Microgrids

Sizing a microgrid

ELEN0445-1

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Version 3 - October 2019

Previously on ELEN0445-1

In previous lectures we have learned what are the main components of a microgrid, what are the main value mechanisms, and how to plan the operation of a microgrid. We also had an introduction to optimization, in particular to linear programming and mixed integer programming

In this lecture we will learn how to design and size a microgrid from a clean sheet.

What is microgrid sizing

Given information of a site

- consumption (energy and power)
- renewable generation potential (incl. land size, available rooftops, etc.)
- availability of a public grid
- budget constraints (maximum investment, ROI, etc.)
- reliability requirement

Determine the best migro-grid design

- which components?
- which ratings?
- (which network topology?)

Compare to a traditional grid-tied situation

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Agenda

1. Use cases
2. What are the criteria that we should optimize?
3. How do we solve the problem?
4. Use case results

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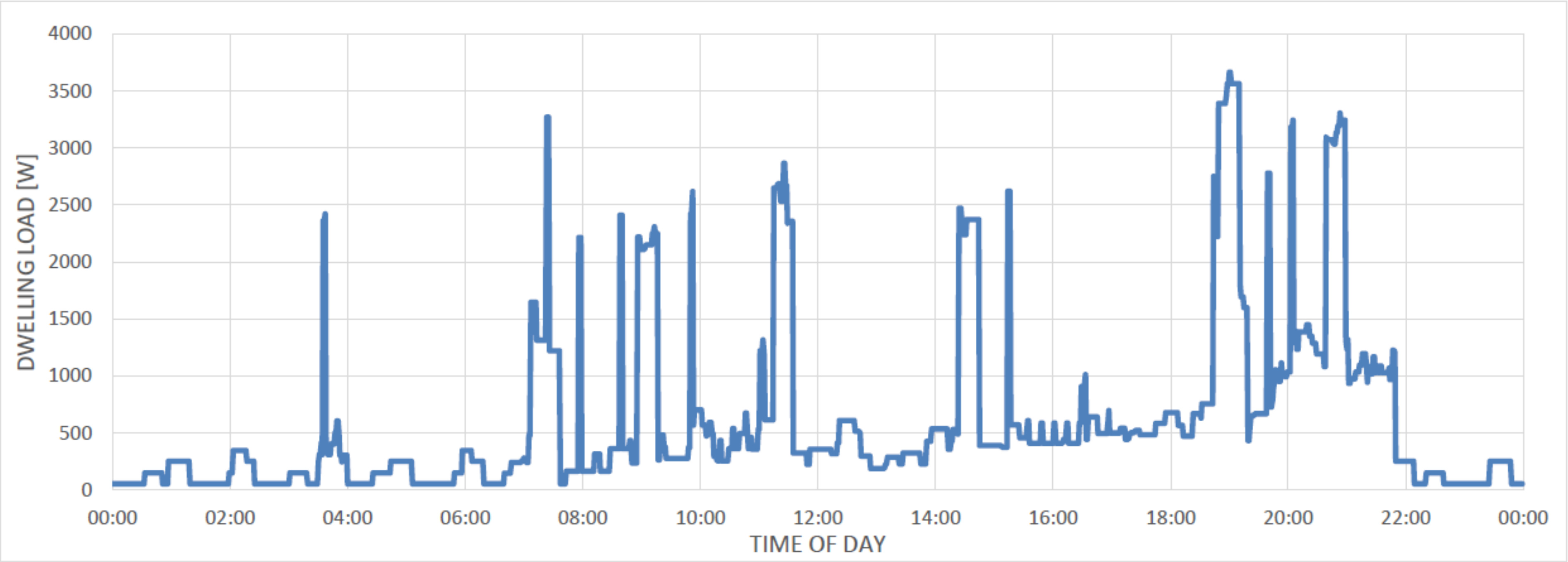
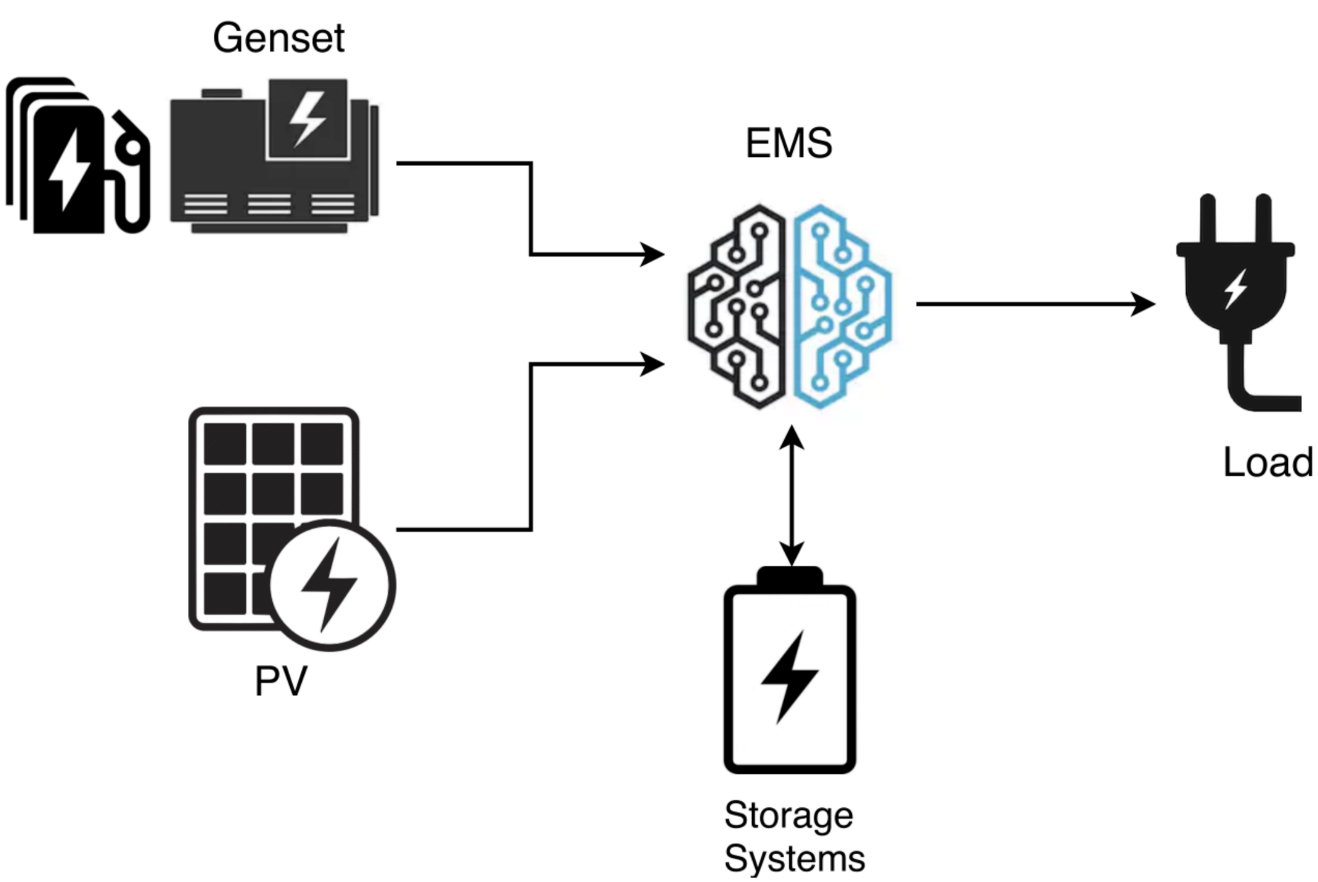
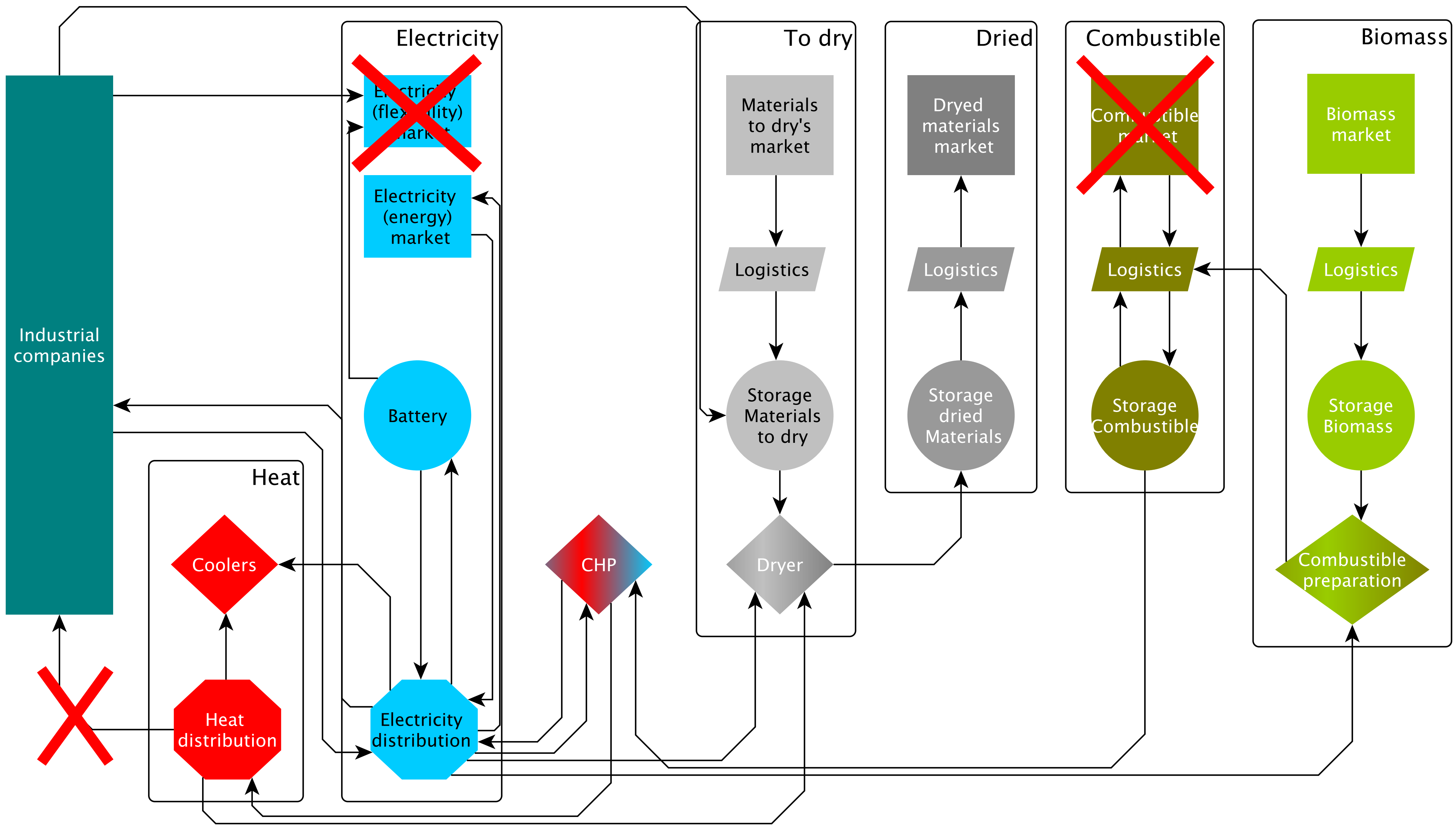
Examples

