulation are signal builder for irradiation and temperature, PV array, MPPT, boost converter, bidirectional DC converter and battery module with li-ion selection. Monitorable data with the current topology are momentary power, voltage and current changes, voltage rise after boost converter, battery state of charge, voltage and current.

Table 4. Data of PV&Battery used in simulation

Parameters	**PV**		**Parameters**	**Lithium-ion Battery**
Maximum Power of Module (W)	213,5		Nominal voltage (V)	24
Open circuit voltage (V)	36,3		Rated capacity (Ah)	50
Voltage at maximum power point (V)	29		Initial state of charge (%)	60
Parallel strings	5		Battery response time (s)	1
Series	1		Capacity at nominal voltage (Ah)	45,21
Series Resistance (Ω)	0,39		Nominal discharge current (A)	21,73
Shunt Resistance (Ω)	313,39		Fully charged voltage (V)	27,93

7.2 System components

7.2.1 Solar Module

PV array works with a given value of number of parallel strings and series connection of solar modules. For this application to obtain 1 kW, 5 parallel strings with 1 module that gives approximate power of 200 W used. In the photovoltaics applications receiving the possible high voltage output should be aimed for higher energy utilization. Therefore, maximum power point tracking needs to be integrated and with an appropriate boost converter topology higher voltages could be obtained. Model based on solar side is given in the Figure 18. Solar module works with two main parameters which are irradiance and temperature. These data could be set for a constant value as 1000 W/m^2 and 25°C or data profiles could be added with signal builder. Output voltage and current monitored with measure port. The block works with the solar characteristics given in the previous chapter. Calculation is made by the equations listed below [27];

$$I_d = I_0 \left[exp\left(\frac{V_d}{V_T}\right) - 1 \right] \tag{7.1}$$

$$I_d = \frac{kT}{q} * \ nI * N_{cell} \tag{7.2}$$

I_d	Diode current (A)
V_d	Diode voltage (V)
I_0	Diode saturation current (A)
nI	Diode ideality factor, a number close to 1.0
k	Boltzman constant = 1.3806e-23 J.K-1
q	Electron charge = 1.6022e-19 C
T	Cell temperature (K)
N_{cell}	Number of cells connected in series in a module

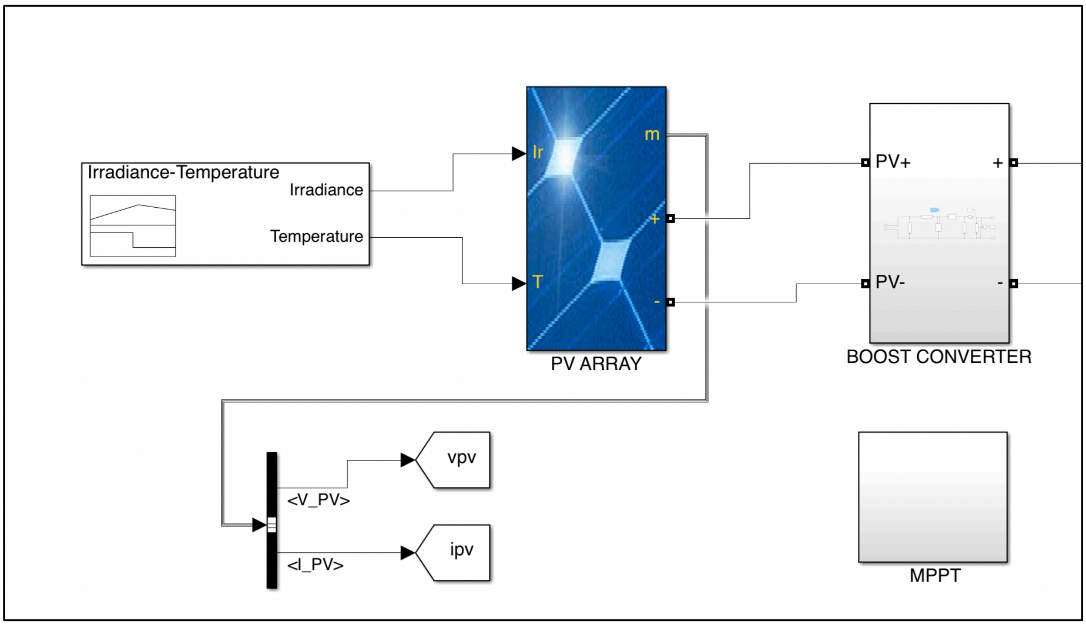

Figure 18. Simulink solar module

7.2.2 MPPT

In the simulation operations controlled by power electronics equipment. One of the important switch on boost converter controlled by a MPPT algorithm. To obtain required power from PV voltage, maximum power point tracking block created manually. To apply switch pulse, PWM generator for DC used, MPPT algorithm controls the duty cycle, adjust voltage and current to obtain maximum power. MPPT matlab code is given in the Appendix 1.

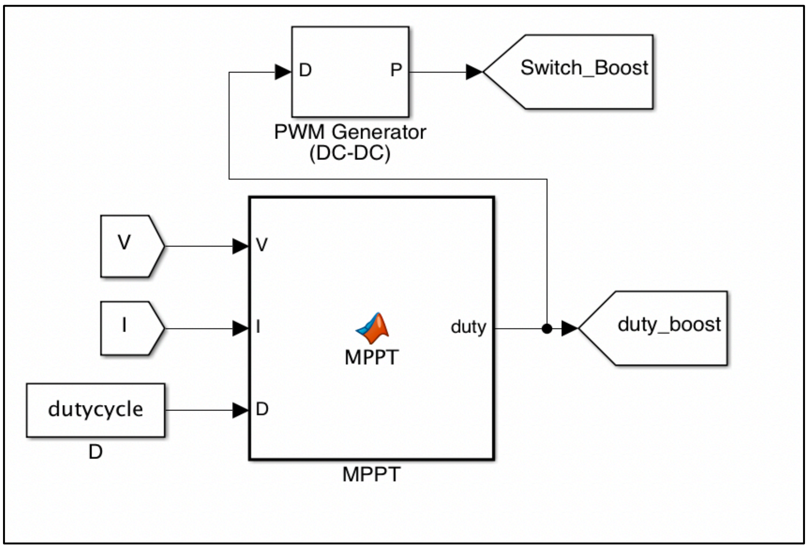

Figure 19. MPPT block

7.2.3. Boost Converter

To increase the voltage output from solar energy before storing in the battery, increasing the voltage is necessary to maximize power. Boost converter is a high efficiency DC/DC converter for stepping up the voltage. This operation can be made by controlling/applying duty cycle. In the simulation basic boost converter topology with IGBT used. Converter topology showed in Figure 20.

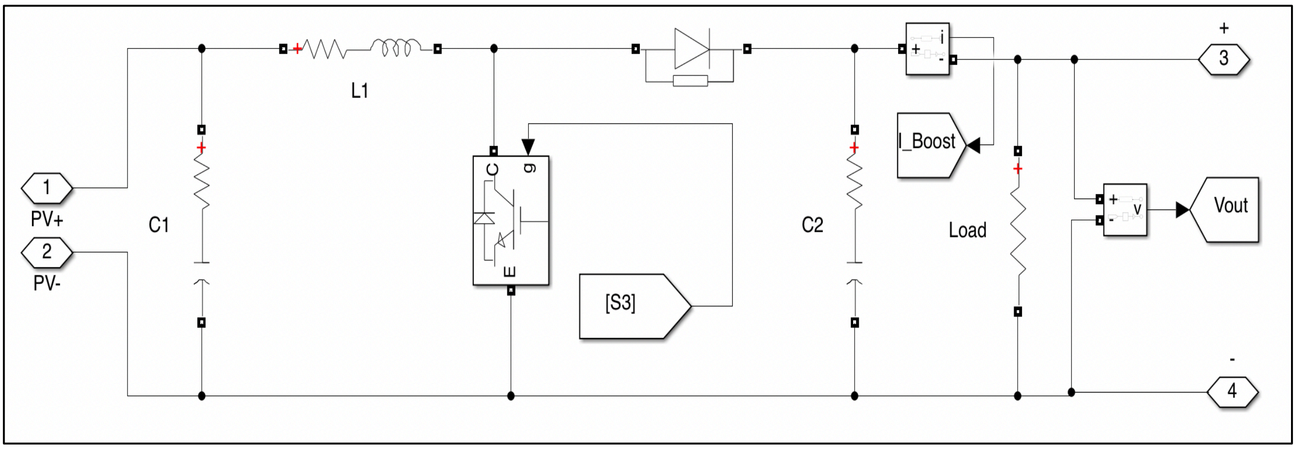

Figure 20. Boost converter topology

7.2.4. Bidirectional DC/DC Converter

A storage application has two operations, charging and discharging, from that point bidirectional converter is necessary to transmit current by working two ways. Switches S1 and S2 controlled by a PI controller for applying pulses.

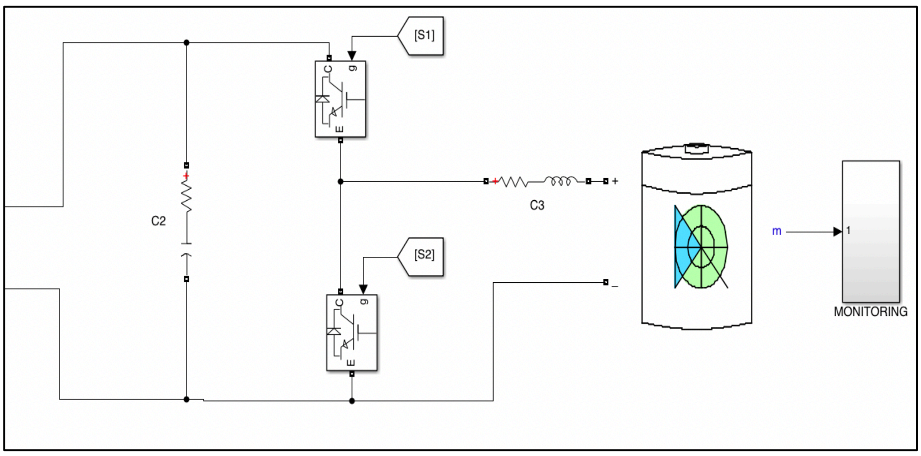

Figure 21. Bidirectional converter topology

7.2.5 PID Controllers

PID stands for proportional integral derivative, for controlling cycles of simulation optimization of voltage is necessary. Controller works basically to decrease fault in the system by applying mathematical inspections. In the simulation PI controllers designed in the methodology given in Figure 22.

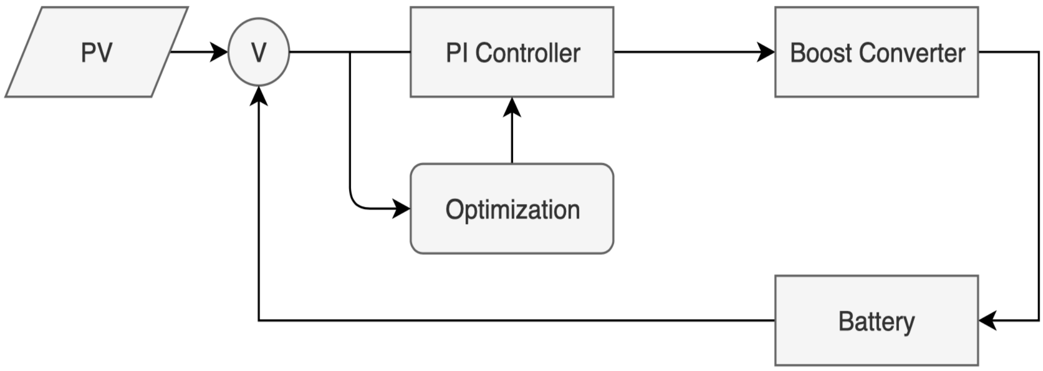

Figure 22. Optimization basic scheme

PI controllers can tune the operation values in the specified scale. In the simulation PI controller used to restore voltage and current values to reference values set in order to receive efficient charge and discharge efficiency. As showed in Figure 23, there are main parameters used for adjusting values, battery voltage and current controlled with a reference value and duty cycle calculating regarding specified limitations. S1 and S2 are the PWM controlled switches, that works on bidirectional converter. S1 operates in the charge, S2 operates in the discharge mode. Reference current of lithium-ion battery set to 22 A and -22 A, because nominal discharge current of the battery is 21,74 A. The reference output voltage of the boost converter is selected 48 V to obtain required current. With that design parameters, when the generated power less than required power load S2 will be active, battery will feed the load. Quite the opposite when PV generates more power, S1 will operate and charge the battery. PI Operation blocks represented in the Figure 23.

