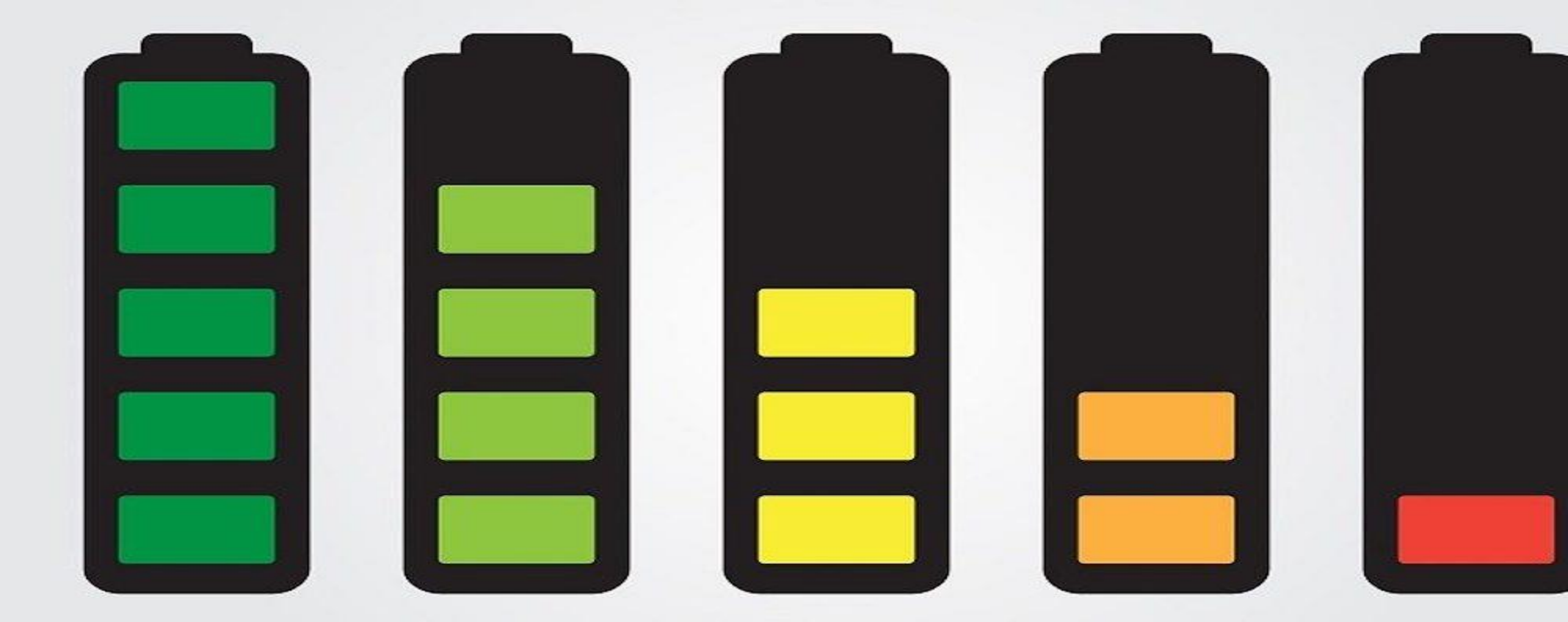

ECODESIGN BATTERIES – FIRST STAKEHOLDER MEETING DRAFT TASK 3

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AGENDA

1. Objectives and Scope

2. Direct energy consumption during use phase – strict product approach
   - Calculation of Functional Unit
   - Calculation of direct losses

3. Selection of base cases
   - EV
   - ESS

4. Direct energy consumption during use phase – extended product approach
   - Deviations from standards
   - Calculation of Application Service Energy
   - Calculation of Functional Unit for base cases
   - Calculation of direct losses for base cases

5. Indirect energy consumption during use phase

6. End-of-Life behaviour

1. OBJECTIVES AND SCOPE

Objective of Task 3

- provide an analysis of the **actual utilization** of batteries
  - in different applications
  - under varying boundary conditions
- provide an analysis of the impact of applications and boundary conditions on batteries' **environmental and resource-related performance**

1. OBJECTIVES AND SCOPE

Based on MEErP methodology, different scoping levels are considered

Strict product approach

- only battery system is considered
- note: cooling/heating just includes passive equipment (plates, tubes), not active equipment (fan, liquid cooling)
- operating conditions (load profile, ambient conditions etc.) as in traditional standards

