Preparatory Study on Ecodesign and Energy Labelling of Batteries under FWC ENER/C3/2015-619-Lot 1

TASK 5

Environment & economics –
For Ecodesign and Energy Labelling

VITO, Fraunhofer, Viegand Maagøe

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Study team leader: Paul Van Tichelen
VITO/Energyville – paul.vantichelen@vito.be

Key technical expert: Grietus Mulder
VITO/Energyville – grietus.mulder@vito.be

Authors of Task 5: Wai Chung Lam – VITO/Energyville
Karolien Peeters – VITO/Energyville
Paul Van Tichelen – VITO/Energyville

Quality Review: Jan Viegand – Viegand Maagøe A/S

Project website: https://ecodesignbatteries.eu/

Version history:

Version 1: version made available in December 2018 for the Stakeholders to comment and for discussion in the first stakeholder meeting.

Version 2 (version made available for the second stakeholder meeting):

- was a more elaborated version with environmental and economic assessments of all seven base cases;

- included several updates on the modelling of battery chemistries and applied parameters based on the updated user parameters, base cases and BOM of Task 3/4.

Version 3 (this version/final version):

- Includes the changes made in the EcoReport tool and LCC calculations, i.e.:
  - lowered the average efficiency of the battery system parameter from 96 % to 92 %
  - corrected the mass imbalance of the extra materials
  - updated the EOL scenario of the “extra materials” category
  - corrected the calculations of the CRM indicator
- Includes textual updates, additions and other corrections

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Contact: Cesar Santos

E-mail: cesar.santos@ec.europa.eu

European Commission
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Contents

List of abbreviations and acronyms

Abbreviations	Descriptions
AD	Acidification
BAU	Business As Usual
BC	Base Case
BEV	Battery Electric Vehicle
BOM	Bill-of-Materials
CAPEX	Capital Expenditure
CF	Characterisation Factor
CMC	Carboxy Methyl Cellulose
CRM	Critical Raw Material
DMC	Dimethyl carbonate
DoD	Depth of Discharge
GER	Gross Energy Requirements
EC	European Commission
EC	Ethylene Carbonate
EMC	Ethyl Methyl Carbonate
EOL	End-of-Life
EPD	Environmental Product Declaration
eq.	equivalent
EU	European Union
EU-28	28 Member States of the European Union
EUP	Eutrophication
FU	Functional Unit
GHG	Greenhous Gases
GWP	Global Warming Potential
HMa	Heavy metals to air
HMw	Heavy metals to water
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LCOE	Levelized Cost Of Energy
LCV	Light Commercial Vehicle
LFP	Lithium-ion Phosphate
LiPF6	Lithium Hexaflurophosphate
LiFSI	Lithium bis(fluorosulfonyl) imide
LMO	Lithium Manganese Oxide
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy-using Products
NCA	Lithium Nickel Cobalt Aluminium
NCM	Lithium Nickel Manganese Cobalt Oxide
NMC	Lithium Nickel Manganese Cobalt Oxide
NiMh	Nickel-Metal hydride
NPV	Net Present Value
OPEX	Operational Expenditure
PAH	Polycyclic Aromatic Hydrocarbons

Abbreviations	Descriptions
PM	Particulate Matter
PC	Passenger car
PC	Propylene Carbonate
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PHEV	Plug-in Hybrid Electric Vehicle
POP	Persistent Organic Pollutants
PVDF	Polyvinylidene fluoride
PWF	Present Worth Factor
QFU	Quantity of Functional Units
Sb	Antimony
SBR	Styrene-Butadiene Rubber
SoC	State of Charge
TOC	Total Cost of Ownership
VAT	Value Added Tax
VOC	Volatile Organic Compounds
ZrO2	Zirconium Oxide
WEEE	Waste Electrical and Electronic Equipment

5. Task 5: Environment and economics

5.0. General introduction to Task 5

The objective of Task 5 is to define one or more average EU product(s) or a representative product category as "Base Case" (BC) for the whole of the EU-28 and calculate the Environmental Impact Assessment and the Life Cycle Costs for consumer for the base cases in business as usual per unit and as EU totals.

Throughout the rest of the study, most of the environmental Life Cycle Assessment (LCA), Life Cycle Costs (LCC) and scenario analyses will be built on these BCs. The BC is a conscious abstraction of the reality, necessary for practical reasons (budgetary and time constraints). The question whether this abstraction will lead to inadmissible conclusions for certain market segments will be addressed in the impact and sensitivity analysis of Task 7.

Task 5 consists of four subtasks:

- **Subtask 5.1 – Product specific inputs**
  The product specific inputs are compiled by collecting the most appropriate information from Task 1 to 4. Based on these inputs BCs are defined; thus the description of a BC is a synthesis of the previous tasks. The following seven BCs are defined within this preparatory study:
    - Passenger car battery electric vehicle with a high battery capacity (PC BEV HIGH),
    - Passenger car battery electric vehicle with a low battery capacity (PC BEV LOW),
    - Passenger car plug-in hybrid electric vehicle (PC PHEV),
    - Truck battery electric vehicle (Truck BEV),
    - Truck plug-in hybrid electric vehicle (Truck PHEV),
    - Residential storage (Residential ESS),
    - Grid stabilisation (Commercial ESS).
- **Subtask 5.2 – Base Case environmental impact assessment**
  An environmental LCA per BC is done with the Ecodesign EcoReport 2014 tool to calculate the consumed resources and materials and the related emissions for the impact categories in MEErP format for the different life cycle stages for all BCs in a BAU, Business As Usual, situation. The GREET2 Model by UChicago Argonne, LLC[1] and the PEFCR on rechargeable batteries[2] are used for the life cycle inventory datasets of some battery specific materials that are not included in the EcoReport tool, but can be added to the EcoReport manually as "extra materials" (more explanation on this is included in section 5.1.3.1). The Critical Raw Material (CRM) indicator is also presented in this subtask. The CRM indicator calculations are done with the formula of the MEErP method[3] but with updated values to calculate the CRM characterisation factors.
- **Subtask 5.3 – Base Case Life Cycle Costs**
  In addition to environmental impacts, the financial impact for the consumer and society are assessed by means of a separate LCC spreadsheet instead of using the EcoReport LCC tool, in order to include more complex functionalities for the calculation.

[1] https://greet.es.anl.gov/greet.models
[2] http://ec.EURpa.eu/environment/eussd/smgp/pdf/Batteries%20PEFCR%20-%20Life%20Cycle%20Inventory.xlsx
[3] https://ecodesignbatteries.eu/faq

- **Subtask 5.4 – EU totals**
  In the final subtask of Task 5, the data from the LCA and LCC are aggregated to EU-28 level by using the stock and market data from Task 2.

This Task 5 report concludes with a comparison with the Product Environmental Footprint (PEF)[4] pilot on rechargeable batteries (section 5.5), a comparison with other literature sources (section 5.6), and the conclusions (section 5.7).

5.1. Subtask 5.1 – Product-specific inputs

AIM OF SUBTASK 5.1:

This subtask collects the relevant quantitative Base Case (BC) information per BC from Tasks 1 to 4 that is needed for the LCA and LCC.