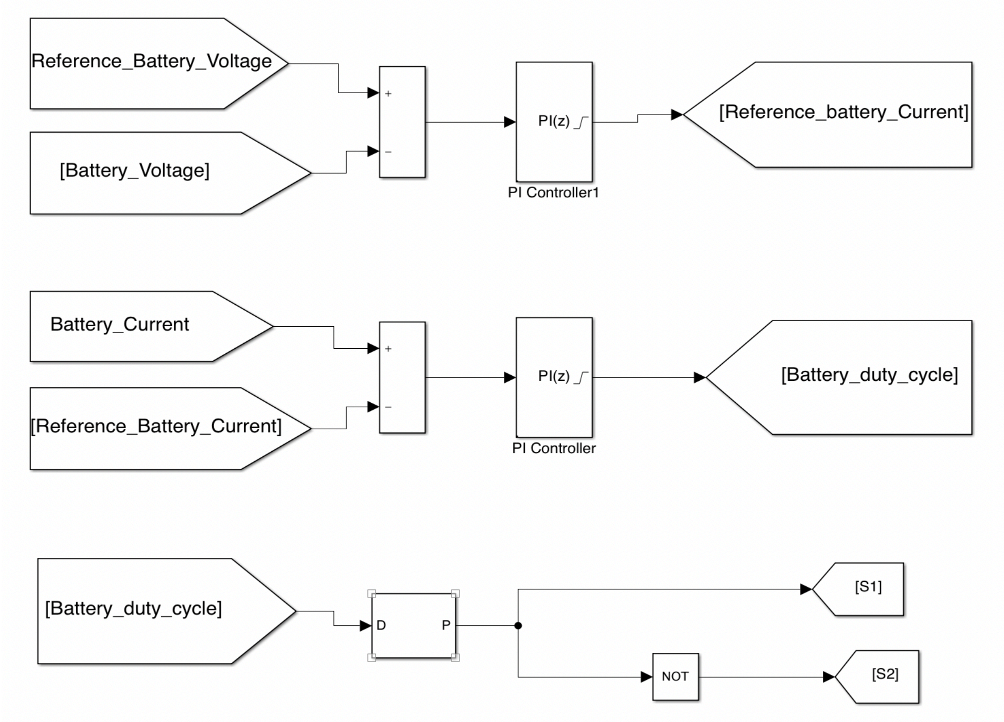

Figure 23. Simulation PI controller working flow

7.2.6. Temperature-Irradiance

Simulink has several different features to implement data for a parameter. In this simulation signal builder block used to import random created irradiance and temperature profile. Temperature and irradiance graph used to generate electricity from solar energy is given in Figure 24.

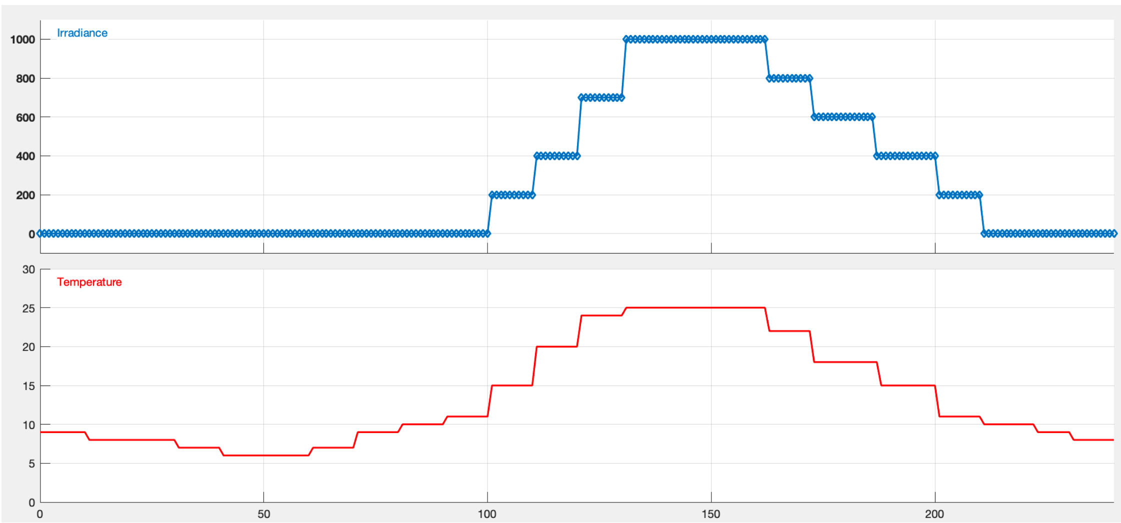

Figure 24. Irradiance and temperature profile

7.3 Results

After simulation run, because of irradiance 0 in the beginning battery started to discharge. As seen in the Figure 25. Battery current proceed discharging and charging by following battery reference voltage specified. Irradiance and temperature profile was selected in order to have solar power during the day time as usual. After irradiance increases, battery current is carry on with negative value. It is possible to observe change in state of charge, battery reacts to power output coming from solar and charges.

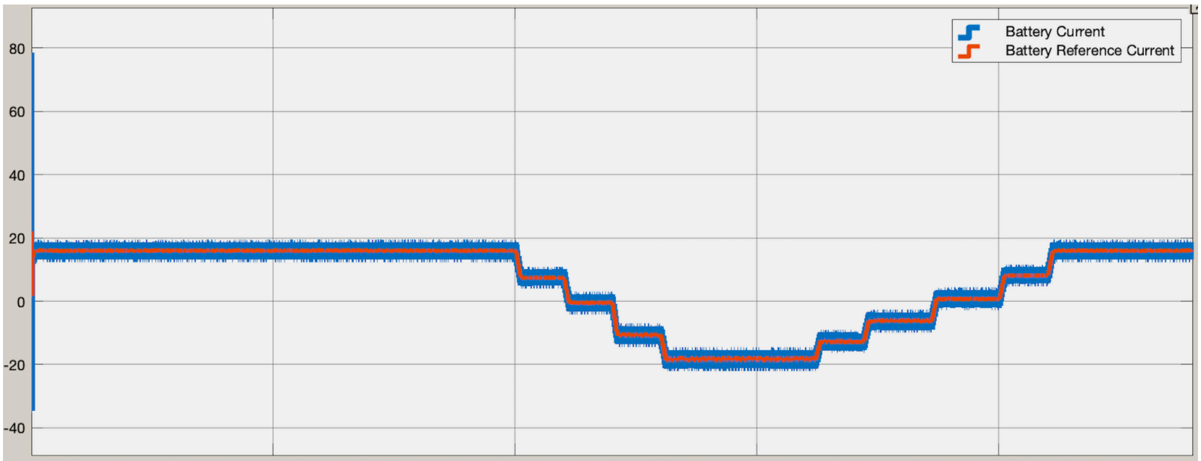

Figure 25. Battery current graph

As a result, configuration of the system related with power electronics and with a control mechanism of PI controllers, basic system that could be integrated in a home simulated successfully. With updating data to required values for a specific change, different charge-discharge characteristics could be observed.

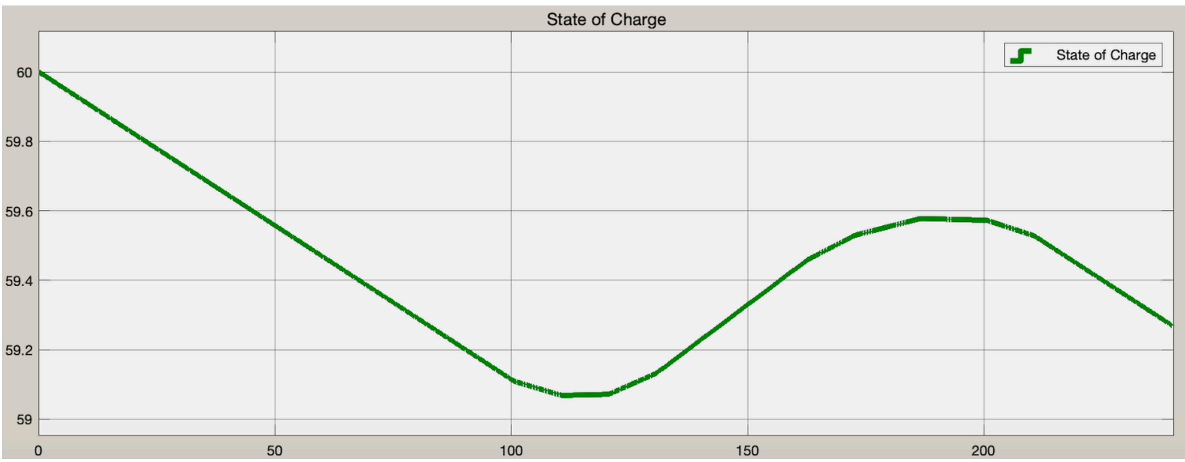

Figure 26. State of charge

8. ELECTRICITY PRODUCTION COSTS

8.1. Levelized Cost of Energy (LCOE)

Designing an energy system is a detailed progress with several important parameters. Energy investments require high capital costs. Thus return of the investment needs to be projected. In solar or other energy projects, levelized cost of energy method used to determine forecast possible costs in the operating time of power plant or a small scale application. The levelized cost method is valuable calculation to compare different power generation applications. It is basically, calculating the average cost of electricity during the energy system's lifetime. Main formula for calculating levelized costs for the new power plant is showed below in the equations below.

Levelized Cost of Electricity basic formula [28];

$$\text{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electrical energy produced over life time}} \quad (8.1)$$

Calculation formula for the LCOE [29];

$$\text{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}} \quad (8.2)$$

I_0	Investment expenditure in EUR
A_t	Annual total cost in EUR per year t
$M_{t,el}$	Produced amount of electricity in kWh per year
i	Real interest rate in %
n	Economic operational lifetime in years
t	Year of lifetime

LCOE calculated with possible maximum and minimum cost. As showed in Figure 27. Wind onshore costs are lowest comparing to the other elements, wind offshore has higher cost according to their distance from the main grid. They need more specific technologies and more power electronics applications to transmit power. If solar compared with wind energy, it is available to see levelized costs are quite similar. On the other hand, energy storage systems combined with the solar could have high costs depending on application scale. In addition to levelized costs, the main parameter that constitutes investment strategy, specific investment costs in euro per kW listed in Table 6.

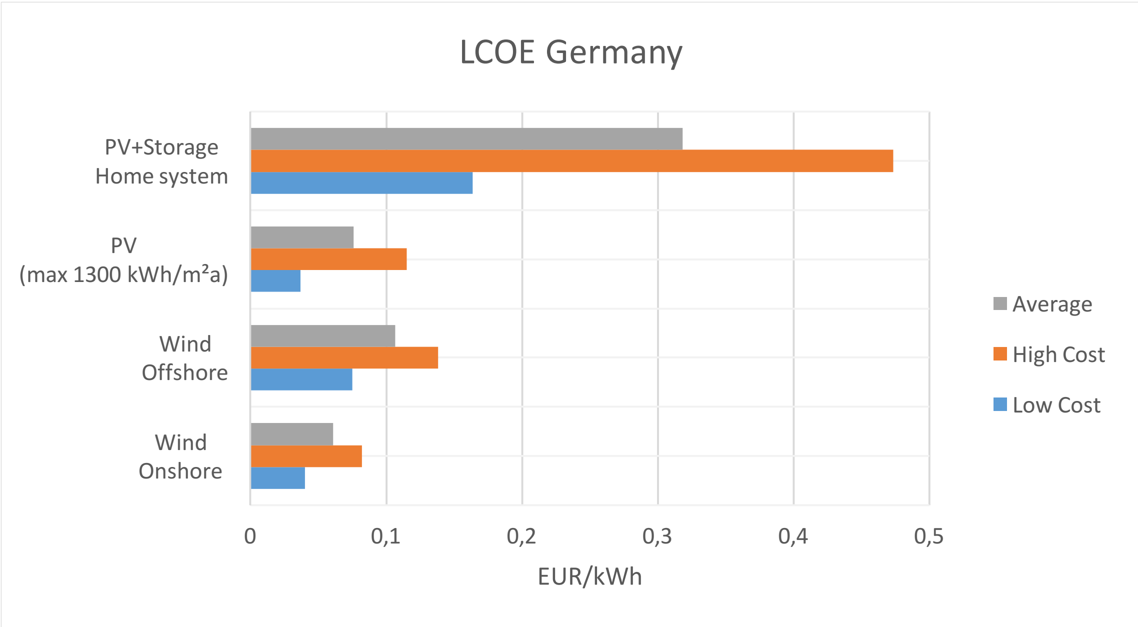

Figure 27. LCOE Germany by source [29,30]

Table 5. Germany LCOE EUR/kWh [29,30]

Scenario	EUR per kWh			
	Wind Onshore	Wind Offshore	PV (max 1300 kWh/m²a)	PV+Storage Home system
Low Cost	0,04	0,075	0,037	0,1634
High Cost	0,082	0,138	0,115	0,4734
Average	0,061	0,1065	0,076	0,3184

Table 6. Specific investment cost in Euro per kW [29]

Source	Investment cost	
PV	600-1400	EUR/kW
Wind Onshore	1500-2000	EUR/kW
Wind Offshore	3100-4700	EUR/kW

8.2 Electricity Production Costs

8.2.1Capacity Factor

Capacity factor is another parameter used in evaluating cost of an energy application. It possible be calculate capacity factor for conventional power plants operate based on a fuel or renewable power plants. Capacity factor could be defined as the actual electrical energy output over capacity of the plant with the related time during production. With today's technology, power plants dependent on a fossil fuel have higher value as long as they have enough fuel to realize energy production. On the other hand, capacity factor for renewables especially solar and wind are quite lower. Because their fuel is natural sources, thus the coverage could change during the operation. Capacity factor changes not only be dependent on source availability. Source for electricity generation be it is optimal point, however if there is no demand or prices are not valuable, power plant could prefer to not operate. From that point renewables combined with a storage would not have waste energy by storing mentioned non-urgent capacity. The main formula for calculating capacity factor is given below.

$$Capacity\ Factor = \frac{Actual\ energy\ produced\ (kWh)}{Time * Capacity} \qquad (8.3)$$

8.2.2 Solar Photovoltaic

Solar energy price development for photovoltaic applications is leading the renewable market by rapid decrease in investment costs. Improvements in the technology and falling prices of materials as silicon declined the solar system module costs. In the last decade, integration of solar energy not only for industrial purposes but also in the small scale projects, contributed inevitable price sinking. Investment cost between 2010 and 2018 fall down 75% pro kW. Another huge update occurs in levelized cost for solar was quite higher than other renewables, but nowadays cost analysis show that photovoltaic applications have competitive values.

