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Assessment of hydrogen based long-term electrical energy storage in residential energy systems

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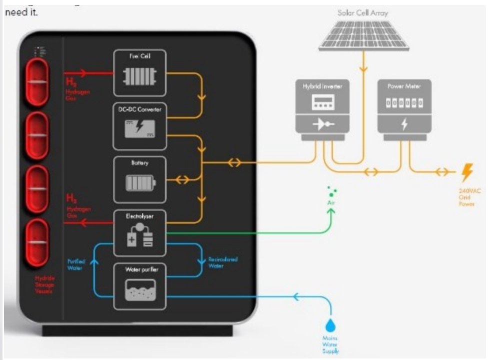
Context

Companies are proposing electrical energy storage systems based on hydrogen

- Small modular components
  - To exploit economies of scale
- For residential sector and small businesses
- A few examples:
  - Picea (Germany)
  - LAVO (Australia)
  - Enapter (Germany)



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Aim of the study

- Evaluating the potential of residential hydrogen storage systems in the Italian context
  - Through the analysis of representative case studies
    - To account for the numerous different climatic zones
  - Work in progress!

Structure of the work, tools and work environments

Step 1	Step 2	Step 3	Step 4
Renewables.ninja, Istat, RAMP (Stochastic multi-energy load profiles), python	MESS Multi Energy System Solver; julia, Fortran	SciPy; python	python
Energy demand modelling	Dwelling energy system modelling	Optimization	Optimal configuration analysis and post process

Step 1 → Step 2 → Step 3 → Step 4

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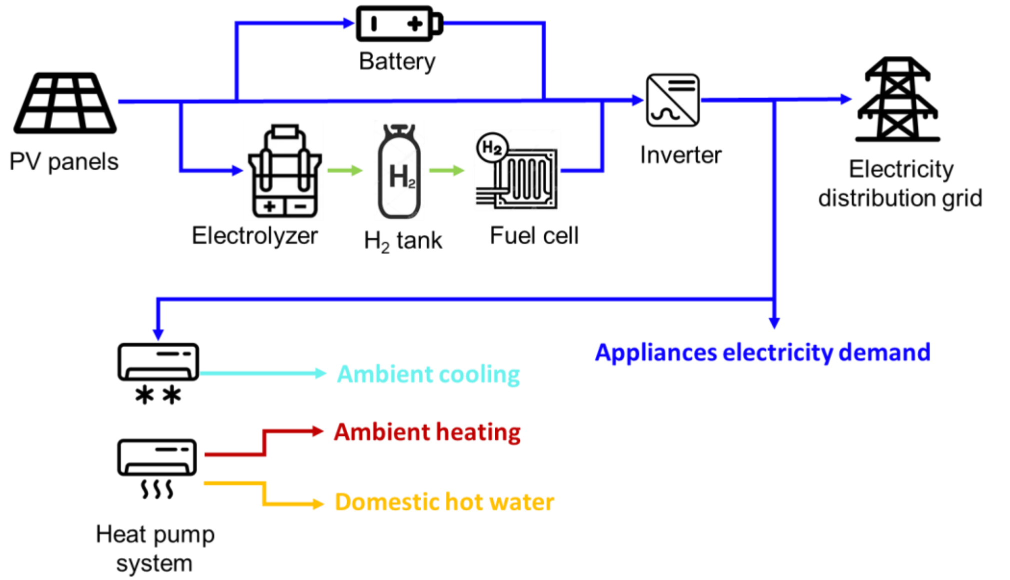
Case study – System configuration

- Electricity produced by PV panels or imported from the grid
- Electrochemical battery
  - For hourly load variations
  - Capacity fixed: 10 kWh
- Hydrogen storage system
  - Electrolyzer
  - H_2 tank
  - Fuel cell
- Heat pump system
  - To cover demand of
    - Ambient heating
    - Ambient cooling
    - Domestic hot water



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Case study – Assumption and hypotesis

- Florence province
  - 43.7799368, 11.1709281
  - 1821 HDD
  - Ambient data have been obtained from Renewables.ninja
    - https://www.renewables.ninja/
- Main hypothesis
  - Electricity price increase of 25%
  - Reference year 2030-2040
  - Interest rate 5%
  - Fully electrified dwelling
  - Rural context

Technology	Cost	Lifetime
PV panels	1300 €/kW_p	25 years
Electrolyser	250-2000 €/kW	20 years
Fuel cell	250-2000 €/kW	20 years

