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MODEL BASED DISPATCH OPTIMISATION FOR RESIDENTIAL DISTRICTS – ANALYSING THE INTEGRATION OF ELECTRICITY STORAGE SYSTEMS AND THEIR ENVIRONMENTAL IMPACT

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INTRODUCTION

I. Electricity consumption of the EU
  - households account for 27% of total electricity consumption
  - mainly covered to 74% by conventional power plants *(eurostat 2017, eurostat 2018a)*

II. Addressing climate change
  - switch to fluctuant renewable

III. Electricity storage systems
  - close the temporal shift between electricity generation and consumption *(Samsatli and Samsatli 2018)*
  - assessment of environmental impacts *(Baumann et al. 2017)*

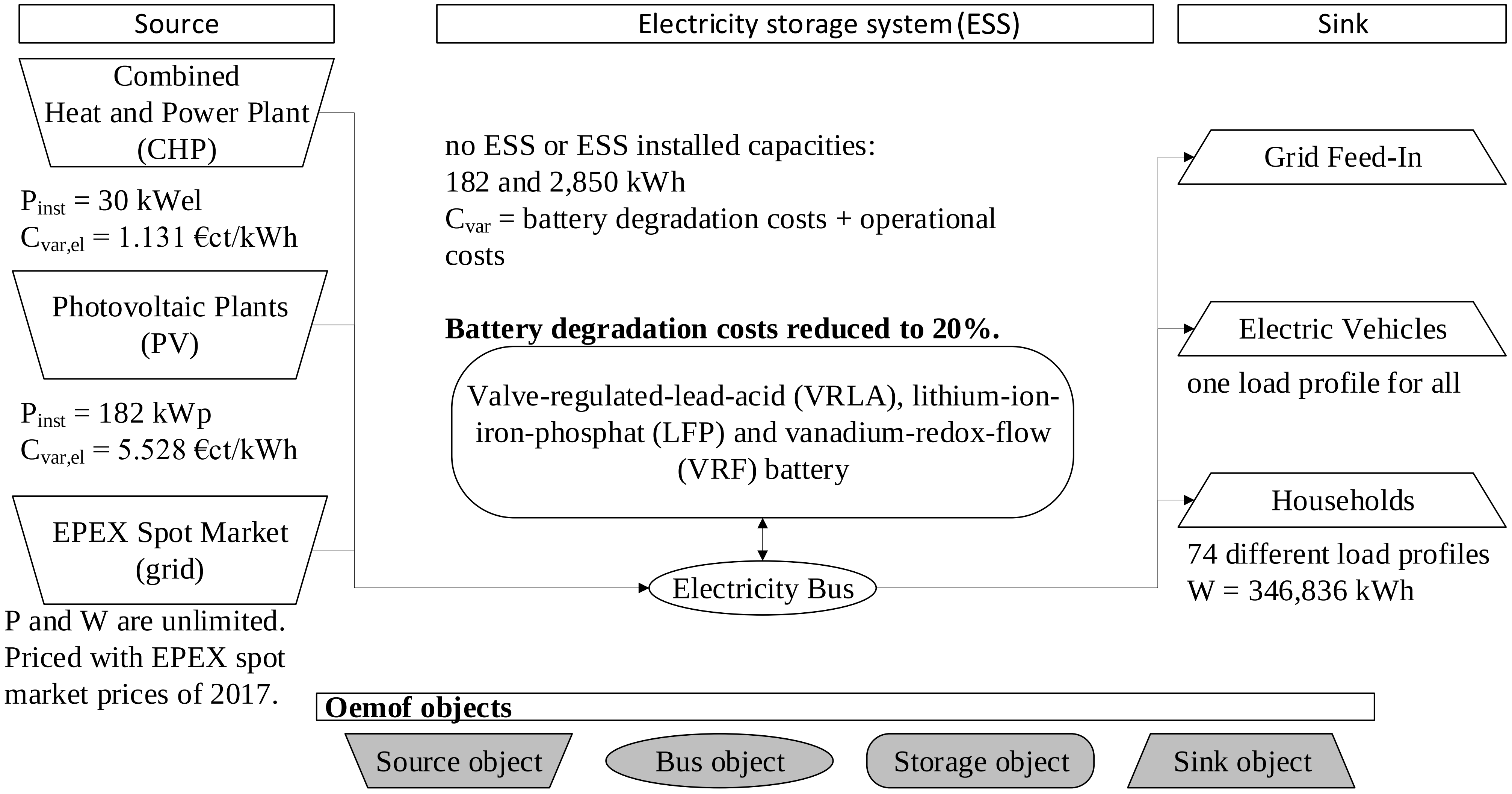
GOAL DEFINITION

I. Development of an open-source model
   - optimise the electricity dispatch for residential districts
   - dispatch analysis of electricity storage systems with renewables, combined heat and power as well as electricity grid

II. Life Cycle Assessment of electricity storage systems
   - calculation of potential environmental impacts
   - for method and results please refer to the full paper

DISPATCH OPTIMIZATION – METHOD & ASSUMPTIONS

Simplified Energy System Modell *(objects adopted from oemof documentary 2019)*



Source

Combined Heat and Power Plant (CHP)

P_{inst} = 30 kWel
$C_{var,el}$ = 1.131 €ct/kWh

Photovoltaic Plants (PV)

P_{inst} = 182 kWp
$C_{var,el}$ = 5.528 €ct/kWh

EPEX Spot Market (grid)

P and W are unlimited. Priced with EPEX spot market prices of 2017.

