LEAFS – Assessment of Electricity Storage System and Flexible Loads in the Distribution Grid

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Overview

- Generic distribution network section consisting of 207 customers (private households and small businesses).
- A private household may have distributed generation (PV system), a battery storage system and/or flexible loads.
- Each household pursues a operation strategy for its storage systems and flexible loads (e.g. minimize electricity procurement costs).

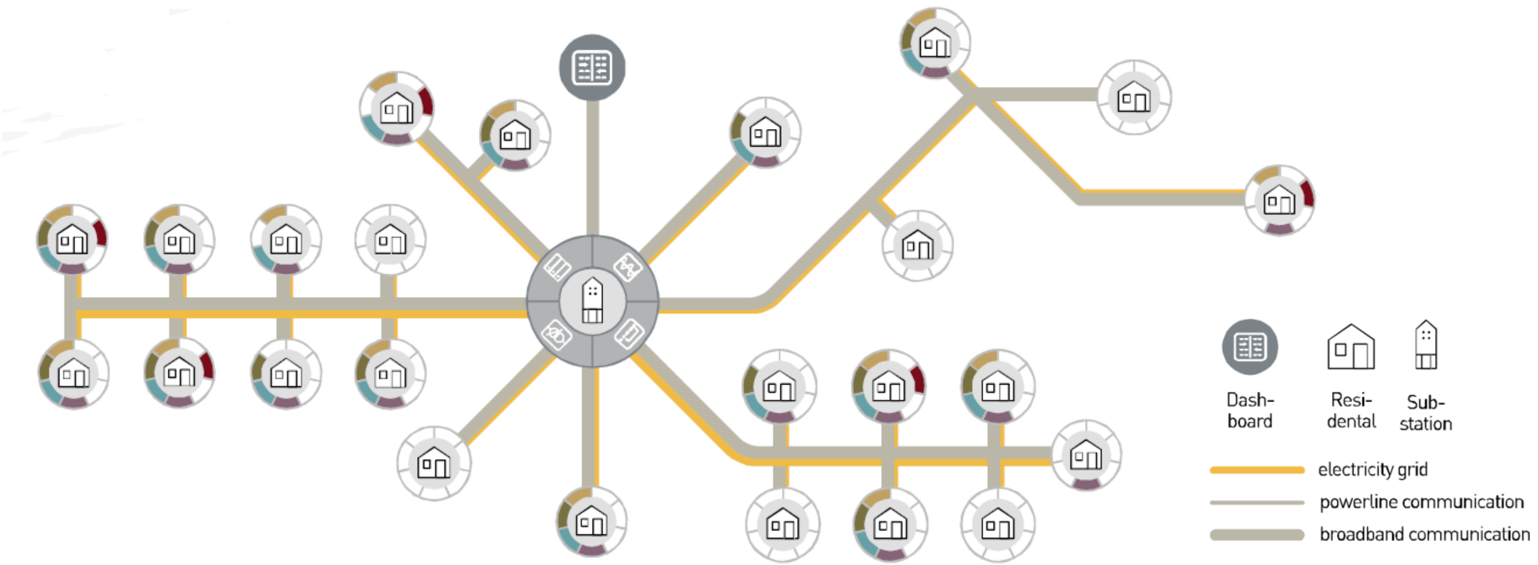


Figure 1. Schematic representation of the distribution grid section. APA-Auftragsgrafik, Source: AIT

Method 1/3

- A household (prosumer) may have a PV system, a battery storage system, flexible and inflexible load and pursues an operation strategy.
- Each operation strategy is represented by a linear optimization problem (min. costs):

$$\min_{x} \quad P_{max}^{procure} \cdot p^{grid_{kW}} + \sum_{t} \left[(q_t^{load_{procure}} + c_t^{grid}) \cdot (p_t^{el} + p^{grid_{kWh}} + p^{tax}) - q_t^{PV_{feed-in}} \cdot p^{PV} \right] \qquad (1)$$

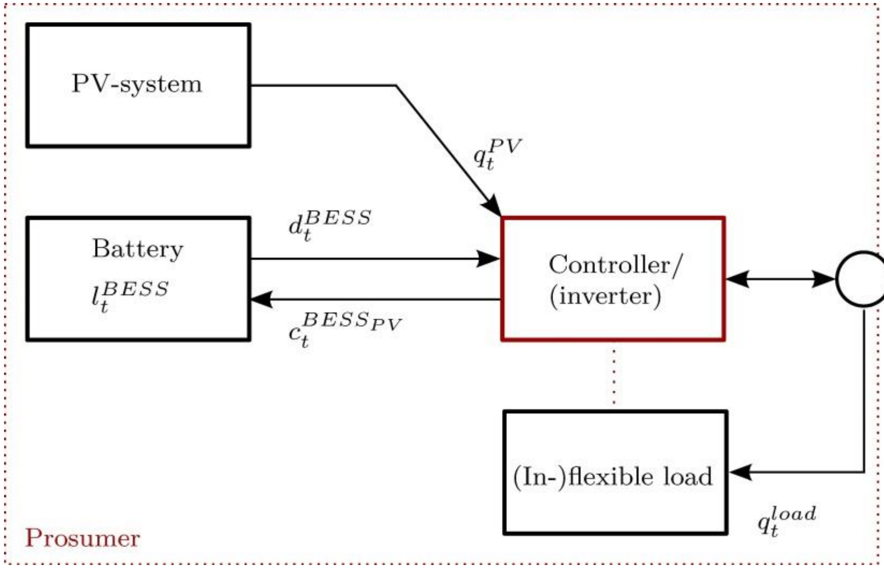


Figure 2. Schematic representation of a prosumer.

$P_{max}^{procure}$	peak load (kW)
$q_t^{load_{procure}}$	energy procured from the grid in t (kWh)
c_t^{grid}	energy charged from the grid into BESS in t (kWh)
$q_t^{PV_{feed-in}}$	PV generation fed into the grid in t (kWh)
p_t^{el}	electricity price (spot price) (EUR/kWh)
$p^{grid_{kW}}$	end-user grid tariff kW rate (EUR/kW)
$p^{grid_{kWh}}$	end-user grid tariff kWh rate (EUR/kWh)
p^{tax}	end-user dues (EUR/kWh)
p^{PV}	PV remuneration (EUR/kWh)

Method 2/3

General constraints of the optimization problem:

$$q_t^{PV} = q_t^{PV_{consume}} + c_t^{PV} + q_t^{PV_{feed-in}} \tag{2}$$

$$q_t^{load} = q_t^{load_{procure}} + d_t^{load} + q_t^{PV_{consume}} \tag{3}$$

$$q_t^{load} = q_t^{load_{inflex}} + q_t^{load_{flex}} \tag{4}$$

q_t^{PV}	PV generation in t (kWh)
$q_t^{PV_{consume}}$	PV generation consumed in t (kWh)
c_t^{PV}	PV energy charged into the BESS in t (kWh)
$q_t^{PV_{feed-in}}$	PV generation fed into the grid in t (kWh)
$q_t^{load_{procure}}$	energy procured from the grid in t (kWh)
d_t^{load}	energy discharged to supply the load in t (kWh)

Constraints due to demand response of flexible loads (electric loads with thermal storage such as refrigerators, freezers, water boilers, heat pumps, radiators):

$$E_\pi^{input} = \sum_{t=1+(\pi-1)\cdot delay}^{\pi\cdot delay} q_t^{load_{input}} \tag{5}$$

$$E_\pi^{flex} = \sum_{t=1+(\pi-1)\cdot delay}^{(\pi)\cdot delay} q_t^{load_{flex}} \tag{6}$$

$$\sum_T q_t^{load_{input}} = \sum_T q_t^{load_{flex}} \tag{7}$$

$$E_\pi^{flex} = E_\pi^{input} + E_{\pi-1}^{shift+} - E_\pi^{shift+} \qquad \forall \pi \in \Pi \tag{8}$$

Method 3/3 - Overview of different operation strategies

$$\min_{x} \quad P_{max}^{procure} \cdot p^{grid_{kW}} + \sum_{t} \left[(q_t^{load_{procure}} + c_t^{grid}) \cdot (p_t^{el} + p^{grid_{kWh}} + p^{tax}) - q_t^{PV_{feed-in}} \cdot p^{PV} \right] \quad (9)$$

Operation strategy	Parameters and constraints
Maximize self-consumption	$p^{grid_{kW}} = 0$ (10) $p_t^{el} = \text{constant}$ (11)
Minimize electricity procurement costs	$p^{grid_{kW}} = 0$ (12) $p_t^{el} = \text{time variable}$ (13)
Minimize PV curtailment	$p^{grid_{kW}} = 0$ (14) $p_t^{el} = \text{constant}$ (15) $q_t^{PV_{feed-in}} \leq q_{max}^{PV_{feed-in}}$ (16)
Minimize procurement power	$p^{grid_{kW}} = \text{constant}$ (17) $p_t^{el} = \text{constant}$ (18)

Input Data and Assumptions

- **Household-load time series** were generated by means of a load profile generator [1] considering the household's annual energy consumption.
- **PV generation time series** are based on historical time series.