5.1.1. Selection of Base Cases and Functional Unit

Within the scope of this preparatory study 'High Specific Energy Rechargeable Batteries for Mobile Applications with High Capacity' seven BCs have been defined. An overview of the selected BCs and their technical parameters are presented in Table 1.

The functional unit (FU) is set on the same unit as the one defined within the Product Environmental Footprint Category Rules (PEFCR) on High Specific Energy Rechargeable Batteries for Mobile Applications (version H February 2018) (Recharge 2018).

The **functional unit FU is 1 kWh** (kilowatt-hour) of the total output energy delivered over the service life by the battery system (measured in kWh).

For the LCA and LCC calculations within Task 5, the calculations are done on application level (BC), meaning that the number of batteries needed to deliver the total kWh over the service life required by the application is considered (as described in section 3.3 of the PEFCR). In addition, if a battery system has not reached its end-of-life (EOL) yet while the service lifetime of the application has been fulfilled, then the complete environmental and economic impact of the production and EOL of the not-fully used battery is considered in the calculations and not only the "proportional use" of the impacts of the production and EOL of the battery. This would result in a zero impact allocation to the second life in case a second life would be the case. The complete impact is considered to align the system boundaries of the LCA with the LCC and because second life applications are not considered as BAU yet.

[4] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

Table 1: Complete overview of technical parameters of selected Base Cases (based on Task 3 and 4)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Economic lifetime of application (Tapp) [yr]	13	14	13	14	12	20	20
Kilometres per year [km/yr]	14 000	11 000	7 000	50 000	50 000	n.a.	n.a.
Electricity consumption [kWh/km]	0.20	0.16	0.18	1.20	1.40	n.a.	n.a.
Application service energy (AS) [kWh/Tapp]	43 680	29 568	19 656	940 800	890 400	40 000	120×10^6
Max. calendar lifetime installed battery (no cycling ageing) [yr]	20	20	20	20	20	25	25
Maximum SoC - maximum DoD (Stroke) [%]	80	80	75	80	75	80	80
Average stroke (SoC - DoD) [%]	24	31	73	50	69	60	75
Energy delivered in first cycle (Edc) [kWh/cycle]	64	32	7	24	12	8	8
Number of cycles per year [-]	120	120	120	300	600	250	250
Max. number of cycles for battery system until EOL (no calendar ageing) [-]	1 500	1 500	2 000	2 000	3 000	8 000	10 000
Service life of battery (Tbat) [y]	14.40	13.43	10.67	8.04	5.33	17.02	17.02
Typical capacity of the application [kWh]	80	40	12	360	160	10	30 000
Nominal battery system capacity [kWh]	80	40	12	30	20	10	10
Number of batteries in the application [-]	1	1	1	12	8	1	3 000

Continuation of Table 1: Complete overview of technical parameters of selected Base Cases (based on Task 3 and 4)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Number of battery application systems per Tapp (Ass) [-]	1	2	2	2	3	2	2
Average efficiency of battery system [%]	92	92	92	92	92	92	92
Charger efficiency [%]	85	85	85	92	92	98	98
Brake energy recovery [%]	20	20	20	12	6	n.a.	n.a.
Thermal management efficiency [%]	99	99	99	99	99	99	99
Self-discharge (@STC) [%]	2	2	2	2	2	2	2
Weight of one battery [kg]	609	304	126	256	210	128	128
Volume of one battery [m^3]	0.16	0.08	0.05	0.08	0.08	0.05	0.05

5.1.2. Economic input parameters and product service life

5.1.2.1. Introduction to Life Cycle Costs and Levelized Cost Of Energy

The MEErP methodology is usually based on an analysis of life cycle costs (LCC). An LCC calculation provides a summation of all of the costs incurred for the end-user along the life cycle of the product. This makes it relevant to consumers because this cost can then be related to potential savings. It is used in Task 6 to find the LLCC, Least Life Cycle Cost, for the identified design options.

The Total Cost of Ownership (TCO) or LCC is a concept that aims to estimate the full cost of a system. Therefore, the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) are calculated. CAPEX is used to acquire the battery system and consists mainly of product costs; cost for decommissioning is also a CAPEX. The OPEX is the ongoing cost of running the battery system and consists of costs for replacement services and electricity costs for energy losses.

The purpose of the discount rate in LCC/LCOE calculations is to convert all life cycle costs to their net present value (NPV) taking into account OPEX for energy and other consumables.

The LCC in MEErP studies is to be calculated using the following formula:

$$LCC[€]= \Sigma CAPEX + \Sigma(PWF\ x\ OPEX)$$

where,

LCC is the life cycle costing,

CAPEX is the purchase price (including installation) and decommissioning costs or so-called capital expenditure,

OPEX are the operating expenses per year or so-called operational expenditure,

PWF is the present worth factor with PWF = $1/(1+r)^N$

N is the product life in years,

r is the discount rate which represents the return that could be earned in alternative investments.

The Levelized Cost Of Energy (LCOE) is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital. The LCOE is defined for the purpose of these calculations as:

$$\mathrm{LCOE}[€/\mathrm{kWh}] = \frac{\text{net present value of sum of costs of electricty stored over its lifetime}}{\textit{sum of electrical energy delivered over its life time}}$$

The LCOE calculation of costs per kWh generated aligns with the FU defined in Task 1. In this definition the life cycle environmental impacts of the battery system or component are normalized to 1 kWh of electricity stored.

As a consequence there is a direct relationship between LCOE, LCC and the quantity of FUs (QFU) of a battery system:

LCOE = LCC/QFU [euro/kWh]

Using this approach will allow that comparison in Task 6 for improvement options will be done per in LCC per functional unit or in other words in LCOE.

5.1.2.2. Consumer expenditure data for Base Cases

An overview of the assumed values for CAPEX and OPEX of the seven BCs are shown in the next table.

Table 2: Overview of CAPEX and OPEX assumptions of the Base Cases (based on Task 3)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
CAPEX battery system cost per declared initial capacity [EUR/kWh]	206	206	254	220	212	683	683
OPEX battery replacement [EUR/service]	700	700	700	400	400	100	100
CAPEX decommissioning at EOL [EUR]	1 200	600	180	450	300	150	150

5.1.2.3. Market stock and/or sales data for calculation EU totals

Based on Task 2 the sales and stock data of the year 2018 are presented in Table 3. The number of units per BC are calculated by dividing the total amount of GWh capacity installed by the capacity per battery system or application.

