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FLEXIBLE OPERATION OF COGENERATION PLANTS - CHANCES FOR THE INTEGRATION OF RENEWABLES

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MOTIVATION AND CHALLENGES

The “Integrated Energy and Climate Programme (IEKP)” was established by the German Government on August 23rd 2007 to implement the European decisions on climate and energy policy [1]. This programme sets ambitious climate protection targets. It aims at expanding renewable energies (REN) and increasing the energy efficiency up to 2020.

Figure 1 shows various key points of this programme that affect directly or indirectly the future development of Germany’s combined heat and power plant stock (CHP) as well as the CHP electricity generation.

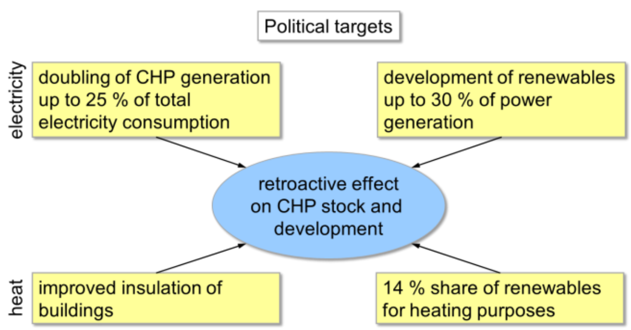

Figure 1: Influence of the IEKP on the development of CHP

The CHP power generation will have to be doubled from currently about 12 % to 25 % of electricity production. Other targets of the IEKP, however, will have exactly the opposite effect on the CHP. The demand for heat will be reduced due to an improved insulation of buildings. An increase of renewables for heat production will further lower the market potential for CHP, at least as far as the production of heat is concerned. Regarding the production of electricity, the increase of production from renewables to 30 % affects the production of CHP. Renewable energy sources are mostly “must-run”-facilities. Their production depends on weather conditions but not on consumer load. The increased feed-in from renewables leads to lower mean price at the wholesale market for electricity and thus, lowers the margins of CHP plants.

As the feed-in from renewables fluctuates wildly, the consequences are lower prices and higher price fluctuations at the markets. In the case of negative prices the feeding plants have to pay a certain amount to stay at grid. In short the volatile electricity prices increase the incentive for a more flexible operation of power plants. Contrary to wind or solar energy, operation of CHP can be influenced by decoupling heat and electricity production.

The subordinate project "Flex: Flexible operation of CHP" [2] analyses the technical possibilities of making CHP operation more flexible with the aim of integrating the renewable energies more efficiently. In addition it keeps in mind the political targets for CHP.

ANALYSIS OF LOAD PROFILES

The political targets for Germany's energy industry are very ambitious. Nevertheless they seem to be reachable when looking solely at the energy amounts. But as demonstrated in Figure 2, saturation effects occur in the politically motivated IEKP-scenario which makes it necessary to look at load profiles and power curves.

Figure 2 illustrates such a possible scenario for profiles of load and generation from renewables and CHP when reaching the IEKP targets. The generation from renewables was modeled mainly through wind power plants. At some points, the production from CHP and renewables is higher than the consumers' load. This surplus of electricity cannot be used, but is wasted. This means that an additional development of must-run-capacities isn't sufficient to reach the ambitious political targets. Other measures will have to be taken to increase the share of electricity from renewable energies and cogeneration plants.

