TECHNOLOGY MODELLING OF A PV-HYBRID RENEWABLE ENERGY POWER PLANT - CASE STUDY ON INDUSTRIAL COMPANIES IN GERMANY

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ABSTRACT: This paper examines possible operating options of a grid-connected hybrid energy system (HES), including a photovoltaic (PV) system. Different technologies are examined, including fluctuating renewable energy sources (RES), especially PV and wind power, electrical energy storage (EES) and a biomass power plant. The aim of the work is to illustrate an optimal system design in combination with a most cost-effective operation of such a power plant. An existing optimization model is extended in order to analyse the operation and design of a hybrid energy system. The system design and operation is optimized under technical, economic and regulatory constraints within a single model. This optimization model is able to provide a market-oriented operation of the hybrid system under the consideration of energy demand, renewable energy resources and achieved market prices. The paper focuses on the cost-efficient electrical supply of an industrial company by the optional use of renewable energy sources at a location in Germany. Various scenarios are analysed to better define the properties and the sensitivity of the model. Thus, effects of external technical and economic conditions, such as variable market prices or fixed self-consumption, are examined for plant operation and system design. With the help of this work, it is shown under which conditions the investment in a HES with RES for an industrial company is optimal and how such a hybrid plant would be operated in the ideal case.

Keywords: Large Grid-connected PV systems, PV System, Sizing, Design, PV Market

1 INTRODUCTION

In Germany and worldwide more and more industrial companies supply themselves with energy from renewable energy sources (RES) for different reasons. Main drivers are the electricity price development and the RES cost development. In Germany, after the introduction of the law to integrate renewables (BGBl, 2000), additional costs and especially taxes are increased. This caused an increase of the total electricity prices for most consumers. Beside this the levelized costs for electricity generation by RES especially wind and photovoltaic (PV) already reached grid parity under certain conditions and, will decrease within the next years remarkably (Kost and Mayer et al., 2013). Self-consumption of PV or wind generated electricity is already cheaper for most consumers. Using PV systems as own generation capacity for self-supply of electricity becomes economically attractive for many companies and other consumers. Therefore, this paper describes a model development for the optimization of a hybrid system including PV and other renewable energy (RE) options for electricity supply and consumption of an industrial manufacturing facility. The results of the model analysis provide important answers to the question how the system should be designed best and how it interacts.

2 APPROACH

The approach of this paper includes the development of an optimization model, which is adapted and extended from Kost et al. (2013), to model the different RE technologies at the site of an industrial company with large electricity consumption through manufacturing facilities. The objective function of this mixed integer program is to minimize the electricity costs of the company with specific implementation of the cost for construction and operation of a grid-connected hybrid energy system (HES). With this approach it is possible to define the optimal size and layout of the PV plant which should become a major energy source for the company.

3 MODEL DESCRIPTION

The HES is described by a mixed-integer problem, in which decision variables are set for the size of the generation technologies and energy storage (ES) system. Further variables are used to model power plant operation. System layout and operation are constrained by different technical and economic characteristics (see Figure 1). Input data includes the energy generation through the fluctuating RES of wind power and PV for a site close to Stuttgart, electricity market and fuel prices and the load profile of the company. The objective function minimizes the annual costs for the electricity supply of defined hourly electrical demand.

Minimize

$$total_{annual\ costs} = costs_{grid} - revenues_{grid} + costs_{PV} + costs_{wind} + costs_{biomass} + costs_{DG} + costs_{battery}$$

Where,
$costs_{grid}$ are the annual costs for electricity purchase from the public electrical grid,
$revenues_{grid}$ are the annual revenues for selling electricity to the grid,
$costs_{PV}$ are the annual costs for the PV-array,
$\mathrm{costs_{wind}}$ are the annual costs for the wind turbines,
$\mathrm{costs_{biomass}}$ are the annual costs of the biomass power plant,
$\mathrm{costs_{DG}}$ are the annual costs for the diesel generators (DG) and
$\mathrm{costs_{battery}}$ are the annual costs.

The annual costs consist of the operation costs and the expenses for constructing and installing the HES minus the cost difference for avoided electricity purchase and the proceeds for electricity disposal to the grid.