- **Optimization**
  - **Parameter to be optimized: Net Present Value after 20 years**
  - **Varying: electrolyser size, fuel cell size**

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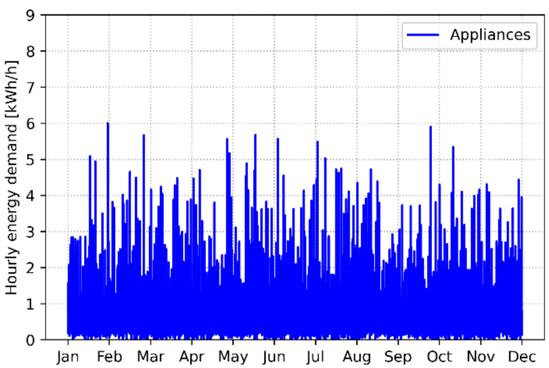
Demand curves

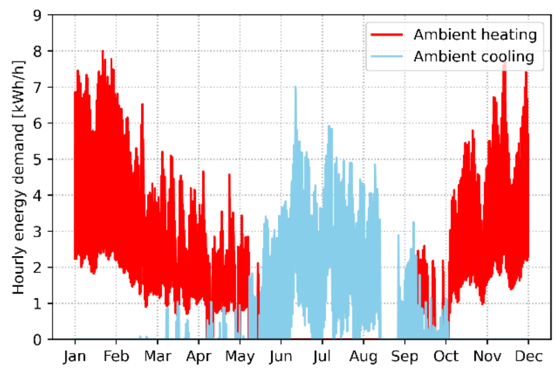
- Demand curves have been obtained through RAMP
  - Open-source bottom-up stochastic model for generating multi-energy load profiles
  - Developed by University of Liege and Politecnico di Milano
    - https://github.com/RAMP-project/RAMP
  - Applied to the Italian context using data from ISTAT
    - Italian national institute for statistics
    - Database storing information on energy usage in the residential sector of real dwellings
    - https://www.istat.it/it/archivio/142173

RAMP Stochastic multi-energy load profiles

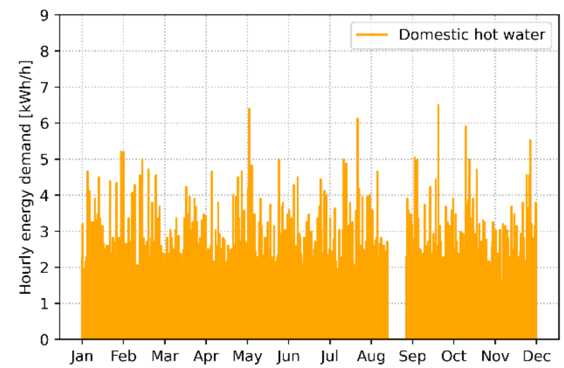
Istat



5082 kWh/y



H: 15900 kWh/y C: 5220 kWh/y



3750 kWh/y

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Dwelling energy system model

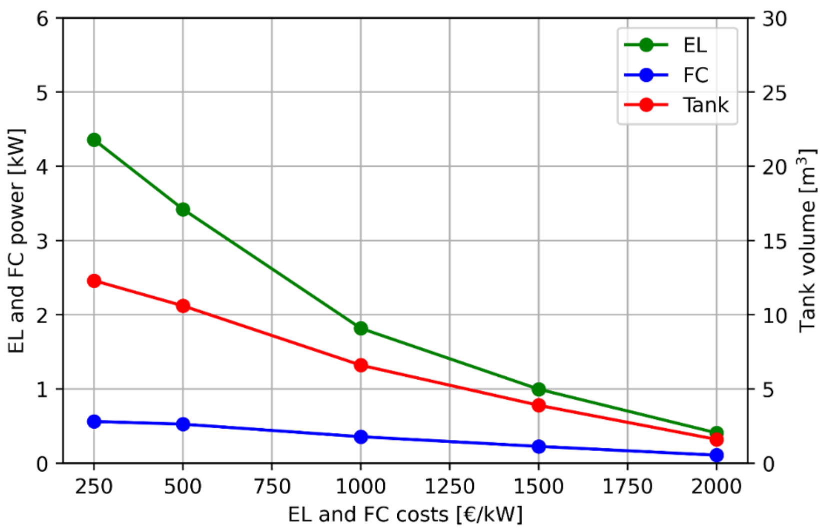
- Energy system modelled through MESS – Multi-Energy System Model
  - Recently developed open-source simulation model by UNIFI, eurac and TU Wien
  - Bottom-up, modular model
  - Analytical programming approach
    - i.e., based on a series of endogenous priorities and pre-defined procedures for simulating the operation of units that are freely dispatchable as defined by Lund et al.
  - Model written in both Julia and Fortran
  - Thoroughly descripted in https://www.mdpi.com/1996-1073/14/18/5724

