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Renewable District Heating and Cooling in a Technology Park in Catalonia

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Abstract

As part of the SmartReflex project, supported by the Intelligent Energy Europe Programme, the region of Catalonia is performing a study to increase the number of smart and flexible district heating and cooling (DHC) systems with a high percentage of renewable energy sources (RES). This regional strategy includes analysis of case studies for development of new DHC and the integration of renewable energy in existing DHC.

One case study is of a Commercial Technology Park. A detailed study to design a new DHC plant, including DHC demand characterization, shall be carried out using energyPRO, incorporating combinations of several renewable energy technologies comprising biomass, geothermal heat exchanger and solar cooling.

The objective is to evaluate the environmental, technical and economic feasibility of the RES DHC and which combination of renewable energies is best suited for this new DHC.

Keywords: *Solar cooling, district heating and cooling, smart cities, energy infrastructure*

1. Introduction

The region of Catalonia is located in north east Spain, next to the Mediterranean Sea and bordering France at the Pyrenees. Having various climatic zones, Catalonia has different characteristics that justify the demand of establishing district heating and cooling (DHC) networks over its territory. As of 2015, Catalonia had 84 district heating and cooling networks, according to the Spanish association of district heating and cooling (ADHAC). Majority of the networks are small heating networks and four of them provide heating and cooling simultaneously. Biomass is the main renewable energy source used in the small networks.

As part of the SmartReflex project (Smart and Flexible 100 % Renewable District Heating and Cooling Systems for European Cities, 2016), supported by the Intelligent Energy Europe Programme, the region of Catalonia (along with five other European regions) is pursuing different activities to increase the number of smart and flexible district heating and cooling systems with a high percentage of renewable energy sources including solar, biomass, biogas and geothermal energy. One of the activities is the performance of studies to promote the construction of new networks by proving their technical and economic feasibility.

This paper presents the results of the case study named “Parc de l´Alba”, which is a Technology Park in Cerdanyola del Vallès (near Barcelona) in Catalonia, Spain. Currently, the Park comprises of a Particle Accelerator (Synchrotron), a data center and some office buildings. In the coming years, there is a forecast of construction of several non-residential buildings, implying an increase in the cooling, heating and electricity demands. The new consumers shall be mainly office buildings and data centers. An existing Combined Heat and Power plant (ST-4) satisfies the present day demand of the existing DHC network. The components of ST-4 plant are shown in Fig. 1. A new plant (ST-5) shall be built in the future along with an extension of the DHC network in order to accommodate the increased demand. By 2020, there will be a total of 9 buildings with total floor area being 112,230 m^2 . The large area indicates a high demand of cooling and heating and thus is an encouragement to integrate renewable energy in the district heating and cooling plant.

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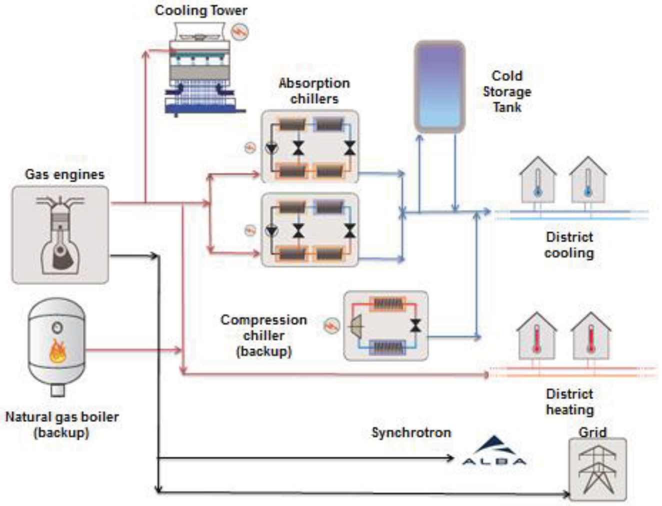

Fig. 1 Scheme of operation of the existing ST-4 plant at Parc de l'Alba

A detailed study to design the new DHC plant is carried out using the EnergyPRO (EMD International A/S, 2016) software, by performing simulations from present day (2016) till 2020. The plant will incorporate several combinations of renewable energy technologies.

2. Objectives and Methodology

The main objective is to determine if the construction of a new RES DHC is an environmental, technical and economically feasible option and which combination of renewable energies is best suited for this new DHC. The most feasible options(s) shall be decided by several Key Performance Indicators (KPIs), namely the Net Present Value (NPV), primary energy consumption and carbon dioxide (CO_2) emissions obtained in each scenario.