Flexible electric load	Deferral period (h)
water boiler	12
heat pump	1
radiator	1
refrigerator	1
freezers	4

Table 2. Deferral periods of various flexible electric loads according to [2].

Parameter	Value	Unit
Electricity price (constant)	6.5	ct./kWh
Electricity price (time variable), EPEX Spot Intraday Continuous DE/AT 2016	Ø 6.5	ct./kWh
Grid tariff kWh rate	5	ct./kWh
Grid tariff kW rate	40	EUR/(kW*a)
Taxes	3	ct./kWh
PV remuneration	4.5	ct./kWh
PV feed-in limit as fraction of the installed capacity	70	%

Table 3. Assumptions regarding electricity costs and tariffs. Own presumptions based on [3].

Economic parameters for discounted cashflow analysis

Storage parameter (Fronius Battery Systems)	Value			Unit
Useable capacity (at DOD = 80%)	3.6	4.8	7	kWh
Customer price incl. space cost, installation, discounts, subsidies and taxes (manufacturer's information)	8.3 (2.31)	9.4 (1.96)	11.7 (1.67)	kEUR (kEUR/kWh)
Cycle lifetime	7000			cycles
calendric lifetime (= evaluation period)	20			years
Installation cost	1.5			kEUR
space cost	250			EUR/m2
Subsidy (based on nominal capacity)	400			EUR/kWh
Average storage operation cost [4]	2.2			EUR/(kWh*yr)
Taxes	20			%
customer discount	10			%

- aDSM cost: 80 EUR/yr. (hardware + installation cost)
- Customer **interest rate = 2%/yr**; average **inflation rate = 2%/yr**
- Inverter change after 10 years (extra cost of 1 kEUR considered)
- **Random variation of revenues** (for each operation strategy (see next slides) as of changing PV generation and consumption patterns) within 10% bandwidth

Results duration curves

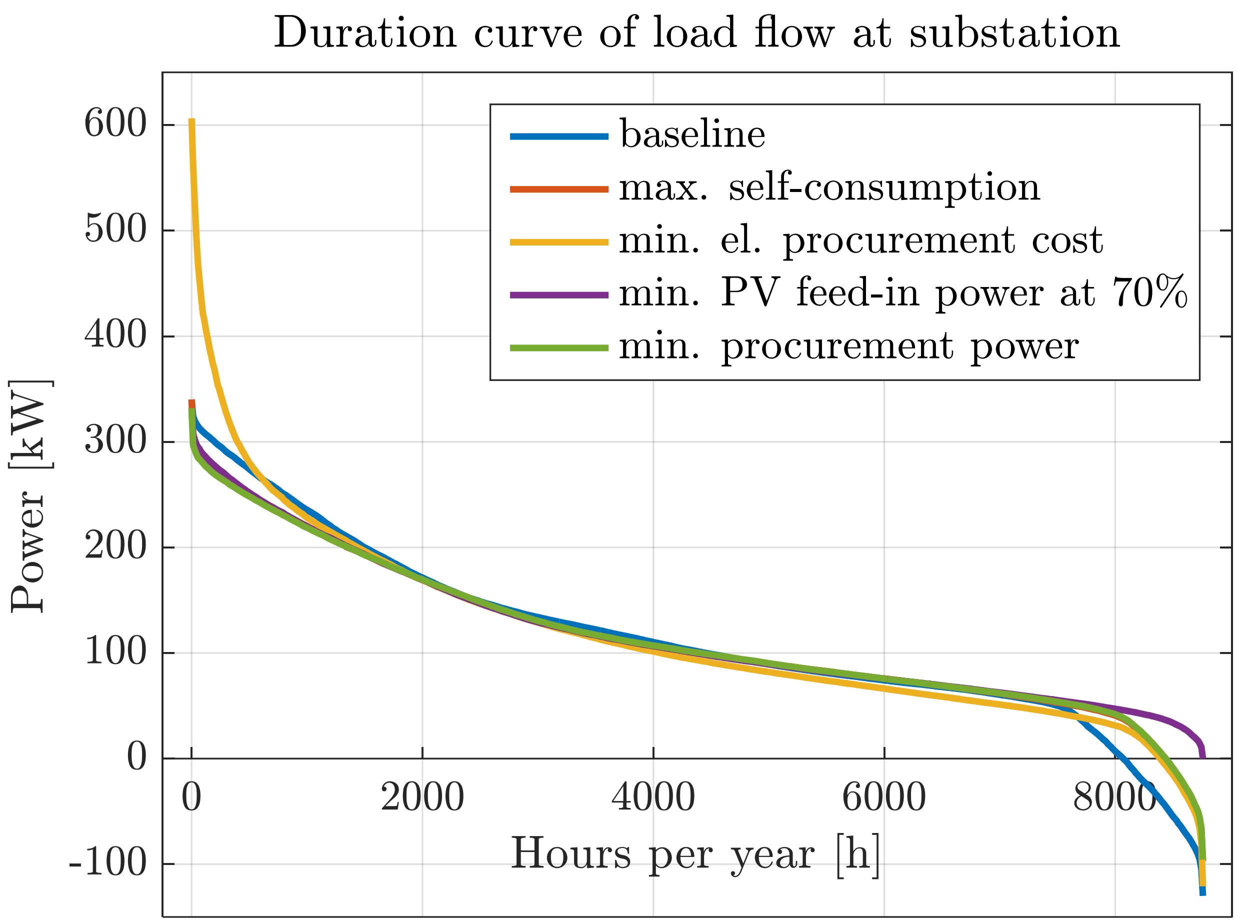
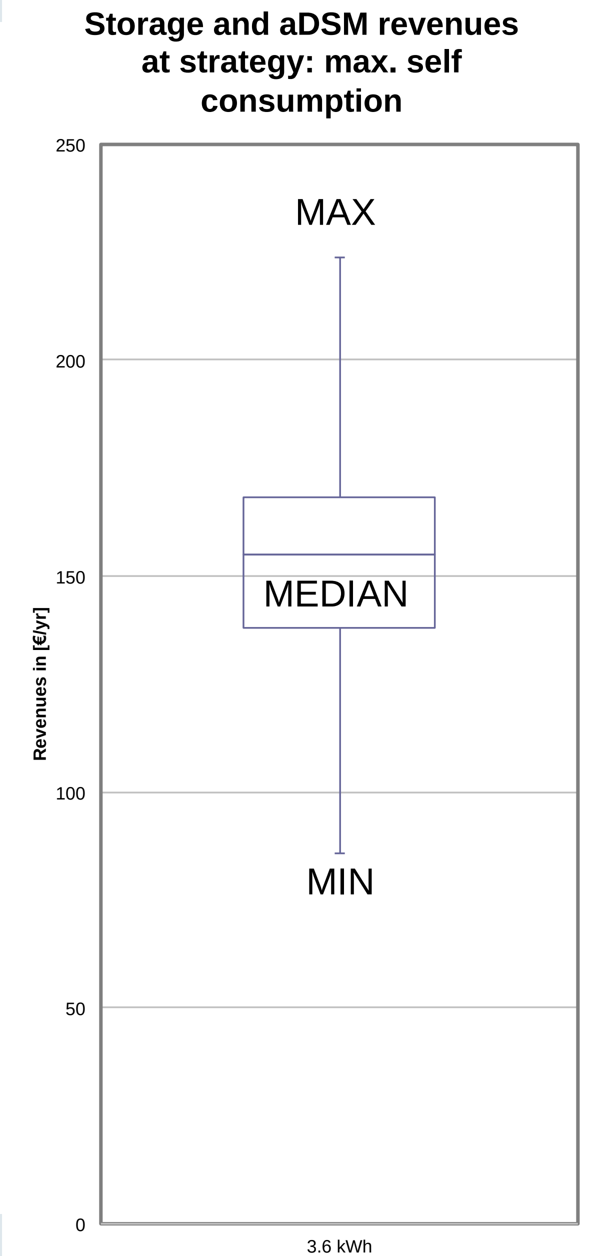
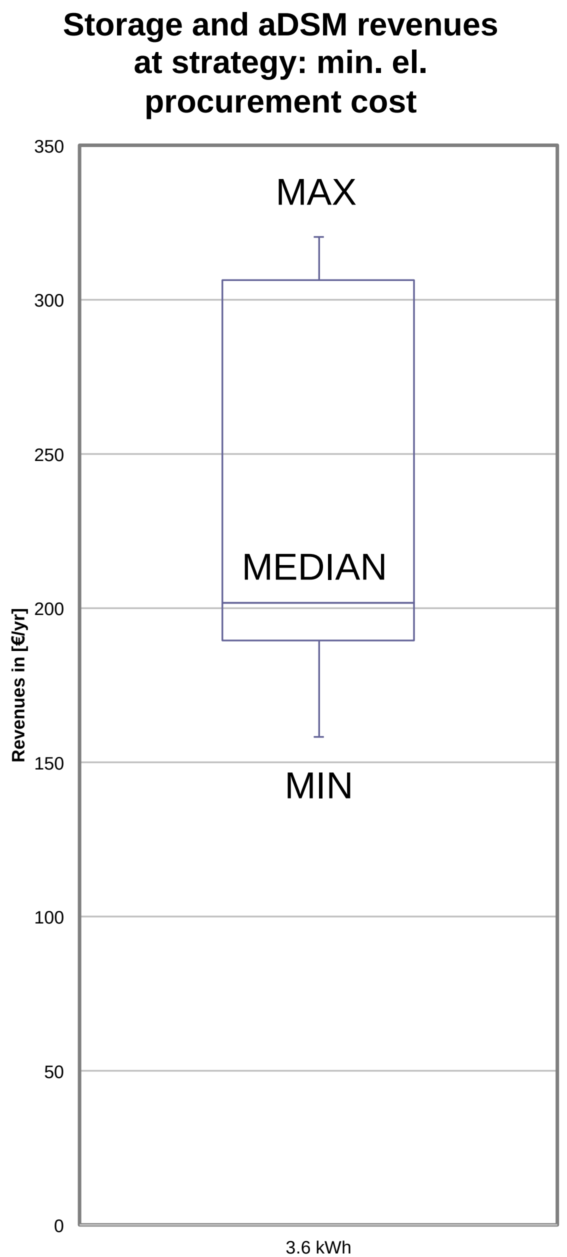