Use case 1: Off-grid microgrid





Use case 2: A CHP project



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Use case 3: Accounting for storage degradation and reinvestment

Dakir, S., & Cornélusse, B. (2020). **Combining optimization and simulation for microgrid sizing**. Paper submitted to PSCC 2020 XXI Power Systems Computation Conference, Porto, Portugal.

TABLE I: Input parameters.

PV cost	800 €/kWp
BESS cost	300 €/kWh
η^{charge}, $\eta^{\text{discharge}}$	95 %
N	25 years
n	2 %
Δ_t	1 h
$\lvert\mathcal{T}\rvert$	24 h
$I^{\max}$, $E^{\max}$	1600 kW

- Battery degrades as a function of the number of cycles.
- After 3500 cycles, the residual capacity of the BESS is 70%.
- A reinvestment must be done.

Techno-economic and sizing principles

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What is this section for?

- Making an investment is always a tradeoff between costs, benefits, value, risk, etc.
- The value of money varies with time
- Investing requires a financing scheme (e.g. a constant annuity loan)
- Besides the technical constraints, it is thus key to determine
  - Which financial objective to optimize (e.g. minimize costs?)
  - Whether the investment can be funded
  - How to present results from a financial perspective

Time-value of money

- The value of money evolves with time as a function of (mainly) three factors:
  - the inflation rate (d_t) : the reduction of purchase-power of money (when $d > 0$)
  - the loan rate (l_t)
  - the interest rate (i_t): the cash you have on your bank account
- Usually we have $d_t < i_t < l_t$
- Example: value in n years of money on your bank account = $(1+i)^n / (1+d)^n$ x value now

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Inflation rate

Source: `http://www.inflation.eu/inflation-rates/belgium/historic-inflation/hicp-inflation-belgium.aspx`

Economic evaluation based on the cost of electricity

- COE = CAPEX + OPEX

- Notes:
  - More accurate if we consider the net present value, accounting for time value of money
  - Value of reliability should also be accounted for to rank several options.

Capital expenditure - CAPEX

The CAPEX in EUR/kWh is defined as

$$CAPEX = \frac{TIC\ FCR}{8760h\ CF}$$

with

- TIC [EUR/kW] the total installation cost divided by the rated power of the installation
- FCR the fixed charge rate, accounting fot the time value of money
- CF the charge factor, i.e, the fraction of the year the system is operating af the rated power.

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Fixed charge rate (FCR)

- In its simplest form, it is equal to the inverse of the number of years over which the investment is amortized

- But in principle represents "the percentage of capital costs that must be recovered each year in order to cover all investment costs, including return on debt and equity."*

  - Accounting for the time value of money, tax rebates, depreciation method, etc.

*T.E. Drennen and J. Andruski, "Power systems life cycle analysis tool (Power LCAT)", U.S. National Energy Technology lab, DOE/NETL-2012/156,6, May 2012.

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Operational expenditure - OPEX

- All the costs and revenues of the microgrid after the investment is made
- Should also include maintenance costs

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The Total life cycle cost - TLCC

- Total cost over the microgrid life cycle taking into account:
  - The investment and reinvestments costs
  - Operating & maintenance costs
  - A discount cash flow factor
- Good financial indicator to be minimized in the case of an off-grid microgrid.

The Net Present Value - NPV

Investment cost Revenues Operating cost

$$NPV(c,\lambda) = \sum_{t=0}^{N} \frac{-I_t(c_{[t]}) + R_t(c_{[t]}, a_{[t]}) - O_t(c_{[t]}, a_{[t]})}{(1+d)^t}$$

Discount factor

- This indicator takes into account the same parameters as the TLCC with the addition of revenues.
- Good financial indicator to be maximized in the case of a grid-tied microgrid.
- The NPV becomes positive when the payback period is within the lifetime of the microgrid.
- In an off-grid case, the NPV is equal to the opposite of the TLCC.

LCOE

- The Levelized Cost of Electricity (LCOE) can be used to compare the costs of different energy production resources.

$$LCOE(c, \lambda) = \frac{\sum_{t=0}^{N} \frac{I_t(c_{[t]}) - R_t(c_{[t]}, a_{[t]}) + O_t(c_{[t]}, a_{[t]})}{(1+d)^t}}{\sum_{t=0}^{N} \frac{P_t}{(1+d)^t}}$$

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How to present results?

Cash flow diagram

- A cash flow diagram describes how a budget evolves along time
- The cashflow representation depends on the role of an entity in a project
  - Microgrid entrepreneur borrows money, then spends money on equipment, then uses the assets, and pays back the money lender
  - The money lender (the bank), provides some cash, applies an interest rate, and waits for his money back
- We take the role of the microgrid entrepreneur

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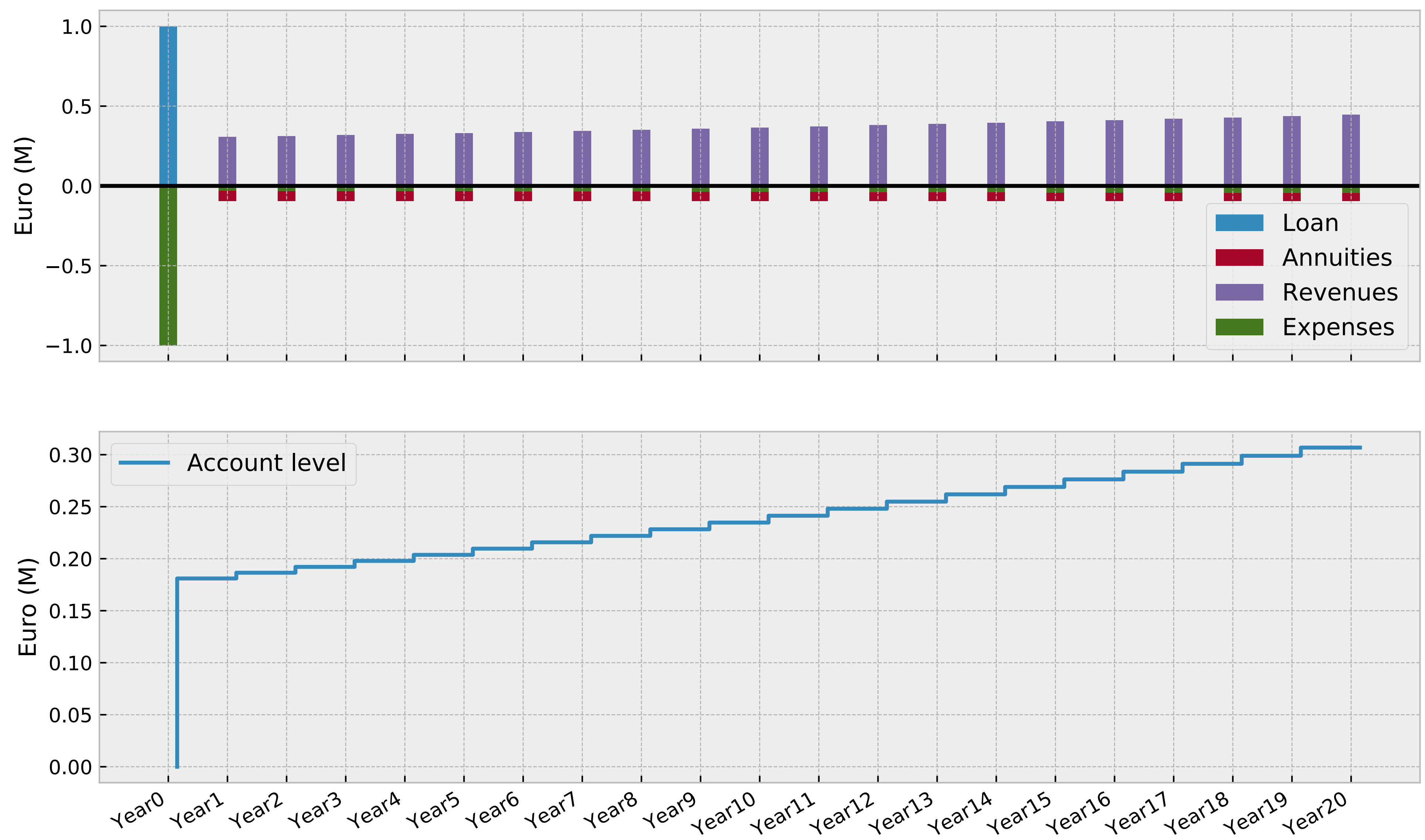
Cash flow diagram example



When are you “profitable”?

