OPTIMIZATION OF GAS TURBINE-BASED MICROGRIDS: AN AIRPORT CASE STUDY

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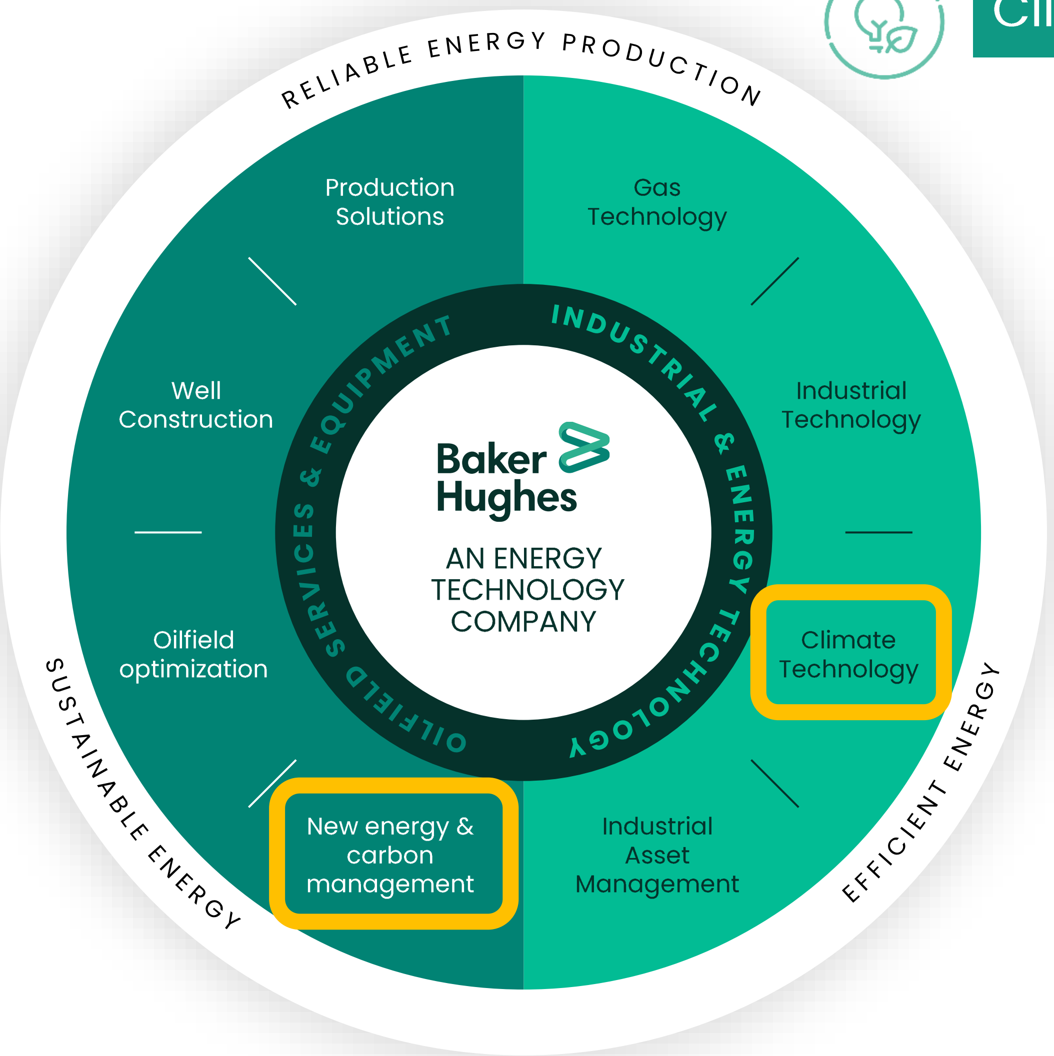
INTRODUCTION

We are Baker Hughes – Energy transition pioneers



Climate Technology/New energy and carbon management

- **Hybrid microgrids**: heat & power generation with RES integration for LNG and industrial sectors
- **CCUS**: Carbon Capture, Utilization and Storage
- **BESS**: Battery Energy Storage Solutions integration
- **Hydrogen solutions**: H2 production/storage/reuse