Figure 3. Duration curve of accumulated load flow at the substation of the distribution grid segment. ‚baseline' = no storage/ no flexible load; ‚max. self-consumption' = fixed kWh-based el. prices; ‚min. el. procurement cost' = time variable end-user prices; ‚min. procurement power'= 40 EUR/kW*yr. kW-based grid tariff.

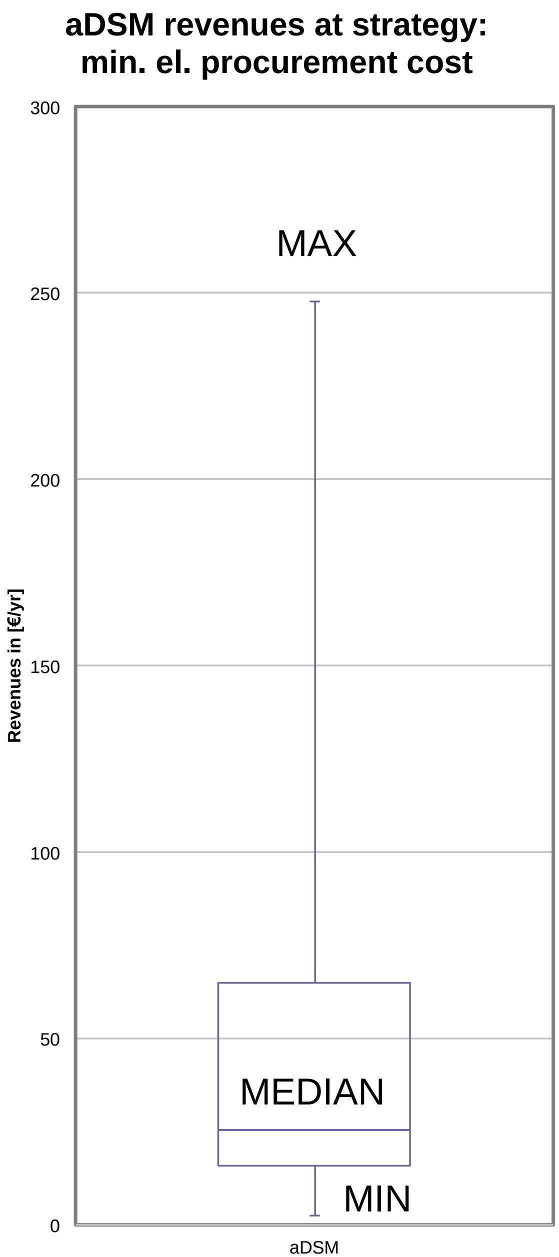
Results for operation strategy: max. self-consumption



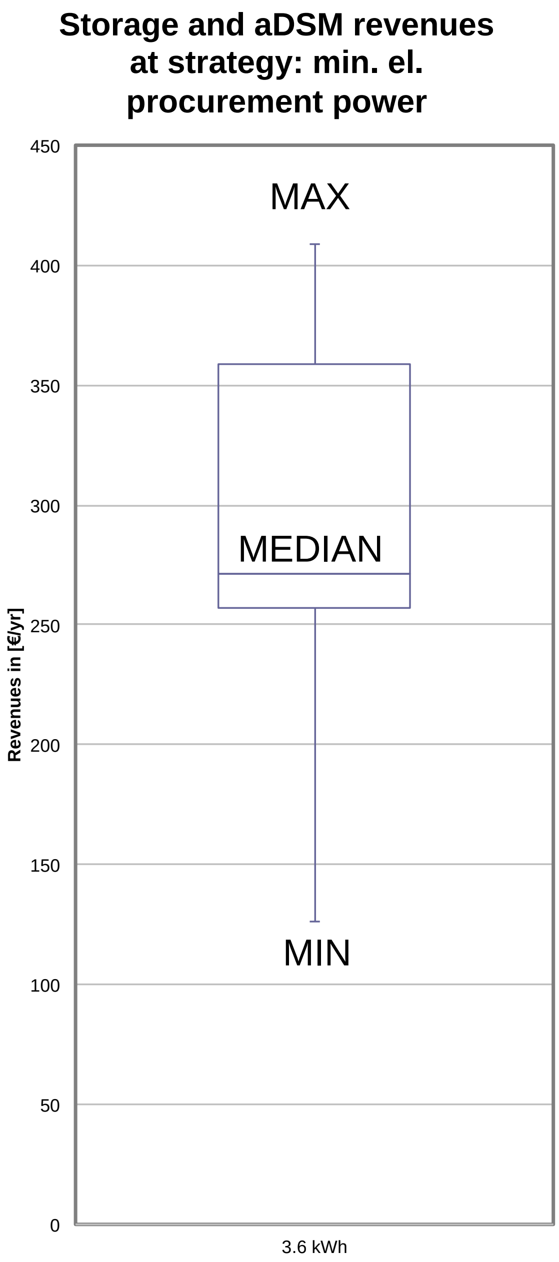
Results for operation strategy: min. electricity procurement cost

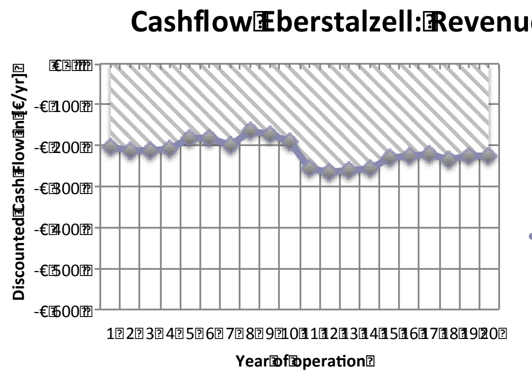


Results for operation strategy: min. electricity procurement cost

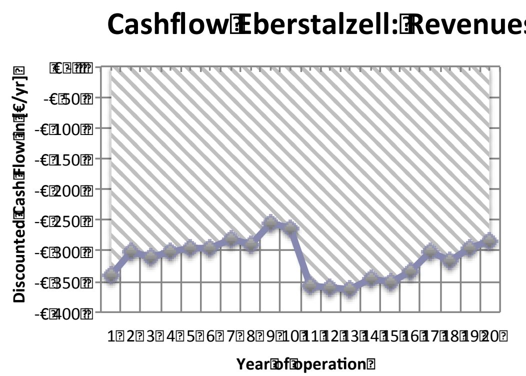


Results for operation strategy: min. procurement power

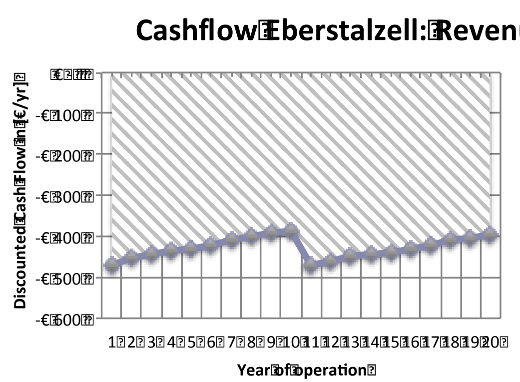




Revenue bandwith: [MAX; MAX*0.9]



