SmartCHP
COGENERATING A RENEWABLE FUTURE

Financial and economic analysis of SmartCHP: an innovative biomass-based cogeneration installation

www.smartchp.eu

Objectives of this report

This report was developed in the context of the SmartCHP project, funded by the European Commission.

It aims at summarising the findings of the "Final financial and economic analysis" of the project in a short and impactful manner.

For more details on the project: visit our Zenodo!

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 815259.

Financial and economic analysis

SmartCHP is an innovation biomass-based cogeneration installation, where heat and power generation are combined in a modified hybrid diesel generator and flue gas boiler system, fuelled with fast-pyrolysis bio-oil (FPBO).
This provides a flexible heat-to-power ratio that aims at covering a wide range of energy needs with the minimum intervention of external production units (grid/gas boiler) to cover the energy not served.

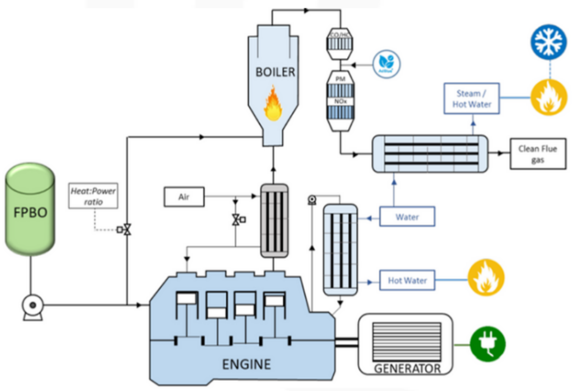
A techno-economic analysis was conducted to demonstrate the commercial potential of SmartCHP as a local energy production system in the medium-term. Indeed, by its end, the R&I EC funded project has achieved a first prototype at TRL5. Until the installation is ready for commercial deployment, technical and economic improvements are indeed still expected.

SmartCHP components

A diesel generator has been modified to run on FPBO and generate heat and power. A boiler has been added to provide a more flexible installation, and a flue gas treatment ensures reduced and clean emissions.

The original mode of functioning is as follows:

- When power demand is high and heat demand is low, there is no need to generate extra heat, so only the diesel generator operates, and the boiler is off.
- If heat demand is high, heat from the CHP engine might not be enough to cover it. Therefore, extra heat should be generated by the system: burner/boiler.



Alternatives SmartCHP

The flexibility of the diesel engine can be enhanced by different solutions other than the boiler. Alternative systems (combination with electrical heaters or heat pumps) have therefore been explored to convert the electricity produced by SmartCHP to heat. The Techno-Economic Analysis (TEA) shows that:

- Both solutions prove to be very flexible, added to a SmartCHP installation.
- With the same amount of electricity input, electrical heaters produce less heat than heat pumps. Alternatives with electrical heaters will therefore have higher costs for heat not served than alternatives with heat pumps.
- As a results, if SmartCHP is combined with heat pumps rather than electrical heaters, more electricity produced in excess will stay available for valorisation (through a sell-back to the grid).
- Regarding CAPEX, electrical heaters are significantly less expensive than heat pumps.

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Use cases' selection

Results of the market analysis

The Market Analysis, realised in the project, identified and selected five countries of interest (based on the availability of biomass) and six key sectors (based on their size and average energy consumption levels).

Selected countries and identified biomass feed for FPBO production:

Greece
Olive kernel oil

Netherlands
Softwood dust from Sweden

Sweden
Softwood dust

Croatia
Miscanthus

Romania
Corn stover

Market potential at EU level:

HOTEL
More than 32 million beds in **hotels**

More than 160 000 **greenhouses**

2.5 million beds in **hospitals**

Millions of **retail buildings**

1 million **educational buildings**

2000 million of **office buildings**

Seven use cases

Based on the market analysis, seven use cases have been identified through literature review and direct contact:

Four use cases in Greece:

HOTEL

One use case in Croatia:

One use case in the Netherlands:

One use case in Romania:

ESCO

Five of these use cases are presented in the pages below.