Electricity storage system (ESS)

no ESS or ESS installed capacities:
182 and 2,850 kWh
C_{var} = battery degradation costs + operational costs

Battery degradation costs reduced to 20%.

Valve-regulated-lead-acid (VRLA), lithium-ion-iron-phosphat (LFP) and vanadium-redox-flow (VRF) battery

Electricity Bus

Sink

Grid Feed-In

Electric Vehicles

one load profile for all

Households

74 different load profiles
W = 346,836 kWh

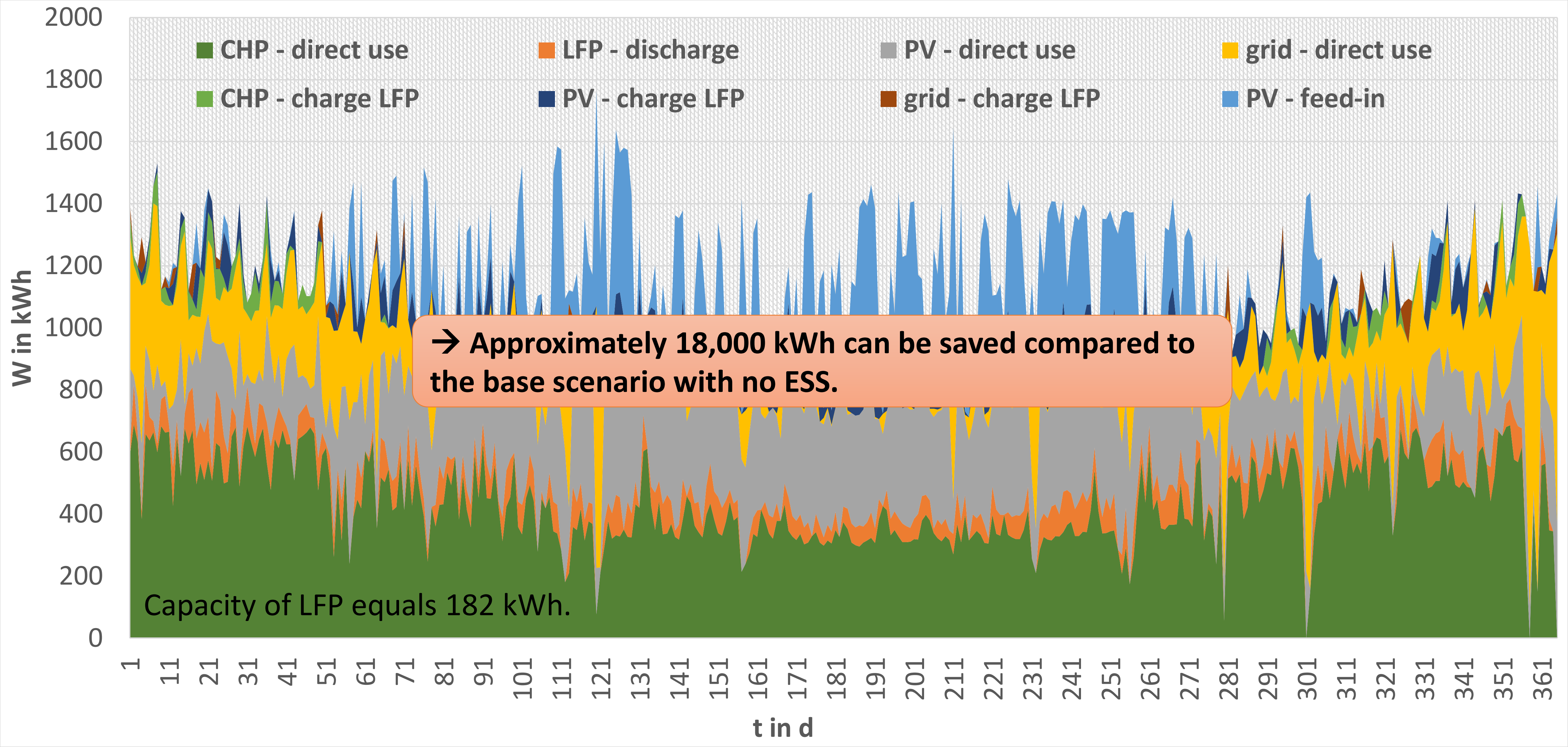
Oemof objects

Scenario I: on-grid, no electric vehicle

Scenario II: on-grid, 74 electric vehicles

Scenario III: off-grid, no electric vehicle

DISPATCH OPTIMIZATION - RESULTS



Capacity of LFP equals 182 kWh.