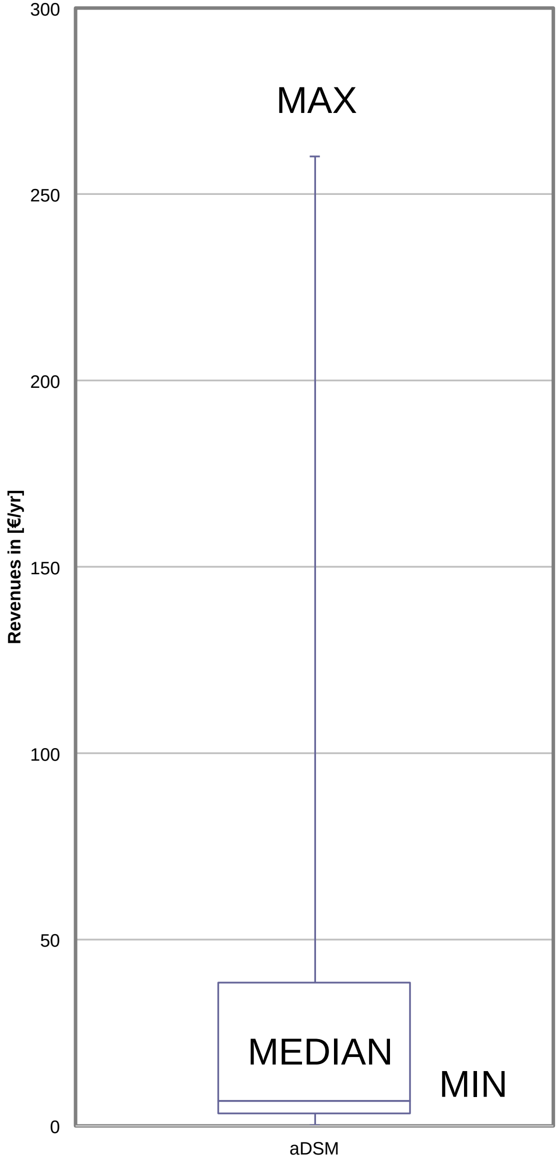
Revenue bandwith: [MED*1.1; MED*0.9]

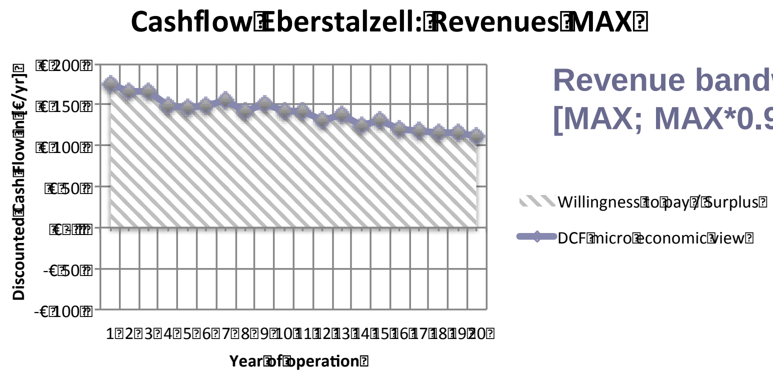


Revenue bandwith: [MIN*1.1; MIN]

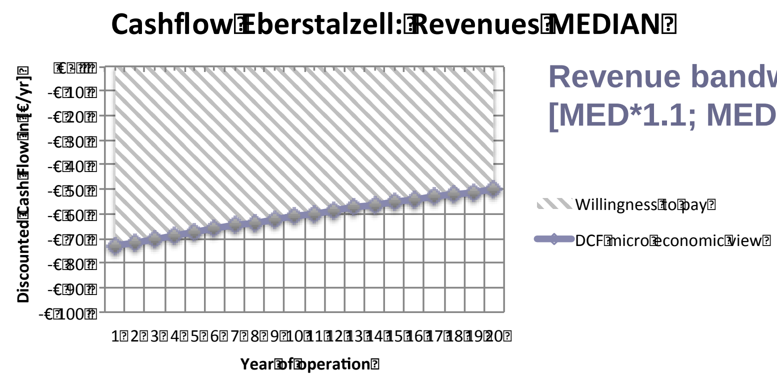
Results for operation strategy: min. procurement power

aDSM revenues at strategy: min. el. procurement power

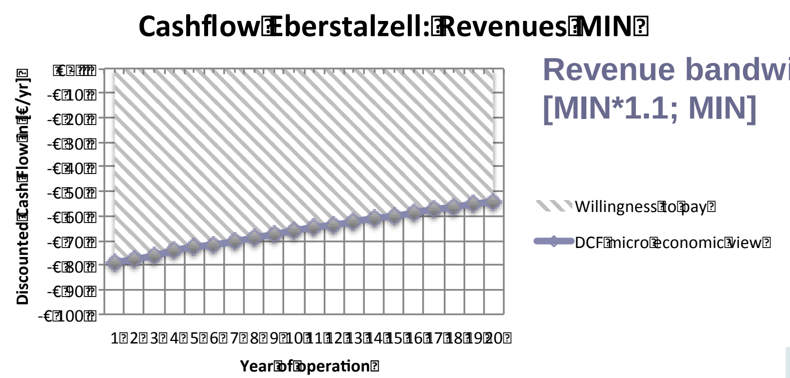




Revenue bandwith:
[MAX; MAX*0.9]



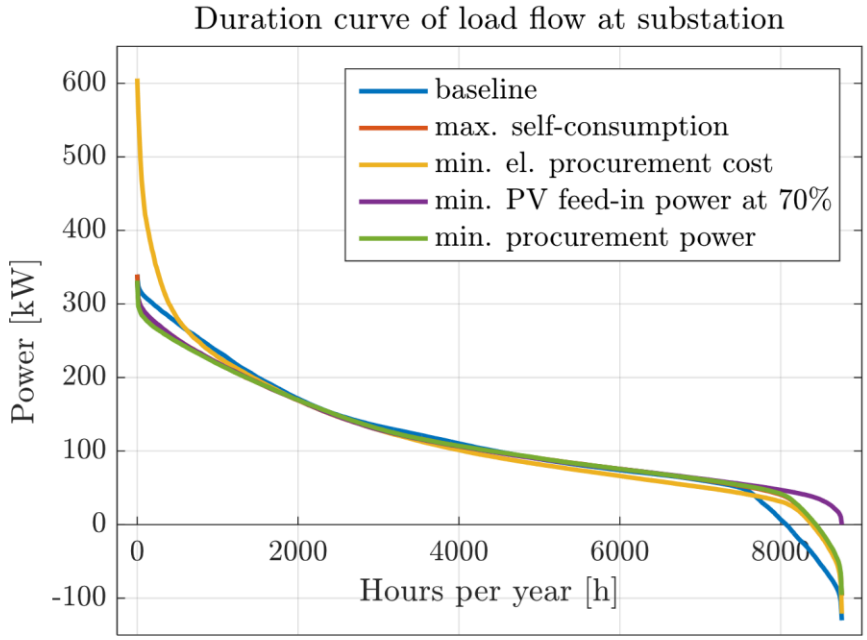
Revenue bandwith:
[MED*1.1; MED*0.9]



Revenue bandwith:
[MIN*1.1; MIN]

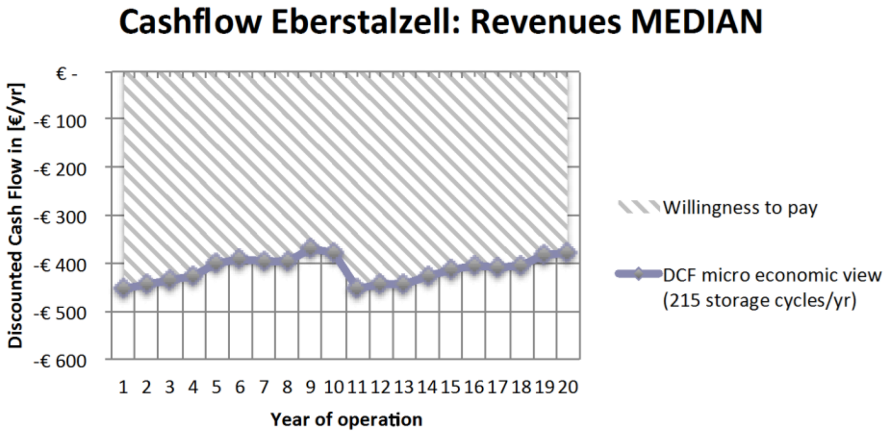
Conclusions and Outlook

- **Fixed kWh-based** end-user **prices** and tariffs (OS. max. self-consumption) do not provide incentives to operate a storage system/flexible loads in a grid beneficial way (no reduction in accumulated peak load or peak feed-in)
- **Time variable end-user electricity prices** result in significantly higher peak loads (+80%) at substations (high simultaneity).
- A reduction of the **individual customers peak load** does not reduce the peak load at the substation (due to lack of simultaneity).
- **'Willingness to pay'** for battery storage systems needed of about **200 – 500 EUR/yr**.



Outlook

- Comparison to bulk battery energy storage system (100kWh).
- Voltage band consideration (power system simulation)
- **Possible increase in consumption** due to a **shift from kWh-based to kW-based prices** was not considered but should be kept in mind (energy efficiency).



Acknowledgements

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[3] E-Control Tariff calculator, https://www.e-control.at/konsumenten/service-und-beratung/toolbox/tarifkalkulator , as consulted online on 26 April 2017.

