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Documentation of the German Energy System Reference Model in EnergyPLAN

Version 2, May 2020

by

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1 Introduction

In the context of the change of the energy policy in Germany it is necessary to provide many different forms of energy simultaneous. The aim is to create an overview of the complex energy systems and to control them efficiently. An energy system is a system that combines all parameters for the production, conversion, supply and use of energy [1]. Especially the interaction between conventional and renewable energy sources is an important aspect for the future. Both the correct use of available energy and the avoidance of overproduction are of great importance. Furthermore, the correlation between electricity, heating and cooling networks must be taken in account. There is a variety of simulation possibilities for the analysis of these dependencies and the possible resulting effects.

Currently many different programs for the simulation of energy systems are provided. These differ in terms of data requirements, technology specification and computing needs. Some programmes have been developed explicitly for one country or scheme, while others can be used in an international context. Distinctions are also made regarding sectoral coverage and the time step. For example, there is a dynamic system investment model (DSIM), which considers the electricity system per minute, or an EU-oriented simulation model for energy systems with annual consideration of all energy sectors (PRIMES). In this thesis the simulation software EneryPLAN was used, which provides an hourly simulation of the energy systems including the sectors electricity, heat, cooling, industry and transport. EnergyPLAN is described as an advanced energy system analysis computer model and belongs to a group of progressively programs that can be used to investigate specific technical possibilities with cost and emission implications. They are mostly based on historical data, while other simulations programs such as PRIMES or POLES introduce in moderate technological details using a macroeconomic approach. For teaching at the University of Applied Science in Leipzig EnergyPLAN is used in the module “Networked Energy Systems”. The choice for this program is based on the facts that it is a widespread free software with a great clarity, which can be used by everyone after a brief introduction. This program also presents the influence of CO_2 emissions, so that CO_2 emissions from the simulation can be compared with real data to verify the accuracy and realism of the work. [2, 3]

As part of this paper the EnergyPLAN version 14.2 of January 2019 was used to simulate Germany. The aim was to simulate the current situation in Germany in 2015 and create a baseline model for future scenarios. In the following, the individual tab sheets will be illustrated after a short instruction and the researched values will be explained with reference to the source.

2 Change Log

Version 2:

- All the distributions were renamed with shorter, more legible names.
- The distributions for photovoltaic, onshore and offshore capacity factors were supplemented. Biases occurred in future scenarios, because the building rate of the different renewable energy plants in the referenced year was included in the original distributions. Two new distributions for each of the mentioned energy sources from different sources [34, 35] are now available.
- The Model was created with EnergyPLAN version 15.0 of September 2019

3 Instruction

The following documentation is also shown in Excel in table form. There the columns “tab sheet“, “headline“, “designation“, “researched value“, “unit“, “conversion“ and “comment“ are displayed. The inputs are listed one after the other in the order of the simulation program EnergyPLAN and are indicated with the researched values. If a value was not changed, it was designated as “default”.

The documentation listed in this paper begins with the description of the Demand tab. In this sheet, the individual tab sheets are briefly explained, a section of the filled sheet is illustrated and the origin of the researched value is explained. Inputs are only explained, if their value was changed for the model. In the process of the documentation the same procedure is used to describe the Supply and Balancing and Storage tab. The Cost tab sheet is not explained, because the values were transferred from the existing “Paper model Germany 2015”. Finally, the results and experiences with EnergyPLAN are summarized. After a mention and acknowledgement of all participants, the documentation concludes with the list of references.

4 Demand

4.1 Electricity

The “Demand: Electricity”-tab sheet is used to define the different kinds of electricity demand like the overall demand, the demand for heating and cooling or for the transportation. The filled tab sheet is shown in the Figure 1 below. Each input is explained afterwards, if the value was changed for the model.

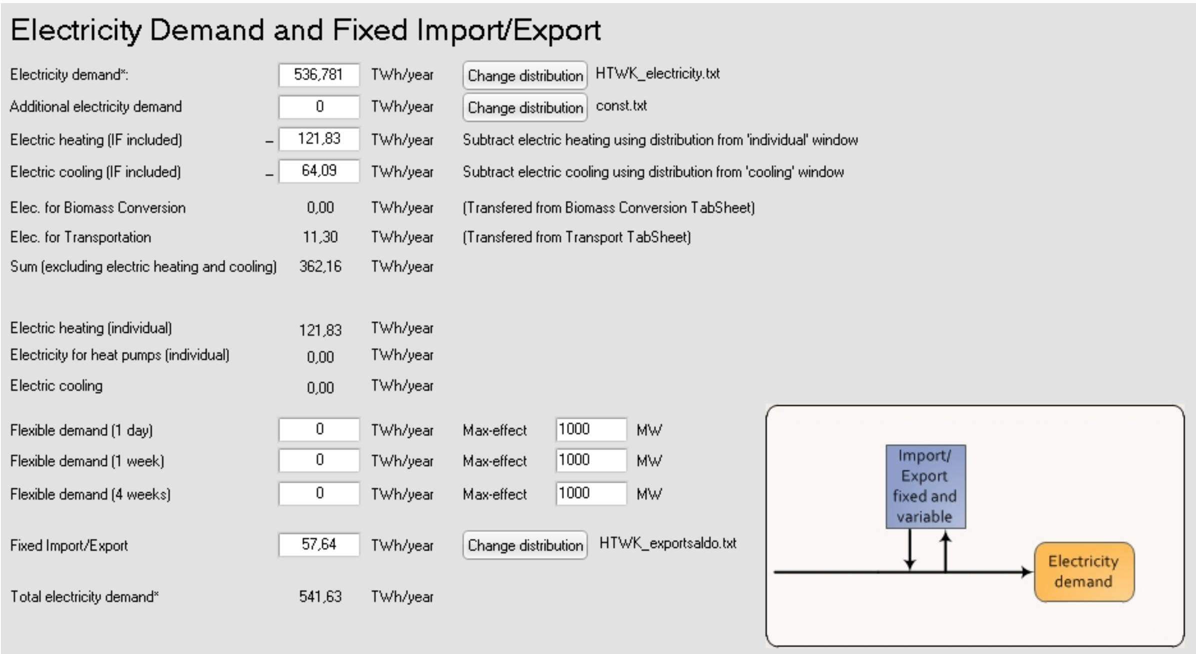


Figure 1: Electricity Demand

Electricity demand	536,781 TWh/a
	This value is calculated as the difference between the actual electricity demand of Germany minus the demands for transportation and individual heat pumps shown on the tab sheet. The actual electricity demand was calculated through hourly values from the Agorameter [4] and is 551,581 TWh/a. $$D_E \qquad = D_{EA} - D_{ET} - D_{EHP}$$

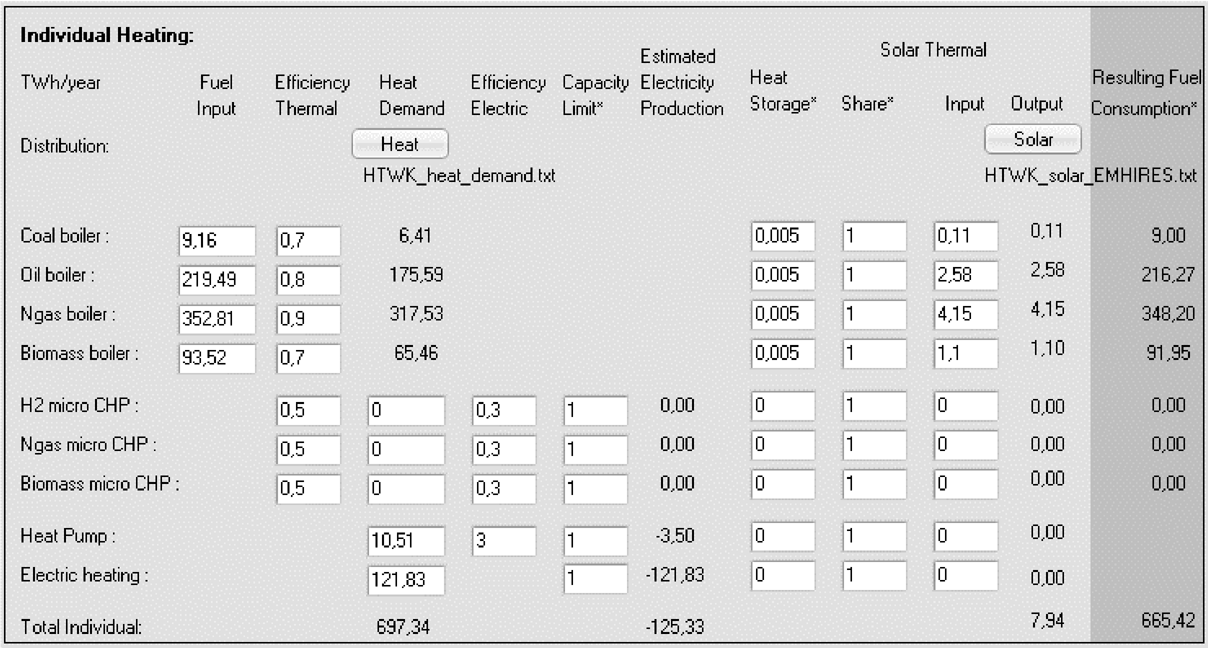
	D_E annual electricity demand D_{EA} annual electricity demand including the electricity demands for transportation and heat pumps D_{ET} annual electricity demand for transportation D_{EHP} annual electricity demand for heat pumps $D_E = 551{,}581\frac{TWh}{a} - 11{,}3\frac{TWh}{a} - 3{,}5\frac{TWh}{a}$ $D_E = 536{,}781\frac{TWh}{a}$
	The distribution is “HTWK_electricity.txt”. It was generated with data provided by the Agorameter [4]
Electric heating	121,83 TWh/a
	Refers to the electric heating heat demand in the tab sheet “Demand: Heating”
Electric cooling	64,09 TWh/a
	Refers to the electricity consumption for cooling in the tab sheet “Demand: Cooling”
Fixed Import/Export	57,64 TWh/a
	Export balance, calculated through hourly values from the Agorameter [4]
	The distribution is “HTWK_exportsaldo.txt”. It was generated with data provided by the Agorameter [4]

4.2 Heating

The “Demand: Heating”-tab sheet provides information about different heat demands and supply routes for households, trade, commerce and service. The inputs are subdivided into three groups. Group 1 is “Total Heat Demand”, group 2 is “Individual Heating” and group 3 is “District Heating”. The inputs for each group are shown in the figures and explained in the text below.

Figure 2: Total Heat Demand

Demand Per Building	39110 kWh/a
	This value is calculated with the building-related final energy consumption for room heating, room cooling, hot water and lighting [5] divided by the numbers of buildings in Germany [6, 7]. The amount of final energy for lighting refferd only to non-residential buildings. $H_{Building} = \frac{E_{fec-building}}{n_{rb}+n_{nrb}}$ $H_{Building}$ annual heating demand per building $E_{fec-building}$ building-related final energy consumption n_{rb} number of residential buildings n_{nrb} number of non-residential buildings $H_{Building} = \frac{3102\ PJ}{18732000+3300000}$ $= 1{,}408 \cdot 10^{-4}\ PJ$ $= 39110 \frac{kWh}{a}$



Individual Heating:

TWh/year	Fuel Input	Efficiency Thermal	Heat Demand	Efficiency Electric	Capacity Limit*	Estimated Electricity Production	Solar Thermal Heat Storage*	Solar Thermal Share*	Solar Thermal Input	Solar Thermal Output	Resulting Fuel Consumption*
Distribution:			Heat HTWK_heat_demand.txt						Solar HTWK_solar_EMHIRES.txt		
Coal boiler :	9,16	0,7	6,41				0,005	1	0,11	0,11	9,00
Oil boiler :	219,49	0,8	175,59				0,005	1	2,58	2,58	216,27
Ngas boiler :	352,81	0,9	317,53				0,005	1	4,15	4,15	348,20
Biomass boiler :	93,52	0,7	65,46				0,005	1	1,1	1,10	91,95
H2 micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Ngas micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Biomass micro CHP :		0,5	0	0,3	1	0,00	0	1	0	0,00	0,00
Heat Pump :			10,51	3	1	-3,50	0	1	0	0,00	
Electric heating :			121,83		1	-121,83	0	1	0	0,00	
Total Individual:			697,34			-125,33				7,94	665,42