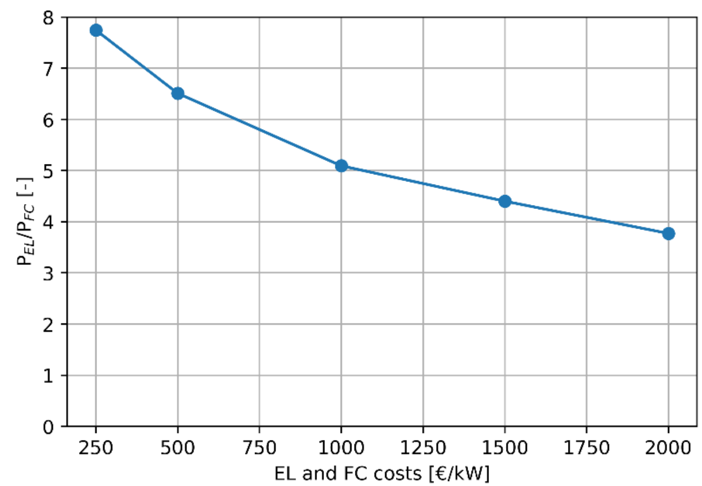
- Here MESS has been used in a black box optimization procedure
  - Letting the optimizer work only on input and output files
  - Analysing then the optimal solution

Results – Optimization

- FC size always < 1kW
- EL to FC sizes ratio increases with decreasing components cost
  - $3.5 < P_{EL}/P_{FC} < 7.7$

PV area = 50m^2
FC size: 0 kW < P_{FC} < 1 kW
EL size: 0.5 kW < P_{FC} < 4.5 kW
Tank volume: 2 m^3 < V < 13 m^3





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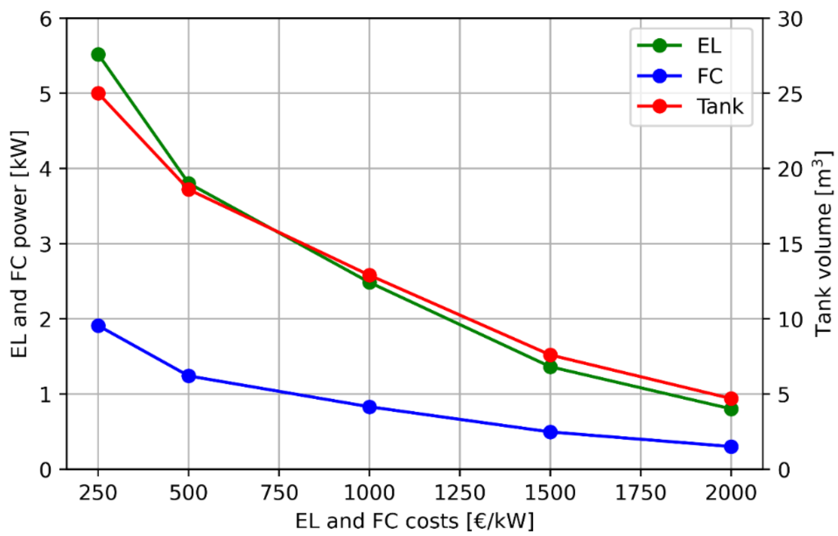
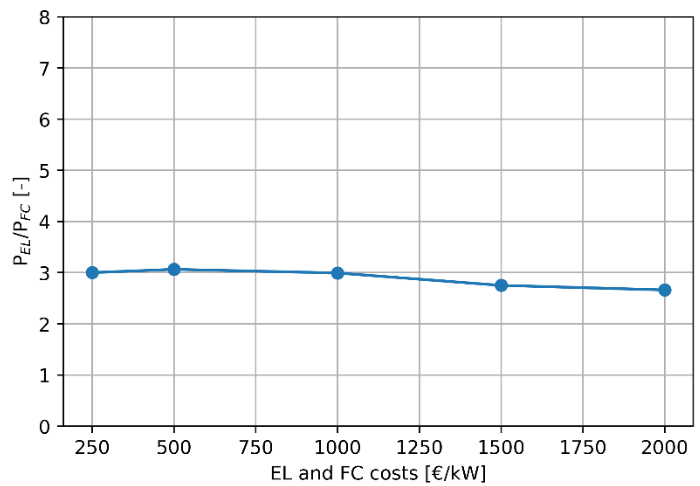
Results - Optimization