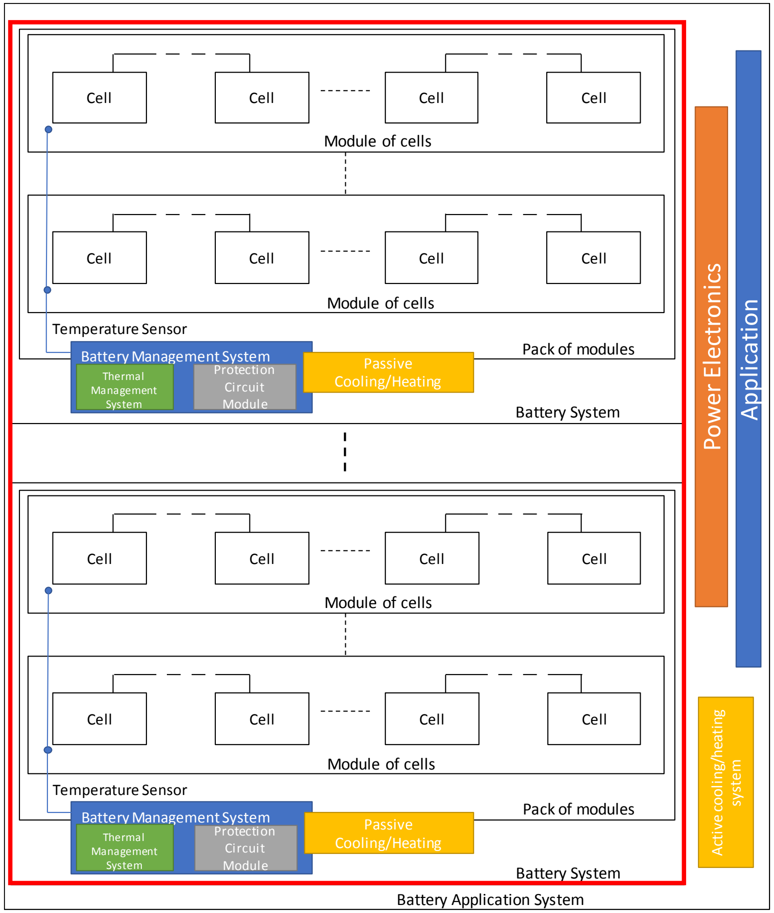
Extended product approach

- same battery system definition as in strict product approach
- actual utilisation and energy efficiency of a battery system under real-life conditions
- real-life deviations from standards according to actual load profiles and operating conditions

Technical system approach

- additional components such as power electronics, active cooling/heating, applications

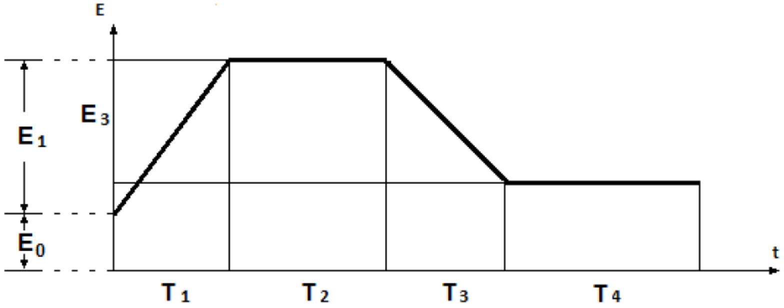
➢ considered as indirect losses



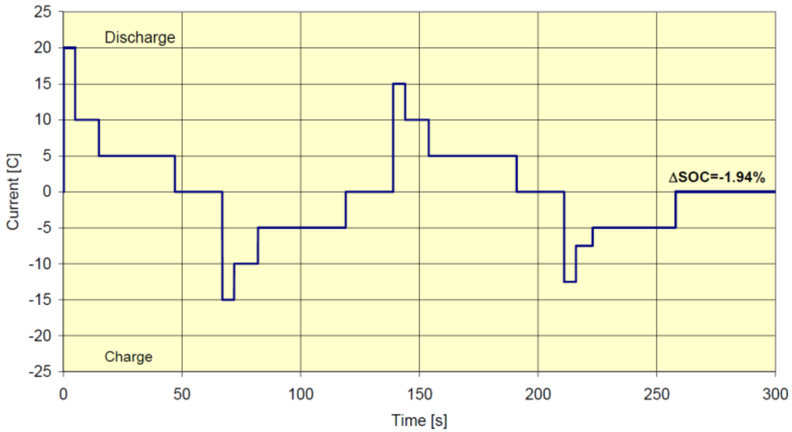
2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