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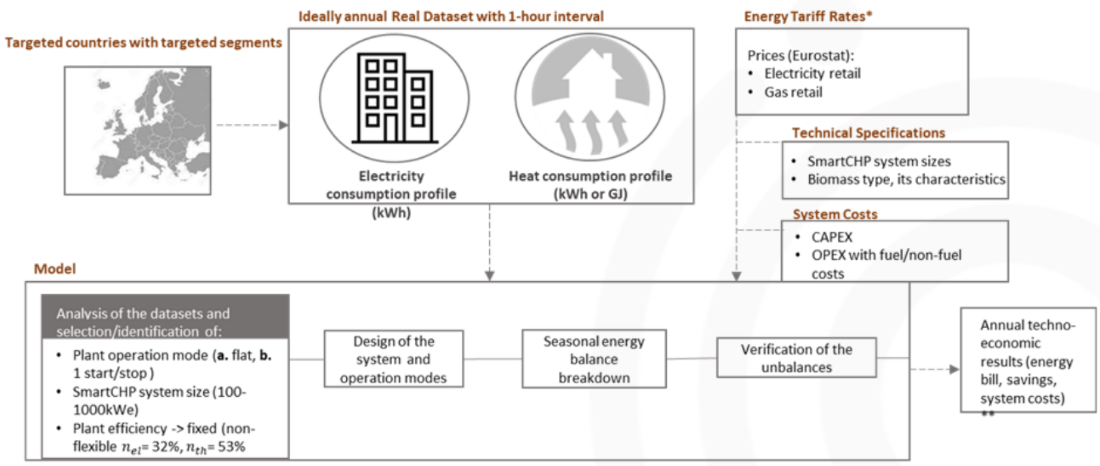
Methodology and approach of the TEA

The methodology consists in four main successive steps:

- Definition of the sizing and operation modes of SmartCHP
- Calculation of energy unbalances
- Economic and financial analysis
- Sensitivity analyses.

For the calculations, an Excel simulator was developed. It is based on the hourly energy consumption data for a year, the energy prices in the different countries (source: Eurostat), the engine size and the operation mode (engine load, start/stops, seasonal breaks, etc.)



** Source: Eurostat*
*** Transportation costs are not considered*

Precautionary approach

The approach used to structure the TEA is crucial: a precautionary approach was chosen to prevent strong discrepancies between this initial profitability analysis and future ones that will need to be conducted closer to the commercial phase.

- Precautionary approach on the electricity efficiency:

The profitability analyses for each use cases was firstly conducted based on a 32% electricity efficiency, which is considered a conventional efficiency rate for cogeneration by the literature.
An electricity efficiency of 40%, the target of SmartCHP, was then tested as part of a sensitivity analysis for each use case. This is because SmartCHP prototype was not running at the time the TEA was developed, and therefore the 40% electricity efficiency could not be confirmed by that time.

- Precautionary approach on discount rate of the present value:

The discount rate is the investment rate of return that is applied to the present value calculation. It is highly subjective because it represents the expected rate of return you would receive if you had invested today's money for a period of time.
A risk-free rate is the minimum return an investor expects for any investment. This is often calculated based on treasury bills (around 3-4% in Europe in November 2023, depending on the country).
For the financial analysis of SmartCHP, a rather high discount rate of 8% has been chosen, to ensure that, on the long-term, it can still be considered "risk-free", and maybe even as a financial investment besides its purely economic profitability. The financial calculation presented in the use cases' results below are based on this approach.

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Main assumptions of the TEA

As the prototype was not yet running when this TEA was developed, several assumptions have been taken:

Heat base following mode

In order to fully benefit from the energetic and environmentally added value that the use of CHP facilities can offer, they are usually run in a heat-driven way.

It should thus be decide whether the base or peak loads should be covered by the CHP, keeping in mind that all initial energy demand must be covered.

Covering the maximum heat demand is interesting, as it allows having only one installation for the entire heat production. However, this causes CHP to switch on and off, which often affect their lifetime and (notably in the case of SmartCHP), the energy consumption (higher amounts of FPBO are used when switching SmartCHP on and off).

Operation scenarios

The collected data used in most of the use cases are hourly consumption data. This means that the energy unbalances can be calculated at the hourly scale.
The question is then the following: in the case of a fixed control, how often shall we consider a change in the production mode?
The answer to this question has a major impact to decrease the energy imbalances and wastes: the closer the CHP production is adjusted to the real-time consumption, the more energy efficient it will be.

For tractability reasons, we adopted a modification of the operation mode at about a monthly time step. This appeared as a trade-off between the average heat needs following the seasonal cycle and the setting of operation points without any control system.