- FC optimal sizes increase more than EC sizes
  - $2.5 < P_{EL}/P_{FC} < 3.0$
- Tank size reaches unfeasible volumes

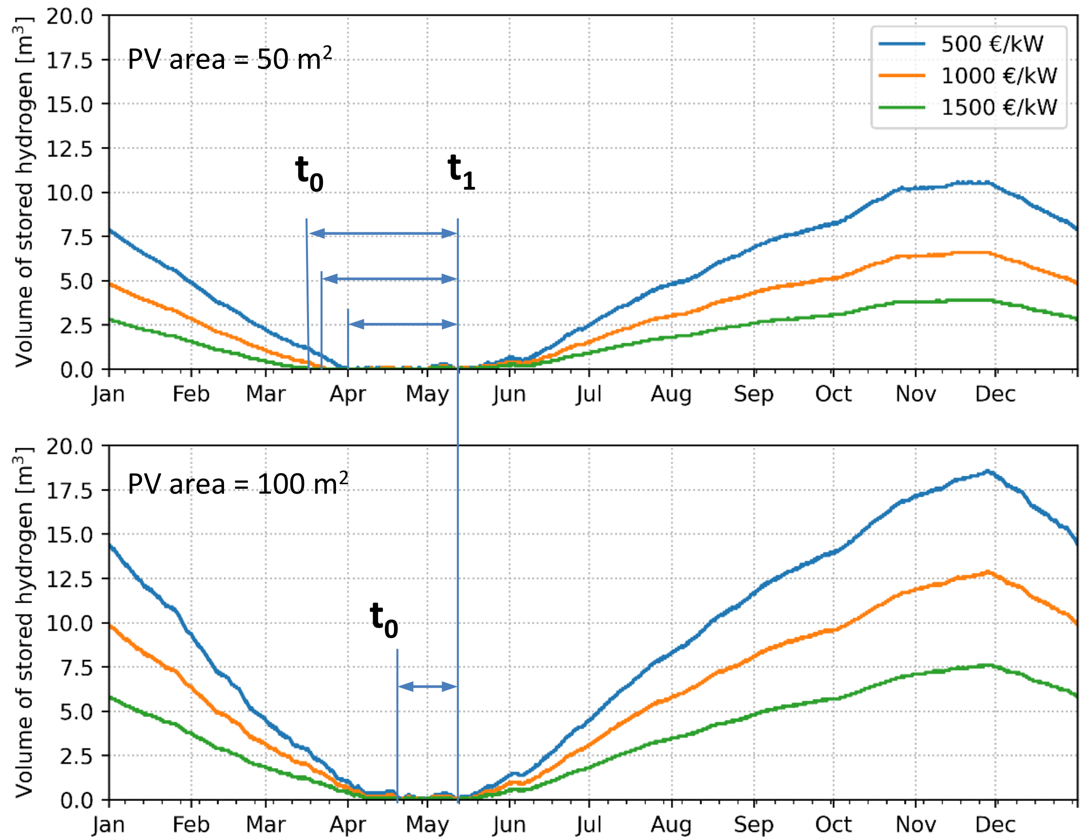
PV area = 100m^2
FC size: 0.5 kW < P_{FC} < 2 kW
EL size: 1 kW < P_{FC} < 5.5 kW
Tank volume: 5 m^3 < V < 25 m^3