↓

develop and deliver a portfolio of
INTEGRATED DECARBONIZATION SOLUTIONS

↓

Engineering support: Energy Management & Electrical Plant Integration CoE

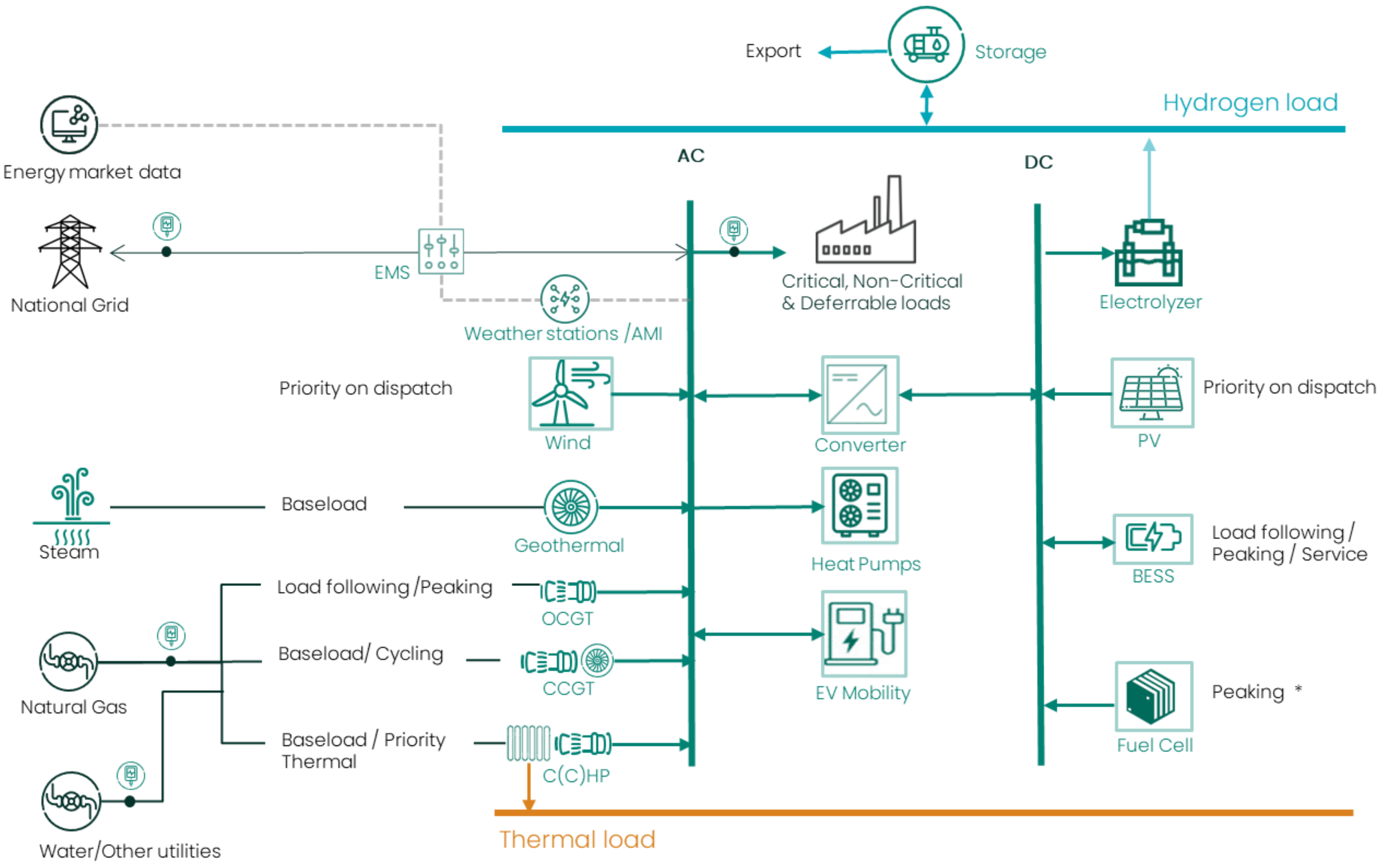
Clean power generation: our vision

Hybrid microgrid with integrated decarbonization solutions

- Thermal power sources/loads
- RES (renewable energy sources) and BESS
- H2 production/storage/reuse
- Fuel cells
- Heat pumps & thermal storage
- Load management (EV & dispatchable loads)

OPTIMIZATION:

- HANDLING COMPLEXITY
- PROFITS MAXIMIZATIONS



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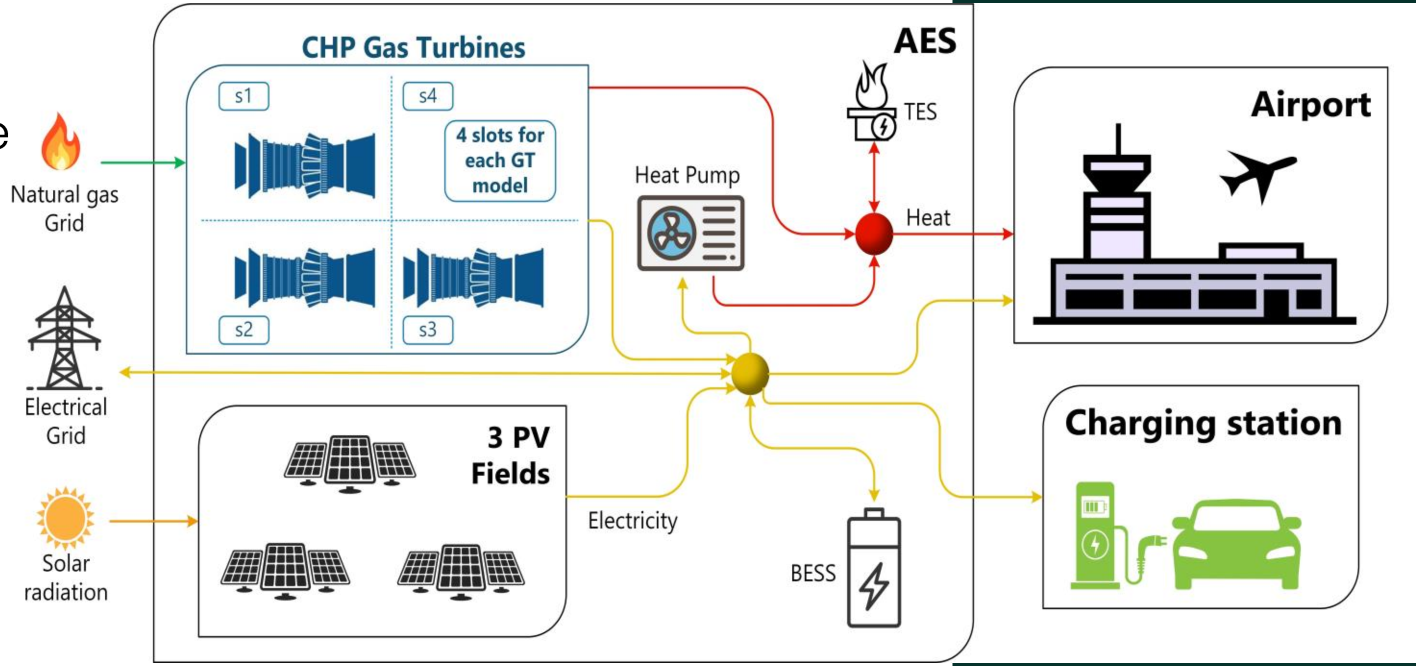
STUDY CASE and MODELLING APPROACH

Study case – Sizing of hybrid microgrids for airports

DEVELOP MICROGRID SOLUTIONS FOR AIRPORT INDUSTRY

- Middle-size airport (Incheon Airport, Seoul)
- EV (electric vehicle) charging infrastructure
- Thermal and electrical loads
- Open cycle gas turbine
- PV (photovoltaic) plant, BESS
- Heat pump, TES (thermal energy storage systems)