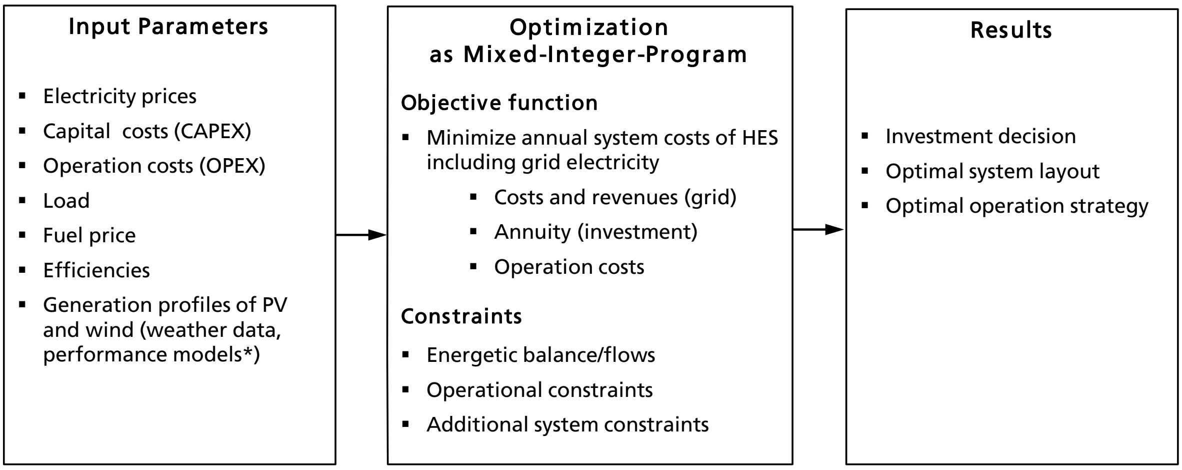

Figure 1: Modeling of HES by using MIP optimization and performance models

Expenses for construction and installation are calculated by using annuities. Operational costs mostly depend on the energy generated by the different generation technologies or on the load and unload energy for the electrical storage unit. For example the operation costs for the diesel generator comprises diesel consumption, diesel price and an additional purchase fee.

The optimization problem includes several constraints that concern, among others, the energy flow, technical characteristics and efficiencies. The main constraint is the guaranteed supply of electricity to satisfy the energy demand of the consumer in every hour of the year. Technical constraints help to describe the operation of the used technologies. The storage is modelled with an hourly energy loss and a depth of discharge. For the diesel generator and the biomass unit different efficiencies are set for different operation status. The grid connection power is limited to a reasonable level with fix costs depending on the yearly maximal power connection. A detailed model description including main equations of the optimization model can be found in the appendix.

4 MODEL ASSUMPTIONS

This cases study is executed for a HES installation on the site of an industrial company close to Stuttgart. This representative company of a manufacturing facility has an annual electricity demand of 20 GWh. The location has an elevation above sea level of 297m and coordinates of 48.8 ° latitude and 9.2 ° longitude. For the site an average annual wind speed of 5.7 m/s at 100 m and an annual global horizontal radiation of 1090.4 kWh/m² are given by Meteonorm (METEOTEST, 2011).

Within this case study the optimal size of each technology and its operation within the HES are optimized. The selected HES consists of different technologies. All technologies are presented together with relations and placement in the total system in Figure 2.

The HES considers two wind turbines types with both a rated power of 2MW and manufactured by Gamesa. They differ in their rotor diameter and have different power curves.

The PV-array consists of 308 Suntech Power STP 320 modules and has a size of 100 kW. 5 Refusol 24 kW 480eV inverters settle the PV-array. The PV-array can so be scaled with a size of 100 kWp. As thermal units two identical biomass power plants and four different diesel generators support the fluctuating RES. The DGs have a rated power of 256 kWel, 508 kWel, 1020 kWel and 2180 kWel. A sodium sulfur (NaS) battery bank with a size of 100 kWh completes the HES. The HES is grid-connected and has to supply an annual demand of 20 GWh.

5 SCENARIO FRAMEWORK

The first scenario evaluates a HES with integration of an electrical energy storage (EES) unit, a biomass power plant and a generator set in addition to PV. In a second scenario, the use of wind turbines is granted in addition to the plant design in scenario 1. In scenario 1 and 2 no additional requirements concerning the generation or self-consumption are applied to the model. In the third scenario, the annual RES generation must be superior to the sum of the annual load to demonstrate a 100% supply by RES generation on the balance-sheet. An overview over the different scenarios is given in Table 1.

