Final project in Energy Management

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1 Introduction

Based on information given about an hourly electrical and thermal load of a user in Benevento, Italy, a feasibility study has been carried out for an energy system consisting of a CHP plant and a wind power park. By comparing different scenarios and assumptions such as investment costs, height, and electrical power of the wind turbines as well as different gas engines in the CHP plant, the study has been optimized to achieve favorable technical and economic indicators.

2 User Load Analysis

From the data set given to us, it is possible to analyze the hourly electric power and the thermal power needed for our user. In figure 1 the electrical power load is presented and in figure 2 the thermal power load is presented. In figure 2 it is possible to see that the thermal load is always over 600 kW. Therefore, the CHP will provide the thermal load and the wind turbines will cover the other energy request.

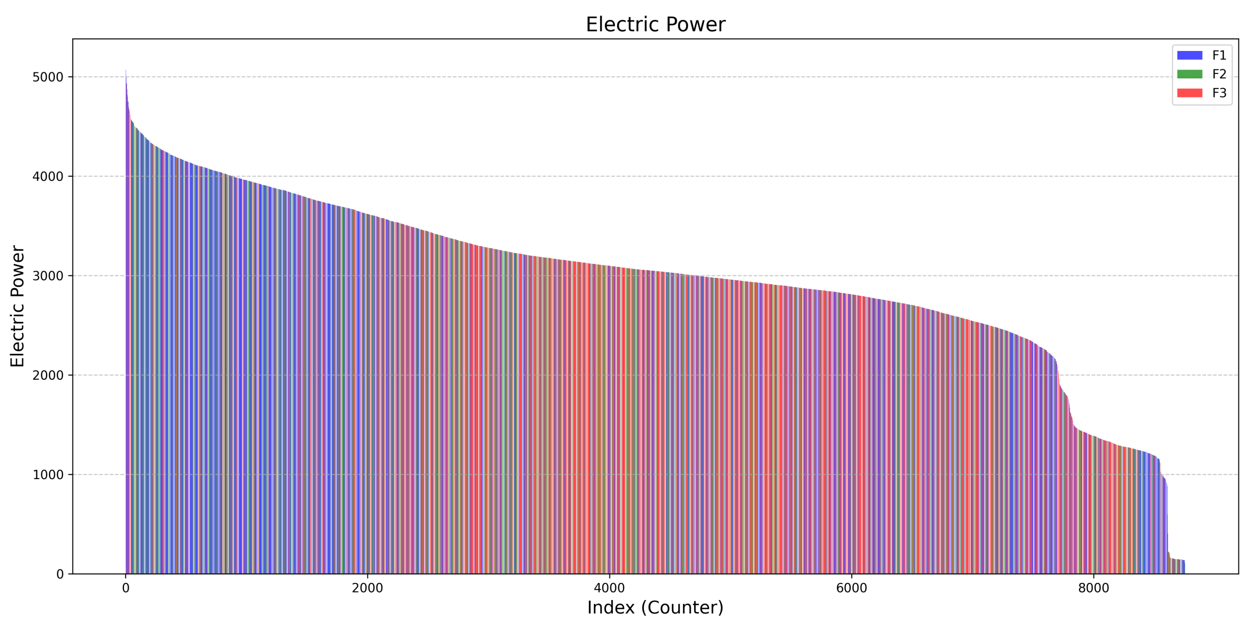

Figure 1: Electrical power load during the indexed hours

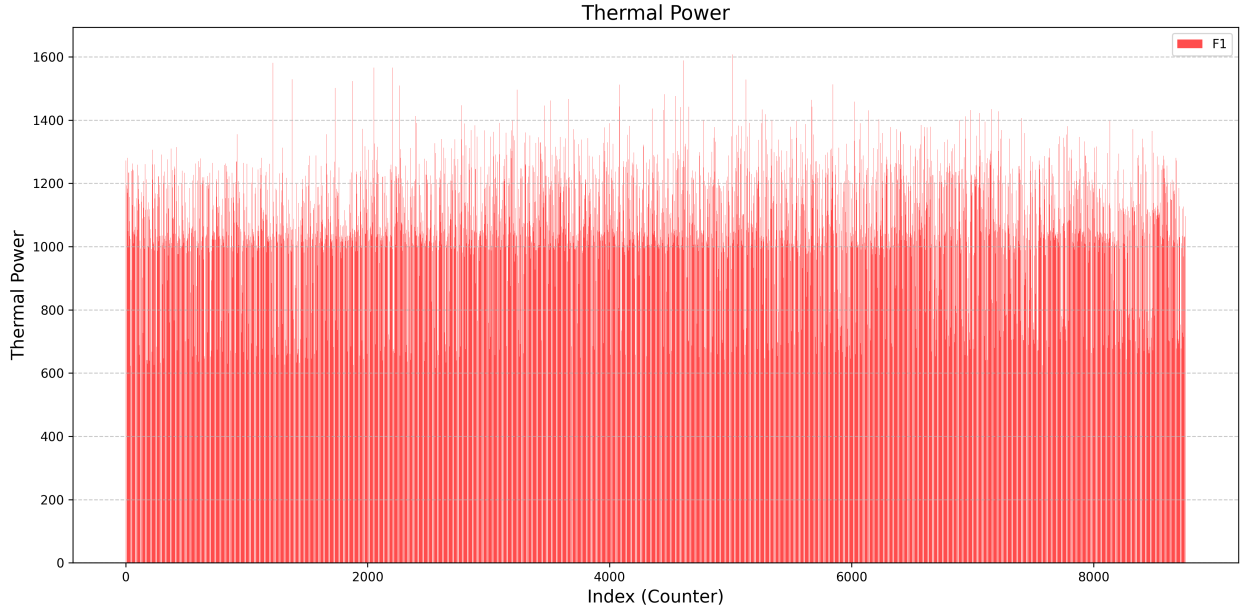

Figure 2: Thermal power load during the indexed hours

In figure 3, 4 and 5 is it possible to see the comparison between daily average, the minimum and the maximum daily thermal and electric loads and we can also see that the thermal load and the electrical load are in sync with eachother.

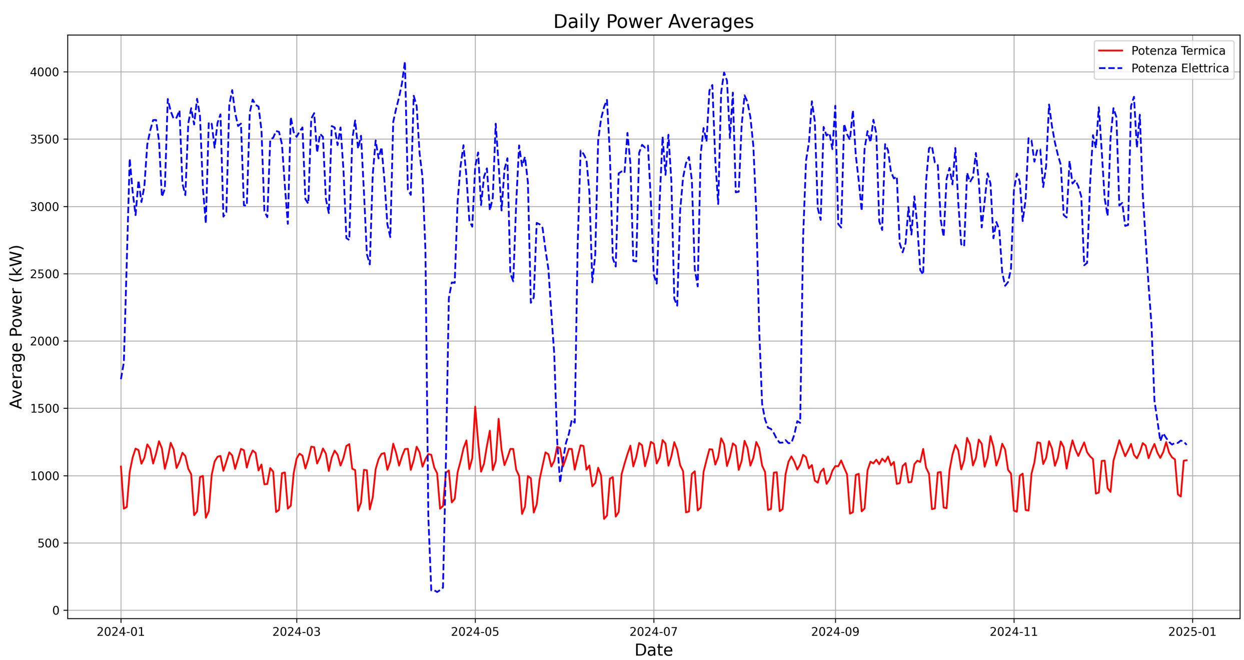

Figure 3: Graph over the daily power averages for the thermal and electrical loads