Two key goals must be fulfilled to reach this objective:

- To model the energy demand growth until 2020, including demand characterizations of space heating, space cooling and Domestic Hot Water (DHW) of the new consumers
- To create 5-years scenarios incorporating several renewable energy sources (RES) in the DHC plants comprising biogas, biomass, geothermal heat pumps and solar thermal cooling.

3. Base model validation

As an initial step, a base model was created in 2015 by obtaining real data from the plant (from 2014); validation was done by comparing simulation results with the real plant operation. This was done to ensure that analysis of future scenarios will be accurate.

EnergyPRO (version 4.4) is a powerful and flexible computing tool to model district heating and cooling systems. On the basis of several inputs such as the demand profile, meteorological conditions, efficiencies and capacities of various energy conversion units and tariffs, energyPRO calculates annual productions in steps of typically one hour, giving a comprehensive output on economics, emissions and operational strategy. Instead of the traditional approach of chronological hour-by-hour calculations of energy production, energyPRO is able to place productions in the most favorable time periods of the year, i.e., in the cheapest production unit /tariff combination, and so on, until the complete demand is met or there is no more production capacity left of the energy conversion units in the model.

Time Series, which are data sets of typically 8,760 time steps, are an integral part of the energyPRO software. Hourly temperature and solar irradiation data for Barcelona were input to the software as Time Series, along with some other time series to generate the Spanish electricity markets (to consider the changes in electricity pool price). For the base model, Tab. 1 shows the details of the energy conversion units which were provided as input to the software.

Tab. 1 Details of energy conversion units and cold storage unit at Parc de l' Alba presently (2015)

Unit type	Quantity	Specifications (each unit)	Comments
Cogeneration Engines	3	3.28 MW_{th}; 3.35 MW_e; η_{el} = 44.9%	Turned on simultaneously whenever electricity spot markets are high
Single Effect Absorption Chiller	1	3 MW_c; COP = 0.7	Driven by hot water from the engines at 90 ºC
Double Effect Absorption Chiller	1	5 MW_c; COP = 1.3	Driven by exhaust gases of the engines at 398 ºC
Natural gas boiler	1	5 MW_{th}; η_{th} = 60%	Back-up
Compression Chiller	1	5 MW_c; COP = 5	Back-up
Cold water storage tank	1	4000 m^3; 21 MWh_c	
Total plant capacity: 8.0 MW_c , 9.8MW_{th} and 10.1 MW_e			

Tab. 2 shows the various revenues generated by the ST-4 plant in 2015, while Tab. 3 and Tab. 4 show the expenses incurred. Details of the two consumers served by the plant, i.e. Synchrotron facilities and an office building (referred to as "Plot 1") are shown in Tab. 5.

Tab. 2 Prices for heating, cooling and electricity sales at Parc de l'Alba for base model (2015)

Payment	Value for heating	Value for cooling	Value for electricity (Synchrotron)	Value for electricity (grid)
Connection payment	48.21 €/kW_{th} connected	145.77 €/kW_c connected	-	-
Capacity payment	13.98 €/kW_{th}/ year	23.01 €/kW_c /year	617,132 €/year	529,193 €/year
Variable price	34.84 €/MWh_{th} sold	34.84 €/MWh_c sold	114.24 €/MWh_e sold	113.20 €/MWh_e sold

Tab. 3 Fuel expenditure at Parc de l' Alba for base model (2015)

Fuel	Value
Natural gas	0.402 €/m^3
	37.78 €/MWh
Electricity imported	40.73 €/MWh_e

Tab. 4 Maintenance expenditure at Parc de l'Alba for base model (2015)

Maintenance type	Value
Fixed maintenance	245,064 €/year
Variable maintenance	13.27 €/MWh_e from gas engines
Overhaul of engines	6.83 €/hour operation

Tab. 5 Energy demands at Parc de l' Alba for base model (2015)

Type of demand	Consumer	Value
Cooling demand	Synchrotron	21,710 MWh_c
	Plot 1	651 MWh_c
Heating demand	Synchrotron	895 MWh_{th}
	Plot 1	532 MWh_{th}
Electricity demand	Synchrotron	20,419 MWh_e
	In-house consumption and losses	5,314 MWh_e

4. Key Performance Indicators

After the base model validation, simulation models were created for the years 2016, 2017, 2018 and 2020 (2019 is assumed to have identical performance as 2018) incorporating new demands. Different combinations of RES were used to satisfy this demand. The best combination was evaluated on the basis of CO_2 emissions, Primary Energy consumption and Net Present Value (NPV)

The CO_2 emissions were calculated by the software simulation once the user had entered specific emission factors of each fuel, while primary energy consumption was calculated by multiplying the fuel consumption with their respective primary energy factors (PEFs). Specific emission factors and PEFs were taken from a Joint Resolution of the Ministries of Industry, Energy and Tourism and Ministry of Development (Resolución conjunta de los Ministerios de Industria, Energía y Turismo, y Ministerio de Fomento, 2016) of Spain. They are shown in Tab. 6.

