Greening the University Campuses:
The University of West Attica Vision

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Presentation Outline

- UNIWA Presentation
- Energy Consumption in Universities
- Energy Saving & Rational Energy Use
- Cogeneration and Poly-generation
- Energy Consumption of UNIWA’s Campuses
- Problem One to be Solved (CHP Sizing)
- Problem Two: Optimum Financial Operation of CHP
- Problem Three: Optimum Environmental Operation of CHP
- PV Solution
- Conclusions

Introduction

- The University of West Attica is a new entity established in 2018, following the merger of the Technological Educational Institutes of Athens and Piraeus (1983), as well as of the National School of Public Health (1929) - Public Institution
- 3rd biggest University in Greece with over 50.000 students and more than 1000 employees.
- Six (6) Schools ("Engineering", "Administrative, Economics & Social Sciences", "Food Sciences", "Applied Arts & Culture", "Health Professions & Care", "Public Health")
- High-level undergraduate (26) and postgraduate (65) programs and more than 200 PhD candidates.
- Advanced research activities combined with strong partnerships with national and international educational & research bodies

Uniwa Campuses 1-2-3








U.NI.W.A' s Campuses

- Total area 65.500m^2
- Building area 22.500m^2
- 16 buildings
- 2.500 – 2.900MWh_e

Egaleo Park (C-1)

Ancient Olive Grove (C-2)

- Total area 90.000m^2
- Building area 30.000m^2
- 8 buildings
- 3.000 – 3.450MWh_e

- Total area 6.000m^2
- School of Public Health
- 1.500MWh_e

Athens (C-3)

CAMPUS 2 – Ancient Olive Grove

- Schools of Engineering and Economy
- Area of ~$90.000m^2$ (Plato's Academy)
- Olive grove covering ~25% of the area
- 10 main buildings
- Modern facilities – Easy access (bus, subway)
- CHP of 600kW and heating / cooling network
- Solar EV Charging Station

LAB FACILITIES

Energy Consumption of Universities

- One of the most energy consuming sectors is the Public sector.
- University campuses belong to these high energy consumption facilities due to various reasons, e.g. absence of an energy saving strategy or even zero energy consumption management.
- This fact is quite disappointing, since most Universities do have modern engineering departments and high qualification teaching and energy research staff. Normally, the University campuses should present the optimum energy consumption performance, being also a successful real world example for young engineers.
- The standard solution adopted up to now by the Universities is to purchase electricity from the national grid and consume oil or NG. The utilization of small air-conditions for each office, mainly for cooling purposes, complete the energy consumption pattern.

Energy Saving & Rational Energy Use

- Energy saving and rational energy use are the basis for the most environmental friendly solutions used to meet the continuous energy consumption increase of contemporary societies.

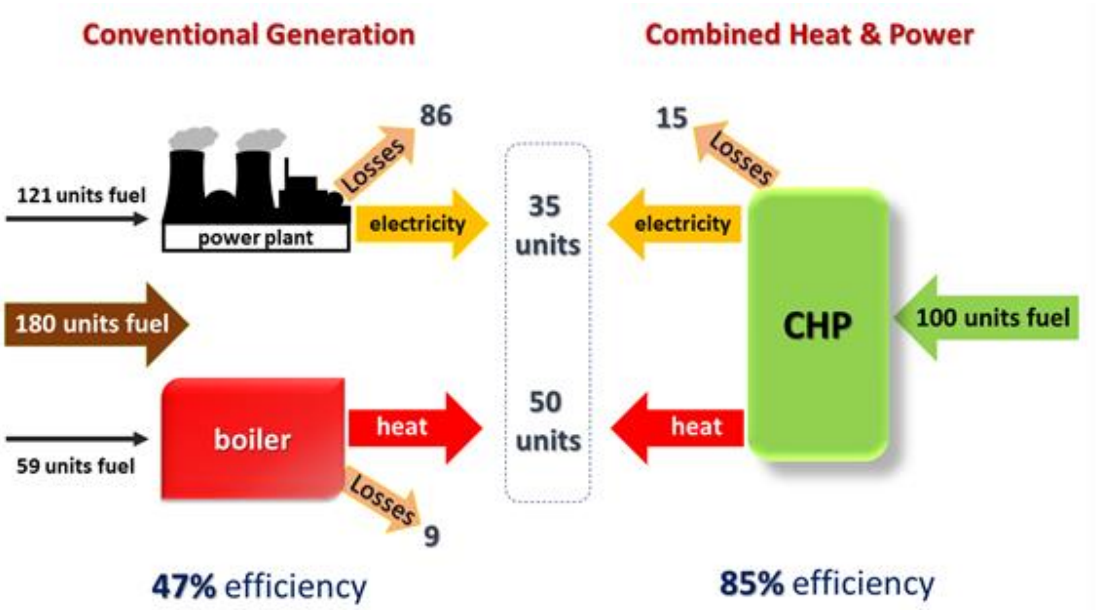
- These solutions in combination with distributed generation based either on RES or NG constitute an interesting and technically equivalent option in comparison to large centralized power stations.

Cogeneration & Poly-generation

- Cogeneration/polygeneration (parallel production of electricity and heat or cooling) is one of the most promising energy saving techniques, since the "waste heat" of the electricity generation process is used to cover the heating/cooling demand.
- Cogeneration (CHP) has similar function to conventional thermal power plants, but in a more efficient way. CHP power plants generate electricity using NG or a renewable fuel (e.g. biogas) while the remaining energy in the exhaust gases is exploited for space and water heating purposes.
- The combination of a CHP system with an absorption chiller converts the waste heat into chilled water, for cooling purposes, known as "trigeneration" or combined cooling, heating and power.