Reference price: costs of energy

To assess the profitability of SmartCHP, a reference point was needed. Therefore, a reference energy bill as been calcultated for each use case, resulting from the actual energy consumption valorised at the local energy market prices.
These bills are fictive, as real customers bill depend on many factors that were not available for this study.
Two major assumptions have been made:

- For heat production, the gas price serves as a reference. Since heat efficiency produced from gas being around 90%, the heat price of the reference bill is calculated using the gas price +10%.
- Energy prices are taken directly on Eurostat (prices of the reference year 2021 for non-residential clients in each country of interest, for the class of consumption corresponding to the segment), both for electricity and gas.

Transport

The impact of the transport of FPBO on SmartCHP profitability has been taken into account both in the market analysis (when selecting the potential countries of interest and ensuring that they have access to sufficient biomass) and in the modelling of CAPEX and OPEX by ABM.
Indeed, part of the OPEX used for the profitability analysis represents the impact of the local terrestrial transport of fuel, estimated at 7€/tonne, considering an average distince of 50km.

For the use case in the Netherlands, as the FPBO would come from Sweden, the costs for maritime transport were estimated based on a collection of transport quotes.

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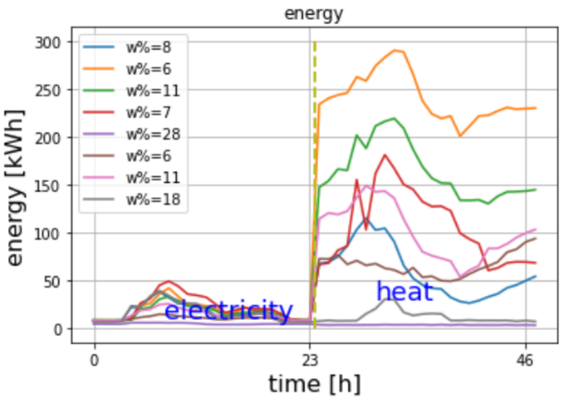
Flexible control

One key benefit of SmartCHP's concept (including its newest alternatives) is based on the ability to increase and exploit the cogeneration's flexibility. However, the flexibility range will only be operated to its fullest if an appropriate control is created. This task has been carried out by SmartCHP's partner DTU and aimed at using the capacities of both the engine and the boiler to create the flexibility of the control. The algorithm has been designed for SmartCHP prototype (50 kWe) and tested on three use cases, with the adaptation of the data to fit the prototype's size.

To build the model, the daily energy consumption profiles of a user are analysed and grouped into "clusters". A cluster is a group of days with similar energy consumption profiles, which may not be consecutive or even be in the same months. Each cluster has a "weight" which corresponds to the number of days with similar profiles for one year. The "weight" reflects thus its relative importance.

The profitability is then resulting from the valorisation of the energy flows (energy served, energy not served based on the energy balance), and the costs linked to the flexible control.



Example of the clusters and their weight for a use case

The following conclusions can be drawn on the profitability of the flexible control: in a heat-base mode, the system proves to be very efficient, with almost no heat produced in excess, and therefore almost no energy loss. The flexible control is also very much aligned with the electricity needs, which is an important difference between the results obtained with the fixed control and the flexible control.
However, FPBO costs are raised compared to the fixed control. Being more aligned with the power consumption also means that there is less electricity produced in excess, and that the valorisation opportunities are reduced. This can be adapted in case the objective of the end-user would be to sell electricity back to the grid.

Hybrid use cases

Reference point: a paper from Greg Perkins* states that " integration of solar PV and the production and combustion of biocrude and biogas using fast pyrolysis of biomass leads to competitively priced dispatchable renewable energy that is forecast to be cheaper that using solar PV and batteries for the foreseeable future".

Can this be demonstrated by SmartCHP?

Through SmartCHP's use cases, a number of conditions appear to maximise its value:

- The **local contractual framework** for valorising the electricity in excess should be in place.
- Operating the SmartCHP system in a **heat based following mode** (as for conventional cogeneration) enables to capture the energy value (of each vector: energy value of heat and energy value of electricity) according to the assumed efficiency levels.
- The hybrid system would be **relevant in a more flexible mode of operation**.

All in all, to further increase the potential of hybrid SmartCHP, one should further study different operation mode that enable 'internal conversions' between heat and electricity, irrespectively of the heat and / or electricity demand.

*Greg Perkins, "Techno-economic comparison of the levelised cost of electricity generation from solar PV and battery storage with solar PV and combustion of bio-crude using fast pyrolysis of biomass", Energy conversion and Management 171 (2018) 1573-1588.