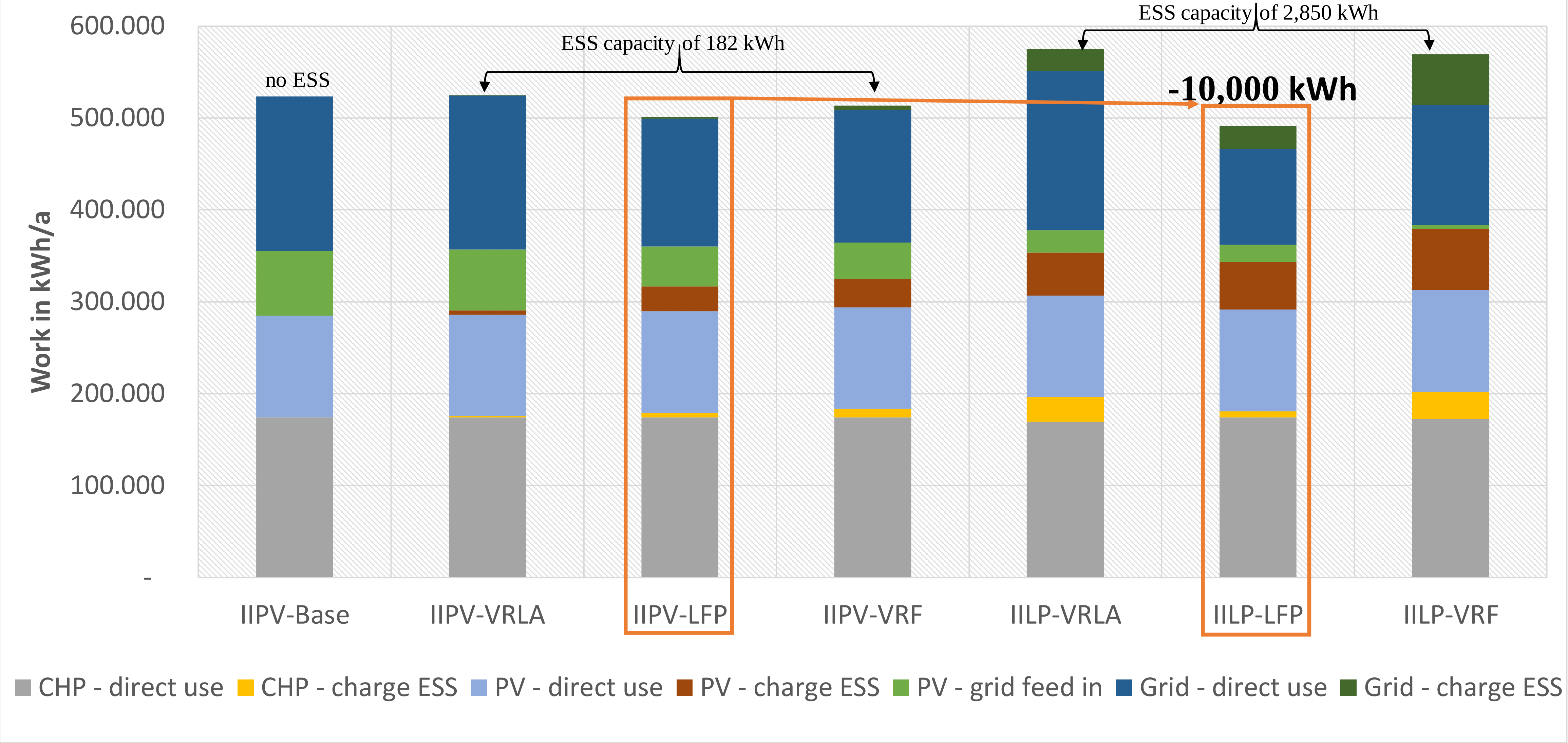
→ Approximately 18,000 kWh can be saved compared to the base scenario with no ESS.