Cogeneration & Poly-generation

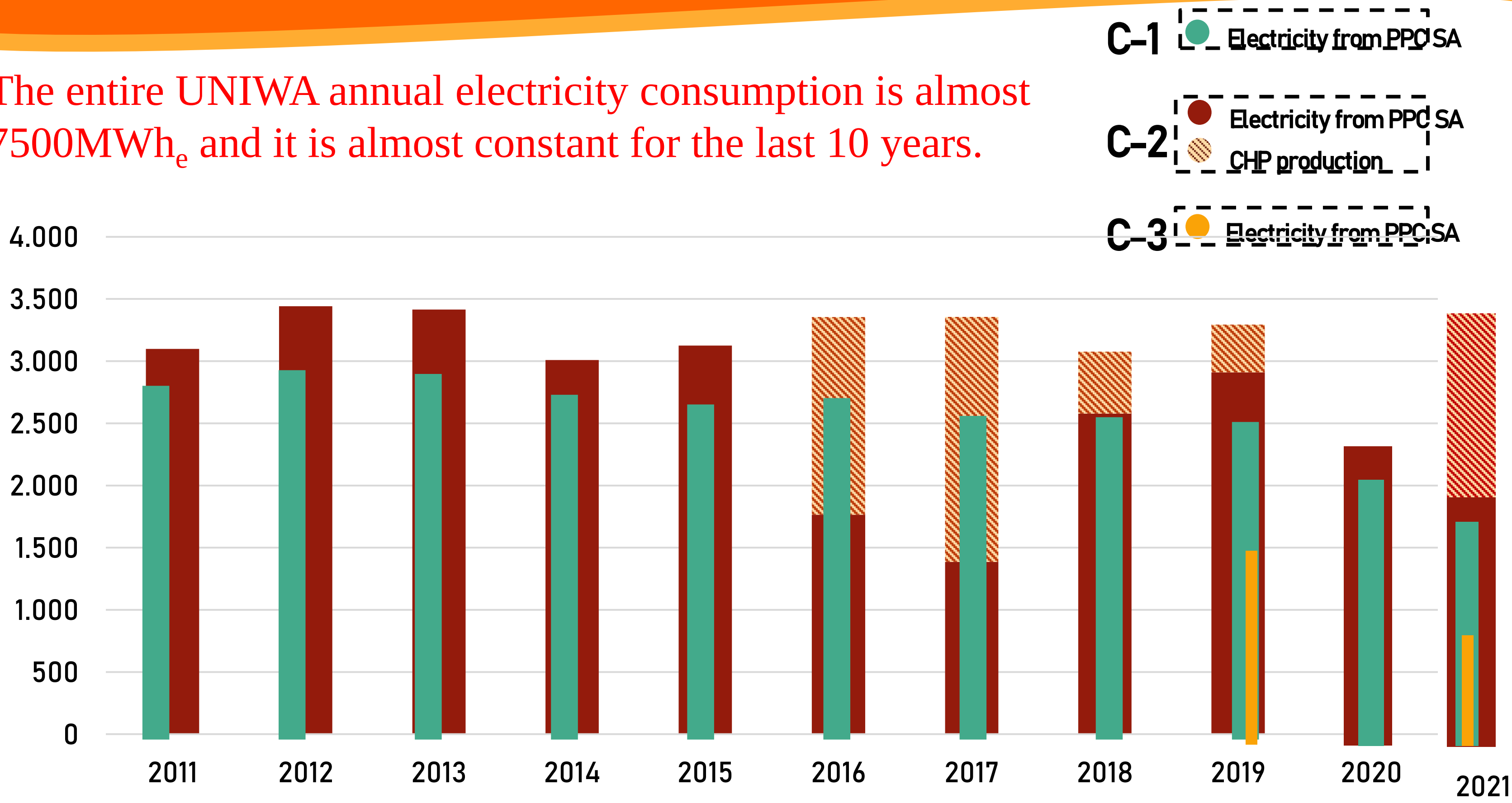
- The main components of a CHP system include a thermal engine which actuates an electrical generator and a heat exchanger recovering waste heat in hot water. CHP represents a distributed energy resource aiming to match thermal and electrical demands. Thus for the successful operation of a similar installation the **simultaneous demand** of electricity and heat or cooling is required.



Depending the CHP technology used, the overall efficiency of plants can reach 80 %. Cogeneration not only represents an environmental friendly way to save energy, but has a greater economic profit compared to conventional TPPs.

Electricity Consumption of UNIWA

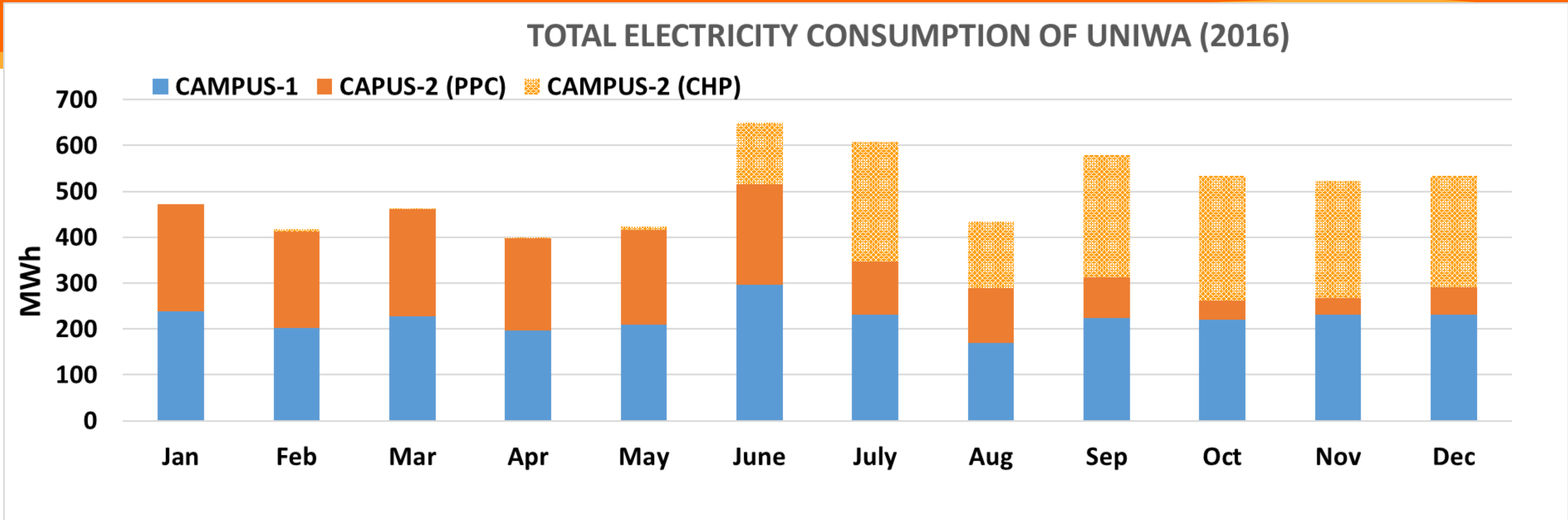
The entire UNIWA annual electricity consumption is almost 7500MWh$_e$ and it is almost constant for the last 10 years.

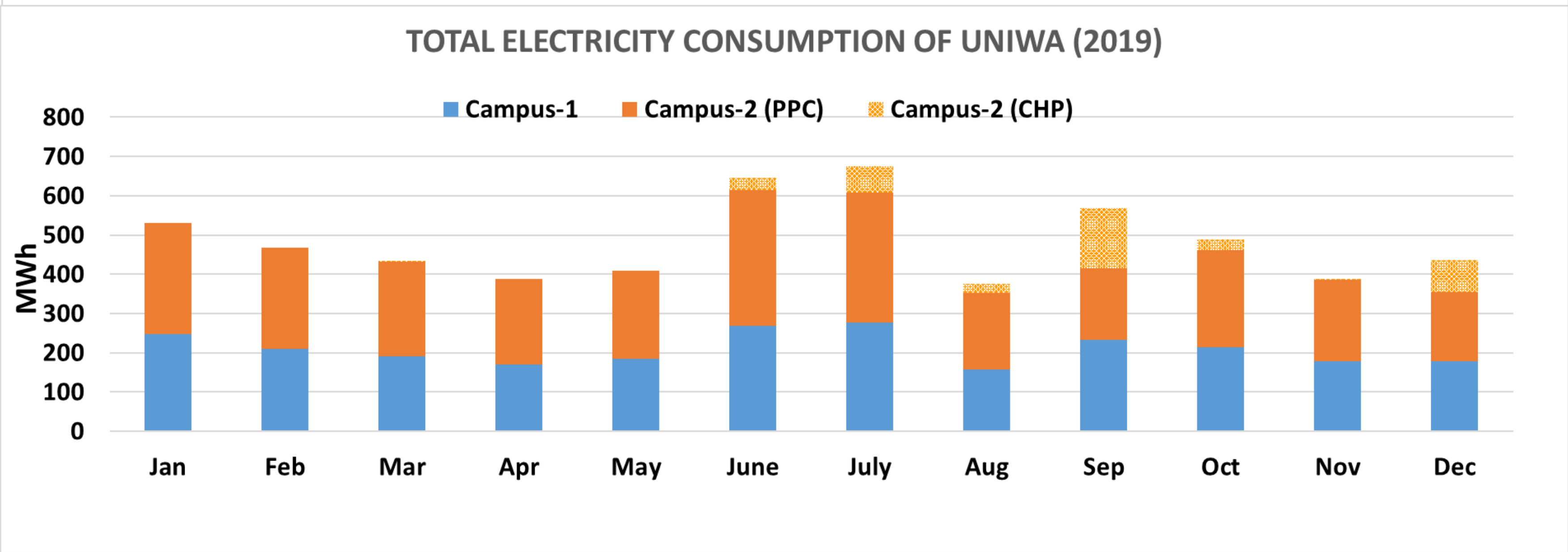


The total electricity consumption of both major Campuses 1&2 is approximately 3000MWh$_e$/year, while the annual electricity consumption of Campus-3 is almost 1600MWh$_e$/year.

