‘Biomass CHP in the clean energy transition’

SmartCHP, a novel small-scale cogeneration unit based on a modified diesel engine to produce renewable heat and electricity from biomass

BIOOCOGEN 2030 webinar, December 7th, 2021

SmartCHP WP6 leader: Athanase Vafeas, Dowel Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 815259.

Outline

- The smartCHP project in brief
- Findings from SmartCHP market assessment
- Profitability analysis: a first use case
- Conclusions and next steps

NB: some of the results included in the presentation are part of recently submitted deliverable (not yet approved by the EC). The results represent the view of the authors (A. Vafeas Dowel Innovation, C. Alasis Exergia) with the support of coordinator and project partners

SmartCHP

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SmartCHP in a nutshell

SmartCHP is an EU-funded research project coordinated by Biomass Technology Group (**BTG**).

It involves European industrial companies, universities and innovation experts

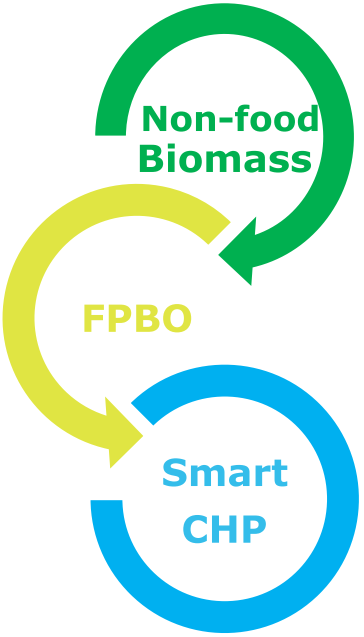
10 Partners

6 Countries

June 2019 to Nov. 2023

4 million

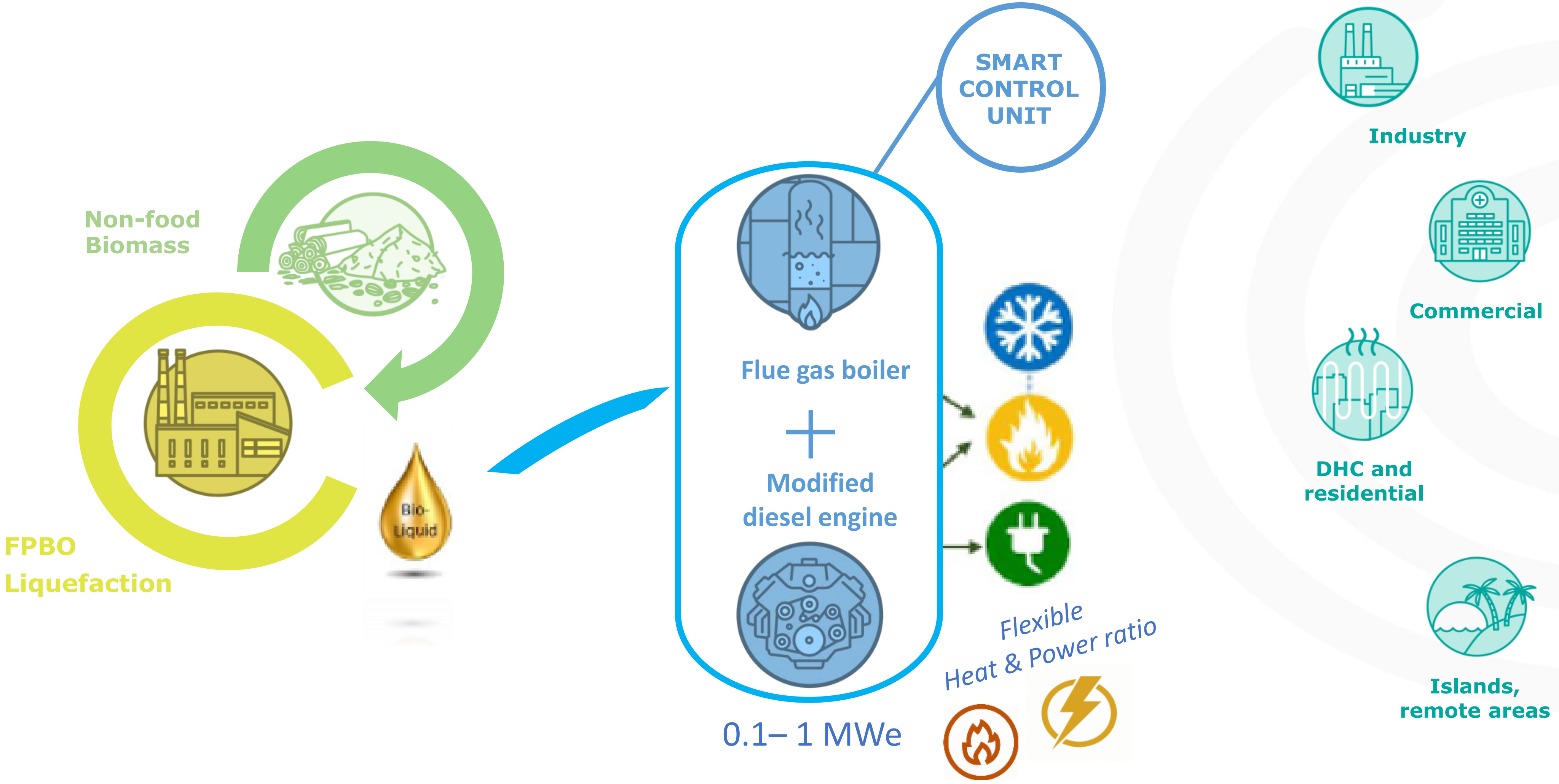
SmartCHP research project:
A combination of Cogeneration and Renewables