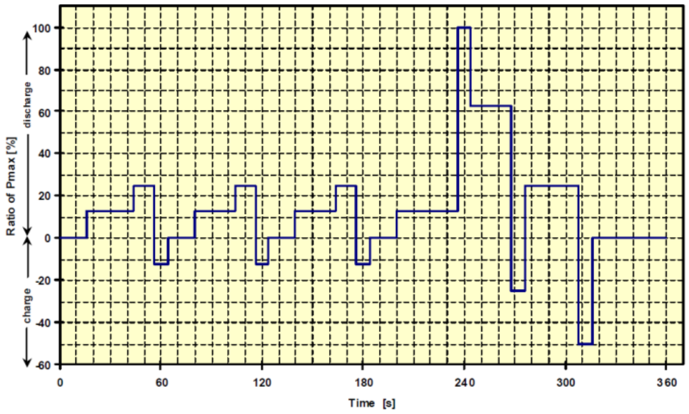
Testing conditions are defined in standards on cell and partially system level

- Usually C-rate, temperature, state of charge (SOC) or a range of SOC are specified



Typical ESS charging/discharging cycle (IEC 62933-2)





Cycle test profile PHEV (left) and BEV (right) (discharge-rich) (ISO 12405-1/2)

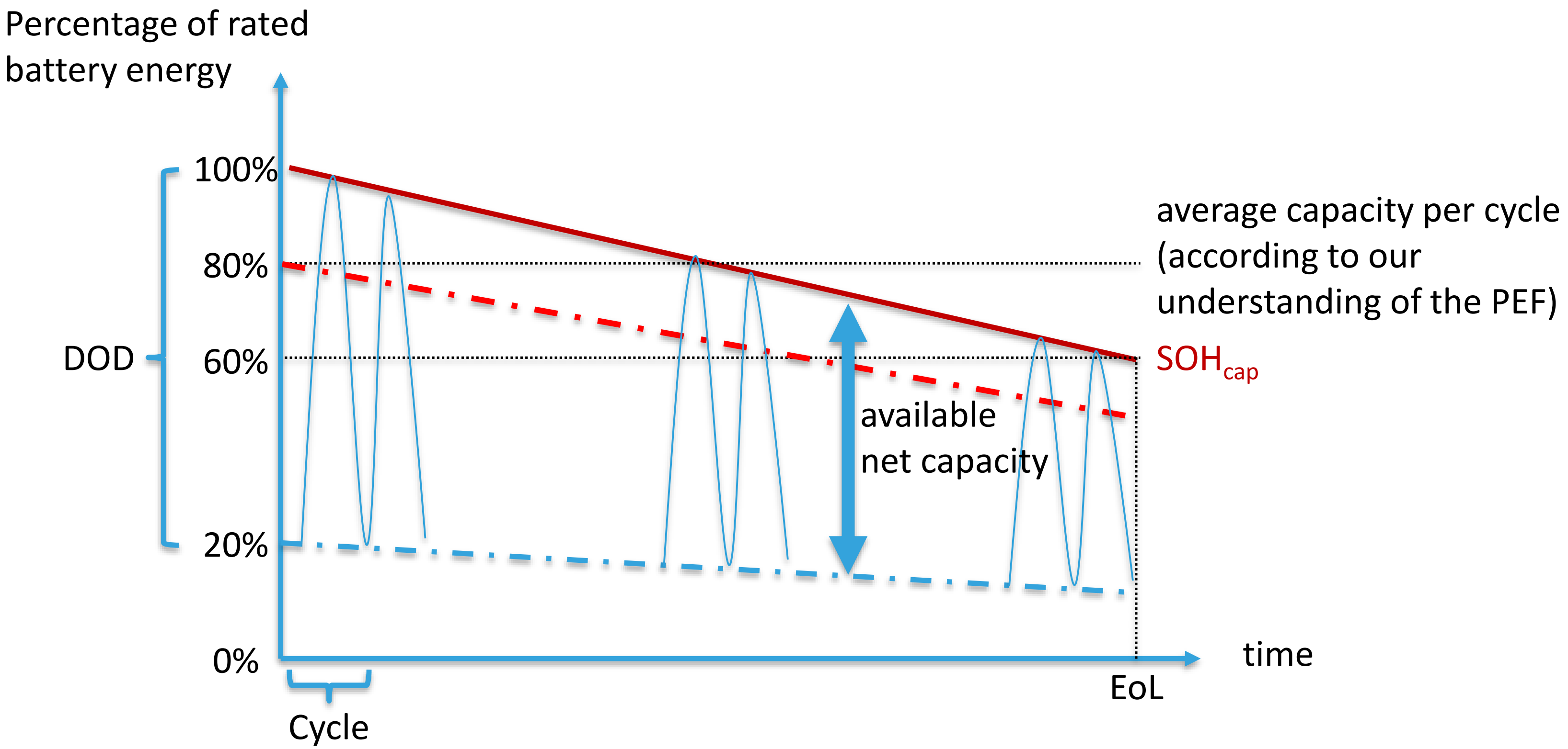
2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