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Conclusions

Most impacting factors on profitability

Power sell-back 01

Its impact highly depends on the heat-to-electricity ratio (high heat needs and low power needs means electricity in excess and high payback) and on the local regulation. Some countries value all power feed-back to the grid with a net-metering system, while other have an auction system or no reward mechanism at all.

Energy price 02

Variations have here been calculated between 2021 and 2022 energy prices period during which energy prices have had an exceptional increase, thus strongly impacting the use cases profitability. This can be observed in the use cases factsheets below.

OPEX 03

FPBO accounts for the major part of the OPEX costs. Other components include diesel, rinsing fluid, depreciation and maintenance.
The FPBO consumption will vary from one case to another and increase with each "stop and go".

CAPEX 04

Can account up to around 30% of the total yearly costs of SmartCHP. This is especially true for the smaller sizes of SmartCHP. The higher the engine size, the less it weighs on the total costs.

Recommendations

For future TEA of SmartCHP:

This TEA has been realised at an early-stage (TRL 5 by the end of the project), with a "worst case scenario" approach and some unified data to facilitate comparisons.
Several data were not known, and others, including the most impacting factors on profitability, will largely evolve until SmartCHP is ready for a market launch.

Future TEA will be needed, with refined data, including:

- An updated market analysis.
- A refined analysis of terrestrial transport costs for each country.
- An update of FPBO prices per country.
- The comparison with non-fictional energy contracts for each use case, to narrow down uncertainties in the TEA.

Policy recommendations:

SmartCHP is a sustainable way of producing both heat and electricity. Its development should therefore be more supported at European level by the Member States.
These are encouraged to:

- Facilitate the payback of electricity produced sustainability in excess and sold back to the grid. Electricity payback indeed largely facilitates the investment in new energy installations, as it makes them more attractive and reliable for new customers.
- Support the production of FPBO to allow the deployment of biomass-based energy installations. This could indeed be beneficial to reach climate targets and largely decrease the price of SmartCHP.

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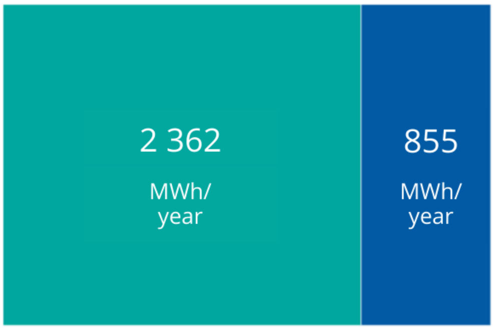
Use Case: hotel in Greece

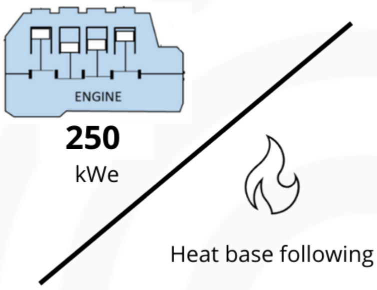
- **Hourly consumption data**
- **Luxury hotel under construction** in the south-suburb of Athens.
- Total surface of 20 000m².

Hotels is one of the six target sectors of SmartCHP. With over 9900 hotels, 40% of which having more than 25 bedrooms, Greece has the largest hotels offer among SMartCHP's target countries.

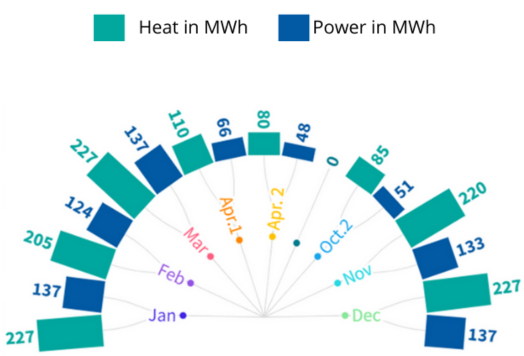
Yearly heat and electricity needs



Engine size and operation

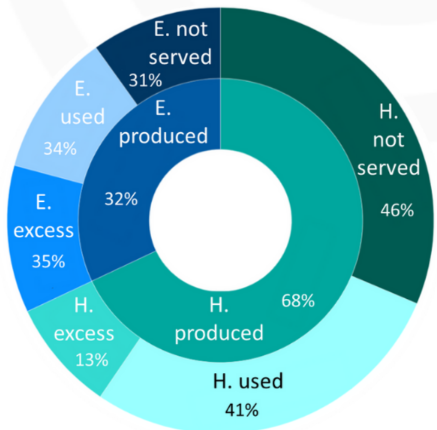


Resulting monthly energy production



SmartCHP is turned off during summer, as heat needs are low. The operation mode is changing mid-April and mid-October, as these are transition months with important change in the energy needs.