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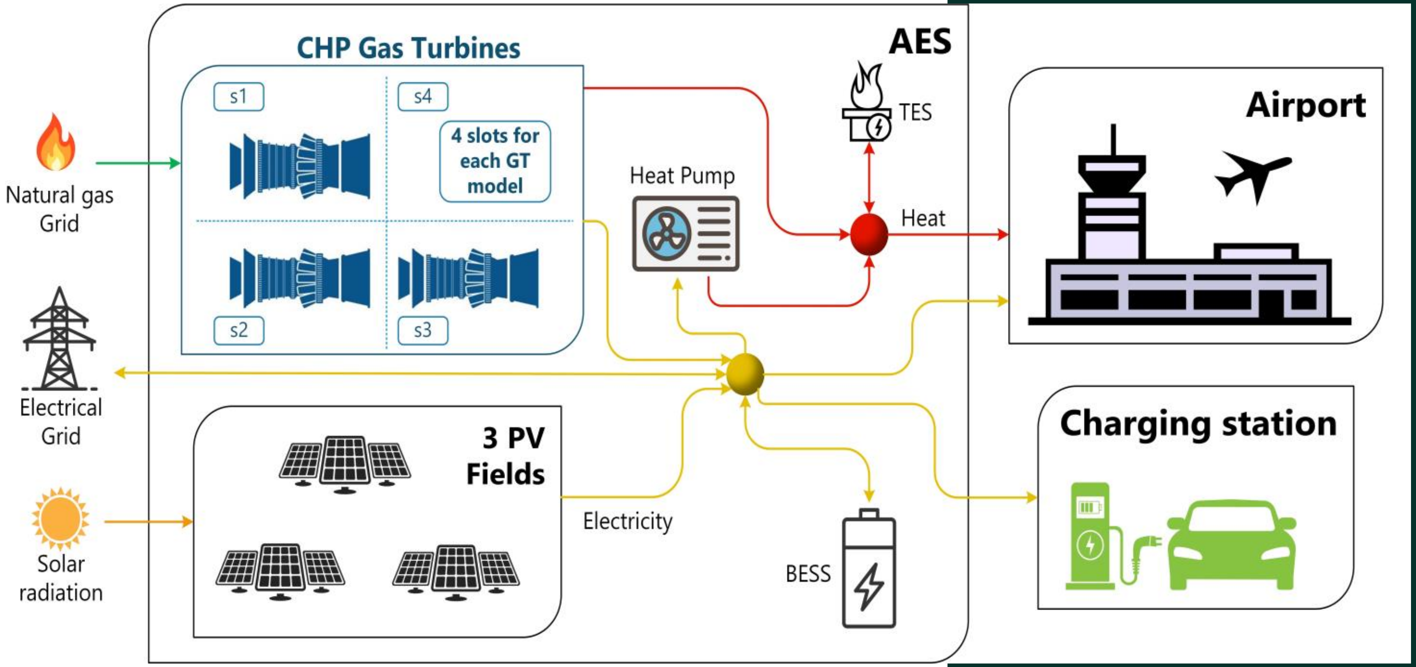
Study case – Sizing of hybrid microgrids for airports

Microgrid **SIZING problem**

Select:

- number and model of CHP GT
- model of heat pump (from catalogue)
- size of each PV field
- size of TES and BESS
- size of grid connection
- size of charging station (considering EVs a dispatchable load: **load management**)



GOAL: TAC* (total annual cost) **minimization**

- TAC f(CAPEX, OPEX)
- OPEX: O&M, start-up, fuel, carbon tax, electricity

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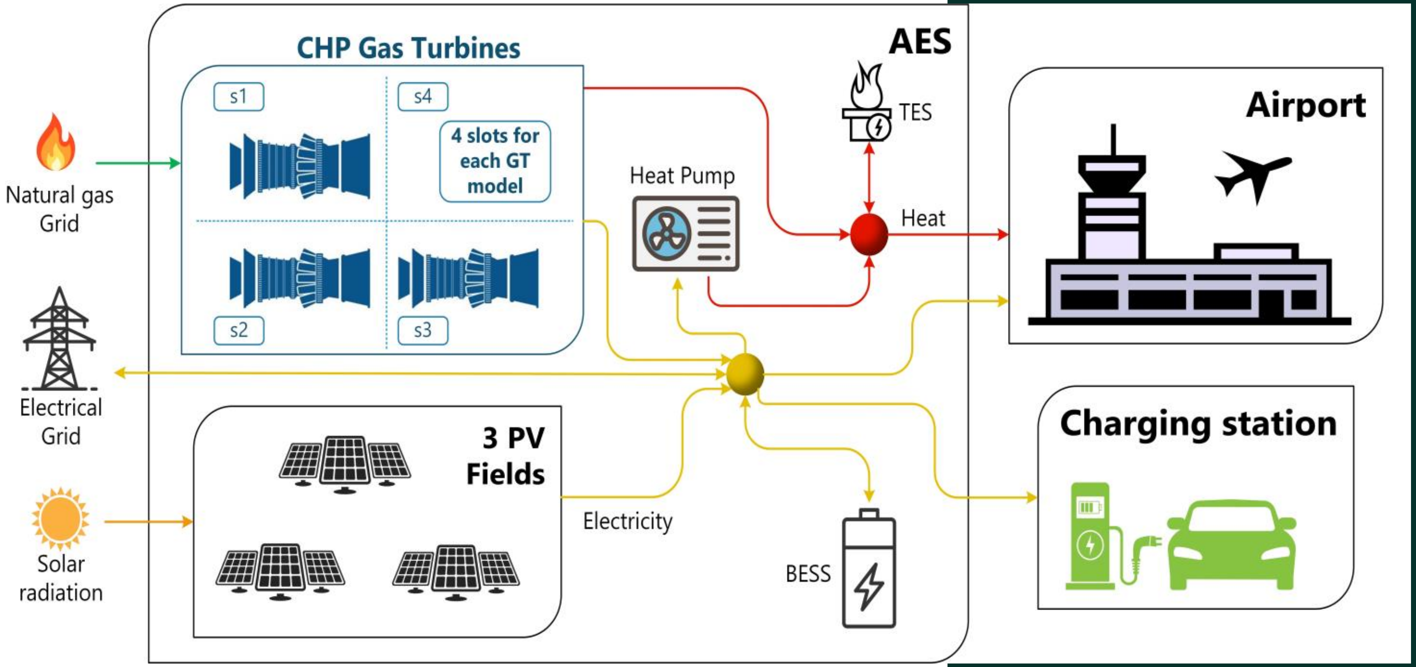
Study case – Sizing of hybrid microgrids for airports