Figure 3: Individual Heating

Distribution: Heat	The distribution is “HTWK_heat_demand.txt”. It was generated with data provided by the “Wärmeverteilung 2015” [8]. The table is a result of a lecture at the “HTWK Leipzig” and was created by mister T. Radisch.
Distribution: Solar	The distribution is “HTWK_ solar_EMHIRES.txt”. It was generated with data provided by [34]. Alternatively, you can use “HTWK_ solar_NINJA.txt” [35] or ““HTWK_ solar_2015.txt” [4].
Coal boiler – Fuel Input	9,16 TWh/a
	This value is calculated with the final energy demands of lignite and hard coal for households, trade, commerce and service from the table “AGEB Energiebilanz” [9]. The values can be found in the cells C75 to J75.
Coal boiler – Solar Thermal – Heat Storage	0,005
	This value was taken from the “Paper model Germany 2015” [33]
Coal boiler – Solar Thermal – Input	0,11 TWh/a
	The solar thermal input for coal boilers is 1% of the total heat demand [10] in relation to the fuel input of all boilers. The value is calculated as follows:

	$$Q_{Solar-M-coal} = 0{,}01 \cdot Q_{total} \cdot \frac{F_{M-coal}}{F_{M-total}}$$ $Q_{Solar-M-coal}$ annual heat production from solar thermal in individual coal boiler systems Q_{total} annual total heat demand F_{M-coal} annual fuel demand for individual coal boilers $F_{M-total}$ annual total fuel demand for individual boilers $$Q_{Solar-M-coal} = 0{,}01 \cdot 795{,}89\ TWh/a \cdot \frac{9{,}16\ TWh/a}{674{,}98\ TWh/a} = 0{,}11 \frac{TWh}{a}$$
Oil boiler – Fuel Input	219,49 TWh/a
	This value is calculated with the final energy demands of oil for households, trade, commerce and service from the table “AGEB Energiebilanz” [9]. The values can be found in the cells K75 to U75.
Oil boiler – Solar Thermal – Heat Storage	0,005
	This value was taken from the “Paper model Germany 2015” [33]
Oil boiler – Solar Thermal – Input	2,58 TWh/a
	The solar thermal input for oil boilers is 1% of the total heat demand [10] in relation to the fuel input of all boilers. The value is calculated as follows: $$Q_{Solar-M-oil} = 0{,}01 \cdot Q_{total} \cdot \frac{F_{M-oil}}{F_{M-total}}$$ $Q_{Solar-M-oil}$ annual heat production from solar thermal in individual oil boiler systems Q_{total} annual total heat demand F_{M-oil} annual fuel demand for individual oil boilers $F_{M-total}$ annual total fuel demand for individual boilers

	$$Q_{Solar-M-oil} = 0{,}01 \cdot 795{,}89\ TWh/a \cdot \frac{219{,}49\ TWh/a}{674{,}98\ TWh/a}$$ $$= 2{,}58 \frac{TWh}{a}$$
Ngas boiler – Fuel Input	352,81 TWh/a
	This value is calculated with the final energy demands of Ngas for households, trade, commerce and service from the table "AGEB Energiebilanz" [9]. The values can be found in the cells V75 to Y75.
Ngas boiler – Solar Thermal – Heat Storage	0,005
	This value was taken from the "Paper model Germany 2015" [33]
Ngas boiler – Solar Thermal – Input	4,15 TWh/a
	The solar thermal input for Ngas boilers is 1% of the total heat demand [10] in relation to the fuel input of all boilers. The value is calculated as follows: $$Q_{Solar-M-Ngas} = 0{,}01 \cdot Q_{total} \cdot \frac{F_{M-Ngas}}{F_{M-total}}$$ $Q_{Solar-M-Ngas}$ annual heat production from solar thermal in individual Ngas boiler systems Q_{total} annual total heat demand F_{M-Ngas} annual fuel demand for individual Ngas boilers $F_{M-total}$ annual total fuel demand for individual boilers $$Q_{Solar-M-Ngas} = 0{,}01 \cdot 795{,}89\ TWh/a \cdot \frac{352{,}81\ TWh/a}{674{,}98\ TWh/a}$$ $$= 4{,}15 \frac{TWh}{a}$$
Biomass boiler – Fuel Input	93,52 TWh/a
	This value is calculated with the final energy demands of biomass for households, trade, commerce and service from the table "AGEB Energiebilanz" [9]. The values can be found in the cells AA75 to AB75.

Biomass boiler – Solar Thermal – Heat Storage	0,005 This value was taken from the "Paper model Germany 2015" [33]
Biomass boiler – Solar Thermal – Input	1,10 TWh/a The solar thermal input for Biomass boilers is 1% of the total heat demand [10] in relation to the fuel input of all boilers. The value is calculated as follows: $$Q_{Solar-M-bio} = 0{,}01 \cdot Q_{total} \cdot \frac{F_{M-bio}}{F_{M-total}}$$ $Q_{Solar-M-bio}$ annual heat production from solar thermal in individual biomass boiler systems Q_{total} annual total heat demand F_{M-bio} annual fuel demand for individual biomass boilers $F_{M-total}$ annual total fuel demand for individual boilers $$Q_{Solar-M-bio} = 0{,}01 \cdot 795{,}89\, TWh/a \cdot \frac{93{,}52\, TWh/a}{674{,}98\, TWh/a}$$ $$= 1{,}10 \frac{TWh}{a}$$
Heat Pump – Heat Demand	10,51 TWh/a This value was taken from the "AGEE Zeitreihen" [11], Table 5.
Electric Heating – Heat Demand	121,83 TWh/a The value was taken from the database of the diagram "Wärmeverbrauch nach Energieträgern" [12]

The impact of micro CHP on the heat demand of Germany is relatively small, therefor they were not included in this model. Same applies to the solar thermal assistance for heat pumps or electric heating.

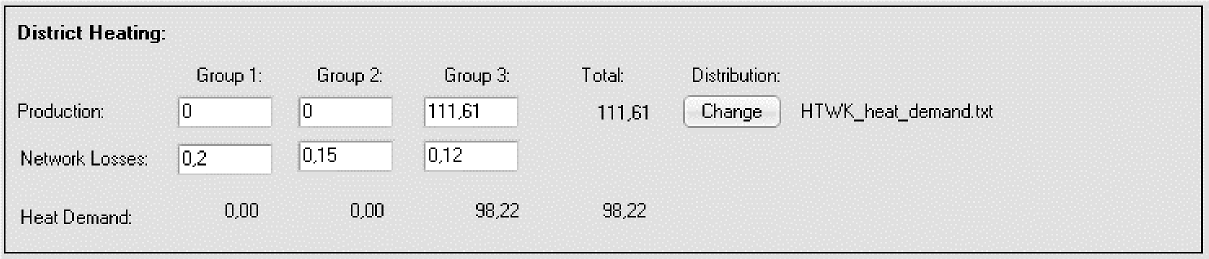


Figure 4: District Heating

Production – Group 3	111,61 TWh/a
	The value can be found in the table "AGEB Energiebilanz" [9] at the cell AF52.
Network Losses – Group 3	0,12
	The value is listed in the "AGFW Hauptbericht 2015" [13] on page 9.
Distribution	The distribution is "HTWK_heat_demand.txt". It was generated with data provided by the "Wärmeverteilung 2015" [8]. The table is a result of a lecture at the "HTWK Leipzig" and was created by mister T. Radisch.

In this model all the district heat demands and supplies are arranged in group 3, because we couldn't clearly classify the various heat demands and productions in the different groups. A clearer distinction is a certain possibility.

4.3 Cooling

In the "Demand: Cooling"-tab sheet is the annual electricity consumption and the annual cooling consumption for the demand depicted. The annual cooling consumption is defined in three district heating groups with COP. Figure 5 shows the filled tab sheet. The explanation for each input is given afterwards, if the value was changed for the model.

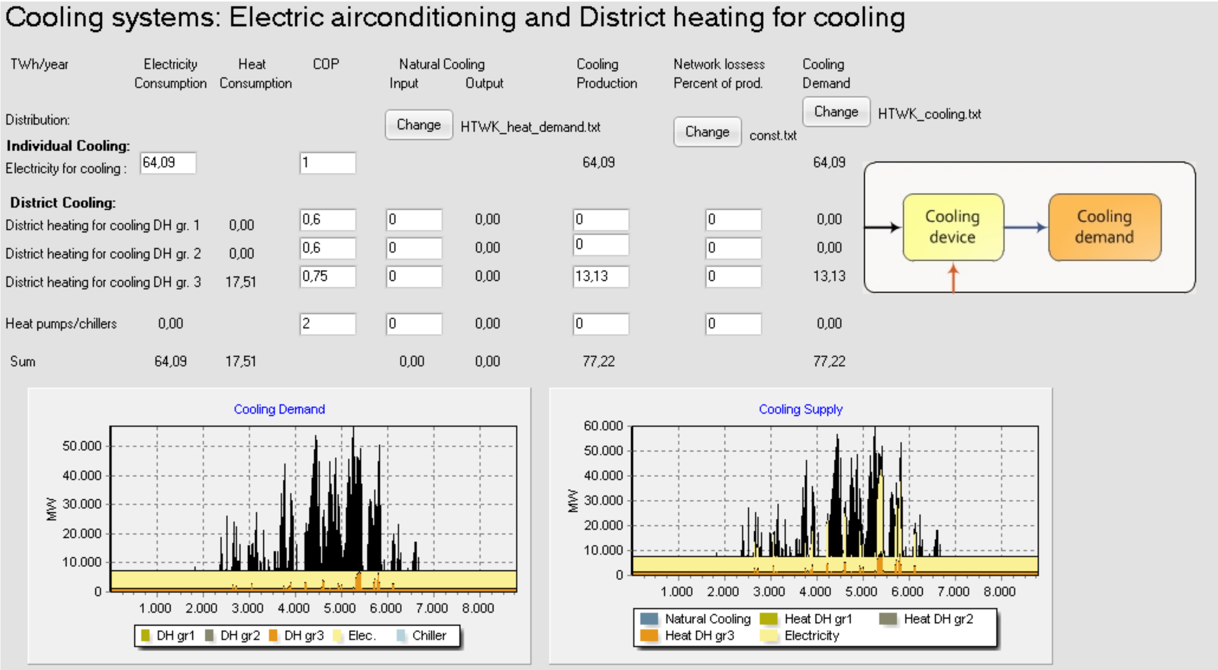


Figure 5: Cooling Demand

Electricity for Cooling – Electricity Consumption	64,09 TWh/a
	The cooling demand corresponds approximately 14 % of the electricity consumption in Germany. 83 % of this value is accounted for applications that run on electricity. The calculation was based on a study of the VDMA. [14] $$D_{Cool} \quad = e_{e,c} \cdot D_{EA} \cdot e_{a,e}$$ D_{Cool} Annual electricity demand for cooling $e_{e,c}$ Percentage of refrigeration technology on the total electricity consumption D_{EA} Actual electricity demand $e_{a,e}$ Percentage of refrigeration applications that run on electricity $$D_{Cool} \quad = 0{,}14 \cdot 551{,}581\ TWh \cdot 0{,}83$$ $$= 64{,}09\ TWh$$

Electricity for cooling – COP	1,0
	This entry is based on a mean value of different technologies of the paper "Basics for Absorption Chillers" from Vincent A. Sakraida. [15]
	The distributions for natural cooling and cooling demand are "HTWK_ heat_demand.txt" and "HTWK_cooling.txt". It was generated with data provided by the "Wärmeverteilung 2015" [8]. The table is a result of a lecture at the "HTWK Leipzig" and was created by mister T. Radisch.
District heating for cooling DH gr. 3 – COP	0,75
	This entry is based on the paper "Basics for Absorption Chillers" from Vincent A. Sakraida. [15]
District heating for cooling DH gr. 3 – Cooling Production	13,13 TWh/year
	The cooling demand corresponds 14 % of electricity consumption in Germany. 17 % of this value accounts for non-electrical energy consumption. The calculation was based on a study of the VDMA. [14] $C_{Cool3} = e_{e,c} \cdot D_{EA} \cdot e_{a,n}$ C_{Cool3} Annual demand for cooling in DH group 3 $e_{e,c}$ Percentage of refrigeration technology of electricity consumption D_{EA} Actual electricity demand $e_{a,n}$ Percentage of refrigeration applications that don't run on electricity $C_{Cool3} = 0{,}14 \cdot 551{,}581\ TWh \cdot 0{,}17 = 13{,}13\ TWh$

4.4 Industry and Fuel

The primary energy that's consumed by the industry for providing process heat and fuelling industrial CHP-processes is defined in the "Industry and Other Fuel Consumption" tab sheet. This excludes the fuel for power and heat plants. Primary energy that is not accounted for energetic use, is defined in this tab sheet as well. The figure down below shows the inputs for this model. Please note that the fuel losses are added to the Industry-input, because we were not able to enter the absolute or relative values in this column.