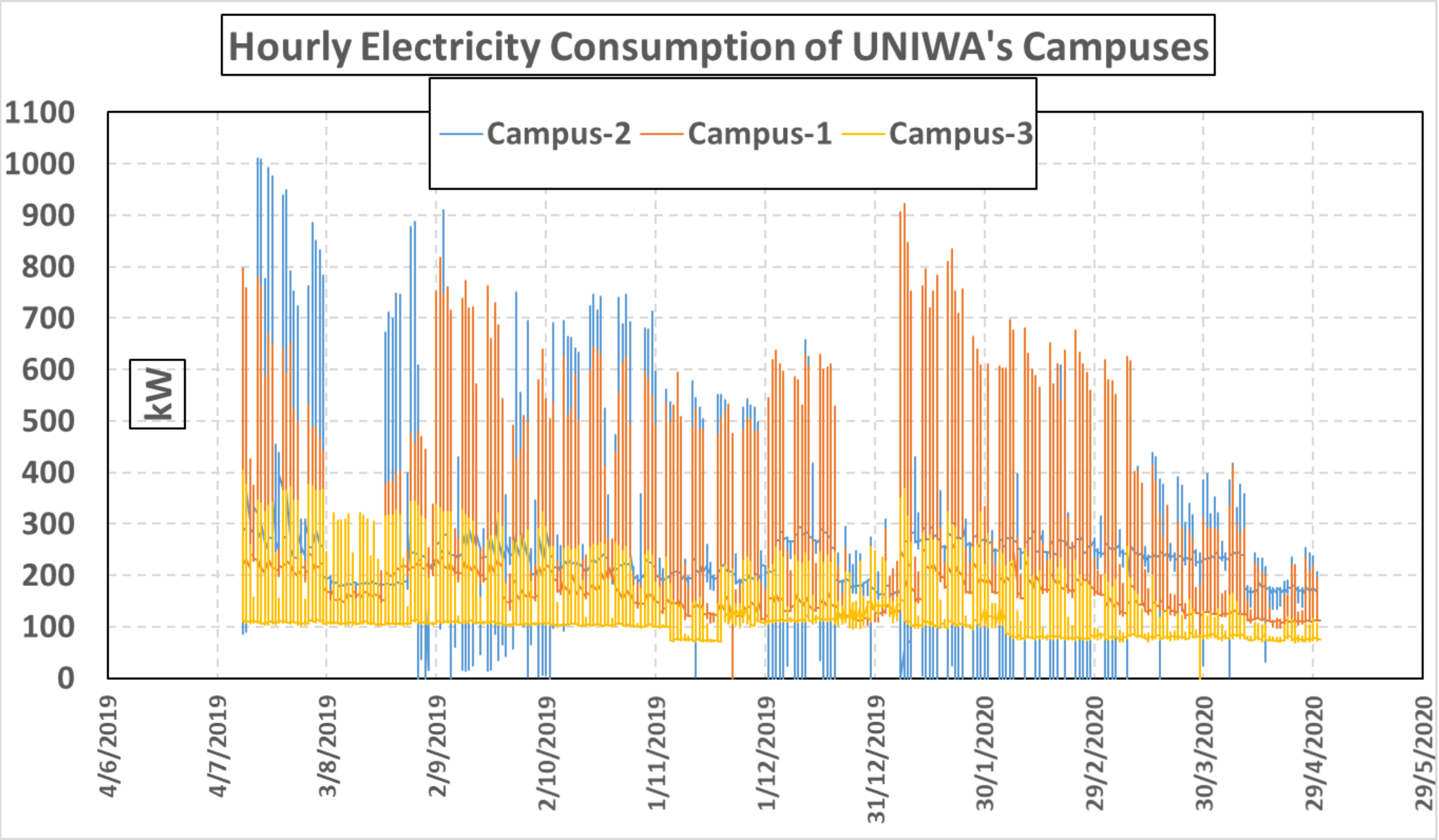
The contribution of a local CHP is considerable, partially covering the load of Campus-2.