Key parameters for the calculation of the functional unit

- **Functional unit (FU)** of a battery is defined as one kWh of the total energy delivered over the service life of a battery, measured in kWh at battery system level" (according to PEF)
  - ➔ quantity of FU defines the total energy delivered over the service life of a battery
- **Rated energy E_{Rated} [kWh]** is the supplier's specification of the total number of kWh that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature, discharge cut-off voltage, etc. (similar to ISO 12405-1 "rated capacity") (@ t=0). E.g.: 60 kWh/cycle
- **Depth of Discharge DOD [%]** is the percentage of rated energy discharged from a cell, module, pack or system battery (similar to IEC 62281) (similar to PEF "Average capacity per cycle"): e.g. 80%
- **Full cycle FC [#]** refers to one sequence of fully charging and fully discharging a rechargeable cell, module or pack (or reverse) (UN Manual of Tests and Criteria) according to the specified DOD (= PEF "Number of cycles"): e.g. 2000
- **Capacity degradation SOH_{cap} [%]** refers to the decrease in capacity over the lifetime as defined by a standard or declared by the manufacturer, e.g. 60% in IEC 61960. Assuming a linear decrease the average capacity over a battery's lifetime is then 80% of the initial rated capacity.
- **State of charge SOC [%]** is the available capacity in a battery pack or system expressed as a percentage of rated capacity (ISO 12405-1).

2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

Key parameters for the calculation of the functional unit



2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

Calculation of the functional unit

- The **quantity of functional units of a battery $\mathbf{Q_{FU}}$** a battery can deliver during its service life can be calculated as follows:

$$\boldsymbol{QU_a = Edc * Nc * Acc\ (see\ PEF)}$$

We assume:

$$\boldsymbol{Q_{FU}} = \underbrace{E_{Rated} * \mathrm{DOD}}_{PEF\ energy\ delivered\ per\ cycle} * \underbrace{\mathrm{FC}}_{PEF\ number\ of\ cycles} * \underbrace{\left(100\% - \tfrac{1}{2}\left(100\% - \mathrm{SOH}_{cap}\right)\right)}_{PEF\ average\ capacity\ per\ cycle}$$

$$= 60 * 80\% * 2{,}000 * (100\% - \tfrac{1}{2}(100\% - 60\%)$$

$$= 76{,}800\ \mathrm{FU}\ (\mathbf{kWh\ per\ battery\ service\ life})$$

2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

Main direct energy losses

1. **Energy efficiency η_E (energy round trip efficiency) (%)** - each FU provided over the service life of a battery is subject to the battery's energy efficiency. It can be defined as the ratio of the net DC energy (Wh discharge) delivered by a battery during a discharge test to the total DC energy (Wh charge) required to restore the initial SOC by a standard charge (ISO 12405-1). E.g. 96% (PEF) ← improvement of Task 3 report
2. **Self-discharge/charge retention SD (%SOC/month)** - each battery that is not under load loses part of its capacity over time (temporarily). Charge retention is the ability of a cell to retain capacity on open circuit under specified conditions of storage. It is the ratio of the capacity of the cell/battery system after storage to the capacity before storage (IEC 62620). E.g. 2%/month

- **Cycle life L_{Cyc} (FC)** is the total number of full cycles a battery cell, module or pack can perform until it reaches its End-of-Life (EoL) condition related to its capacity fade or power loss. E.g. 2000 FC
- **Calendar life L_{Cal}/storage life (a)** is the time in years, that a battery cell, module or pack can be stored under specified conditions (temperature) until it reaches its EoL condition (see also SOH in section 3.1.1.2.3). It relates to storage life according to IEC 62660-1, which is intended to determine the degradation characteristics of a battery. E.g. 12 years

2. DIRECT ENERGY CONSUMPTION DURING USE PHASE – STRICT PRODUCT APPROACH

Calculation of direct losses

deviation from Task 3 report

- The **losses (kWh)** of a battery, with number of annual full cycles FC_a (FC/a) (e.g. 200 FC/a) and average state of charge SOC_{Avg} (%) (e.g. 50%) can be calculated as follows:

$$\mathbf{Losses} = E_{Rated} * DOD * \min\{L_{Cyc}; L_{Cal} FC_a\} * \left(100\% - \frac{1}{2}\left(100\% - SOH_{cap}\right)\right) * (1 - \eta_E)$$

$$+SD * \underbrace{\min\left\{\frac{L_{Cyc}}{FC_a}; L_{Cal}\right\} * 12}_{\text{actual service life in months}} * SOC_{Avg} E_{Rated}$$

$$= 60 * 80\% * \min\{2{,}000; 12 * 200\} * \left(100\% - \frac{1}{2}(100\% - 60\%)\right) * (1 - 0{,}96)$$