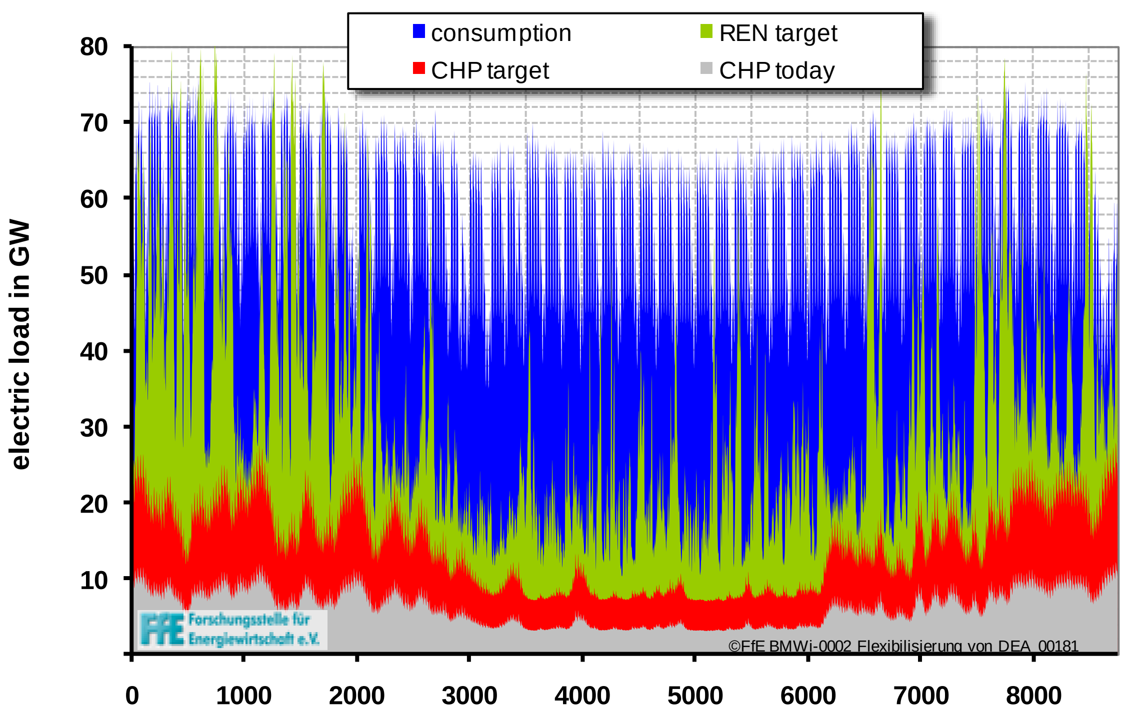

Figure 2: Electric load profiles regarding Germany's political targets [2]

MARGINAL UTILITY OF MUST-RUN-EXPANSION

In a next step the installed must-run power capacity will be varied and the resulting electricity generation will be analysed. For simplicity, the production profiles for renewable power generation and cogeneration are combined to one profile for must-run power.

In Figure 3 the installed capacity of this must-run power was gradually scaled. The electricity generation is plotted over the additional capacity of must run compared to the situation today. The present production of 100 TWh from must-run power plants is situated in the origin at 0 GW additional capacity. The left figure illustrates absolute values for electricity production, whereas the right figure shows relative values on total coverage of electricity consumption.

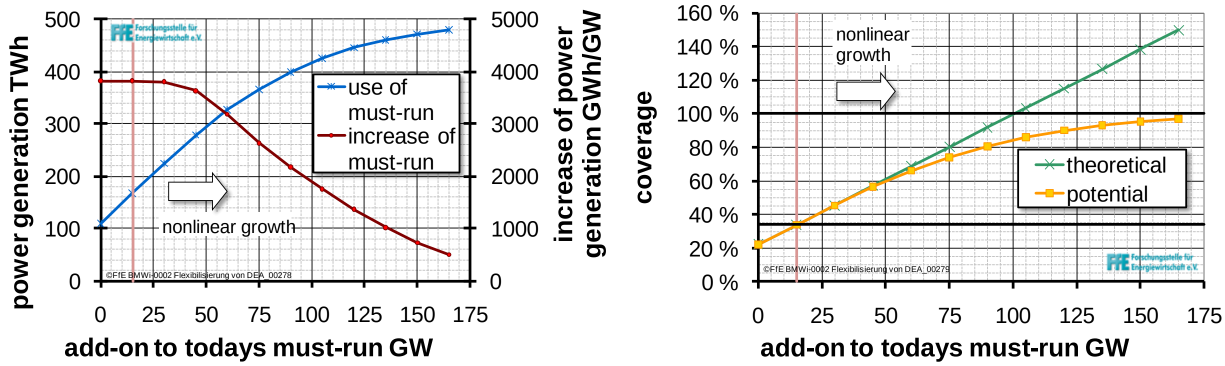

Figure 3: Variation of development of must-run generation [2]