Microgrid SIZING problem

- 71 million passengers/years
- Middle latitudes (annual average solar irradiance: 1780 kWh/m^2)
- 1.1 million electric vehicles/year
- High reliability requirements (islanded scenario)



GTs selected from commercial software's catalogue of gas turbines generators (CHP)

GTurbA, GTurbB, GTurbC, GTurbD, GTurbE

Different nominal power, efficiency and costs

CHP: combined heat and power

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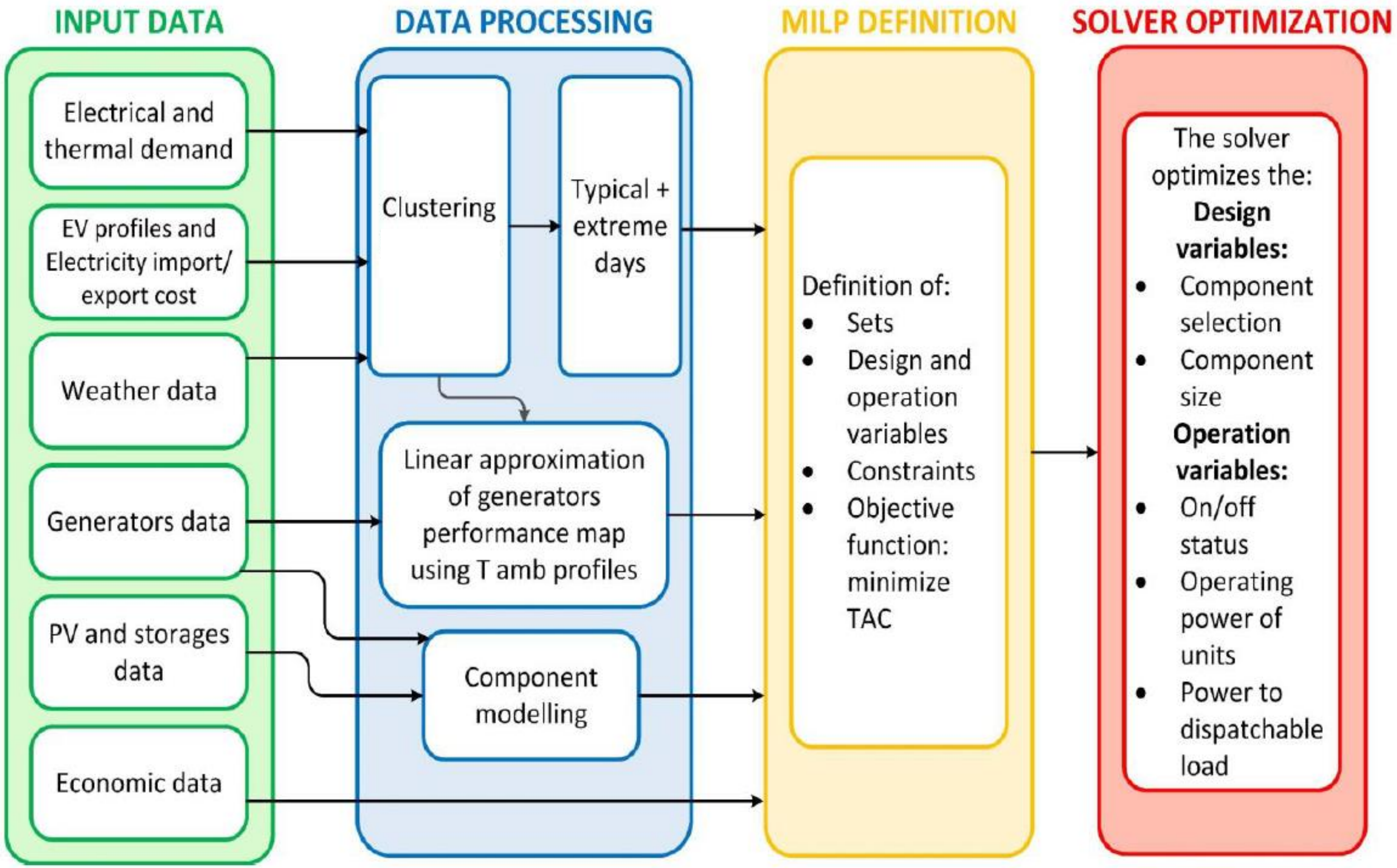
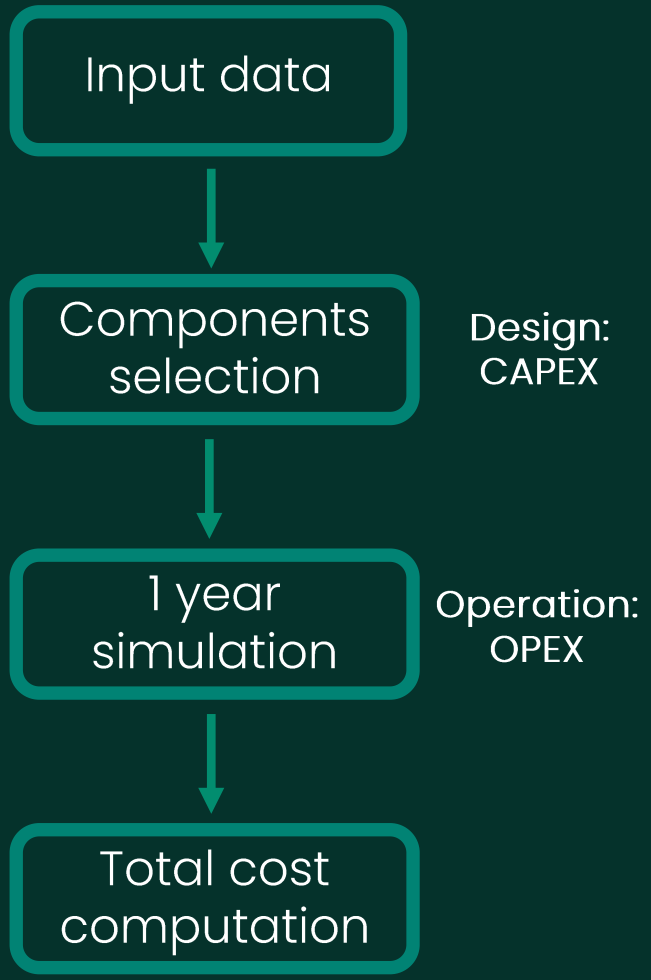
Modeling approach – MILP problem