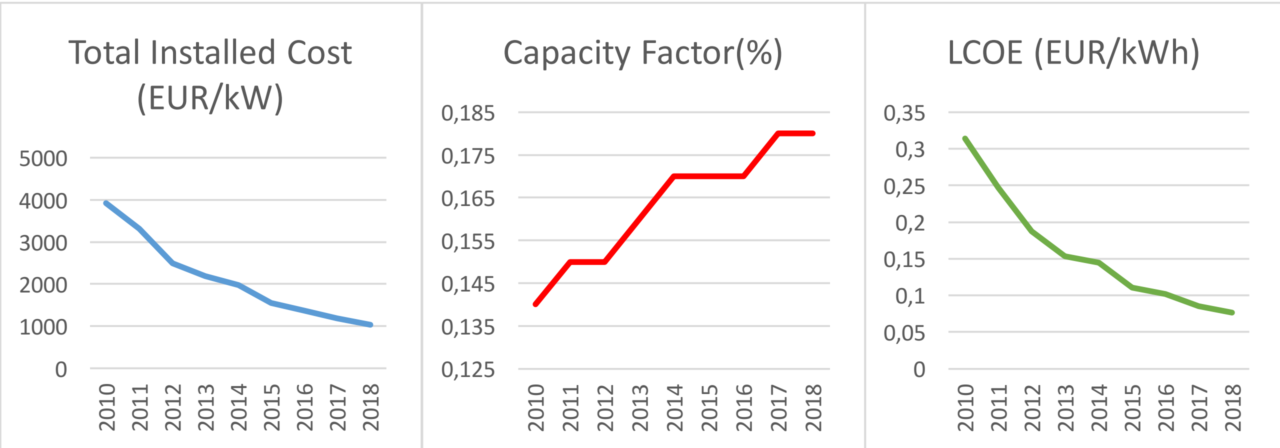

Figure 28. PV price analysis [33]

Local conditions of a photovoltaic solar utilization are the most important aspect for determining levelized cost. Irradiation rate and the hours with optimal solar power will effect production. An area with high solar irradiation rate days would have less levelized cost compare to an area with cloudier days by examining production values. By considering curves listed in Figure 28, it is possible to forecast solar LCOE and total cost of system especially for small scale combined with storage will continue to decrease next years.

8.2.3 Wind Onshore

Onshore wind installations continue to increase with a better capacity factor. Main reason for that is the development in the turbine configuration. Turbine design did not change as a concept. However, capacity of a single wind turbine expanded parallel to size. The improvement in turbine and construction techniques, more capacity could be obtained by less turbines. That leads the capacity factor to rise in the last 5 years. Turbine design and competitive prices determine the reduction of levelized cost wind onshore even to compete with a fossil fuel power plant.

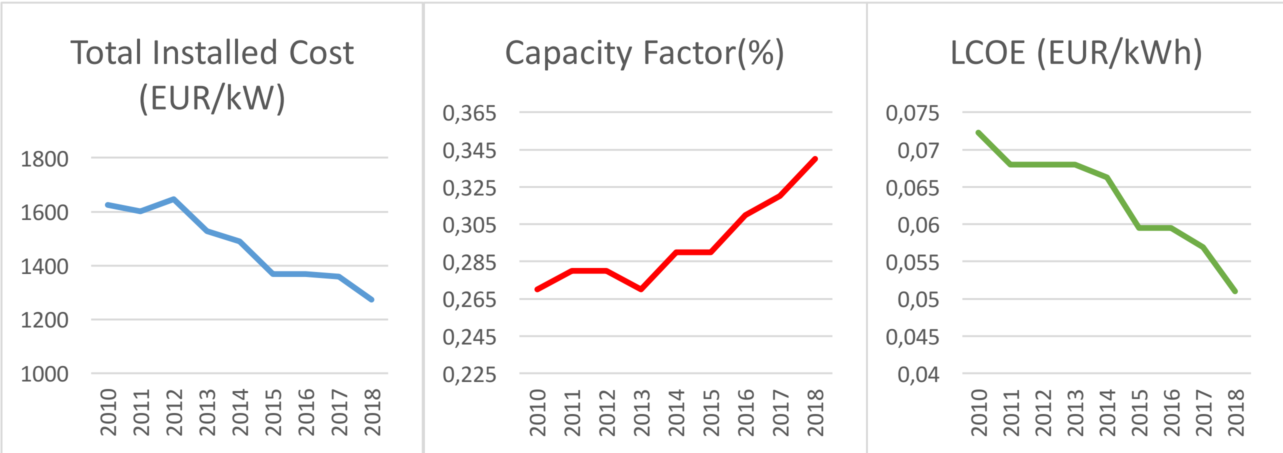

Figure 29. Wind onshore price analysis [31]

Today onshore wind energy is a reliable source of energy with a high amount of market integration. In other words, share of wind energy in electricity generation increases and in parallel the financial models and competitive prices are assembling the prices. The advantages gained by increasing the scale of turbines are showing the development in this field will focus on high capacity turbines. Current LCOE for wind onshore is effected by wind sites with low capacity. Projections are showing that with increased wind coverage and scale, production rate will increase while operation and maintenance costs are decreasing. That will result a positive change in levelized cost of wind onshore.

8.2.4 Wind Offshore

Because of their unique operation areas, wind offshore present particular data comparing to wind onshore. Most challenging part of offshore applications are the construction and transmission of produced electricity from the offshore wind site. Therefore, total installed cost pro kW comprises of related components and installation properties. As a reason advanced engineering in offshore site, even it is decreased between 2015 and 2016, still quite higher than other available sources. The exact opposite, offshore site has a huge wind potential, coverage of wind flow is more than onshore site. That makes the capacity factor high for the wind offshore. As similar to onshore wind , new turbine design with improved scale bring forward lower operation and maintenance cost with it. Levelized cost of wind offshore made a huge improvement in the last years and then stabilized.

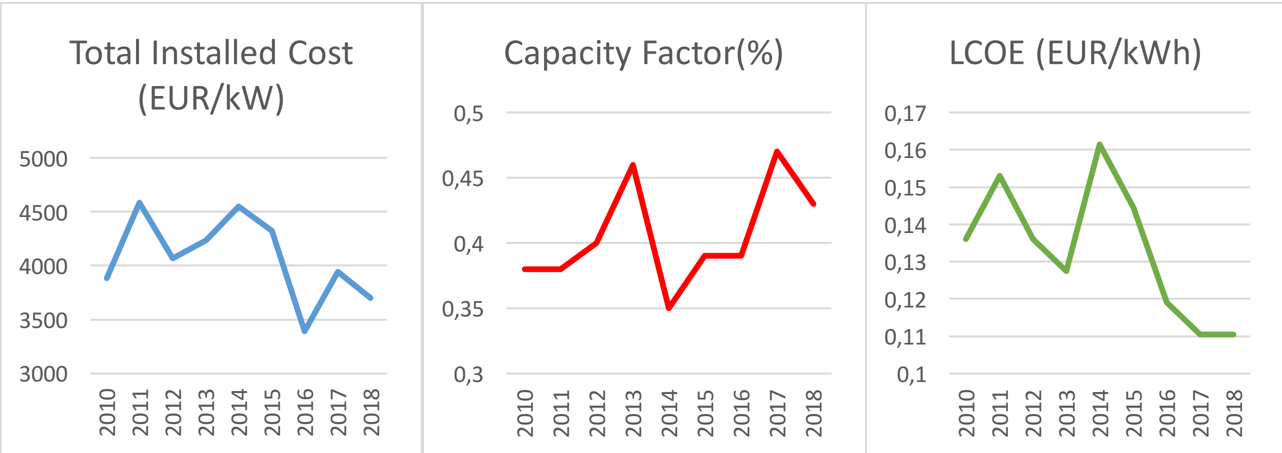

Figure 30. Wind offshore price analysis [31]

In the near future, further decrease in levelized cost can be expected from offshore wind energy. Above mentioned costs are increasing final investment value and inaccessibility of these sites, advanced engineering costs result it to improve the price slower than the onshore. However, utilizing wind in a high capacity makes it a reliable type of application. With the further improvements prices will come close to onshore site values.

8.3 Input Data

In the work package, renewable energy systems analysed with an energy storage. In the calculations, renewable source data created with NASA MERRA reanalysis on a web application and detailed values listed in appendix. Load profiles used for Germany and Turkey showed below. For Germany detailed profile used for household and commercial by day groups, for Turkey average load is not published as same method in Germany, data could be obtained totally for the country. Daily average total profile for Turkey showed in Figure 33. According to International Energy Agency [32], Turkey electricity consumption is 49% less than Germany, by using this information and actual total load profile, average load profile assumed and used in the calculations as showed in Table 8. For electric vehicle there are many options depending on capacity, electric vehicle selected with an average capacity, real test values made by ADAC used to determine extra consumption for the household.

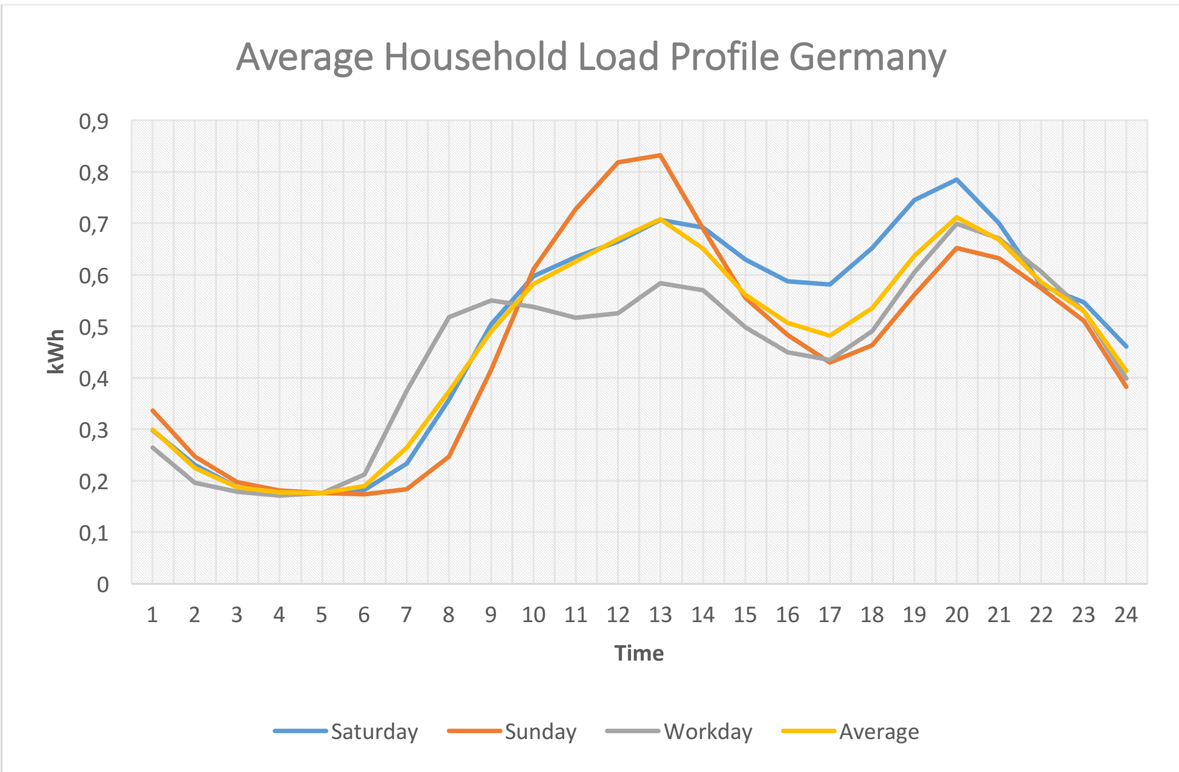

Figure 31. Average household load profile Germany [33]

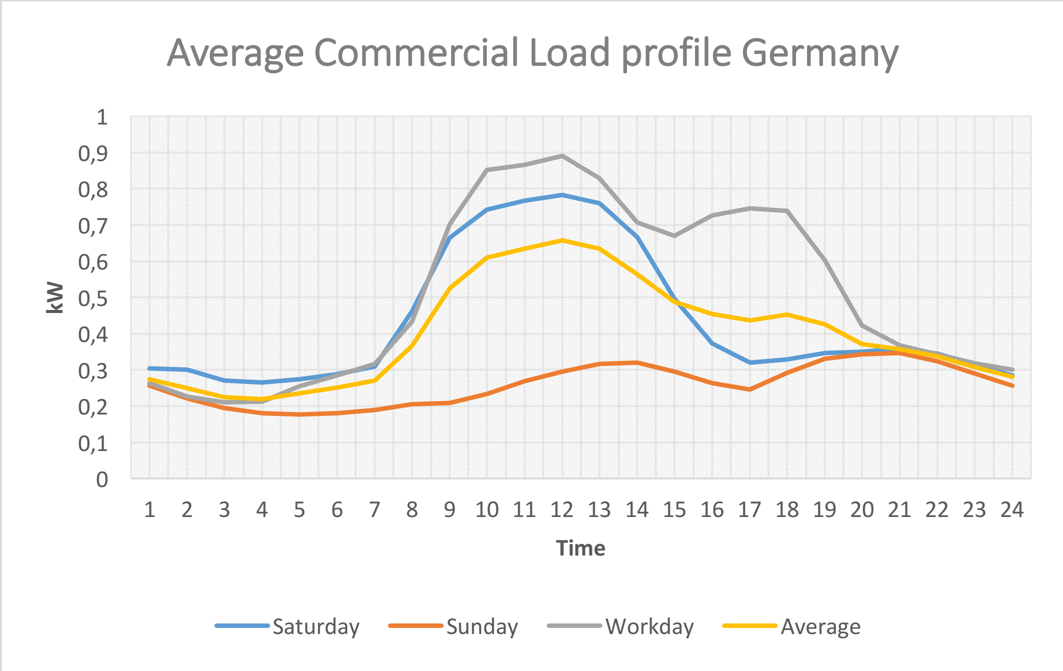

Figure 32. Average Commercial load profile Germany [33]