Up to 30 GW the increase of generation (blue curve) is proportional to the increase of must-run power. But when reaching about 15 GW the power curves already exceeds the consumers’ load: part of the climate friendly production can no longer be used. This can be seen in the decline of generation increase (red curve) which is the gradient of the blue curve.

With a further increase of the must-run capacity, the usable production continously rises. But this rise is no longer linear since saturation effects occur. The must-run growth also is the marginal utility of further extension. It tells us how much electricity is produced by1 GW of additionally installed power. This value drops the more often a peak of must-run load exceeds the consumer load. In this scenario calculation the marginal utility declines from 3 800 GWh per GW to below 500 GWh/GW for the last installed GW shown in the chart.

In the second chart on the right the must-run-coverage is shown which is currently at about 22 %. With about 100 GW of additional power capacity, a theoretical coverage of 100 % could be achieved. Since part of the potential production cannot be used due to the reasons mentioned before, the possible coverage is on a lower level. However, we recognize that the loss by not usable generation has relatively little impact until a coverage of 60 %. Only at a additional capacity of 50 GW the deviation of theoretical coverage from potential coverage grows significantly.

OPTIONS FOR A FLEXIBLE OPERATION OF CHP

The German legal framework renewables can feed into the grid with higher priority than conventional power plants [3]. Since wind and solar power generators produce electricity only when solar radiation or wind is available, the only way to change their power output is to switch them off or reduce their power. That is not an option regarding the aim of a sustainable and eco-friendly power supply. In case of grid restrictions the TSO is allowed to shut down the facilities temporarily in exceptional cases [3].

CHP power also has this priority arrangement [4] in order to ensure that the heat demand in district heating grids is preferably covered by CHP. Only electricity that is generated at the same time as heat is called CHP power. Therefore the simultaneity of heat and electricity demand is the condition for cogeneration. As opposed to renewable energies the production characteristic of CHP can be affected by proper measures which allow to decouple generation of heat and electricity. This may increase the share of CHP without the effects shown in Figure 3.

Provided that the electricity demand will not decline significantly - which would enhance the relative share of CHP - there are mainly two technical options for extending the coverage of CHP without restricting the targets for the renewables.

- **Modulation of the power and heat ratio**
  Different possibilities to modulate the CHP coefficient can be applied: in particular variating the amount of the extracted steam mass flow in extraction condensing turbines shows great success.
- **Thermal storage**
  Heat can be stored without any great technical efforts. Thus one possibility to uncouple the CHP heat- and electricity generation is to use thermal storages. As a result, the plant utilisation period of the CHP electricity-generation can be increased.

To evaluate these options, it is necessary to analyze their potential by considering not only expansion potential but the possibilities of a flexible operation. Collected and simulated data are converted into a regional energy system model, in which it is possible to test the various options concerning their requirements and technical potential. Beside this a simulation model for the operation of a flexible CHP-plant is used.

MODEL OF A FLEXIBLE CHP-SYSTEM

The dynamic behavior of a CHP plant is modeled and analysed with a simulation programme [2, 5]. The programme allows to model any CHP plant based on technical parameters of the steam generator and individual turbine stages. Consequently, both extraction condensing and back pressure turbines can be simulated. In the case of a combined cycle power plant electricity is produced by the steam generator.

In Figure 4 the entire assembly of a flexible CHP-system is illustrated.