Tab. 6 Specific emission factors and Primary Energy Factors for fuels used in Parc de l' Alba

Fuel	Specific emission factor (kg CO_2/unit fuel)	Primary Energy Factor
Imported Electricity	0.357 kg/kWh	2.368
Natural gas	2.681 kg/m^3	1.195
Biogas	0.62 kg/m^3	0.500
Biomass	0.0621 kg/kg	0.034

The NPV is basically the difference in the between present value of cash inflows and present value of cash outflows. A positive NPV indicates that the projected earnings exceed the expected costs, while it is the other way around for a negative NPV. To calculate NPV for each scenario, an extensive economic calculation is done by construction of Profit and Loss (P & L) sheets from the present year (2016) up to the end of concession period (2037) for each scenario, as explained by Ross et al. (2014) in Fundamentals of Corporate Finance. The NPV is calculated by eq. 1.

$$NPV = -C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+i)^t} \qquad \text{(eq. 1)}$$

Where

C_0 (€) = Free Cash Flow in year zero, i.e., in 2016

T (years) = Lifetime of technology (21 years)

i (%) = Interest rate (assumed as 10%)

C_t (€) = Free Cash flow in year‘t’

The Free Cash Flow in each year is calculated by eq. 2.

$$Free\ cash\ flow = Operating\ Cash\ Flow - Increase\ in\ Working\ capital - CAPEX \qquad \text{(eq. 2)}$$

CAPEX refers to the capital expenditure. The inflation applied to natural gas prices, variable and fixed prices of heating and cooling was 7.48%, which is the increase in gas prices in Spain in the past 13 years according to International Energy Agency (IEA, Energy Policies of IEA countries – Spain 2015 Review). Similarly, an inflation of 9.72% was applied to variable price of electricity, as per IEA. For all other revenues and expenses, the inflation was assumed as 2%, according to the European Central Bank. Information of taxes for 2016 was received from Parc de l'Alba; they are the IAE (city council tax for business activity), IBI (city council tax for property), IS (national corporation tax), tax on electricity export (7% of total export earnings) and tax on natural gas consumption (0.00234 €/kWh gas consumed).

5. Demand characterization

The demands of Parc de l'Alba from 2016 till 2020 are shown in Tab. 7.

Tab. 7 Present and future energy demands of Parc de l' Alba

	2016	2017	2018	2020
Cooling demand (MWh_c/year)	23,600	25,368	26,048	31,848
Heating demand (MWh_{th}/year)	1,426	2,386	2,738	3,398
Electricity demand (MWh_e/year)	22,847	22,768	23,921	48,429

The main consumers are the Synchrotron facilities (cooling and electricity), office buildings (cooling and heating) and data centers (cooling and electricity). The Synchrotron has a cyclic operation throughout the year and hence its cooling and electricity demand was modelled accordingly (shown in Fig. 2), as per information received from Parc de l' Alba. For offices, the cooling demand was modelled according to the Barcelona Energy Improvement Plan (Pla de Millora Energètica de Barcelona, 2002), while the heating demand was based on a study by Pedersen and Ulseth (2006), as shown in Fig. 3. Finally, the cooling and electricity profiles of data centers (Fig. 4) were modelled on the basis of real data (operation of IT loads throughout the day) simulated in the Renew IT project (European Union, 2013).

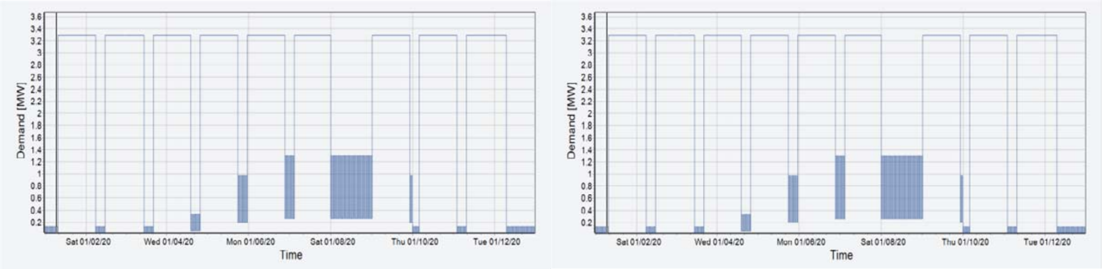

Fig. 2 Annual cooling (left) and annual electricity (right) demand profiles of Synchrotron facilities