Scope: The design and development of…

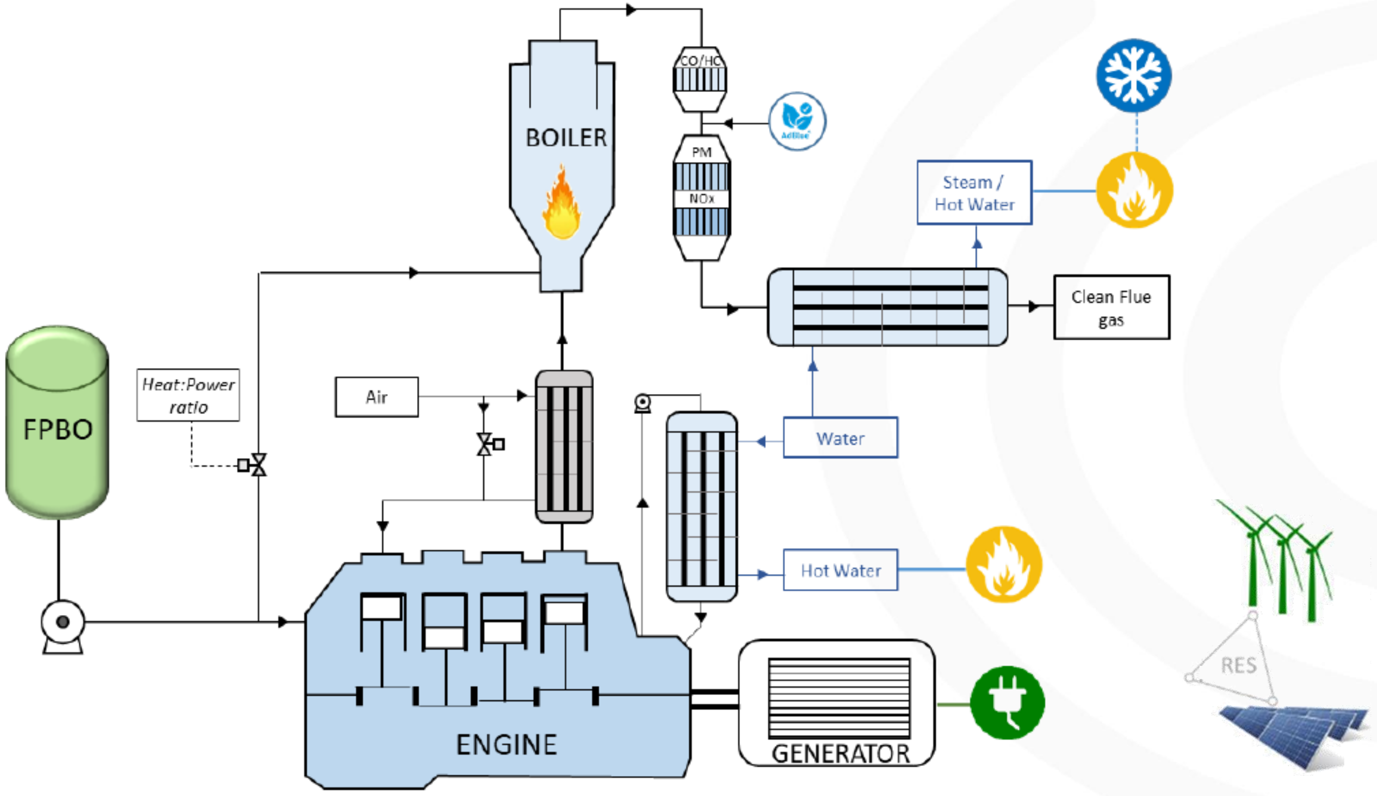
- ☑ A **highly flexible** small-scale Combined Heat and Power (CHP) system (100–1,000 kWe),…
- ☑ Fueled with **Fast Pyrolysis Bio-Oil** (FPBO) produced…
- ☑ From different types of **lignocellulosic biomass and/or residues** (agricultural, forestry or organic waste residues).

SmartCHP Project: from fields to energy demand



A clean cost-efficient energy system in the class of 0.1-1 MWe offering:

1. **High flexibility** of the heat to power ratio
2. **Integration** with other RES (PV, Wind)
3. **Standardized** fuel characteristics
4. Possibility of **retrofitting/revamping** old systems
5. **Ease of use** for targeted end-customers compared to other biomass-related solutions (e.g. fresh wood chips)
6. **Reduction of GHG emissions** compared to fossil fuels



SmartCHP

SmartCHP KPIs

Technical objectives

- Overall Energy Efficiency **>85%**
- Electric efficiency **> 40%** (@ 80% engine load)
- Variable **heat-to power** ratio ranging from **1:1 to 10:1** within a wide engine load range (from 30 to 100%) enabling to respond directly to actual energy demand

Environmental objectives

- **>80% GHG emission reduction** compared to fossil fuels (RED2 Methodology)

Economic objectives

- **CAPEX < 1,200 €/kWe** and
- **OPEX < 150 €/MWh** (100 €/MWh for electricity and 50 €/MWh for heat)

(at a FPBO price of 210-220 €/ton @ 16 GJ/ton)

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SmartCHP

Target Market segments

CHP of 150 kWel in Hotel Mons in Slovenia (source: Code2)

Commercial sector

- **Hotels**
- **Health Facilities**
- Leisure centers
- Shops and malls
- **Office buildings**
- **Public buildings for science and education**

DHC and residential sector

- Small scale District Heating / Cooling
- Large residential complexes

Industry and Agribusiness

- **Greenhouses**
- Agri-Business

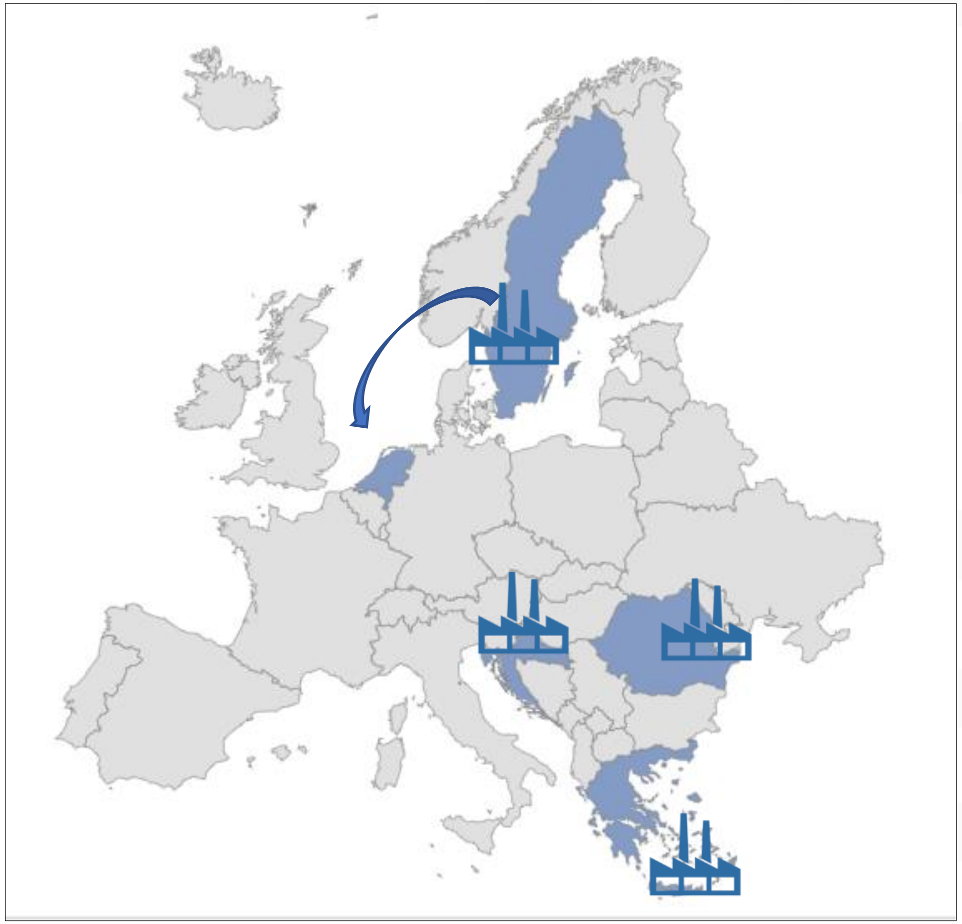
CHP of 330 kWel in Evangelisches Krankenhaus Hubertus Hospital in Berlin, Germany (source: Code2)