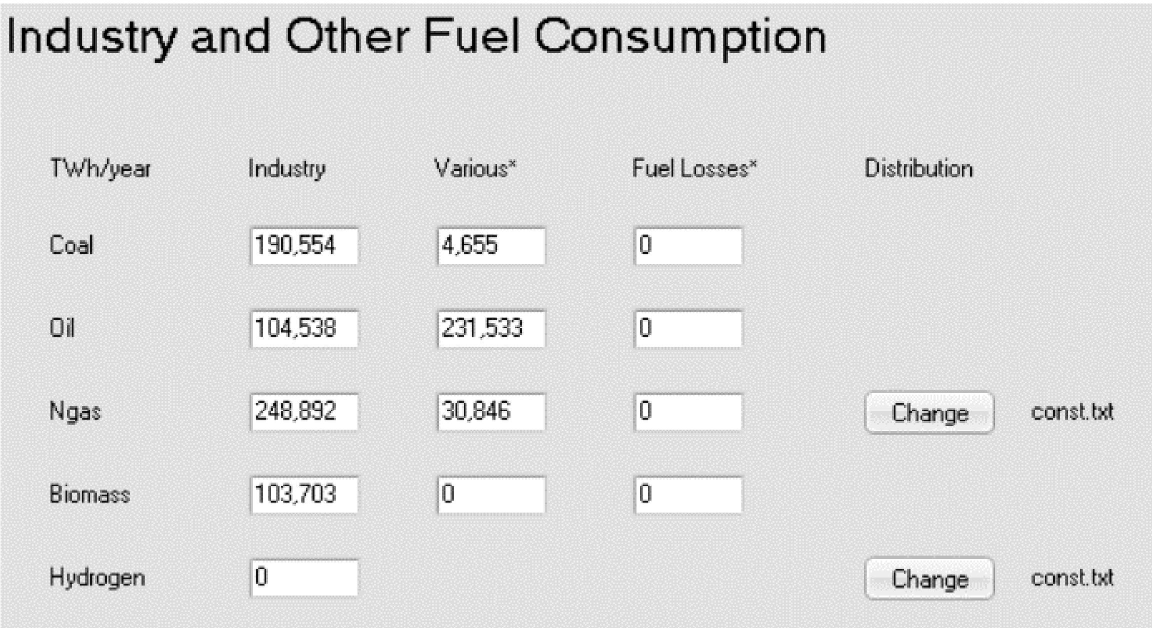


Figure 6: Industry and Fuel

Coal – Industry	190,554 TWh/a
	This input is calculated by adding the energy demands of hard coal and lignite in the industrial sector. The different values are provided by the table "AGEB Energiebilanz" [9]. They can be found in the cells C67 to J67 added with E24. $$F_{I-coal} = 599145\ TJ$$ F_{I-coal} annual coal demand for Industry

	The value of the coal losses is also included in this category, because we were not able to accurately enter a value in the losses column. It represents the fuel lost and energy used during the transformation of coal and lignite into secondary energy carriers like briquettes. It's provided by the table "AGEB Energiebilanz" [9]. The value is calculated as follows: $F_{L-coal} = F_{hc,trans} + F_{lignite,trans} + E_{lignite,trans}$ F_{L-coal} annual coal losses $F_{hc,trans}$ annual hard coal transformation difference $F_{lignite,trans}$ annual lignite transformation difference $E_{lignite,trans}$ annual energy used for lignite transformation $F_{hc,trans}$ is the difference between C16 and E39 $F_{lignite,trans}$ is the difference between G16 and I28 added with the difference between G17 and H29 to I29 $E_{lignite,trans}$ can be found by adding the cells G47 to J47 $F_{L-coal} = 78857\ TJ - 857\ TJ + 8849\ TJ$ $= 86849\ TJ$ $F_{total-coal} = F_{I-coal} + F_{L-coal}$ $= 599145\ TJ + 86849\ TJ$ $= 685994\ TJ = 190{,}554 \frac{TWh}{a}$
Coal – Various	4,655 TWh/a
	This is the total value of the hard coal and lignite demands for non-energy usage. It can be found in the table "AGEB Energiebilanz" [9] in the cells C50 to J50

Oil – Industry	104,538 TWh/a
	This input is provided by the table "AGEB Energiebilanz" [9]. It can be found by adding the cells K67 to U67 with R16. $F_{I-oil} \quad = 85117\ TJ$ F_{I-oil} annual oil demand for Industry The value of the oil losses is also included in this category, because we were not able to accurately enter a value in the losses column. It represents the fuel lost and energy used during mineral oil processing and other transformation processes. It's also provided by the table "AGEB Energiebilanz" [9]. The value is calculated as follows: $F_{L-oil} \quad = F_{oil,trans} + E_{oil,trans}$ F_{L-oil} annual oil losses $F_{oil,trans}$ annual oil transformation difference $E_{oil,trans}$ annual energy used for oil transformation $F_{oil,trans}$ is the difference between K25 to U26 and K39 to U39 $E_{oil,trans}$ can be found bey adding the cells K47 to U47 $F_{L-oil} \quad = 78780\ TJ + 212440\ TJ$ $= 291220\ TJ$ $F_{total-oil} \quad = F_{I-oil} + F_{L-oil}$ $= 85117\ TJ + 291220\ TJ$ $= 376337\ TJ = 104{,}538 \frac{TWh}{a}$

Oil – Various	231,53 TWh/a
	This is the total value of the oil demand for non-energy usage. It can be found in the table “AGEB Energiebilanz” [9] in the cells K50 to U50.
Ngas – Industry	248,892 TWh/a
	This value represents the Ngas demand in the industrial sector as well as the usage of Ngas in facilities for renewable energies. The inputs can be found in the table “AGEB Energiebilanz” [9] in the cells X21 to Y21 and X67 to Y67. $F_{I-Ngas} = 824763\ TJ$ F_{I-Ngas} annual Ngas demand for Industry The value of the Ngas losses is also included in this category, because we were not able to accurately enter a value in the losses column. The losses are defined by the usage of this energy source for transformation processes of other energy carriers and for transportation losses. The values are also provided by “AGEB Energiebilanz” [9] and can be calculated by adding the cells X47 to Y48. $F_{L-Ngas} = 71247\ TJ$ F_{L-Ngas} annual Ngas losses $F_{total-Ngas} = F_{I-Ngas} + F_{L-Ngas}$ $= 824763\ TJ + 71247\ TJ$ $= 896010\ TJ = 248{,}892 \frac{TWh}{a}$
Ngas – Various	30,846 TWh/a
	This is the annual value of the Ngas demand for non-energy usage. It can be found in the table “AGEB Energiebilanz” [9] in the cell X50.

Biomass – Industry	103,703 TWh/a
	This value represents the Biomass demand in the industrial sector as well as the usage of Biomass in facilities for renewable energies. The inputs can be found in the table "AGEB Energiebilanz" [9] in the cells AA21 and AA67. $$F_{I-bio} = 350483\ TJ$$ F_{I-bio} annual biomass demand for Industry The value of the biomass losses is also included in this category, because we were not able to accurately enter a value in the losses column. The biomass losses are defined by the usage of this energy source for transformation processes of other energy carriers and for transportation losses. The values are also provided by "AGEB Energiebilanz" [9]. The Losses can be calculated by adding AA47 and AA48. $$F_{L-bio} = 22849\ TJ$$ F_{L-bio} annual biomass losses $$F_{total-bio} = F_{I-bio} + F_{L-bio} = 350483\ TJ + 22849\ TJ = 373332\ TJ = 103{,}703\ \frac{TWh}{a}$$

4.5 Transport

The tab sheet “Demand: Transport” describes the different fuel Inputs like jet petrol, diesel, petrol, natural gas, and LPG in the transport sector. The completed entry is illustrated in the figures below.

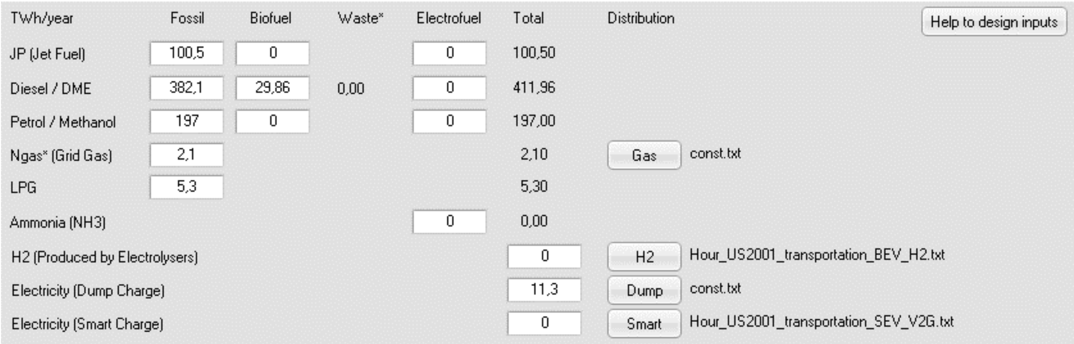


Figure 7: Transport Demand

JP (Jet Fuel) - Fossil	100,5 TWh/a
	In “AGEB Energiebilanz” [9] line 72 column N the fossil fuel input of JP is given. The value in TWh is calculated by dividing 361651 TJ by 3600.
Diesel / DME – Fossil	382,1 TWh/a
	In “AGEB Energiebilanz” [9] line 72 column O the fossil fuel input of diesel is given. The value in TWh is calculated by dividing 1375430 TJ by 3600.
Diesel / DME – Biofuel	29,86 TWh/a
	In “AGEB Energiebilanz” [9] line 72 column AA the biofuel input of diesel is given. The value in TWh is calculated by dividing 107506 TJ by 3600.
Petrol / Methanol – Fossil	197 TWh/a
	In “AGEB Energiebilanz” [9] line 72 column L the fossil fuel input of petrol/methanol is given. The value in TWh is calculated by dividing 709225 TJ by 3600
Ngas (Grid Gas) – Fossil	2,1 TWh
	In “AGEB Energiebilanz” [9] line 72 column X the fossil fuel input of Ngas is given. The value in TWh is calculated by dividing 7407 TJ by 3600.

LPG – Fossil	5,3 TWh
	In “AGEB Energiebilanz” [9] line 72 column S the fossil fuel input of LPG is given. The value in TWh is calculated by dividing 18963 TJ by 3600.

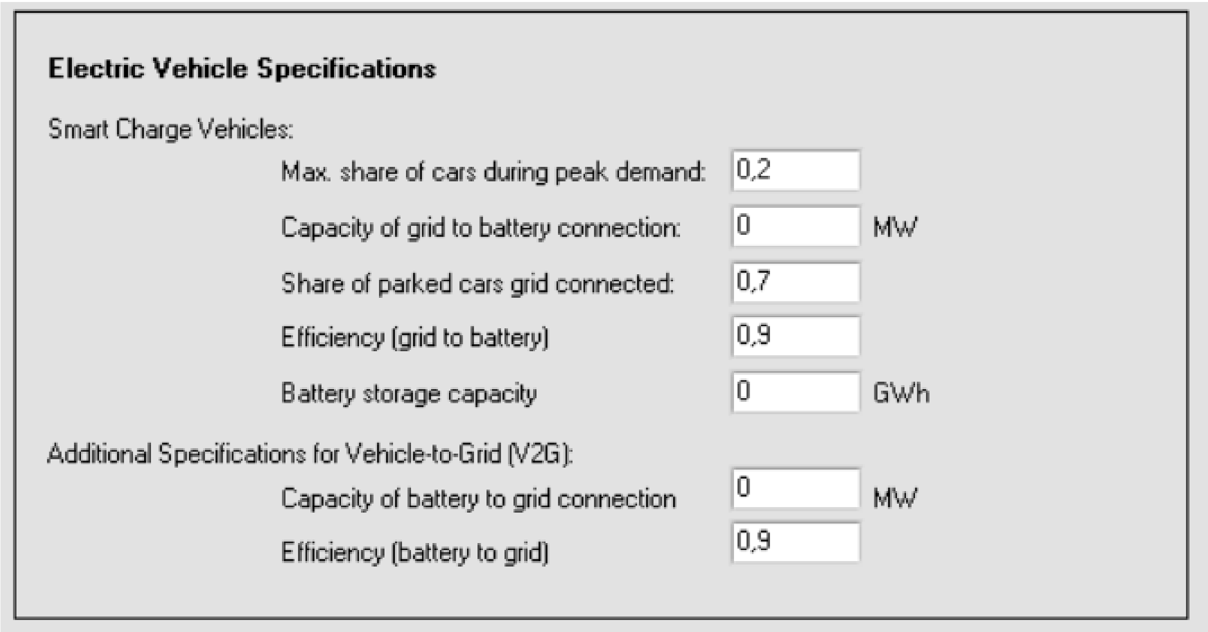


Figure 8: Electric Vehicle Specifications

Electricity (Dump Charge) – Total	11,3 TWh
	In “AGEB Energiebilanz” [9] line 72 column AD the fuel input of electricity (dump charge) is given. The value in TWh is calculated by dividing 40605 TJ by 3600.

In this tab sheet is also the opportunity to display the total numbers of km per year during the process. It is given with 737 billion km/year. According to research of “Kraftfahrt-Bundesamt” the number in Germany in 2015 was about 716 billion km/year [16]. Therefore, the simulation is close to reality.