DISPATCH OPTIMIZATION - RESULTS

Scenario I: on-grid, no electric vehicle

Scenario II: on-grid, 74 electric vehicles

Scenario III: off-grid, no electric vehicle



DISPATCH OPTIMIZATION - RESULTS

<table>
<tr><th>Barriers</th><th>Chances</th></tr>
<tr><td colspan="2">Scenario I: on-grid, no electric vehicle</td></tr>
<tr><td>**Expensiveness of ESS**
VRLA: not dispatched
VRF: high losses at high capacities
VRF: higher share of grid electricity at higher capacities</td><td>LFP and VRF: potential to reduce electricity generation (up to 18,000 kWh)
Reduction of grid supply (VRF & LFP with 182 kWh)
Better intra day electricity distribution
Increased utilisation of electricity generated by photovoltaic and combined heat and power</td></tr>
<tr><td colspan="2">Scenario II: on-grid, 74 electric vehicles</td></tr>
<tr><td></td><td>LFP: Increasing demand - higher capacities meaningful</td></tr>
<tr><td colspan="2">Scenario III: off-grid, no electric vehicle</td></tr>
<tr><td>No autarky possible by utilisation of ESS</td><td>LFP: reduction of extra power supply to 25%</td></tr>
</table>

CONCLUSIONS

1. ESS only dispatched at decreased battery degradation costs
    - energy industry framework not taken into account (e.g. costs for grid usage, promotions for photovoltaics or combined heat and power)
2. Small installed capacities preferable
3. Designing ESS: electricity generation and demand must be considered
4. VRF vs. LFP
    - VRF: lower resource depletion but higher inefficiencies
    - probably a mix of LFP and VRF should be used, LFP in times electricity is a rare resource (for PV: winter); VRF when electricity production is high
5. Problem shifting towards countries with resources extraction (e.g. South Africa for Vanadium)

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Thank you!

For references and further information please look at the full paper "Model based dispatch optimisation for residential districts – analysing the integration of electricity storage systems and their environmental impact".

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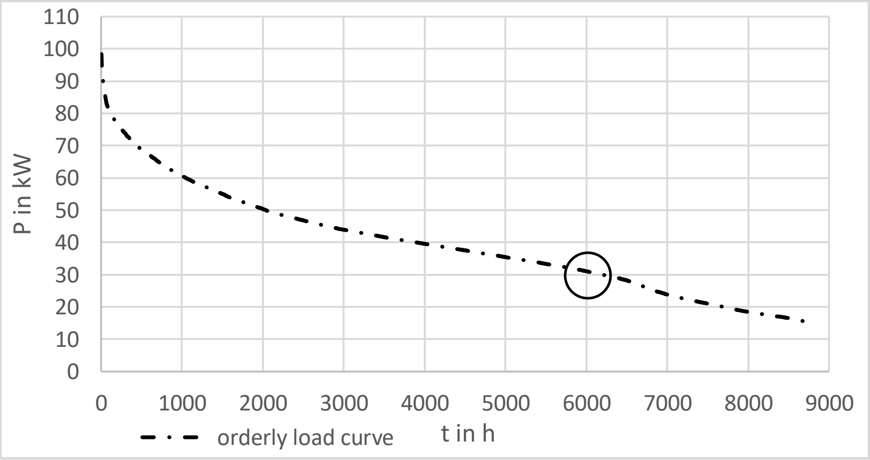
BACKUP - CHP

1. Designing: according to electricity consumption of the district

- Assumption: heat generation is completely sold to a heat sink (e.g. heat grid) at break even prices
- With 30 kWel: 6,000 full load hours reached = 180,000 kWh

2. Variable costs calculation

- maintenance contract (including insurance)(ASUE e.V. 2011), fuel (EGIX 2017), lubricating oil (Panos 2017)
- no labour costs (VDI 2067)
- allocation of costs to heat and electricity with total efficiency method (Hörner 2013)

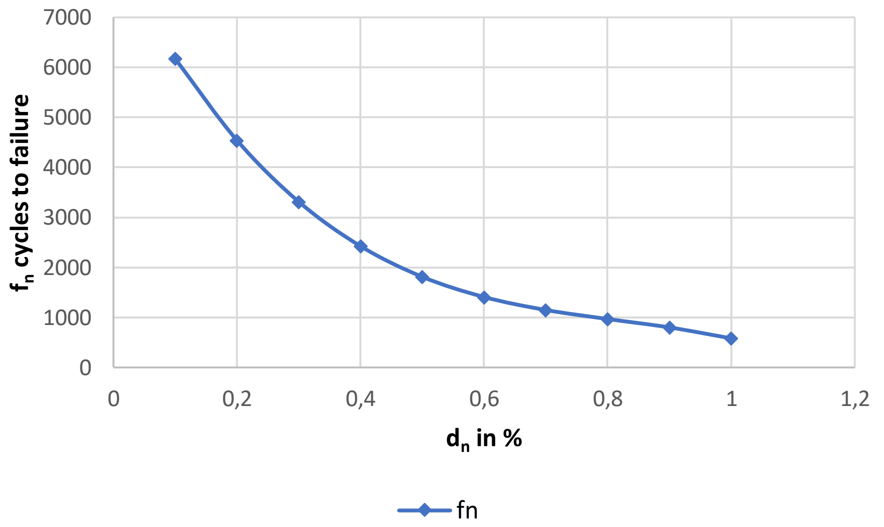


BACKUP - PHOTOVOLTAIC

- 6,964 kWh per year for a 7 kWp system (PV GIS)
- http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
- System losses of 15% (Kaltschmitt 2013)
- Total generation of 26 á 7 kWp systems: 181,074 kWh per year
- Variable costs:
- Average costs including maintenance, operation, other costs (Kaltschmitt 2013)