[4] Leipziger Institut für Energie, „Wirtschaftlichkeit Batteriespeicher”, Kurzexpertise, Leipzig 2014

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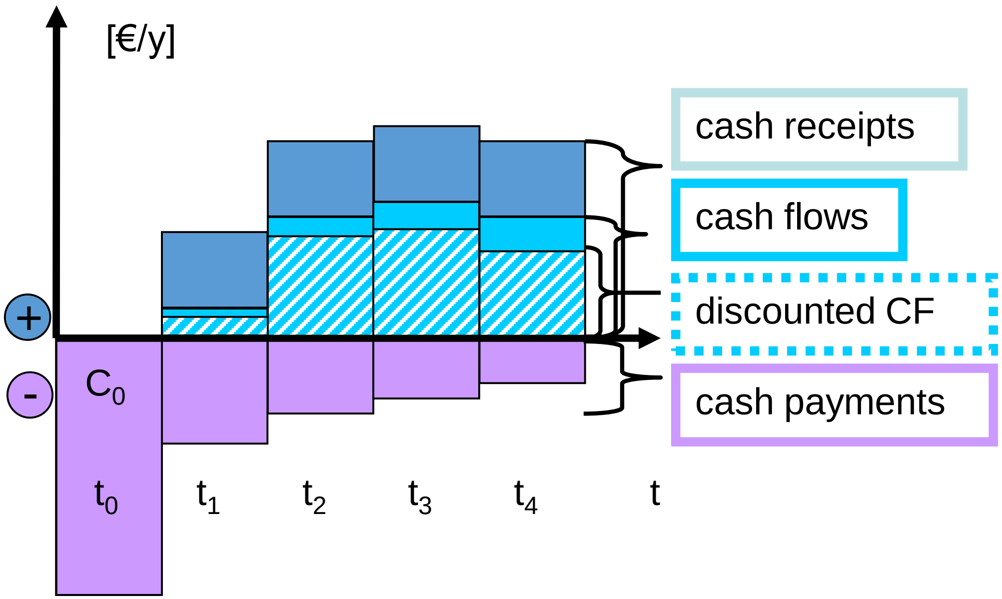
Discounted cash flow, Net present value (NPV)

Methodology:

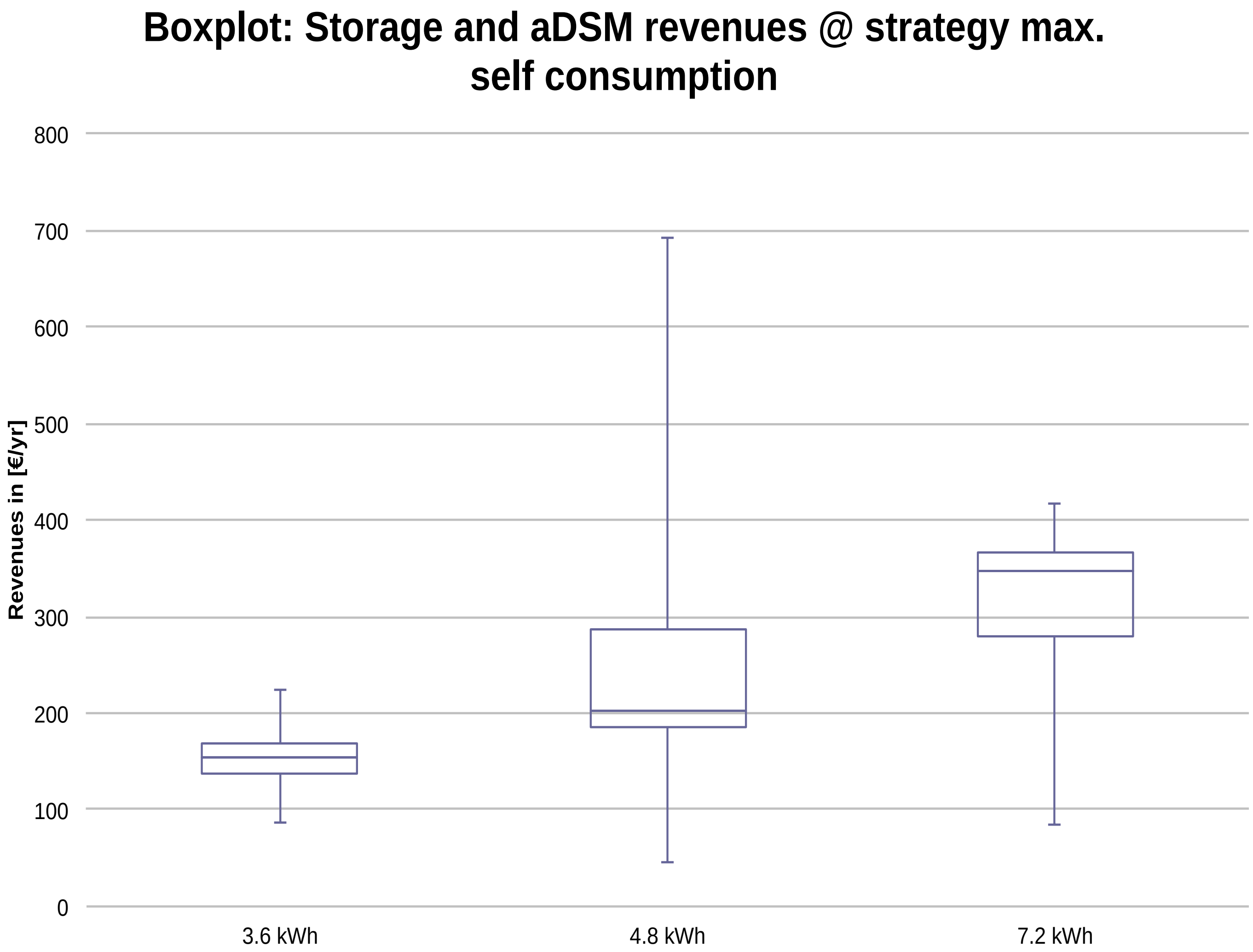
Summing discounted cashflows over the lifetime/investment-period of a project.

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_0$$

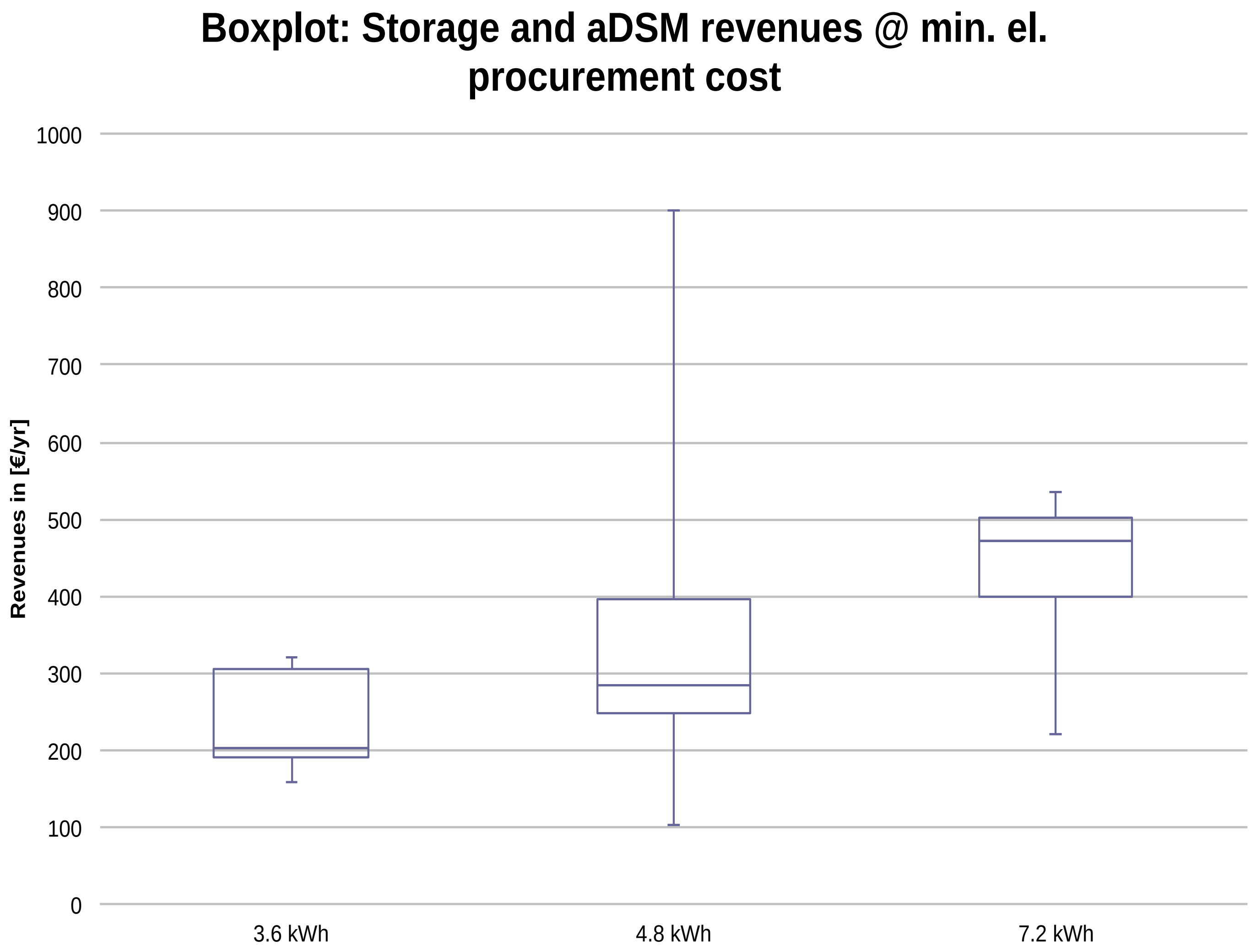
- NPV — Net Present Value [€]
- n — Lifefime/investment-period [y]
- C_t — Cash flow in year t [€]
- r — rate of return [1]
- C_0 — Initial investment [€]