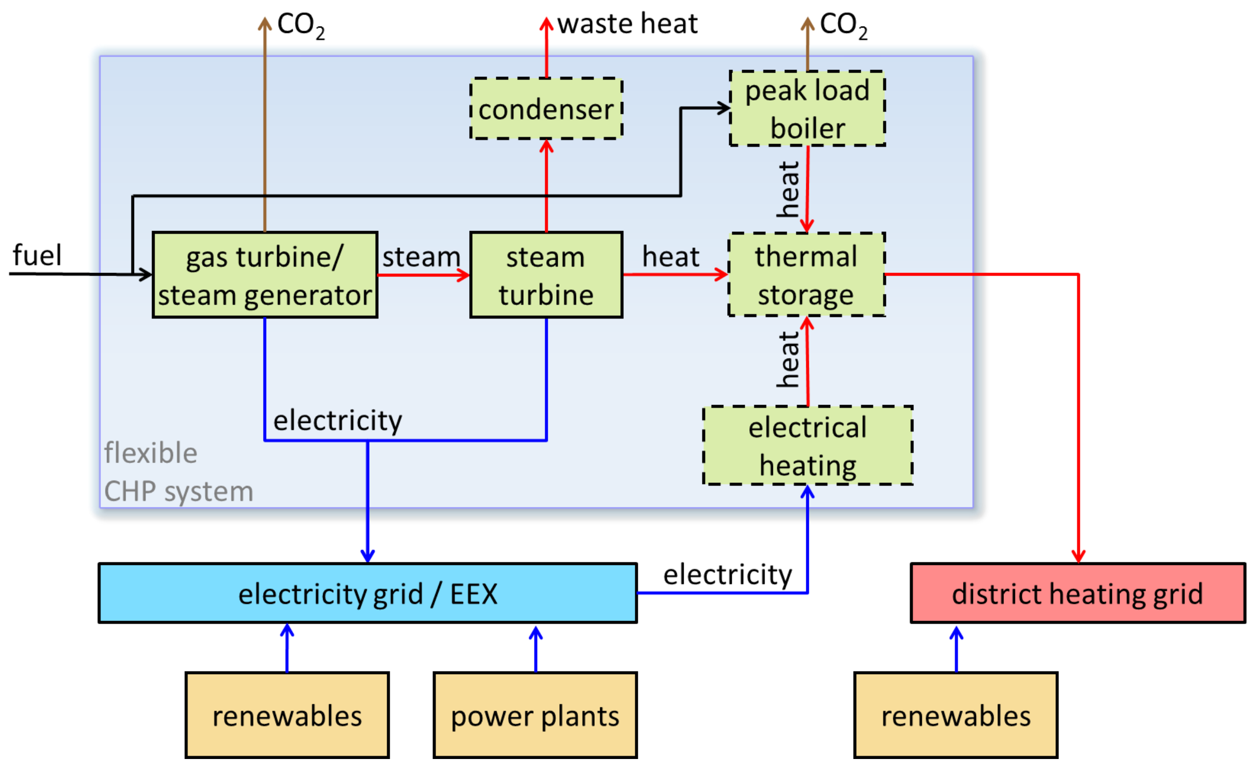

Figure 4: System integration of flexible CHP

Gas turbine respectively steam generator and steam turbine build up the core component of the flexible CHP-system. Optionally, a heating plant, a condenser, a thermal storage and an electric heating system can be integrated. Depending on the study objective, the optional components can be taken into account.

Electricity produced by the flexible CHP-System is fed into the electricity grid. This is represented by the electric load profile that has to be covered by conventional power plants as well as renewables and CHP. The electricity prices at the European energy exchange (EEX) are mainly influenced by the residual load which is consumer load minus the feed-in of all must run power plants [6]. Thus, scenarios for electricity prices were developed from scenarios for the residual load with statistical methods. Negative electric balancing energy can be provided by using the electrical heating system of the flexible CHP. This can be a central electric boiler or a heat pump that feeds into the thermal storage or the district heating grid.