Table 3: Overview of the sales, stock, capacity, and service life of the Base Cases (based on Task 2 and 3)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Sales [GWh]	2.76	5.99	2.58	0.02	0.03	0.95	0.50
[Units of battery systems]	34 552	149 694	214 974	825	1 600	95 105	49 964
[U. of bat. appl. systems]	34 552	149 694	214 974	69	200	95 105	17
Stock [GWh]	6.79	18.89	10.04	0.20	0.16	6.83	2.27
[Units of battery systems]	84 877	472 348	836 283	6 600	8 000	682 811	226 510
[U. of bat. appl. systems]	84 877	472 348	836 283	550	1000	682 811	76
Nominal battery system capacity [kWh]	80	40	12	30	20	10	10
Typical capacity of the application [kWh]	80	40	12	360	160	10	30 000
Service life of application [yr]	13	14	13	14	12	20	20
Service life of battery [yr]	14.40	13.43	10.67	8.04	5.33	17.02	17.02

5.1.2.4. Battery system service life and link to the economic lifetime of the application

Definitions:

An application can require several battery systems over its economic lifetime, in order to explain the relationships and assumptions the following definitions will be used:

- AS = The application service energy which is the energy required by the application per service life [kWh]
- Tapp = The economic lifetime of the application in years [y]
- Edc = The energy delivered in the first cycle [kWh/cycle]
- Ass = The number of battery application systems during Tapp [-]
- Tbat = The lifetime of the battery system in years [y]

Calculation of the application service energy (AS)

For the xEV BCs the AS is calculated by multiplying Tapp with the annual kilometres, the electricity consumption, and the additional battery loading due to regenerative braking. For example for BC1:

- the AS = 13 yr * 14 000 km/y * 0.20 kWh/km * (1+20 %) = 43 680 kWh.

Table 4 gives an overview of the assumed parameters needed to calculate the AS for BC1-B5.

Table 4: Overview of the assumptions to calculate the application service energy of the xEV BCs (BC1-BC5).

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV
Economic lifetime of application (Tapp) [yr]	13	14	13	14	12
Kilometres per year [km/yr]	14 000	11 000	7 000	50 000	50 000
Electricity consumption [kWh/km]	0.20	0.16	0.18	1.20	1.40
Brake energy recovery [%]	20	20	20	12	6
Application service energy (AS) [kWh/Tapp]	43 680	29 568	19 656	940 800	890 400

The AS of the ESS BCs (BC6 and 7) are calculated differently. It is calculated by multiplying Tapp with Edc, the number of cycles per year, and the number of batteries in the application. The number of batteries in the application is determined by dividing the typical capacity of the application by the nominal battery system capacity. E.g. in case of BC7:

- the number of batteries in the ESS application = 30 000 kWh / 10 kWh = 3 000 batteries and
- the AS = 20 yr * 8 kWh/cycle * 250 cycles * 3 000 batteries = 120 000 000 kWh.

The assumptions for calculating the AS of BC6 and BC7 is shown in the table below.

Table 5: Overview of the assumptions to calculate the application service energy of the ESS BCs (BC6-BC7).

	BC6 Resid. ESS	BC7 Comm. ESS
Economic lifetime of application (Tapp) [yr]	20	20
Energy delivered in first cycle (Edc) [kWh/cycle]	8	8
Number of cycles per year [-]	250	250
Typical capacity of the application [kWh]	10	30 000
Nominal battery system capacity [kWh]	10	10
Number of batteries in the application [-]	1	3 000
Application service energy (AS) [kWh/Tapp]	40 000	120 000 000

Calculation of the number of battery application systems for the economic service life of application (Ass)

To calculate the Ass, the service lifetime of the application (Tapp) is divided by the service lifetime of the battery system (Tbat) and rounded up:

- Ass = Int (Tapp / Tbat) + 1

Tbat is calculated by taking the inverse of the inverse of the maximum calendar lifetime of the installed battery plus the inverse of maximum number of cycles for the battery system divided by the multiplication of the number of cycles per year and average stroke. For example the calculation of Tbat of BC1 looks like:

- Tbat = 1 / (20^-1 + (1 500 / (120 * 24 %))^-1) = 14.40

This formula is an early approximation open to a significant margin of error depending on the specific Li-ion battery design.

Table 6: Overview of the assumptions to calculate the number of battery application systems of the BCs

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Max. calendar lifetime installed battery (no cycling ageing) [yr]	20	20	20	20	20	25	25
Max. number of cycles for battery system until EOL (no calendar ageing) [-]	1 500	1 500	2 000	2 000	3 000	8 000	10 000
Number of cycles per year [-]	120	120	120	300	600	250	250
Average stroke (SoC - DoD) [%]	24	31	73	50	69	60	75
Service life of battery (Tbat) [yr]	14.40	13.43	10.67	8.04	5.33	17.02	17.02
Economic lifetime of application (Tapp) [yr]	13	14	13	14	12	20	20
Number of battery application systems per Tapp (Ass) [-]	1	2	2	2	3	2	2
Number of replacement battery application systems during Tapp [-]	-	1 [5]	1	1	2	1	1

The battery at the end of life of Tbat and Tapp still has potential left to be reused in other cars or applications (see section 4.2.4.2 of the Task 4 report for general information on second-life applications). This is relevant to explore for second life improvement options in Task 6.

5.1.2.5. Other economic parameters

Discount rate:

The ‘discount rate’ is set at 4 %, following the MEErP. This will be applied to all costs apart from electricity[6]. For electricity, the applied electricity rates in this study are based on the more

[5] In practice, this replacement will probably not be executed, given the small difference between Tbat and Tapp.

[6] The MEErP methodology (2011) also introduced a so-called escalation rate that corrects the discount rate for electricity, if 4 % escalation rate is used, it will cancel the 4% discount rate (i.e, calculate with 0% discount rate).

up-to-date PRIMES model (energy price data provided by the European Commission) and are already recalculated to the Net Present Value of year 2015 (see Table 7), therefore no discount rate needs to be applied.

Table 7: Decomposition of electricity generation costs and prices (€ per MWh) historical and forecast values (based on PRIMES with data supplied by the EC services) (inflation corrected to reference year 2015)

	Prices reference Year 2015									
	END USER PRICE (in c€/kWh)									
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity										
Average price	12.0	13.9	14.7	15.6	16.1	16.4	16.9	16.8	16.7	16.6
Industry	8.6	9.9	9.8	10.0	10.1	10.2	10.3	10.4	10.3	10.3
Households(HH)	15.9	17.5	19.4	20.7	21.3	21.7	22.1	22.0	21.5	21.3
Services	12.9	15.1	16.0	17.4	18.0	18.3	18.7	18.6	18.4	18.2

Electricity cost:

The energy rates applied in the analysis are based on the PRIMES forecasted end user prices for industry and households. Based on Table 7, the following end user prices for 2025 are taken as a representative average price during the economic lifetime of a battery application:

- Industry: 0.101 EUR per kWh.
- Households: 0.213 EUR per kWh.

5.1.3. Product life cycle information

This section includes the data used to model the following life cycle stages:

- Production phase, i.e. raw materials use and manufacturing,
- Distribution phase,
- Use phase,
- End-of-life phase.

5.1.3.1. Production phase

The EcoReport contains life cycle impact assessment (LCIA) data of 55 common materials, such as certain plastics and metals. However, those materials do not cover all the materials needed to manufacture battery cells properly. The latest version of EcoReport dating from 2014 (original EcoReport was developed in 2011) enables the user to enter LCIA data for other materials as “extra materials”.