MILP: Mixed-Integer Linear Programming

Conceptual process



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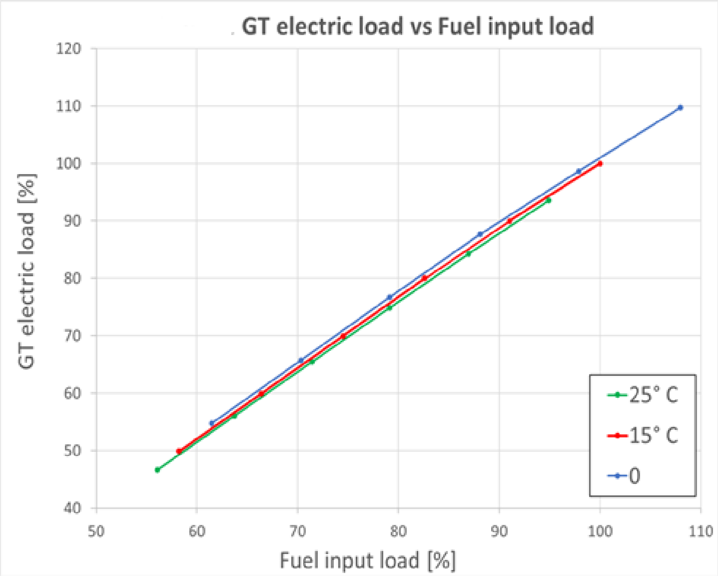
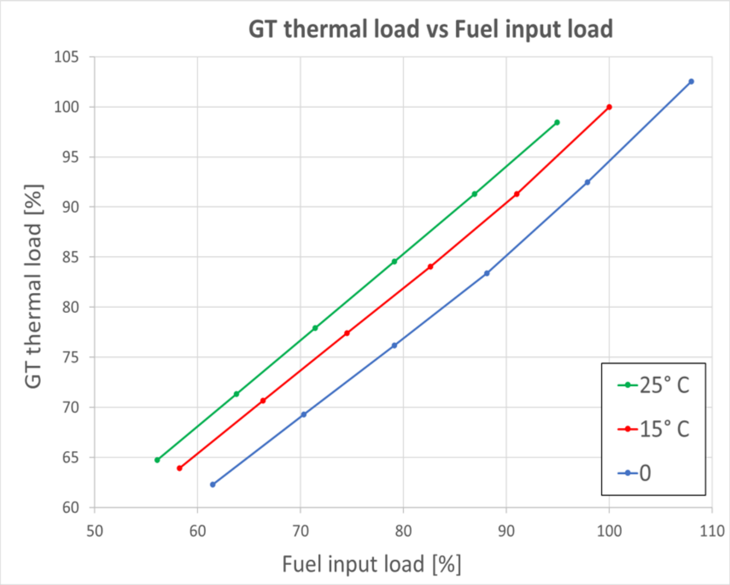
Modeling approach: linear modeling

- Main parameters (GT, TES, BESS, PV)
  - Nominal power
  - Efficiency
  - Investment cost
  - O&M cost
  - Start-up cost

- GT modeled via linearized maps
  - Inputs: natural gas
  - Outputs: electrical power, thermal power, CO_2 emissions





Notes:

- Up to four battery storage (higher reliability): max 4 · 20 MW

- Up to three PV plants (higher reliability): maximum 3 · 80 MW

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Modeling approach: N-1 reliability constraint

a) Instantaneous spinning reserve (ISR)