Table 1: Overview over different scenarios

Scenario Number	Scenario Name	Scenario description
0	Status-quo	Actual electricity supply by grid – no on-site generation
1	Base Case	HES including PV, EES, biomass and generator sets
2	Wind integration	HES technologies according to case 1 plus additionally wind power
3	100 % RES	The sum of annual load $\leq$ annual RES generation
4	Stand-alone	No grid connection available

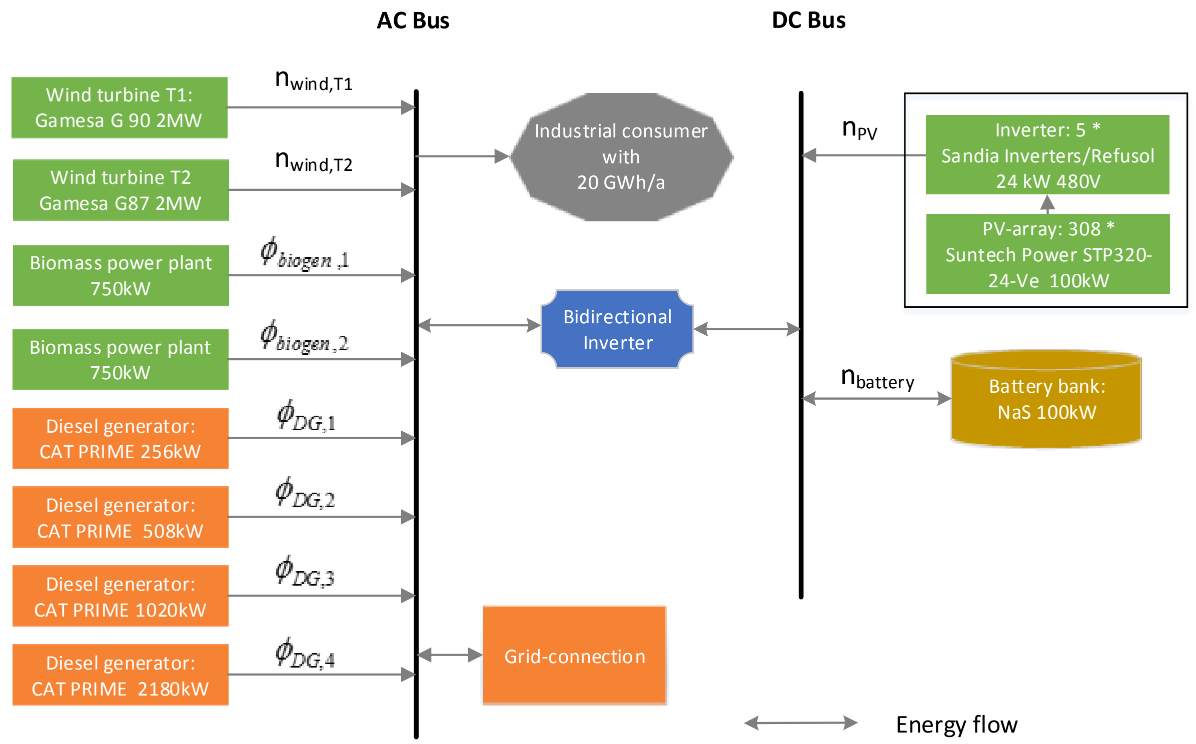

Figure 2: Components of analyzed HES (*scalable)

6 RESULTS

Related to the specific scenario assumptions regarding the use of the different technologies, the supply system of the industrial companies is very different after optimization of the system. The reference case (status quo) is used to obtain a cost comparison compared to the standard situation if no own HES system is used. In this scenario, no other technologies are installed on site (Figure 3). The plant design varies for each case.

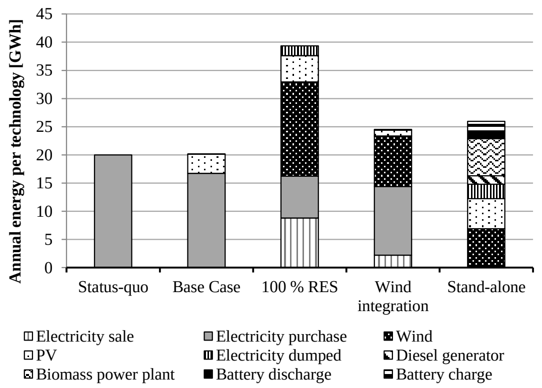

Figure 3: Layout of supply system

In the Base Case scenario a PV-array of 3.3 MWp is installed without the use of the other potential options such as storage system or biomass power plant. In the Wind integration scenario it is shown that wind turbines are cost superior to PV installations, when a wind turbine can be integrated into the HES onsite. In this case, 4 MW of wind power are installed and only 1 MW of PV power. But wind turbines are very often not allowed to be installed at the site of the industrial company.