System specifications		unit
Location:	Pforzheim	
Latitude	48.891	decimal degrees
Longitude	8.703	decimal degrees
Elevation	256	m
Radiation database	PVGIS-CMSAF	
Slope	36	deg. (opt) (optimum)
Azimuth:	-7	deg. (opt) (optimum)
Nominal power of the PV system (crystalline silicon) (kWp):	7.0	kWp
System losses (%):	15	%

DISPATCH OPTIMISATION - METHOD



Battery electricity storages variable costs

based on the lifetime of a battery

lifetime: a) calendric life and b) cycle life

a) is set to 10 years (minimum calendric lifetime of VRLA) (Baumann et al. 2017)

b) Utilisation of the watthours throughput model: over the lifetime of the battery a limited amount of electricity can be charged and discharged (Bindner 2005)

$$LT_{total} = \frac{\sum_{l=1}^{n} LT_n}{n} = \frac{1}{n} * \sum_{l=1}^{n} (Q_{inst,bat} * d_n * f_n)$$

$$LT_{per\ year} = \frac{LT_{total}}{T}$$

DISPATCH OPTIMISATION - METHOD

Battery electricity storages variable costs

battery degradation costs

$$BDC_{kWh}[\frac{€ct}{kWh_{LT}}] = i * \frac{C_{rep}\left[\frac{€ct}{kWh}\right] * Q_{inst,bat}\ [kWh]}{LT_{total}\ [kWh_{LT}]}$$

BDC_{kWh}= battery degradation costs

C_{rep} = replacement costs

LT_{total} = total watthours throughput of the battery

$Q_{inst,bat}$ = installed battery capacity

i = adjustment factor (set to 0.2)

operational costs

$$c_{var,op}[\frac{€ct}{kWh}] = \frac{C_{op}\ [\frac{€ct}{a}]}{LT_{per\ year}\ [kWh_{LT}]}$$

$c_{var,op}$ = variable operational costs

C_{op} = operational costs per year

$LT_{per\ year}$ = yearly watthours throughput of the battery (10 years of operation)

adopted from (Bordin 2015)

BACKUP BEV’S

- Based on a questioning conducted by the “Deutschen Mobilitätspanel” (Karlsruher Institut für Technologie 2012)
  Load profile: BEV only charged at home (Heinz 2018)
- 1,433 kWh per year
- Car pool: small, compact and average class account for 61% - rest higher classes
- Different for week days and weekend days
- Only one car per household assumed

BACK UP DISPATCH OPTIMISATION - METHOD

Techno-economic bottom-up model for a residential district based on hourly data is optimised for one year.

Modelling Framework: the „open energy modelling framework“ (oemof) *(Hilpert et al. 2018)*