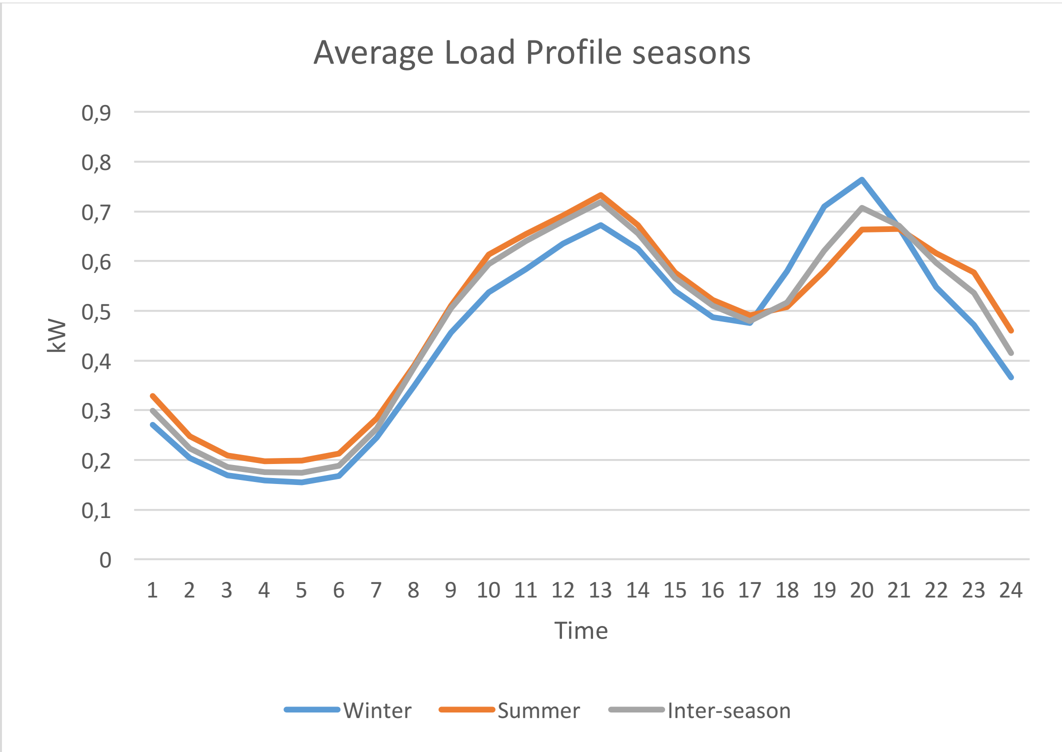

Figure 33. Average load profile for seasons [33]

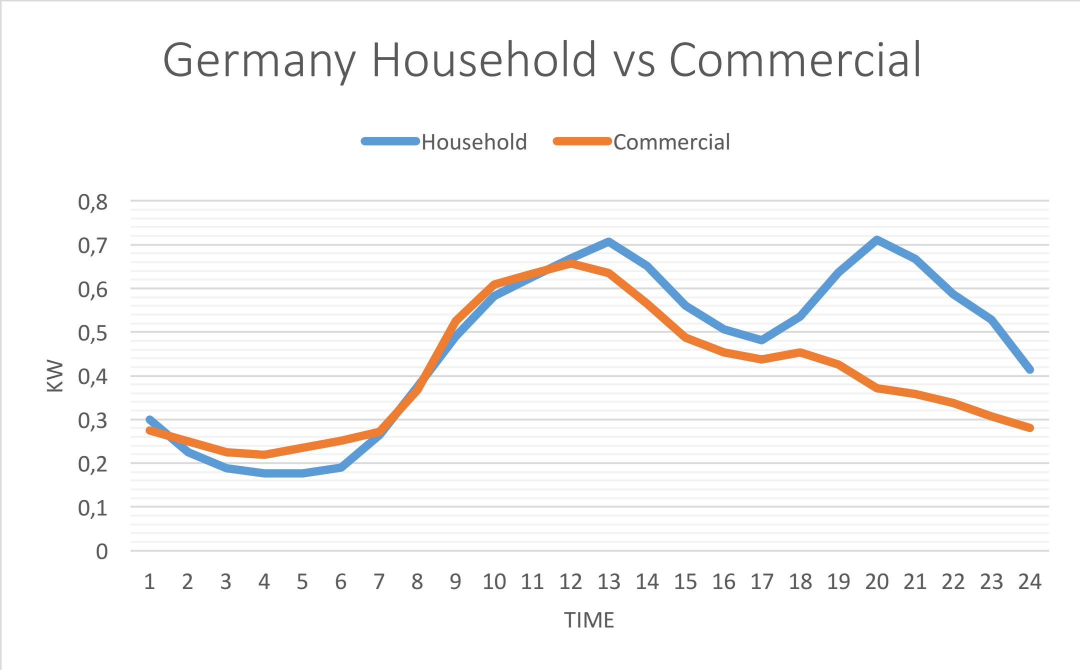

Figure 34. Germany household and commercial consumption comparison

Germany household load profile for shows similarity with the commercial profile till 17:00. That is because after mentioned time commercial consumers are closing the business and they also contribute household consumption as showed in the Figure 34.

Table 7. Electricity prices [35,36,37,38]

Source	Cent/kWh
	Germany
Solar Feed-in	8,64
Wind Feed-in	5,42
Average Household Electricity Price [36]	29,88
Average Commercial Electricity Price [37]	22,22

Table 8. Electric car properties [39]

VW e-Golf		
Range	231	km
Consumption	15,8	kWh/100 km
Full Charging Time (AC 1-phase wallbox / charging station 7.2 kW)	318	minute
	5,3	h
Monthly distance	700	km
Monthly Consumption	110,6	kWh
Daily Consumption	3,69	kWh

Table 9. Renewables system cost [40]

Source	System Cost (EUR/kW)		
	Min.	Max.	Average
PV	600	1400	1000
Wind Onshore	1500	2000	1750
Wind Offshore	4700	3100	3900

8.4 Results

8.4.1 PV+Storage+Household with Average load profile Germany,Hannover

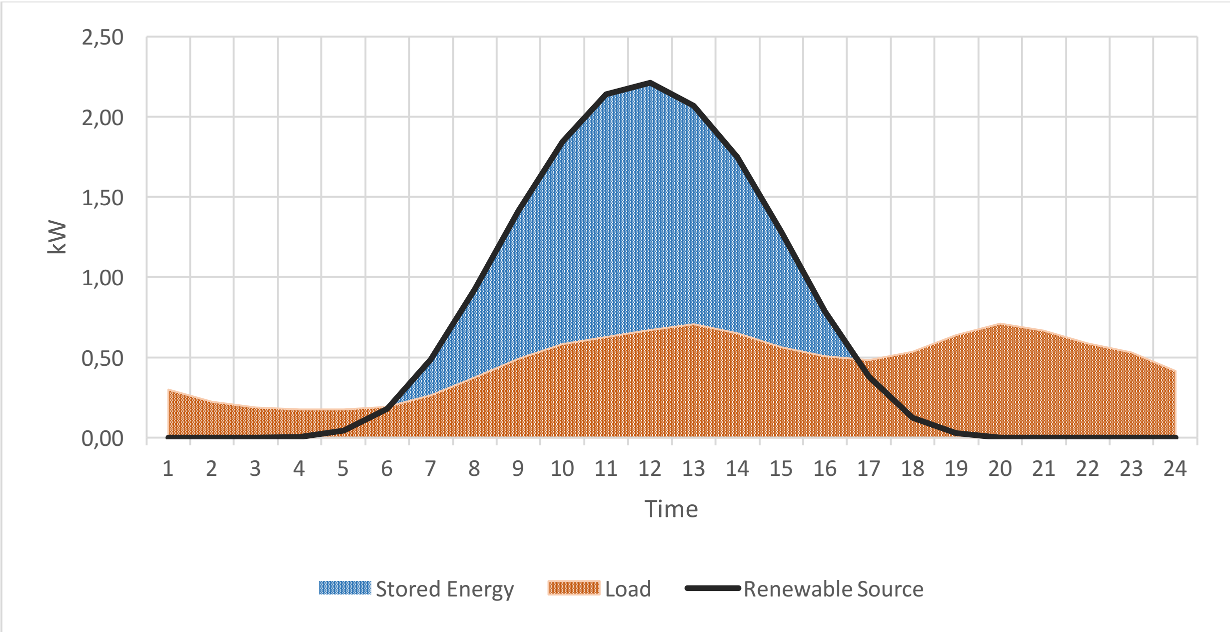

Figure 35. Daily Load-source curve

Germany load profile shows characteristic of peak electricity demand between 10:00- 15:00 and 19.00-22.00 time slots. In the meantime, solar power reaches it is maximum value between 12:00-13.00. As showed in the Figure 35, surplus energy occurs during the day, this amount of energy will be stored in the battery, released to sell energy to grid or be used when necessary by considering economic parameters.

Table 10. Low Cost Analyzes for household average load profile

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1949,18	3390,12	582,41	292,91	289,51
	2	1673,93	2959,86	500,17	255,73	244,44
	3	1424,02	2569,20	425,50	221,98	203,52
	4	1193,02	2208,07	356,47	190,78	165,70
	5	1022,53	1941,44	305,53	167,74	137,79
Without Battery	-	2252,55	3864,33	673,06	333,88	339,19
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	49,68	94,75	135,67	173,49	201,39
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	-10,83	-17,04	-19,11	-18,08	-7,14
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	1949,18	1673,93	1424,02	1193,02	1022,53
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1768,31	1994,01	2198,93	2388,35	2528,16
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1056,67	1191,54	1314,00	1427,19	1510,73
Annual Final Cost (Renewable System+Storage)	EUR/a	636,70	630,48	628,41	629,44	640,39

Table 11. High Cost Analyzes for household average load profile

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1945,73	3485,38	581,38	301,14	280,25
	2	1662,54	3135,62	496,77	270,92	225,85
	3	1400,00	2811,34	418,32	242,90	175,42
	4	1155,88	2509,79	345,38	216,85	128,53
	5	973,47	2284,39	290,87	197,37	93,50
Without Battery	-	2252,55	3864,33	673,06	333,88	339,19
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	58,94	113,34	163,76	210,66	245,69
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	31,71	67,97	108,20	151,96	207,58
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	1945,73	1662,54	1400,00	1155,88	973,47
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1771,13	2003,34	2218,63	2418,81	2568,39
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1058,36	1197,12	1325,76	1445,39	1534,77
Annual Final Cost (Renewable System+Storage)	EUR/a	679,24	715,49	755,72	799,48	855,10

8.4.2 PV+Storage+Commercial with Average load profile Germany,Hannover

Table 12. Low Cost Analyzes for commercial average load profile

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1417,02	3447,37	314,86	297,85	17,01
	2	1139,15	3012,98	253,12	260,32	-7,20
	3	890,32	2623,96	197,83	226,71	-28,88
	4	756,44	2414,47	168,08	208,61	-40,53
	5	705,61	2334,71	156,79	201,72	-44,93
Without Battery	-	1721,88	3923,90	382,60	339,02	43,58
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	26,57	50,78	72,46	84,11	88,51
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	12,28	26,92	44,10	71,30	105,75
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	1417,02	1139,15	890,32	756,44	705,61
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1720,67	1948,53	2152,56	2262,35	2304,02
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1028,21	1164,36	1286,29	1351,89	1376,79
Annual Final Cost (Renewable System+Storage)	EUR/a	659,81	674,45	691,62	718,82	753,27

Table 13. High Cost Analyzes for commercial average load profile

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1413,75	3543,34	314,14	306,14	7,99
	2	1128,56	3191,08	250,77	275,71	-24,94
	3	866,42	2867,26	192,52	247,73	-55,21
	4	719,74	2685,92	159,93	232,06	-72,14
	5	665,03	2618,09	147,77	226,20	-78,43
Without Battery	-	1721,88	3923,90	382,60	339,02	43,58
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	35,59	68,52	98,79	115,71	122,01
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	55,07	112,79	173,17	246,90	331,26
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	1413,75	1128,56	866,42	719,74	665,03
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1723,35	1957,21	2172,16	2292,44	2337,30
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1029,81	1169,55	1298,00	1369,87	1396,68
Annual Final Cost (Renewable System+Storage)	EUR/a	702,59	760,31	820,69	894,42	978,78

8.4.3 PV+Storage+Household with P2Heat, Hannover

Table 14. Low Cost Analyzes for household P2Heat load profile

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1884,22	3473,83	563,01	300,14	262,87
	2	1605,69	3038,44	479,78	262,52	217,26
	3	1352,78	2643,09	404,21	228,36	175,85
	4	1119,35	2278,16	334,46	196,83	137,63
	5	955,86	2022,48	285,61	174,74	110,87
Without Battery	-	2189,96	3951,73	654,36	341,43	312,93
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	50,06	95,67	137,08	175,30	202,06
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	-11,21	-17,97	-20,53	-19,90	-7,80
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	1884,22	1605,69	1352,78	1119,35	955,86
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1698,57	1926,97	2134,35	2325,77	2459,82
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1015,00	1151,48	1275,40	1389,79	1469,89
Annual Final Cost (Renewable System+Storage)	EUR/a	636,31	629,55	626,99	627,62	639,72

Table 15. Low Cost Analyzes for household P2Heat load profile

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1880,74	3569,83	561,96	308,43	253,53
	2	1595,10	3217,04	476,62	277,95	198,66
	3	1329,11	2888,50	397,14	249,57	147,57
	4	1081,64	2582,82	323,19	223,16	100,04
	5	906,26	2366,10	270,79	204,43	66,36
Without Battery	-	2189,96	3951,73	654,36	341,43	312,93
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	59,40	114,27	165,36	212,89	246,57
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	31,25	67,04	106,60	149,72	206,70
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	1880,74	1595,10	1329,11	1081,64	906,26
CO_2 Avoidance (Coal)	kgCO2eq/kWh	1701,42	1935,65	2153,76	2356,68	2500,49
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1016,70	1156,67	1287,00	1408,26	1494,20
Annual Final Cost (Renewable System+Storage)	EUR/a	678,78	714,56	754,12	797,24	854,22

8.4.4 PV+Storage+Household with Electric Vehicle, Hannover

Electric vehicle creates an extra consumption from depending on usage, the consumption accepted as given in the input section. When the load is lower between 01:00 and 08:00, charging operation decided to realize at specified time slot by spreading extra load. To simulate the case, electric car selected as e-golf with range of 231 km and 15,8 kWh consumption for 100 km. By assuming 700 km monthly distance will be made, total daily consumption corresponds to 3,69 kWh. This consumption leads to a load profile with higher values. Charging time decided to be made in the night time and extra load deployed as showed in Figure 36.