Host Countries for pilot implementation of SmartCHP Technology

Selection of pilot / focus countries based on

- Feedstock potential and availability
- Quality of biomass
- Electricity and heat prices
- Enabling Environment
- Geographical spread
- Logistics and infrastructure aspects

Country	Region	Biomass feedstock
Croatia	Central Europe	Miscanthus
Greece	Southern Europe	Olive kernel
Romania	Eastern Europe	Corn stover
Sweden	Northern Europe	Softwood forestry residues
The Netherlands	Western Europe	Pyrolysis oil import scenario from Sweden



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Qualification of Market potential (public deliverable D6.1)

- ***Geographic wise:*** 5 focus countries
- ***Market segment wise:*** 6 tentative profiles
- ***Market size wise:*** for each 5X6 segments an assessment based on characteristics of such segment in EU27

Croatia	Greece	The Netherlands	Romania	Sweden

Hotels	Office Buildings	Retail
Hospitals	Educational buildings	Greenhouses

Market segment	EU27
Hotels	○ >14 million bed places ○ ~6,7 million bedrooms ○ Annual average energy consumption: 200 to 400 kWh/m^2
Hospitals	○ ~2,5 million total available beds ○ Total average energy consumption: ~11,500 kWh/bed/year

Market segment	Croatia	Greece	The Netherlands	Romania	Sweden
Hotels (more than 100 rooms)	5 -50	25 - 250	10 - 120	5 -80	10 - 70
Hospitals (more than 200 beds)	2 - 3	4 - 5	5 - 6	10 - 15	2 - 3

Quantification of Market potential (public deliverable D6.1)

	Sisak, miscanthus	Kapariana, olive pomace	Import Sweden	Slobozia, corn stover	Borås, softwood
Market segment	**Croatia**	**Greece**	**The Netherlands**	**Romania**	**Sweden**
Hotels (more than 100 rooms)	5 -50	25 - 250	10 - 120	5 -80	10 - 70
Hospitals (more than 200 beds)	2 - 3	4 - 5	5 - 6	10 - 15	2 - 3
Office Buildings (more than 1000 m2)	50 - 100	25 - 150	25 - 400	25 - 300	25 - 800
Educational Buildings (more than 1000 m2)	20 - 100	25 - 50	50 - 100	Up to 400	50 - 100
Retail sector	5-50	3-30	25-240	12-120	20-200
Greenhouses (more than 8000 m2)	25 - 50	100 - 250	More than 100	200 - 500	10 - 15
Estimation of SmartCHP units	100 - 350	180 - 735	200 - 1000	350 - 1400	120 - 1200

Nb. of units

Our first Case study: hospital in Greece

Outline

- The smartCHP project in brief
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  --> The daily operation of a SmartCHP system in Venizelio hospital in Heraklion, Crete
- Conclusions and next steps

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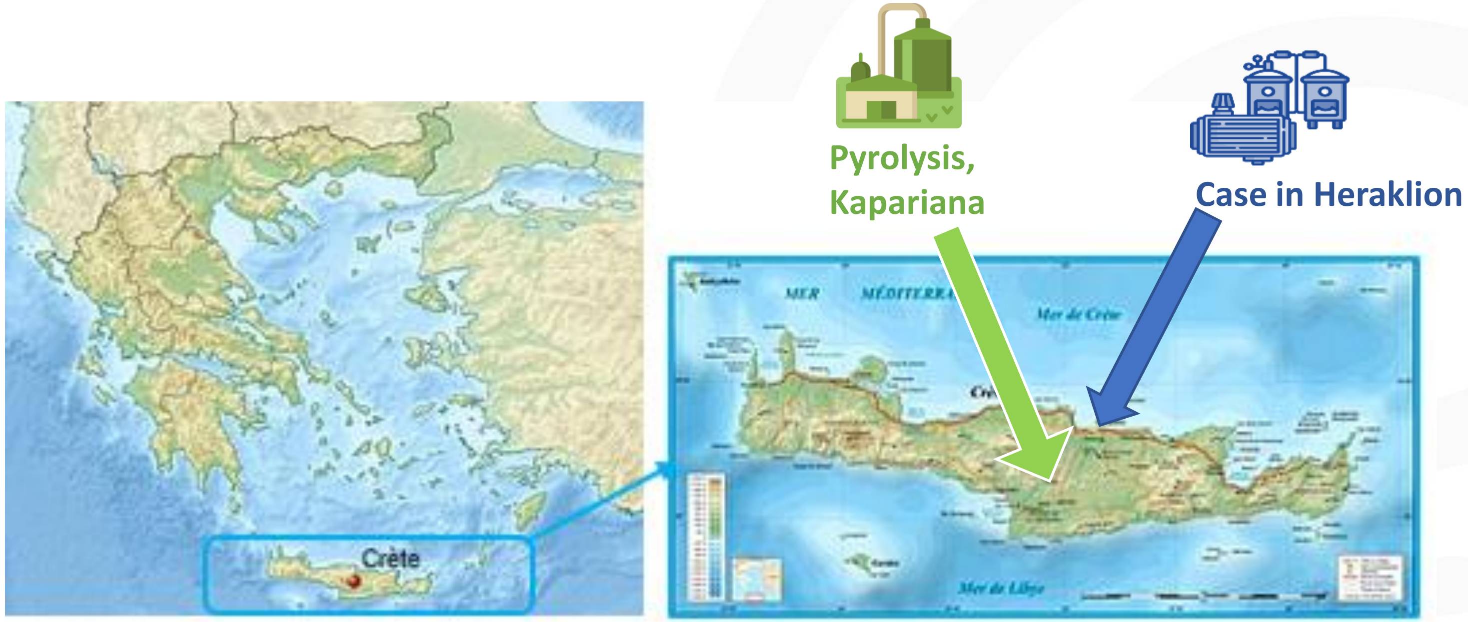
Framework of Use Case analysis: focus on ③ and ④

	Key parameters along the value chain stage			
	Biomass	Pyrolysis	SmartCHP	Integration and Use
What are the generic parameters?	Use case template Economic and financial parameters common to the analysis			
		❷	❸	
What are the locally based features?	❶			❹

The proposed case study: The Venizelio hospital in one of the targeted countries (Greece)

- Case selected since **documented** in terms of energy needs and energy bills
- Venizelio hospital in **Heraklion, Crete**: 26 172 m2, 440 beds, 1000 employees
- Established in **1967**, quite old energy systems with low efficiency, dependance on thermal oil
- Located at **50 km** from the pyrolysis plant



source J. Vourdoubas, **Energy Consumption and Carbon Emissions in Venizelio Hospital in Crete, Greece: can it be Carbon Neutral?** Journal of Engineering and Architecture, 2018)

The seasonal energy needs of the Venizelio case

Annual, reported

- Electricity needs 4895 MWh
- Thermal needs 2444 MWh

Seasonal, assumption proxies

Seasonal needs (MWh)	Winter	Spring	Summer	Autumn	Total
Flat for Electricity	1224	1224	1224	1224	**4895**
Limited seasonal variation for Heat	733	611	489	611	**2444**