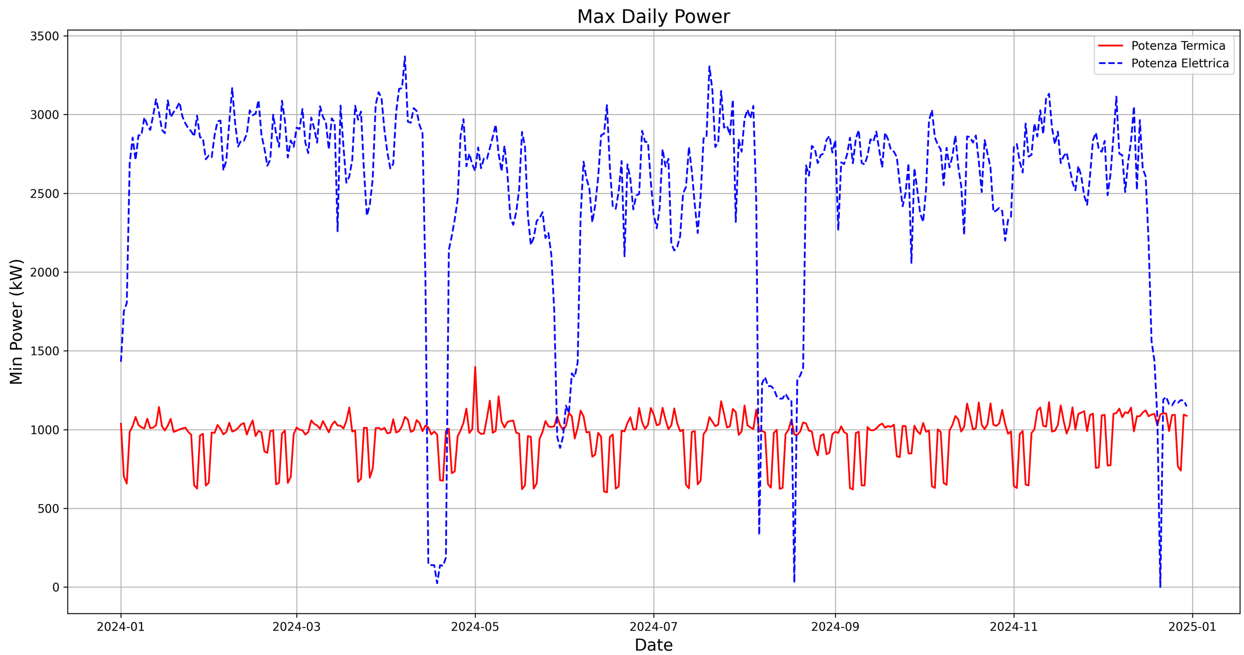

Figure 4: Graph over the daily minimum values for the thermal and electrical loads

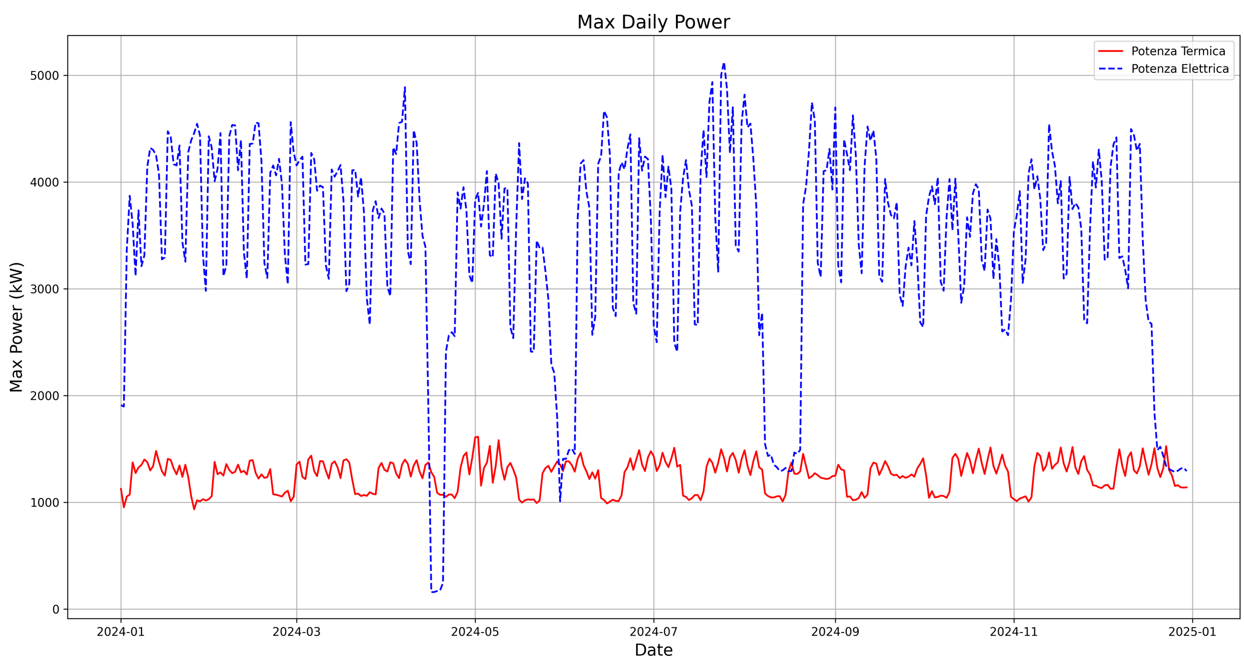

Figure 5: Graph over the daily maximum values for the thermal and electrical loads

3 Reference system description

Table 1: **Energy analysis** of the reference system

Supplied Energy	
Supplied By Boiler [MWh]	8580,00
Primary Energy Consumption	
Primary Energy Consumption Boiler [MWh]	9530,00