Electricity Consumption of UNIWA

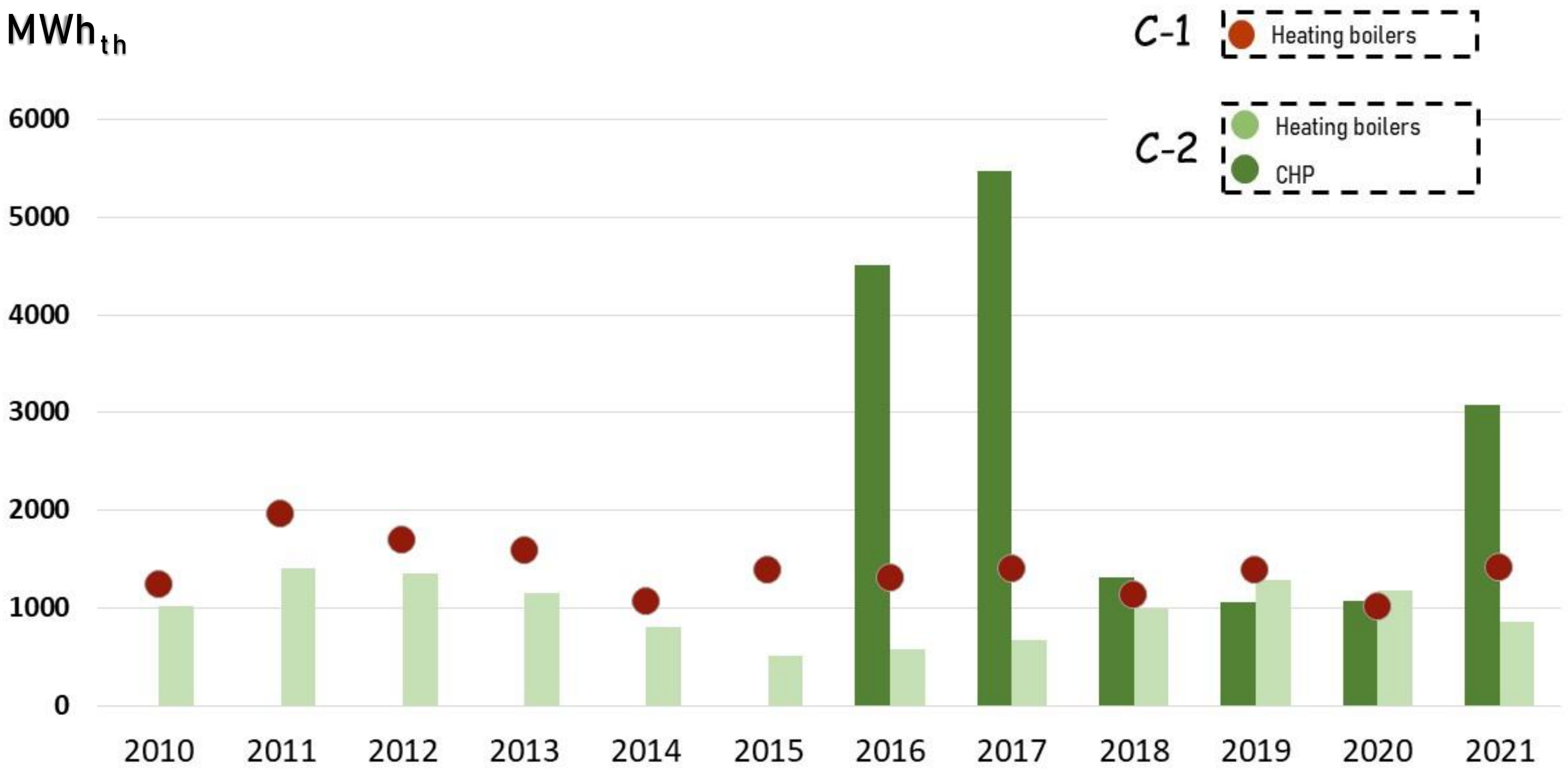




Electricity Consumption of UNIWA

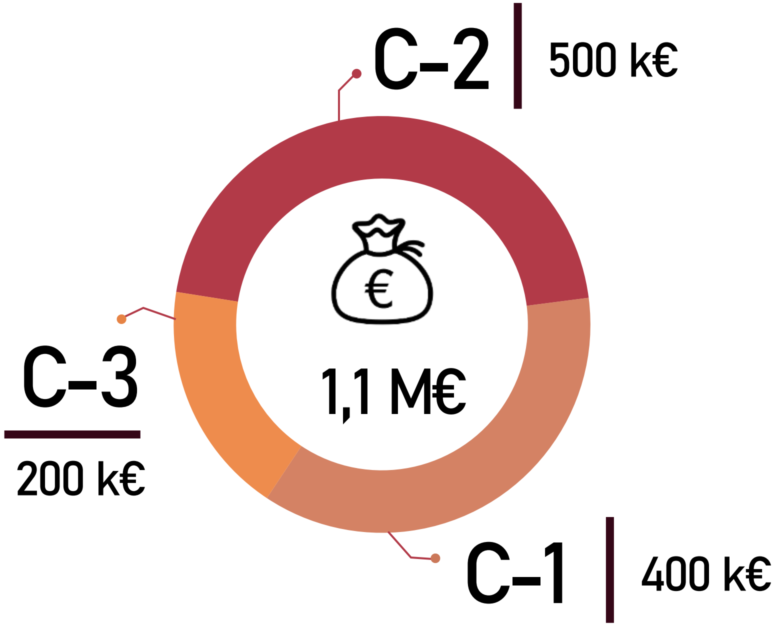


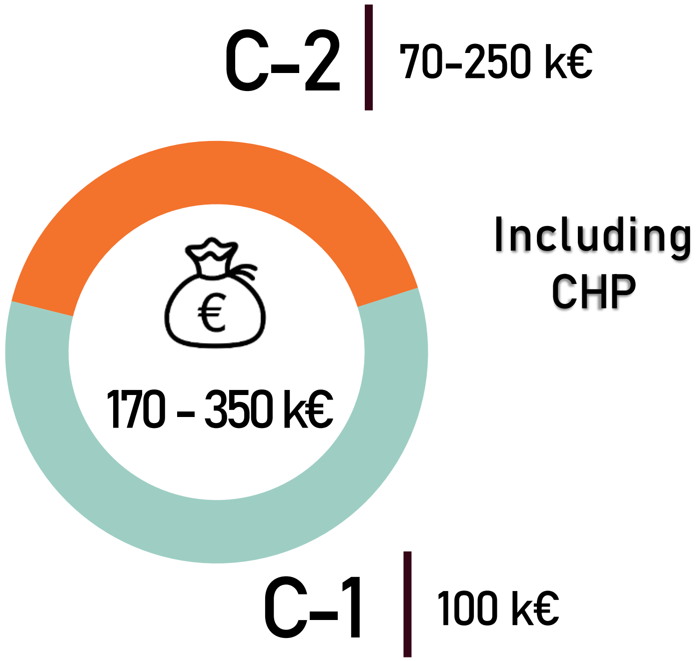
Natural Gas Consumption of UNIWA



Energy Consumption Total Cost

ELECTRICITY COST





NATURAL GAS COST

Problem One:
Verification of CHP Unit Sizing

Cogeneration Unit Installation

The new CHP selected has an electrical power output equal to 600 ± 10%kW$_e$, using NG and including heat recovery strategies concerning the hot outgases and the hot water from the engine cooling subsystem.

Any heat recovery is used to cover the heat load of the campus mainly during the winter, while it can also be used for providing cold water for cooling purposes via the absorption technique.

Moreover the selected installation has the ability to operate in collaboration with the national grid or autonomously in case of black outs covering also selected high priority loads of Campus-2.

The CHP unit is also integrated with a thermal storage tank of hot water, used for feeding the boilers in case of extremely cold days.

Cogeneration Unit Installation

The CHP installation includes:

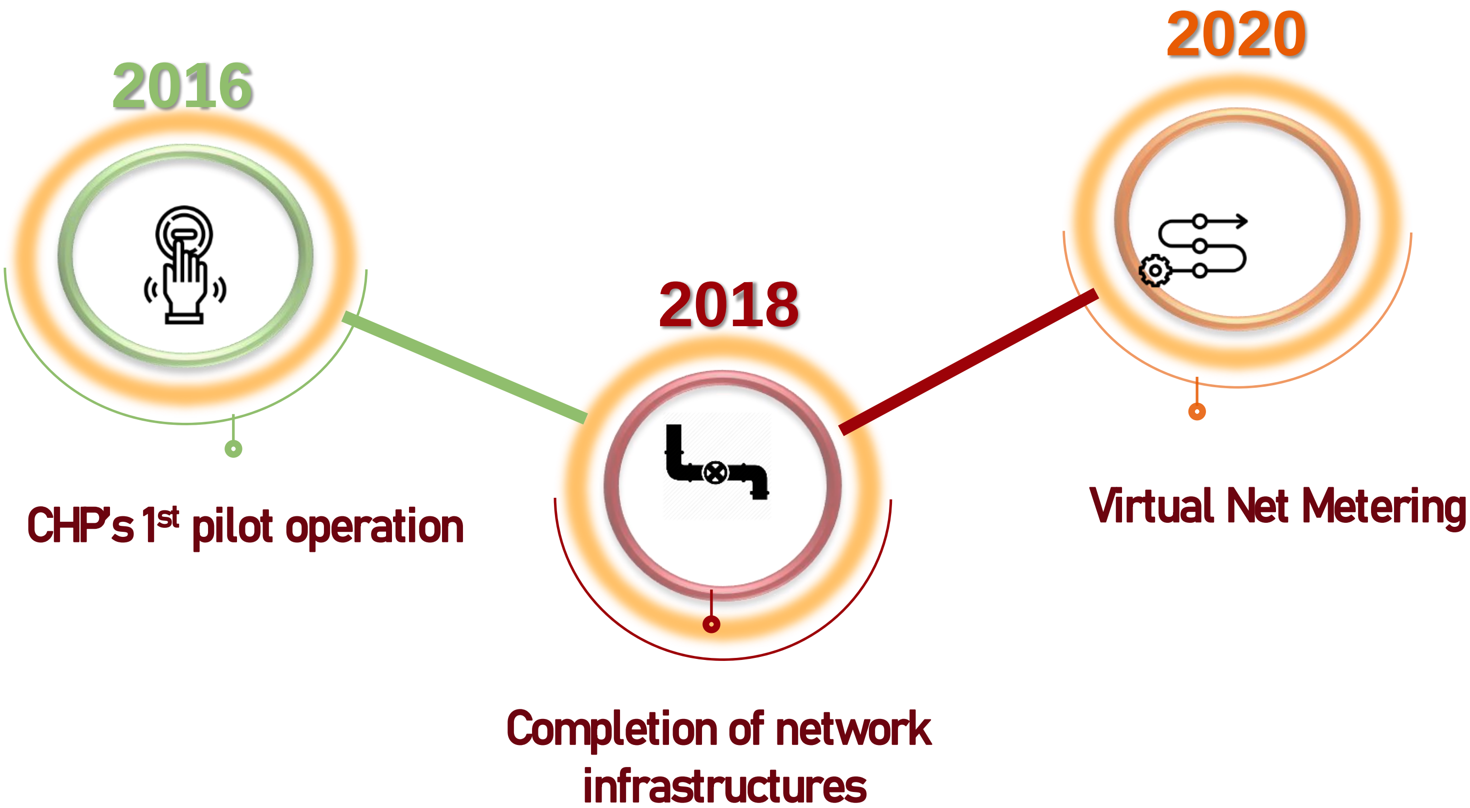
An internal combustion turbocharged engine, NG ($SFC=0.25Nm^3/kWh_e$) operating at 1,500 rpm.