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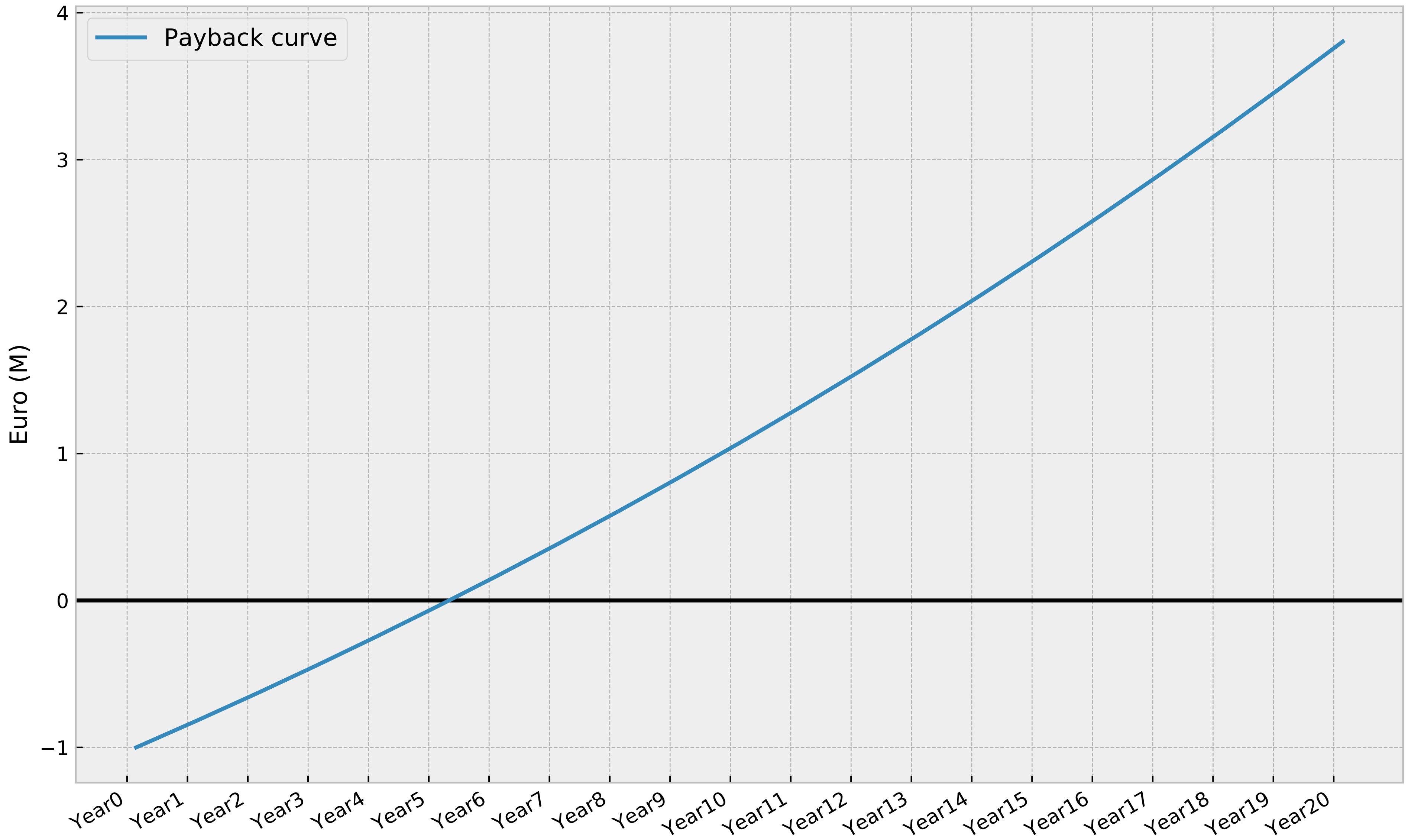
Return on investment



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Funding the investment - constant annuity loan example

$$a = M \frac{r}{1 - (1+r)^{-n}}$$

with

- a: annuity
- M: amount borrowed
- r: interest rate (e.g. per year)
- n: duration (e.g in years)

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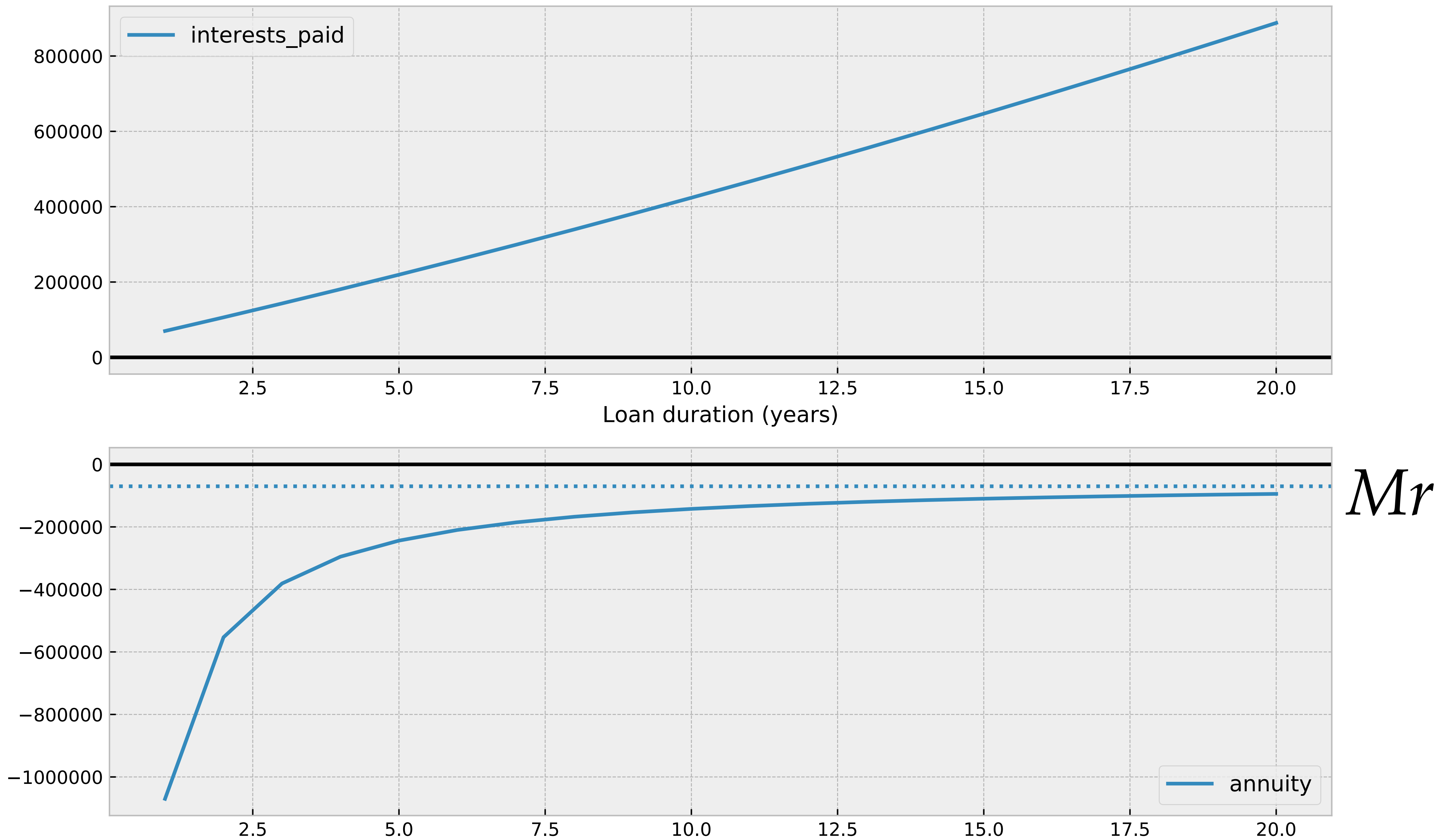
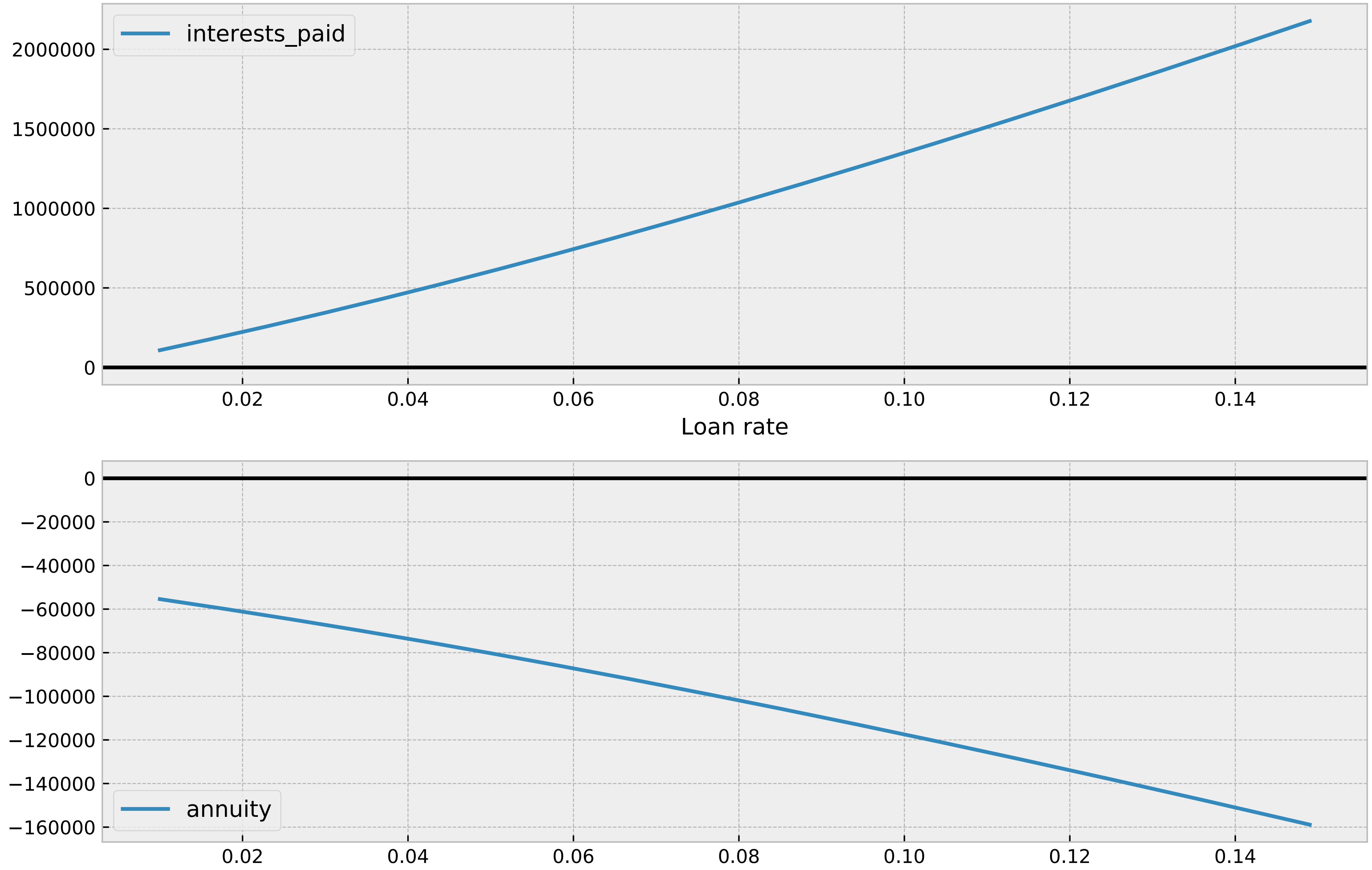
Impact of loan **duration**