Supplied Electricity			
F1	F2	F3	Total
9450,00	5530,00	10390,00	25370,00

Supplied To User [MWh]	8580,00
Primary Energy Consumption	
Consumption of reference thermal-power system [MWh]	55200,00
Overall Energy Balance	
Supplied Energy (Heat + Electricity) [MWh]	33900,00
Primary Energy Consumption [MWh]	64700,00
Supplied Energy + Surplus [MWh]	34200,00
Primary Energy Consumption + Surplus [MWh]	65300,00
Total Fuel Efficiency	0,52
CO_2 Emissions [t]	14100000,00

Table 2: Economic analysis of the **natural gas costs** of the reference system

Annual Consumption [Sm^3]	994000,0000
Charge [e/Sm^3]	0,6
Tax Regime	Civile
Raw Material & Gas Network Use [M]	0,5965
Taxes [M]	0,1080
Total Natural Gas Costs [M]	0,7045

Table 3: Economic analysis of the **electrical costs** of the reference system

F1 Charge [e/kWh]	0,169
F2 Charge [e/kWh]	0,174
F3 Charge [e/kWh]	0,163
Energy Fee [M]	3,1808
Committed Power [kW]	5125,00
Power Fee [M]	0,1630
Total Tax Fee [M]	4,4200
Monthly Consumption [kWhe/Month]	2110000,00
Tax Ee [e/kWh]1	0,0075
Tax Ee [e/kWh]2	0,0125
Total Tax [M]	0,0073
Total Electricity Costs [M]	4,4200
Total Net Costs [M]	5,1300

4 Proposed CHP System

For the CHP two solutions were tried. In table 4 and figure 6 the values for the first solution are presented and in table 5 and figure 7 the values for solution 2 are presented. The cost is calculated with the python program "03-KWhCHPCostCalculator.py"

Table 4: Values for CHP solution 1

CHP Solution 1
600 kW - 8000 hours - Fixed
Model: Jenbacher ICE 312
$P_e = 600$ kW
$\eta_e = 0.389$
$P_t = 730$ kW
$\eta_t = 0{,}473$
$\eta_e + \eta_t = 0{,}862$
Hours: 8000
Cost per kWh produced by the CHP : 0,090 €/kWh
Thermal energy provided by CHP: 5804, 23 MWh
Thermal surplus: 35,77 MWh
Boiler Integration: 2776,84 MWh
Operating costs P.S: 4,98 M
Operating costs ref: 15,82 M
Difference: -10,83 M

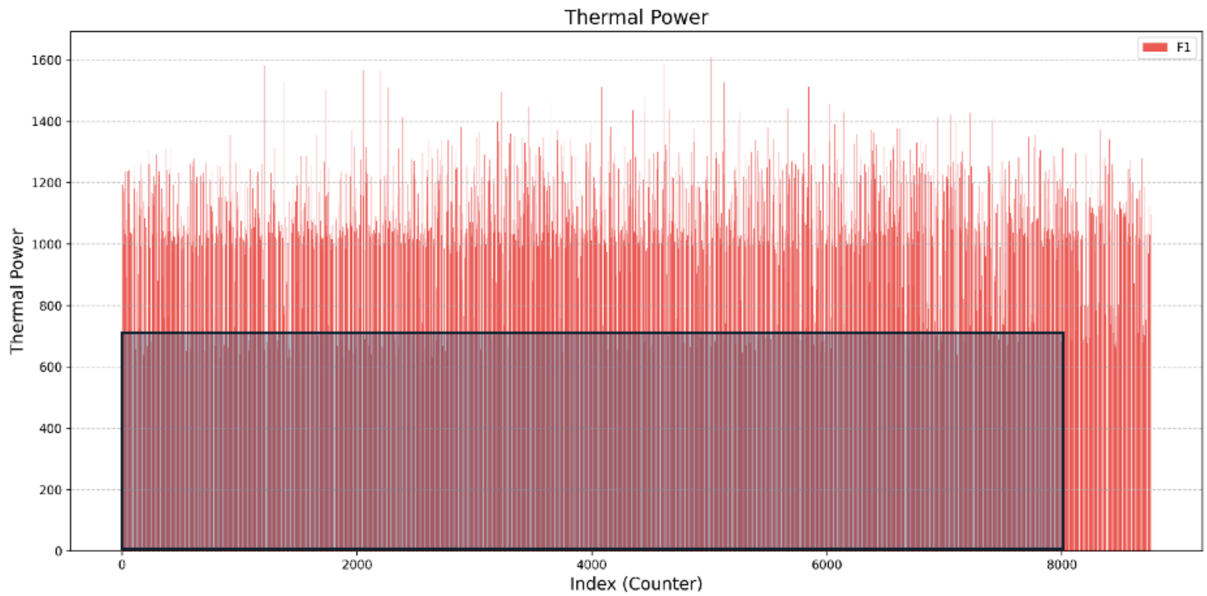

Figure 6: Graph for CHP solution 1

Table 5: Values for CHP solution 2

CHP Solution 2
8000 hours - Fixed
Model: Jenbacher ICE 316
$P_e = 800$ kW
$\eta_e = 0.390$
$P_t = 970$ kW
$\eta_t = 0{,}473$
$\eta_e + \eta_t = 0{,}863$
Cost per kWh produced by the CHP : 0,089 €/kWh
Thermal energy provided by CHP: 7500,20 MWh
Thermal surplus: 259,80 MWh
Boiler Integration: 1080,87 MWh
Operating costs P.S: 4,98 M
Operating costs ref: 15,82 M
Difference: -10,83 M