A synchronous AC electrical generator of 750kVA, operating at 50Hz.

An integrated heat exchanger system recovering the waste heat of the engine, $655kW_{th}$ and a system of air cooling chillers in case of rejecting the heat load of the engine.

The control panel of the installation, supporting both the stand-alone and the parallel to the grid operation.

Cogeneration Unit Implementation Steps



Proposed Green Solution Improvement (1/3)

In order to meet the electricity demand of all the buildings along with the heat/cooling load of UNIWA Campus-2, the following steps have been implemented:

Systematic energy saving efforts (mainly inform and educate the personnel and install the necessary BEM equipment). The expected energy saving is 10-15% of the total electricity consumption of the University, thus the expected new electricity consumption will be less than 3500MWh_e per year.

Operate the existing CHP plant under the **status of net-metering**. Actually, up to 2019, under the status of self-producer, one has the opportunity to cover only own loads using a CHP unit in collaboration with the central electrical grid; however any energy deficit is purchased from the national grid, while any energy surplus is "donated" to the local grid.

Proposed Green Solution Improvement (2/3)

On the contrary, under the net (or virtual for all Campuses of UNIWA) metering solution, the CHP power plant may operate continuously storing any electricity surplus to the local grid. In case that the load demand is higher than the maximum available power of the CHP, the stored energy is exploited to cover the University consumption through the electrical network, practically free of charge.

Under this virtual metering strategy the CHP unit is not obliged to follow the load but it may operate near its optimum efficiency (or minimum SFC) point, and if assuming a realistic technical availability value one may expect an annual electricity yield of 2900MWh_e/year.

In order to cover the annual energy deficit of 600MWh_e/year one may exploit the excellent solar potential of West Attica region along with the available area for the installation of modern high performance PV panels of almost 0.4 to 0.6MW_p.

Proposed Green Solution (3/3)

Moreover, since the UNIWA is strongly supporting electro-mobility, one should take into consideration the possibility of charging (e.g. $15kWh_e$/day) approximately 150 vehicles, thus an additional $2.3MWh_e$ may be required for every working day, adding another $500MWh_e$ per year. This additional load is expected to be covered by installing appropriate flexible PV panels at the parking area.

Finally, the existing CHP unit is going to provide almost 600MW of continuous heat or 800MW cooling power covering the corresponding heat/cooling load of Campus-2, where the CHP is installed.

Summarizing, the proposed solution fulfil the energy needs of Campus-2 by exploiting the existing partially used up to now CHP unit and suggests the installation of $0.6MW_p$ of PV panels, using a modular strategy directly related with the electro-mobility progress of the University.