4.6 Desalination

The tab sheet “Demand: Desalination” describes the demand in connection with desalination and storage as well as different used pumps. Fresh water demand from desalination and storage is for Germany not relevant. The filled tab sheet is shown in the Figure 9 below.

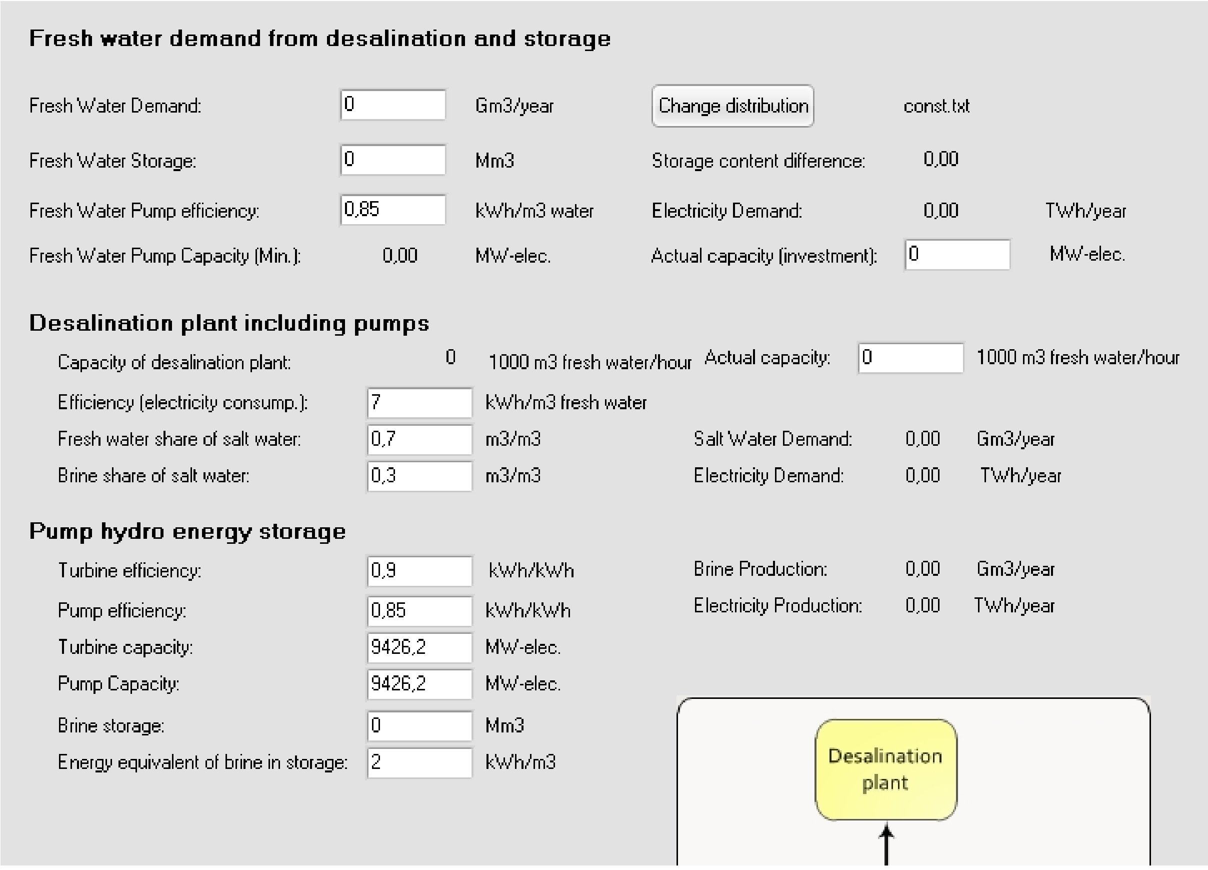


Figure 9: Desalination Demand

Pump hydro energy storage – Turbine capacity	9426,2 MW
	This value bases on the table “Kraftwerksliste 2015” [17]
Pump hydro energy storage – Pump capacity	9426,2 MW
	This value bases on the table “Kraftwerksliste 2015” [17]

5 Supply

5.1 Heat and Electricity

The “Heat and Electricity” tab sheet contains the largest amount of the heat supply for the model. The heat is provided through heat and CHP plants. Therefore, a portion of the electricity supply can also be found here. The tab sheet is subdivided into the three categories Boilers, CHP and Industrial CHP. They are shown on the figures below.

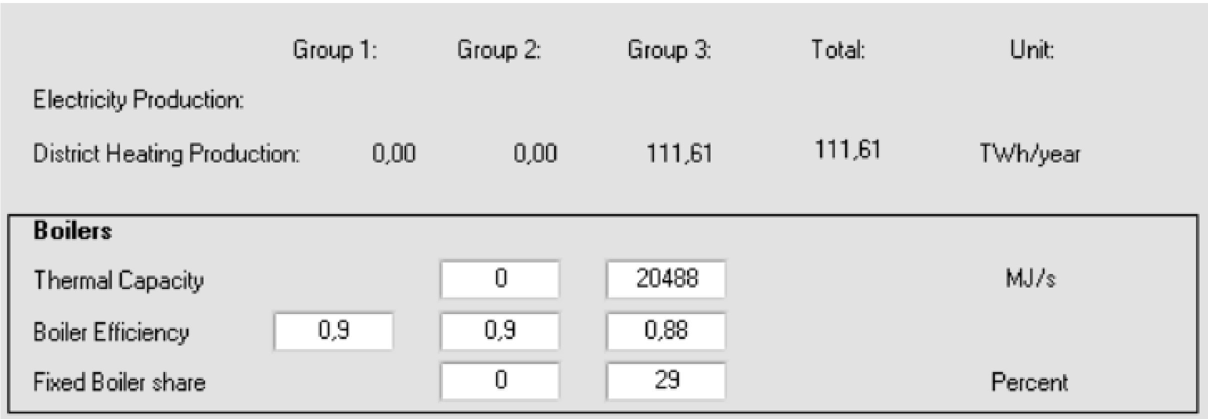


Figure 10: Boilers

Thermal Capacity – Group 3	20488 MJ/s
	This value can be found in the “AGFW Hauptbericht 2015” [13] on page 18.
Boiler Efficiency – Group 3	0,88
	This value was calculated as the quotient of the heat production and the total fuel input. Both values can be found in the “AGFW Hauptbericht 2015” [13] on page 18. $$\rho_{B3} = \frac{Q_B}{F_{B,total}}$$ ρ_{B3} thermal efficiency of boilers in district heating group 3 Q_B annual heat production from boilers of heating group 3 $F_{B,total}$ annual total fuel input in boilers of heating group 3

	$\rho_{B3} = \frac{36023\,TJ}{41142\,TJ} = 0{,}88$
Fixed Boiler share – Group 3	29%
	The fixed boiler share was used to adjust the heat production of the boilers through their fuel consumption. The fuel consumption can be found in part 3.4.

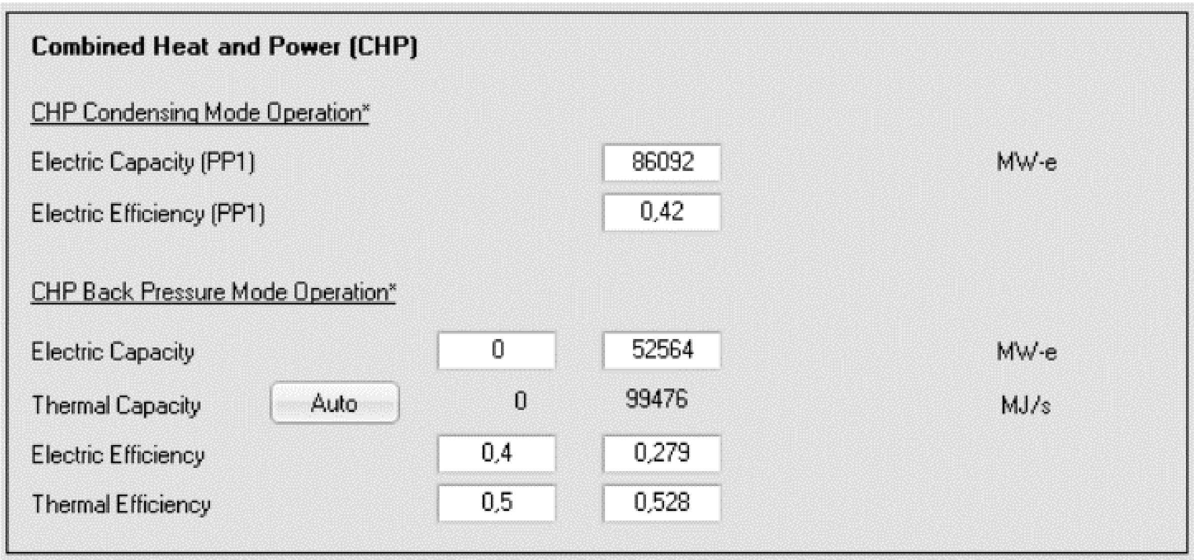


Figure 11: Combined Heat and Power

Electric Capacity (PP1)	86092 MW
	This value can be found in the table "Kraftwerksliste 2015" [17]. It's the total value of the column Q with the following filter settings: • Column I: everything but empty lines • Column J: everything but "Endgültig Stillgelegt 2011" to "Endgültig Stillgelegt 2014" • Column K: everything but "Kernenergie", "Laufwasser", "Pumpspeicher", "Solare Strahlungsenergie", "Speicherwasser (ohne Pumpspeicher)", "Windenergie (Offshore-Anlage)" and "Windenergie (Onshore-Anlage)"

Electric Efficiency (PP1)	0,42
	approximated electric efficiency for 2015, read off the diagram "Entwicklung des durchschnittlichen Brutto-Wirkungsgrades fossiler Kraftwerke" [18]
Electric Capacity – Group 3	52564 MW
	This value can be found in the table "Kraftwerksliste 2015" [17]. It's the total value of the column Q with the following filter settings: • Column I: everything but empty lines • Column J: everything but "Endgültig Stillgelegt 2011" to "Endgültig Stillgelegt 2014" • Column K: everything but "Kernenergie", "Laufwasser", "Pumpspeicher", "Solare Strahlungsenergie", "Speicherwasser (ohne Pumpspeicher)", "Windenergie (Offshore-Anlage)" and "Windenergie (Onshore-Anlage)" • Column P: only "Ja"
Electric Efficiency – Group 3	0,279
	This value was calculated as the quotient of the electricity production and the total fuel input. Both values can be found in the "AGFW Hauptbericht 2015" [13] on page 20. $\mu_{CHP3} = \frac{E_{CHP3}}{F_{CHP3,total}}$ μ_{CHP3} electric efficiency of CHP in district heating group 3 E_{CHP3} annual electricity production from CHP in heating group 3 $F_{CHP,total}$ annual total fuel input in CHP-plants of heating group 3 $\mu_{CHP3} = \frac{26993\, GWh}{348559\, TJ} = \frac{97174\, TJ}{348559\, TJ}$ $= 0{,}279$

Thermal Efficiency – Group 3	0,528
	This value was calculated as the quotient of the heat production and the total fuel input. Both values can be found in the “AGFW Hauptbericht 2015” [13] on page 20. $\rho_{CHP3} = \frac{Q_{CHP3}}{F_{CHP3,total}}$ ρ_{CHP3} thermal efficiency of CHP in district heating group 3 Q_{CHP3} annual heat production from CHP in heating group 3 $F_{CHP3,total}$ annual total fuel input in CHP of heating group 3 $\rho_{CHP3} = \frac{183926\,TJ}{348559\,TJ} = 0{,}528$

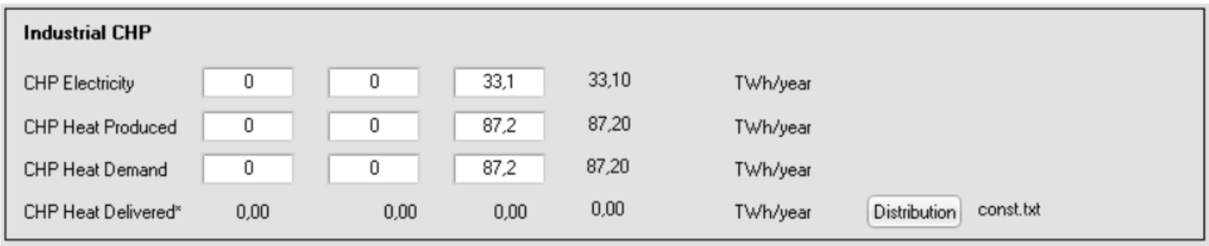


Figure 12: Industrial CHP

CHP Electricity – Group 3	33,1 TWh/a
	This value can be found in the article “Kraft-Wärme-Kopplung 2008 bis 2016 – Einfluss der Bilanzgrenze” [19] in the table “Strom- und Wärmeerzeugung aus Kraft-Wärme-Kopplung, 2008 bis 2016 in TWh”.
CHP Heat Produced – Group 3	87,2 TWh/a
	This value can be found in the article “Kraft-Wärme-Kopplung 2008 bis 2016 – Einfluss der Bilanzgrenze” [19] in the table “Strom- und Wärmeerzeugung aus Kraft-Wärme-Kopplung, 2008 bis 2016 in TWh”.