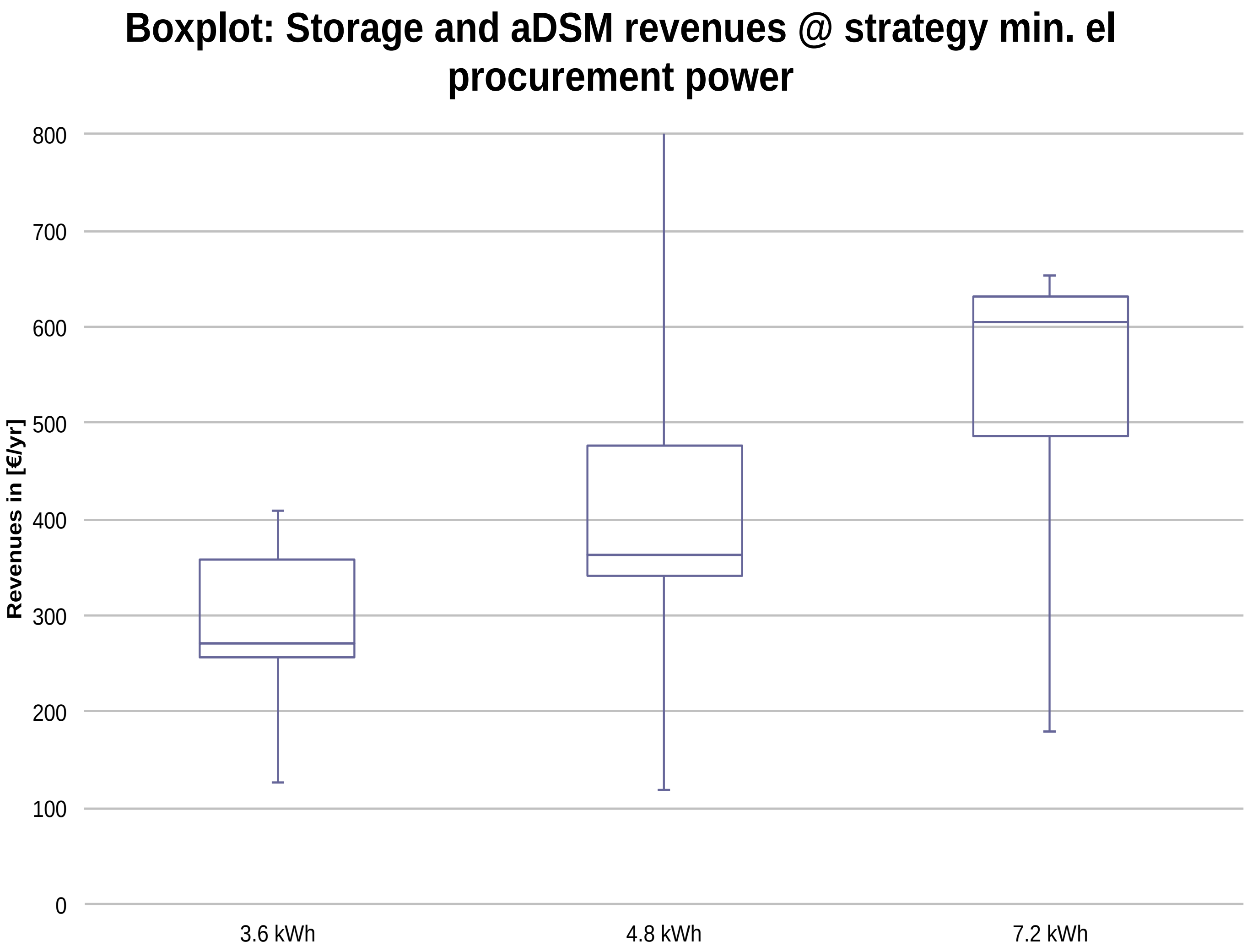
Appendix - Revenue parameters I



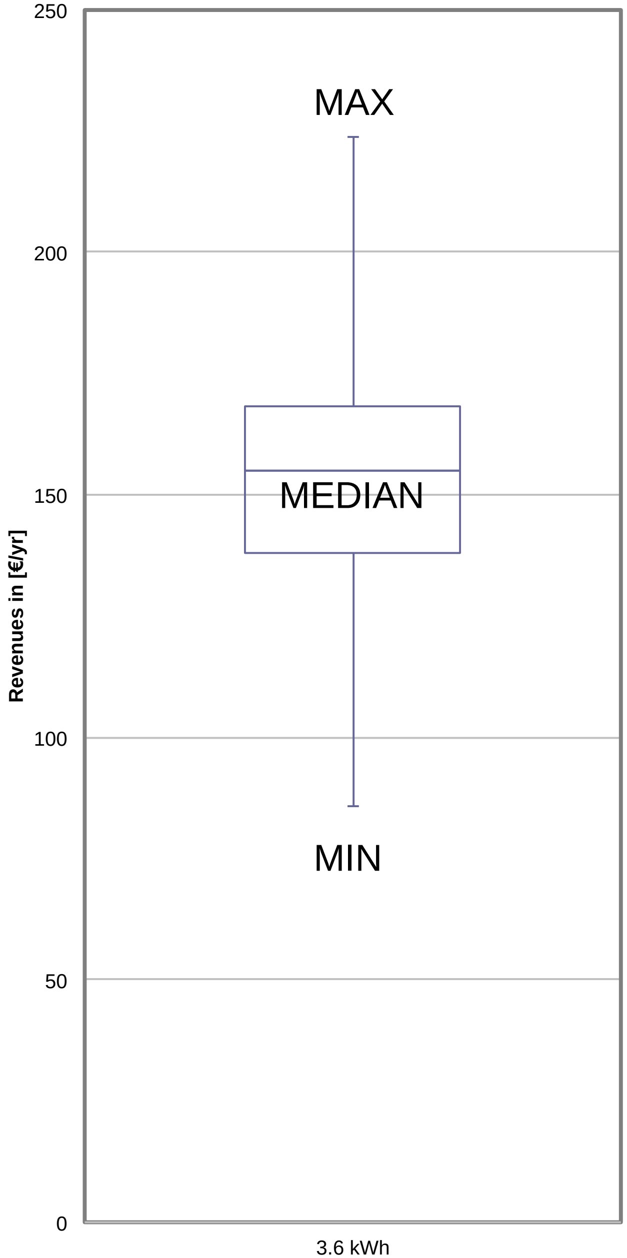
Appendix - Revenue parameters II

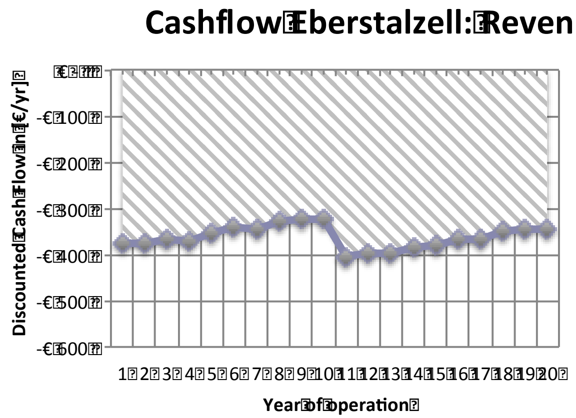


Appendix - Revenue parameters III

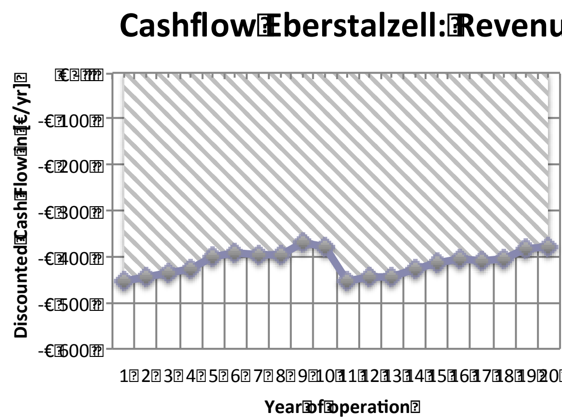


Storage and aDSM revenues at strategy: max. self consumption





Revenue bandwith:
[MAX; MAX*0.9]