If 100% of the energy demand has to be generated by renewable energy sources with the assumption of selling and purchasing surplus electricity to and from the grid, according to the model results 8 MW of wind power and 4.5 MW of PV power are installed at the site. To independently supply the energy demand with RES, the optimal design is a combination of wind and PV technology as well as the use of a diesel generator, biomass plant and a small storage system. In the Base case, the PV system supplies 16.9% of the demand. In the 100% RES scenario, still 37.1% of the electricity demand have to supplied by the grid as the cost efficient layout for the HES consisting of PV and wind cannot provide electricity during all hours of demand. In case of wind integration, at least 38.9% of the electricity demand is supplied by the HES. The optimal layout and generation in the Stand-alone scenario provides at each hour 100% of the electricity demand by local electricity generation.

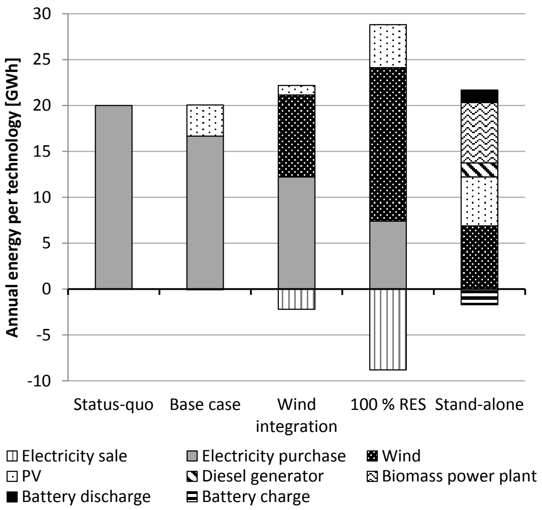

Figure 4: Annual energy use per technology

A share of 12.5% of potential electricity generation cannot be used by the isolated system.

When comparing total annual system costs in each scenario, costs of the status quo are undercut by the Base case scenario and the Wind integration scenario. This means that the use of PV or wind power (or both in combination) is always more competitive as generation costs of PV and wind power are often below electricity purchase from the grid. However, this is only valid up to a certain size of the PV (3.3 MW) and wind power plant (4 MW). However, annual costs of a system generating 100% of the energy demand are only slightly above the Status quo scenario. The Stand-alone scenario indicates a cost increase by 34% compared to the Base case.

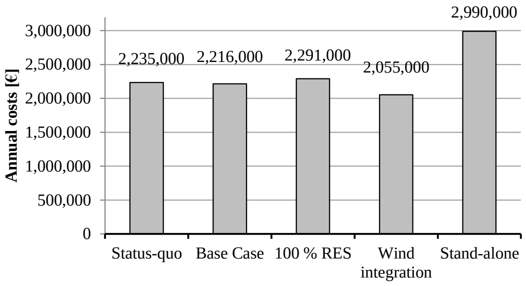

Figure 5: Comparison of different scenarios

To analyse the hourly operation of the different entities of HES, an exemplary plant operation for a time period of 36 hours is presented. Generation profiles of PV and electricity generation are shown in Figure 6. At days with good solar irradiation the demand of the company fits very well to the PV generation profile. However, a part of the electricity generated by PV has to be stored in the storage system.

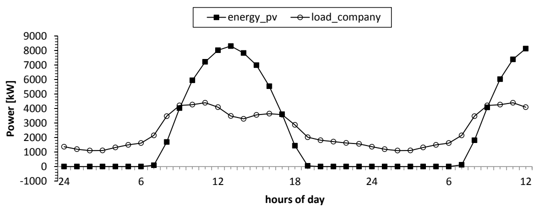

Figure 6: Electricity generation by RES and load of a manufacturing company

Electricity is loaded into the ES during hours of PV generation and unloaded in hours of no solar radiation (Figure 7). The state of charge (SOC) describes the charge level of the electrical storage unit. In Figure 8 it is visible that the grid exchange also depends on the electricity generation through PV. The EES is mainly used during the evening or early morning during hours of high electricity prices. The electricity purchase from the grid is reduced during the day when the sun is shining as well as during hours when the storage supplies the demand, i.e. during hours of high electricity prices. The figures on the hourly operation clearly show the need for a very flexible HES, which uses an energy management system to optimize generation, purchase and sale of electricity from the grid as well as the operation of the energy storage.