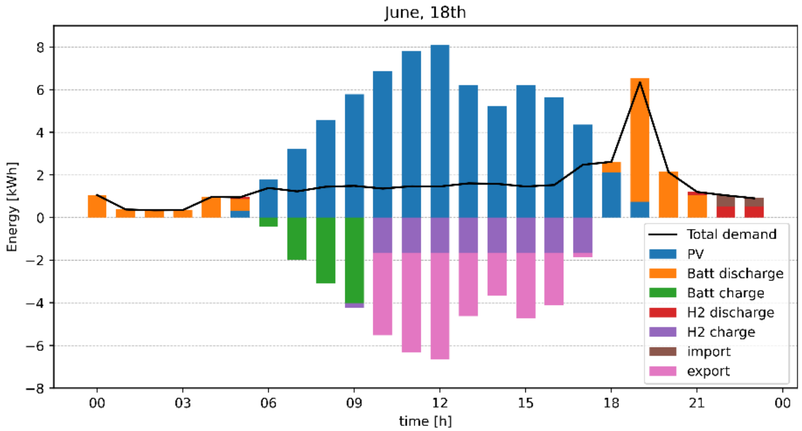
Results – Optimal solutions analysis

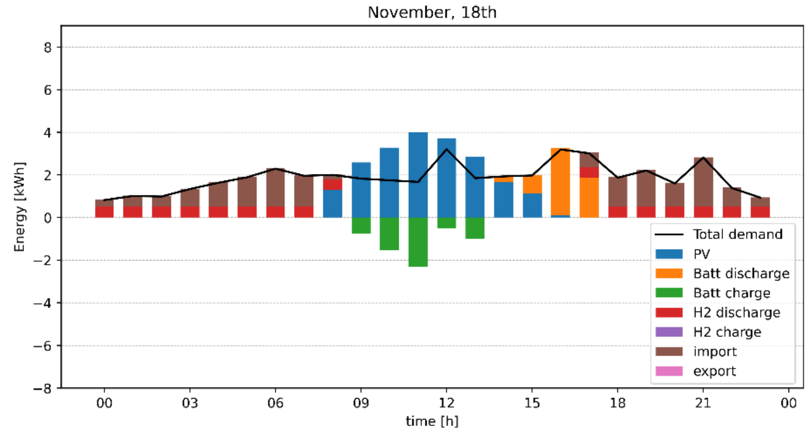
- t_0 time when H_2 tank is emptied
  t_1 time when H_2 production starts to increase steadily
- If PV area = 50 m^2
  - t_1 - t_0 decreases with decreasing components' prices
- If PV area = 100 m^2
  - t_1 - t_0 approx. constant
- When PV area = 100 m^2 fuel cell requires all winter to discharge
  - Around May battery is enough to balance production and demand
  - Why P_{EL}/P_{FC} = 3?



Results – Optimal solutions analysis

- Summer day: H_2 tank charging
  - When excess PV and battery is full, central hours of the day
- Winter day: H_2 tank discharging
  - Low PV production, battery does not reach maximum SoC, H_2 discharging for most hours of the day
- H_2 tank discharges for more hours during winter days than charges during summer ones
  - Ratio of about 3:1





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Conclusions

- Optimization has given relevant EL and FC sizes for components' costs < 1000 €/kW
- Tank volume of approx. 6 m^3 and 14 m^3 when optimizing for 1000 €/kW
- EL optimal size always > FC optimal size
  - Might be due to more hours/day discharging in winter with respect to hours/day charging in summer
  - Ratio varies for 50 m^2 and is constant for 100 m^2 of PV panels

Future work

- Sensitivity analysis on the assumptions made
- Extension to other Italian climatic zones
  - To evaluate the impact of
    - Different insolation
    - Different ambient heating and cooling load curves
- Extension to different household types
  - Single vs multi-family houses
  - Different dwelling types
  - New constructions vs renovated buildings
- Evaluation of the impact of incentives on the system economics

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Thank you for your attention!

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Backup slides

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Electrolyzer model

Linear regression to approx V-I curve of the electrolyzer

Finding the working point of the electrolyzer by explicitly solving the system:

PowerInput=CellCurrDensity*CellActiveArea*Vstack

Vstack=B*CellCurrDensity+A

Checking if resulting current density is high enough for the electrolyzer to start, otherwise hydrogen prod = 0

Computing electrolyzer's efficiency and hydrogen energy output (eta faraday → eta el)

Hydrogen production

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Fuel cell model

Linear regression to approx V-I curve of the fuel cell

Finding the working point of the electrolyzer by explicitly solving the system:

ReqPower=FC_CellCurrDensity*FC_CellArea*FC_Vstack

FC_Vstack=coeffBfc(iloc)*FC_CellCurrDensity+coeffAfc(iloc)

Computing FC's efficiency and hydrogen energy demand

Hydrogen demand

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Optimization

DUAL ANNEALING

Stochastic approach

Taken from the Scipy library:
https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.dual_annealing.html#scipy.optimize.dual_annealing