Impact of loan **rate**



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Solution methods

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Simulation based

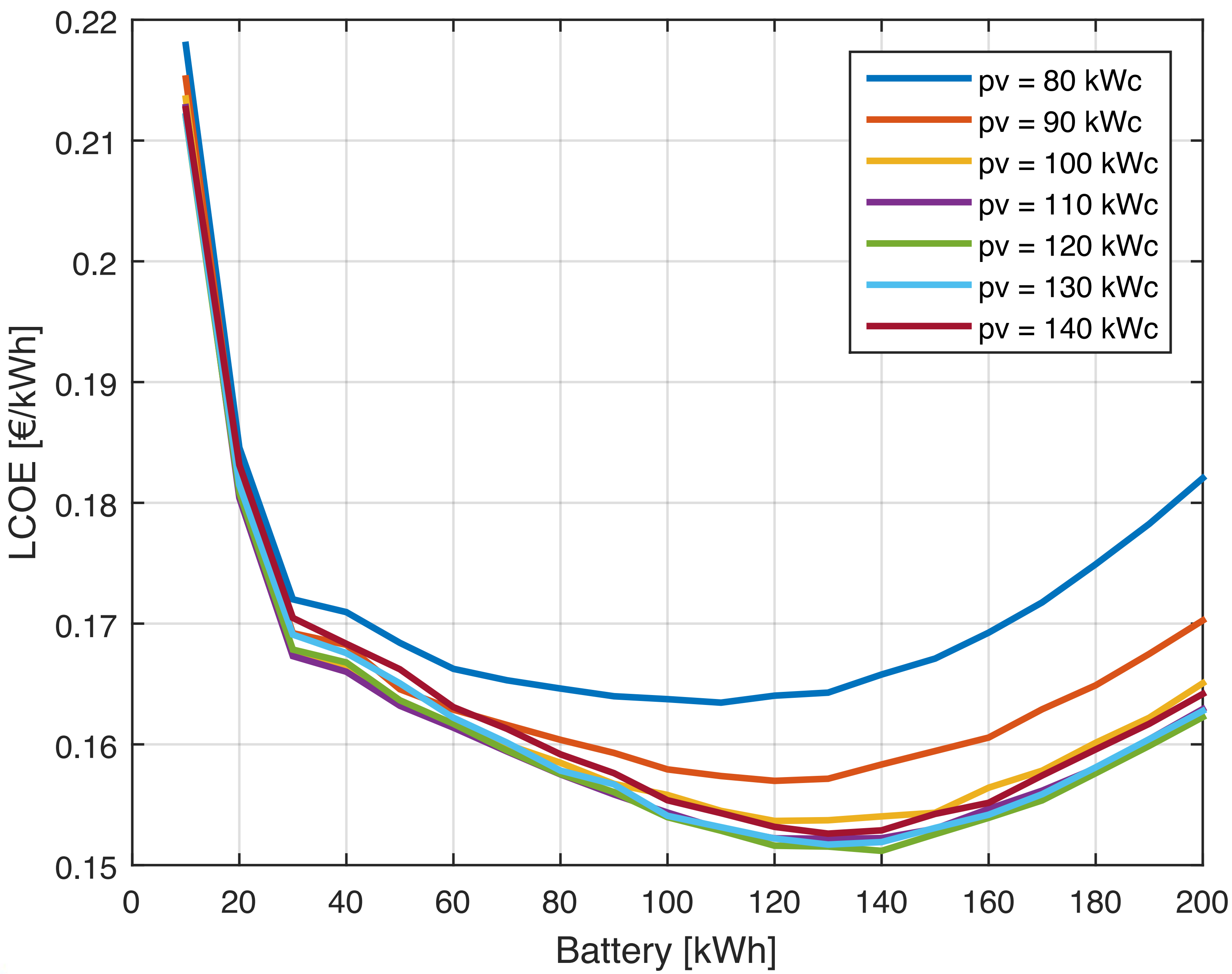
- Advantage of simulation:
  - It can easily incorporate non-linear models
  - a simulation is relatively fast
  - microgrids are relatively small systems, so not so many combinations to test
- Disadvantage:
  - when the interaction model with the grid is complex, requires to commit in advance, it is difficult to come up with an operational policy without operational planning, i.e. optimization
- E.g. Homer software

"At its core, HOMER is a simulation model. It will attempt to simulate a viable system for all possible combinations of the equipment that you wish to consider. Depending on how you set up your problem, HOMER may simulate hundreds or even thousands of systems.

HOMER simulates the operation of a hybrid microgrid for an entire year, in time steps from one minute to one hour."

Use case 1 - Battery + PV + genset

- Impose genset capacity to maximum demand



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Optimization based

A two-level optimization problem where design decisions form the first level, and operation decisions form the second level:

- min LCOE
- s.t.
    - CAPEX definition
    - OPEX definition
    - operational constraints

Use case 2 (...)

The system operation is modeled by a linear program:

- A process prepares the purchased biomass
- The prepared biomass supplies a cogeneration plant
- The heat is recovered in a drying process
- An "integral" constraint links the use of heat to the granting of green certificates (60% of the heat must be properly used to give rise to 1.6*1.5 green certificate per MWhe produced)
- Electricity supplies the auxiliaries (boiler, drying, cooler, fuel preparation).
  - The balance is sold (either to the market at 35 EUR/MWhe or to local industries at 77.5 EUR/MWhe).
  - Market import are possible (120 EUR/MWhe).