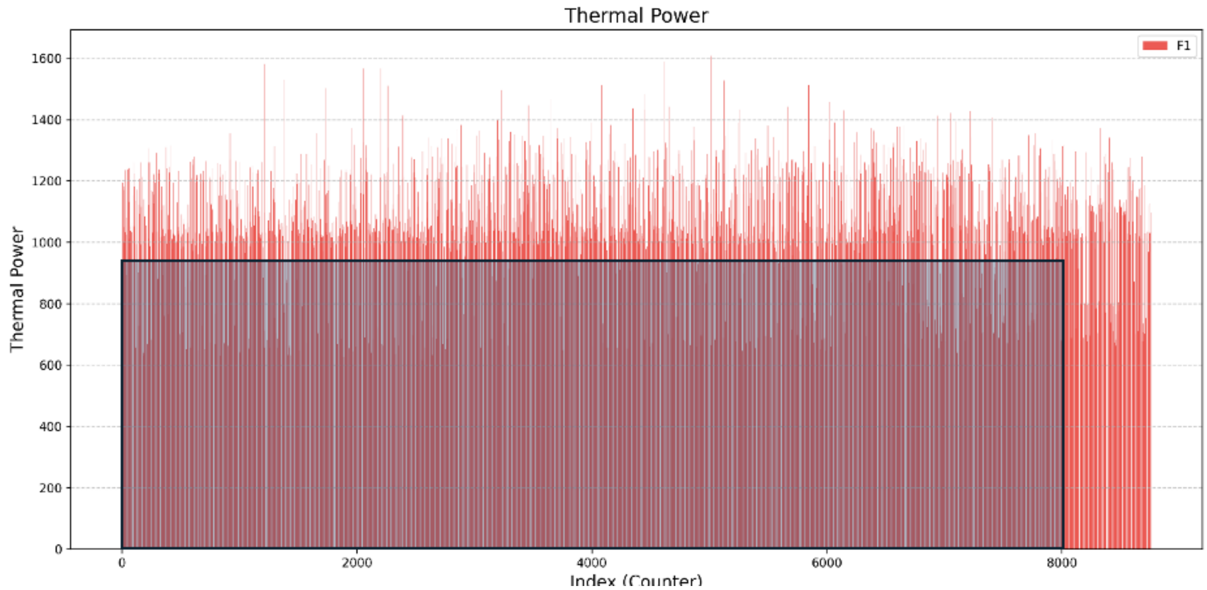

Figure 7: Graph for CHP solution 2

Based on the results, solution 2 is chosen. It has a small reduction of costs compared to solution 1 even if there is a thermal surplus of 260 MWh. The following is a complete analysis of energy and costs that can be obtained by running the Python program "04-COG_Fixed.py"

Table 6: **Energy analysis** of the proposed system

Supplied Energy	
Recovered From CHP Plant [MWh]	7500,00
Supplied By Boiler [MWh]	1080,00
Total [MWh]	8580,00
Primary Energy Consumption Boiler [MWh]	1200,00

Supplied Electricity				
-	F1	F2	F3	Total
Supplied By CHP	2290,00	1360,00	2750,00	6400,00
Self-Consumption	2290,00	1360,00	2750,00	6400,00
Surplus	0.00	0.00	0.00	0.00
Integration	7160,00	4170,00	7645,00	18970,00

Supplied To User [MWh]	25400,00
Primary Energy Consumption	
CHP Plant [MWh]	16400,00
Integration From National Grid [MWh]	41200,00
Total [MWh]	57600,00
Overall Energy Balance	
Supplied Energy (Heat + Electricity) [MWh]	33950,00
Primary Energy Consumption [MWh]	58800,00
Total Fuel Efficiency [MWh]	0,00
CO_2 Emissions [t]	12600000,00

Table 7: Economic analysis of the **natural gas costs** of the proposed system

Annual Consumption [Sm^3]	1836000,00
Charge [e/Sm^3]	0,6
Tax Regime	Industriale 64,69%
Tax Exemption Factor [Sm^3/kEhe]	0,22
Free-Tax Annual Consumption [Sm^3]	1408000,00
Raw Material & Gas Network Use [M]	1,1020
Taxes [M]	0,0080
Total Natural Gas Costs [M]	1,1100