The extra materials which have been added for this preparatory study were modelled and calculated in SimaPro version 8.52 with version 3.4 of the ecoinvent database. The source of the life cycle inventory (LCI) data of the different battery chemistries is the 2018 version of the

GREET2 Model by UChicago Argonne, LLC[7]. In addition, the PEFCR on rechargeable batteries[8] was used to determine the LCI data records for most of the other extra materials. GREET2 was used to model the chemistries, as GREET2 contains LCI data of more different chemistries than PEF and therefore it was possible to model all the needed chemistries based on GREET2 instead of using a mix of the two sources. An overview of the data set used for the extra materials is shown in Table 8 and Table 9. The LCIA data of the extra materials are presented in Annex A.

In the calculations of the production phase, the impact of auxiliary materials, and the energy use and related emissions which occur during manufacturing have also been added. The data are taken from the LCI of the PEF pilot. Due to lack of other useable data sources the same data have been used for all seven base cases. Table 10 shows an overview of the added manufacturing processes.

Table 8: Data set extra materials: chemistries (modelling all based on GREET2 model)

Chemistries	LCI data record	Amount (/kg product)	Unit
NCM622	NMC622 precursor (see below for LCI)	0.95	kg
	Lithium carbonate {GLO}| production, from concentrated brine | Cut-off, U	0.38	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	22.90	MJ
NCM622 precursor	Nickel sulfate {GLO}| market for | Cut-off, U	1.01	kg
	Cobalt {GLO}| market for | Cut-off, U (used as worst proxy for proxy Cobalt Sulfate, like PEF)	0.34	kg
	Manganese sulfate {GLO}| market for | Cut-off, U	0.33	kg
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U	0.88	kg
	Ammonia, liquid {RoW}| market for | Cut-off, U	0.12	kg
	Water, deionised, from tap water, at user {RoW}| market for water, deionised, from tap water, at user | Cut-off, U	0.64	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.04	GJ
NCM424	NMC424 precursor (see below for LCI)	0.95	kg
	Lithium carbonate {GLO}| production, from concentrated brine | Cut-off, U	0.38	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	22.90	MJ

[7] https://greet.es.anl.gov/greet.models

[8] http://ec.EURpa.eu/environment/eussd/smgp/pdf/Batteries%20PEFCR%20-%20Life%20Cycle%20Inventory.xlsx

Continuation of Table 8: Data set extra materials: chemistries (modelling all based on GREET2 model)

Chemistries	LCI data record	Amount (/kg product)	Unit
NCM424 precursor	Nickel sulfate {GLO}| market for | Cut-off, U	0.68	kg
	Cobalt {GLO}| market for | Cut-off, U (used as worst proxy for proxy Cobalt Sulfate, like PEF)	0.34	kg
	Manganese sulfate {GLO}| market for | Cut-off, U	0.34	kg
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U	0.90	kg
	Ammonia, liquid {RoW}| market for | Cut-off, U	0.12	kg
	Water, deionised, from tap water, at user {RoW}| market for water, deionised, from tap water, at user | Cut-off, U	0.64	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.04	GJ
NCM111	NMC111 precursor (see below for LCI)	0.95	kg
	Lithium carbonate {GLO}| production, from concentrated brine | Cut-off, U	0.38	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	22.90	MJ
NCM111 precursor	Nickel sulfate {GLO}| market for | Cut-off, U	0.56	kg
	Cobalt {GLO}| market for | Cut-off, U (used as worst proxy for proxy Cobalt Sulfate, like PEF)	0.56	kg
	Manganese sulfate {GLO}| market for | Cut-off, U	0.55	kg
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U	0.89	kg
	Ammonia, liquid {RoW}| market for | Cut-off, U	0.12	kg
	Water, deionised, from tap water, at user {RoW}| market for water, deionised, from tap water, at user | Cut-off, U	0.64	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.04	GJ

Continuation of Table 8: Data set extra materials: chemistries (modelling all based on GREET2 model)

Chemistries	LCI data record	Amount (/kg product)	Unit
NCM532 [9]	NMC532 precursor (see below for LCI)	0.95	kg
	Lithium carbonate {GLO}| production, from concentrated brine | Cut-off, U	0.38	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	22.90	MJ
NCM532 precursor [9]	Nickel sulfate {GLO}| market for | Cut-off, U	0.84	kg
	Cobalt {GLO}| market for | Cut-off, U (used as worst proxy for proxy Cobalt Sulfate, like PEF)	0.34	kg
	Manganese sulfate {GLO}| market for | Cut-off, U	0.49	kg
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U	0.89	kg
	Ammonia, liquid {RoW}| market for | Cut-off, U	0.12	kg
	Water, deionised, from tap water, at user {RoW}| market for water, deionised, from tap water, at user | Cut-off, U	0.64	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.04	GJ
LMO	Lithium carbonate {GLO}| production, from concentrated brine | Cut-off, U	0.20	kg
	Manganese(III) oxide {GLO}| market for | Cut-off, U	0.87	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	0.02	MJ
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.01	GJ
NCA [10]	Lithium hydroxide {GLO}| market for | Cut-off, U	0.25	kg
	Oxygen, liquid {RoW}| market for | Cut-off, U	0.04	kg
	NCA (80/15/5) precursor (see below for LCI)	0.95	kg
	Electricity, medium voltage {CN}| market group for | Cut-off, U	26.18	MJ

[9] NCM532 and its precursor are not such modelled within the GREET2 model. Therefore, the LCI of NCM532 is drafted based upon the modelling of the NCM compositions that are in GREET2 and the chemical equation of NCM532.

[10] In the BOM an amount of NCA (80/15/5) as well as NCA (82/15/3) is included. In the GREET2 model only NCA (80/15/5) is included, therefore the two NCA compositions are assumed as identical and only modelled as NCA (80/15/5).

Continuation of Table 8: Data set extra materials: chemistries (modelling all based on GREET2 model)

Chemistries	LCI data record	Amount (/kg product)	Unit
NCA precursor	Ammonia, liquid {RoW}| market for | Cut-off, U	0.37	kg
	Nickel sulfate {GLO}| market for | Cut-off, U	1.36	kg
	Cobalt {GLO}| market for | Cut-off, U (used as worst proxy for proxy Cobalt Sulfate, like PEF)	0.26	kg
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U	0.88	kg
	Aluminium sulfate, without water, in 4.33% aluminium solution state {GLO}| market for | Cut-off, U	0.09	kg
	Water, deionised, from tap water, at user {RoW}| market for water, deionised, from tap water, at user | Cut-off, U	0.64	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.04	GJ
LFP	Lithium hydroxide {GLO}| market for | Cut-off, U	0.27	kg
	Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}| market for | Cut-off, U	0.37	kg
	Iron sulfate {GLO}| market for | Cut-off, U	0.57	kg
	Heat, district or industrial, natural gas {RoW}| market for heat, district or industrial, natural gas | Cut-off, U	0.03	GJ