oemof objects: e.g. source, sink, transformer and bus

objective function: minimise overall variable costs

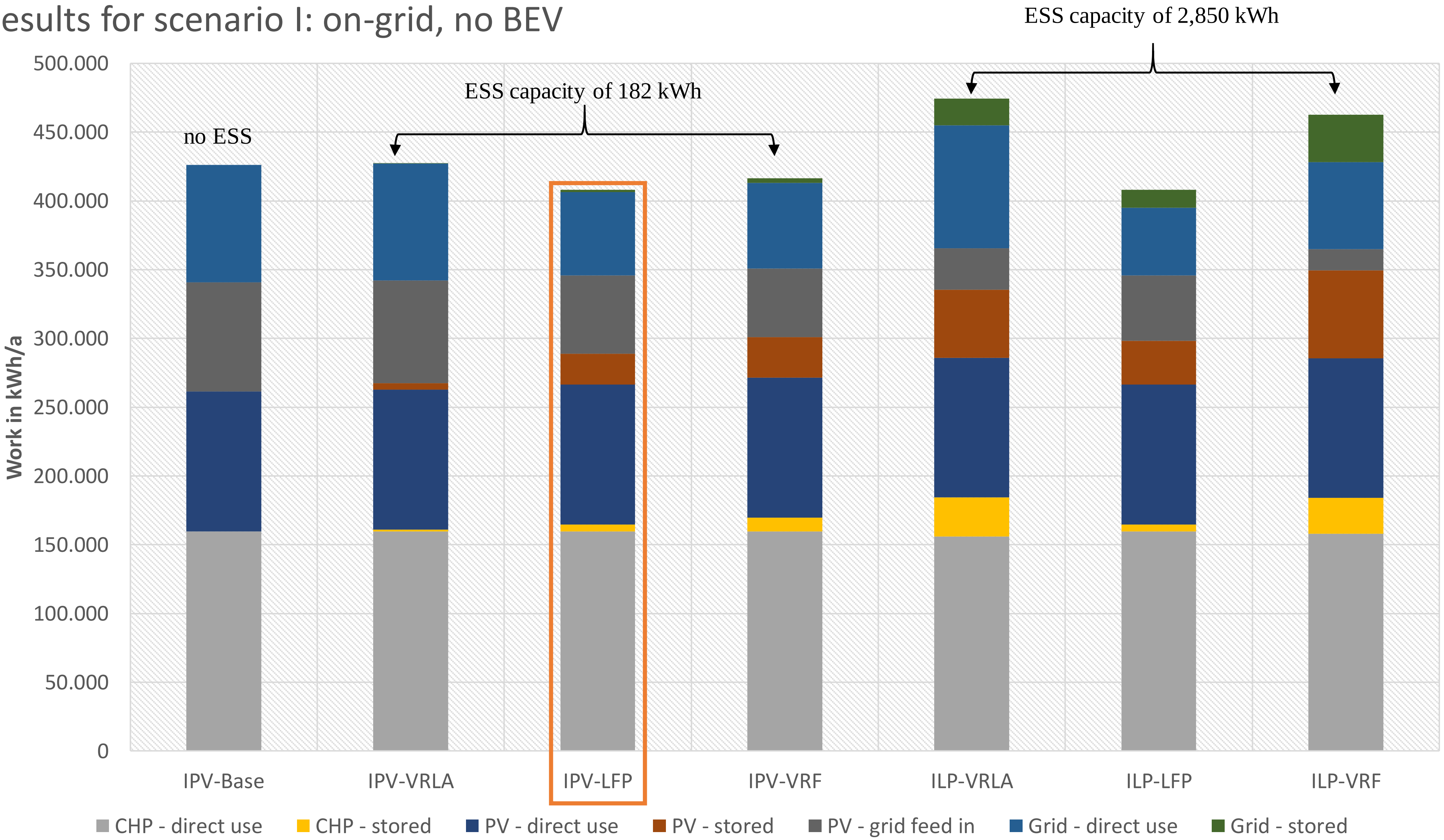
t = timestep
p = predecessor component
s = successor component

$$min: \sum_{t \in T} \sum_{(p,s) \in F} \overset{\text{variable