Table 8: Economic analysis of **electrical costs** of the proposed system

Maintenance Charge [e/kWh]	0,015
Maintenance Costs [M]	0,0960
F1 Charge [e/kWh]	0,169
F2 Charge [e/kWh]	0,174
F3 Charge [e/kWh]	0,163
Energy Fee [M]	3180000,000
Committed Power [kW]	4325,00
Power Fee [M]	0,1375
Total Tax Fee [M]	3,3200
Monthly Consumption [kWhe/Month]	2110000,00
Tax Ee [e/kWh]1	0,0075
Tax Ee [e/kWh]2	0,0125
Total Tax [M]	0,0073
Total Electricity Costs [M]	3,4200
Sale Of Electricity	
F1 Sell [e/kWh]	0,137
F2 Sell [e/kWh]	0,142
F3 Sell [e/kWh]	0,131
Total Revenue [M]	0,0000
Total Net Costs [M]	4,5300

Table 9: Comparison between the reference system and the proposed system

-	Proposed System	Reference system	Difference
Primary Energy Consumption [MWh]	58800,00	64700,00	-5900,00
CO_2 Emissions [t]	12600000,00	14100000,00	-1500000,00
Operating Costs	4,86	5,42	-0,56

5 Proposed Wind system

For the wind speeds a file containing the wind data for one year in the region of Benevento, Italy, is used. The committed power of the proposed CHP system is 4 MW, so a wind turbine with a power of 2 MW to 6 MW is being analyzed. As we can see in figure 8 the wind speed distribution at 10 meters is concentrated in the lower speed region which suggest a low cut-in.

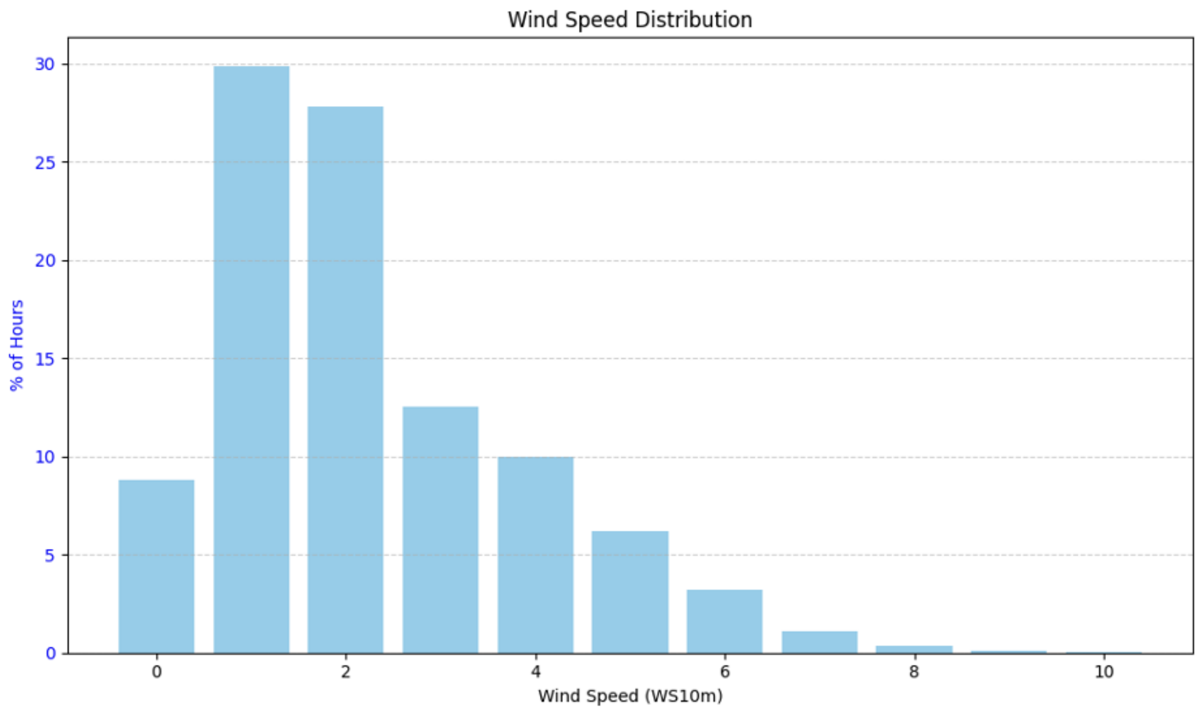

Figure 8: Wind speed distribution at the height of 10 meters

The three wind turbines used to simulate which scenario would be the best is the Vestas V100/2000, the Vestas V112/3450 and the Vestas V117/4000. Table 11, table 10
and table 12 are calculated with the python program "05-Wind.py"
The Vestas V100/2000 is 120 meters high and has an electric power of 2000 kW.