CHP Heat Demand – Group 3	87,2 TWh/a
	This value is an assumption. Industrial CHP don't deliver heat for the district heating systems in Germany.

5.2 Central Power Production

In the tab sheet "Supply: Central Power Production" is defined which input is from renewable energy source, from nuclear power or from hydro power. The filled tab is shown in Figure 13.

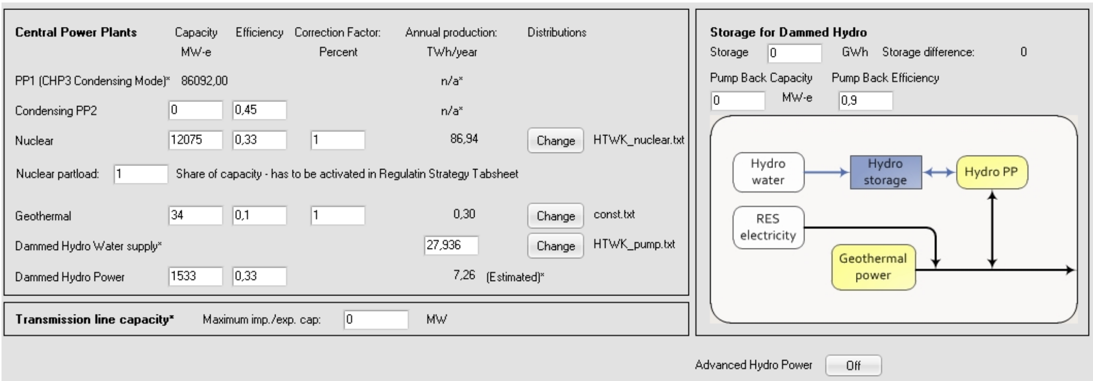


Figure 13: Central Power Production Supply

Nuclear – Capacity	12075 MW
	The value of the nuclear power capacity is proven by the table "Kraftwerksliste 2015" [17]
Geothermal – Capacity	34 MW
	The value of the geothermal power capacity is proven by the table "Kraftwerksliste 2015" [17]
Geothermal – Efficiency	0,1
	The Efficiency for the calculation of the annual amount of fuel is given by the homepage of Lexicon of Sustainability. [20]
	27,936 TWh/year

Dammed Hydro Water supply – Annual production	The value is calculated with Agorameter. It results from the sum of the column "pump" and is divided by the efficiency. [4]
Dammed Hydro Power - Capacity	1533 MW
	The value of the dammed hydro power capacity is proven by the table "Kraftwerksliste 2015" [17]
	The distributions for nuclear power and dammed hydro power are "HTWK_ nuclear.txt" and "HTWK_pump.txt". They are generated with data provided by the Agorameter. [4]

5.3 Variable Renewable Electricity

The tab sheet "Supply: Variable Renewable Electricity" gives the electricity production from the different renewable energy sources, which will be calculated with the capacity and the specified hourly distribution. Figure 14 shows the filled tab sheet.

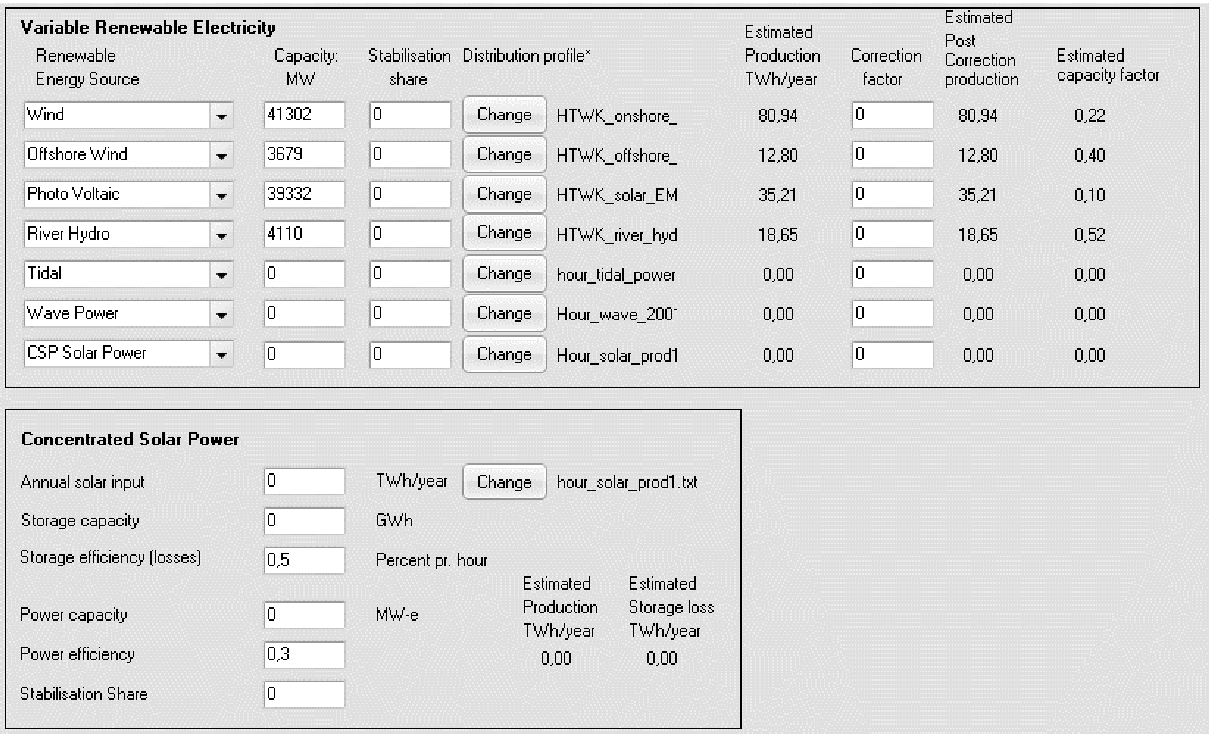


Figure 14: Variable renewable electricity supply

Wind – Capacity	41302 MW
	The capacity of wind in Germany in 2015 is given by the table “Kraftwerksliste 2015” [17]
Offshore Wind – Capacity	3679 MW
	The capacity of offshore wind in Germany in 2015 is given by the table “Kraftwerksliste 2015” [17]
Photo Voltaic – Capacity	39332 MW
	The capacity of photovoltaic in Germany in 2015 is given by a report from Volker Quaschning. [21]
River Hydro – Capacity	4110 MW
	The capacity of river hydro in Germany in 2015 is given by a report from “Bundesverband deutscher Wasserkraftwerke”. [22]
	The hourly distributions for wind-, photovoltaic-, offshore wind- and river hydro-power are “HTWK_onshore_EMHIRES.txt”, “HTWK_offshore_ EMHIRES.txt”, “HTWK_solar_EMHIRES.txt”, and “HTWK_river_hydro.txt”. They are generated with data provided by [34] and [4]. Alternatively, you can use the NINJA distributions [35] or the 2015 distributions [4]

5.4 Heat Only

The “Supply: Heat Only” tab sheet defines the heat supply from solar thermal, compression heat pumps, geothermal absorption heat pumps and from industrial excess heat. The used values are shown in figures below.

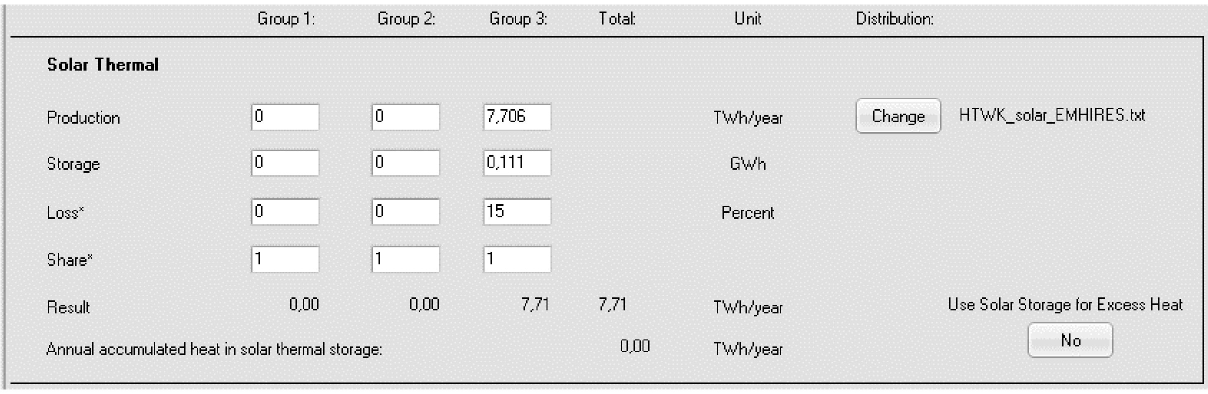


Figure 15: Solar Thermal

Solar Thermal: Production – Group 3	7,706 TWh/a
	The value for solar thermal production bases on a report from the "Argentur für erneuerbare Energien". [23]
Solar Thermal: Storage – Group 3	0,111 GWh
	The value for usable solar storage capacity in Germany bases on a report about solar energy storage monitoring. [24]
Solar Thermal: Loss – Group 3	0,15
	The value for the loss when storing solar energy was calculated from the mean value of different solar storage content. [25]
	The hourly distribution for solar thermal production is "HTWK_ solar_EMHIRES.txt". It's generated with data provided by [34]. Alternatively, you can use "HTWK_ solar_NINJA.txt" [35] or ""HTWK_ solar_2015.txt" [4].

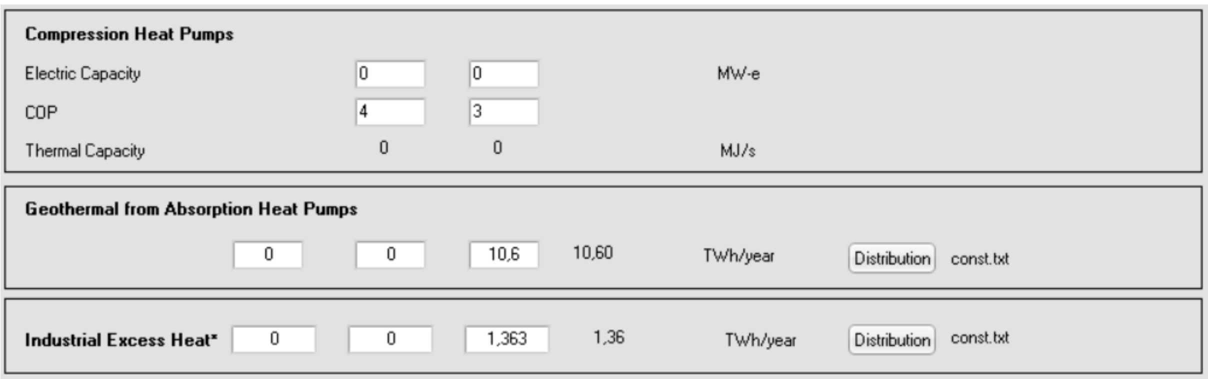


Figure 16: Heat Pumps and Industrial Excess Heat

Geothermal from Absorption Heat Pumps – Group 3	10,6 TWh/a
	The value for the geothermal supply from absorption heat pumps adds up to 1 TWh deep-geothermal energy and 9,6 TWh near-surface geothermal energy. [26]
Industrial Excess Heat – Group 3	1,363 TWh/a
	In “AFGW-Jahresbericht 2015” page 10 the industrial excess heat is given with 2% of heat network feed-in. The value in TWh is calculated by dividing 4907 TJ by 3600. [13]

5.5 Fuel Distribution

This tab sheet contains information about the fuel input for the heat and CHP plants described in chapter 4.1. The values are shown in the figure down below.