costs}}{c^{var}_{(p,s),t}} * \overset{\text{flows}}{f_{(p,s),t}} * \overset{\text{length of timestep}}{\tau_t}$$

(Wingenbach et al. 2017)

DISPATCH OPTIMIZATION - RESULTS

Results for scenario I: on-grid, no BEV



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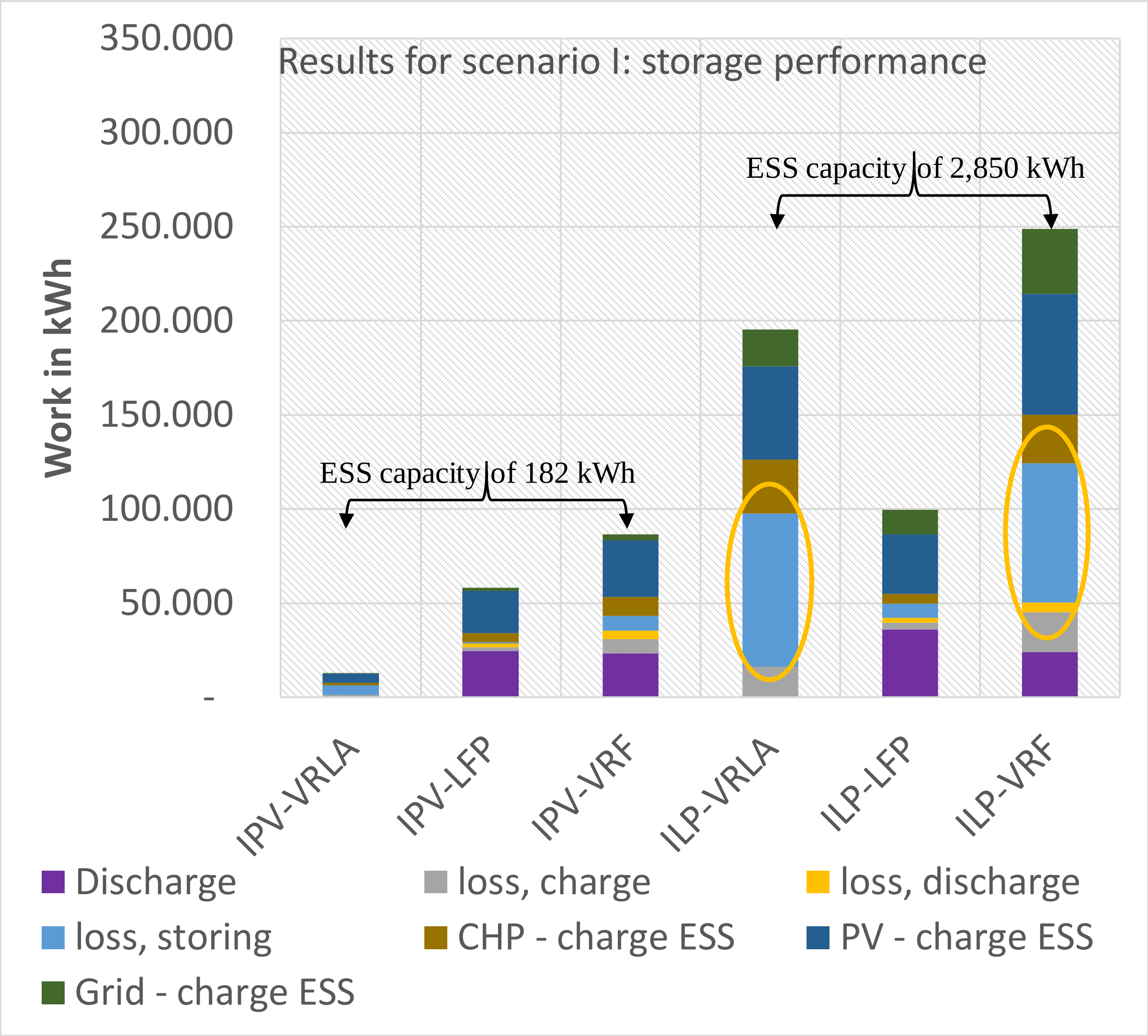