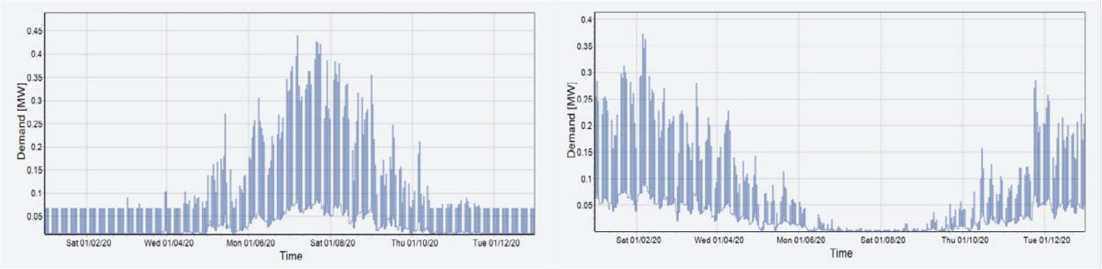

Fig. 3 Annual cooling (left) and annual heating (right) demand profile of office buildings

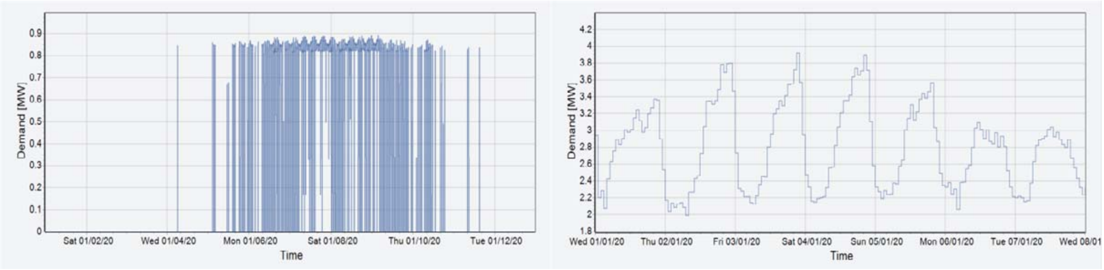

Fig. 4 Annual cooling (left) and weekly electricity (right) demand profile of data centers

6. Supply modeling

In order to supply the growing energy demand of Parc de l' Alba, three different scenarios have been considered, namely:

- Scenario 1: Solar cooling and Biomass cooling (SCBC)
- Scenario 2: Ground Source Heat Pumps (GSHPs)
- Scenario 3: Business As Usual (BAU)

All three scenarios involve the incorporation of a biogas boiler in the ST-4 plant from 2017 till 2019, while for 2020 each of the scenarios incorporates different energy conversion technologies in the new ST-5 plant. Each scenario shall be described in detail, including specifications of the energy conversion units and CAPEX (capital expenditures). Common to all scenarios are some miscellaneous investment costs (engineering, monitoring, permits, legalization etc.) which are taken as 25 % of the total physical investment of the equipment, as recommended in the guide published by the Catalan Energy Institute (Institut Català d'Energia, 2010). In the SCBC and GSHPs scenarios, it is assumed that electricity for new data centers is purchased from the grid and sold to the data centers. For the BAU scenario, the new gas engines installed at the ST-5 plant are used to directly sell electricity to the new data centers while any excess is exported to the grid. The costs of fuels in 2020 for all scenarios are shown in Tab. 8. The prices of energy sales after transformation are according the ones in Tab. 2 updated by inflation.

Tab. 8 Fuel costs in 2020 (all scenarios)

Fuel	Cost (€/MWh)
Imported electricity	60-68
Natural gas	50
Biomass	33

For the biogas boiler, all information is received from the Parc de l' Alba management. The fuel used is landfill gas, with a current price of 8 €/MWh and a calorific value of 6.2 kWh/m^3. The percentage of methane in this gas is 60 %, the specific emission factor of CO_2 is 0.62 kg/m3 and the PEF is 0.5. The biogas boiler has a capacity of 1.5 MW_{th} and currently costs € 147,500. The aim is to use this boiler to substitute the existing 5 MW_{th} natural gas (backup) boiler since it is oversized for heating demands till 2020.