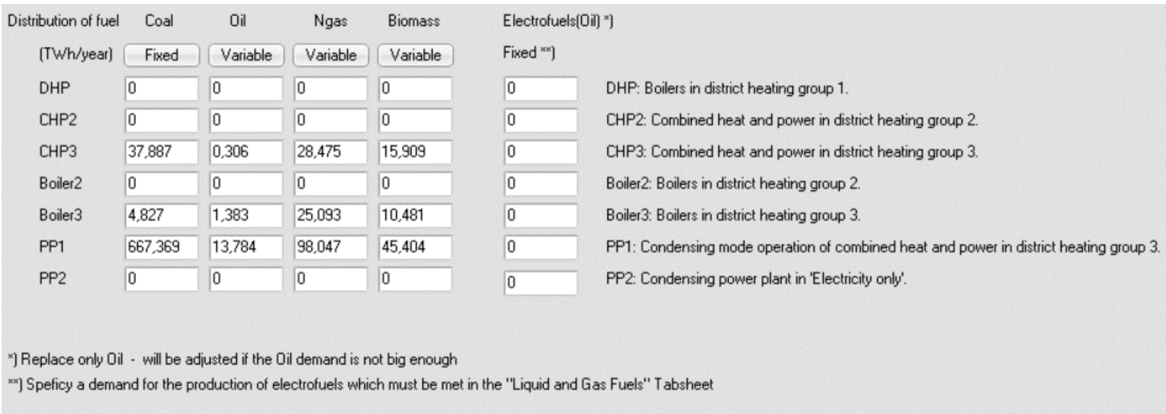


Figure 17: Fuel Distribution

CHP3 – Coal	37,887 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells C22 to J22.
CHP3 – Oil	0,306 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells K22 to U22.
CHP3 – Ngas	28,475 TWh/a

	The value is provided by the table “AGEB Energiebilanz” [9] in the cells X22 to Y22.
CHP3 – Biomass	15,909 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cell AA22.
Boiler3 – Coal	4,827 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells C23 to J23.
Boiler3 – Oil	1,383 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells K23 to U23.
Boiler3 – Ngas	25,093 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells X23 to Y23.
Boiler3 – Biomass	10,481 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cellAA23.
PP1 – Coal	667,369 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells C18 to J19.
PP1 – Oil	13,784 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells K18 to U19.
PP1 – Ngas	98,047 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells X18 to Y19.
PP1 – Biomass	45,404 TWh/a
	The value is provided by the table “AGEB Energiebilanz” [9] in the cells AA18 and AA19.

Please note that the fuel consumption for coal is defined as “Fixed” due to its big impact on the CO_2 emission. If this is not done, the coal consumption will decrease around 60 TWh because of the relative calculation method of EnergyPLAN.

5.6 Waste

In the tab sheet "Supply: Waste" biomass energy is defined, which has to be burned regularly. The waste is divided into three district heating groups. The following figure shows the used values.

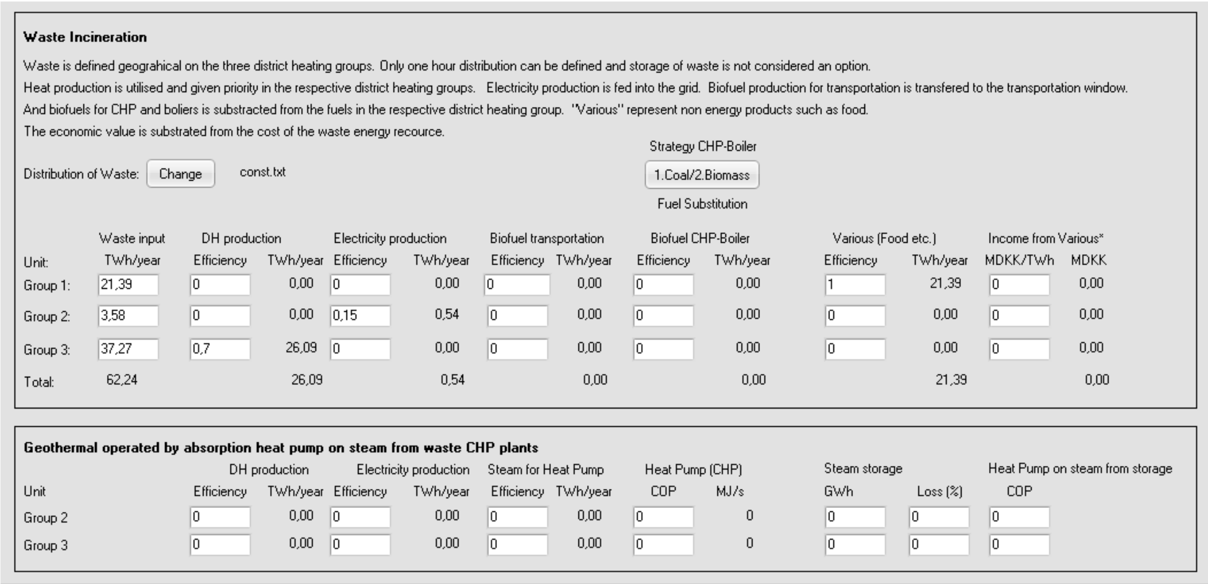


Figure 18: Waste supply

Waste Incineration: Group 1 – Waste Input	21,39 TWh/a
	The value is from “AGEB Energiebilanz” [9] from non-renewable waste into column AC line 47 and 49.
Waste Incineration: Group 1 – DH production Efficiency	0
	No combustion takes place, but industrial use as in the “Industry and Fuel” tab sheet.
Waste Incineration: Group 1 – Various Efficiency	1
	Full use is assumed.
Waste Incineration: Group 2 – Waste Input	3,58 TWh/a
	The value is from “AGEB Energiebilanz” [9] in column AC line 19.

Waste Incineration: Group 2 – Electricity production Efficiency	0,15
	The value is proven by a scientific report from "Bund für Umwelt und Naturschutz" Germany. [27]
Waste Incineration: Group 3 – Waste Input	37,27 TWh/a
	The value is from a scientific report by "Bund für Umwelt und Naturschutz" Germany. [27]
Waste Incineration: Group 3 – DH production Efficiency	0,7
	The value is proven by a scientific report from "Bund für Umwelt und Naturschutz" Germany. [27]

5.7 Liquid and Gas Fuels

This tab sheet was not edited. All the inputs are the default values from EnergyPLAN. The exact values are listed in the tabulated documentation.

5.8 CO2

The “Supply: CO2”-tab sheet is used to define the CO_2-emissions of the different fuels and which CO_2 can be captured and stored by CCS. It is assumed that in Germany no CO_2 is captured by CCS. The filled tab sheet is shown in the Figure 19below.

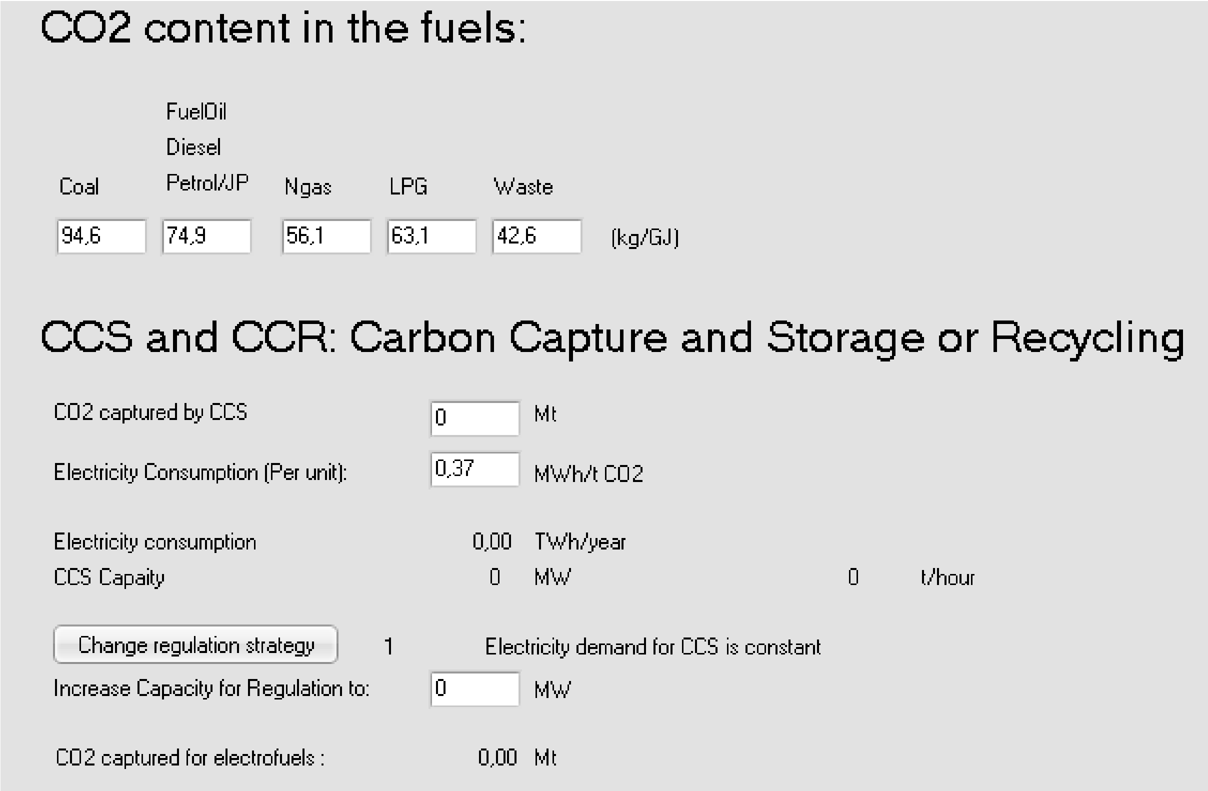


Figure 19: CO2 supply

CO2 content in the fuels – Coal	94,6 kg/GJ
	The value bases on a table by Volker Quaschning about specific carbon dioxide emissions of different fuels. [28]
CO2 content in the fuels – FuelOil, Diesel, Petrol/JP	74,9 kg/GJ
	The value bases on a table by Volker Quaschning about specific carbon dioxide emissions of different fuels. [28]
CO2 content in the fuels – Ngas	56,1 kg/GJ
	The value bases on a table by Volker Quaschning about specific carbon dioxide emissions of different fuels. [28]

CO2 content in the fuels – LPG	63,1 kg/GJ
	The value bases on a table by Volker Quaschning about specific carbon dioxide emissions of different fuels. [28]
CO2 content in the fuels – Waste	42,6 kg/GJ
	The value bases on a report by the “TU Wien” about carbon dioxide emissions of waste incineration plant. [29]

6 Balancing and Storage

6.1 Electricity

This tab sheet contains information about different rules to avoid critical excess electricity production and for electricity storages as well as for the grid stabilisation. The input for this model is shown in the figure below.

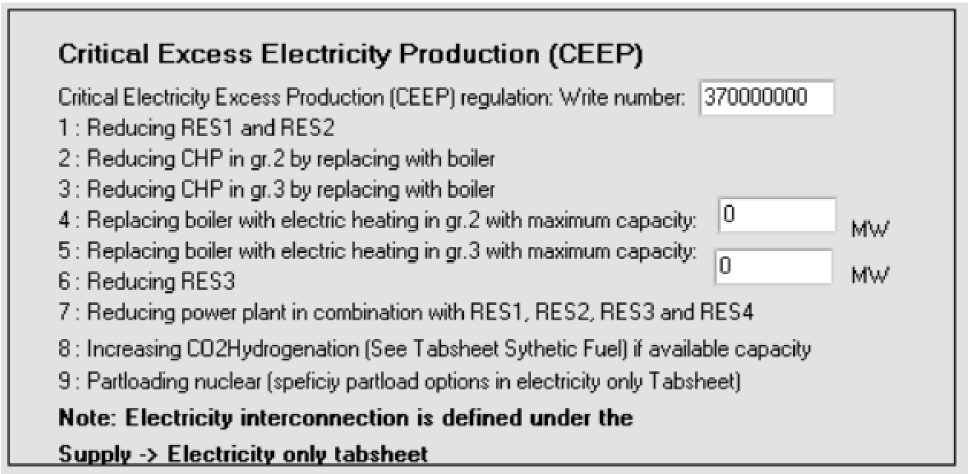


Figure 20: CEEP

CEEP regulation	37
	This input is an attempt to define rules for prioritized energy supply. Out of the given options renewable energy sources should be preferred to conventional power plants. In order to activate the boilers for district heating, we applied rule three to reduce the capacity of the CHPs.

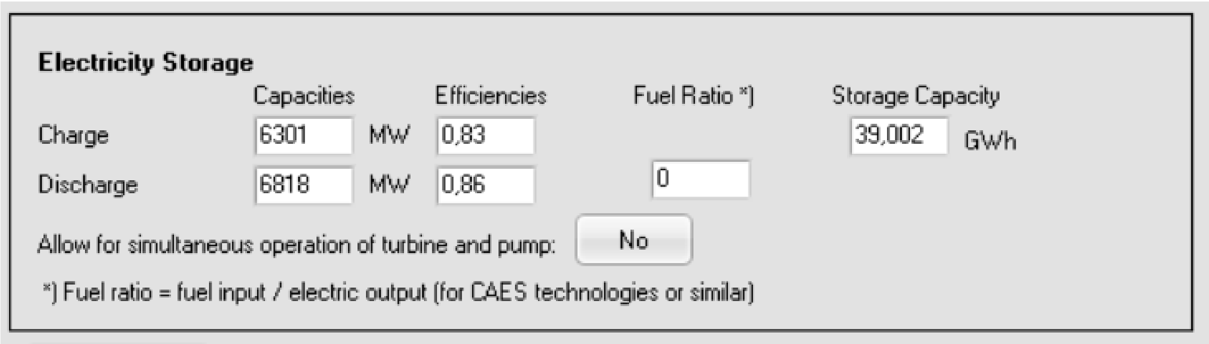


Figure 21: Electricity Storage

Charge – Capacities	6301 MW
	This value can be found in the table "Elektrospeicher 2015" [30] in the cell C87. The table is a result of a lecture at the "HTWK Leipzig" and was created by Mister T. Radisch.
Charge – Efficiencies	0,83
	This value can be found in the table "Elektrospeicher 2015" [30] in the cell C90. The table is a result of a lecture at the "HTWK Leipzig" and was created by Mister T. Radisch.
Charge – Storage Capacity	This value can be found in the table "Elektrospeicher 2015" [30] in the cell C88. The table is a result of a lecture at the "HTWK Leipzig" and was created by Mister T. Radisch.
Discharge – Capacities	6818 MW
	This value can be found in the table "Elektrospeicher 2015" [30] in the cell C86. The table is a result of a lecture at the "HTWK Leipzig" and was created by Mister T. Radisch.
Discharge – Efficiencies	0,86
	This value can be found in the table "Elektrospeicher 2015" [30] in the cell C89. The table is a result of a lecture at the "HTWK Leipzig" and was created by Mister T. Radisch.