1st step: assessing the profitability of a simple cogeneration system with no activation of the 'smart' operation mode (no 'heat booster'), annual simulation

- Based on the thermal annual needs we opted for a **cogeneration system of 500 kWe fed by pyrolysis oil:**
  - Design of the CHP based on the **base heating demand**
  - Operation mode: **5000 hours** and Capacity Factor of **70%** recommended and used by ABM to provide first estimations of CAPEX and OPEX
  - A first estimation of FPBO unit cost taken at **0.35€/l** (or 5.4 €/kWh input)
  - We considered fixed efficiencies for the smartCHP unit, respectively at **32%** for electric and **53%** for heat efficiency
  - We considered **contractual energy prices** as reported from the hospital energy bills
- Under these assumptions and data, annual energy savings are estimated at **37 k€/year** but a number of bias result from the **annual simulation**
  - Unability to capture unbalances (electricity in excess, heat flaring, energy not served)
  - Mode of operation too rigid

2nd step: we need to simulate the daily operation to better grasp the profitability:

- Amount of daily energy needs
- Hourly profiles for typical days

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The energy demand of the case: thermal needs

Volumes

Seasonal breakdown of demand

Seasonal needs (MWh)	Winter	Spring	Summer	Autumn	Total
Flat for Electricity	1224	1224	1224	1224	**4895**
Limited seasonal variation for Heat	733	611	489	611	**2444**

Daily (typical days in winter and summer seasons): assuming 91 days per season

Venizelio hospital thermal needs	Winter	Summer	Total
Seasonal thermal needs (MWh)	733	489	2444
Thermal needs for a typical day (MWh)	8,033	5,359	6,695

8.0 MWh/winter day

5.4 MWh/summer day

SmartCHP

The energy demand of the case: electric needs

Volumes

Seasonal breakdown of demand

Seasonal needs (MWh)	Winter	Spring	Summer	Autumn	Total
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Daily (typical days in winter and summer seasons): assuming 91 days per season

13.4 MWh/day

Same amount for a winter day and a summer day

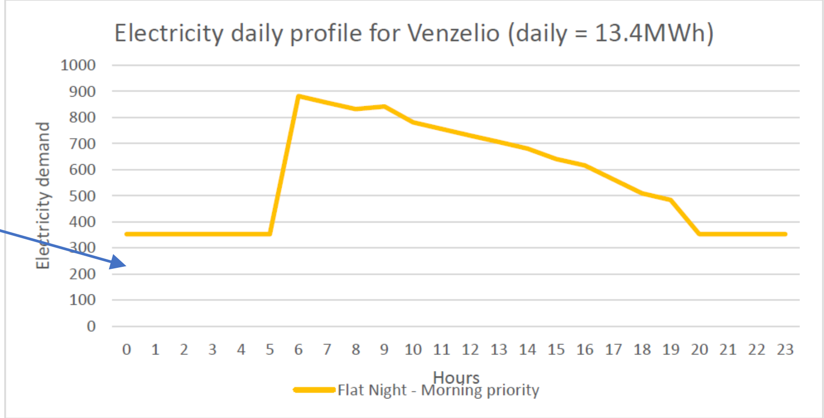
Daily load demand patterns in Venizelio hospital

Demand profiles

Electricity daily consumption

13.4 MWh/day

Electricity profile: flat night, priority morning



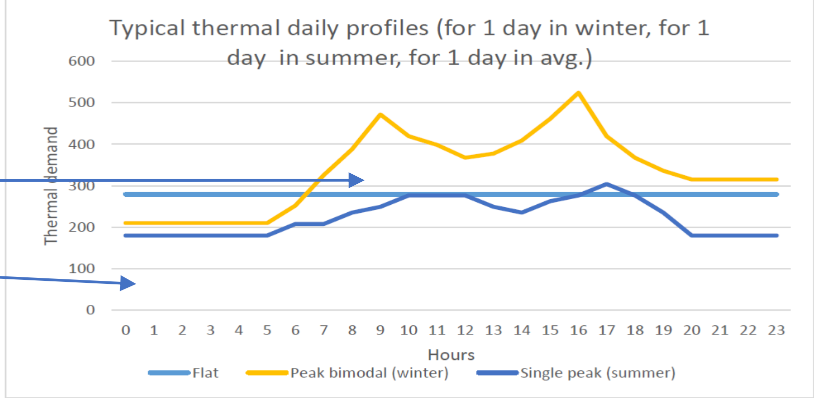
Profiles created using literature on energy demand and adjusted to the daily amounts

Thermal profile: flat night, 1 peak in summer, 2 in winter

Thermal daily consumption

8.0 MWh/winter day

5.4 MWh/summer day



Let's compare two operation modes, both compliant with the operating constraints: N= 5000 hours per year at a capacity factor 70% per year

Cogeneration profiles

Operation mode 1 'Flat':

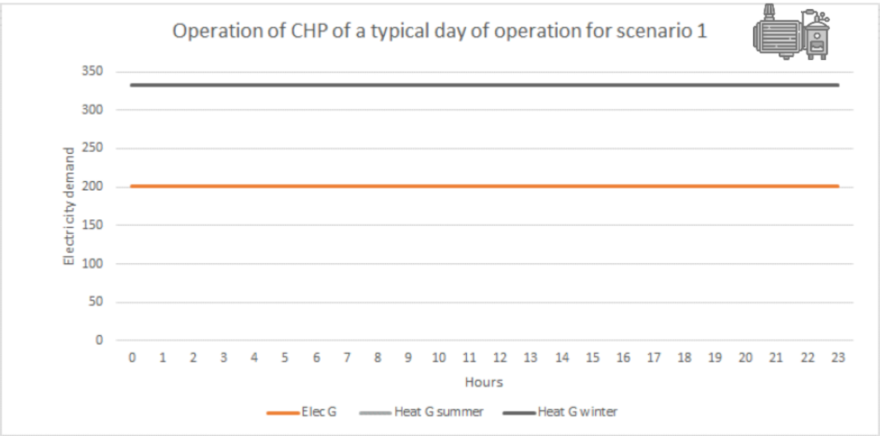
- no daily variation
- priority to summer for a total of 5000h/year

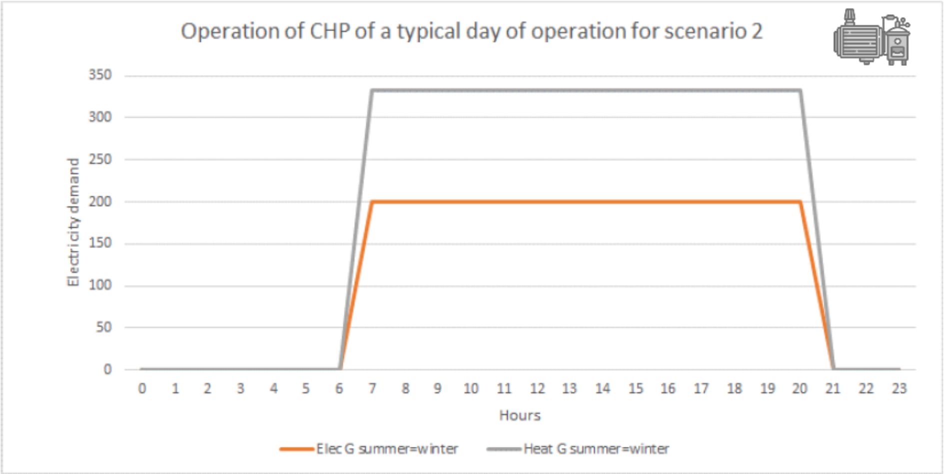
Winter	Spring	Summer	Autumn
0	26 days	91 days	91 days