$$+0{,}02 * \min\left\{\frac{2{,}000}{200};\ 12\right\} * 12 * 50\% * 60$$

$$= 3{,}072 + 72 = 3{,}144$$

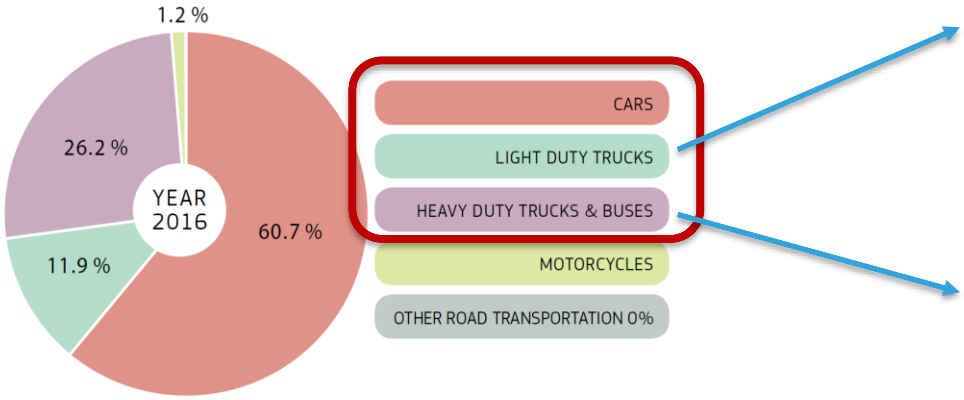
- **impact of energy efficiency on losses a lot bigger than self-discharge**

3. SELECTION OF BASE CASES

EV

- Looking at global battery demand (Task 2) **EV and stationary ESS** stand out

GHG-Emissions from Road Transport 2016 EU 28 (correspond to energy consumption)



main emitters of GHG in that group are **light commercial vehicles (LCV) (GVW<3.5 tonnes)** (German study – Wietschel et al. 2017)

main emitters of GHG in that group are **heavy-duty trucks (HDT) (GVW 12 to 26 tonnes)** and **heavy-duty tractor units (HDTU) (up to 40 tonnes)** (German study – Wietschel et al. 2017)

[Source: European Commission (2018): Statistical Pocketbook 2018. EU Transport in Figures.]()

- According to Gnann (2015) for passenger cars **battery electric vehicles (BEV)** and **plug-in hybrid electric vehicles (PHEV)** are most promsing
- According to Wietschel et al. (2017) for **LCV BEV**, for **HDT BEV** and for **HDTU PHEV** are most promising

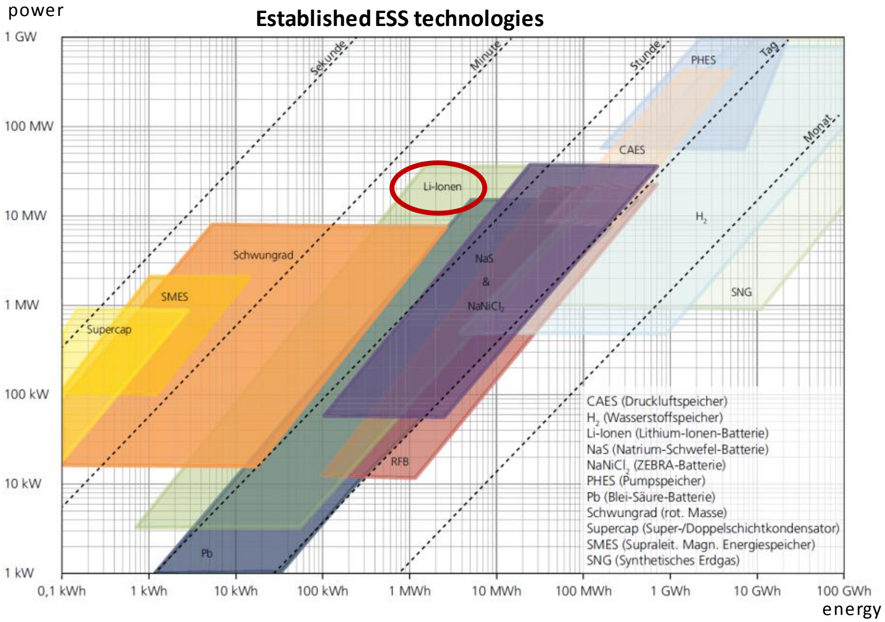
3. SELECTION OF BASE CASES

ESS

- **residential ESS** and the provision of grid services, referred to as **commercial ESS,** seem to have the highest market potential (see Thielmann et al. (2015) and Task 2)