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Use case 2's linear program

- The main variables are the size of the installation
  - turbine
  - boiler
  - dryer
  - cooler
  - fuel preparation
- Auxiliary variables model the flows in 15-minute steps (market period for electricity)
  - they make it possible to express operating constraints (e.g. limit on the time variation of a given process)
- => The processes are linear: Out = alpha x In

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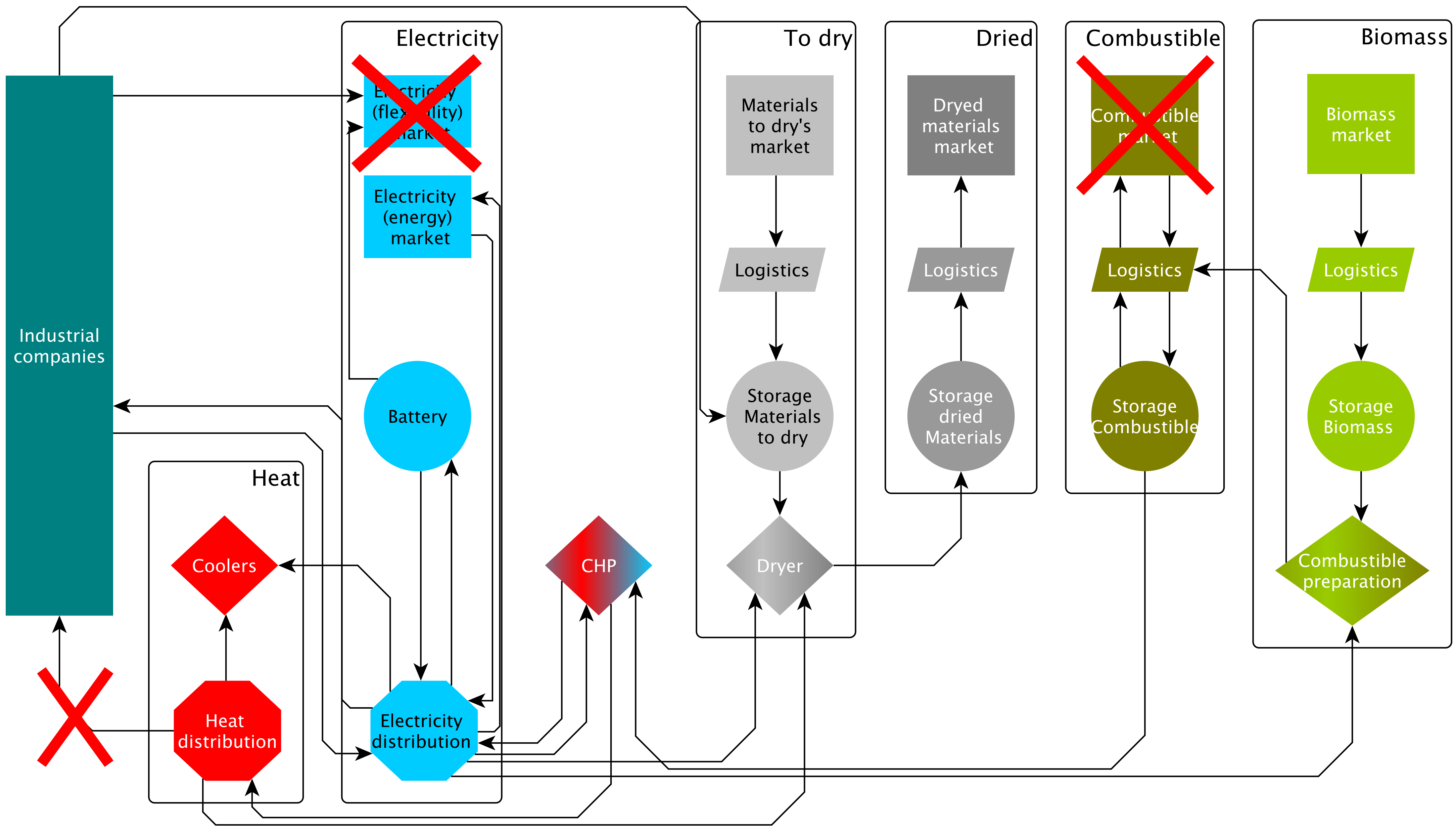
Use case 2: A CHP project



Constraints

- Constraint on the use of heat (granting of green certificates)
- Limit of variation of the cogen (0.8 MW / hour) upwards or downwards
- Logistics limits on the transport of raw materials, biomass, wet matter, dried matter
- The power plant and purchases cover the electrical consumption of auxiliaries, but the consumption of industries is satisfied in part if profitable

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Key parameters

- green certificate price [65 EUR], number of green certificates [2.4]
- Spread between "purchase of dry material and resale of dry material" [0 to 4 EUR]
- Logistics limits [80 to 160 t/h] !!!!!
- Operating and maintenance costs [3% to 8%]
- Cost of purchasing biomass [0 to 30 EUR/t]
- The demand to serve

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Use case 2 results

- Without satisfying industrial demand, the business case is profitable
- The big constraint is on the supply of the materials to be dried
- The optimal size of the plant is very sensitive to it
- E.g. Unfavourable scenario: biomass at 30 EUR/t, no drying gain (for the CHP operator), O&M at 8%
  - 80 t/h for m.p. => 3MWe cogen
  - 160 t/h => 6MWe

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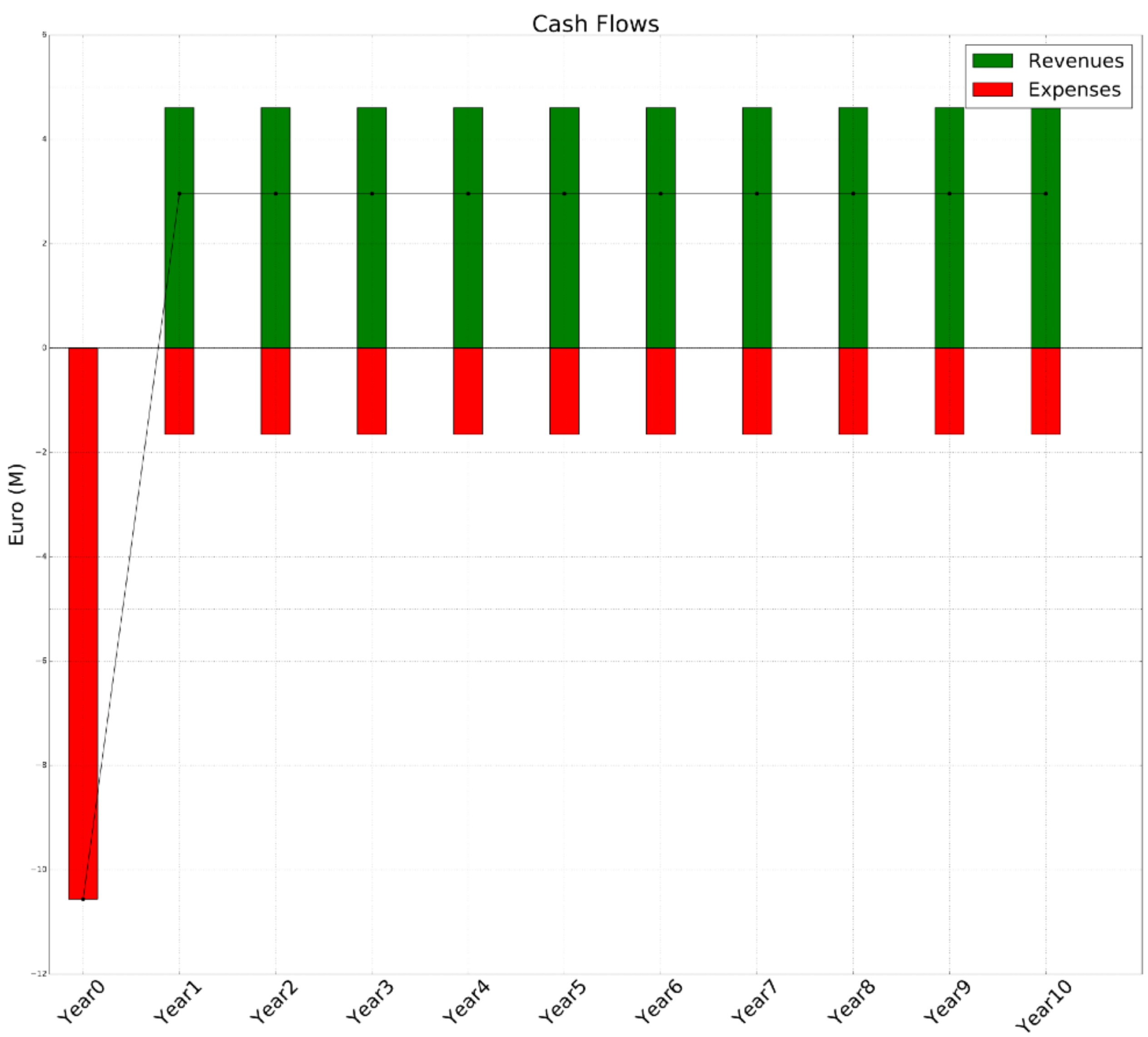
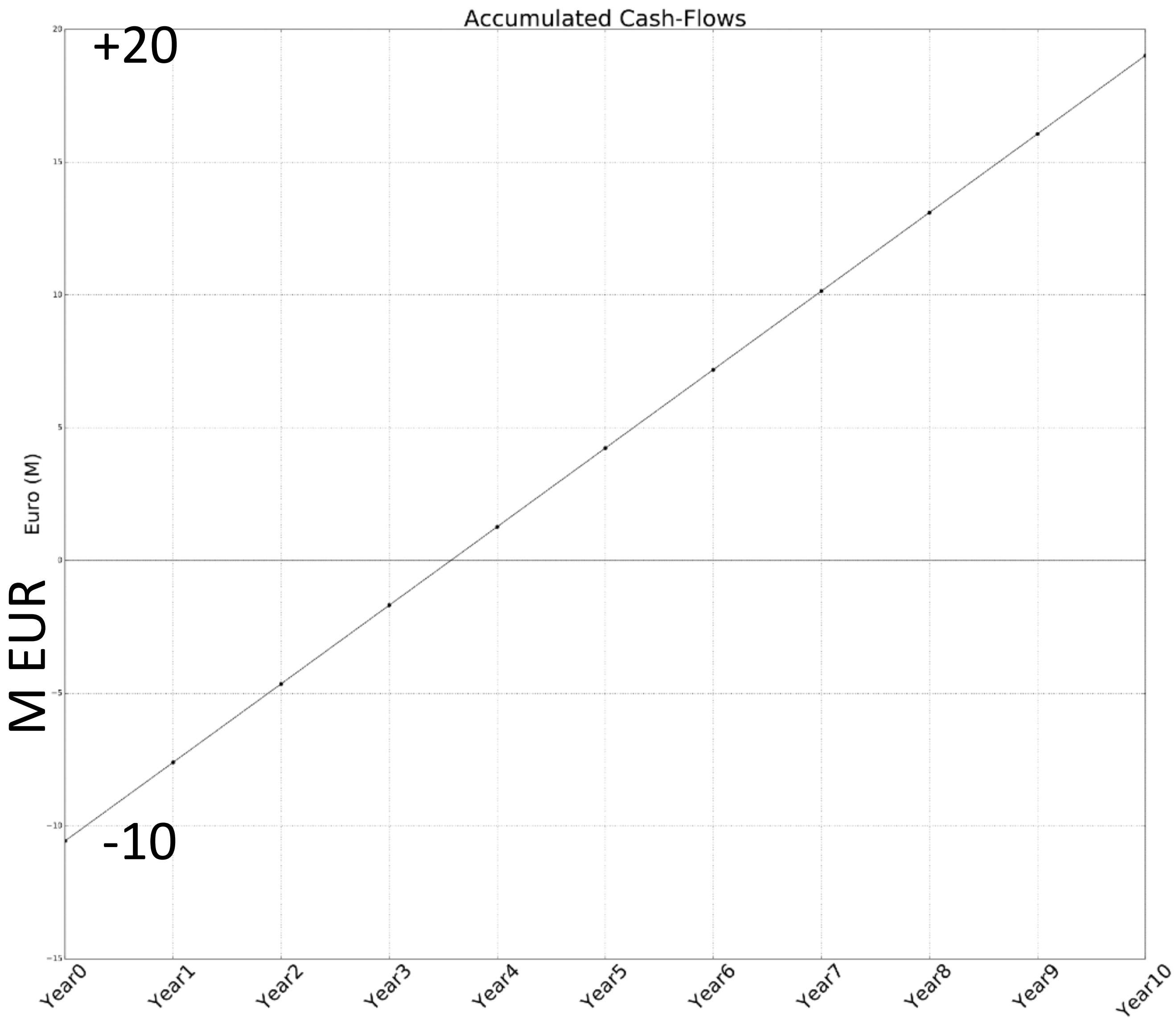
Caution