Operation mode 2 ' Day on – Night off'

- Operation during 15 hours a day for a total of 5000h/year,
- 30 days 'off' in summer

Winter	Spring	Summer	Autumn
91 days	91 days	60 days	91 days





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Cogeneration profiles

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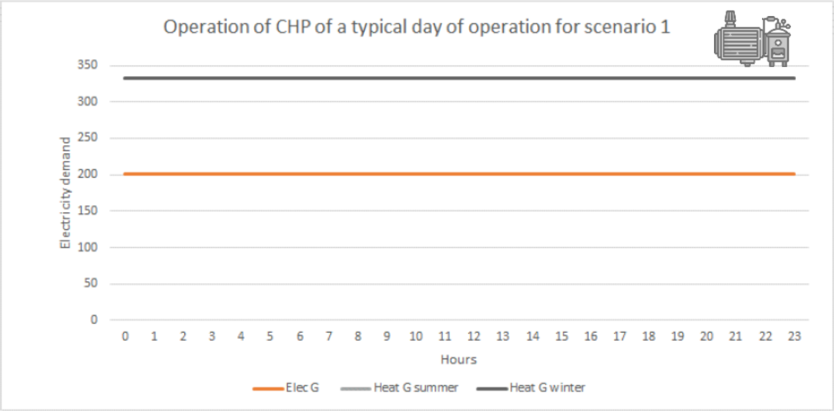

Operation mode 2 ‘ Day on – Night off’

- Operation during 15 hours a day for a total of 5000h/year,
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Winter	Spring	Summer	Autumn
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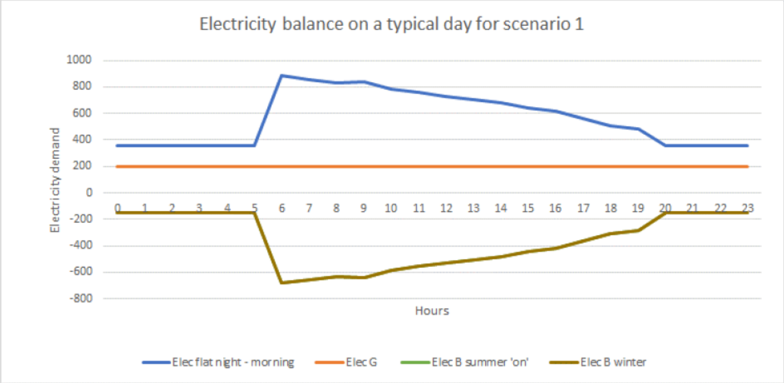
Energy balance: demand-generation (for a typical day 'scenario 1')

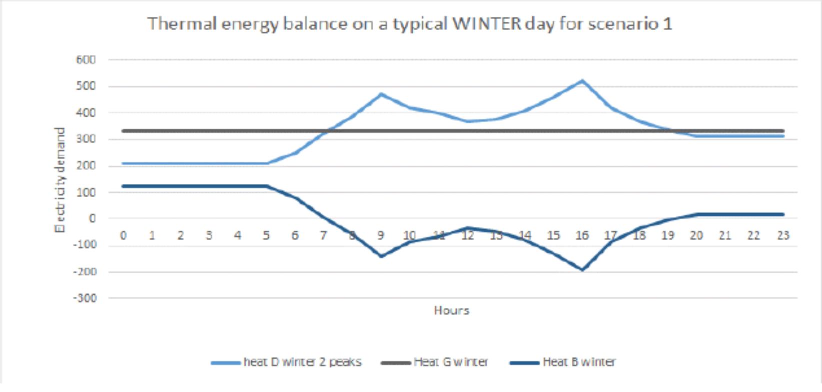
Electricity balance (Winter day= Summer day)



13.4 MWh/day

- CHP is working during 26 winter +182 summer days
- For a winter day 'on'= summer day 'on': Electricity balance is always <0
- No excess electricity

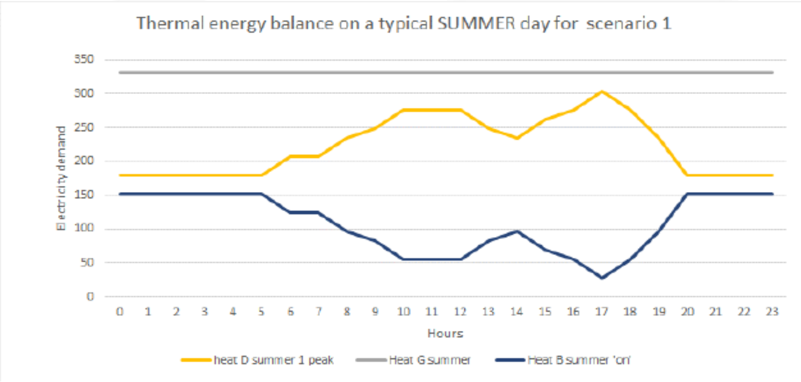
Thermal energy balance (winter day)



8.0 MWh/winter day

- Winter day: Thermal balance is >0 for 0am to 5am=> **heat in excess and heat flaring!**

Thermal energy balance (summer day)



5.4 MWh/summer day

- Summer day: Thermal balance is very >0 all the day=> **heat flaring!**

⇒ **Which impacts on energy not served and energy savings for the 'flat' operating scenario of a 500 kWe system, 5000h, priority summer?**

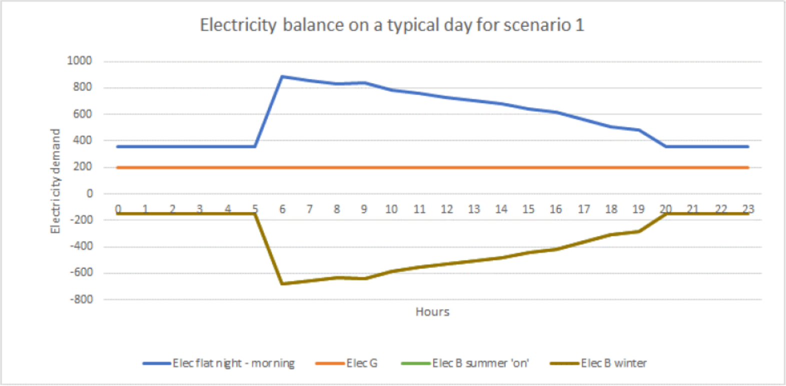
(assuming the contractual energy prices as reported by the hospital)