➢ they will be in the scope of this study

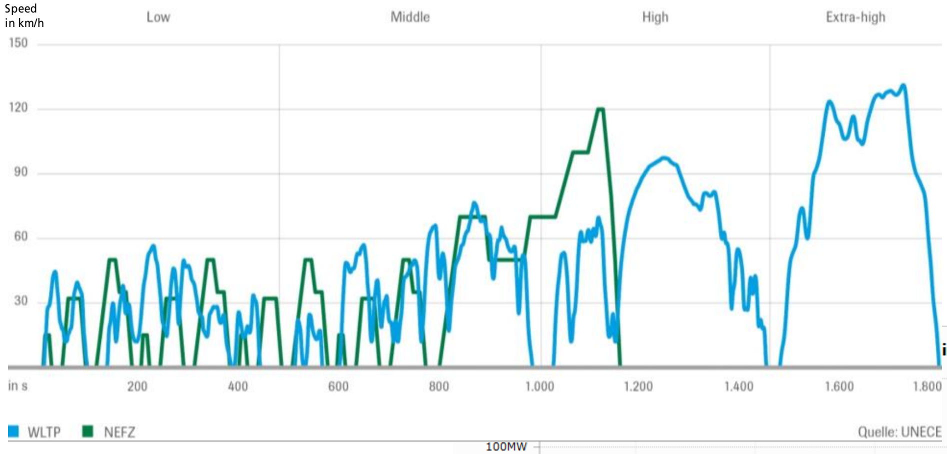
- for larger power and energy quantities other technologies are more promising



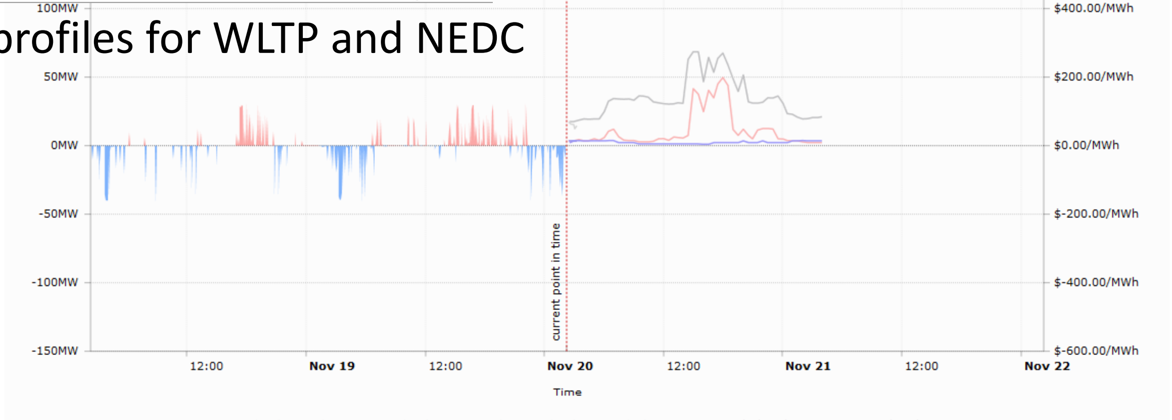
Source: Thielmann et al. (2015)

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Test standards and real-life utilisation differ



Comparison of speed profiles for WLTP and NEDC (Source: VDA (2018))


in SA (as at 20th Nov 2018, 02:17 UTC+10)

Load profile of commercial ESS (Source: Hornsdale Power Reserve (2018))

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

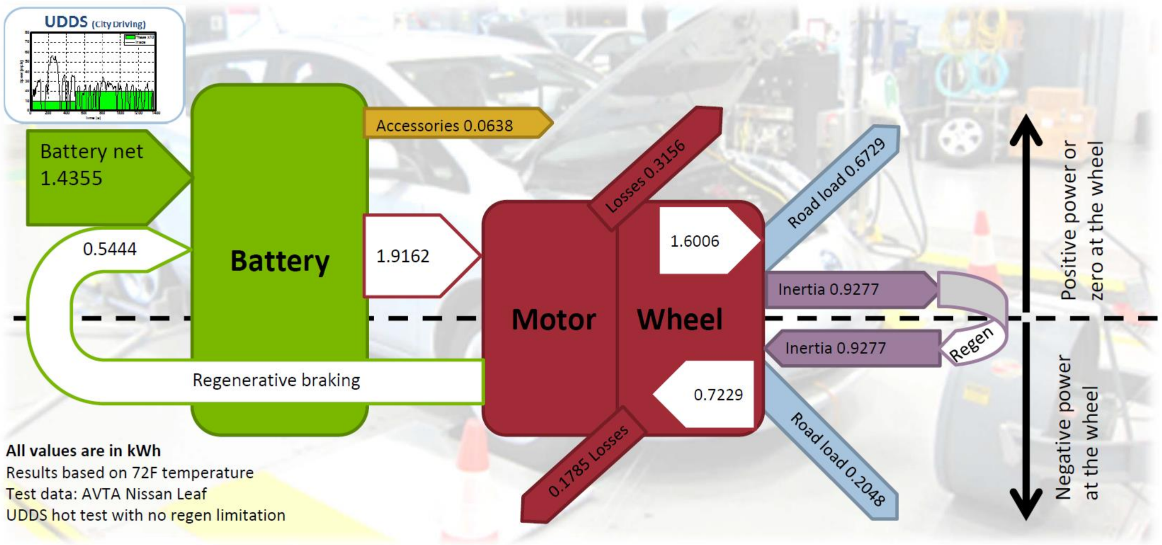
Real-life deviations from standard test conditions