As a basic rule, the heat demand of the supplied object, which is normally a district heating grid, has to be covered by the flexible CHP-plant. Contrarily to electricity it is not possible to distribute heat widely without high losses. So thermal balancing energy cannot be provided by distant facilities. To provide positive thermal balancing power, a peak load boiler or a thermal storage is included. The condenser allows to decrease thermal power output and to increase the electricity production. But only electricity that is produced together with usable heat is CHP-electricity. The condenser virtually splits up the system into a CHP-unit and a conventional condensing turbine power plant.

With this additional components the simulation programme can be used to dynamically replicate the operation of a single plant and the aggregated total German CHP electricity. Operation of the flexible CHP-plant is based on the leading parameters heat demand and electricity price. Both values can be very high. The heat demand can also be zero and the electricity prices can even be negative.

OPERATION MODES OF A FLEXIBLE CHP SYSTEM

Figure 5 shows a portfolio of different operation modes for four extreme conditions. The feed-in of renewable energies is represented by the icon of the wind turbines. The electricity grid respectivley the electricity prices and district heating grid symbolise the consumers‘ demand. In between the flexible CHP-plant is integrated.

A high feed-in of renewables and simultaneous low electricity demand results in negative electricity prices. In this case electricity can be used either to heat up the thermal storage (lower left side) or to directly cover the heat demand. The CHP-unit will not generate electricity, even in the case of a high heat demand. Thus the peak load boiler has to provide the necessary heat as shown in the upper left side.

At high electricity prices the CHP-plant will produce electricity and will fill up the storage if the heat demand is low. This operation mode is profitable if the electricity price is higher than the electricity generation costs of the plant. When the heat demand rises, the operation mode changes to the upper right situation. All heat generators except the electrical heating system will provide the heat. So a maximum of electricity can be sold at the EEX.