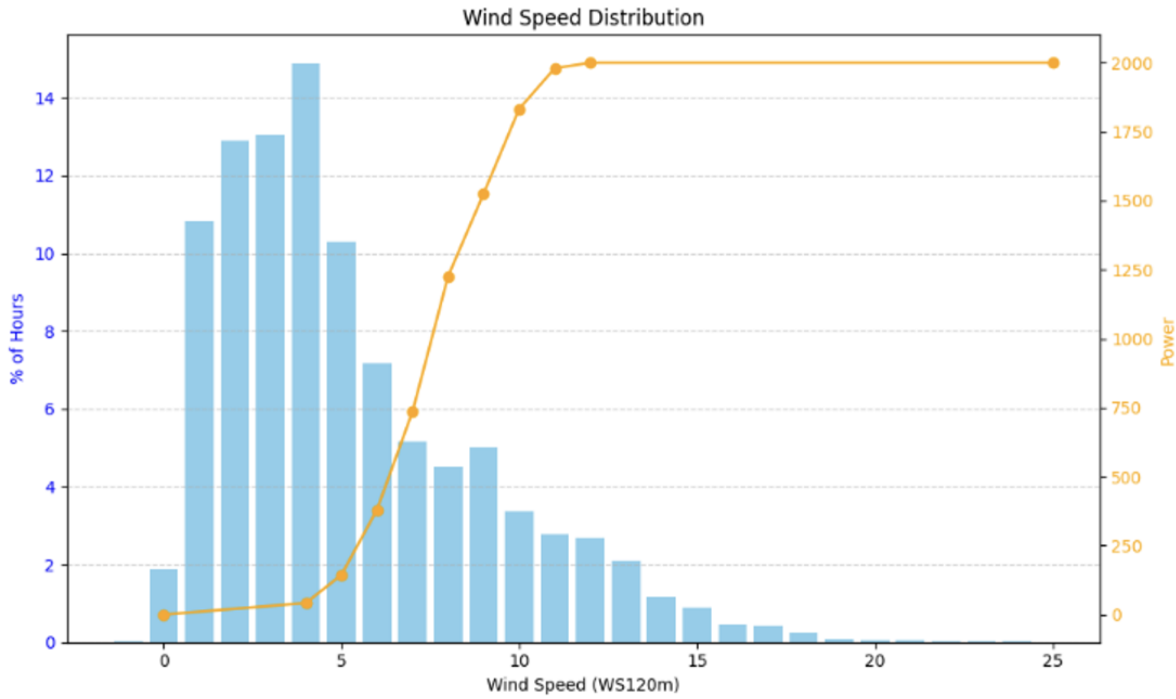

Figure 9: Graph for wind speed and power for the Vestas V100/2000

Table 10: Values for the Vestas V100/2000

Total Produced Energy [kWh]	4440000,00
Heq	943,00
Unit Energy Cost [€/kWh]	0,13
Total Revenue [€]	792000,00
Installation Cost [€]	6000000,00
Annual Maintenance [€]	180000,00
Payback [Years]	9,8

The Vestas V112/3450 is 80 meters high and has an electric power of 3500 kW.