Revenue bandwith:
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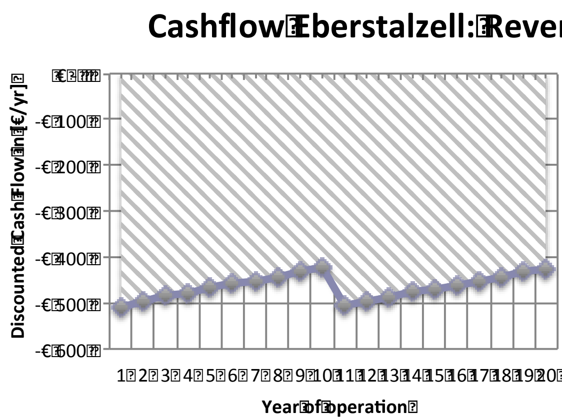

Revenue bandwith:
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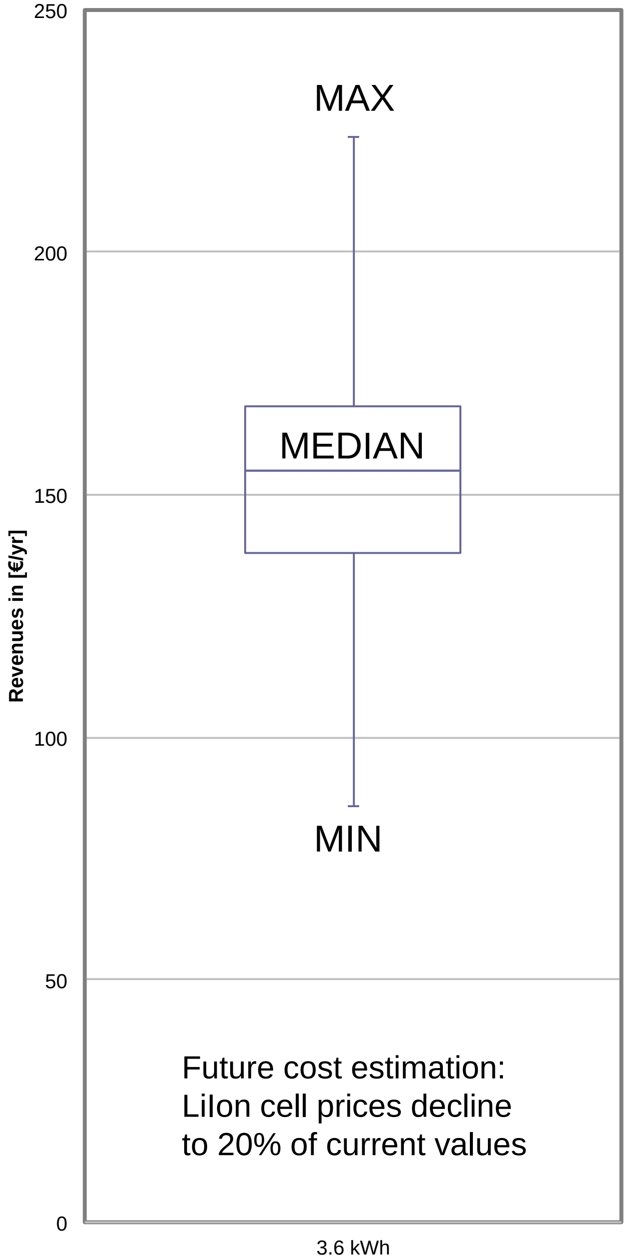

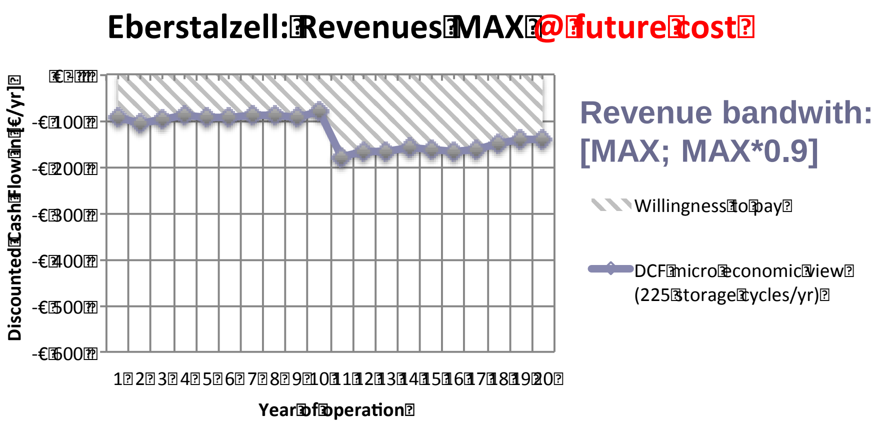

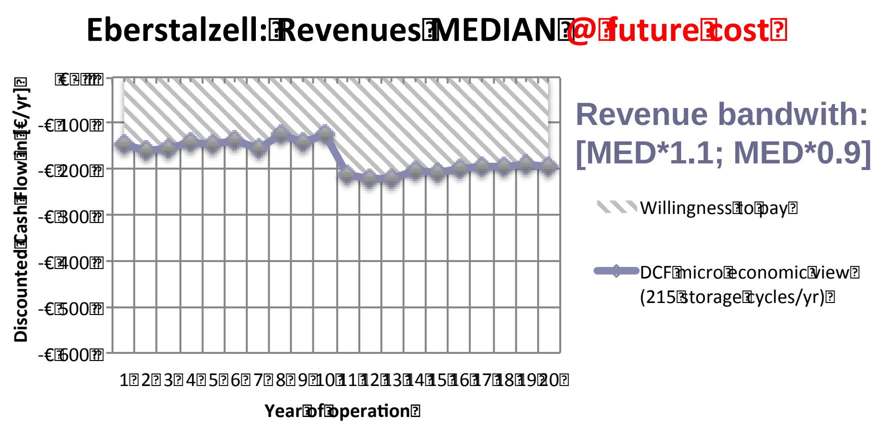

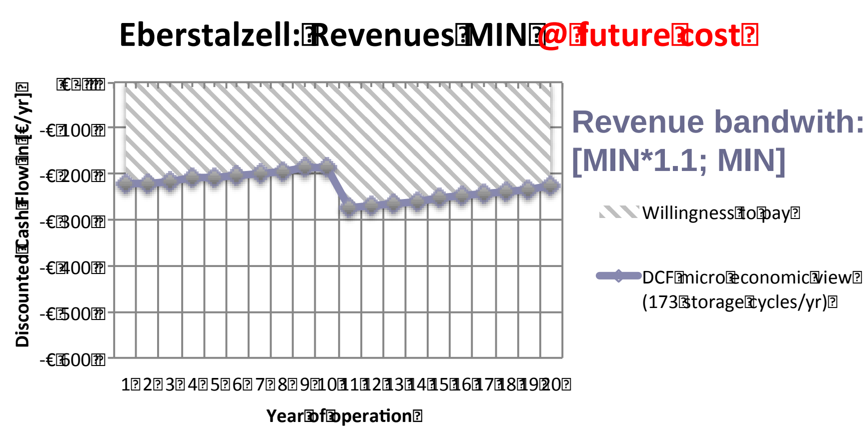

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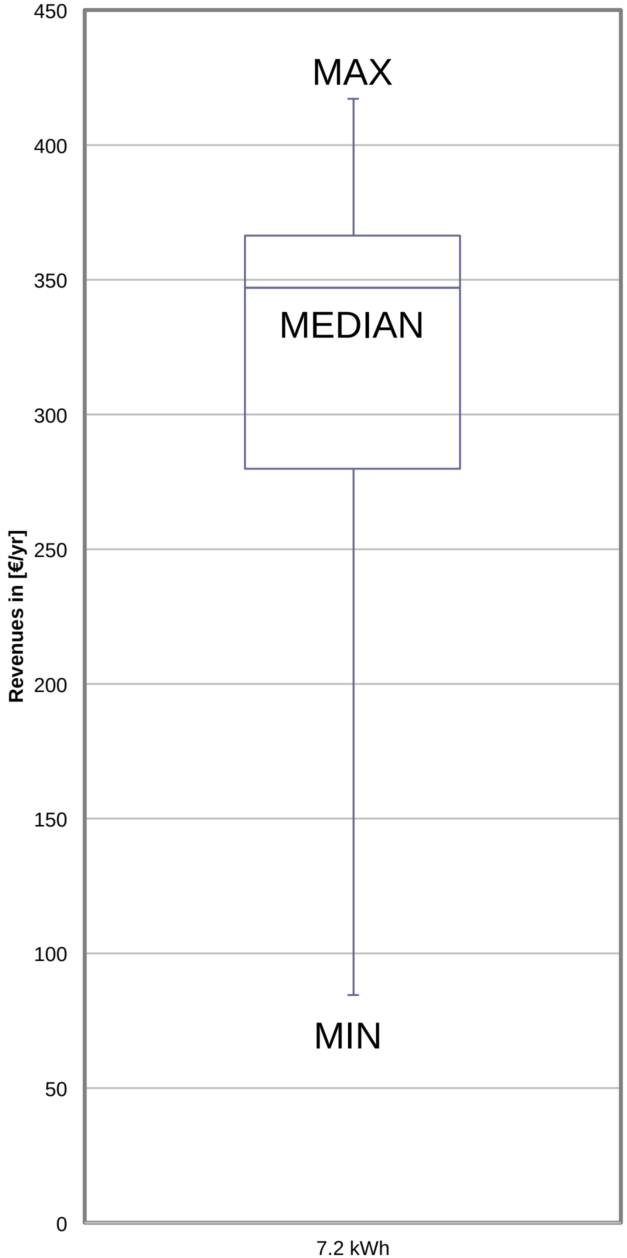