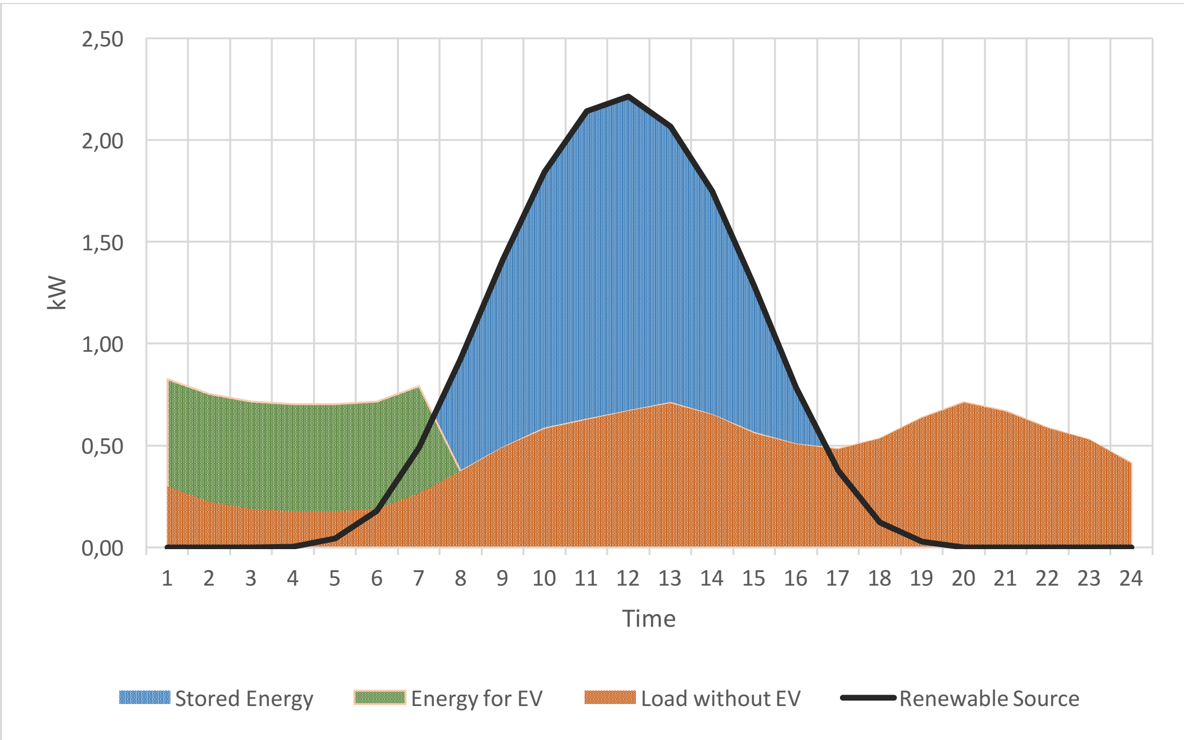

Figure 36. Daily Load profile with electric vehicle

Table 16. Low Cost Analyzes for household with EV load profile

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	3285,65	2812,39	981,75	242,99	738,76
	2	3030,99	2414,34	905,66	208,60	697,06
	3	2799,25	2052,09	836,42	177,30	659,11
	4	2585,10	1717,34	772,43	148,38	624,05
	5	2381,91	1399,70	711,71	120,93	590,78
Without Battery	-	3574,61	3264,05	1068,09	282,01	786,08
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	47,32	89,02	126,96	162,03	195,30
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	-8,47	-11,32	-10,41	-6,62	-1,04
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	3285,65	3030,99	2799,25	2585,10	2381,91
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2248,71	2457,53	2647,56	2823,16	2989,78
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1343,74	1468,52	1582,08	1687,01	1786,58
Annual Final Cost (Renewable System+Storage)	EUR/a	639,06	636,21	637,11	640,90	646,48

Table 17. High Cost Analyzes for household with EV load profile

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	3281,95	2902,61	980,65	250,79	729,86
	2	3017,74	2576,30	901,70	222,59	679,11
	3	2774,62	2276,03	829,06	196,65	632,41
	4	2548,85	1997,17	761,60	172,56	589,04
	5	2335,38	1733,51	697,81	149,77	548,04
Without Battery	-	3574,61	3264,05	1068,09	282,01	786,08
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	56,22	106,97	153,67	197,04	238,04
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	34,43	74,33	118,29	165,57	215,22
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	3281,95	3017,74	2774,62	2548,85	2335,38
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2251,74	2468,40	2667,76	2852,89	3027,93
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1345,55	1475,02	1594,15	1704,77	1809,37
Annual Final Cost (Renewable System+Storage)	EUR/a	681,96	721,86	765,81	813,10	862,75

8.4.5 Wind Onshore+Storage+Household with Average load profile Germany,Hannover

Table 18. Low Cost Analyzes for household for wind onshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
	kWh	kWh	kWh	EUR	EUR	EUR/a
Calculation Type	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	994,19	1523,65	297,06	82,58	214,48
	2	906,28	1386,05	270,80	75,12	195,67
	3	851,53	1300,26	254,44	70,47	183,96
	4	811,09	1236,16	242,35	67,00	175,35
	5	777,70	1182,20	232,38	64,08	168,30
Without Battery	-	1171,49	1800,95	350,04	97,61	252,43
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	37,95	56,76	68,47	77,08	84,13
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	0,90	20,95	48,09	78,33	110,13
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	994,19	906,28	851,53	811,09	777,70
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2551,39	2623,48	2668,37	2701,53	2728,92
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1524,61	1567,69	1594,52	1614,33	1630,69
Annual Final Cost (Renewable System+Storage)	EUR/a	454,17	474,21	501,35	531,60	563,39

Table 19. High Cost Analyzes with household for wind onshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	984,37	1569,72	294,13	85,08	209,05
	2	885,98	1448,04	264,73	78,48	186,25
	3	822,29	1369,21	245,70	74,21	171,49
	4	776,17	1311,50	231,92	71,08	160,84
	5	736,18	1260,70	219,97	68,33	151,64
Without Battery	-	1171,49	1800,95	350,04	97,61	252,43
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	43,38	66,18	80,94	91,59	100,79
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	47,27	115,12	191,02	271,02	352,48
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	984,37	885,98	822,29	776,17	736,18
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2559,45	2640,12	2692,35	2730,17	2762,96
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1529,42	1577,63	1608,84	1631,44	1651,04
Annual Final Cost (Renewable System+Storage)	EUR/a	500,54	568,39	644,29	724,28	805,74

8.4.6 Wind Onshore+Commercial with Average load profile Germany,Hannover

Table 20. Low Cost Analyzes with commercial for wind onshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	695,50	1823,00	154,54	98,81	55,73
	2	607,03	1684,06	134,88	91,28	43,61
	3	550,99	1594,62	122,43	86,43	36,00
	4	508,01	1525,60	112,88	82,69	30,19
	5	472,04	1467,53	104,89	79,54	25,35
Without Battery	-	858,88	2078,59	190,84	112,66	78,18
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	22,45	34,58	42,18	47,99	52,84
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	16,40	43,13	74,37	107,41	141,42
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	695,50	607,03	550,99	508,01	472,04
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2312,31	2384,86	2430,82	2466,06	2495,55
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1381,75	1425,10	1452,56	1473,62	1491,24
Annual Final Cost (Renewable System+Storage)	EUR/a	469,67	496,39	527,64	560,68	594,69

Table 21. High Cost Analyzes with commercial for wind onshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	689,15	1868,79	153,13	101,29	51,84
	2	592,77	1749,20	131,71	94,81	36,91
	3	531,83	1672,47	118,17	90,65	27,52
	4	486,03	1614,44	108,00	87,50	20,49
	5	447,89	1565,85	99,52	84,87	14,65
Without Battery	-	858,88	2078,59	190,84	112,66	78,18
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	26,34	41,28	50,66	57,69	63,53
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	64,31	140,03	221,30	304,92	389,73
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	689,15	592,77	531,83	486,03	447,89
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2317,52	2396,56	2446,53	2484,08	2515,36
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1384,86	1432,09	1461,95	1484,39	1503,08
Annual Final Cost (Renewable System+Storage)	EUR/a	517,58	593,29	674,57	758,19	843,00

8.4.7 Wind Onshore+Storage+Household with P2Heat, Hannover

Table 22. Low Cost Analyzes with household P2Heat for wind onshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	927,26	1603,27	277,06	86,90	190,17
	2	835,36	1459,42	249,61	79,10	170,50
	3	777,93	1369,43	232,44	74,22	158,22
	4	735,85	1302,46	219,87	70,59	149,28
	5	701,28	1246,63	209,54	67,57	141,97
Without Battery	-	1110,67	1890,13	331,87	102,44	229,42
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	39,25	58,92	71,20	80,14	87,45
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	-0,40	18,79	45,35	75,26	106,81
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	927,26	835,36	777,93	735,85	701,28
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2483,28	2558,64	2605,73	2640,23	2668,58
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1483,91	1528,94	1557,08	1577,70	1594,64
Annual Final Cost (Renewable System+Storage)	EUR/a	452,86	472,05	498,62	528,53	560,08

Table 23. High Cost Analyzes with household P2Heat for wind onshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	918,52	1652,68	274,45	89,58	184,88
	2	815,08	1524,76	243,55	82,64	160,90
	3	749,36	1443,40	223,91	78,23	145,68
	4	699,97	1381,41	209,15	74,87	134,28
	5	659,55	1330,05	197,07	72,09	124,98
Without Battery	-	1110,67	1890,13	331,87	102,44	229,42
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	44,54	68,52	83,75	95,14	104,44
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	46,11	112,79	188,21	267,47	348,83
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	918,52	815,08	749,36	699,97	659,55
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2490,45	2575,26	2629,16	2669,65	2702,80
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1488,19	1538,88	1571,08	1595,28	1615,09
Annual Final Cost (Renewable System+Storage)	EUR/a	499,38	566,05	641,48	720,74	802,09

8.4.8 Wind Onshore+Storage+Household with Electric Vehicle,Hannover

Table 24. Low Cost Analyzes with household EV for wind onshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	2183,65	822,97	652,47	44,61	607,87
	2	2132,59	743,07	637,22	40,27	596,94
	3	2099,86	691,80	627,44	37,50	589,94
	4	2072,57	649,05	619,28	35,18	584,10
	5	2050,57	614,57	612,71	33,31	579,40
Without Battery	-	2303,93	1011,06	688,42	54,80	633,62
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	25,75	36,67	43,67	49,51	54,22
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	13,11	41,03	72,88	105,89	140,04
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	2183,65	2132,59	2099,86	2072,57	2050,57
CO_2 Avoidance (Coal)	kgCO2eq/kWh	3152,35	3194,21	3221,06	3243,44	3261,48
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1883,72	1908,74	1924,78	1938,15	1948,93
Annual Final Cost (Renewable System+Storage)	EUR/a	466,37	494,30	526,15	559,16	593,31

Table 25. High Cost Analyzes with household EV for wind onshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	2174,23	850,81	649,66	46,11	603,55
	2	2114,97	777,54	631,95	42,14	589,81
	3	2075,54	728,76	620,17	39,50	580,67
	4	2044,68	690,56	610,95	37,43	573,52
	5	2017,80	657,29	602,92	35,62	567,29
Without Battery	-	2303,93	1011,06	688,42	54,80	633,62
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	30,07	43,81	52,94	60,09	66,32
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	60,58	137,50	219,02	302,52	386,94
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	2174,23	2114,97	2075,54	2044,68	2017,80
CO_2 Avoidance (Coal)	kgCO2eq/kWh	3160,07	3208,67	3241,00	3266,31	3288,35
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1888,34	1917,37	1936,69	1951,82	1964,99
Annual Final Cost (Renewable System+Storage)	EUR/a	513,85	590,77	672,28	755,78	840,21