Potential deviation from standards	Explanation	How it is considered
driving profiles	different load profiles of battery in urban, freeway and highway traffic	only considered via average fuel consumption measured with a specific test cycle
driving patterns	different driving distances and duration on weekdays/ at weekend	Average daily driving distances and durations assumed per base case
charging strategy	charging C-rates, frequency and duration vary	Standard charge strategy defined for each base case
temperature	ambient temperatures vary (winter, summer, region, etc., even daily)	TMS is expected to be standard, thus not considered

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Energy consumption of EVs

- energy consumption stated in data sheets or measured with testing drive-cycles is net energy consumption
- regenerative braking has to be added to net energy consumption, if total energy consumption (supplied by battery) has to be calculated



All values are in kWh
Results based on 72F temperature
Test data: AVTA Nissan Leaf
UDDS hot test with no regen limitation

Energy distribution of Nissan Leaf (2012) (Source: Lohse-Busch et al. (2012))

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Calculation of application service energy

- The **application service (AS) (kWh)** is the energy required by the application per service life (PEF)
- The following formula is applied for the calculation **AS of EV:**

$$AS = Economic\ life\text{-}time\ application * all\text{-}electric\ annual\ vehicle\ kilometers$$

$$* \frac{Fuel\ consumption}{100km} * (1 + recovery\ braking)$$

$$= 14 * 13{,}000 * \frac{19}{100} * 1{,}2 = 41{,}496\ kWh$$

- The following formula is applied for the calculation **AS of ESS:**

not specified in PEF

$$AS = Economic\ life\text{-}time\ application * FC * E_{rated} * DOD$$

$$= 15 * 250 * 10 * 90\% = 33{,}750\ kWh$$

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Calculation of application service energy

	passenger BEV	passenger PHEV	LCV BEV	HDT BEV	HDTU PHEV	Residential ESS	Commercial ESS
Economic life time application [a]	14	14	11	10	6	15	20
Annual vehicle kilometres [km/a]	13,000	13,000	17,500	64,000	114,000		
All-electric annual vehicle kilometres [km/a]	13,000	5,200	17,500	64,000	39,000	-	-
Energy consumption [kWh/100km]	19	28	19	125	140	-	-
Recovery braking [% energy consumption]	20%	20%	20%	12%	6%	-	-
All-electric range [km]	240	35	200	175	100	-	-
Annual full cycles [FC/a]	-	-	-	-	-	250	225
DoD [%]	80%	80%	80%	80%	80%	90%	90%
Application battery system energy [kWh]	40	12	33	240	160	10	30,000
min	20	4	20	170	n/a	1	250
max	100	20	40	1000	n/a	20	130,000
Application service energy	**41,496**	**24,461**	**43,890**	**896,000**	**347,256**	**33,750**	**121,500,000**

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Calculation of functional unit for applications

	passenger BEV	passenger PHEV	LCV BEV	HDT BEV	HDTU PHEV	Residential ESS	Commercial ESS
nominal battery system capacity according to ISO [kWh]	40	12	35	240	160	10	30.000
SoH @ EoL of battery system relative to declared capacity (SoHcap) [%]	80%	80%	80%	80%	80%	50%	70%
Average capacity per cycle (Acc) [kWh/cycle]	90%	90%	90%	90%	90%	75%	85%
DoD [%]	80%	80%	80%	80%	80%	90%	90%
Energy delivered per cycle (Edc) [%]	32	10	28	192	128	9	27,000
Average net capacity per cycle until EoL [kWh]	29	9	25	173	115	7	22,950
Nc (Number of cycles for battery system over its service life) [-]	1,500	5,000	1,500	1,500	5,000	10,000	10,000
Q_{FU} over battery system lifetime [kWh]	**43,200**	**43,200**	**37,800**	**259,200**	**576,000**	**67,500**	**229,500,000**
N_{bat} number of batteries needed to fulfil the application service	1.0	0.6	1.2	3.5	0.6	0.5	0.5