- We've probably overestimated efficiency parameters
- Some costs are neglected (engineering, network development, roads, storage, pollution control) => adds fixed costs mainly
- There is no forced shutdown period
- The quarter-hourly peak is not penalized (but very flat profiles and very little grid import).

Unfavourable case: no external demand to satisfy, limit to 80t/h





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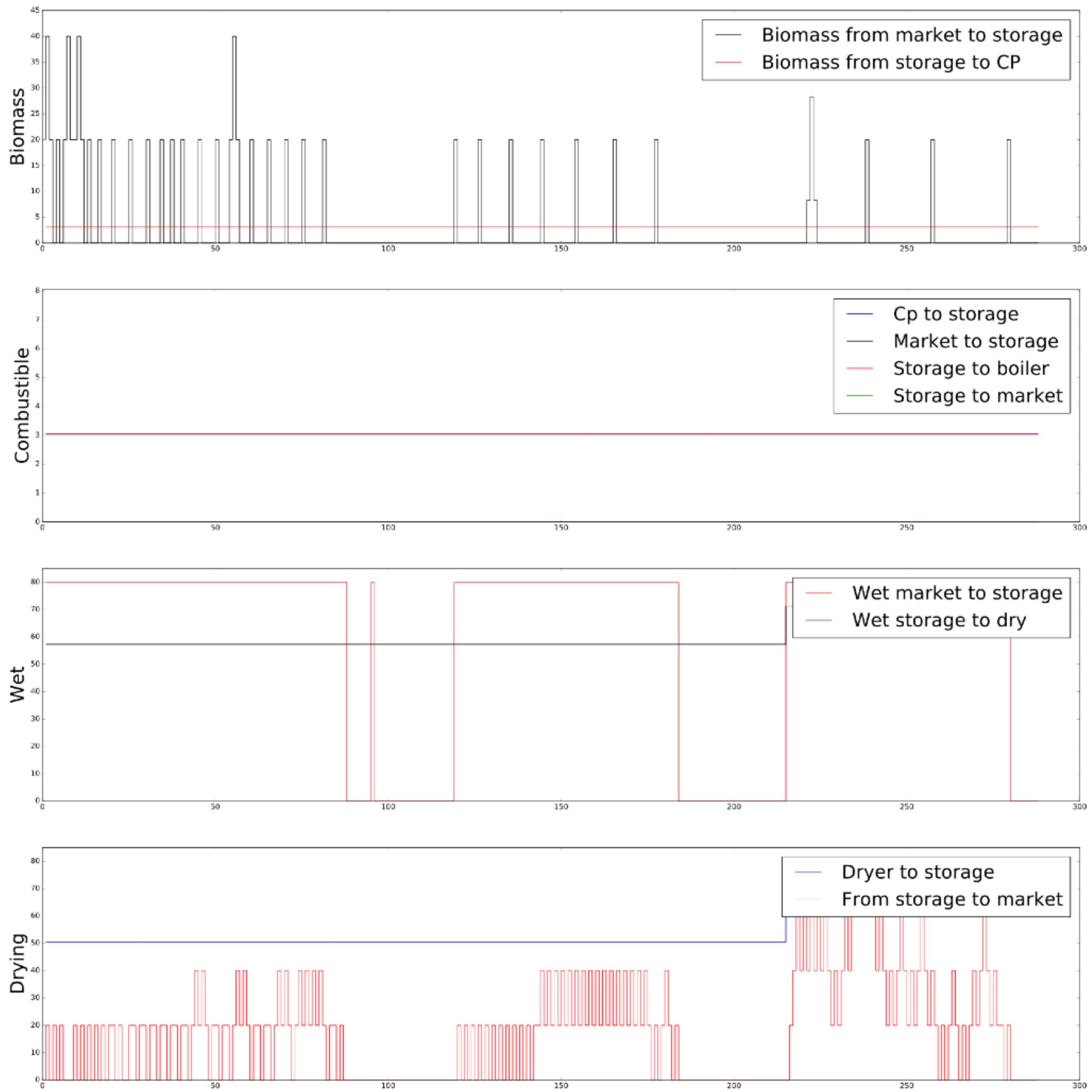

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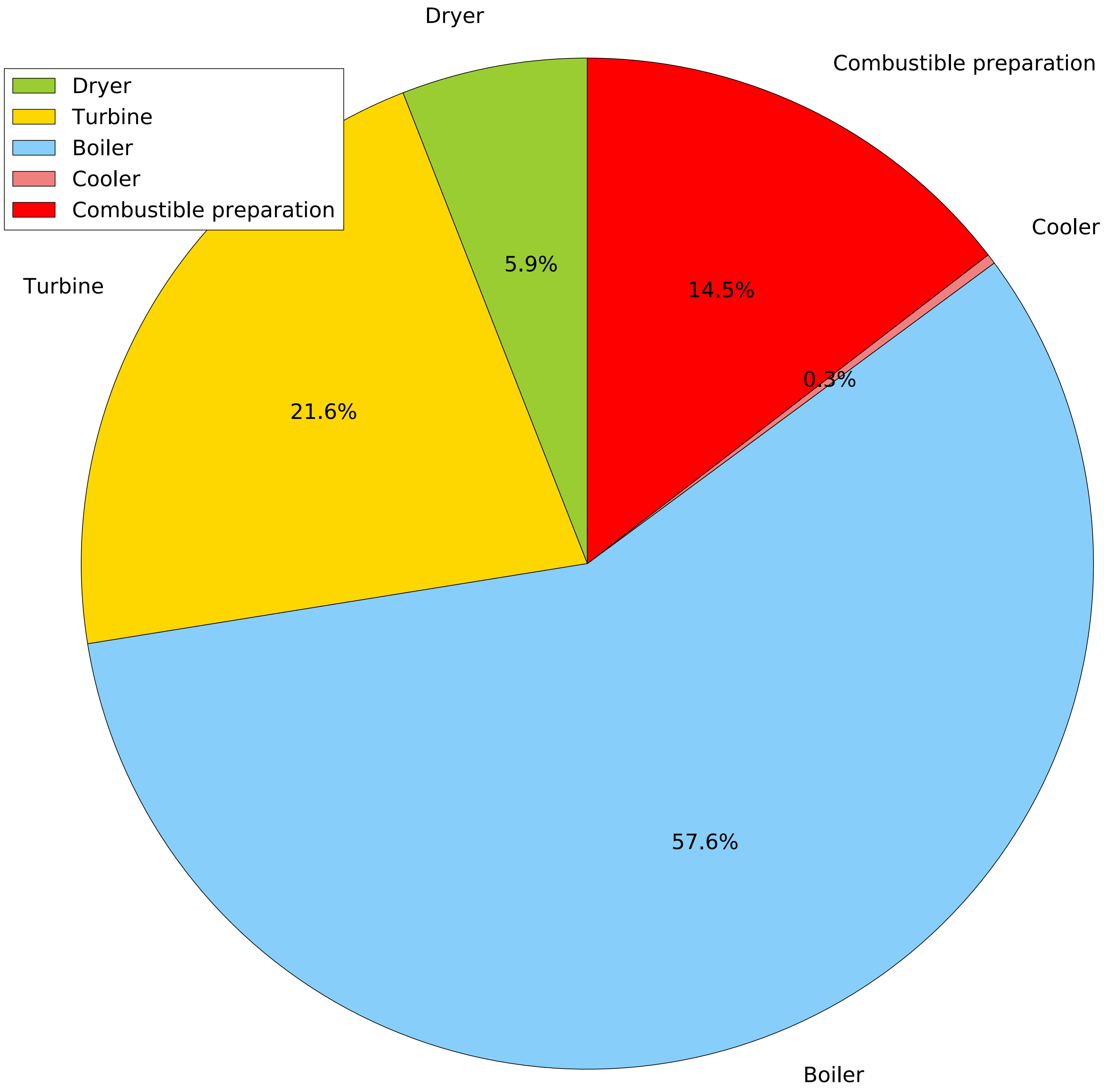