p_E	0,139	€/kWh
p_H	0,108	€/kWh
p_fpbo	0,054	€/kWh

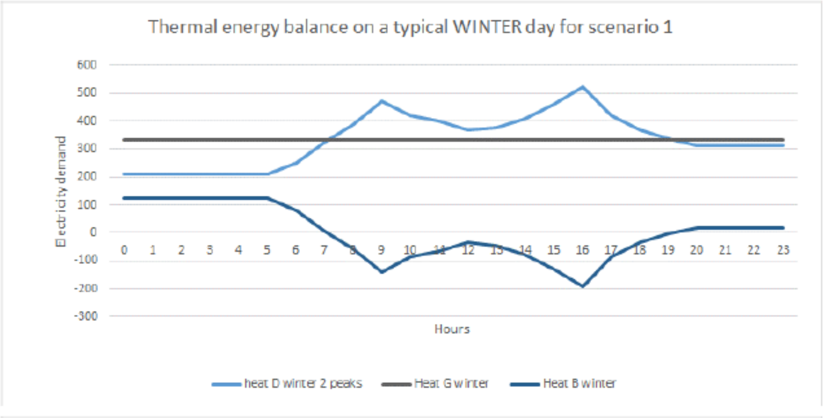
SmartCHP

Value and savings (for a typical day ‘scenario 1’, 1st trial)

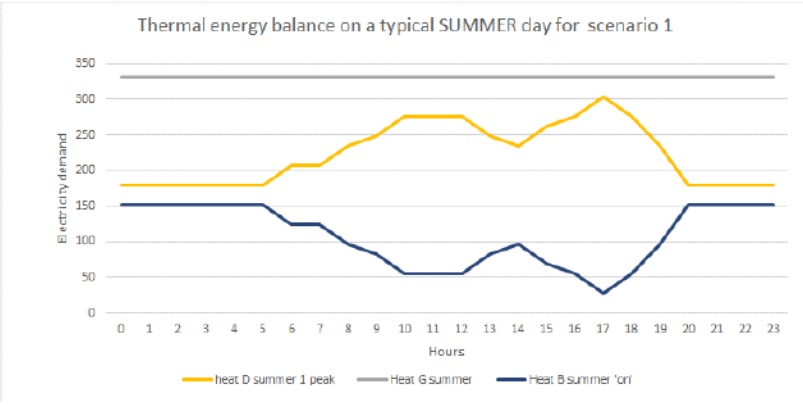
Electricity balance (Winter day= Summer day)



Thermal energy balance (winter day)



Thermal energy balance (summer day)



€/typical day	Scenario 1: flat 5000 hours			
	day winter 'on'	day summer 'on'	day winter 'off'	Total 1 year
Nb such days	*26*	*182*	*157*	*365*
REVENUE 1 day	1430	1245	0	263832
Value E	669	669	0	139068
Value H	762	577	0	124764
E Selling back	0	0	0	0
Heat flaring	124	363	0	69312
COST 1 day	1123	1123	310	282241
Cost of EnS	1297	1194	2727	679318
Savings 1 day	**308**	**123**	**-310**	**-18409**

⇒ Last scenario not profitable due to the high number of ‘off days’

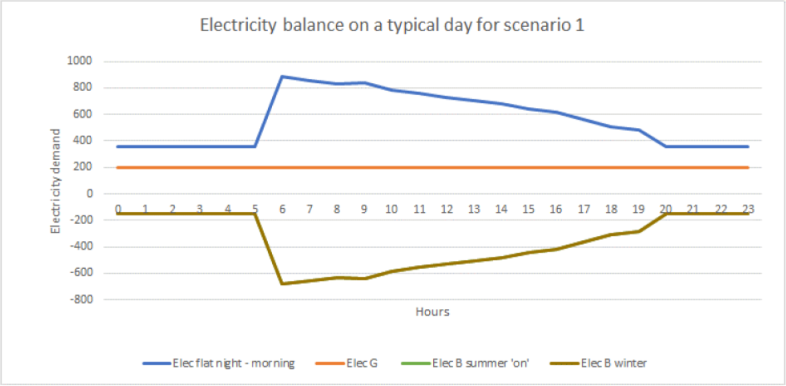
⇒ We would need to relax the 5000h constraint, meaning more operating days in winter.

⇒ Let’s add 30 days of operation in winter

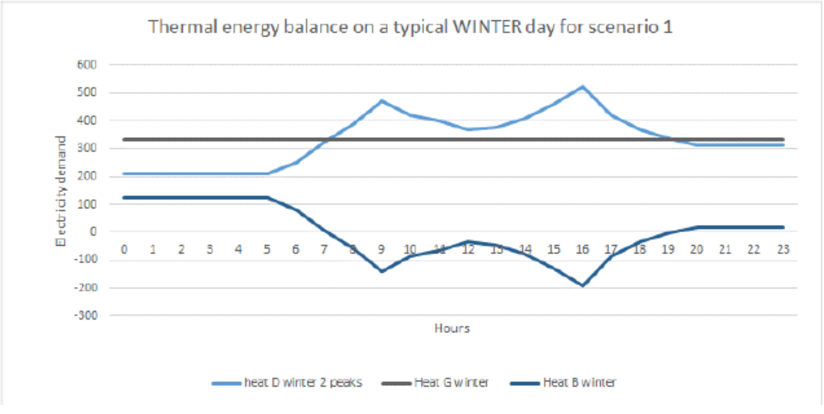
SmartCHP

Value and savings (for a typical day 'scenario 1', 2nd trial)

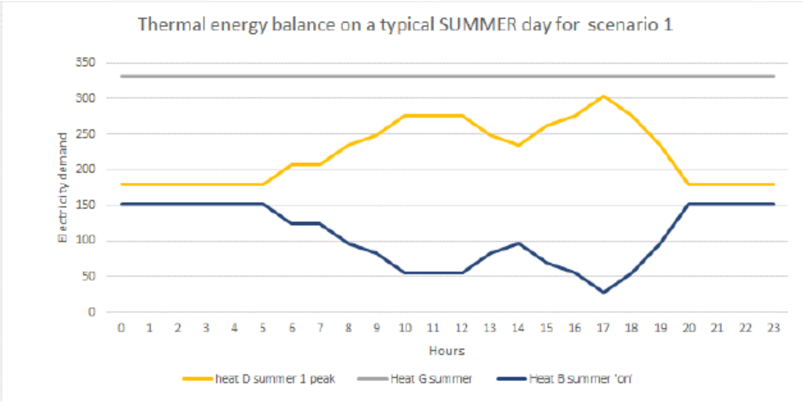
Electricity balance (Winter day= Summer day)



Thermal energy balance (winter day)



Thermal energy balance (summer day)



€/typical day	Scenario 1: flat 5700 hours			
	day winter 'on'	day summer 'on'	day winter 'off'	Total 1 year
Nb such days	*56*	*182*	*127*	*365*
REVENUE 1 day	1430	1245	0	306744
Value E	669	669	0	159126
Value H	762	577	0	147618
E Selling back	0	0	0	0
Heat flaring	124	363	0	73032
COST 1 day	1123	1123	310	306606
Cost of EnS	1297	1194	2727	636406
Savings 1 day	**308**	**123**	**-310**	**138**