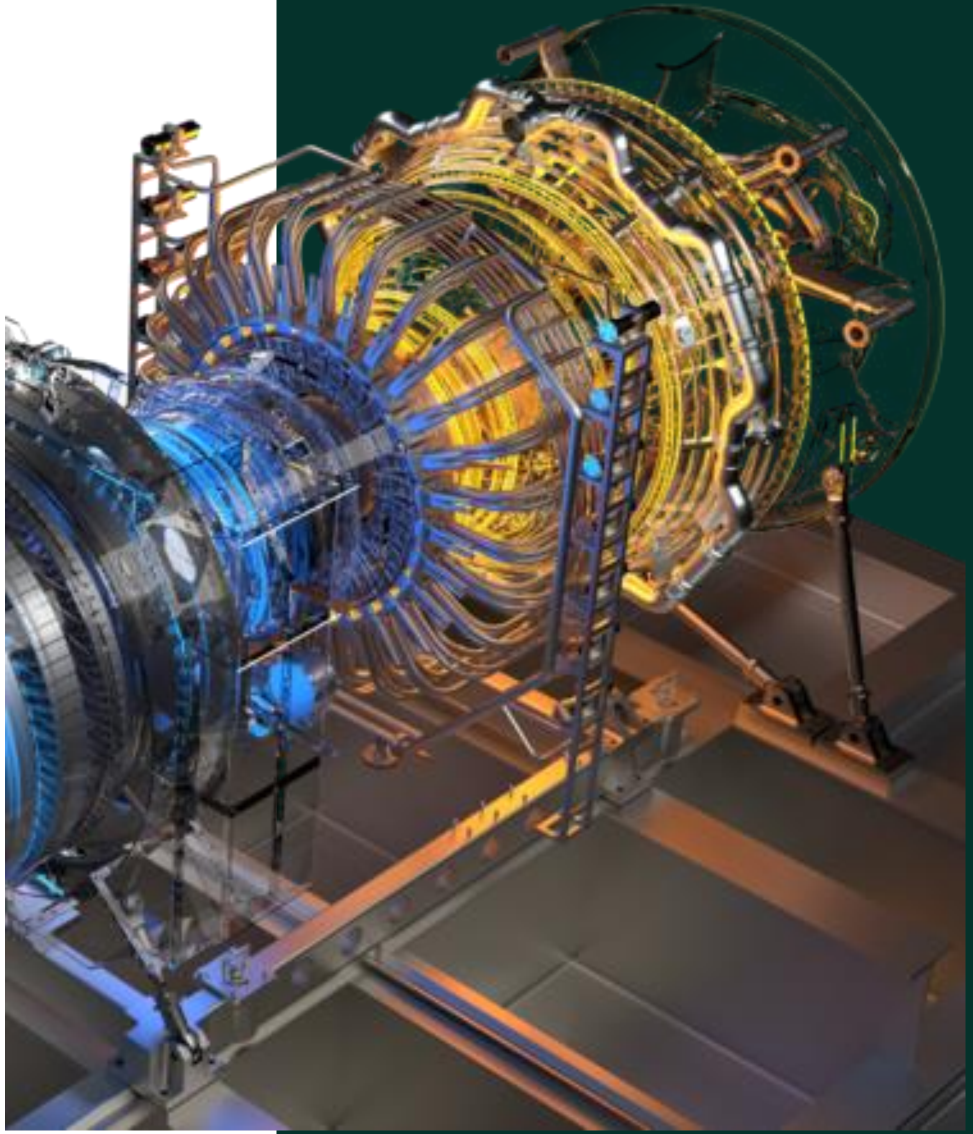
- "GT allowance": BESS power reserve + running GT inertia (25% of GT nominal power)
- instantaneous compensation one failure (GT/PV/BESS)

b) Upward reserve (first 30 minutes after failure)

- enough available power (GT/BESS) to compensate the failed unit
- BESS energy enough for 30 min upward reserve
- enough upward reserve to compensate PV/load fluctuations (-20%/+10%)

c) Spare unit:

- 1 spare GT from catalogue (turn-on time: 30 min)
- spare GT optimal size to replace any failing unit



Modeling approach: EV charging

Optimal sizing of charging station (smart charging approach)

- EVs' electrical demand: adjustable load to be optimally scheduled
- EVs to be fully charged within 24 hours (min parking time)
- Size of the charging station: highest total power delivered to the EVs
- Cost of charging station included in the objective function (investment cost)

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RESULTS

Results – Scenario description

REFERENCE CASE	OFF-GRID CASE	GRID-CONNECTED CASE
• Non optimized • Electrical energy from grid • Thermal power from boiler	• N-1 reliability constraints • Thermal and electrical power produced locally	• No reliability constraints • Market participation (electrical energy)

MAIN PARAMETERS

- **Natural gas:** 5.5 $/GJ (Europe 2020)
- **Carbon tax:** 50 $/ton
- **CO_2 emissions** (grid purchased electricity): 400.4 $kgCO_2$/MWh
- **Electricity import price:** 135-160 $/MWh
- **Electricity export price:** 20-120 $/MWh

Results – Off-grid design

TES: 30 MWh

HEAT PUMP: 0 MW

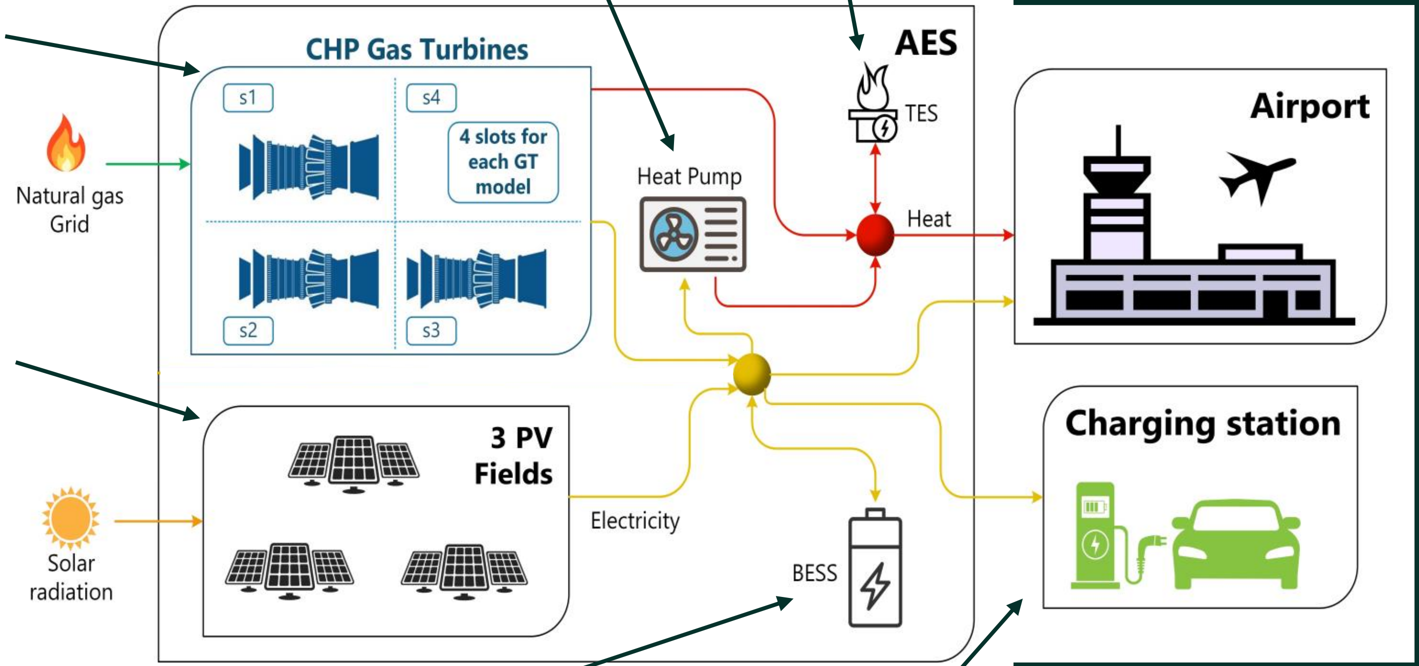
- thermal demand satisfied by TES + GT (cogeneration)