Table 9: Data set extra materials: other

Extra material: other	LCI data record	Based on
Carbon	Carbon black {GLO}| market for | Cut-off, U	PEF
PVDF	Polyvinylfluoride {GLO}| market for | Alloc Rec, U (adapted to PVDF, no Polyvinylidene fluoride in ecoinvent database available)	-
Graphite	Carbon black {GLO}| market for | Cut-off, U (as proxy)	PEF
CMC	Carboxymethyl cellulose, powder {GLO}| market for | Cut-off, U	-
LiPF6	Lithium hydroxide {GLO}| market for | Cut-off, U (as proxy)	PEF
LiFSI	Lithium hexafluorophosphate {GLO}| market for | Cut-off, U (as proxy)	-
EC (Ethylene carbonate)	Ethylene carbonate {GLO}| market for | Cut-off, U	PEF
DMC (Dimethyl carbonate)	Dimethyl carbonate {GLO}| market for dimethyl carbonate | Cut-off, U	PEF
EMC (Ethyl methyl carbonate)	Dimethyl carbonate {GLO}| market for dimethyl carbonate | Cut-off, U (as proxy)	PEF

Continuation of Table 9: Data set extra materials: other

Extra material: other	LCI data record	Based on
PC (Propylene carbonate)	Polycarbonate {GLO}| market for | Cut-off, U (as proxy)	PEF
Hydrochloric acid	Hydrochloric acid, without water, in 30% solution state {RER}| market for | Cut-off, U	PEF
n-Methylpyrolidone (NMP)	N-methyl-2-pyrrolidone {GLO}| market for | Cut-off, U	PEF

Table 10: LCI data auxiliary materials and the energy use during manufacturing, based on PEF.

Input manufacturing	**Amount (/ kg battery)**	**Unit**
n-Methylpyrolidone (NMP)	0.143	kg
Hydrochloric acid mix (100%)	0.37	kg
Power electrode	40	MJ
Power cell forming	1.2	MJ
Power battery assembly	0.001	MJ

In addition to the data sets presented above, the following assumptions have been made when composing the EcoReports for the seven BCs:

- For the SBR anode binder (position number 17 in the EcoReport) the standard EcoReport material ABS is used as proxy as SBR.
- For the sandwich materials composed of polyethylene and aluminium oxide coating used for cell separators (pos. nr. 31, 32 and 34) the standard EcoReport material 'aluminium sheet/extrusion' is assumed as worst case proxy.
- For the nickel-plated iron case of the cell packaging (pos. nr. 50) cast iron is chosen as proxy based on the assumption that nickel already is included in position number 48.

The following subsections provides the Bill-of-Materials (BOM) information per selected BC. The BOM information is provided in the EcoReport format and are based on the data presented in Table 3 and 4 of subtask 4.2 (see section 4.2.1. of Task 4 report).

5.1.3.1.1. BOM BC1 – passenger car BEV with a higher battery capacity

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 80 kWh,
- a total of 43 680 kWh delivered over an economical lifetime of 13 years (functional units),
- 1 battery application system with 1 battery system with a service lifetime of 14.40 years, thus meaning no replacement needed,
- with a battery weight of 609 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.014 kg/kWh.

Table 11: BOM BC1 – passenger car BEV with a higher battery capacity (per FU)

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: INPUTS Assessment of Environmental Impact

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

Nr	Product name	Date	Author
	Batteries - BC1 passenger car with higher battery capacity	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	1.09E+00	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	0.00E+00	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	0.00E+00	8-Extra	102-NCM111	
5	Cathode active material: LMO	4.26E-01	8-Extra	104-LMO	
6	Cathode active material: NMC 523	1.55E-01	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	1.01E-01	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	7.90E-01	8-Extra	105-NCA	
9	Cathode active material: LFP	6.01E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	2.01E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	1.63E-01	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	5.69E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	2.00E+00	8-Extra	110-Graphite	
17	Anode binder: SBR	2.85E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	2.85E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	1.21E+00	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	5.23E-02	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	2.15E-01	8-Extra	112-LiPF6	
24	Fluid: LiFSI	1.99E-04	8-Extra	113-LiFSI	
25	Solvent: EC	5.59E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	5.59E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	2.50E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	1.18E-02	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	5.17E-02	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	1.69E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	5.04E-02	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	5.15E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	1.99E+00	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 11: BOM BC1 – passenger car BEV with a higher battery capacity (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	0.00E+00	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	9.97E-03	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	1.11E-02	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	3.22E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	2.84E-02	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	2.71E-01	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	5.30E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	2.85E-01	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	3.63E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	1.95E-01	1-BlkPlastics	4 -PP	
55	Steel	1.32E-01	3-Ferro	22 -St sheet galv.	
56	Electronics	6.97E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	2.23E-01	3-Ferro	22 -St sheet galv.	
60	Copper	2.79E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	5.57E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	5.02E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	5.57E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	1.17E+00	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	8.36E-02	1-BlkPlastics	4 -PP	
70	Steel	3.34E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	8.36E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.2. BOM BC2 – passenger car BEV with a lower battery capacity

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 40 kWh,
- a total of 29 568 kWh delivered over an economical lifetime of 14 years (functional units),
- 2 battery application systems with 1 battery systems with a service lifetime of 13.43 years, thus meaning 1 replacement needed[11],
- with a battery weight of 304 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.021 kg/kWh.

[11] In practice, this replacement will probably not be executed, given the small difference between the service lifetime of the application and the lifetime of the battery system.

Table 12: BOM BC2 – passenger car BEV with a lower battery capacity (per FU)

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS | EcoReport 2014: INPUTS Environmental Impact | Assessment of

Nr	Product name	Date	Author
	Batteries - BC2: passenger car with lower battery capacity	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	1.61E+00	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	0.00E+00	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	0.00E+00	8-Extra	102-NCM111	
5	Cathode active material: LMO	6.30E-01	8-Extra	104-LMO	
6	Cathode active material: NMC 523	2.30E-01	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	1.49E-01	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	1.17E+00	8-Extra	105-NCA	
9	Cathode active material: LFP	8.88E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	2.97E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	2.41E-01	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	8.40E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	2.95E+00	8-Extra	110-Graphite	
17	Anode binder: SBR	4.22E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	4.22E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	1.79E+00	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	7.72E-02	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	3.17E-01	8-Extra	112-LiPF6	
24	Fluid: LiFSI	2.94E-04	8-Extra	113-LiFSI	
25	Solvent: EC	8.25E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	8.25E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	3.69E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	1.75E-02	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	7.64E-02	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	2.50E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	7.44E-02	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	7.61E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	2.94E+00	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 12: BOM BC2 – passenger car BEV with a lower battery capacity (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	0.00E+00	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	1.47E-02	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	1.65E-02	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	4.75E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	4.19E-02	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	4.00E-01	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	7.82E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	4.20E-01	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	5.36E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	2.88E-01	1-BlkPlastics	4 -PP	
55	Steel	1.94E-01	3-Ferro	22 -St sheet galv.	
56	Electronics	1.03E-02	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	3.29E-01	3-Ferro	22 -St sheet galv.	
60	Copper	4.12E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	8.23E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	7.41E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	8.23E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	1.73E+00	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	1.23E-01	1-BlkPlastics	4 -PP	
70	Steel	4.94E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	1.23E-01	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.3. BOM BC3 – passenger car PHEV

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 12 kWh,
- a total of 19 656 kWh delivered over an economical lifetime of 13 years (functional units),
- 2 battery application system with 1 battery system with a service lifetime of 10.67 years, thus meaning 1 replacement needed,
- with a battery weight of 126 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.013 kg/kWh.