⇒ With 5700 hours of operation, a balance is reached for the 'flat' mode of operation under these assumptions on demand, profiles and values

Let’s compare two operation modes, both compliant with the operating constraints: N= 5000 hours per year at a capacity factor 70% per year

Operation mode 1 ‘Flat’:

- no daily variation
- priority to summer for a total of 5000h/year

Winter	Spring	Summer	Autumn
0	26 days	91 days	91 days

Operation mode 2 ‘ Day on – Night off’

- Operation during 15 hours a day for a total of 5000h/year,
- 30 days ‘off’ in summer

Winter	Spring	Summer	Autumn
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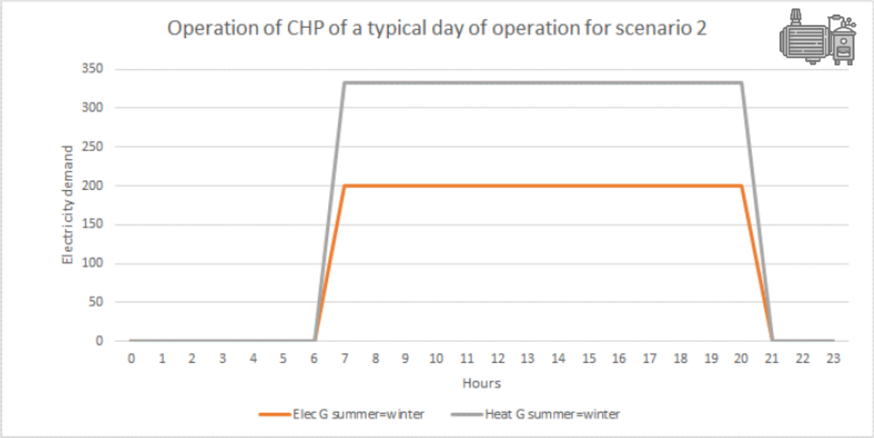
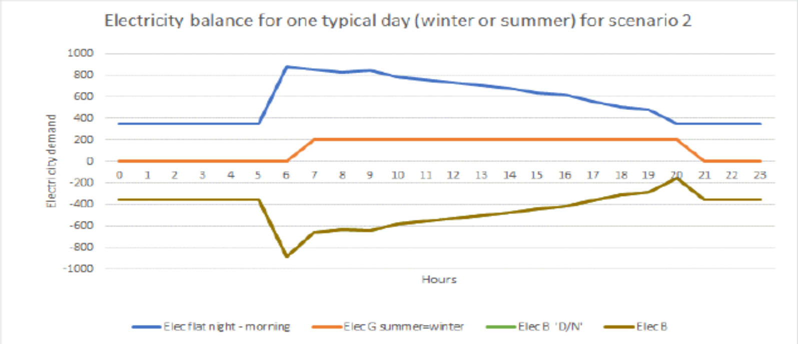


Energy balance: demand-generation (for a typical day scenario 2)

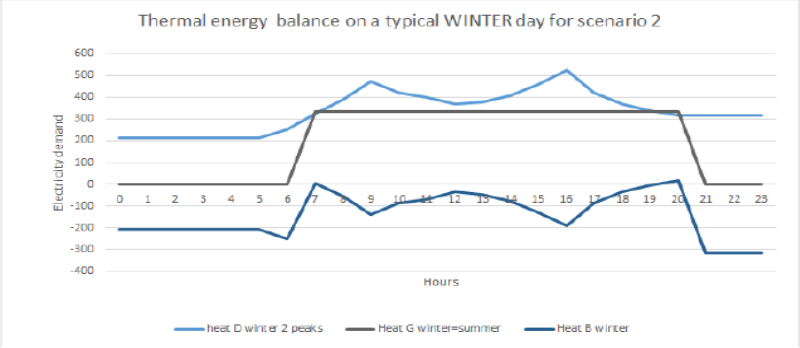
Electricity balance (Winter day= Summer day)



13.4 MWh/day

- For a winter day= Summer day, Electricity balance is always <0 , no excess electricity

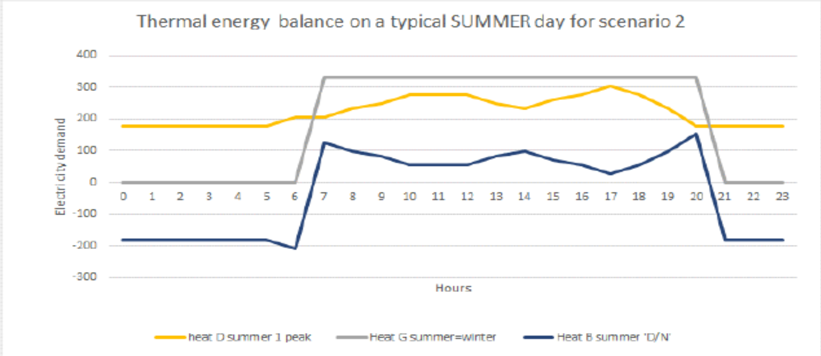
Thermal energy balance (winter day)



8.0 MWh/winter day

- Winter day: Thermal balance is <0 during almost day and quite balanced from 7pm to 12pm

Thermal energy balance (summer day)



5.4 MWh/summer day

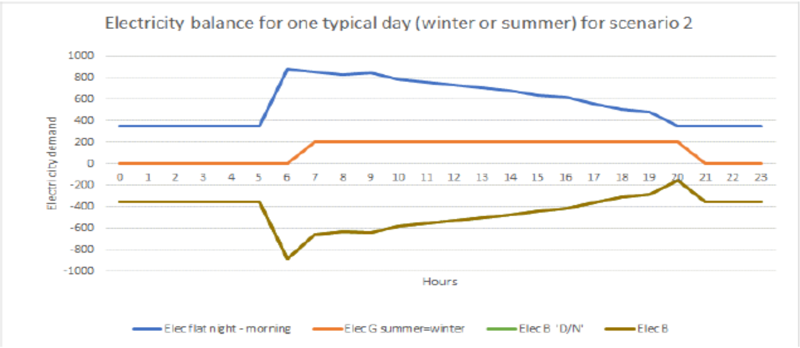
- Summer day: Thermal balance is <0 during night (CHP is 'off') and **slightly in excess during daytime in summer**=> heat flaring or need to adjust CF during these periods

⇒ Impacts on energy savings is expected to be improved compared to scenario 1

(assuming the contractual energy prices as reported by the Venizelio hospital)

Value and savings (for a typical day scenario 2)

Electricity balance (Winter day= Summer day)



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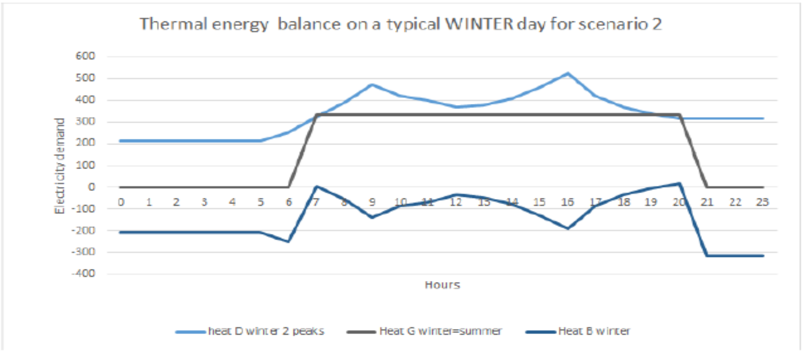