6.1. Scenario 1: Solar cooling and biomass cooling (SCBC)

For the SCBC scenario, a part of the rooftop of the ST-5 plant was used for installing Parabolic Trough Collectors (PTCs) that would be connected to a double effect absorption chiller. For the remainder (major) cooling demand, a biomass boiler connected to another absorption chiller was used.

Currently, EnergyPRO can only model flat plate or evacuated tube solar collectors. Because of this, TRNSYS software was used to model the PTCs, with TRNSYS Type 536 (Linear Parabolic Concentrating Solar Collector with Capacitance and Flow Modulation). Data for the simulations was acquired from the Swedish manufacturer "Absolicon Solar Collector AB". The chosen collector model for simulations was

T160 by Absolicon. Data on the solar collectors' field simulated on TRNSYS are shown in Tab. 9

The output of the TRNSYS simulation was an hourly time series of the heating energy produced by the solar field, with 8,760 time steps. This time series was then provided to EnergyPRO as the heat input to the double effect absorption chiller.

Tab. 9 Parameters for modeling parabolic trough collectors for solar thermal cooling in Parc de l' Alba

Parameter	Value
Aperture area of each collector	10.37 m^2
Total number of collectors	105
Total aperture area	1088 m^2
Outlet temperature from collectors	180°C
Return temperature to collectors	160°C

According to the manufacturer, the present day cost of the PTCs is approximately 300 €/m^2 while the cost of the absorption chiller was assumed as 640 USD/kW_c (570 €/kW_c), as quoted by Shirazi et al. (2016). The total investment for the solar thermal cooling system was calculated by doubling the sum of the cost of the collectors and chiller, assuming that roughly 50% of the total system cost is of the buffer storage tank, piping connections, cooling tower, control system, etc. For the biomass boiler, the investment cost was taken from a study conducted by IREC for a project, while costs of the large absorption chillers were provided by the Parc de l' Alba management.

Tab. 10 Details of energy conversion units and storage units modelled for SCBC scenario

Unit type	Quantity	Specifications (each unit)	Cost
Parabolic trough collectors	1	1,088 m^2 ; 298 kW_{th} (417 kW_c)	€ 353,468
Absorption chiller (connected to solar collectors)	1	450 kW_c; COP = 1.4	€ 277,449
Biomass boiler	1	2,500 kW_{th}; $\eta_{th} = 90\%$	€ 1,171,659
Absorption chiller (connected to biomass boiler)	1	3,300 kW_c; COP:1.4	€ 658,616
Cold water storage tank	1	6,400 m^3; 29.8 MW_c	€ 1,394,574
Hot water storage tank	1	200 m^3; 5.8MW_{th}	€ 97,419
Total plant capacity: 3,717 kW_c and 2,500 kW_{th} **Total CAPEX: € 5,730,128**			

6.2. Scenario 2: Ground Source Heat Pumps (GSHPs)

For the GSHPs scenario, the cooling and heating demands are served by ground source heat pumps that simultaneously produce cooling and heating. For every unit of electricity input, 3.2 units of cooling are produced (Energy Efficiency Ratio: 3.2) while 4.2 units of heating are produced (Coefficient of Performance: 4.2). The COP and EER are similar to the ones calculated for ground source heat pumps in Mollet hospital near Barcelona, as part of the Green Hospital project (European Commission, 2015). For Parc de l'Alba, the GSHPs are oversized in terms of heating capacity since cooling demand is higher than heating demand but the units have a heating output higher than the cooling output (for the same electricity input). The investment cost of the GSHPs for Parc de l'Alba was assumed as 1,583 €/kW_{th}, in accordance with a study done in France by Boissavy (2015). Additionally, the rooftop of the plant was used to install mono crystalline solar photovoltaic (PV) panels, manufactured by Suntech Power. Costs of this PV system were taken from IEA.

Tab. 11 Details of energy conversion units and storage units modelled for GSHPs scenario

Unit type	Quantity	Specifications (each unit)	Cost
Solar PV system	1	1800 m^2; 275 kW_e; $\eta_{el} = 15.4\%$;	€ 389,675
Ground Source Heat Pumps	1	Input: 1,214 kW_e ; Output: 3,900 kW_c and 5,113 kW_{th}	€ 8,761,075
Cold water storage tank	1	6400 m^3; 29.8 MW_c	€ 1,394,574
Hot water storage tank	1	200 m^3; 5.8MW_{th}	€ 97,419
Total plant capacity: 3,900 kW_c and 5,113 kW_{th} **Total CAPEX: € 13,303,429**			

6.3. Scenario 3: Business As Usual (BAU)

In this scenario, cogeneration engines are installed at the new plant so as to directly sell electricity to the data centers connected in 2020. The exhaust heat of the engines would be used to serve the heat demand and to power an absorption chiller to serve the cooling demand. A backup boiler is also installed.