Problem Two:
Optimum Operation of CHP Unit

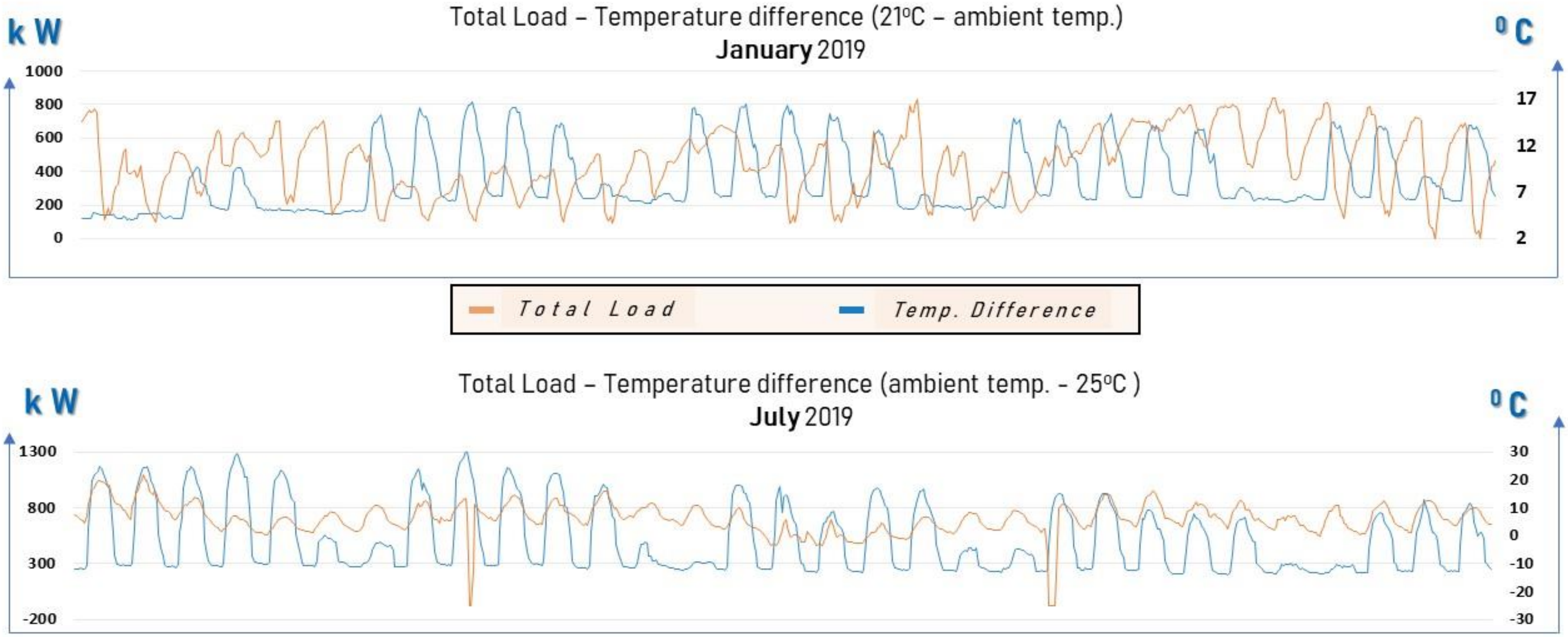
Optimum Operation of CHP Unit

The TARGET

Simultaneous meeting of needs

Electricity of C-2 & C-3

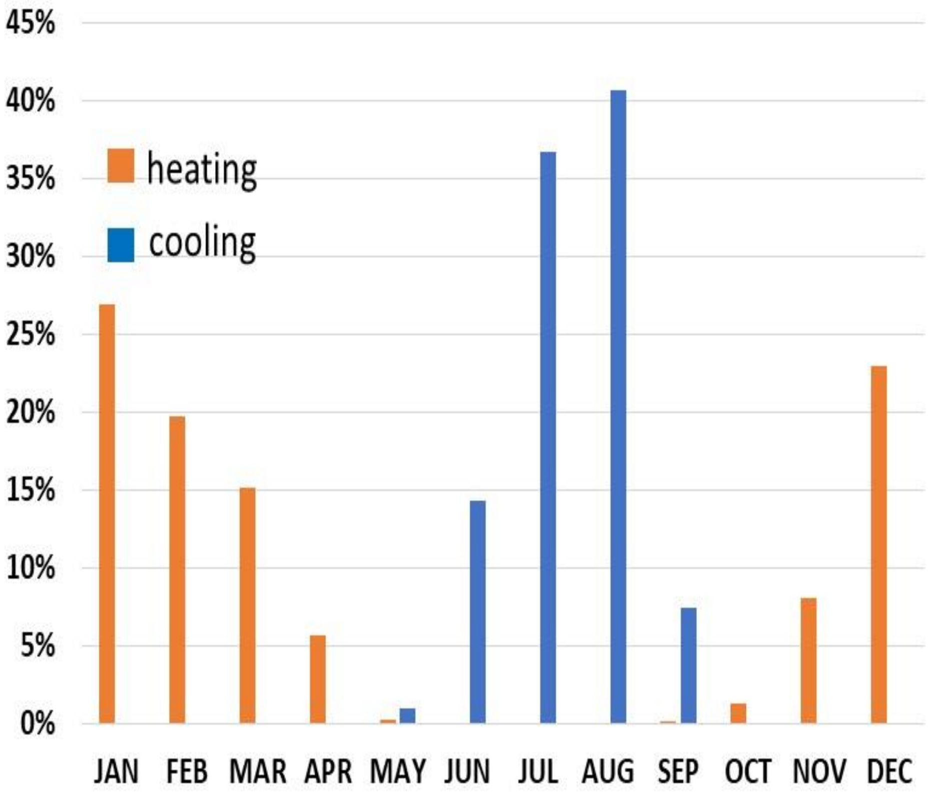
Heating/cooling load of C-2



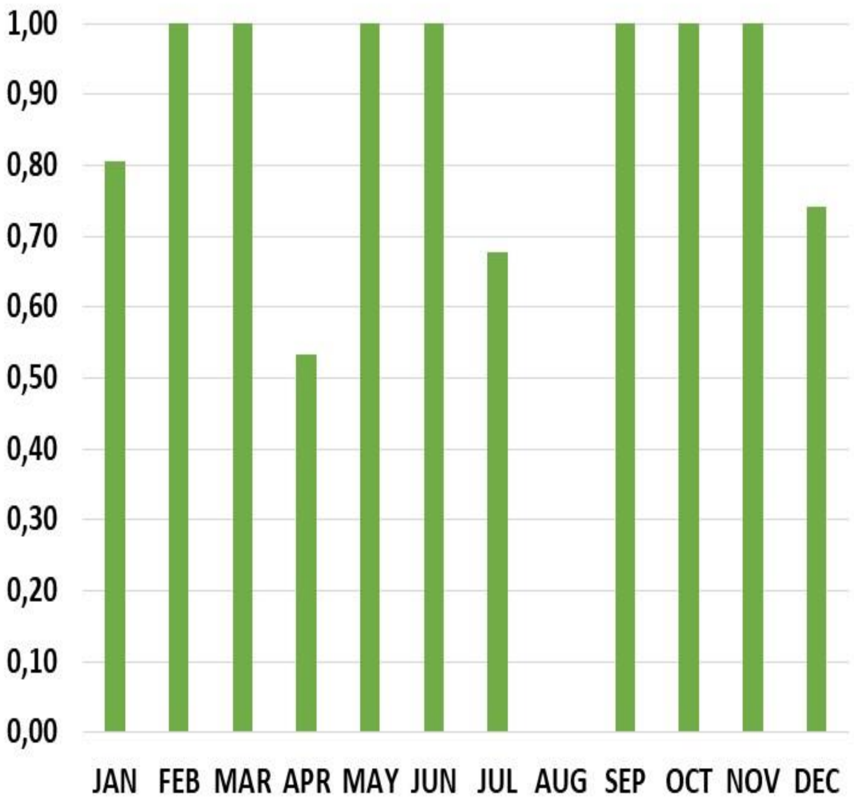
Minimize CHP operation only for electricity load fulfillment!

Optimum Operation of CHP Unit

Annual **average** heating/cooling **degree days distribution** concerning **utilization** of the facilities



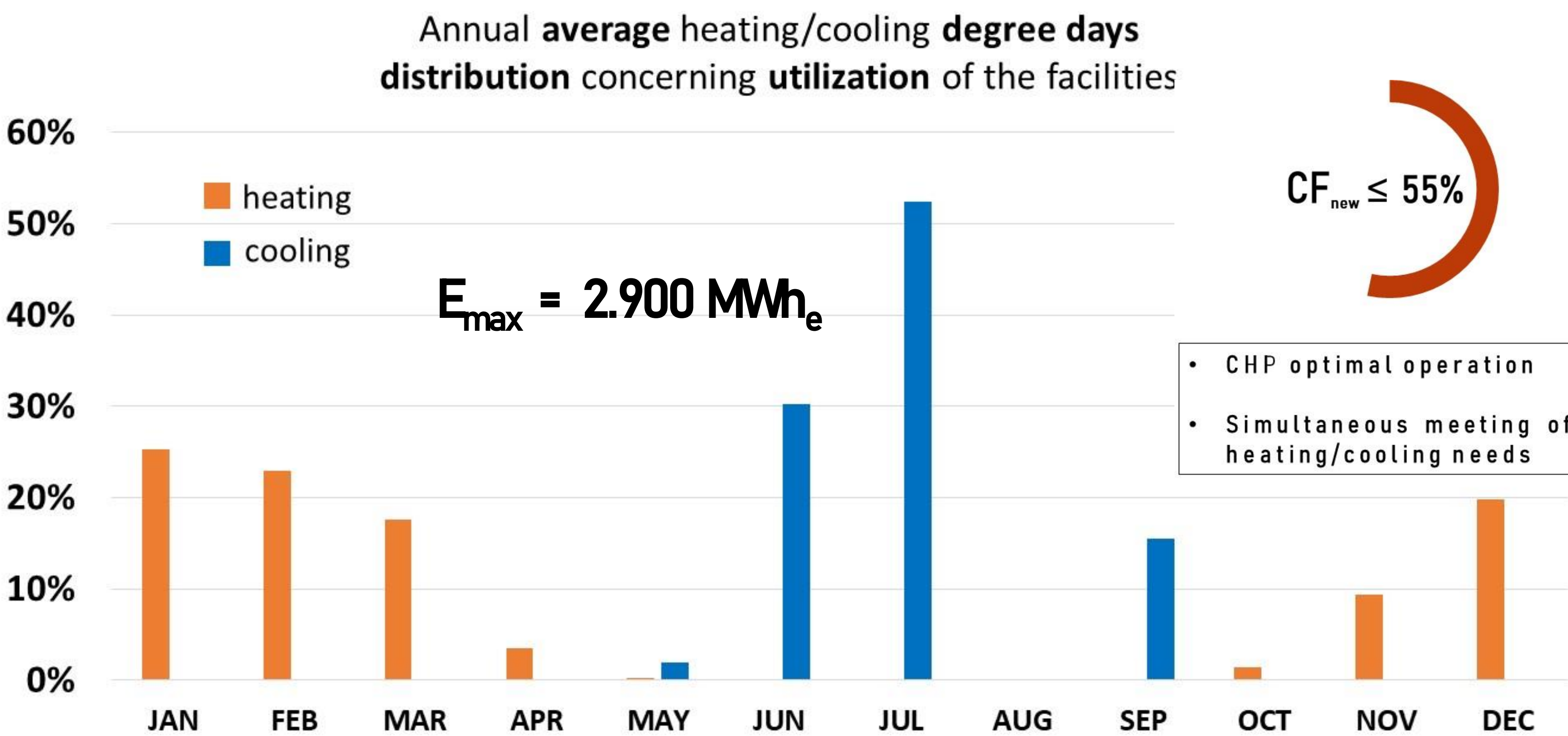
Monthly **utilization factors** of the **Ancient Olive Grove (C-2)**