Energy unbalances



Heat in excess is a lost energy. Heat not served will be compensated by a gas boiler and electricity not served by the grid. Electricity in excess will be sold back to the grid.

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Financial analysis

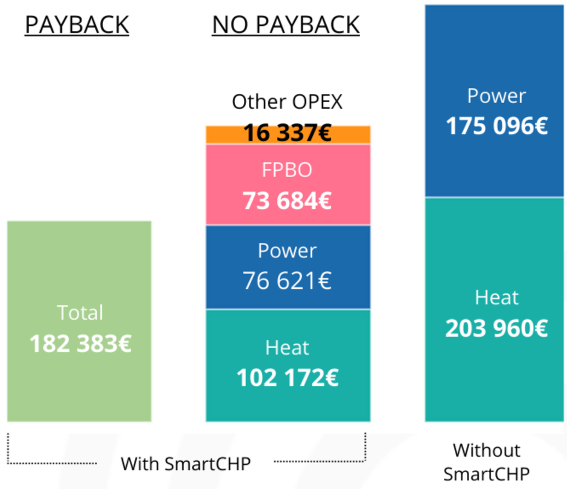
1 360 519 €

Gained over 15 years of operation with SmartCHP compared to no SmartCHP (cumulative cash flows in present value, with 8% interest rate)

3 years

Until the initial CAPEX investment is paid back

Yearly costs and gains with and without SmartCHP



Yearly energy bill with variation of power, heat and FPBO prices 2021 vs 2022

SmartCHP is more profitable than no SmartCHP both in 2021 and 2022.

This diagram shows that **SmartCHP is drastically more resilient to energy price volatility than no SmartCHP**.

Key takeaways

- Greece has hight energy prices, which offers a fertile ground for alternative installations such as SmartCHP.
- A very profitable use case in the current context, even when the payback is not taken into account.
- Regulation favourable to CHP thanks to a net-metering mechanism
- The sensitivity analysis shows that, in this use case, SmartCHP has a large profitability's window.

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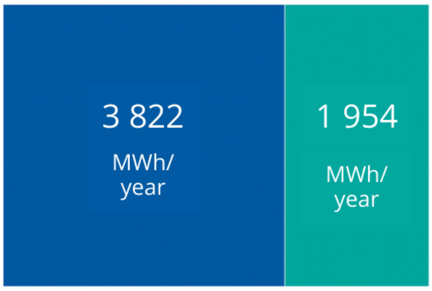
Use Case: Office Building in Greece

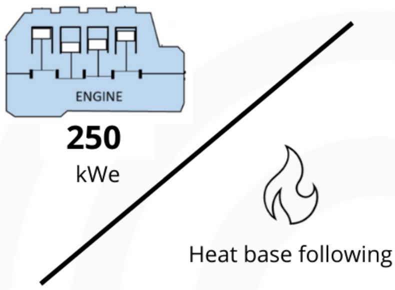
- **Hourly consumption data**
- **Office building under construction** in the south-suburb of Athens
- 38 floors and a total of 29 982m²

Approximatly 2 050 million m² of office spaces exist in Europe. Their energy intensity grow over time, due to their always higher connectivity. SmartCHP will target office buildings above 1000m² of surface floor.

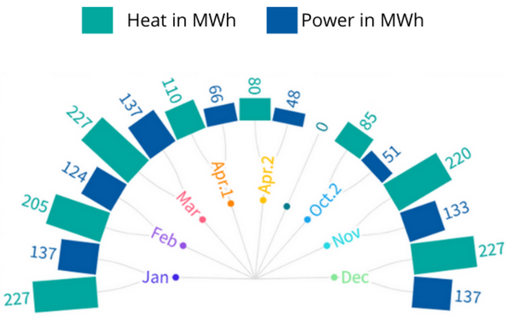
Yearly heat and electricity needs



Engine size and operation

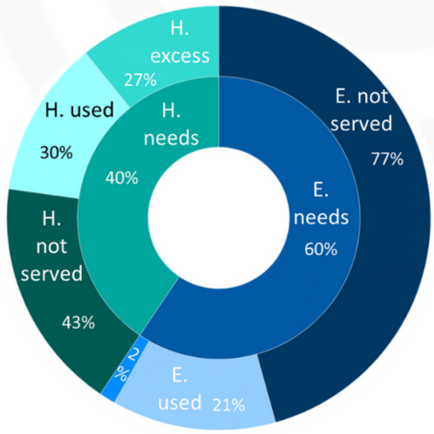


Resulting monthly energy production



There are no heat needs during the summertime, and lower heat needs during spring and the beginning of autumn than winter. SmartCHP therefore mostly operates at full capacity from November to March included.