Tab. 12 Details of energy conversion units and storage units modelled for BAU scenario

Unit type	Quantity	Specifications (each unit)	Cost
Cogeneration engine	3	3.28 MW_{th}; 3.35 MW_e; $\eta_{el} = 44.9\%$	€ 4,931,299
Double effect absorption chillers	1	5 MW_c; COP = 1.3	€ 997,902
Natural gas boiler (backup)	1	5 MW_{th}; $\eta_{th} = 60\%$	€ 123,214
Cooling tower	1	-	€ 493,812
Cold water storage tank	1	6,400 m^3; 29.8 MW_c	€ 1,394,574
Hot water storage tank	1	200 m^3; 5.8MW_{th}	€ 97,419
Total plant capacity: 5,000 kW_c, 9,840 kW_{th} and 10,050 kW_e **Total CAPEX: € 10,047,775**			

7. Results

The important results obtained from the energyPRO simulations and economic analyses are presented in this section. The results from 2016 till 2018 are shown first, and then results for 2020 are shown for all scenarios.

7.1. Energy Performance of the three scenarios

From 2016-2018, the simulation models of each year are the same for all three scenarios. Tab. 13 shows the energy balance of all scenarios from 2016 till 2018. Energy demand can be checked in Tab. 7.

Tab. 13 Energy balance at Parc de l'Alba from 2016 to 2018 (MWh/year)

	2016	2017	2018
Energy Consumption			
Imported Electricity	16,842	16,957	17,525
Natural gas	92,890	94,854	92,378
Biogas	-	9,176	9,107
Primary Energy Consumption			
Imported electricity	39,881	40,154	41,499
Natural gas	111,004	113,348	110,391
Biogas	-	4,588	4,554
Total	150,885	158,090	156,444

In 2020, increase in demand is enough to implement the new plants according to the different scenarios (SCBC, GSHPs and BAU). The energy distribution depending on the scenarios is shown in Tab. 14.

Tab. 14 Energy balance at Parc de l'Alba in 2020 (MWh/year)

	SCBC	GSHPs	BAU
Energy Consumption			
Imported Electricity	41,383	44,964	10,067
Natural gas	93,528	98,304	288,712
Biomass	13,756	-	-
Primary Energy Consumption			
Imported electricity	97,995	106,475	23,838
Natural gas	111,765	117,473	345,010
Biomass	468	-	-
Total	210,228	223,948	368,848

From Tab. 14, it can be noticed that biomass contributes with primary energy nearly zero and heat pumps have slightly higher electricity consumption in comparison to SCBC scenario. The BAU scenario consumes a large amount of natural gas in comparison to the two RES based scenarios. This higher consumption is due to the fact that cogeneration engines at the ST-4 plant are running more hours than they were in the SCBC and GSHPs scenarios, since there are no RES-based energy conversion units (in BAU scenario). Also, in the BAU scenario, the backup boiler at the ST-4 plant is now allowed to operate throughout the whole year and not only in winter months like SCBC and GSHPs scenarios, where RES are prioritized. Finally, the ST-5 plant now has three cogeneration engines and another backup boiler, implying further use of natural gas.

7.2. Environmental assessment of the three scenarios

Tab. 15 shows the CO_2 emissions of all scenarios from 2016 till 2018, while emissions produced in 2020 for each scenario are shown in Tab. 16

Tab. 15 CO_2 emissions in Parc de l' Alba from 2016 till 2018

	2016	2017	2018
CO_2 emissions (tons/year)	29,418	30,872	30,443

Tab. 16 CO_2 emissions in Parc de l' Alba for 2020 (all scenarios)

	SCBC	GSHPs	BAU
CO_2 emissions (tons/year)	38,588	40,822	76,342

Tab. 16 clearly shows that the BAU scenario produces almost three times the amount of CO_2 when compared to the RES based scenarios, only because it is burning much more natural gas because of the new cogeneration engines, new backup boiler and the longer running hours of the old engines and old boiler.

7.3 Economic assessment of the three scenarios

Tab. 17 shows the main economic indicators of all scenarios from 2016 till 2018.