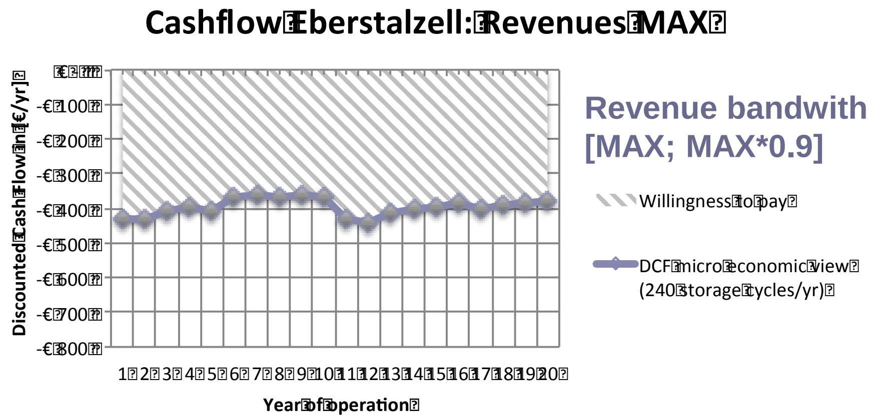

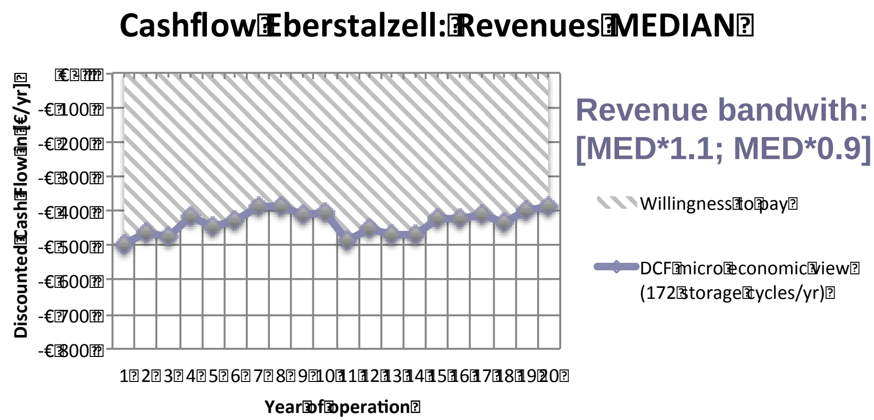

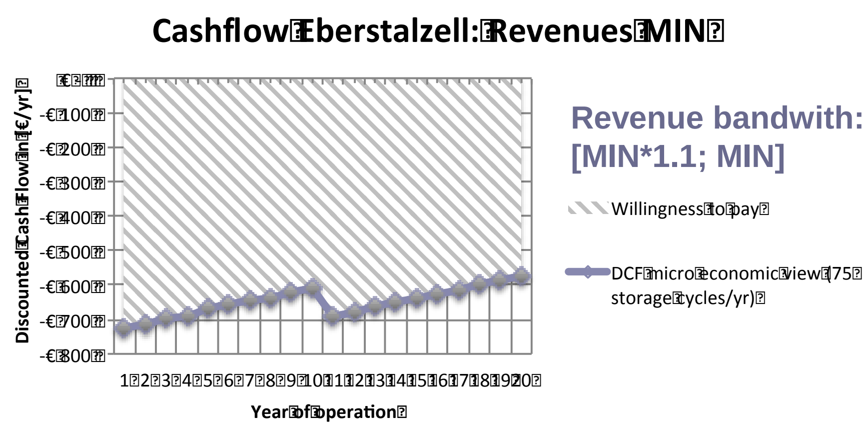

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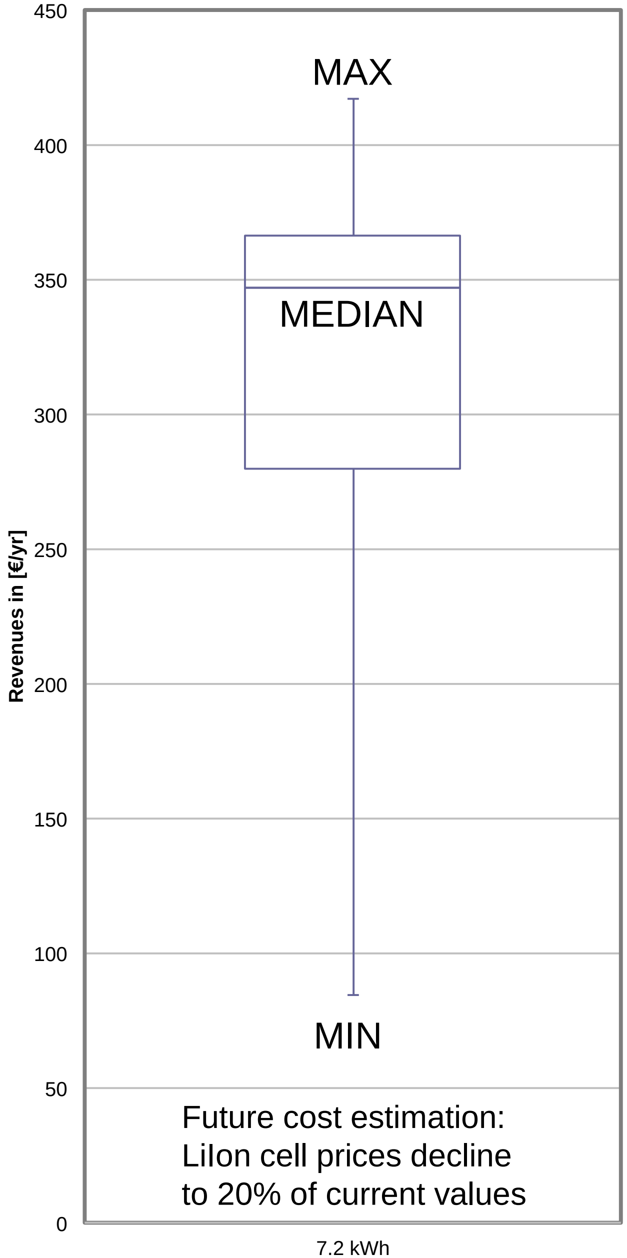

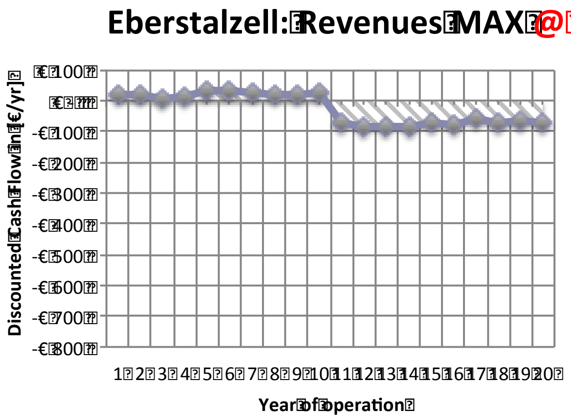

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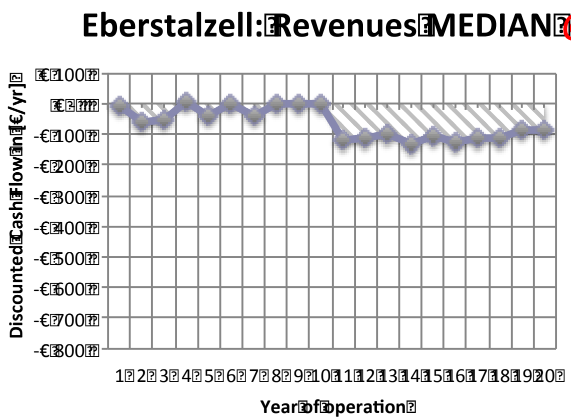
[MAX; MAX*0.9]



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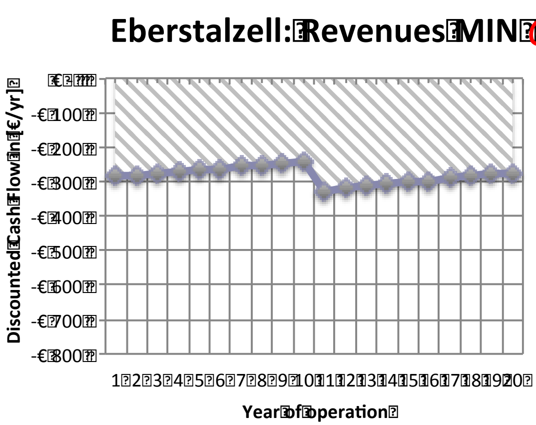

Revenue bandwith:
[MIN*1.1; MIN]

Evaluation outlook