The with EnergyPLAN V15 added Rockbed Storages were not utilized.

6.2 Thermal

The “Thermal” tab sheet provides information about the thermal storage capacities in Germany. The values are shown in the figure below.

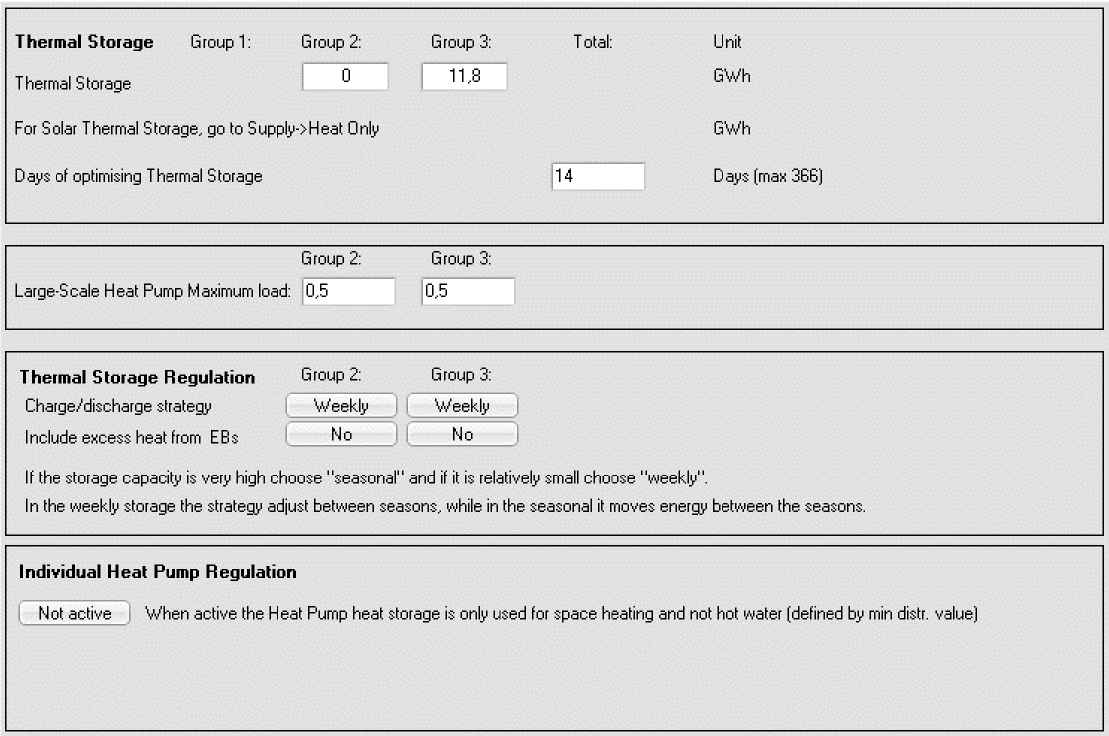


Figure 22: Thermal Storage

Thermal Storage – Group 3	11,8 GWh
	This value can be found in the table “Thermische Speicher 2015” [30] in the cell D34. The table is a result of a lecture at the “HTWK Leipzig” and was created by Mister T. Radisch.

6.3 Liquid and Gas Fuel

This tab sheet contains the information of different fuel storages. The input values are shown below.

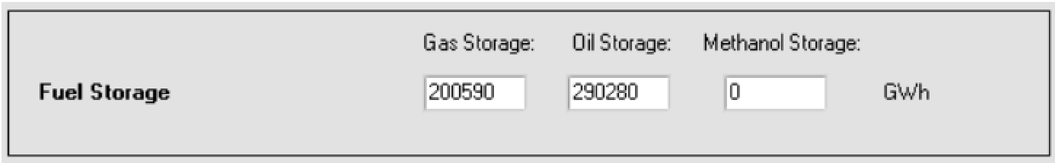


Figure 23: Fuel Storage

Gas Storage	200590 GWh
	This value can be found in the table “Treibstoffspeicher 2015” [30] in the cell C18. The table is a result of a lecture at the “HTWK Leipzig” and was created by Mister T. Radisch.
Oil Storage	290280 GWh
	This value can be found in the table “Treibstoffspeicher 2015” [30] in the cell C28. The table is a result of a lecture at the “HTWK Leipzig” and was created by Mister T. Radisch.

7 Cost

This category contains the different cost of the energy system. All values were taken from the “Papermodel” for Germany in consent with EnergyPLAN. For further information about these values, please contact EnergyPLAN or the person listed on the website. The values are listed in the tabulated documentation.

8 Simulation

This tab sheet shows the possible strategies to define the simulation rules. The chosen strategies can be seen in the figure below:

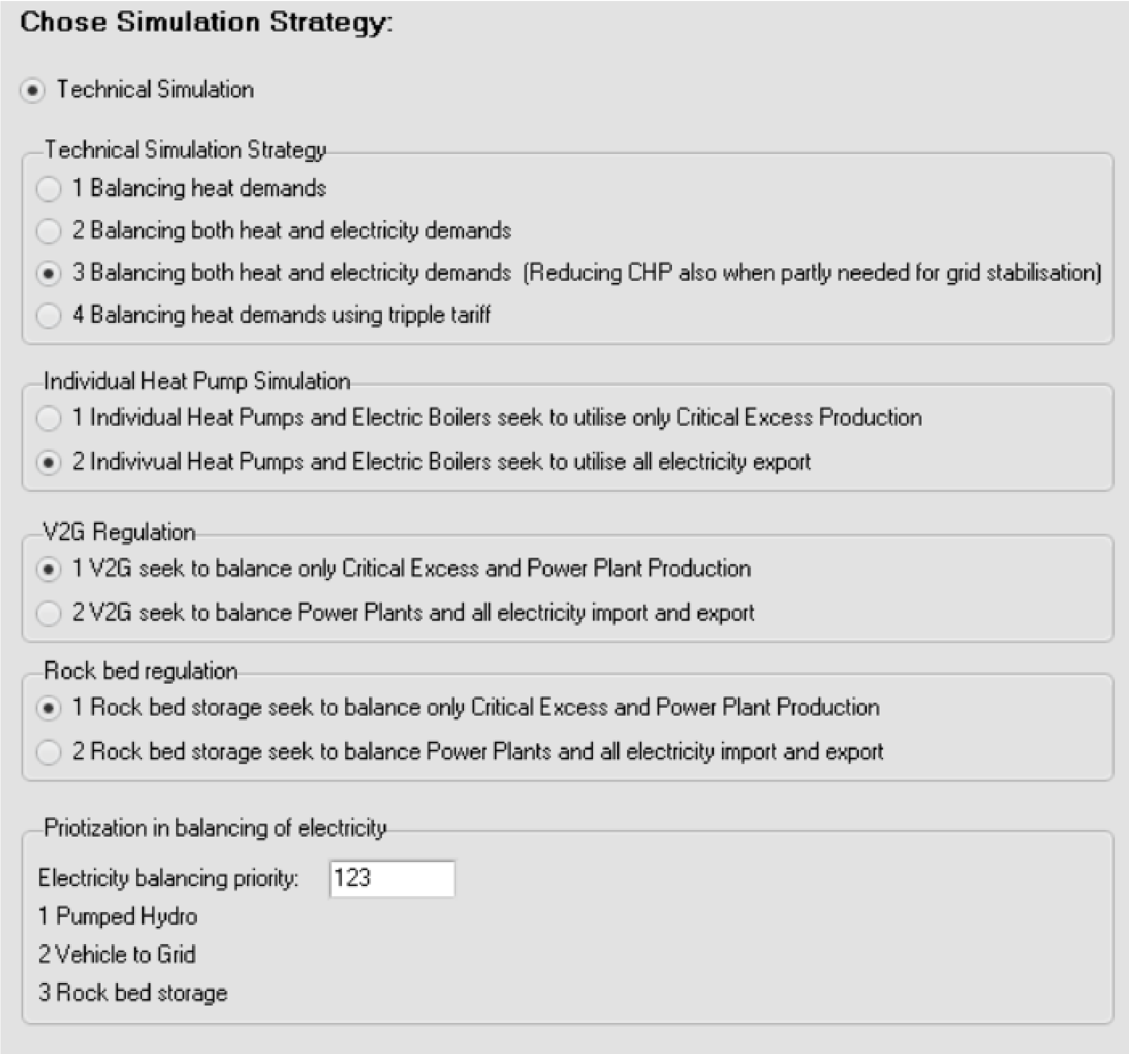


Figure 24: Simulation Strategies

9 Simulation results

The results of the simulation can be found in the annex. They were calculated with version 14.2 of EnergyPLAN and the 2015 distributions. To enable a comparison of the simulated parameters with the real values, table 1 and 2 were created. They show the difference between the primary energy demand and the CO_2 emissions as absolute number and in percentage compared to the real values. The comparison values originate from the “Umweltbundesamt” and the “AG Energiebilanzen” [31, 32].

Table 1: Comparison of the Primary energy demand [32]

Energy Carrier	**Real Values**	**Simulation Results**	**Difference**	
	TWh	TWh	TWh	%
Coal	915	914	1	0,1
Oil	1248	1241	7	0,6
Ngas	769	754	15	2,0
Biomass	299	346 [1)]	-47	-15,7
Renewable	158	163	-5	-3,2
Nuclear	278	263	15	5,4
Others [2)]	63	0	63	-
Total	**3730**	**3681**	**49**	**1,3**

1) Includes non-renewable waste
2) Includes non-renewable waste and excess heat

As shown in table 1 above, the total difference of the primary energy demand is 49 TWh. The greatest deviation is the biomass demand. This originates from the definition of biomass in EnergyPLAN. Non-renewable waste is also considered as biomass. For the real values, this demand is defined as “Others”. In order to compare the biomass demand properly, the demand of the category “Others” must be included in the calculation, which results in a real biomass demand of 362 TWh. This value is 16 TWh or 4,4% greater than the simulated result.

Table 2: Comparison of the CO_2 emission [31]

Real Value	Simulation Result	Difference	
Mt	Mt	Mt	%
906,752 [1)]	809,027	97,725	10,8
840,062 [2)]	809,027	31,035	3,7
1) Total CO_2 emission of all sectors 2) Adjusted CO_2 emission without emissions of the agriculture sector			

The total CO_2 emission comparison result in a difference of around 98 Mt. This means that the simulation results are 11% lower compared to the real value. But it must be considered, that EnergyPLAN don't display the emissions of the agriculture sector. According to the "Umweltbundesamt", the equivalent emission of this sector is 66,69 Mt CO_2 [31]. In comparison to this adjusted value, the difference of the emission is only around 31 Mt.

10 Conclusion

The purpose of this paper is to create and document a simulation model of the energy systems of Germany in 2015 as realistic as possible. The focus was mainly on the energetic simulation, any cost data were adopted from other models for the sake of completeness. The comparison benchmarks for the validation and valuation of the model are the equivalent CO_2 emissions and the primary energy demands, which were provided by the "Umweltbundesamt" and the "Arbeitsgemeinschaft Energiebilanzen e.V.". This work doesn't assert a claim to completeness, therefore debates about the model are welcome.