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Use case 2 results when industrial consumption taken into account

- Even if we consider 160 t/h in continuous flow for 16 hours a day
- That's more than 900,000 tons of material to be dried per year!
- The optimal size of the cogen is around 5 to 6 Mwe
  - (at 80 t/h, we fall to 3 Mwe)
- The demand of the other industrials on the site (4.5 Mwe in peak) is not covered, they are left with the variable...

- There is nevertheless, according to certain hypotheses, an interest in building a microgrid in this case
- But we did not take into account the additional costs, delays and worries (network layout, authorizations, etc.)

- The process should be made more flexible, or the demand of other industries.

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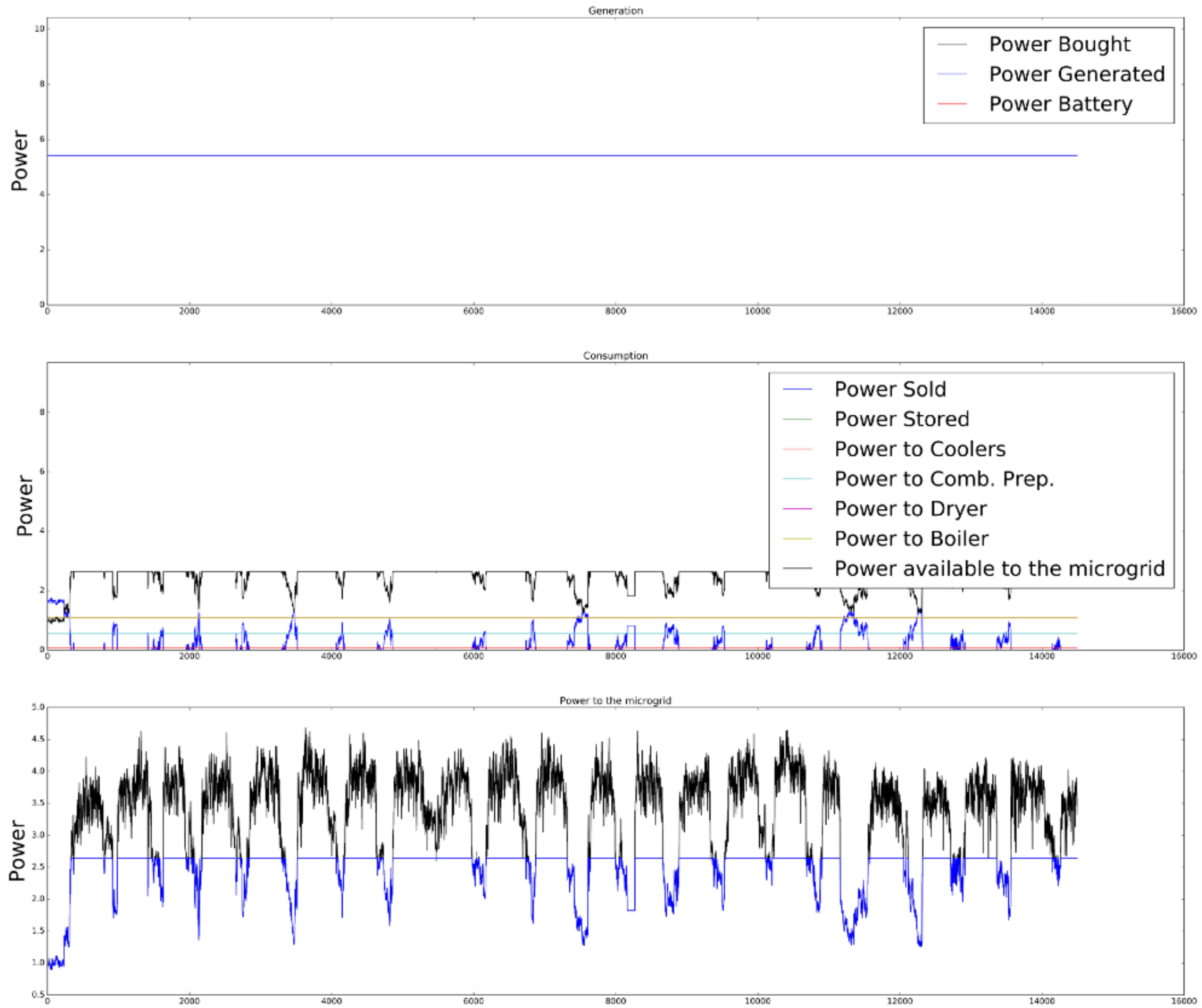
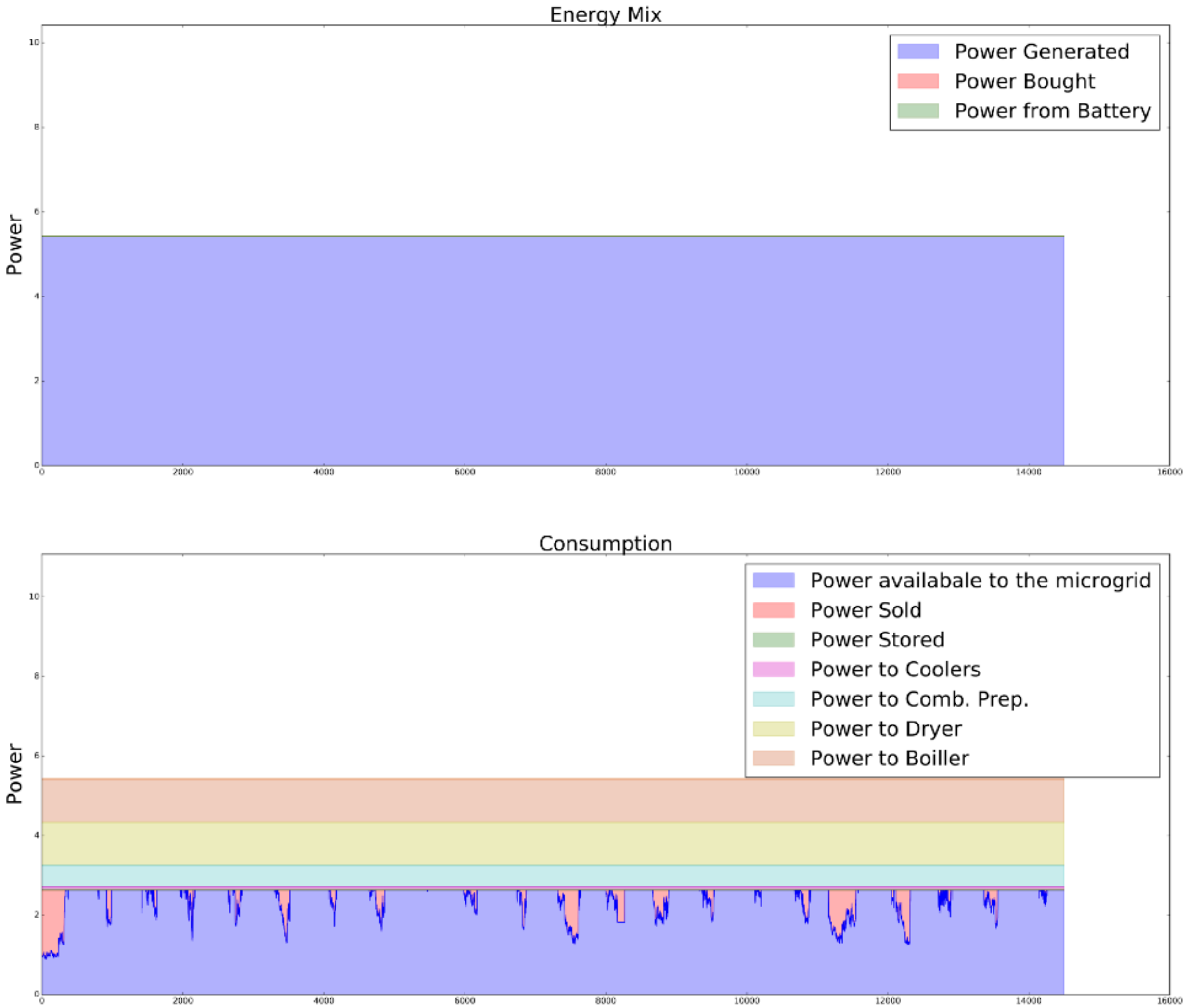
Unfavorable case, request from industrials, limit to 160 t/h