Define the CHP operation period for simultaneous fulfillment of electricity and heating/cooling

Optimum Operation of CHP Unit

Degree days final distribution



E_{max} = 2.900 MWh_e

$CF_{new} \leq 55\%$

- CHP optimal operation
- Simultaneous meeting of heating/cooling needs

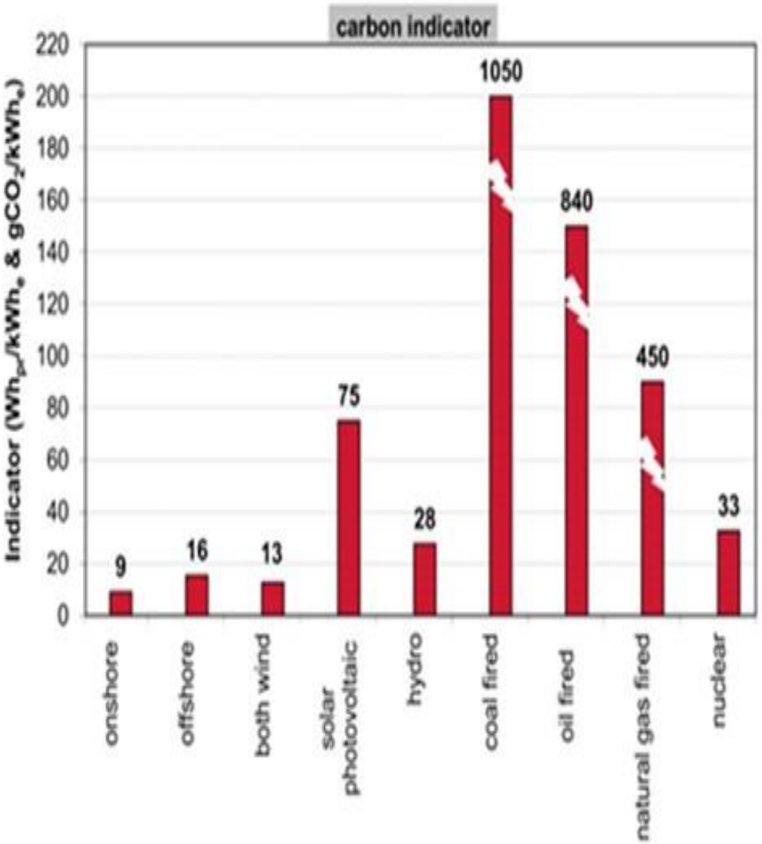
remaining of 600 MWh

Problem Three:
CHP Unit Environmental Optimization

Problem Modelling: CO_2 Quantification

- CO2 is the product of reaction between carbon and oxygen molecules during a complete combustion process
- The carbon footprint of energy supplied by the National Grid depends on the fuel mix of the Greek economy:
  - Lignite
  - Natural Gas
  - Wind Energy
  - Solar Energy
  - Hydropower
  - Other sources
- The emissivity coefficient of the National Grid can be described as the weighted average of individual emissivity coefficients:
  - w_i: the percentage contribution of each energy source ($\sum w_i = 1$)
  - ε_i: the respective emissivity coefficient

$$\varepsilon_{grid} = w_{lign}\varepsilon_{lign} + w_{ng}\varepsilon_{ng} + w_{wind}\varepsilon_{wind} + w_{solar}\varepsilon_{solar} + w_{hydro}\varepsilon_{hydro} + w_{other}\varepsilon_{other}$$



Compare the CO_2 footprint between grid provided electricity and CHP operation, under variable national fuel mix.

Problem Modelling: Demand Management

The university's energy needs (up to 2016) were covered by:

- Electricity demand D_{el} by the Greek national grid
- Thermal demand D_{th} by natural gas-fueled boilers

Leading to total emissions:

$$e = e_{el} + e_{th} = \varepsilon_{grid} \cdot D_{el} + \varepsilon_{ng} \cdot D_{th}$$

implying that there is a linear connection between total Univerisity's CO_2 emissions (***e***) and the Greek national grid emissions coefficient (ε_{grid}).

CHP Unit quantification:

- CHP is able to simultaneously supply electricity ($S_{el,chp}$) and heat ($S_{th,chp}$), while emitting CO_2 related to electricity production, only.
- The heat supply from CHP unit does not create extra emissions, while it is equal to: $S_{th,chp} = (1/c) \cdot S_{el,chp}$
- *c*: power-to-heat ratio, ranging between 0.7 - 0.9, depending on engine's operating level
- Excessive CHP heat production can be released to the environment (*possibility of heat transfer to nearby buildings*)

Problem Modelling: Constraints

<u>The fundamental objective of the model:</u>

The minimization of CO_2 emissions, while fully covering the University's electricity (**D_{el}**) and thermal (**D_{th}**) needs.

Objective function: $Min(Z) = e = \varepsilon_{grid} \cdot S_{el,grid} + \varepsilon_{ng} \cdot S_{th,ng} + \varepsilon_{chp} \cdot S_{el,chp}$

Under the restraints:

$D_{el} = S_{el,grid} + S_{el,chp}$	Electricity demand has to be fully covered, but excess in supply cannot be sold
$D_{th} \leq S_{th,ng} + S_{th,chp} = S_{th,ng} + (1/c) \cdot S_{el,chp}$	Thermal demand has to be covered, and excessive heat can be released
$S_{th,ng} \leq D_{th}$	However, the heat supply from Natural Gas boilers should not exceed the thermal demand
$S_{el,chp} \leq max[S_{el,chp}] = P_{el,chp} \cdot CF \cdot 8760$	Physical limitations of CHP maximum power and Capacity Factor
$S_{el,grid}, S_{th,ng}, S_{el,chp} \geq 0$	Solutions implying negative values of $S_{el,grid}$, $S_{th,ng}$ *and* $S_{el,chp}$ *have to be prevented*

Model Application

	Variables	Values	Units
Input Data	D_{el}	3,000	MWh_e
	D_{th}	605	MWh_{th}
	c	0.85	-
	$P_{el,chp}^{max}$	550	kW
	ε_{grid}	0.90	$kgCO_2/kWh_e$
	ε_{ng}	0.25	$kgCO_2/kWh_t$
	ε_{chp}	0.45	$kgCO_2/kwh_e$
Output Data	$S_{el,grid}$	0	MWh_e
	$S_{th,ng}$	0	MWh_{th}
	$S_{el,chp}$	3,000	MWh_e
	$S_{th,chp}$	3,450	MWh_{th}
	e' (model)	1,350,000	$kgCO_2$
	e (conventional)	2,851,250	$kgCO_2$
	Δe (emissions reduction)	53	%