Energy unbalances



The office building has higher electricity than heat needs. As it is heat following, this means that an important part of the power needs are not served. A lot of heat will also not be served: however, the above engine size of SmartCHP would provide too much heat in excess.

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Financial analysis

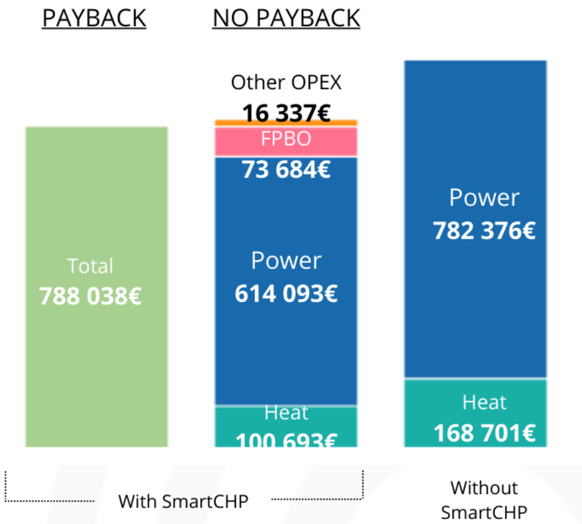
1 072 630 €

Gained over 15 years of operation with SmartCHP compared to no SmartCHP (cumulative cash flows in present value, with 8% interest rate)

3 years

Until the initial CAPEX investment is paid back in present value

Costs and gains with and without SmartCHP



Yearly energy bill with variation of power, heat and FPBO prices 2021 vs 2022

In 2021 and 2022, the energy bill is mainly driven by the costs of electricity.

However, providing a small proportion of it through SmartCHP (which is not dependant to the electricity market) proves to be beneficial and reduce the total bill.

Key takeaways

Greece has hight energy prices, which offers a fertile ground for alternative installations such as SmartCHP.

Regulation favourable to CHP thanks to a net-metering mechanism

A profitable use case in the current context, The payback doesn't change the profitability much, as very few power is produced in excess.

The sensitivity analysis shows that, in this use case, SmartCHP has a large profitability's window.

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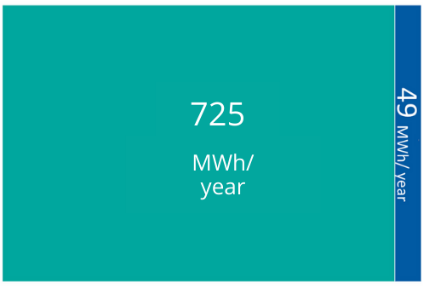
Use Case: Greenhouse in Greece

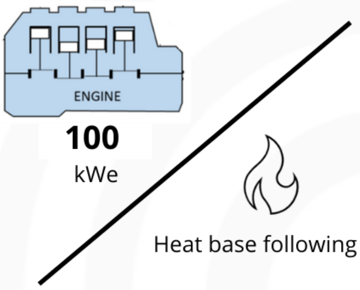
- Greek greenhouse in Crete operated for the cultivation of flowers.
- Covers an area of 3 300m².
- Annual consumption data are retrieved from a scientific paper from J. Vourdoubas.

Crete's economy is based both on the cultivation of vegetables and flowers, and the production of olive oil. It makes it a good candidate for SmartCHP, as it provides both biomass for FPBO production and consumption sites such as greenhouses.