GT: 2 GTurbB (~60 MWe) + 1 GTurbB spare

- low investment cost (~450 $/kWel), high efficiency

PV: 48.8 MWe (3 · 18.3 MWe)

+: lower COE (66.2 $/MWh) than GTurbB (108.8 $/MWh)
–: needs BESS for reliability (PV + BESS: high COE)
–: needs additional spinning reserves (uncertainty in production forecasts)
–: no contribution to thermal power (thermal solar to be investigated)



BESS: 35.3 MWh (2 · 17.7 MWh)

EVs charging infrastructure: 17.47 MW

COE: cost of energy

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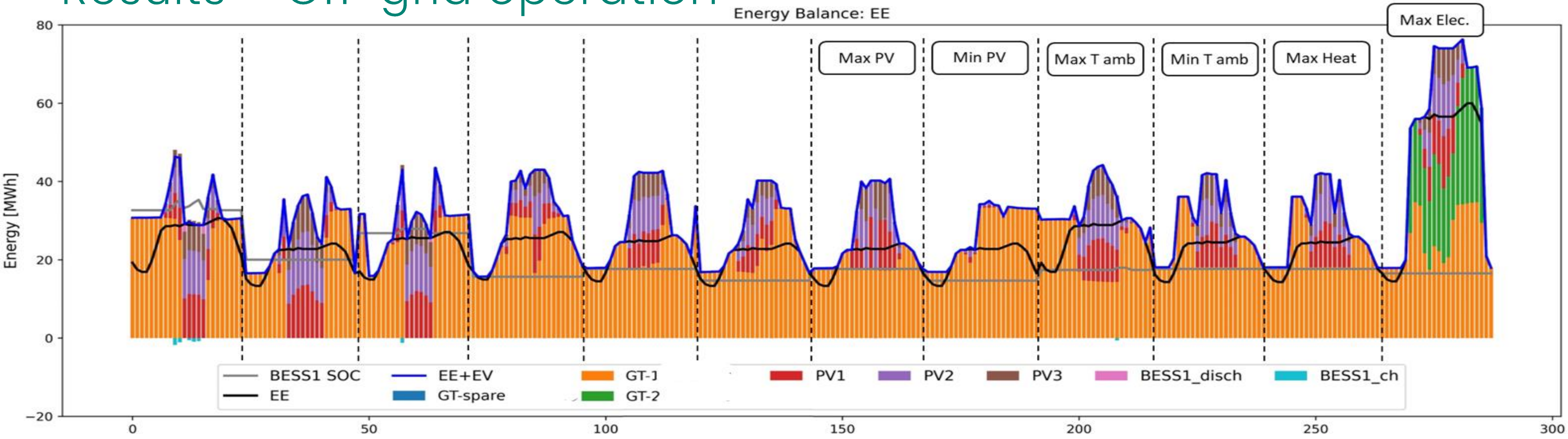
Results – Off-grid operation



- GTs:
  - GT-1: 7784 hours/year, average load of 72%
  - GT-2: used only during extreme day with max load (spare GT never turned on)
- BESS: mainly for spinning reserve (slightly used on first and third typical days)
- EVs charging infrastructure:
  - greater than max power required for non-flexible solution (16.1 MW)
  - cost-effective to exploit PV to charge the EVs installing more chargers, instead of peak shaving

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Results – Grid connected design

TES: 47.4 MWh

- bigger than islanded to meet thermal demand during peaks of PV production (GT off)

HEAT PUMP: 0 MW

- thermal demand satisfied by TES + GT (cogeneration)

GT: 1 GTurbB (~30 MWe)

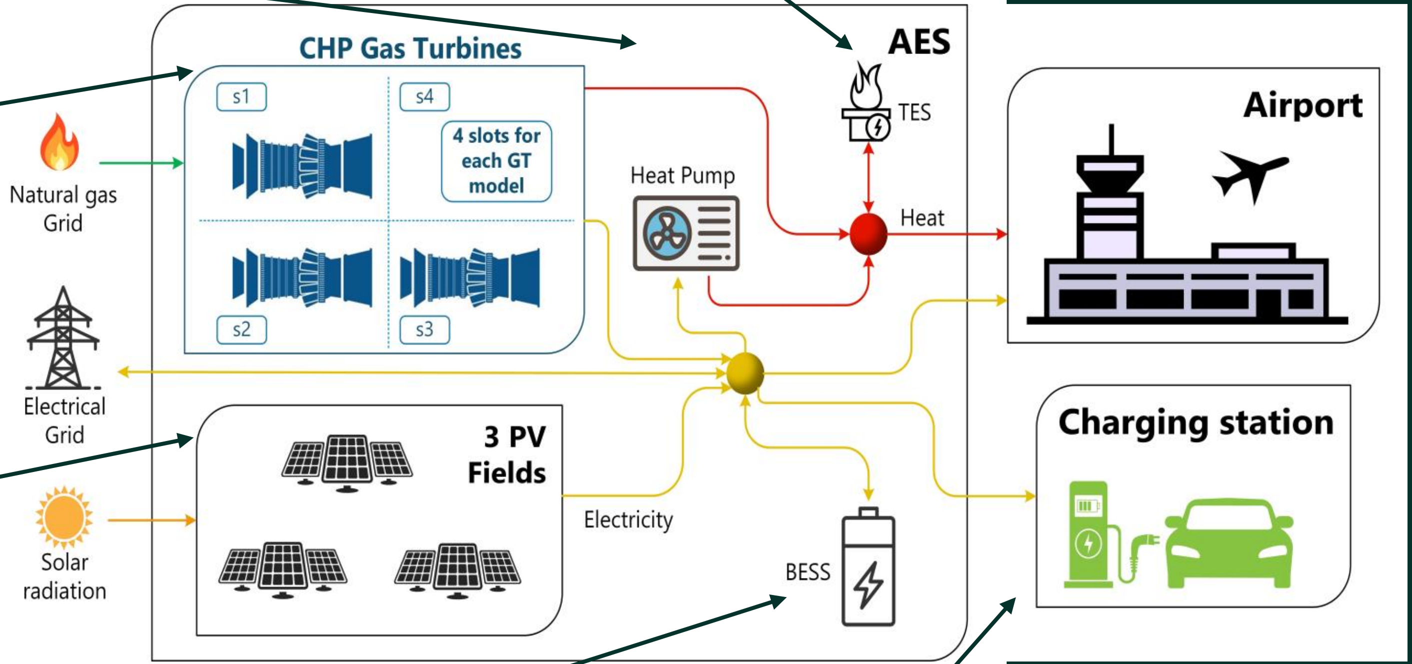
- no spare (no reliability constraint)
- lower COE (99.04 $/MWh) than grid (used only to meet demand peaks)
- 62% of total electricity produced