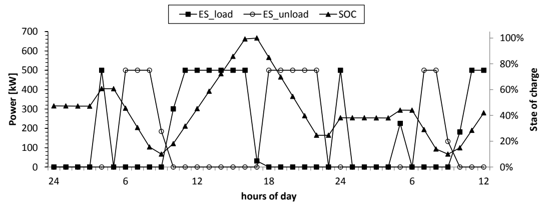

Figure 7: Operation of electrical storage within 36 hours

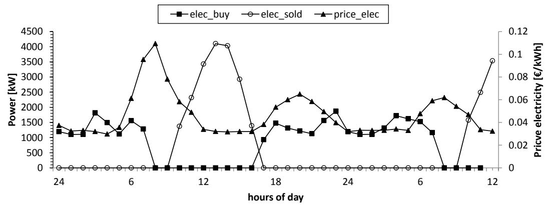

Figure 8 : Hourly purchase and disposal of electricity with grid, stock market price for Germany in 2013

7 SENSITIVITY

The model tries to predict the operation and the system size by optimizing the annual system costs. Modelling has uncertainties which are tried to be kept within a low level. In order to obtain a feeling for the uncertainties of the model, a sensitivity analysis is executed. This tries to evaluate the quality of the model and its input data. To analyse the effect of input data on the model results and how they interact, selected values are varied.

As it can be seen in Figure 9, a change in technology costs and costs for electricity purchase from the grid have the highest impact on the total annual system costs. Grid connection costs have less influence.

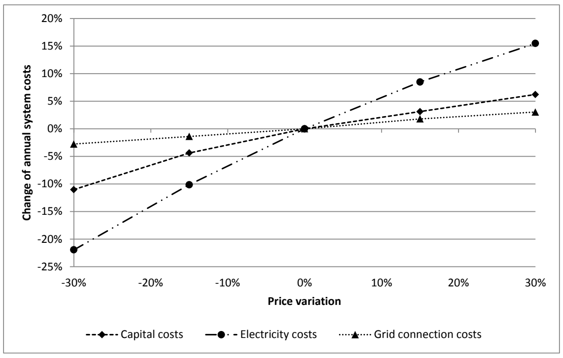

Figure 9: Change of total annual costs due to a price variation for Wind integration scenario

8 CONCLUSIONS

The model analysis shows different options for the company to use PV and other RES options for its own electricity consumption. The use of PV is completely competitive to electricity supply from the grid as the optimization model prefers using the PV system for electricity supply in any case. However, the PV system size is often limited to the average maximum peak demand of the industrial client to avoid oversupply and sales of PV electricity to the grid.

In case of the possibility to use wind power at the site of the company, a large share of the electricity consumption is supplied by wind turbines. However, the roof of the company is also fully used for the installation of a PV plant. The optimization shows that the use of both energy sources, wind and PV, is economically beneficial for the company to avoid electricity consumption from the grid.

To support the fluctuating RES units in a Stand-alone scenario, an electrical energy storage unit and thermal generation, such as biomass power plants and diesel generator sets, has to be integrated into the HES. In this case total annual system costs are strongly increasing compared to cases with combined use of local electricity supply from the HES and electricity purchase from the grid.

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10 APPENDIX

Detailed model description

The annual grid costs consist of hourly costs and annual costs for grid access and are expressed by the following equation:

$$costs_{grid} = \sum_{t=0}^{T} \Big(\big(p_{grid}(t) + k_{purchase}\big) * x_{elec,purchase}(t) \Big)$$

$$x_{elec,purchase}(t), x_{grid,max} \geq 0$$

Where,

$p_{grid}(t)$ is the electricity price that depends on T (EEX, day-ahead price of 2013,

$k_{purchase}$ is the purchase fee (0.06 EUR/kWh),

$x_{elec,purchase}(t)$ is the amount of electricity purchased from grid in hour t,

k_{grid} is the grid access costs and

$x_{grid,max}$ is size of the grid connection.

Grid revenues are dependent on the amount of electricity to the grid and on the prices and are described as following:

$$revenues_{grid} = \sum_{t=0}^{T} \Big(\big(p_{grid}(t) - k_{selling}\big) * x_{elec,selling}(t) \Big)$$

$$x_{elec,selling}(t) \geq 0$$

Where,

$k_{selling}$ is the purchase fee.