8.4.9 Wind Offshore+Storage+Household with Average load profile Germany,Breitling

Table 26. Low Cost Analyzes with household for wind offshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1412,89	455,33	422,17	24,68	397,49
	2	1358,93	369,57	406,05	20,03	386,02
	3	1327,62	318,97	396,69	17,29	379,41
	4	1307,57	285,97	390,70	15,50	375,20
	5	1290,58	257,77	385,63	13,97	371,66
Without Battery	-	1561,39	687,53	466,54	37,26	429,28
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	31,79	43,26	49,87	54,08	57,62
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	7,07	34,44	66,68	101,33	136,63
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	1412,89	1358,93	1327,62	1307,57	1290,58
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2208,06	2252,30	2277,98	2294,42	2308,35
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1319,45	1345,89	1361,23	1371,06	1379,38
Annual Final Cost (Renewable System+Storage)	EUR/a	512,13	539,51	571,75	606,40	641,70

Table 27. High Cost Analyzes with household for wind offshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1400,02	488,15	418,32	26,46	391,87
	2	1336,11	408,08	399,23	22,12	377,11
	3	1296,79	358,20	387,48	19,41	368,07
	4	1268,80	322,31	379,12	17,47	361,65
	5	1250,05	297,83	373,51	16,14	357,37
Without Battery	-	1561,39	687,53	466,54	37,26	429,28
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	37,41	52,17	61,21	67,63	71,91
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	53,24	129,14	210,75	294,98	381,36
Fluctuating Load	kWh	4105,64	4105,64	4105,64	4105,64	4105,64
Purchase From Grid(With Battery)	kWh	1400,02	1336,11	1296,79	1268,80	1250,05
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2218,62	2271,02	2303,26	2326,21	2341,59
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1325,76	1357,07	1376,34	1390,05	1399,24
Annual Final Cost (Renewable System+Storage)	EUR/a	558,31	634,21	715,81	800,05	886,43

8.4.10 Wind Offshore+Storage+Commercial with Average load profile Germany,Breitling

Table 28. Low Cost Analyzes with commercial for wind offshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1004,45	647,27	223,19	35,08	188,11
	2	945,73	553,79	210,14	30,02	180,13
	3	904,74	488,01	201,03	26,45	174,58
	4	872,17	435,40	193,80	23,60	170,20
	5	850,96	400,54	189,08	21,71	167,37
Without Battery	-	1132,05	848,44	251,54	45,99	205,56
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	17,45	25,43	30,97	35,36	38,18
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	21,40	52,27	85,58	120,05	156,07
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	1004,45	945,73	904,74	872,17	850,96
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2058,98	2107,13	2140,74	2167,45	2184,84
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1230,37	1259,14	1279,22	1295,18	1305,58
Annual Final Cost (Renewable System+Storage)	EUR/a	526,47	557,34	590,65	625,11	661,14

Table 29. High Cost Analyzes with commercial for wind offshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	995,90	678,93	221,29	36,80	184,49
	2	927,83	593,51	206,16	32,17	174,00
	3	882,09	535,65	196,00	29,03	166,97
	4	845,55	489,16	187,88	26,51	161,37
	5	813,74	448,52	180,81	24,31	156,50
Without Battery	-	1132,05	848,44	251,54	45,99	205,56
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	21,07	31,56	38,59	44,19	49,05
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	69,59	149,75	233,37	318,42	404,21
Fluctuating Load	kWh	3515,40	3515,40	3515,40	3515,40	3515,40
Purchase From Grid(With Battery)	kWh	995,90	927,83	882,09	845,55	813,74
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2065,99	2121,81	2159,32	2189,28	2215,36
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1234,55	1267,91	1290,32	1308,23	1323,81
Annual Final Cost (Renewable System+Storage)	EUR/a	574,65	654,81	738,44	823,49	909,28

8.4.11 Wind Offshore+Storage+Household with Average load profile Germany,Breitling

Table 30. Low Cost Analyzes with household P2Heat for wind offshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1319,51	504,33	394,27	27,33	366,93
	2	1260,76	411,05	376,71	22,28	354,43
	3	1225,48	354,23	366,17	19,20	346,97
	4	1203,14	317,66	359,50	17,22	342,28
	5	1185,96	289,13	354,36	15,67	338,69
Without Battery	-	1481,49	757,63	442,67	41,06	401,61
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	34,67	47,17	54,63	59,32	62,91
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	4,18	30,53	61,92	96,08	131,34
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	1319,51	1260,76	1225,48	1203,14	1185,96
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2161,64	2209,81	2238,74	2257,05	2271,15
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1291,71	1320,50	1337,78	1348,73	1357,15
Annual Final Cost (Renewable System+Storage)	EUR/a	509,25	535,60	566,99	601,15	636,41

Table 31. High Cost Analyzes with household P2Heat for wind offshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	1306,18	541,04	390,29	29,32	360,96
	2	1236,14	453,38	369,36	24,57	344,79
	3	1193,67	399,58	356,67	21,66	335,01
	4	1161,66	358,72	347,10	19,44	327,66
	5	1140,55	331,33	340,80	17,96	322,84
Without Battery	-	1481,49	757,63	442,67	41,06	401,61
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	40,64	56,82	66,60	73,95	78,77
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	50,01	124,49	205,36	288,67	374,50
Fluctuating Load	kWh	3955,65	3955,65	3955,65	3955,65	3955,65
Purchase From Grid(With Battery)	kWh	1306,18	1236,14	1193,67	1161,66	1140,55
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2172,56	2229,99	2264,82	2291,07	2308,38
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1298,24	1332,56	1353,37	1369,05	1379,40
Annual Final Cost (Renewable System+Storage)	EUR/a	555,08	629,55	710,43	793,73	879,57

8.4.12 Wind Offshore+Storage+Household with Average load profile Germany,Breitling

Table 32. Low Cost Analyzes with household EV for wind offshore

Battery With Low Cost (80% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	2936,46	99,97	877,42	5,42	872,00
	2	2909,52	57,83	869,36	3,13	866,23
	3	2895,33	35,63	865,13	1,93	863,19
	4	2886,86	22,37	862,59	1,21	861,38
	5	2881,07	13,30	860,86	0,72	860,14
Without Battery	-	3007,98	211,78	898,78	11,48	887,31
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	300	600	900	1200	1500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	15,31	21,08	24,11	25,92	27,16
Annual Cost of Storage (5% interest rate)	EUR/a	38,85	77,70	116,55	155,41	194,26
Final Annual Cost of the Storage Application	EUR/a	23,54	56,63	92,44	129,48	167,09
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	2936,46	2909,52	2895,33	2886,86	2881,07
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2535,04	2557,14	2568,77	2575,72	2580,47
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1514,84	1528,04	1535,00	1539,15	1541,99
Annual Final Cost (Renewable System+Storage)	EUR/a	528,61	561,69	597,51	634,55	672,16

Table 33. High Cost Analyzes with household EV for wind offshore

Battery With High Cost (90% Charge&Discharge Efficiency)						
Calculation Type	kWh	kWh	kWh	EUR	EUR	EUR/a
	Nominal Capacity	Purchase From the Grid	Feed-in Energy	Cost for Electricity Purchase	Feed-in Benefit	Summarized Cost of the Electricity
With Battery	1	2930,89	116,55	875,75	6,32	869,43
	2	2897,27	75,01	865,71	4,07	861,64
	3	2878,98	52,38	860,24	2,84	857,40
	4	2866,48	36,93	856,51	2,00	854,50
	5	2858,74	27,35	854,19	1,48	852,71
Without Battery	-	3007,98	211,78	898,78	11,48	887,31
Battery Nominal Capacity	kWh	1	2	3	4	5
Cost of the Storage	EUR	700	1400	2100	2800	3500
Annuity Factor (10 years)	-	0,1295	0,1295	0,1295	0,1295	0,1295
Annual Savings After Storage	EUR/a	17,87	25,67	29,91	32,80	34,60
Annual Cost of Storage (5% interest rate)	EUR/a	90,65	181,31	271,96	362,61	453,27
Final Annual Cost of the Storage Application	EUR/a	72,78	155,64	242,05	329,81	418,67
Fluctuating Load	kWh	6027,98	6027,98	6027,98	6027,98	6027,98
Purchase From Grid(With Battery)	kWh	2930,89	2897,27	2878,98	2866,48	2858,74
CO_2 Avoidance (Coal)	kgCO2eq/kWh	2539,61	2567,18	2582,18	2592,43	2598,78
CO_2 Avoidance (Gas)	kgCO2eq/kWh	1517,57	1534,04	1543,01	1549,13	1552,93
Annual Final Cost (Renewable System+Storage)	EUR/a	577,85	660,71	747,12	834,88	923,74

8.5 Analysis

Analysis made for PV, wind onshore and wind offshore as renewable energy source. Fluctuating source data simulated for one year for the capacities of 5 kW solar, 2 kW wind onshore and 1 kW wind offshore peak power. Calculations for the electricity prices with associated cost components analysed by using low cost and high cost battery with considering different efficiencies. Prices are selected as 300 Euro and 700 euro with 80% and 90% of charge and discharge efficiencies respectively. Renewable energy system investment cost be used as average values listed in Table 6.

In the simulation for average household load of the Germany combined with photovoltaic capacity of 5 kW peak power. For the 1 kWh nominal capacity, annual cost of electricity calculated with approximate value of 280 Euro for both low and high cost battery cases. Main difference observed in the cost of storage application. In case of using battery with lower price, battery cost amortized and even bring forward a small profit. On the other hand, high cost calculation projected 31.71 euro annual cost for the application without including energy systems investment. Capacity increase gave efficient results for electricity cost and with a low cost battery final cost did not change remarkably while high cost battery application increased final cost almost 200 euro for 5 kW, which corresponds the approximate saving in summarized cost of electricity.

As showed in Figure 34, commercial load shows different characteristic after 18.00. Household load increasing with that time because of home arrivals from work and commercial load decreasing possibly because of many commercial sector stops operating. Additionally, the electricity price for commercial consumer equal to average value of 22,22 cents/kWh, which is lower than household feed-in value. Because of these price advantages in both batteries cost selections, cost of electricity projected as profit because of lower purchase benefit.

In the calculation of power to heat, load profile for winter used as fluctuating load. As showed in Figure 33, winter electricity consumption characteristic shows similar behaviour with a small decrease in the nominal load values. Comparing household values with power to heat values gives similar results for the solar application.

With the nominal average load values of Germany, household fluctuating load without electric vehicle equals to 4105 kWh. An electric vehicle with the selected properties and charging scenario, load corresponds to 6027 kWh. To supply that energy, purchase from the grid increasing. Calculation for different capacities showed that annual electricity price could be decreased by integrating a storage system. In the low cost calculation, annual final cost combined with renewable and battery system is continues to be stabile while summarized electricity cost is decreasing. In the high cost battery case, it is possible to observe change with capacity increase, but for using an electric vehicle that cost could be afforded with better quality and higher efficiency battery.

Wind energy source profile differs from the solar energy source profile. With solar energy systems, energy production stops during night or cloudy days. Wind energy has the same issues with non-windy or less windy days. Even so, wind energy is giving better results depending on the capacity. As showed in the Table 18 and Table 19, in both cases purchase from the grid less than solar energy cases. From that point, it is possible to say that battery system cost could be more decisive for selection criteria because of higher annual cost increased in the final cost.

Wind offshore calculation outcomes are especially give efficient results with low battery cost due to applications higher capacity factor than to onshore type. However, after considering energy system cost, annual final results draw near to onshore type because of high system investment cost.

Another important point carbon emissions avoidance calculated to compare coal and gas power station emissions. Because of the renewable applications, all cases gave important CO_2 avoidance results. But because of the less electricity purchase from the system, wind energy applications give higher avoidance values.

Renewable energy sources combined with different storage capacity levels showed that, both for household and commercial applications in a small scale that have nominal consumptions could be balanced without investing higher values for the battery. Increasing capacity of the battery for the certain load type resulted to higher annual costs, even though high storage capacity decrease summarized electricity cost for all cases significantly.

9. CONCLUSION

In this dissertation, the determination of the necessary energy storage requirements for different renewable energy sources and different types of consumer loads is aimed. Energy production from renewable sources such as solar with photovoltaics, wind onshore, and wind offshore examined with respective energy storage combination. Current and future energy production overview discussed with financial statistics. In the report, basic and important points for every module aimed to be covered with examples and comparisons. The target was to evaluate renewable energy systems adaptation for a specific location by applying battery as a storage for different load profiles in the development of the study, microgrid concept principally small scale applications and their control, management strategies are used for defining study objectives. To categorize the investigation of electricity production costs, reference problems stated as renewable sources combined with energy storage for different consumer types. According to the reference problem, microgrid operation and necessary components researched. Main reference problem selected as small-scale photovoltaics with a lithium-ion battery for the household consumer. Solar energy basic principles and design criteria explained, especially for the small scale application field. In the same manner, battery technologies were identified and compared by mainly researching lithium-ion technology broadly. Besides the technical equipment such as renewable energy systems and batteries, necessity of peak load shaving is discussed with possible operation methodology for achieving more benefit from the actual energy system. To realize this theory part, an example simulation was made on MATLAB Simulink. In the simulation photovoltaic panel with 1 kW peak capacity operated with a lithium-ion battery. In the simulation, unreal irradiation and temperature profile generated. The aim was to observe battery reaction for solar power output changes. To construct the model, power electronics components are used as explained in the theory part. The targeted result was obtained, with a given microgrid scheme by monitoring energy storage charge and discharge behavior. Levelized cost of energy researched to investigate necessary input data. As a main topic of the study, renewable sources combined with different load profiles examined and varying results were gained. Results show that the mentioned load balancing is obtained by using different capacities with storage and average load profiles. Two different locations used to generate energy production data for observing changes in the annual cost for the consumer. Results showed that, apart from the renewable energy system investment, energy storage is an essential way of balancing load even for the high-cost scenario. From that point, the consumer could use energy storage with a certain renewable application without paying annual high costs. Additionally, according to the results, the selected source for a specific location affects load balancing and cost directly because of generation output value and feed-in, feed-out tariff. Another important aspect of the study was to show electrical energy from renewable sources with respective energy storage is an effective way of reducing CO2 emissions. In all cases, the avoidance of carbon dioxide emissions is listed. Results pointed up that even a small-scale application could make a significant effect on emission reduction policies. To conclude, the study shows that different renewable sources can be adapted to a system with a small scale concept and balance load with optimizing cost.