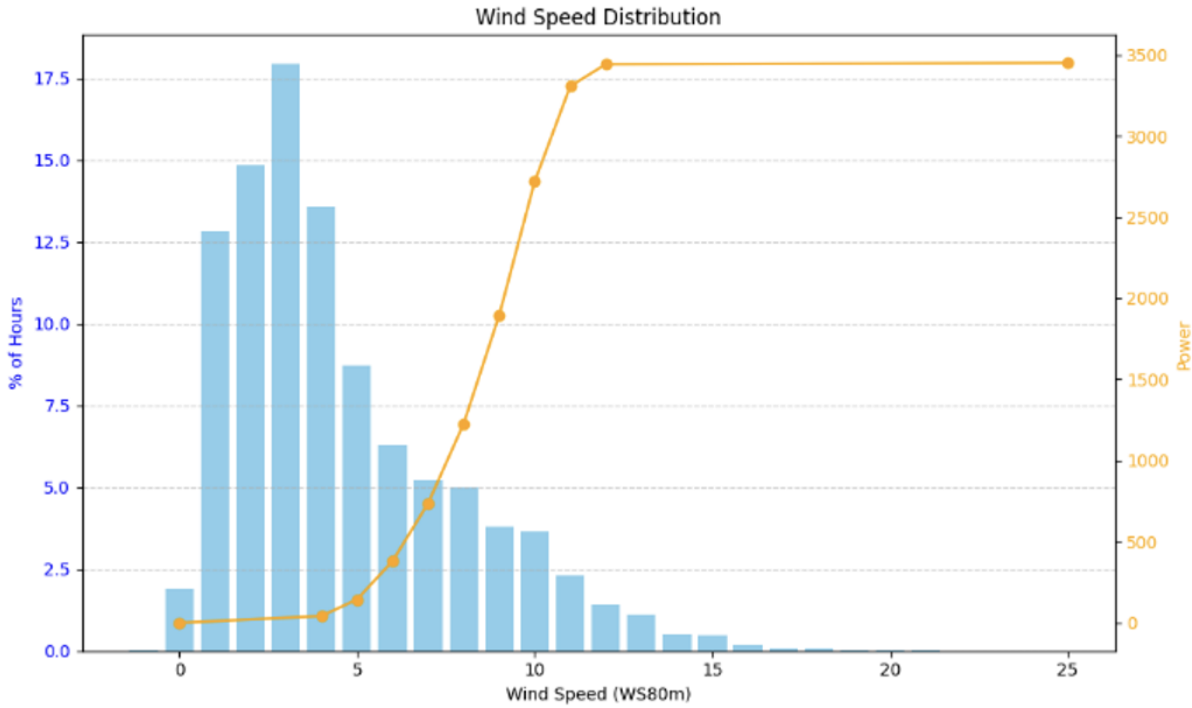

Figure 10: Graph for wind speed and power for the Vestas V112/3450

Table 11: Values for the Vestas V112/3450

Total Produced Energy [kWh]	4680000,00
Heq	1136,00
Unit Energy Cost [€/kWh]	0,11
Total Revenue [€]	895000,00
Installation Cost [€]	5250000,00
Annual Maintenance [€]	157500,00
Payback [Years]	7,1

The Vestas V117/4000 is 90 meters high and has an electrcial power of 4000 kW.

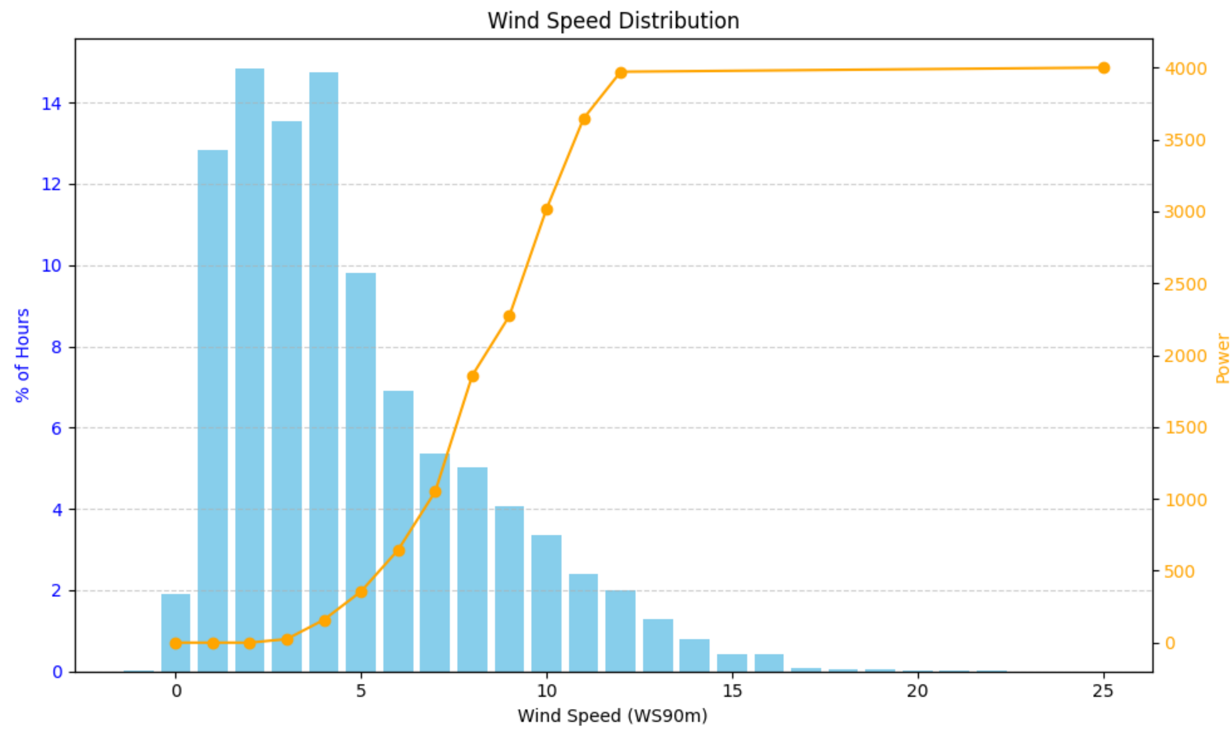

Figure 11: Graph for wind speed and power for the Vestas V117/4000

Table 12: Values for the Vestas V117/4000

Total Produced Energy [kWh]	6520000,00
Heq	1386,00
Unit Energy Cost [€/kWh]	0,09
Total Revenue [€]	1280000,00
Installation Cost [€]	6000000,00
Annual Maintenance [€]	180000,00
Payback [Years]	5,4

We choose to use the Vestas V117/4000 because it has a higher Heq and a payback time of 5,4 years.

6 CHP + Wind

We chose to use the Vestas V117/4000 combined with the CHP Jenbacher ICE 316 to obtain the best results. The results of the calculations can be seen in table 13 and obtained from the python program "06-CHP_Wind.py".

Table 13: Values from the CHP + Wind calculations

CHP + Wind calculations
Primary Energy Savings: 18,95%
CO2 Reductions: 8723,00 t
Total Installation Costs: 5,65 M
Annual Saving: 0,96 M
Simple Payback Period: 5,88 Years
Net present Value: 6320000,00 €
Profability Index: 2,12
Internal Rate of Return: 16,15%