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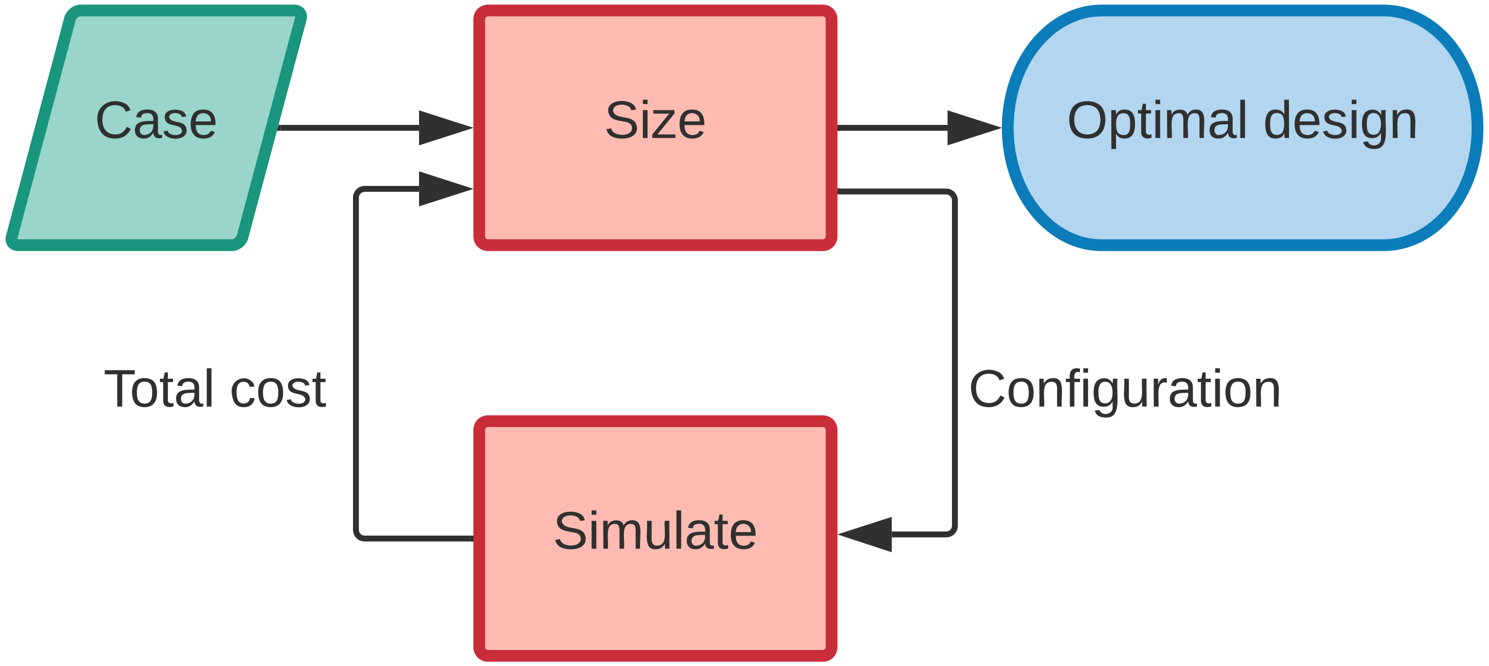
Simulation and optimization



- Dakir, S., & Cornélusse, B. (2020). **Combining optimization and simulation for microgrid sizing**. Paper submitted to PSCC 2020 XXI Power Systems Computation Conference, Porto, Portugal.

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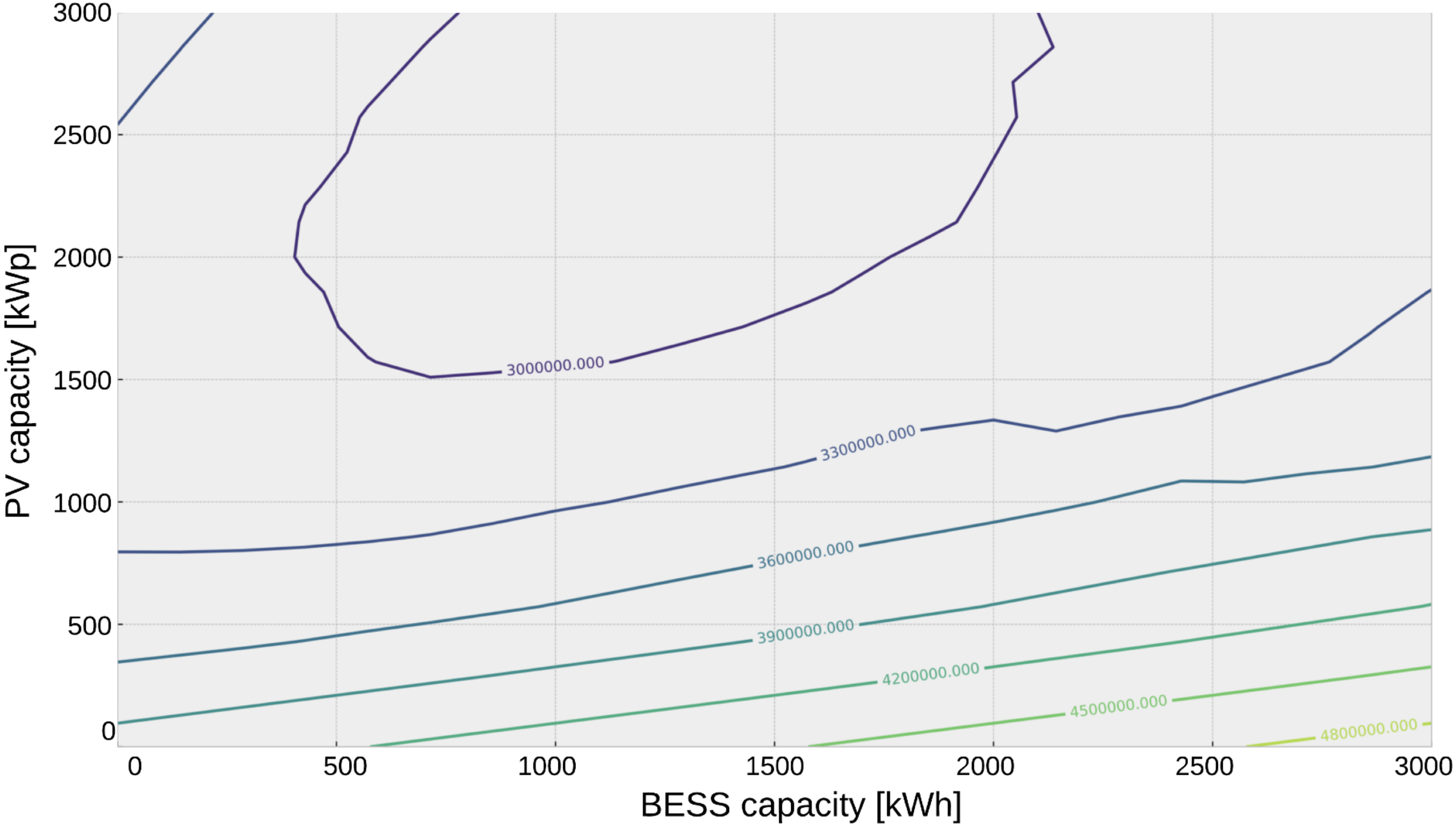
Use case 3 results



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Other use cases

- Cold storage
  - Dakir, S., Boukas, I., Lemort, V., & Cornélusse, B. (2019). **Sizing and Operation of an Isolated Microgrid with Cold Storage.** Powertech Milano 2019 Proceedings.
- Building thermal dynamics
  - Dakir, S., Boukas, I., Lemort, V., & Cornélusse, B. (2019). **Sizing and Operation of an Isolated Microgrid with Building Thermal Dynamics and Cold Storage**. EEEIC Genoa 2019
- Short-term & long-term storage
  - François-lavet, V., Gemine, Q., Ernst, D., & Fonteneau, R. (2016). **Towards the Minimization of the Levelized Energy Costs of Microgrids using both Long-term and Short-term Storage** Devices, 1–16.

Difficulties

- Finding data
    - Since the microgrid does not exist yet, there is not necessarily past usage data easily available
    - Prices of equipment are not always easily available and can evolve significantly
- Foreseeing demand evolution
    - the creation of the microgrid, especially in remote villages, may attract new people, and may create new needs

References

- Kwasinski, A., Weaver, W., & Balog, R. S. (2016). Microgrids and other local area power and energy systems. Cambridge University Press. Chapter