Tab. 17 Economic indicators of Parc de l' Alba from 2016 till 2018

	2016	2017	2018
Revenues	€ 7,651,061	€ 8,819,717	€ 10,155,051
Operating Costs	€ 5,079,909	€ 5,603,887	€ 5,887,325
EBITDA	€ 2,571,152	€ 3,215,829	€ 4,267,726
Free Cash Flow	€ 629,143	€ 1,962,362	€ 2,722,148

EBITDA refers to the earnings before interest, taxes, depreciation, and amortization. The main economic indicators of 2020 for each scenario are shown graphically in Fig. 5 and in tabular form (with NPV and CAPEX) in Tab. 18.

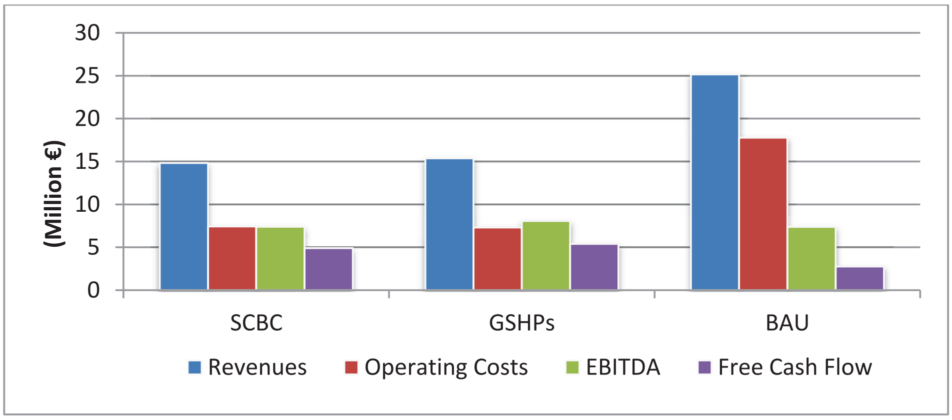

Fig. 5 Economic indicators of Parc de l' Alba for 2020 (all scenarios)

Tab. 18 Economic indicators of Parc de l' Alba for 2020 (all scenarios)

	SCBC	GSHPs	BAU
Revenues	€ 14,824,125	€ 15,371,743	€ 25,153,832
Operating Costs	€ 7,433,577	€ 7,299,363	€ 17,779,229
EBITDA	€ 7,390,549	€ 8,072,380	€ 7,374,604
Free Cash Flow	€ 4,894,266	€ 5,403,243	€ 2,765,192
NPV	€ 62,629,325	€ 61,226,405	€ 60,680,186
CAPEX	€ 5,730,128	€ 13,303,429	€ 10,047,775

Tab. 18 shows that the most profitable scenario is the SCBC scenario with the highest NPV and lowest CAPEX, followed by the GSHPs scenario and finally the least profitable being the BAU scenario. As mentioned in section 6 (page 7), the GSHPs were oversized in terms of the heating capacity since there is not a balanced demand between heating and cooling. The main consumers of Parc de l'Alba, located in a Mediterranean climate, are offices and data centers and hence cooling demand is significantly higher than heating. Hence, the option of using GSHPs is perhaps more profitable when there is a large demand of heating; the heat that is being 'wasted' to the soil could then have been sold to bring additional revenues. GSHPs have average energy efficiency roughly four times better than boilers burning biomass and using heat in absorption chillers of SCBC scenario. However, price of electricity is double the price of biomass and CAPEX of GSHPs is nearly three times higher than CAPEX of SCBC. Another important conclusion that can be drawn, in the case of Parc de l'Alba, is that it is apparently more profitable to import electricity from the grid and then sell it to the data centers at a profit, rather than self-production by cogeneration engines. Basically, the BAU scenario has higher taxes because of higher electricity export to the grid and higher natural gas consumption and hence it has a lower free cash flow.

Conclusions can be summarized in Fig. 6, which shows the environmental benefits and economic cost-effectiveness together. It is clear that the solution with the best results is the system with solar thermal cooling and biomass with absorption chillers (SCBC scenario).