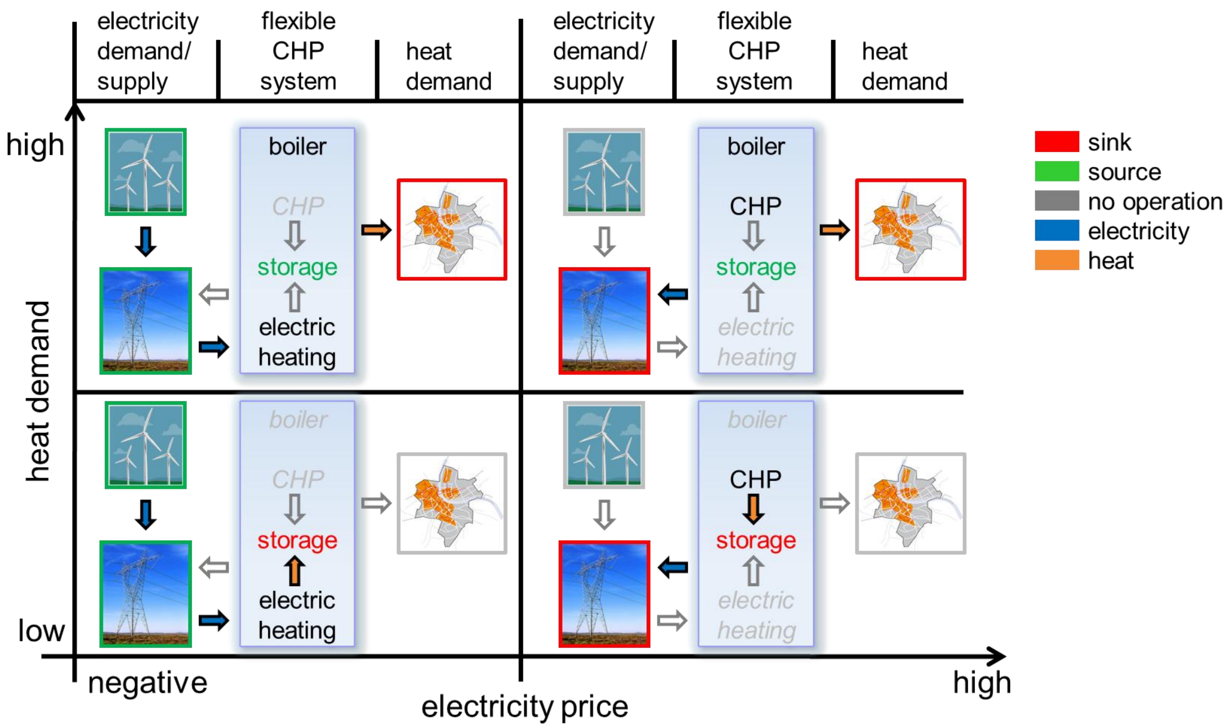

Figure 5: Operation Portfolio for flexible CHP-Systems

As shown, the flexible CHP-system consumes electricity at times of low or negative prices. When electricity prices are high, electricity is fed into the grid. Because of this characteristic it could be seen as kind of "electrical" storage. But compared to classic electrical storage systems it has some advantages:

- Energy losses of the thermal storage tank are much lower than those of conventional electrical storage systems [7].
- A thermal storage tank costs less than an electrical storage sytem [2].

USE OF THERMAL STORAGE SYSTEMS TO INCREASE CHP-COVERAGE

How can thermal storage systems help to increase the share of electricity from CHP? The first step is to increase the runtime of the CHP-unit and at the same time use the produced heat. Thermal storages help to decouple the demand and the time of its' covering.

Figure 6 illustrates an example of the successful use of a thermal storage in the model. The simulation is based on a CHP unit that has a maximum electrical power output of about 420 MW_{el} and a power to heat ratio of 1. The blue line shows an electrical load profile and the red line a heat load profile.

Between time step 2 and time step 9 the electrical load exceeds the heat load. Without using a thermal storage system, this CHP unit would only be able to produce as much CHP-electricity as heat. So part of the electricity would have to be obtained from the electricity grid or the condensing turbine. By including a thermal storage, all of the electricity can be provided by the CHP plant. From time step 11 the stored heat can be used to cover the heat demand that cannot be provided by the simulated CHP-plant. The peak load boiler is only used if the thermal storage is empty.