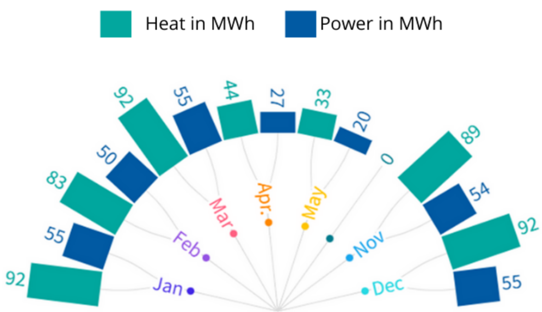
Yearly heat and electricity needs



Engine size and operation

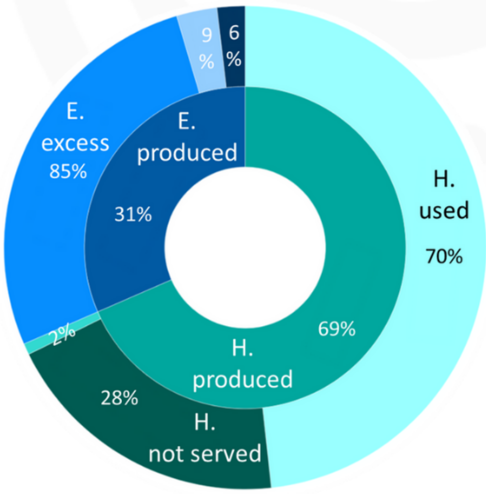


Resulting monthly energy production



The greenhouse needs a temperature of at least 20°C, which is reached naturally from June to the end of October. SmartCHP is therefore not needed during these months.

Energy unbalances



As the power needs are almost irrelevant compared to the heat needs, a lot of electricity is produced in excess. This will be sold back to the grid. Almost no heat is produced in excess, which is energy efficient. The heat not served by SmartCHP will be served by an additional gas boiler.

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Financial analysis

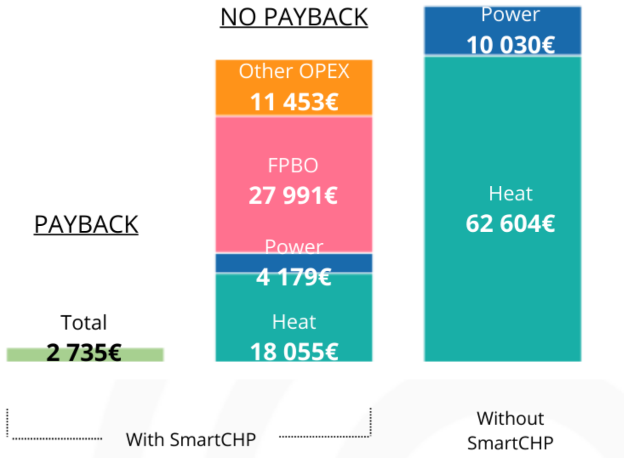
338 533 €

Gained over 15 years of operation with SmartCHP compared to no SmartCHP (cumulative cash flows in present value)

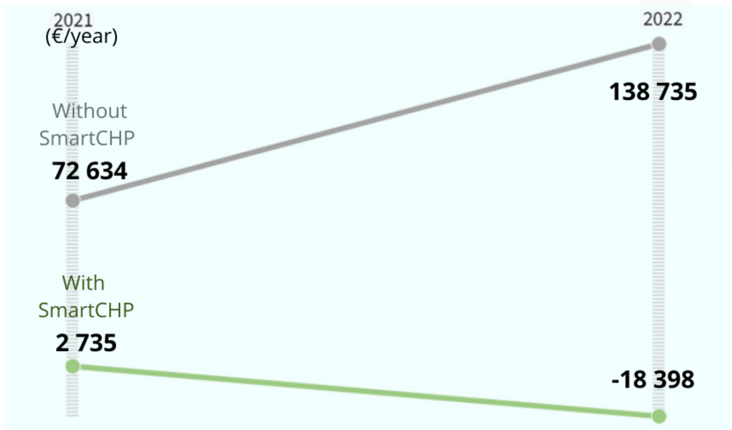
6 years

Until the initial CAPEX investment is paid back in present value

Costs and gains with and without SmartCHP



Yearly energy with variation of power, heat and FPBO prices 2021 vs 2022



The energy bill with SmartCHP is drastically reduced compared to no SmartCHP in 2021.

In 2022 with SmartCHP, due to the electricity produced in excess and therefore a high electricity payback, the greenhouse should even gain more money from its energy production than it should spend for its energy needs.

Key takeaways

- Greece has hight energy prices, which offers a fertile ground for alternative installations such as SmartCHP.
- Regulation favourable to CHP thanks to a net-metering mechanism
- A very profitable use case, especially with payback, as all the electricity produced in almost sold back to the grid.
- The sensitivity analysis shows that, in this use case, SmartCHP has a large profitability's window.