To decide the design of these technologies integer variables are introduced. Table 2 gives an overview over the power plants integer design variables with its lower and upper bounds.

Table 2: Plant integer design variables

Design variable	**Descriptio n**	**Lower bound**	**Upper bound**
$\boldsymbol{n_{PV}}$	PV-array multiple	$\boldsymbol{n}_{PV,min}$	$\boldsymbol{n_{PV}}_{,max}$
$\boldsymbol{n_{battery}}$	Battery multiple	$\boldsymbol{n}_{battery,min}$	$\boldsymbol{n}_{battery,ma}$
$\boldsymbol{n_{wind}}$	Wind turbine multiple	$\boldsymbol{n}_{wind,min}$	$\boldsymbol{n_{wind}}_{,max}$

With the help of these nonnegative integer variable the costs for PV-array, wind turbine and battery can be described. The costs for the PV-array are described in the following equation:

$$costs_{PV} = n_{PV} * \left(\sum_{t=0}^{T} \Big(\big(k_{OM,PV} + k_{fee,RES}\big) * p_{el,PV}(t) \Big) + k_{annuity,PV} \right)$$

$$n_{PV} \geq 0 \ \wedge \ n_{PV} \in \ \mathbb{Z}$$

Where,

$k_{OM,PV}$ describes the operation and management costs for the PV-array,
$k_{fee,RES}$ is a possible fee on electricity generation of RES,
$p_{el,PV}(t)$ is the electricity output of the PV-array and
$k_{annuity,PV}$ is the annualized capital costs for the PV-array.

With the multiple, n_{PV}, the costs for a given PV-array are scaled. The electricity output of a PV-array of fixed size is a parameter that depends on the time t. The costs for the fixed PV-array depend on the annualized capital costs and the energy output of the PV-array. The sum of annualized costs and variable costs over the time t leads to an annual fix value that is scaled to define the size of the PV-array.
Comparatively the costs for the electricity generation of wind turbines can be scaled with the wind turbine multiple:

$$costs_{wind} = n_{wind} * \left(\sum_{t=0}^{T} \Big(\big(k_{OM,wind} + k_{fee,RES}\big) * p_{el,wind}(t) \Big) + k_{annuity,wind} \right)$$

$$n_{wind} \geq 0 \ \wedge \ n_{PV} \in \ \mathbb{Z}$$

Where,

$k_{OM,wind}$ describes the operation and management costs per wind turbine,
$p_{el,wind}(t)$ is the electricity output of the wind turbine and
$k_{annuity,wind}$ is the annualized capital costs for the wind turbine.

Similar to the modelling of the PV-array the wind turbine costs are modelled. The modelling approach for the battery is different to the approaches for wind turbines and PV-array. Regardless, the costs per battery unit are also modelled with an integer decision variable to model an invest decision:

$$costs_{battery} = \sum_{t=0}^{T} \big(k_{OM,battery} * x_{discharge,battery}(t) \big) + n_{battery} * k_{annuity,battery}$$

$$n_{battery} \geq 0 \ \wedge \ n_{battery} \in \ \mathbb{Z}$$

$$x_{discharge,battery}(t) \geq 0$$

Where,

$k_{OM,battery}$ describes the operation and management costs of the battery system,
$x_{discharge,battery}(t)$ displays the energy discharge of the battery system in hour t and
$k_{annuity,battery}$ is the annualized capital costs for the battery system.

The costs for the battery systems depend on the capital costs and the number of cycles. The cycle costs are described by the discharge variable and the operation and management costs. To describe an investment decision and the operation of the biomass power plant and the diesel generator within this model no integer variables are used. The use of efficiencies according to the load level makes modelling of the thermal units with a multiple difficult. Therefore binary design variables are introduced.