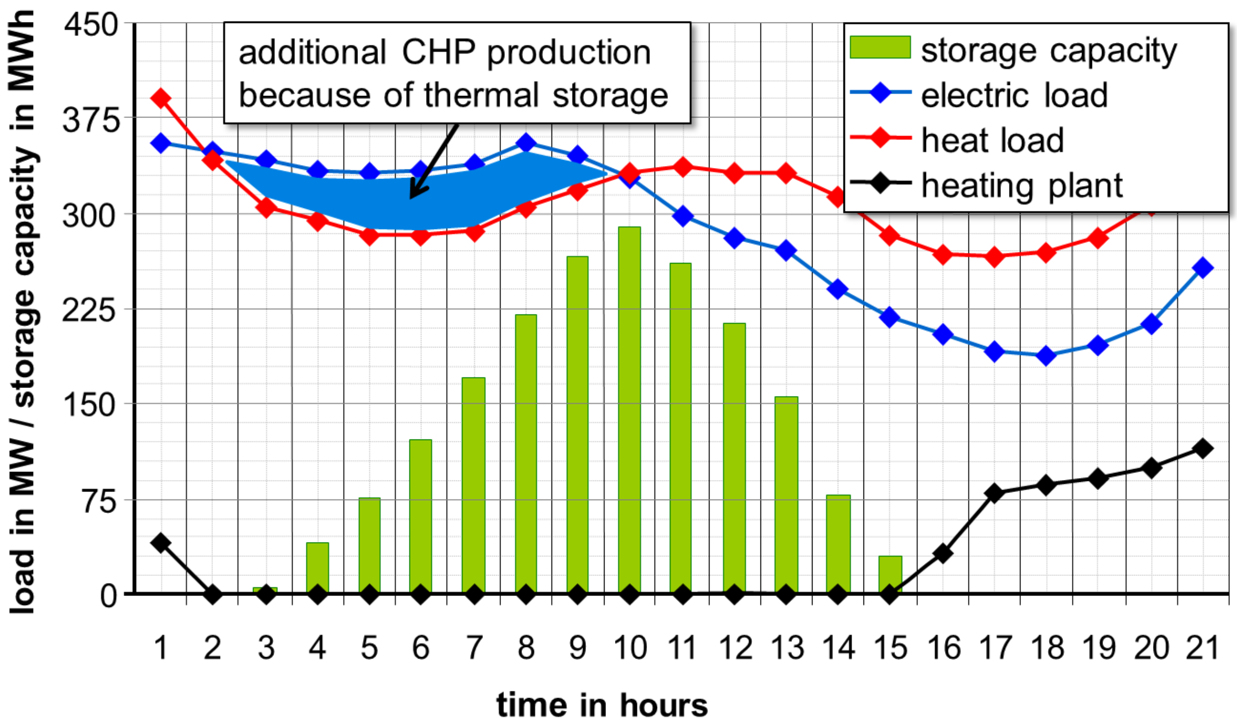

Figure 6: Use of thermal storage to increase the electrical CHP-production

The more often the thermal storage sytem can be charged and discharged in a year the higher is the additional CHP-coverage through the storage system. This additional CHP-electricity and heat increases the profitability of the CHP plan. The more intersections between the red and the blue line occur, the higher is the use of the thermal storage.

Analyses of real load profiles show that these intersections mainly occur in the transitional seasons, springtime and autumn. In winter the heat demand is too high so that the CHP unit and the peak load boiler will run full time while the storage tank is empty. On the other hand in summer the thermal storage is filled up and cannot be used either. At this time of the year the heat demand is low and can be covered by CHP without discharging the storage. In this case, most of the electricity will be produced from the condensing turbine part of the flexible CHP-system or be obtained from the electricity grid depending on the pices at the EEX.

RESULTS OF DIFFERENT SCENARIOS

The simulation model of a flexible CHP-system was used to analyse different scenarios. The residual load respectively the EEX-prices were varied and different possibilities of making the CHP-plant's operation more flexible have been implemented to the model.

In this paper two scenarios are presented. The first scenario is based on today's energy system in Germany. This means that present electricity prices of the EEX were used. The flexible CHP-system itself contains an extraction condensing turbine with technical parameters shown in Table 1 and a thermal storage whose capacity is varied. The additional electrical heating system has a capacity of 300 MW.

Table 1: Technical parameters of the simulated CHP-plant

Capacity in MW	CHP full load	CHP partial load	Condensing mode full load	Condensing mode partial load
Electrical	365	190	420	240
Thermal	250	195	0	0

A second scenario was built up to account for a future development of the energy system. It is based on the "BMU Leitszenario" [8] for the development of installed capacity of renewables:

- 38.05 GW installed wind power capacity in 2020 (23.90 GW in 2008)
- 17.90 GW installed PV capacity in 2020 (5.31 GW in 2008).

In addition it is assumed that 22 GW of conventional base load power (e.g. nuclear power) plants feed into the grid. These plants have lower marginal generation costs than the CHP-plant and therefore reduce the residual load further. Hourly values of the feed-in were generated by FfE simulation tools. The consumer load is not changed, neither in level nor in characteristics as some studies predict an increasing and others a decreasing consumer load until 2020. Data base for the analysis in this paper is the consumer load from 2008 which is the most recent data source which is complete [9]. Taking the simulated residual load into account, electricity prices were derived by using the model published in [6]. The flexible CHP-system is the same as in the first scenario.

Figure 7 shows the maximum possible investment in thermal storage and electrical heating system for a 20 year term and 10 % interest rate. The results of the first scenario can be seen in the blue curves, the results of the second scenario in the red ones.

