Explaining Complex Energy Systems

A Challenge

Tackeling Climate Change with Machine Learning

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TECHNISCHE UNIVERSITÄT DARMSTADT

EINS
ENERGY INFORMATION NETWORKS AND SYSTEMS

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https://github.com/pe0nd/Explaining-Complex-Energy-Systems

The challenge: How to explain innovative energy systems to non-experts

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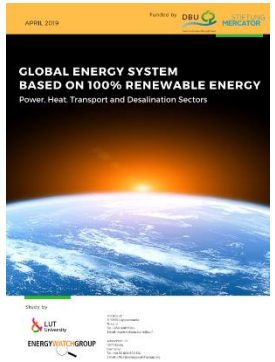
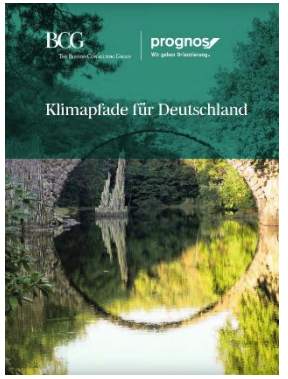
- Innovative energy systems are typically planned based on models that have a simple LP structure but large numbers of variables and parameters
- Outputs are also large scaled and their internal logic is hard to extract



321 pages [1]

810 pages [2]

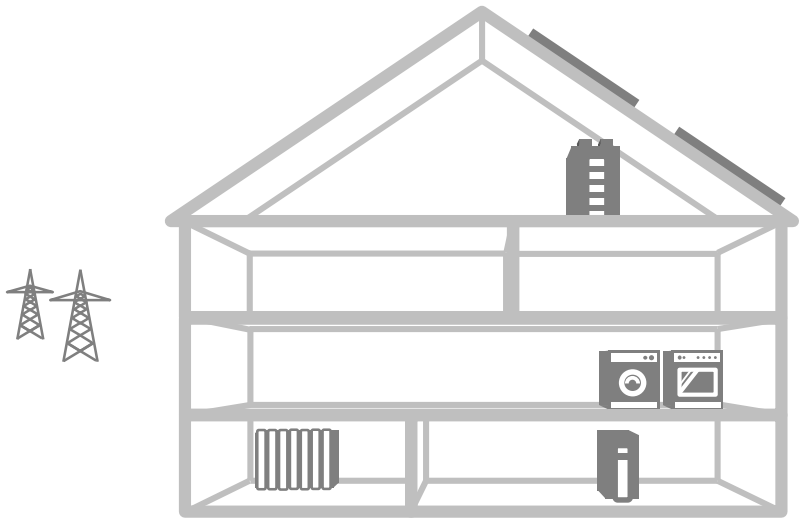
400 pages [3]



290 pages [4]

- ➢ These studies are the basis for desicions made by managers, politicans or citizens (= non-experts)
- ➢ Explanation needed (as for complex ML models)

We provide a simple Energy System Model for test purposes*



Energy system model of single household

- Minimizes cost by choosing PV and battery capacity
- Time series for PV availabilty and electric demand
- One year simulation (hour resultion)

- 4 Inputs – PV price, battery price, electriciy price (from grid), total demand
- 5 Outputs – PV capacity, battery capacity, own generation, TOTEX, CAPEX

*pyomo model available at https://github.com/pe0nd/Explaining-Complex-Energy-Systems

We provide a simple Energy System Model for test purposes

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Input:

Photovoltaik

c_{PV}

Batteriestorage

c_{Bat}

Energy demand

$D(t)$

Power grid

c_{Buy}

Modell:

$$\min_{Cap,p} \text{cost} = c_{PV} \times Cap_{PV} + c_{Bat} \times Cap_{Bat}^{S} + \sum_{t} c_{Buy} \times p_{Buy}(t)$$

s.t.

$$p_{Buy}(t) + p_{PV}(t) + p_{Bat}^{out}(t) - p_{Bat}^{in}(t) = D(t), \forall t$$

$$p_{Bat}^{S}(t) = p_{Bat}^{S}(t-1) + p_{Bat}^{in}(t) - p_{Bat}^{out}(t), t \in 2 \dots T$$

$$0 \leq p_{PV}(t) \leq Cap_{PV} \times avail_{PV}(t) \times \Delta t, \forall t$$

$$0 \leq p_{Bat}^{in}(t),\ p_{Bat}^{out}(t) \leq Cap_{Bat}^{S}, \forall t$$

$$p_{Bat}^{S}(0) = p_{Bat}^{S}(T)$$

$$0 \leq p_{Buy}(t), \forall t$$

Output:

Capacity PV

Cap_{PV}

Capacity battery

Cap_{Bat}^{S}

Own generation

$\sum_{t} p_{PV}(t) \div \sum_{t} D(t)$

CAPEX

$c_{PV} \times Cap_{PV} + c_{Bat} \times Cap_{Bat}^{S}$

TOTEX

$CAPEX + \sum_{t} p_{Buy}(t) \times c_{Buy}$

We provide a simple Energy System Model for test purposes

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Input:

- Photovoltaik
  - c_{PV}
- Batteriestorage
  - c_{Bat}
- Energy demand
  - $D(t)$
- Power grid
  - c_{Buy}

Modell:

$$\min_{Cap,p} \text{cost} =$$ Cost equation $$c_{PV} \times Cap_{PV} + c_{Bat} \times Cap^{S}_{Bat} + \sum_{t} c_{Buy} \times p_{Buy}(t)$$

s.t.

- Energy balance equation
- Battery equation
- PV production limit
- Battery charging limit
- Battery inital state
- Power buying limit

Output:

- Capacity PV
  - Cap_{PV}
- Capacity battery
  - Cap^{S}_{Bat}
- Own generation
  - $\sum_{t} p_{PV}(t) \div \sum_{t} D(t)$
- CAPEX
  - $c_{PV} \times Cap_{PV} + c_{Bat} \times Cap^{S}_{Bat}$
- TOTEX
  - $CAPEX + \sum_{t} p_{Buy}(t) \times c_{Buy}$

How could an explanation look like?

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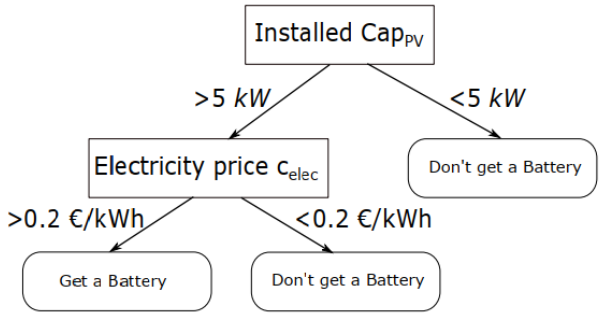
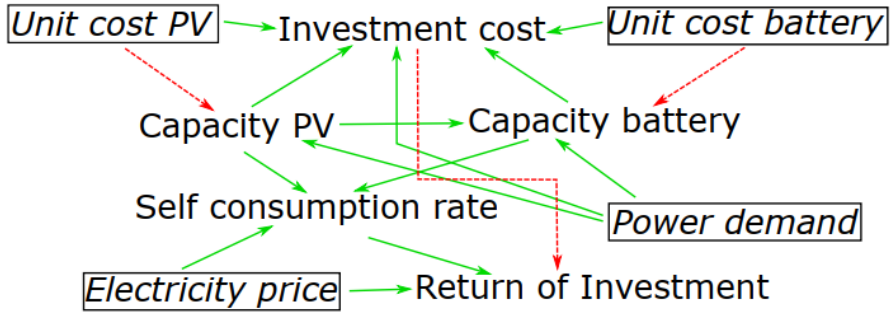
Ideas for the simple energy model

decision tree



structural causal model



Challenge:

- Can interpretable ML methods be used for this purpose?
- How to measure the quality of an explanation?

References

[1] Ram, M., et al. "Global energy system based on 100% renewable energy–power, heat, transport and desalination sectors." *Study by Lappeenranta University of Technology and Energy Watch Group, Lappeenranta, Berlin* (2019).

[2] IEA (2019), *World Energy Outlook 2019*, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2019

[3] IEA (2020), Energy Technology Perspectives 2020, IEA, Paris https://www.iea.org/reports/energy-technology-perspectives-2020

[4] Gerbert, Philipp, et al. *Klimapfade für Deutschland*. BCG, The Boston Consulting Group, 2018.