LIST OF SOURCES

1. AG energiebilanzen 2019 ,Retrieved from https://www.ag-energiebilanzen.de

2. IEA , international energy agency , Energy Policy Review Germany, 2020.

3. GTAI Germany trade&investment ,The energy storage market in germany ,2019

4. Lubna Mariam, Malabika Basu, Michael F. Conlon,
   Microgrid: Architecture, policy and future trends,Renewable and Sustainable Energy Reviews, Volume 64,2016,Pages 477-489,ISSN 1364-0321

5. M.S. Mahmoud, F.M. Al-Sunni, Control and Optimization of Distributed Generation Systems, Springer-Verlag, UK, 2015.

6. Arfeen, ZA, Khairuddin, AB, Larik, RM, Saeed, MS. Control of distributed generation systems for microgrid applications: A technological review. Int Trans Electr Energ Syst. 2019; 29:e12072.

7. Liserre M, Sauter T, Hung JY. Future energy systems, integrating renewable energy sources into the smart power grid through industrial electronics. IEEE Ind Electron Mag 2010;4(1):18–37.

8. R. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, et al., The CERTS microgrid concept, in: White Paper on Integration of Distributed Energy Resources, Prepared for Transmission Reliability Program, Office of Power Technologies, US Department of Energy, 2002.

9. Controls for microgrids with storage: Review, challenges, and research needs , Ramon Zamora , Anurag K. Srivastava

10. Yu, Seung-Yeong & Kim, Hyun-Jun & Kim, Jae-Hyuk & Han, Byung. SoC-Based Output Voltage Control for BESS with a Lithium-Ion Battery in a Stand-Alone DC Microgrid. Energies , 2016.

11. Arfeen, ZA, Khairuddin, AB, Larik, RM, Saeed, MS. Control of distributed generation systems for microgrid applications: A technological review. Int Trans Electr Energ Syst., 2019.

12. Annoni, Filippo, Progress in photovoltaic cells based on Low-Temperature Pulsed-Electron-Deposited Cu(In,Ga)Se2 films , 2017.

13. Bader N. Alajmi, Khaled H. Ahmed Stephen J. Finney, and Barry W. Williams "A Maximum Power Point Tracking Technique for Partially Shaded Photovoltaic Systems in Microgrids" IEEE Transactions on Industrial Electronics, Vol. 60, No. 4, April.

14. Villalva MG, Gazoli JR and Filho ER, "Comprehensive approach to modeling and simulation of photovoltaic arrays," IEEE Trans Power Electron, vol. 24, pp. 1198–1208, 2009.

15. Tao Ma, Hongxing Yang, Lin Lu,Solar photovoltaic system modeling and performance prediction,Renewable and Sustainable Energy Reviews, 2014

16. Juda, Zdzisław & Nabagło, Tomasz & Ocłoń, Paweł & Węglowski, Bohdan & Krawczyk, Mariusz. power efficıency management of photovoltaıc energy source based on mppt algorıthm zarządzanıe sprawnoścıą energetyczną fotowoltaıcznego źródła energıı z użycıem algorytmu mppt. Mechanika. 5. 183-190, 2013.

17. Siang Fui Tie, Chee Wei Tan,A review of energy sources and energy management system in electric vehicles,Renewable and Sustainable Energy Reviews

18. Liu, G., Lu, L., Fu, H., Hua, J., Li, J., Ouyang, M., Wang, Y., Xue, S., & Chen, P. A comparative study of equivalent circuit models and enhanced equivalent circuit models of lithium-ion batteries with different model structures. 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), 1-6 , 2014.

19. Legraive, Maxime. Realisation of a lithium-ion battery model for microgrid applications and validation with real-time simulation platform, Ecole polytechnique de Louvain, 2017.

20. Taheri, Peyman & Mansouri, Abraham & Yazdanpour, Maryam & Bahrami, Majid.Theoretical Analysis of Potential and Current Distributions in Planar

Electrodes of Lithium-ion Batteries. Electrochimica Acta. 133. 197–208. 10.1016/j.electacta.2014.04.040, 2014.

21. Overview of Rechargeable Lithium Battery Systems
Peter Kurzweil, Klaus Brandt, in Electrochemical Power Sources: Fundamentals, Systems, and Applications, 2019

22. Energiespeicher Statista, 2020 Retrieved from https://de.statista.com/statistik/studie/id/31683/dokument/energiespeicher-statista-dossier/

23. Li-ion batteries for mobility and stationary storage applications, Tsiropoulos I., Tarvydas. D., Lebedeva N. ISBN 978-92-79-97254-6 ISSN 1831-9424, 2018.

24. Rahimi A, Zarghami M, Vaziri M, Vadhva S. A simple and effective approach for peak load shaving using Battery Storage Systems. In: Proceedings of the North American Power Symposium, IEEE. p. 1-5, 2013.

25. Energy Storage - ForeFront Power, 2020. Retrieved from, https://www.forefrontpower.com/explore-solutions/storage/

26. Chua KH, Lim YS, Morris S. Energy storage system for peak shaving. Int J Energy Sect Manag, 2016.

27. Mathworks, Retrieved from, https://www.mathworks.com/help/physmod/sps/powersys/ref/pvarray.html

28. Lai, Chun Sing; Locatelli, Giorgio; Pimm, Andrew; Tao, Yingshan; Li, Xuecong; Lai, Loi Lei. "A financial model for lithium-ion storage in a photovoltaic and biogas energy system". Applied Energy. 251: 113179. doi:10.1016/j.apenergy.2019.04.175,2019.

29. Fraunhofer Institute for solar energy systems ise, levelized cost of electricity renewable energy technologies, 2018, Retrieved from, https://www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity

30. STATISTA, Retrieved from,

https://www.statista.com/statistics/974107/estimated-levelized-cost-of-electricity-generation-germany/

31. Renewable power generation costs in 2018. Retrieved from https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

32. International Energy Agency , Retrieved from, https://www.iea.org/data-andstatistics?country=GERMANY&fuel=Energy%20consumption&indicator=ElecConsBySector

33. VDEW-Lastprofile. Retrieved from, http://www.gipsprojekt.de/featureGips/Gips;jsessionid=FB97EF608D23211289E999CA55C808B9?SessionMandant=sw_unna&Anwendung=EnWGKnotenAnzeigen&PrimaryId=133029&Mandantkuerzel=sw_unna&Navigation=J

34. Turkey Market and Financial Settlement Center, Retrieved from, https://rapor.epias.com.tr/rapor/xhtml/piyasaHacimFiziksel.xhtml

35. Bundesagentur, Retrieved from, https://www.bundesnetzagentur.de/

36. Germany Federal Ministry for Economic Affairsand Energy. Retrieved from, https://www.bmwi.de/Redaktion/EN/Artikel/Energy/electricity-price components.html

37. Statista , Retrieved From, https://de.statista.com/statistik/daten/studie/154902/umfrage/strompreise-fuer-industrie-und-gewerbe-seit-2006/#statisticContainer

38. EPDK, Retrieved from, https://www.epdk.gov.tr/Detay/Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari

39. ADAC, Retrieved from, https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/vw/golf/vii-facelift/266575/#technische-daten

40. Fraunhofer Institute for solar energy systems ise, Levelized cost of electricity renewable energy Technologies, 2018 , Retrieved from, https://www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity

41. "IPCC Working Group III – Mitigation of Climate Change, Annex III: Technology - specific cost and performance parameters - Table A.III.2 (Emissions of selected electricity supply technologies (gCO 2eq/kWh))" (PDF). IPCC. 2014. p. 1335.

42. Renewables Ninja. Retrieved from, https://www.renewables.ninja/

APPENDIX

APPENDIX 1. Maximum power point tracking code

```
function duty = MPPT_algorithm(V_pv,I_PV,dutycycle)

duty_init = 0.1;

duty_min=0;
duty_max=0.85;

persistent Vold Pold duty_old;

if isempty(Vold)
    Vold=0;
    Pold=0;
    duty_old=duty_init;
end
P= V_pv*I_pv;
dV= V_pv - Vold;
dP= P - Pold;

duty_old=Duty_cycle;
Vold=V_pv;
Pold=P;

if dP ~= 0 & V_pv>40
    if dP < 0
        if dV < 0
            duty = duty_old – duty_cycle;
        else
            duty = duty_old + duty_cycle;
        end
    else
        if dV < 0
            duty = duty_old + duty_cycle;
        else
            duty = duty_old – duty_cycle;
        end
    end
else
    duty = duty_old;
end


if duty >= duty_max
    duty=duty_max;
elseif duty<duty_min
    duty=duty_min;
end
```

APPENDIX 2. Germany Load Profile-1

Table 34. Germany household average load profile [33]

	Winter			Summer			Inter-season			
Time	Saturday	Sunday	Workday	Saturday	Sunday	Workday	Saturday	Sunday	Workday	Average
1	0,26816	0,31264	0,23324	0,332	0,35844	0,2946	0,2926	0,33716	0,26632	0,29946222
2	0,21148	0,2252	0,1726	0,25732	0,2666	0,21936	0,22508	0,2488	0,19668	0,22479111
3	0,1684	0,18028	0,1582	0,20924	0,21792	0,19912	0,1858	0,1956	0,17716	0,18796889
4	0,1588	0,16448	0,15404	0,20016	0,20244	0,18744	0,17504	0,17716	0,17244	0,17688889
5	0,15384	0,15492	0,15652	0,20192	0,19992	0,19512	0,1726	0,1726	0,17628	0,17596889
6	0,16032	0,15448	0,18736	0,20652	0,19508	0,23704	0,1806	0,17304	0,21056	0,18944444
7	0,2124	0,16384	0,36036	0,25484	0,20532	0,3916	0,23436	0,183	0,37164	0,26415111
8	0,3278	0,19996	0,51772	0,37244	0,27788	0,51884	0,37304	0,26224	0,51888	0,37431111
9	0,47884	0,35412	0,534	0,51348	0,44988	0,56656	0,5188	0,44488	0,54988	0,49004889
10	0,56692	0,554	0,49288	0,623	0,64096	0,57628	0,6016	0,63816	0,54388	0,58196444
11	0,59148	0,69668	0,46484	0,65944	0,74636	0,55696	0,65312	0,74036	0,52816	0,62637778
12	0,61996	0,81112	0,47328	0,68452	0,82296	0,56784	0,68724	0,82076	0,53312	0,66897778
13	0,6664	0,8268	0,52284	0,72848	0,83776	0,63132	0,72556	0,8312	0,59844	0,70764444
14	0,6632	0,69208	0,518	0,70392	0,70148	0,61076	0,7098	0,6746	0,58264	0,65072
15	0,6138	0,54448	0,4614	0,62872	0,57628	0,52708	0,64512	0,54492	0,50712	0,56099111
16	0,5752	0,4664	0,41928	0,59344	0,49748	0,47516	0,59456	0,48404	0,45376	0,50659111
17	0,57888	0,4268	0,42084	0,57944	0,43352	0,45916	0,58612	0,4292	0,42456	0,48205778
18	0,72196	0,5028	0,51468	0,59584	0,43836	0,48996	0,63744	0,447	0,46532	0,53481778
19	0,83764	0,62564	0,66476	0,66592	0,5066	0,56868	0,73316	0,5502	0,5794	0,63688889
20	0,84048	0,70516	0,74832	0,72156	0,60808	0,66068	0,79216	0,64368	0,68756	0,71196444
21	0,68784	0,64048	0,67296	0,69152	0,63764	0,66632	0,72152	0,61888	0,6722	0,66770667
22	0,53636	0,54216	0,56388	0,61528	0,60216	0,6302	0,58936	0,57568	0,6238	0,58654222
23	0,49	0,45904	0,46668	0,59436	0,5608	0,57804	0,55428	0,5106	0,54272	0,52850222
24	0,41564	0,33856	0,34556	0,49864	0,43228	0,44832	0,46604	0,37592	0,40108	0,41356

APPENDIX 3. Germany Load Profile-2

Table 35. Germany commercial average load profile [33]