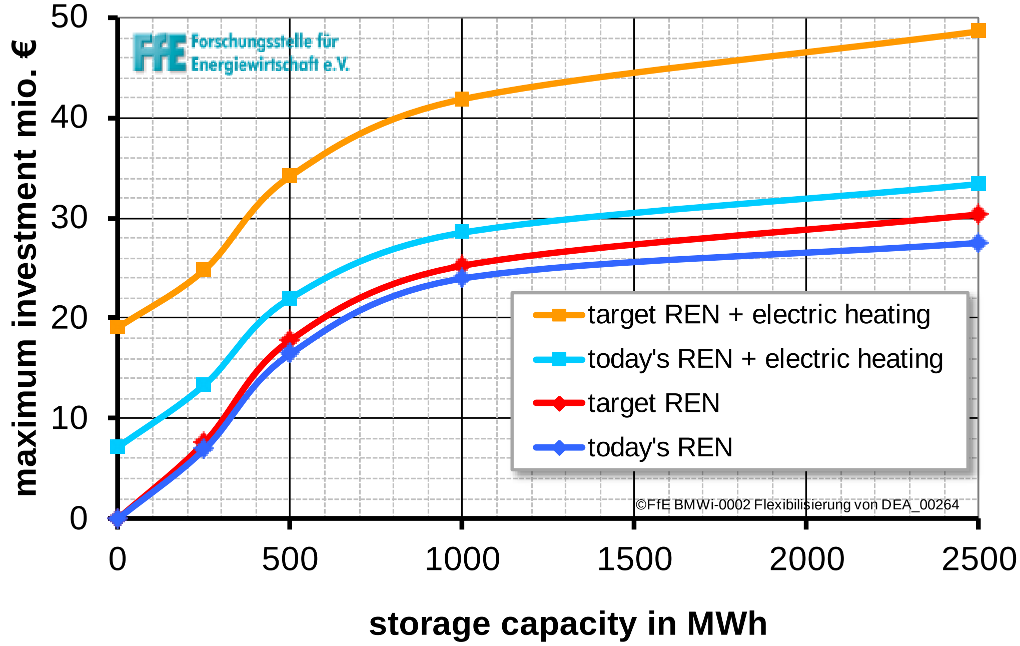

Figure 7: Results of different scenarios with flexible CHP

It is obvious that making CHP operation more flexible allows an additional investment. Regarding the electrical heating system, the economic benefit is determined by the price relation of fuel and electricity prices. Since scenario 2 has lower electricity prices than scenario 1 the maximum investment for the electrical heating system can be significantly higher. The overall level of the curves for electric heating will decline if grid utilisation fees are considered.

Thermal storages are most effective for capacities up to 1 000 MWh in this constellation. Installing larger storages doesn‘t increase the additional benefit much more. That means the specific investment sum drops with larger storage systems.There is no big difference between the scenarios for the political targets and the scenario for today looking at the thermal storage only.

The simulation results reveal costs similar to real thermal storage projects that have been or are to be realised in Germany. The 300 MWh thermal storage system planned in Münster for example has investment costs of about 4.5 mio. € [10].

SUMMARY AND OUTLOOK

The political targets for future shares of renewable energies and CHP on electricity production are often very ambitious. Regarding the hourly production profiles, the challenges for the German energy system will even increase, because the electricity production from CHP and renewables fluctuates. Moreover, it is not correlated to the electricity load. In an attempt to meet the target, one possible way to make their operation more flexible is to decouple electricity generation and heat production of CHPs. A more flexible operation of CHP also seems to be a commercial profitable investment.

But first estimations show that the political targets cannot be reached by making CHP operation more flexible only. Nevertheless, the use of extraction condensing turbines combined with thermal storage can substitute conventional peak load power plants. Thus fluctuating energy sources can be integrated more efficiently and at a lower cost.

Having the energy system view in mind many more analyses for a flexible operation of CHP are possible. What seems to be a good investment for the future is for example networking of plants.. Furthermore it is worth thinking about ways to establish dynamic grid utilisation prices for different transportation distances since the electricity grid seems to be a bottleneck of energy systems with a high share of renewables. Taking these challenges into account, a flexible operation of CHP could be more profitable than shown in this paper. Therefore the fields of application for flexible CHP could even be higher.

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