- **Exclusive electricity and thermal supply by CHP unit**
- **53% reduction of CO_2 emissions can be achieved**
- **Significant excess of CHP thermal output that can be exported and utilised by nearby consumers**
- **CHP Capacity Factor: 62.3% (5,455 hrs annually)**

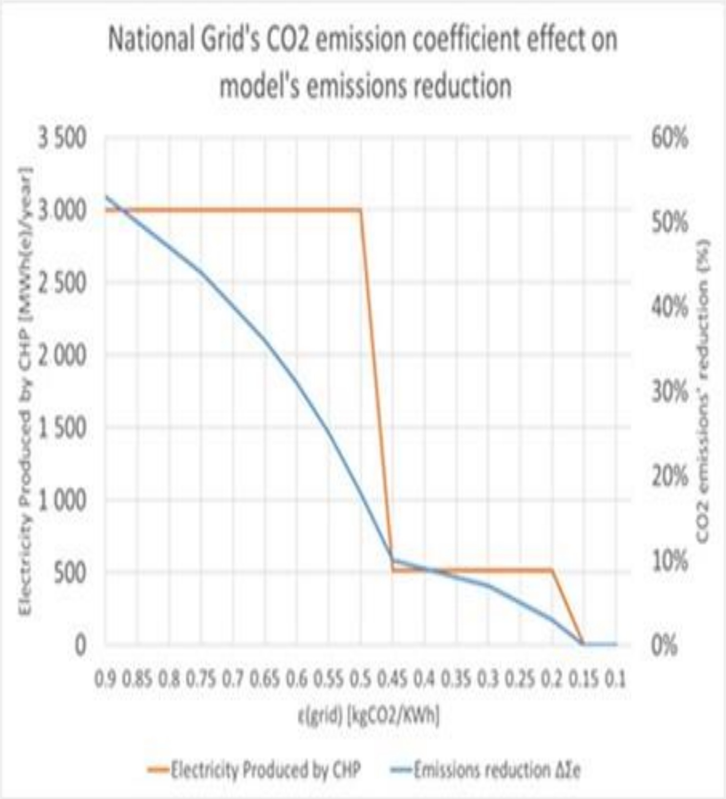
Parametric Analysis

2 categories of Input Variables:

- **Systemic**
  - CHP maximum power ($P_{el,chp}^{max}$)
  - CHP Power-to-Heat ratio (c)
  - CHP Emissivity Coefficient (ε_{chp})
  - Natural Gas boilers Emissivity Coefficient (ε_{ng})
- **External**
  - Electricity Demand (stable ±25% - linearly connected to CHP CF)
  - Thermal Demand (stable ±25% - linearly connected to CHP CF)
  - **National Grid Emissivity Coefficient** ***(ε_{grid})***

- Parametric Analysis is focused on changes of the Greek National Grid emissivity coefficient (ε_{grid})
- CO_2 emission coefficient changes occur over the course of time - due to changes to fuel mix
- Greek Energy Policy is targeted towards a more RES-oriented energy mix - aiming $\boldsymbol{\varepsilon_{grid}}$ to gradually decrease from 0.90 to 0.10 $kgCO_2/KWh_e$ (by 2030)
- The current analysis focuses on parameter's values $0.90 \geq \boldsymbol{\varepsilon_{grid}} \geq 0.10$, with a step of 0.05

Environmental Optimization Results



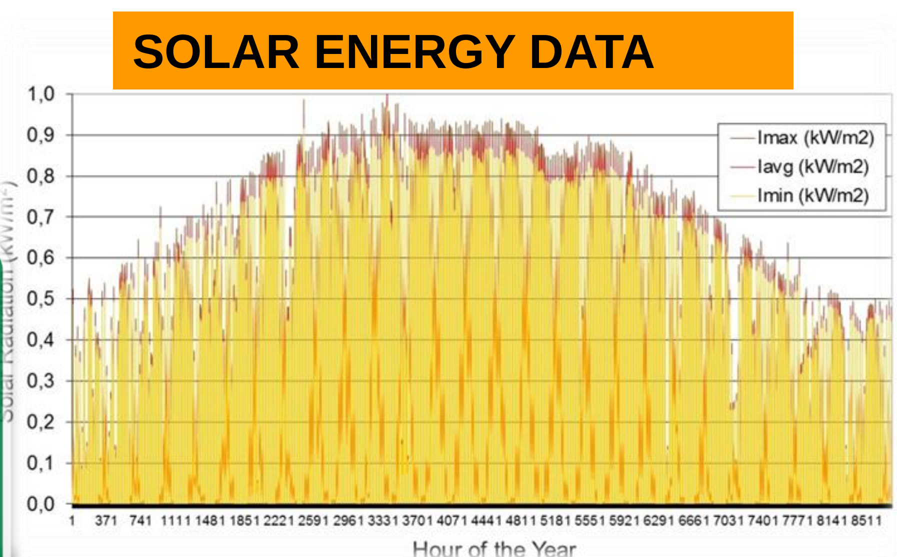
e_{grid} *values*	CHP Optimal Operating Level	CO_2 emissions reduction
[0.90, 0.45)	Full electricity and heat production	53% - 12%
[0.45, 0.15)	Electricity production needed only for full heat production	12% - 2%
[0.15, 0.10]	No production	0%

- There are 3 distinct ranges
- Critical points: {0.15 , 0.45}
- CHP proved to be the optimal solution for CO2 emissions reduction, back in 2015.
- Nowadays, with e_{grid} ranging between 0.45-0.50, CHP is still offering 12-20% carbon dioxide emissions reduction.
- As the Greek National Energy Policy shifts to a cleaner energy mix (e_{grid}<0.45), CHP operation shall be limited to the coverage of thermal needs, and the parallel electricity production
- The University is advised to embrace energy systems with even lower carbon footprint, such as Solar Energy Systems (e_{PV}<0.08)

PV-Solution

Using the excellent solar potential and the available area of Campus-2, 400 kW_p of PV may be installed providing almost 600MWh_e per year.

The area required is 3200-4000m^2, vs. 90.000m^2 (of Campus-2 area), while additional flexible PV panels may be installed in the parking area for EV-charging.



Summary

TARGET

(1) CHP contribution in covering UNIWA's energy needs

(2) Cost reduction in electricity production - heating/cooling

(3) Minimization of CO_2 emissions (footprint)

SUGGESTIONS

(A) Virtual Net Metering for covering 3.500-5.000MWh (C-2 και C-3)

(B) Simultaneous meeting of electricity and heating/cooling needs with $CF_{new} \leq 55\%$ to 63%

(C) PV installation of 400 kW_p for covering the remaining electricity requirements

(D) Energy efficiency intervention

Future Plan

UNIWA's transition to a totally GREEN university

Conclusions

- A systematic effort is under implementation in order to transform the current UNIWA campuses to Green ones.
- In this context, the installation of the 600kW$_e$ CHP unit in Campus-2 of the UNIWA is a very good and pioneering strategy offering environmental and financial benefits to the University members and an excellent working example for the students of the Engineering School. The operation of the CHP should be encouraged in order to cover the entire electricity consumption of UNIWA under the virtual-metering scheme. Special focus is necessary in order to exploit the available heating and cooling opportunities of the CHP minimizing also the carbon dioxide emissions.
- At the same time the gradual installation of 0.4 MW$_p$ of modern PV panels along with the 0.2 MW$_p$ of flexible PVs will ensure the energy autonomy of the UNIWA Campus-2 supporting at the same time the forthcoming electro-mobility plans.

Thank You for Your Attention