Table 3: Overview over binary design variable

Binary design variable	**Description**
$\boldsymbol{\phi_{DG}}$	Decisive variable whether a DG is integrated into the HES or not
$\boldsymbol{\phi_{biomass}}$	Decisive variable whether a biomass power plant is integrated into the HES or not

The costs for all thermal units as diesel generator or biomass power plant are modelled similar. In the following formula the costs for the thermal unit are calculated:

$$costs_{TU} = \sum_{t=0}^{T} \Big(\big(p_{fuel}(t) + k_{fee,fuel} + k_{fee,RES}\big) * x_{cons} \quad + \phi_{on,TU}(t) * k_{on,TU} + \phi_{start,TU}(t) \Big) + \phi_{TU} * k_{annuity,TU}$$

$$x_{consumption,fuel}(t) \geq 0$$

Where,

$p_{fuel}(t)$is the fuel price for every hour t,
$k_{fee,fuel}$ is the purchase fee for fuel,
$x_{consumption,fuel}(t)$describes the fuel consumption by the thermal unit in hour t,

$\phi_{on,TU}(t)$ describes if the thermal unit is on or off in hour t,
$k_{on,TU}$ is the on-time fee for the thermal unit,
$\phi_{start,TU}(t)$ describes the start of the thermal unit in hour t,
$k_{start,TU}$ are the start costs for the thermal unit and
$k_{annuity,TU}$ are the annualized capital costs for the thermal unit.

Fuel consumption and annualized capital costs are the main factors for the costs for the thermal unit. The fuel consumption is multiplied with the fuel price, a purchase fee and a possible fee for electricity generation from RES. Additionally the start and the on-time are influencing the annual costs. The main constrain is the guaranteed supply of electricity to satisfy the energy demand of the consumer in every hour of the year:

$$\begin{aligned} p_{demand,company}(t) &= x_{discharge,battery}(t) \\ &- x_{charge,battery}(t) \\ &+ x_{energy,PV}(t) + x_{energy,wind}(t) \\ &+ x_{energy,DG}(t) + x_{energy,biomass}(t) \\ &- x_{elec,selling}(t) + x_{elec,purchase}(t) \end{aligned}$$

$$x_{charge,battery}(t), x_{energy,wind}(t), x_{energy,DG}(t), x_{energy,}$$
$$\geq 0$$

Where,

$x_{energy,PV}(t)$ is the electricity fed into the HES by the PV-array in hour t,
$x_{energy,wind}(t)$ is the electricity fed into the HES by wind turbine in hour t,
$x_{energy,DG}(t)$ is the electricity fed into the HES by the diesel generator in hour t,
$x_{energy,biomass}(t)$ is the electricity fed into the HES by the biomass power plant in hour t and
$p_{demand,company}(t)$ describes the company demand in every hour t.

The demand has to be supplied through power plant generation, by the grid or by the battery for every hour t. To model a possible electricity output variation for the fluctuating RES the following equations are implied in the model:

$$x_{energy,PV}(t) = n_{PV} * p_{el,PV}(t) - x_{dump,PV}(t)$$

$$x_{energy,wind}(t) = n_{wind} * p_{el,wind}(t) - x_{dump,wind}(t)$$

$$x_{dump,PV}(t), x_{dump,wind}(t) \geq 0$$

Where,

$x_{dump,PV}(t)$ is the electricity of the PV-array dumped in hour t and
$x_{dump,wind}(t)$ is the electricity of the wind turbine dumped in hour t.

The equation tries to imply the possibility to dump electricity generated by wind turbine or PV-array. Technical this means to move the blades out of the wind or to disconnect the PV-array for a certain period of time.

$$\begin{aligned} energy_{RES} = \sum_{t=0}^{T} \Big(& x_{energy,PV}(t) + x_{energy,wind}(t) \\ & + x_{energy,biomass}(t) \Big) \end{aligned}$$

$$energy_{RES} \geq \mathrm{k}_{\mathrm{RES,min}} * \sum_{t=0}^{T} \left(p_{demand,company}(t) \right)$$

Where,

$energy_{RES}$ is the sum of electricity fed into the HES generated by RES within T and
$\mathrm{k}_{\mathrm{RES,min}}$ is the minimum RES factor.

The RES factor describes minimum annual electricity generated by RES fed into the HES depending on the annual demand. This factor describes potential goals for the use of RES that want to be reached with the on-site HES installation.

The modelling of the battery operation is presented in this section. (Kost and Flath et al., 2013) describe the modeling of a storage operation. According to this formula the storage level is illustrated as:

$$\begin{aligned} x_{el,battery}(t) = & \left(1 - \eta_{hourly,loss,battery}\right) \\ & * x_{el,battery}(t-1) \\ & + x_{charge,battery}(t) \\ & * \left(1 - \eta_{battery}\right) \\ & - x_{discharge,battery}(t) \\ & * \left(1 + \eta_{battery}\right) \end{aligned}$$

$$x_{el,battery}(t) \geq 0$$

Where,

$x_{el,battery}(t)$ is the amount of electric energy stored in the battery in hour t,
$x_{charge,battery}(t)$ is the electric energy put into the battery in hour t,
$\eta_{hourly,loss,battery}$ is the hourly loss of the battery and
$\eta_{battery}$ is the round-trip efficiency of the battery.