	Winter			Summer			Inter-season			
Time	Saturday	Sunday	Workday	Saturday	Sunday	Workday	Saturday	Sunday	Workday	Average
1	0,2964	0,24016	0,24472	0,30704	0,2654	0,27032	0,30872	0,26208	0,27464	0,27438667
2	0,29344	0,21152	0,21004	0,30024	0,22752	0,23128	0,30768	0,227	0,24004	0,24986222
3	0,25956	0,18472	0,19336	0,27428	0,20476	0,21456	0,27868	0,1954	0,22124	0,22517333
4	0,25544	0,16984	0,19916	0,26772	0,19232	0,21648	0,272	0,17892	0,22248	0,21937333
5	0,2642	0,16748	0,23808	0,27808	0,18628	0,26	0,28132	0,17468	0,26432	0,23493778
6	0,28264	0,17616	0,26724	0,28984	0,1846	0,28516	0,29012	0,18092	0,3002	0,25076444
7	0,32008	0,19812	0,32212	0,307	0,18792	0,30088	0,29928	0,18188	0,3248	0,27134222
8	0,47264	0,20512	0,46116	0,45444	0,21252	0,40852	0,45472	0,19956	0,43124	0,36665778
9	0,6784	0,19688	0,75388	0,64304	0,21516	0,65436	0,67432	0,21308	0,69732	0,52516
10	0,77452	0,22164	0,9164	0,70404	0,23448	0,7934	0,74912	0,244	0,84528	0,60920889
11	0,81528	0,26408	0,92968	0,72156	0,2656	0,81156	0,76404	0,27632	0,8566	0,63385778
12	0,82968	0,2912	0,95676	0,73996	0,28912	0,83468	0,7802	0,30724	0,88296	0,65686667
13	0,78896	0,3112	0,87932	0,72188	0,30928	0,78568	0,76828	0,33104	0,82144	0,63523111
14	0,68992	0,32032	0,73528	0,63264	0,31644	0,68576	0,67504	0,3252	0,69964	0,56447111
15	0,51676	0,29792	0,69108	0,47136	0,29208	0,66008	0,50364	0,29688	0,66072	0,48783556
16	0,38256	0,26456	0,7622	0,3556	0,25652	0,70172	0,37964	0,26736	0,71532	0,45394222
17	0,33448	0,24956	0,8036	0,30876	0,24052	0,70396	0,31584	0,24808	0,73152	0,43736889
18	0,36496	0,31596	0,81616	0,30144	0,27004	0,6812	0,31924	0,28988	0,718	0,45298667
19	0,38784	0,3678	0,67268	0,31456	0,3016	0,55852	0,33652	0,32116	0,57664	0,42636889
20	0,38756	0,37608	0,46732	0,31872	0,31512	0,39268	0,3466	0,33652	0,40624	0,37187111
21	0,37452	0,35692	0,38232	0,3384	0,33232	0,35576	0,36456	0,35324	0,3644	0,35804889
22	0,34144	0,31324	0,33524	0,34144	0,327	0,34904	0,35176	0,33224	0,34452	0,33732444
23	0,30784	0,28048	0,30436	0,31368	0,29732	0,32344	0,3212	0,29152	0,32672	0,30739556
24	0,27432	0,24684	0,28464	0,2882	0,26304	0,30508	0,29148	0,25988	0,31364	0,28079111

APPENDIX 4. Hannover,Germany Average Solar Production Simulation

Table 36. Hannover average solar production by months (5 kW) [42]

Time	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0,00141935	0,0239	0,00925806	0	0	0	0	0
5	0	0	0	0,00943333	0,12287097	0,1977	0,16103226	0,03935484	0	0	0	0
6	0	0	0,00870968	0,19486667	0,48006452	0,58056667	0,50296774	0,29406452	0,06943333	3,3333E-05	0	0
7	0	0,0137931	0,23232258	0,73333333	1,11006452	1,20993333	1,088	0,84441935	0,5178	0,1101	0,0002	0
8	0,01625806	0,34106897	0,73132258	1,4985	1,75829032	1,8136	1,70019355	1,45748387	1,21296667	0,48026667	0,0936	0,00190323
9	0,19945161	0,958	1,36574194	2,1442	2,27480645	2,25653333	2,26545161	2,04596774	1,9345	0,93576667	0,42623333	0,14035484
10	0,44270968	1,58603448	1,98345161	2,651	2,62190323	2,62033333	2,6726129	2,47619355	2,42976667	1,3724	0,79306667	0,46451613
11	0,67967742	1,89762069	2,404	3,0299	2,83683871	2,85366667	2,93393548	2,66522581	2,6464	1,77326667	1,11823333	0,85167742
12	0,73003226	2,00375862	2,56393548	3,06996667	2,92732258	2,82656667	2,93322581	2,69370968	2,56083333	1,92023333	1,26283333	1,05277419
13	0,62419355	1,88410345	2,40435484	2,889	2,80874194	2,7221	2,71193548	2,49906452	2,3354	1,75923333	1,17016667	0,98
14	0,44725806	1,53255172	1,96551613	2,52173333	2,44958065	2,58336667	2,38980645	2,14890323	2,05496667	1,35746667	0,8794	0,65709677
15	0,18029032	0,96958621	1,39003226	1,96606667	1,9386129	2,15223333	1,99270968	1,68829032	1,5818	0,87793333	0,42383333	0,20945161
16	0,00454839	0,329	0,75303226	1,30716667	1,36474194	1,5692	1,50158065	1,15767742	0,97223333	0,3911	0,06913333	0
17	0	0,00906897	0,19054839	0,64776667	0,81587097	0,97966667	0,888	0,60403226	0,3474	0,04176667	0	0
18	0	0	0,00174194	0,1273	0,33625806	0,42876667	0,37535484	0,18370968	0,0208	0	0	0
19	0	0	0	0,0011	0,08322581	0,14966667	0,10477419	0,01290323	0	0	0	0
20	0	0	0	0	0	0,00263333	0,00019355	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 5. Hannover,Germany Average Wind Onshore Production Simulation

Table 37. Hannover average wind production by months (2 kW) [42]

Time	January	February	March	April	May	June	July	August	September	October	November	December
1	0,75832258	0,68610345	0,85306452	0,5158	0,40154839	0,42856667	0,32487097	0,36651613	0,45223333	0,6236	0,4662	0,70164516
2	0,73254839	0,67051724	0,84270968	0,49706667	0,39309677	0,4254	0,32087097	0,3766129	0,46403333	0,6233	0,45306667	0,69664516
3	0,73290323	0,65865517	0,82877419	0,48033333	0,38245161	0,4248	0,31954839	0,37667742	0,47076667	0,6014	0,4505	0,69483871
4	0,71993548	0,65131034	0,82045161	0,457	0,36774194	0,40993333	0,30829032	0,37409677	0,48663333	0,5927	0,4585	0,69783871
5	0,71577419	0,654	0,80848387	0,42796667	0,32387097	0,3261	0,26	0,36367742	0,48856667	0,57143333	0,46313333	0,6913871
6	0,71119355	0,64968966	0,7996129	0,34946667	0,26741935	0,25646667	0,24516129	0,28829032	0,4725	0,55633333	0,477	0,68803226
7	0,7186129	0,64034483	0,77580645	0,3048	0,3043871	0,27336667	0,28167742	0,27148387	0,4111	0,5279	0,48876667	0,68077419
8	0,72187097	0,60968966	0,78222581	0,33766667	0,36103226	0,3118	0,31709677	0,31767742	0,43056667	0,47113333	0,4853	0,67567742
9	0,69264516	0,55510345	0,84303226	0,40693333	0,39358065	0,34963333	0,3573871	0,38332258	0,51796667	0,46033333	0,45573333	0,66329032
10	0,68109677	0,54993103	0,89393548	0,46696667	0,4153871	0,37203333	0,37880645	0,40890323	0,5773	0,53483333	0,44823333	0,6193871
11	0,69990323	0,58331034	0,90432258	0,49923333	0,43487097	0,40066667	0,38141935	0,40987097	0,60183333	0,58123333	0,4582	0,60419355
12	0,73077419	0,61506897	0,91458065	0,50666667	0,45696774	0,42393333	0,37819355	0,40848387	0,61886667	0,60276667	0,46186667	0,60848387
13	0,74225806	0,62375862	0,9286129	0,50003333	0,47458065	0,43563333	0,37216129	0,40135484	0,62766667	0,60006667	0,4563	0,60106452
14	0,73741935	0,60596552	0,93467742	0,49293333	0,47632258	0,43916667	0,36090323	0,391	0,619	0,58466667	0,43403333	0,59435484
15	0,74819355	0,60203448	0,91516129	0,48796667	0,46387097	0,44193333	0,34522581	0,372	0,5958	0,5457	0,43696667	0,63170968
16	0,79587097	0,62096552	0,85674194	0,48	0,44725806	0,436	0,33567742	0,33858065	0,54766667	0,51373333	0,4958	0,69129032
17	0,82306452	0,66568966	0,82532258	0,47373333	0,42	0,40843333	0,32496774	0,29616129	0,49203333	0,5588	0,53966667	0,71858065
18	0,83225806	0,71003448	0,85774194	0,52883333	0,38658065	0,37136667	0,30777419	0,256	0,47986667	0,61006667	0,5419	0,72970968
19	0,82077419	0,72765517	0,88112903	0,63406667	0,39745161	0,37286667	0,30890323	0,27745161	0,48926667	0,6271	0,535	0,72870968
20	0,80303226	0,72265517	0,88480645	0,66703333	0,42819355	0,42453333	0,33732258	0,32458065	0,47746667	0,62986667	0,51813333	0,72203226
21	0,79412903	0,70624138	0,87432258	0,63713333	0,43274194	0,4689	0,35293548	0,35958065	0,4681	0,637	0,50146667	0,71374194
22	0,78622581	0,69482759	0,86677419	0,61103333	0,42319355	0,47913333	0,35116129	0,377	0,45926667	0,6367	0,4786	0,70854839
23	0,78306452	0,6862069	0,8676129	0,58403333	0,41680645	0,48136667	0,34	0,37774194	0,45436667	0,6332	0,46496667	0,7016129
24	0,77270968	0,69096552	0,86587097	0,5353	0,40864516	0,45993333	0,32274194	0,37312903	0,4518	0,6227	0,4554	0,69893548

APPENDIX 6. Breitling, Germany Average Wind Offshore Production Simulation

Table 38. Breitling average wind offshore production by months (1 kW) [42]

Time	January	February	March	April	May	June	July	August	September	October	November	December
1	0,46129032	0,42206897	0,50619355	0,36316667	0,37032258	0,3345	0,32580645	0,23529032	0,3933	0,38326667	0,30473333	0,42532258
2	0,45787097	0,41213793	0,50690323	0,3452	0,36367742	0,32616667	0,31080645	0,24293548	0,37906667	0,38743333	0,3033	0,42993548
3	0,45070968	0,40851724	0,50322581	0,33176667	0,35690323	0,31996667	0,29948387	0,24929032	0,36996667	0,38556667	0,30556667	0,42941935
4	0,44264516	0,40506897	0,49764516	0,31773333	0,34645161	0,29046667	0,28316129	0,24787097	0,36516667	0,38436667	0,3041	0,42825806
5	0,43916129	0,39768966	0,49177419	0,30173333	0,31445161	0,2386	0,25335484	0,23335484	0,3675	0,38803333	0,30413333	0,428
6	0,43593548	0,39472414	0,48906452	0,267	0,29048387	0,21603333	0,24432258	0,19977419	0,36256667	0,39326667	0,30536667	0,43054839
7	0,43590323	0,39368966	0,48616129	0,25083333	0,31319355	0,22003333	0,25022581	0,19329032	0,35686667	0,381	0,30823333	0,4286129
8	0,43874194	0,37982759	0,49790323	0,26786667	0,34374194	0,24126667	0,26348387	0,21783871	0,3856	0,3502	0,31253333	0,43093548
9	0,4376129	0,37382759	0,52029032	0,2864	0,36287097	0,25716667	0,27719355	0,24854839	0,42193333	0,33026667	0,31043333	0,43587097
10	0,43770968	0,38393103	0,53103226	0,29916667	0,37209677	0,26303333	0,29045161	0,27058065	0,43486667	0,33363333	0,30613333	0,43245161
11	0,44325806	0,39624138	0,53522581	0,30406667	0,3796129	0,26766667	0,30270968	0,27929032	0,43413333	0,3457	0,3058	0,42480645
12	0,44777419	0,41437931	0,53996774	0,30653333	0,38748387	0,26573333	0,31345161	0,27854839	0,42843333	0,3484	0,30706667	0,42374194
13	0,44651613	0,42027586	0,54270968	0,3101	0,39306452	0,26156667	0,32193548	0,27116129	0,42256667	0,3406	0,30643333	0,42274194
14	0,44854839	0,41503448	0,53967742	0,31593333	0,3956129	0,26536667	0,32883871	0,26019355	0,4171	0,3321	0,30856667	0,43106452
15	0,45025806	0,41041379	0,52964516	0,32713333	0,39280645	0,27203333	0,33470968	0,24664516	0,40766667	0,32123333	0,32203333	0,44996774
16	0,45793548	0,4182069	0,51625806	0,3422	0,38583871	0,27643333	0,34177419	0,23135484	0,39453333	0,3206	0,35513333	0,46554839
17	0,4616129	0,43955172	0,50441935	0,35363333	0,36967742	0,28573333	0,34648387	0,20790323	0,38306667	0,3394	0,37413333	0,46877419
18	0,45996774	0,44844828	0,51393548	0,3745	0,3406129	0,3018	0,34406452	0,19580645	0,3916	0,36016667	0,3777	0,46254839
19	0,45854839	0,45782759	0,52070968	0,40346667	0,32306452	0,32286667	0,33829032	0,20145161	0,401	0,36686667	0,37076667	0,45677419
20	0,458	0,46289655	0,52019355	0,4135	0,33009677	0,34523333	0,34522581	0,20525806	0,4029	0,36133333	0,3582	0,45064516
21	0,46022581	0,45903448	0,51925806	0,4089	0,33574194	0,35613333	0,34903226	0,21016129	0,40403333	0,35316667	0,34206667	0,44064516
22	0,45490323	0,44924138	0,5206129	0,4026	0,34232258	0,3599	0,34629032	0,21909677	0,4039	0,35506667	0,32456667	0,43832258
23	0,44764516	0,43355172	0,52367742	0,3954	0,34896774	0,36633333	0,33696774	0,22893548	0,40356667	0,3612	0,31386667	0,43354839
24	0,4413871	0,42451724	0,52196774	0,38536667	0,35032258	0,36633333	0,32274194	0,23503226	0,39883333	0,37113333	0,30453333	0,43245161