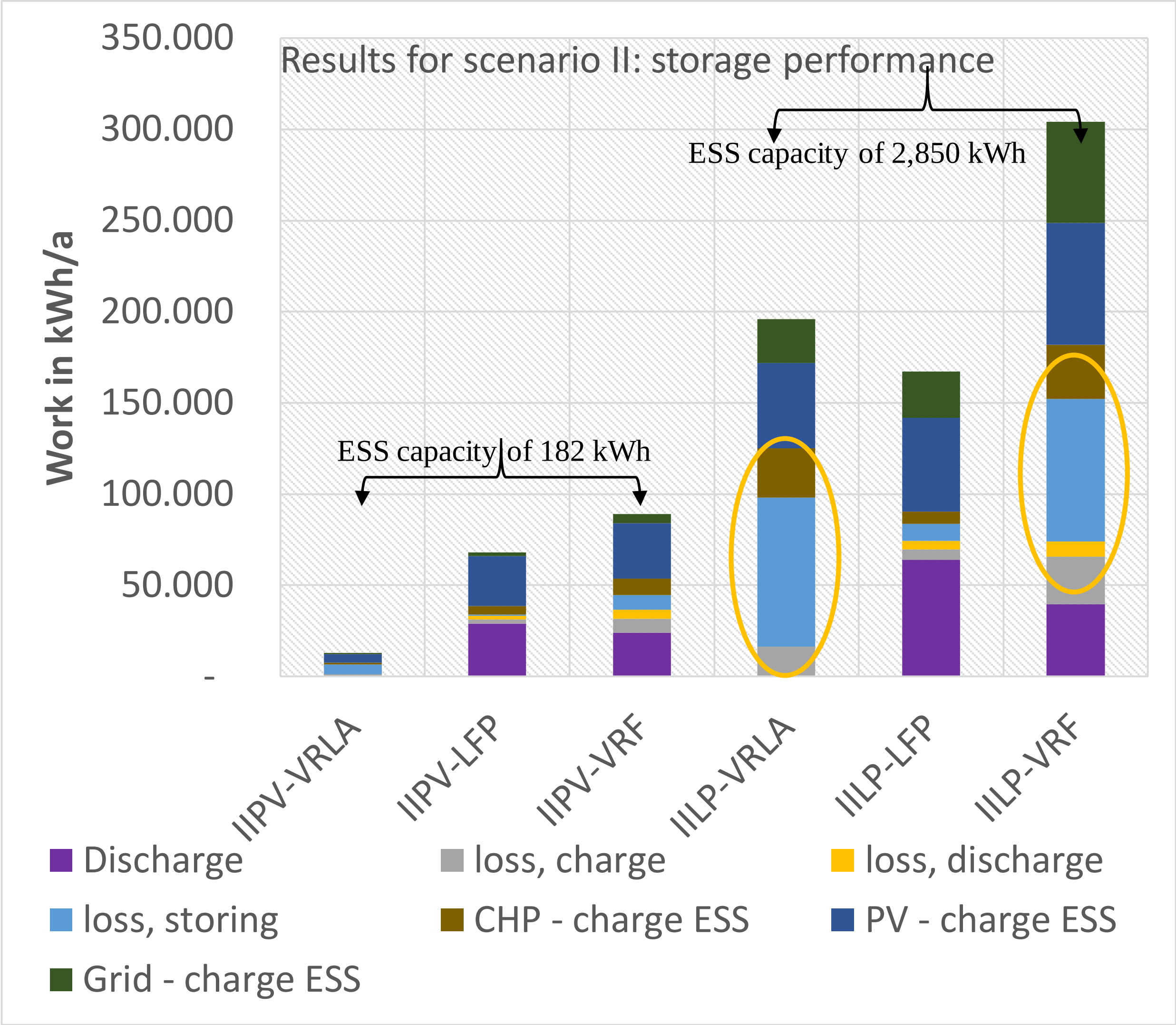

BACKUP - LCA

Functional Unit:

1 MWh usable electricity discharged from the utilised electricity storage system.

Production and Transport:

Life Cycle Inventory for battery electricity storages based on Peters and Weil 2018, Zackrisson et al. 2010, Weber et al. 2018 and Spanos et al 2015.

Background processes: mainly market processes from the database ecoinvent 3.3 (Wernet et al. 2016).

Transport distance for the battery electricity storages in Europe of 600 km (eurostat 2018b)

Use Phase:

converts installed capacity into the maximal watthour throughout of the ESS

market group for electricity, low voltage electricity, low voltage for Europe without Switzerland

LIFE CYCLE ASSESSMENT - METHOD

Life Cycle Assessment: life cycle approach considering all stages of the life of a product or process to evaluate its potential environmental impact (ISO 14044).

Functional unit:
1 MWh usable electricity discharged from the utilised electricity storage system

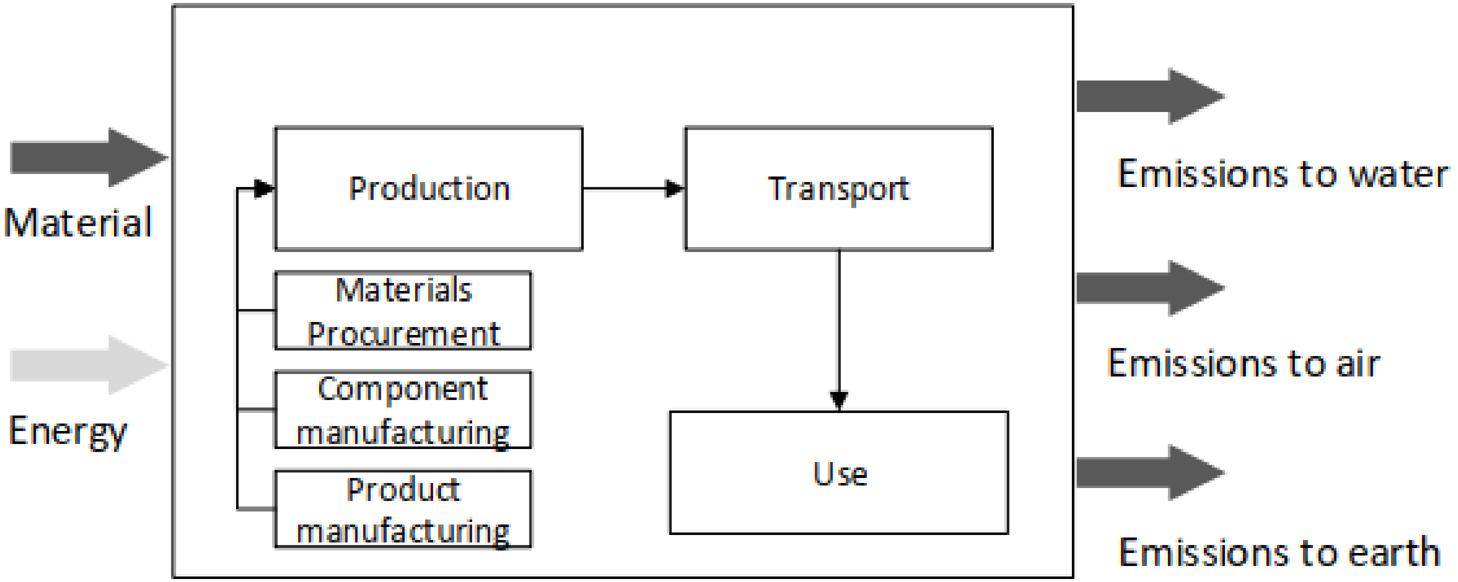

Figure: Analysed product system

LIFE CYCLE ASSESSMENT - RESULTS