PV: 76 MWe (3 · 25.3 MWe)

- 37.9% of total electricity generated

BESS: 0 MWh

- No reliability constraints, no need to compensate PV fluctuations, high cost



EVs charging infrastructure: 16.9 MW

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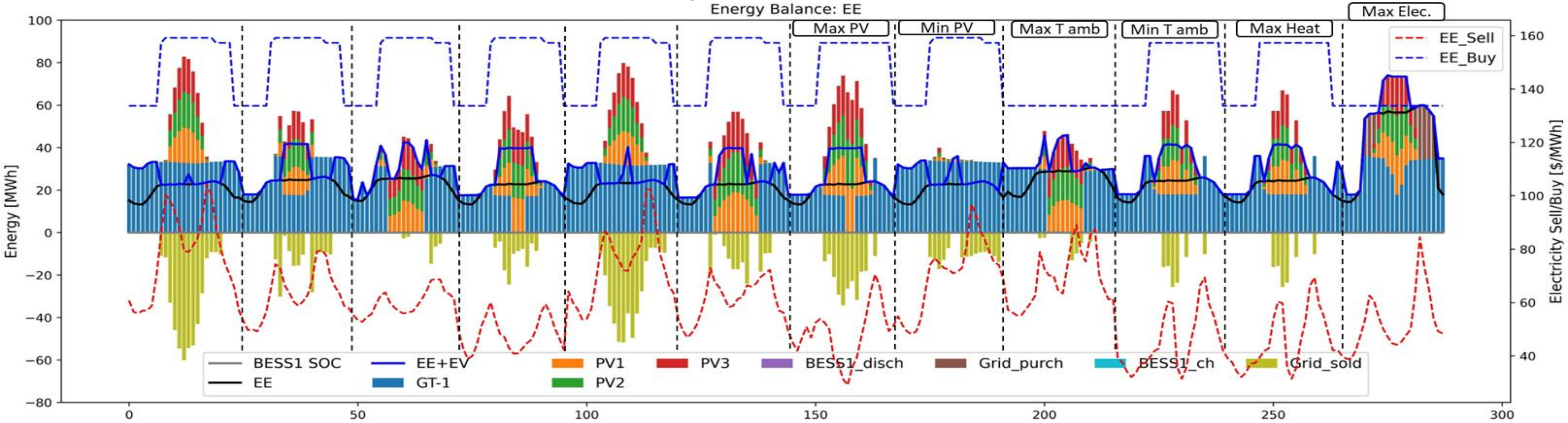
Results – Grid connected operation



- GT:
  - GT-1: 7221 hours/year, average load of 78.4%
- PV:
  - sale of excess electricity (PV COE: 64.02 $/MWh, at some hours lower than electricity selling price)
- EVs charging infrastructure:
  - greater than max power required for non-flexible solution (16.1 MW).
  - cost-effective to exploit PV to charge the EVs installing more chargers, instead of peak shaving

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Results – Scenarios comparison

Scenario	Off-Grid	Grid connected	Reference
Optimal design	GT: 3 CHP GTurbB PV: 48.8 MW BESS: 35.3 MWh TES: 30 MWh	GT: 1 CHP GTurbB PV: 76 MW BESS: 0 MWh TES: 47.4 MWh	All electricity imported from the grid. Boiler size: 31 MWh
TAC [M$/y]	28.2 – COE: 109.6 $/MWh	22.7 – COE: 74.6 $/MWh	45.7 - COE: 179.3 $/MWh
Yearly operational cost [M$/y]	17.9	18.3	45.5
Yearly investment cost [M$/y]	10.3	8.2	0.2
PV electricity [GWh/y]	71.6	115.4	-
GT electricity [GWh/y]	185.5	188.9	-
Electricity exported to the grid [GWh/y]	-	53.1	-
Carbon Intensity [kgCO_2/MWh]	395.3	333.4	454.8

- TAC and CO_2 reduction with optimized design
  - TAC: -38.7% (off-grid)/-50.2% (grid connected)
  - GT: lower COE compared to the cost of purchasing electricity
  - CO_2: -13.1% (off-grid)/-26.7% (grid connected)

- TAC grid-connected lower than TAC islanded
  - absence of reliability requirements → decrease in investment costs (-20.6%): no BESS, 1 GT
  - PV of grid connected plants generates revenues exporting electricity

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CONCLUSIONS

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CONCLUSIONS

- High reliability microgrid design optimization for medium-sized airport with EVs chargers
- MILP model minimizing TAC. Optimization results:
  - lower TAC than reference case (off-grid: -38.7%; grid connected: -50.2%)
  - lower CO_2 emissions than reference case (off-grid: -13.1%; grid connected: -26.7%)
- GT used in CHP configuration show high efficiency and low specific investment cost
- Lower TAC for grid-connected microgrid with respect to off-grid (-19.3%):
  - Reliability guaranteed by main grid (no spare GT, no BESS as spinning reserve)
  - Revenues exporting electricity generated with PV

NEXT STEPS

- Extension to different applications
- Sensitivity analyses
- Introduction of additional technologies

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Thank you for your attention!

Q&A

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