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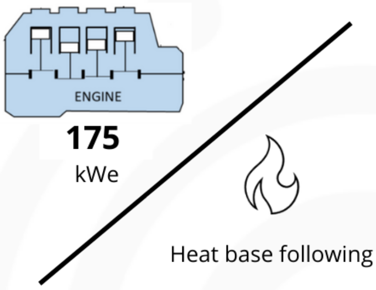
Use Case: Greenhouse in the Netherlands

- Greenhouse located in Wageningen University, in the Horticulture department.
- Data are increased to reflect the consumption of an average greenhouse for tomatoes in the Netherlands.

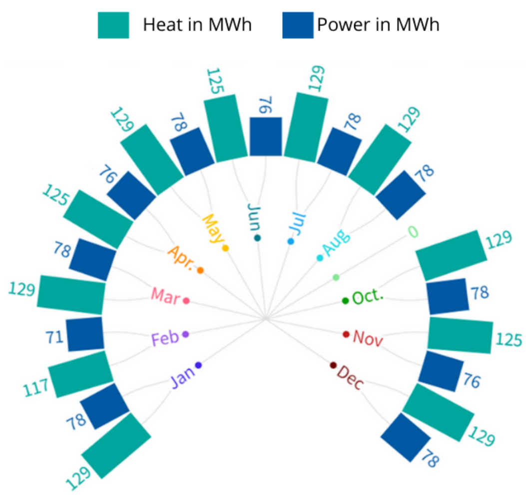
The Netherlands is one of the world's leaders of growing, with more than 9000 greenhouses. Around 45% of this surface is used for vegetables and notably tomatoes, one of the most grown type of crops in the Netherlands (60% of the total greenhouse production).

Yearly heat and electricity needs

Engine size and operation

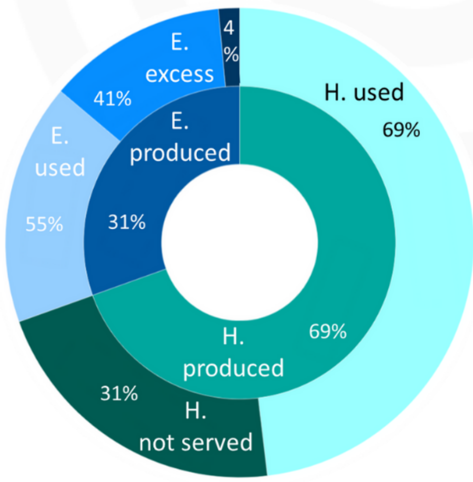


Resulting monthly energy production



SmartCHP is operated on a heat base following mode and runs almost all year long expect in September, when the energy needs are the lowest.

Energy unbalances



No heat is produced in excess, which is very efficient. Additionally, SmartCHP provides almost all the power needs of the greenhouse.

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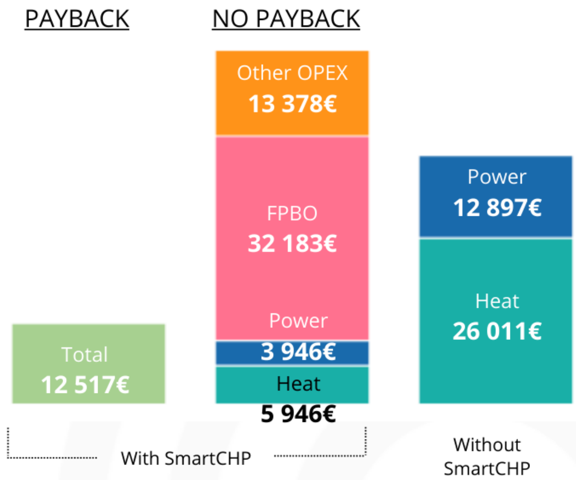
@SmartCHP2020 @SmartCHP project

Financial analysis

No return on investment

During the 15 years of SmartCHP's lifetime, if the cumulative cash flows in present value, with 8% of interest rate is taken into account

Yearly costs and gains with and without SmartCHP



Yearly energy bill with variation of power, heat and FPBO prices 2021 vs 2022

If the electricity produced in excess cannot be valroised, SmartCHP is less profitable than no SmartCHP both in 2021 and 2022.

In the use case, the profitability of SmartCHP therefore highly depends on the local regulation for power payback.

Key takeaways

Energy prices in Croatia are low and provide a good supply whithout further investment.

The regulation provides the opportunity for a high electricity feedback only if the end-user wins specific auctions, which introduces a high risk.

The use case is not profitable use case in the current context, The energy needs and prices are indeed too low to provide a substantial advantage to SmartCHP.

The sensitivity analysis shows that, to be profitable, energy prices should be higher and FPBO price substantially decreased.

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