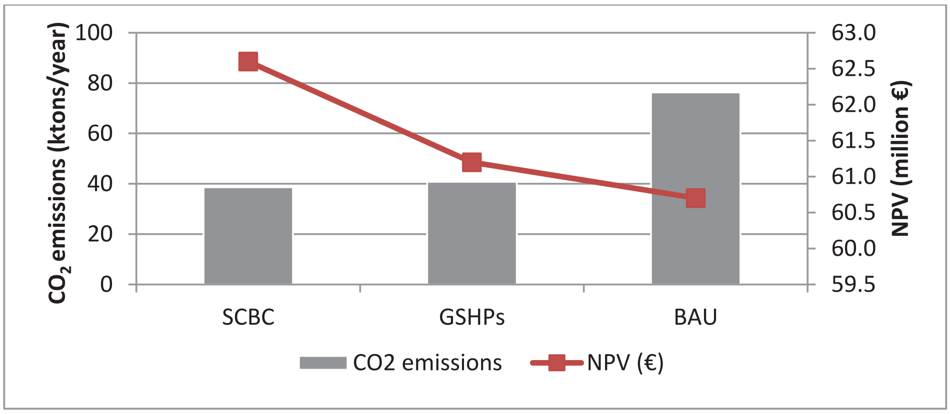

Fig. 6 Relation of environmental and economic key indicators for different scenarios in 2020

8. Conclusion

In this study, a comprehensive feasibility study has been performed to integrate renewable energy systems in the district heating and cooling network at Parc de l' Alba, a technology park in the region of Catalonia in Spain. Three 5-year projection scenarios were created on the energyPRO software, after validating a base model, in order to simulate the energy demand and supply of Parc de l'Alba from 2016 till 2020.

The projected cooling, heating and electricity demand of Parc de l'Alba were modelled on the software in accordance with the nature of the consumers, which were mainly offices, data centers and a particle accelerator. For all scenarios, data for the KPIs, namely primary energy consumption, CO_2 emissions and NPV, was collected by literature review and personal communications with relative authorities. All three scenarios incorporated a biogas boiler in the existing plant from 2016 till 2019. In 2020, different technologies were used to model the energy supply by the new plant. In scenario 1 (SCBC), a biomass boiler connected to an absorption chiller was mainly used to supply the cooling and heating demands. A small part of the cooling demand was provided by the solar thermal collectors installed on the roof of the plant connected to a small absorption chiller. Scenario 2 (GSHPs) mainly utilized ground source heat pumps that simultaneously provided heating and cooling, and the plant rooftop was used for installing solar photovoltaic panels to cater for some in-house electricity consumption of the plant. Scenario 3 (BAU) relied on cogeneration engines, an absorption chiller and a natural gas (backup) boiler to serve not only the cooling and heating demands of Parc de l'Alba, but also the electricity demands of the new data centers.

The results of the simulations and economic evaluation showed that the SCBC scenario is the most feasible option in comparison to the GSHPs scenario, due to its lower primary energy consumption (210,228 MWh/year vs. 223,949 MWh/year), lower CO_2 emissions (38,588 tons/year vs. 40,822 tons/year) and higher NPV (€ 62,629,325 vs. € 61,226,405) with lower CAPEX.

When talking about the SCBC scenario, solar thermal cooling has a great potential for primary energy savings and savings in CO_2 emissions (no combustion of any kind), but in the case of Parc de l'Alba, the limited roof area availability was the reason that solar thermal cooling could only contribute very little in the large cooling demand. Only 2% of the cooling demand of 2020 came from solar thermal cooling. This was expected because the maximum output of the system was 417 kW of cooling, while the total cooling capacity of ST-5 plant was 3,717 kW.

In the GSHPs scenario, the units are producing heating and cooling simultaneously, the former being larger in quantity than the latter, i.e. each kW of electricity (input to compressor) produces 4.2 kW of heating and 3.2 kW of cooling. For Parc de l'Alba, this excess heat has to be rejected to the soil and cannot be taken profit of. Hence, implementation of this technology is not so feasible for offices and data centers located in the Mediterranean climate (Catalonia) where cooling is the major requirement and not heating. Moreover, digging of boreholes to install GSHPs requires large areas of land, which is an additional investment.

In contrast to the solar thermal cooling system and the ground source heat pumps, biomass boilers (burning woodchips) connected to double effect absorption chillers appear to be the most favorable solution in this study. Not only is cost of the fuel low compared to importing electricity for GSHPs (for example in 2020, woodchips cost 33 €/MWh while electricity was imported at an average price of 60 €/MWh), but also there are large savings in primary energy consumption (wood chips have a PEF of 0.034 while for electricity it is 2.368). Additionally, for the same cooling capacities, biomass boilers and absorption chillers require less land space for installation compared to GSHPs and solar thermal cooling systems.

To conclude, in the frame of this study, biomass boilers connected to absorption chillers with support from solar thermal cooling are the most feasible renewable energy systems technology for the large district heating and cooling network of Parc de l'Alba.

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