The energy that is stored in the battery in every hour t is the sum of electricity stored in hour (t-1) and charged energy minus discharged energy. The battery is charge and discharge with the efficiency $\eta_{battery}$. In every hour the battery loses an amount of energy that can be described with the efficiency $\eta_{hourly,loss,battery}$.
The charge level of the battery is limited by the hours of storage and the size of the battery:

$$x_{el,battery}(t) \leq n_{battery} * k_{size,battery} * k_{storagehours}$$

Where,

$k_{storagehours}$ are the hours of storage.

To avoid a deep discharge or even a complete discharge of the battery a lower bound limits the charge level of the battery. A deep discharge can result in a lower lifetime.

$$x_{el,battery}(t) \geq (1 - k_{DoD,max}) * n_{battery} * k_{size,battery} * k_{storagehours}$$

Where,

$k_{DoD,max}$ is the maximum depth of discharge of the battery.

Another important matter is modelled within the following equation:

$$x_{discharge,battery}(t), x_{charge,battery}(t) \leq n_{battery} * k_{size,battery}$$

This limits the discharge and charge variable to a maximum size that depend on the battery multiple.

Both biomass power plant and diesel generator are modelled similar. The electricity output depends on the amount of fuel or biogas burned and the efficiency. To model different efficiencies at different load rates three different efficiencies are introduced. In Figure 10 the different efficiencies with their upper and lower bounds are shown. This points out that during a lower efficiency level more fuel could be consumed to generate the same or even lower amount of electricity.

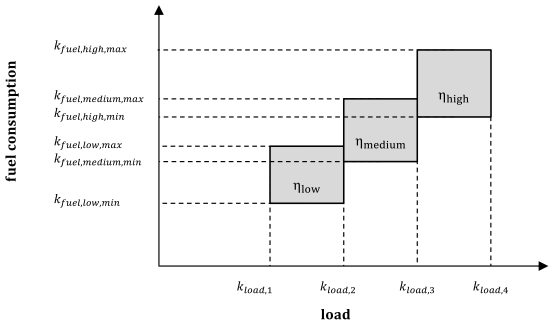

Figure 10: Load rate and fuel consumption of thermal unit

For the biomass power plant the electricity output is defined by:

$$x_{el,biomass}(t) \leq \phi_{biomass} * k_{size,biomass}$$

According to this the diesel generator can be described by:

$$x_{el,DG}(t) \leq \phi_{DG} * k_{size,DG}$$

Further assumptions in the model:

The costs for the grid connection are assumed with 40 €/kW based on the network costs for individual industrial consumers on a medium voltage level of a local supply company in Germany (Stadtwerke Ratingen, 2012). The parameter $k_{selling}$ that presents the fee of selling of electricity to the grid is assumed with 0.01 €/kWh. Network costs depend on the consumption and especially on the maximum size of the grid use. For this case study the chosen values for these parameters are presented in Table 4.

Table 4: Grid costs assumptions for German case study (Source: Assumptions based on (EUROSTAT, 2014) and (Stadtwerke Ratingen, 2012)

	Unit	**Grid**	**Parameter**
Grid connection	[€/kW]	40	k_{grid}
Electricity selling	[€/kWh]	0.01	$k_{selling}$
Electricity purchase	[€/kWh]	0.06	$k_{purchase}$

Fuel costs are the costs for the purchase of diesel fuel or biomass substrate. Fuel costs can vary over the year, but will be assumed as constant in this study. The fuel prices is described by the parameters $p_{diesel}(t)$ and $p_{biomass}(t)$.

The price for diesel fuel is assumed the liter of diesel for 1.35 €. The energy within diesel fuel is calculated according to (Caterpillar Inc., 2014) with a lower heating value (LHV) of 42,780 kJ/kg and a density of 838.9 g/liter. This leads to a diesel price of 0.0743 €/kWh$_{th}$. (Scholwin et al., 2011) calculated biomass substrate prices of 0.03 €/kWh$_{th}$ for the year 2010. Including the storage costs and a price increasing for the year 2013 the biomass substrate prices are assumed with 0.05 €/kWh$_{th}$.