Table 13: BOM BC3 – passenger car PHEV (per FU)

Version 3.06 VHK for European Commission 2011, modified by IZM for european commission 2014				Document subject to a legal notice (see below)
ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS		EcoReport 2014: INPUTS Environmental Impact		Assessment of

Nr	Product name	Date	Author
	Batteries - BC3: passenger car PHEV	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	0.00E+00	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	6.13E-01	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	2.04E-01	8-Extra	102-NCM111	
5	Cathode active material: LMO	2.04E-01	8-Extra	104-LMO	
6	Cathode active material: NMC 523	0.00E+00	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	0.00E+00	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	1.76E-01	8-Extra	105-NCA	
9	Cathode active material: LFP	1.34E+00	8-Extra	106-LFP	
10	Cathode conductor: carbon	2.47E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	1.13E-01	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	4.47E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	1.62E+00	8-Extra	110-Graphite	
17	Anode binder: SBR	4.96E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	2.71E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	9.25E-01	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	1.91E-01	8-Extra	112-LiPF6	
24	Fluid: LiFSI	0.00E+00	8-Extra	113-LiFSI	
25	Solvent: EC	4.77E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	4.77E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	3.43E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	9.15E-02	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	2.05E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	1.12E-02	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	4.74E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	1.83E+00	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 13: BOM BC3 – passenger car PHEV (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	2.54E-02	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	8.14E-02	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	9.77E-02	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	1.43E-02	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	4.29E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	1.91E-02	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	1.15E-01	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	7.63E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	6.32E-02	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	3.88E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	1.20E-01	1-BlkPlastics	4 -PP	
55	Steel	1.26E-01	3-Ferro	22 -St sheet galv.	
56	Electronics	6.41E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	2.56E-01	3-Ferro	22 -St sheet galv.	
60	Copper	3.21E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	6.41E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	5.77E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	6.41E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	1.35E+00	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	9.62E-02	1-BlkPlastics	4 -PP	
70	Steel	3.85E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	9.62E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.4. BOM BC4 – truck BEV

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 30 kWh,
- a total of 940 800 kWh delivered over an economical lifetime of 14 years (functional units),
- 2 battery application system with 12 battery systems with a service lifetime of 8.04 years, thus meaning 1 replacement needed,
- with a battery weight of 256 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.007 kg/kWh.

Table 14: BOM BC4 – truck BEV (per FU)

Version 3.06 VHK for European Commission 2011,
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Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS
Environmental Impact

Assessment of

Nr	Product name	Date	Author
	Batteries - BC4: truck BEV	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	4.56E-01	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	0.00E+00	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	0.00E+00	8-Extra	102-NCM111	
5	Cathode active material: LMO	0.00E+00	8-Extra	104-LMO	
6	Cathode active material: NMC 523	0.00E+00	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	0.00E+00	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	2.20E-01	8-Extra	105-NCA	
9	Cathode active material: LFP	6.70E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	1.29E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	7.50E-02	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	2.80E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	9.30E-01	8-Extra	110-Graphite	
17	Anode binder: SBR	1.51E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	1.51E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	5.87E-01	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	1.07E-01	8-Extra	112-LiPF6	
24	Fluid: LiFSI	8.32E-05	8-Extra	113-LiFSI	
25	Solvent: EC	2.77E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	2.77E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	1.35E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	4.95E-03	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	2.16E-02	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	1.03E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	1.40E-02	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	2.41E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	9.33E-01	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 14: BOM BC4 – truck BEV (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	0.00E+00	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	4.16E-03	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	7.17E-03	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	2.15E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	9.57E-03	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	7.27E-02	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	3.83E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	7.93E-02	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	1.86E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	7.43E-02	1-BlkPlastics	4 -PP	
55	Steel	6.31E-02	3-Ferro	22 -St sheet galv.	
56	Electronics	3.26E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	1.04E-01	3-Ferro	22 -St sheet galv.	
60	Copper	1.30E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	2.61E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	2.35E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	2.61E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	5.48E-01	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	3.91E-02	1-BlkPlastics	4 -PP	
70	Steel	1.57E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	3.91E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.5. BOM BC5 – truck PHEV

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 20 kWh,
- a total of 890 400 kWh delivered over an economical lifetime of 12 years (functional units),
- 3 battery application system with 8 battery system with a service lifetime of 5.33 years, thus meaning 2 replacements needed,
- with a battery weight of 210 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.006 kg/kWh.

Table 15: BOM BC5 – truck PHEV (per FU)

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS

Environmental Impact

Assessment of

Nr	Product name	Date	Author
	Batteries - BC5: Truck PHEV	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	0.00E+00	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	2.70E-01	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	9.02E-02	8-Extra	102-NCM111	
5	Cathode active material: LMO	9.02E-02	8-Extra	104-LMO	
6	Cathode active material: NMC 523	0.00E+00	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	0.00E+00	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	7.75E-02	8-Extra	105-NCA	
9	Cathode active material: LFP	5.90E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	1.09E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	5.01E-02	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	1.98E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	7.14E-01	8-Extra	110-Graphite	
17	Anode binder: SBR	2.19E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	1.20E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	4.08E-01	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	8.42E-02	8-Extra	112-LiPF6	
24	Fluid: LiFSI	0.00E+00	8-Extra	113-LiFSI	
25	Solvent: EC	2.11E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	2.11E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	1.51E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	4.04E-02	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	9.06E-02	1-BlkPlastics	4 -PP	
34	PE-Al2O3	4.94E-03	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	2.09E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	8.10E-01	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 15: BOM BC5 – truck PHEV (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	1.12E-02	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	3.59E-02	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	4.31E-02	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	6.32E-03	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	1.90E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	8.42E-03	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	5.09E-02	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	3.37E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	2.79E-02	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	1.71E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	5.31E-02	1-BlkPlastics	4 -PP	
55	Steel	5.58E-02	3-Ferro	22 -St sheet galv.	
56	Electronics	2.83E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	1.13E-01	3-Ferro	22 -St sheet galv.	
60	Copper	1.42E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	2.83E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	2.55E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	2.83E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	5.94E-01	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	4.25E-02	1-BlkPlastics	4 -PP	
70	Steel	1.70E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	4.25E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.6. BOM BC6 – residential ESS

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 10 kWh,
- a total of 40 000 kWh delivered over an economical lifetime of 20 years (functional units),
- 2 battery application system with 1 battery system with a service lifetime of 17.02 years, thus meaning 1 replacement needed,
- with a battery weight of 128 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.006 kg/kWh.