As shown in the previous chapter, both comparison criterions hardly differ from the real values with a maximum deviation of 1,3% for the total primary energy demand and 3,7% for the adjusted total equivalent CO_2 emissions. Same applies for the individual fuel demand values. This accuracy should be questioned. Starting with the primary energy demand there could be two reasons for its slight deviation. The first thing is, that the boilers or heat plants work with a fixed share for the district heating demand. This was determined, because without this share the CHP plants would meet the total heat demand all by themselves, although there is a demonstrable proportion of boilers on the heating market in Germany. This would lead to an increased CHP-electricity and a decreased conventional power production, which in turn would distort the fuel consumption as well as the CO_2 emission. The second reason for the accuracy of the primary energy demand could be the fixed consumption of coal. Due to the calculation method of the fuel demand and the given input, the consumption of coal would decrease when the distribution is defined as variable by around 60 TWh as stated in the chapter "Fuel Distribution". This would distort the fuel balance and thereby the CO_2 emission. For the CO_2 emission itself there is little to discuss. It relies heavily on the fuel consumption itself, which was covered by the points before and on the emission factors. Latter can only be defined for a small amount of fuels and are basically average values for each of the primary energy carriers. Considering the structure of the program these basic factors are justified and appropriated.

Overall this model is suitable to simulate the energy systems and situations properly and more accurate than presumed. Same applies to EnergyPLAN itself, which is able to display the complex energy flows with relatively simple inputs and comprehensible operations.

Acknowledgement

This documentation is the scientific result of a master project at the University of Applied Science Leipzig under the direction of Prof. Dr.-Ing- Jens Schneider. It was developed by Martin Hafemann and Stefanie Penzel.

We thank our contact person at EnergyPLAN Kenneth Hansen for many helpful remarks and answering our questions. Our thanks also go to Agorameter for providing their database. We would also like to thank our fellow students, who have done various groundwork within the framework of the modul "Networked Energy Systems": Susanne Fischer, Marc Philipp Gönrich, Christian Hecht, Nils Hönemann, Thomas Hutzel, Robert Jonen, Hannes Lange, Christian Möller, Felix Plettner, Tom Radisch and Marcus Ruff.

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Annex

Input Germany_2015_HTWK.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	350,86	Fixed imp/exp.	57,64
Electric heating + HP	125,33	Transportation	11,30
Electric cooling	64,09	Total	609,22

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	111,61	111,61
Solar Thermal	0,00	0,00	7,71	7,71
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	103,90	103,90

Wind	41302 MW	71,29	TWh/year	0,00 Grid
Photo Voltaic	39332 MW	38,76	TWh/year	0,00 stabili-
Offshore Wind	3679 MW	8,28	TWh/year	0,00 sation
River Hydro	4110 MW	18,65	TWh/year	0,00 share
Hydro Power	1533 MW	7,26	TWh/year	
Geothermal/Nuclear	12109 MW	87,24	TWh/year	

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			4,00
Boiler		0		0,90	
Group 3:					
CHP	52564	99476	0,28	0,53	
Heat Pump	0	0			3,00
Boiler		20488		0,88	
Condensing	86092		0,42		

Heatstorage: gr.2: 0 GWh gr.3: 12 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 29,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,54
Gr.3:	33,10	0,00

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	370000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Distr. NamHTWK_electricity_prices.txt		
Addition factor	0,00	DKK/MWh
Multiplication factor	0,90	
Dependency factor	0,00	DKK/MWh pr. MW
Average Market Price	40	DKK/MWh
Gas Storage	200590	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	6301	39	0,83	
Hydro Turbine:	6818		0,86	
Electrol. Gr.2:	0	0	0,73	0,05
Electrol. Gr.3:	0	0	0,73	0,05
Electrol. trans.:	0	0	0,73	
Ely. MicroCHP:	0	0	0,73	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	679,60	2,10	0,00
Household	9,16	219,49	352,81	93,52
Industry	190,55	104,54	248,89	103,70
Various	4,66	231,53	30,85	0,00

Output

	District Heating: Demand Distr. heating MW	DH Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Electricity Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange: Payment Imp Million DKK	Exp
January	22837	162	4332	0	14103	0	0	4263	0	-22	41660	1286	666	0	23149	0	0	15584	834	11714	3829	7452	35361	100	0	0	0	0	0	0
February	23283	436	4332	0	14326	0	0	4263	0	-73	41736	1286	680	0	23635	0	0	12190	782	11764	3829	7570	39647	100	0	0	0	0	0	0
March	17546	824	4332	0	8633	0	0	4263	0	-505	46121	1286	500	0	17373	0	0	16237	803	10312	3829	4562	37369	100	0	0	0	0	0	0
April	14147	1299	4332	0	5325	0	0	4263	0	-1071	45813	1286	389	0	13522	0	0	15724	821	10051	3829	2814	33700	100	0	0	0	0	0	0
May	10484	1291	4332	0	1973	0	0	4263	0	-1374	47420	1286	273	0	9488	0	0	16967	884	9944	3829	1042	28359	100	0	0	0	0	0	0
June	9779	1413	4332	0	993	0	0	4263	0	-1221	49677	1286	234	0	8124	0	0	15920	891	9266	3829	525	32979	100	0	0	0	0	0	0
July	9616	1437	4332	0	757	0	0	4263	0	-1172	51284	1286	206	0	7155	0	0	17840	912	6839	3829	400	34403	100	0	0	0	0	0	0
August	9781	1353	4332	0	817	0	0	4263	0	-985	50261	1286	200	0	6951	0	0	14619	807	9605	3829	432	34487	100	0	0	0	0	0	0
September	10496	971	4332	0	2096	0	0	4263	0	-1165	50339	1286	276	0	9593	0	0	14615	788	10100	3829	1107	39142	100	0	0	0	0	0	0
October	14918	553	4332	0	6206	0	0	4263	0	-437	47935	1286	416	0	14479	0	0	10237	775	9056	3829	3279	42942	100	0	0	0	0	0	0
November	16347	328	4332	0	7738	0	0	4263	0	-314	50034	1286	462	0	16064	0	0	18686	812	10311	3829	4089	38906	100	0	0	0	0	0	0
December	17450	256	4332	0	8687	0	0	4263	0	-88	44461	1286	497	0	17268	0	0	18382	809	10337	3829	4590	35333	100	0	0	0	0	0	0
Average	14699	861	4332	0	5946	0	0	4263	0	-703	47239	1286	399	0	13870	0	0	15595	827	9932	3829	3142	36031	100	0	0	0	0	Average price	
Maximum	33899	5707	4332	0	25219	0	0	4263	0	0	71652	1286	1013	0	35223	0	0	48542	1533	12109	3829	13326	55764	100	0	0	0	0	(DKK/MWh)	
Minimum	6776	0	4332	0	0	0	0	4263	0	-4332	16258	1286	162	0	5617	0	0	2091	8	5659	3829	0	14225	100	0	0	0	0	40	39
TWh/year	129,12	7,56	38,05	0,00	52,23	0,00	0,00	37,44	0,00	-6,18	414,95	11,30	3,50	0,00	121,83	0,00	0,00	136,98	7,26	87,24	33,64	27,60	316,50		0,00	0,00	0,00	0,00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp	Corrected Net	CO2 emission (Mt): Total	Net
Coal	-	-	37,89	-	4,83	667,37	-	-	-	-	-	-	-	-	-	-	-	-	9,00	195,21	914,29	0,00	914,29	311,37	311,37
Oil	-	-	0,42	-	1,41	7,56	-	-	-	-	-	-	-	-	-	-	-	679,60	216,27	336,07	1241,32	0,00	1241,32	334,71	334,71
N.Gas	-	-	38,89	-	25,61	53,75	-	-	-	-	-	-	-	-	-	-	-	7,40	348,20	279,74	753,59	0,00	753,59	152,33	153,40
Biomass	-	-	21,73	-	10,70	24,89	-	-	62,24	-	31,10	-	-	-	-	-	-	-	91,95	103,70	346,31	0,00	346,31	9,55	9,55
Renewable	-	-	-	-	-	-	2,99	7,26	-	-	-	-	71,29	38,76	8,28	25,91	15,50	-	-	-	162,74	0,00	162,74	0,00	0,00
H2 etc.	-	-	0,00	-	0,00	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-29,86	-	-	-	-	-	-	29,86	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	263,46	-	-	-	-	-	-	-	-	-	-	-	-	-	263,46	0,00	263,46	0,00	0,00
Total	-	-	98,93	-	42,55	753,57	266,45	7,26	62,24	-	1,24	-	71,29	38,76	8,28	25,91	15,50	716,86	665,42	914,72	3681,72	0,00	3681,72	807,96	809,03

28-März-2019 [14:19]

Output specifications   Germany_2015_HTWK.txt   The EnergyPLAN model 14.1

District Heating Production

Gr.1	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00

Gr.2	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

Gr.3	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW
January	22837	162	4332	14103	0	0	4263	0	0	-22
February	23283	436	4332	14326	0	0	4263	0	0	-73
March	17546	824	4332	8633	0	0	4263	0	0	-505
April	14147	1299	4332	5325	0	0	4263	0	0	-1071
May	10484	1291	4332	1973	0	0	4263	0	0	-1374
June	9779	1413	4332	993	0	0	4263	0	0	-1221
July	9616	1437	4332	757	0	0	4263	0	0	-1172
August	9781	1353	4332	817	0	0	4263	0	0	-985
September	10496	971	4332	2096	0	0	4263	0	0	-1165
October	14918	553	4332	6206	0	0	4263	0	0	-437
November	16347	328	4332	7738	0	0	4263	0	0	-314
December	17450	256	4332	8687	0	0	4263	0	0	-88
Average	14699	861	4332	5946	0	0	4263	0	0	-703
Maximum	33899	5707	4332	25219	0	0	4263	0	0	0
Minimum	6776	0	4332	0	0	0	4263	0	0	-4332
Total for the whole year TWh/year	129,12	7,56	38,05	52,23	0,00	0,00	37,44	0,00		-6,18

RES specification	RES1 Wind MW	RES2 Photo \ MW	RES3 Offshoi MW	RES 4-7 ind MW	Total MW
January	12837	815	64	1869	15584
February	8217	2204	216	1553	12190
March	9864	4284	361	1729	16237
April	6334	6858	363	2169	15724
May	6801	6640	648	2878	16967
June	5246	7172	615	2887	15920
July	7232	7272	735	2601	17840
August	4684	6817	857	2262	14619
September	6352	5117	1233	1913	14615
October	3991	2796	1375	2074	10237
November	13003	1650	2167	1867	18686
December	12792	1287	2651	1652	18382
Average	8116	4413	943	2123	15595
Maximum	30628	28708	3295	3045	48542
Minimum	4	0	0	305	2091
Total for the whole year TWh/year	71,29	38,76	8,28	18,65	136,98

Own use of heat from industrial CHP: 87,20 TWh/year

ANNUAL COSTS (Million DKK)

Total Fuel ex Ngas exchange = 105575
Uranium = 1660
Coal = 10533
FuelOil = 17264
Gasoil/Diesel= 41354
Petrol/JP = 20328
Gas handling = 5915
Biomass = 8522
Food income = 0
Waste = 0

Total Ngas Exchange costs = 27477

Marginal operation costs = 2030

Total Electricity exchange = -2340
Import = 0
Export = 0
Bottleneck = 0
Fixed imp/ex= -2340

Total CO2 emission costs = 27955

Total variable costs = 160699
Fixed operation costs = 129341

Annual Investment costs = 176300

TOTAL ANNUAL COSTS = 466340

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	2916	10501	6005	66940	239	31846	118447	0	0	0	0	0	33259	85188	85188	0
February	2916	10667	6733	68183	239	31846	120584	0	0	0	0	0	35396	85188	85188	0
March	2916	6428	6346	49801	239	31846	97577	0	0	0	0	0	12389	85188	85188	0
April	2916	3965	5723	38344	239	31846	83033	0	0	0	0	0	-2155	85188	85188	0
May	2916	1469	4816	26688	239	31846	67974	0	0	0	0	0	-17214	85188	85188	0
June	2916	739	5601	22672	239	31846	64013	0	0	0	0	0	-21175	85188	85188	0
July	2916	563	5843	19854	239	31846	61262	0	0	0	0	0	-23927	85188	85188	0
August	2916	609	5857	19318	239	31846	60785	0	0	0	0	0	-24403	85188	85188	0
September	2916	1560	6647	27172	239	31846	70381	0	0	0	0	0	-14807	85188	85188	0
October	2916	4621	7293	41597	239	31846	88512	0	0	0	0	0	3324	85188	85188	0
November	2916	5762	6607	46324	239	31846	93695	0	0	0	0	0	8507	85188	85188	0
December	2916	6468	6000	49854	239	31846	97324	0	0	0	0	0	12135	85188	85188	0
Average	2916	4428	6119	39640	239	31846	85188	0	0	0	0	0	0	85188	85188	0
Maximum	2916	18778	9470	101874	239	31846	161089	0	0	0	0	0	75901	85188	85188	0
Minimum	2916	0	2416	12852	239	31846	52660	0	0	0	0	0	-32528	85188	85188	0
Total for the whole year TWh/year	25,61	38,89	53,75	348,20	2,10	279,74	748,29	0,00	0,00	0,00	0,00	0,00	0,00	748,29	748,29	0,00

RES Share: 13,8 Percent of Primary Energy   44,6 Percent of Electricity   161,6 TWh electricity from RES   28-März-2019 [14:19]