$$N_{bat} = \frac{AS}{Q_{FU}}$$

improvement of Task 3 report

4. DIRECT ENERGY CONSUMPTION DURING USE PHASE – EXTENDED PRODUCT APPROACH

Calculation of energy efficiency losses and self-discharge

$$\frac{AS}{\frac{net\ capacity\ per\ cycle}{economic\ lifetime\ application}}$$

	passenger BEV	passenger PHEV	LCV BEV	HDT BEV	HDTU PHEV	Residential ESS	Commercial ESS
QFU [kWh]	43,200	43,200	37,800	259,200	576,000	67,500	229,500,000
ŋcoul x ŋv = energy efficiency	96%	96%	96%	96%	96%	96%	96%
Energy losses due to battery energy efficiency [kWh]	**1,728**	**1,728**	**1,512**	**10,368**	**23,040**	**2,700**	**9,180,000**
Self discharge rate [%/month]	2%	2%	2%	2%	2%	2%	2%
Average SOC [%]	50%	50%	50%	50%	50%	50%	50%
Battery cycle life [cycle]	1,500	5,000	1,500	1,500	5,000	10,000	10,000
Battery calendar life [a]	10	8	10	10	8	15	20
Annual full cycles [FC/a]	103	202	158	519	502	250	225
Daily vehicle kilometers [km/d]	40	40	60	245	440		
Operational days per year [d/a]	336	336	313	260	260	300	300
Operational hours per day [h/d]	1	1	1,5	4	8	16	8
Operational time per year [h/a]	336	336	470	1,040	2,080	4,800	2,400
Idle time per year [h/a]	96%	96%	95%	88%	76%	45%	73%
Energy losses due to self-discharge (only when idle) [kWh]	**46**	**11**	**38**	**73**	**117**	**8**	**52,274**

5. INDIRECT ENERGY CONSUMPTION DURING USE PHASE

Calculation of indirect losses

- charger
- cooling/heating energy

$$\frac{Q_{FU}}{Share\ AC\ charge * \eta_{AC\ charger} + (1 - Share\ AC\ charge) * \eta_{DC\ charger} * \frac{\eta_{E\ DC\ charging}}{\eta_{E}}} - Q_{FU}$$

$$= \frac{43{,}200}{0{,}8 * 0{,}85 + (1 - 0{,}8) * 0{,}93 * \frac{0{,}94}{0{,}96}} - 43{,}200$$

	passenger BEV	passenger PHEV	LCV BEV	HDT BEV	HDTU PHEV	Residential ESS	Commercial ESS
Charger efficiency AC [%]	85%	85%	85%	92%	92%		
Charge power AC [kW]	3,8	3,8	3,8	22	22		
Charger efficiency DC [%]	93%	93%	93%	93%	93%		
Charge power DC [kW]	50	50	50	150	150		
Share AC charge [%]	80%	80%	70%	50%	50%		
Battery efficiency charge [%]	94%	94%	94%	94%	94%		
Charger no load loss []	?	?	?	?	?		
Energy consumption due to charger energy efficiency (incl, battery efficiency reduction) [kW]	**6,909**	**6,909**	**5,739**	**23,982**	**53,293**		
Heating/cooling energy of battery packs charging [kWh/h]	?	?	?	?	?	?	?
Heating/cooling energy of battery packs fast charging [kWh/h]	?	?	?	?	?	?	?
Heating/cooling energy of battery packs operating [kWh/h]	?	?	?	?	?	?	?
Heating/cooling energy of battery packs idle [kWh/h]	?	?	?	?	?	?	?
Energy consumption due to cooling and heating requirements [kWh]	?	?	?	?	?	?	?

6. END-OF-LIFE BEHAVIOUR

End of life behaviour product use and stock life

	L_{Cyc}			L_{Cal}		
Service life	**Application**	**Battery**		**Application**	**Battery**	
passenger BEV	1,500	1,500	🟨	14	10	🟥
passenger PHEV	3,000	5,000	🟩	14	8	🟥
LCV BEV	1,750	1,500	🟥	11	10	🟨
HDT BEV	5,000	1,500	🟥	10	10	🟨
HDTU PHEV	3,000	5,000	🟩	6	8	🟩
residential ESS	3,750	10,000	🟩	15	15	🟨
commercial ESS	4,500	10,000	🟩	20	20	🟨

6. END-OF-LIFE BEHAVIOUR

End of life behaviour collection rates and second hand use

- **Collection rates (see PEF)**

Collection rate for second-life or recycling	Unidentified stream
95%	5%

- percentage of recyclable batteries?

- **Estimated second hand use, fraction of total and estimated second product life (in practice)**

	Estimated share of end of first life batteries used in second-life applications coming from	
	EV	**ESS**
share of total number of batteries	tbd	tbd
share of battery energy per battery	tbd	tbd

THANK YOU FOR YOUR ATTENTION

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