Given: function, bounds, max number of iterations

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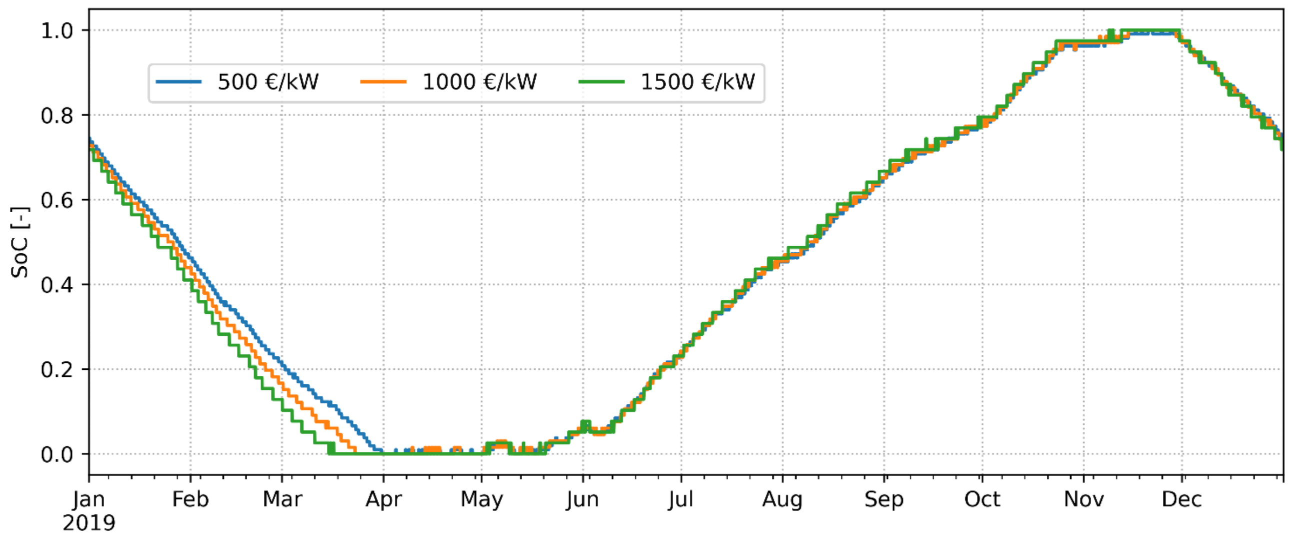
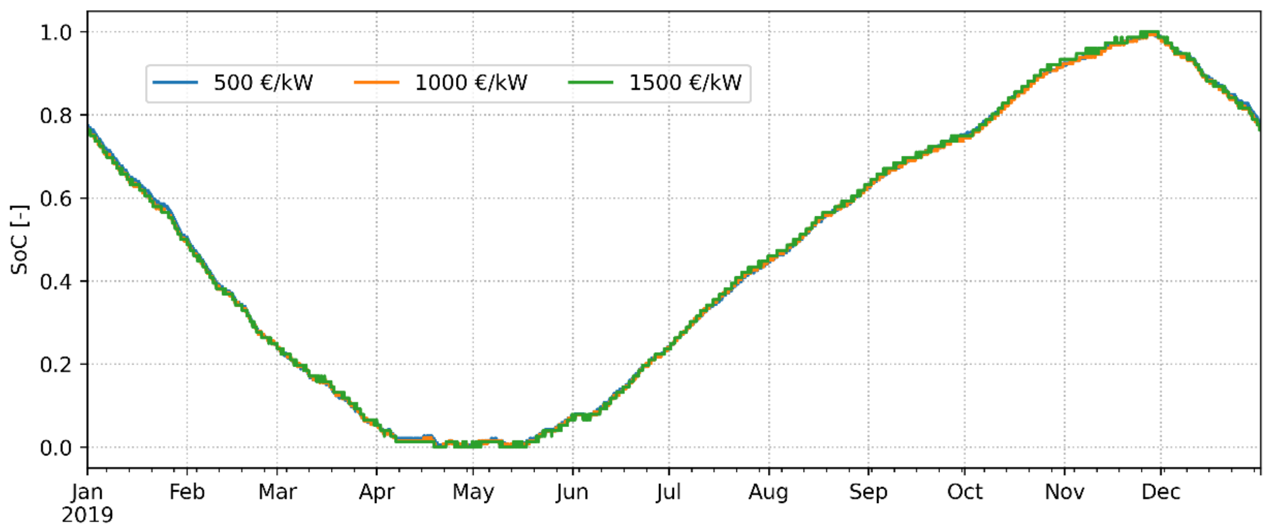
Results

50 m2, tank SoC



Results

100 m2, tank SoC



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