Table 16: BOM BC6 – residential ESS (per FU)

Version 3.06 VHK for European Commission 2011,
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Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS

Assessment of Environmental Impact

Nr	Product name	Date	Author
	Batteries - BC6: residential ESS	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	7.44E-02	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	0.00E+00	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	0.00E+00	8-Extra	102-NCM111	
5	Cathode active material: LMO	0.00E+00	8-Extra	104-LMO	
6	Cathode active material: NMC 523	0.00E+00	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	0.00E+00	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	7.19E-02	8-Extra	105-NCA	
9	Cathode active material: LFP	8.75E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	1.31E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	4.90E-02	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	2.11E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	7.24E-01	8-Extra	110-Graphite	
17	Anode binder: SBR	1.73E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	1.73E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	4.55E-01	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	9.58E-02	8-Extra	112-LiPF6	
24	Fluid: LiFSI	1.36E-05	8-Extra	113-LiFSI	
25	Solvent: EC	2.41E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	2.41E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	1.63E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	8.08E-04	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	3.53E-03	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	1.34E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	4.59E-03	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	2.37E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	9.15E-01	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 16: BOM BC6 – residential ESS (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	0.00E+00	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	6.80E-04	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	9.38E-03	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	2.81E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	1.25E-02	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	7.06E-02	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	5.00E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	2.59E-02	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	1.99E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	5.47E-02	1-BlkPlastics	4 -PP	
55	Steel	6.31E-02	3-Ferro	22 -St sheet galv.	
56	Electronics	3.20E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	1.28E-01	3-Ferro	22 -St sheet galv.	
60	Copper	1.60E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	3.20E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	2.88E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	3.20E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	2.56E-01	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	1.92E-01	1-BlkPlastics	4 -PP	
70	Steel	7.67E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	6.40E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
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5.1.3.1.7. BOM BC7 – commercial ESS

The calculation of the weight of the battery components is based on:

- a nominal battery energy or battery capacity of 10 kWh,
- a total of 120 000 000 kWh delivered over an economical lifetime of 20 years (functional units),
- 2 battery application system with 3 000 battery system with a service lifetime of 17.02 years, thus meaning 1 replacement needed,
- with a battery weight of 128 kg,
- resulting in a conversion to 1 kWh of functional unit of 0.006 kg/kWh.

Table 17: BOM BC7 – commercial ESS (per FU)

Version 3.06 VHK for European Commission 2011,
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ECO-DESIGN OF ENERGY RELATED/USING PRODUCTS

EcoReport 2014: INPUTS
Environmental Impact

Assessment of

Nr	Product name	Date	Author
	Batteries - BC7: commercial ESS	15/07/2019	vito

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	**Cell cathode**				
2	Cathode active material: NCM 622	7.44E-02	8-Extra	100-NCM622	
3	Cathode active material: NCM 424	0.00E+00	8-Extra	101-NCM424	
4	Cathode active material: NCM 111	0.00E+00	8-Extra	102-NCM111	
5	Cathode active material: LMO	0.00E+00	8-Extra	104-LMO	
6	Cathode active material: NMC 523	0.00E+00	8-Extra	103-NCM532	
7	Cathode active material: NCA (80/15/5)	0.00E+00	8-Extra	105-NCA	
8	Cathode active material: NCA (82/15/3)	7.19E-02	8-Extra	105-NCA	
9	Cathode active material: LFP	8.75E-01	8-Extra	106-LFP	
10	Cathode conductor: carbon	1.31E-01	8-Extra	107-Carbon	
11	Cathode binder: PVDF	4.90E-02	8-Extra	108-PVDF	
12	Cathode additives: ZrO2	0.00E+00	8-Extra	109-ZrO2	
13	Cathode collector: aluminium foil	2.11E-01	4-Non-ferro	27 -Al sheet/extrusion	
14					
15	**Cell anode**				
16	Anode active material: graphite	7.24E-01	8-Extra	110-Graphite	
17	Anode binder: SBR	1.73E-02	1-BlkPlastics	11 -ABS	
18	Anode binder: CMC	1.73E-02	8-Extra	111-CMC	
19	Anode collector: copper foil	4.55E-01	4-Non-ferro	30 -Cu wire	
20	Anode heatresistnt layer: aluminium foil	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
21					
22	**Cell electrolyte**				
23	Fluid: LiPF6	9.58E-02	8-Extra	112-LiPF6	
24	Fluid: LiFSI	1.36E-05	8-Extra	113-LiFSI	
25	Solvent: EC	2.41E-01	8-Extra	114-EC (Ethylene carbonate)	
26	Solvent: DMC	2.41E-01	8-Extra	115-DMC (Dimethyl carbonate)	
27	Solvent: EMC	1.63E-01	8-Extra	116-EMC (Ethyl methyl carbonate)	
28	Solvent: PC	0.00E+00	8-Extra	117-PC (Propylene carbonate)	
29					
30	**Cell separator**				
31	PE 10 micron+AL2O3 6 micron coating	8.08E-04	4-Non-ferro	27 -Al sheet/extrusion	
32	PP 15 micron + AL2O3 6 micron coating	3.53E-03	4-Non-ferro	27 -Al sheet/extrusion	
33	PP/PE/PP	1.34E-01	1-BlkPlastics	4 -PP	
34	PE-Al2O3	4.59E-03	4-Non-ferro	27 -Al sheet/extrusion	
35					
36	**Auxilary materials**				
37	Hydrochloric acid mix (100%)	2.37E+00	8-Extra	118-Hydrochloric acid	
38	n-Methylpyrolidone (NMP)	9.15E-01	8-Extra	119-n-Methylpyrolidone (NMP)	
39					
40					

Continuation of Table 17: BOM BC7 – commercial ESS (per FU)

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
41	**Cell packaging**				
42	Tab with film: Al Tab	0.00E+00	4-Non-ferro	27 -Al sheet/extrusion	
43	Tab with film: Ni Tab	0.00E+00	5-Coating	41 -Cu/Ni/Cr plating	
44	Exterior covering: PET/Ny/Al/PP/ Laminate	6.80E-04	1-BlkPlastics	10 -PET	
45	Collector parts: Al leads	9.38E-03	4-Non-ferro	27 -Al sheet/extrusion	
46	Collector parts: Cu leads	2.81E-02	4-Non-ferro	30 -Cu wire	
47	Collector parts: Plastic fasteners/cover	1.25E-02	1-BlkPlastics	2 -HDPE	
48	Cover: Aluminum	7.06E-02	4-Non-ferro	27 -Al sheet/extrusion	
49	Case: Aluminium	5.00E-01	4-Non-ferro	27 -Al sheet/extrusion	
50	Case: Ni plated Iron	2.59E-02	3-Ferro	24 -Cast iron	
51					
52	**Module**				
53	Al	1.99E-01	4-Non-ferro	27 -Al sheet/extrusion	
54	PP/PE	5.47E-02	1-BlkPlastics	4 -PP	
55	Steel	6.31E-02	3-Ferro	22 -St sheet galv.	
56	Electronics	3.20E-03	6-Electronics	98 -controller board	
57					
58	**System - BMS**				
59	Steel	1.28E-01	3-Ferro	22 -St sheet galv.	
60	Copper	1.60E-01	4-Non-ferro	30 -Cu wire	
61	Printed circuit board	3.20E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
62					
63	**System - thermal management**				
64	Al	2.88E-01	4-Non-ferro	27 -Al sheet/extrusion	
65	Steel	3.20E-02	3-Ferro	22 -St sheet galv.	
66					
67	**System packaging**				
68	Al	2.56E-01	4-Non-ferro	27 -Al sheet/extrusion	
69	PP/PE	1.92E-01	1-BlkPlastics	4 -PP	
70	Steel	7.67E-01	3-Ferro	22 -St sheet galv.	
71	WEEE	6.40E-02	6-Electronics	52 -PWB 6 lay 2 kg/m2	
72					
73					
74					
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80					
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87					

5.1.3.1.8. Additional material loss during production phase

The EcoReport tool contains fixed impacts on weight basis for manufacturing of components. These data are used in the study. The only variable that can be edited in this section is the percentage of sheet metal scrap. The default value given by the EcoReport tool is 25 %. This value is reduced to 10 %, which is a recommended value for folded sheets mentioned in the MEErP methodology report.