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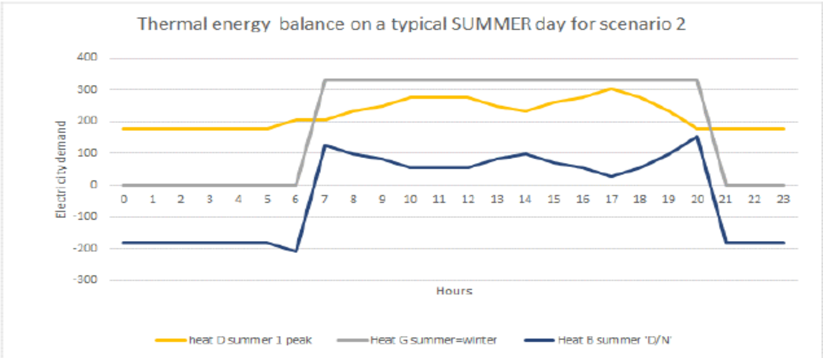
Thermal energy balance (summer day)



5.4 MWh/summer day

- Summer day: Thermal balance is <0 during night (CHP is ‘off’) and **slightly in excess during daytime in summer**=> heat flaring or need to adjust CF during these periods

	Scenario 2: 5000 hours of operation, ‘day & night’			
€/typical day	day winter on	day winter on	summer CHP off	Total 1 year
Nb such days	*273*	*61*	*31*	*365*
REVENUE 1 day	888	771	0	289359
Value E	390	390	0	130265
Value H	498	380	0	159094
E Selling back	0	0	0	0
Heat flaring	3	155	0	10380
COST 1 day	784	784	310	271547
Cost of EnS	1840	1669	2440	679689
Savings 1 day	**104**	**-14**	-310	**17811**

⇒ Impacts are indeed much improved with about the same hours of operations (5010 =334 *15 hours /day)

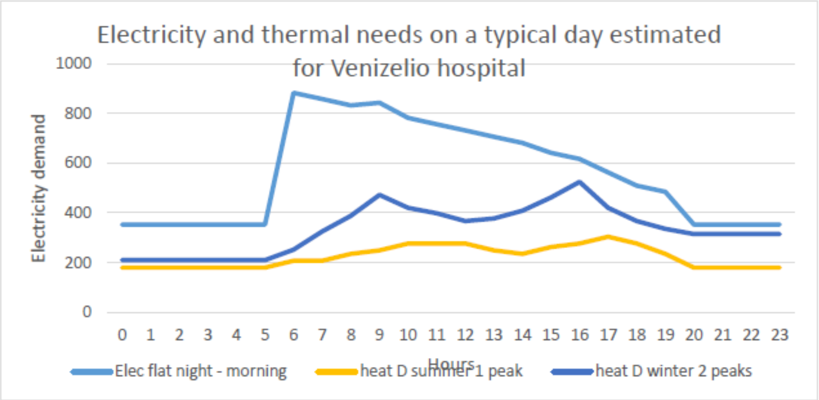
⇒ Mode of operation matters!

Take away:

- Simulation of daily operations according to two very different scenarios highlighted the prime importance of a few parameters:
  - **Cost of biooil**: impacts the Opex (direct cost)
  - **Non-biooil expenditures** including maintenance, depreciation and other ancillary fuels needed to operate the system
  - Contractual **costs of energy** (here: oil and electricity) since impact the revenue model
  - **Operation mode**
  - **SmartCHP CAPEX** for the financial analysis with cumulated DCF
  - Other parameters that have not been considered in the case study (incentives, excess electricity selling back)

...More cases to go forward:

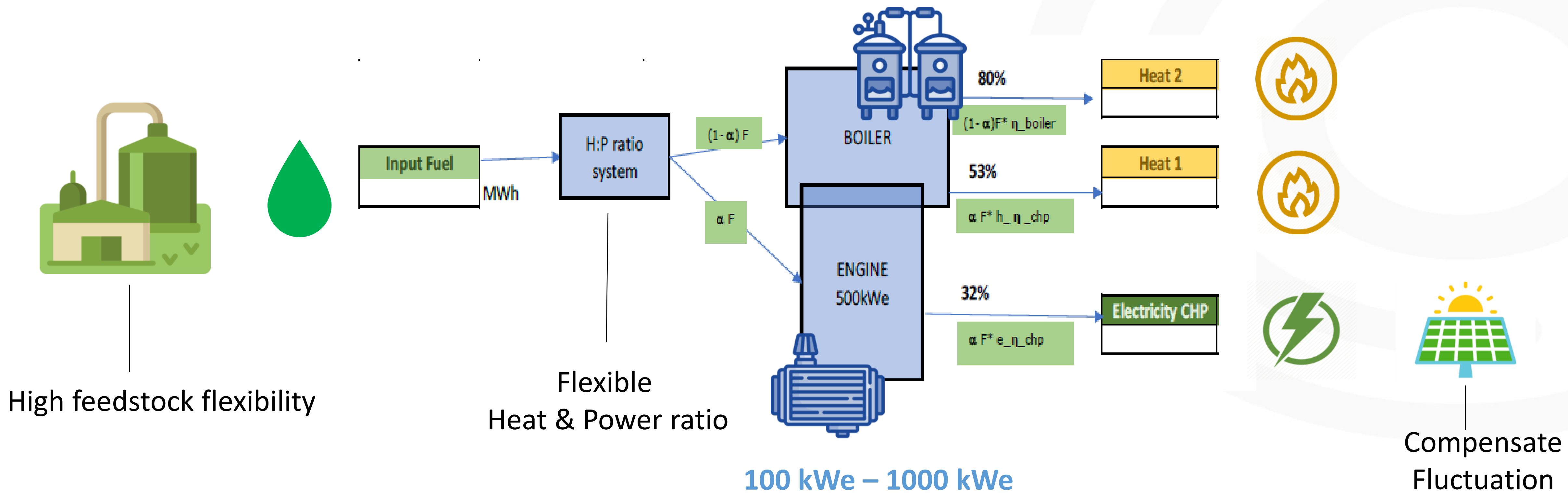
- In the present case electricity needs exceed the heating needs (H:E ratio of the case being close to 0.5)
- ...with Electricity and Heat demand peaks being **decoupled**



- Our next objective is to show the **flexible value of SmartCHP able to adapt to a wide spectrum of H:E**
- Cases with higher H:E will be deployed with a **preference for actual consumption data**
- Should you have candidate use cases, please feel free to contact us!

Flexible operation to match to H:E ratios >1

- **Direct injection of additional biooil in the boiler** in addition to the SmartCHP engine feed-in to adapt to high level of heat demand in comparison to electricity
- This is of particular relevance for combining SmartCHP with RES generation in **hybrid systems**



Thank you!

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