5.1.3.2. Distribution phase

For the distribution phase the Ecoreport tool requires the volume of the final packaged product to be entered as an input. Based on this volume, the impact of transport of the product to the site of installation is calculated. In the distribution phase the final assembly per m^3 packaged final product is also taken into account in the EcoReport tool. Due to lack of information on the transportation packaging of a battery system, 10 % is added to the battery system volume to model the volume of a packaged battery. The volume of one battery of each BC is shown in the table below. To calculate the volume of a battery system the volume of one battery is multiplied with the total number of batteries needed during Tapp.

Table 18: Overview of the volume assumptions of the Base Cases (based on Task 4)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Volume of one battery [m^3]	0.16	0.08	0.05	0.08	0.08	0.05	0.05
Number of batteries in the application [-]	1	1	1	12	8	1	3 000
Number of battery application systems per Tapp (Ass) [-]	1	2	2	2	3	2	2
Total packed product volume [m^3]	0.18	0.18	0.11	2.02	2.19	0.10	298.93
Total packed product volume [m^3/FU]	4.11×10^{-6}	6.07×10^{-6}	5.60×10^{-6}	2.15×10^{-6}	2.46×10^{-6}	2.49×10^{-6}	2.49×10^{-6}

The distribution phase also includes space heating and lighting of offices, executive travels ([row 62] in the EcoReport calculation sheet) per product. As in this preparatory study the FU is not 1 product but 1 kWh delivered energy by the product, the project team changed the calculations for each BC by dividing the calculated impact for [row 62] by the total amount of kWh delivered energy (AS) and multiplying it with the total number of products/batteries in the application including replacements.

In addition to the packed volume, replies to the EcoReport key questions regarding the product type and installation were given as follows for all BCs:

- 'Is it an ICT or consumer electronic product less than 15 kg?' - No.
- 'Is it an installed appliance?' - Yes.

5.1.3.3. Use phase

The following aspects are taken into account to model direct and indirect losses during the use phase.

Table 19: Overview of the use phase assumptions of the Base Cases (based on Task 3 and 4)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Application service energy (AS) [kWh/Tapp]	43 680	29 568	19 656	940 800	890 400	40 000	120 x 10^6
Average efficiency of battery system [%]	92	92	92	92	92	92	92
Charger efficiency [%]	85	85	85	92	92	98	98
Brake energy recovery [%]	20	20	20	12	6	n.a.	n.a.
Thermal management efficiency [%]	99	99	99	99	99	99	99
Self-discharge (@STC) [%]	2	2	2	2	2	2	2

The parameters in Table 19 are used as follow to calculate the direct and indirect losses:

- **Direct losses due to average energy efficiency of battery system** = AS / average efficiency of battery system – AS; e.g. for BC1 the direct losses due to the energy efficiency of the battery system = 43 680 kWh / 92 % - 43 680 kWh = 3 798 kWh.
- **Indirect losses due to the battery charger** = (1 – charger efficiency) * (AS / (1 + brake energy recovery)); for example for BC1 these indirect losses = (1 – 85 %) * (43 680 kWh / (1 + 20 %)) = 5 460 kWh.
- **Indirect losses due to thermal management efficiency** = (1 – thermal management efficiency) * AS; in case of BC1, the indirect losses due to thermal management = (1 – 99 %) * 43 680 kWh = 436.8 kWh
- **Indirect losses due to self-discharge (@STC)** = self-discharge * AS; for BC1 the amount indirectly lost due to self-discharge = 2 % * 43 680 = 873.6 kWh.

The next table gives an overview of the calculated losses during the use stage per BC.

Table 20: Overview of the direct and indirect losses during the use phase per Base Case per Tapp and per FU

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Direct losses due to average efficiency of battery system [kWh/Tapp]	3 798	2 571	1 709	81 809	77 426	3 478	1.04×10^{7}
Indirect losses due to charger efficiency [kWh/Tapp]	5 460	3 696	2 457	67 200	67 200	800	2.40×10^{6}
Indirect losses due to thermal management efficiency [kWh/Tapp]	437	296	197	9 408	8 904	400	1.20×10^{6}
Indirect losses due to self-discharge (@STC) [kWh/Tapp]	874	591	393	18 816	17 808	800	2.40×10^{6}
Total direct and indirect losses [kWh/Tapp]	10 589	7 154	4 756	177 233	171 338	5 478	1.64×10^{7}
Direct losses due to average efficiency of battery system [kWh/FU]	0.087	0.087	0.087	0.087	0.087	0.087	0.087
Indirect losses due to charger efficiency [kWh/FU]	0.125	0.125	0.125	0.071	0.075	0.020	0.020
Indirect losses due to thermal management efficiency [kWh/FU]	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Indirect losses due to self-discharge (@STC) [kWh/FU]	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Total direct and indirect losses [kWh/FU]	0.242	0.242	0.242	0.188	0.192	0.137	0.137

The EcoReport tool considers by default the use of spare parts during the use stage, which corresponds with 1 % of the material considered for the production. As it is unlikely that spare parts will be used for this product in the BAU situation, the amount of spare parts in the use stage is set to zero.

5.1.3.4. End-of-Life phase

For the common materials that are available in the EcoReport tool the default EOL values from the MEErP EcoReport tool have been used. They are provided in Table 21. In the EcoReport tool, EOL scenarios are assigned to material categories. It is not possible to assign EOL scenarios to components.

Table 21: Default end-of-life scenarios from the EcoReport tool

Pos nr	DISPOSAL & RECYCLING Description	1	2	3	4	5	6	7a	7b	7c	8	9
	Per fraction (post-consumer)	Bulk Plastics	TecPlastics	Ferro	Non-ferro	Coating	Electronics	Misc., excluding refrigant & Hg	refrigerant	Hg (mercury), **in mg/unit**	Extra	Auxiliaries
263	EoL mass fraction to re-use, in %						1%					5%
264	EoL mass fraction to (materials) recycling, in %	29%	29%		94%		50%	64%	30%	39%	60%	30%
265	EoL mass fraction to (heat) recovery, in %	15%	15%		0%		0%	1%	0%	0%	0%	10%
266	EoL mass fraction to non-recov. incineration, in %	22%	22%		0%		30%	5%	5%	5%	10%	10%
267	EoL mass fraction to landfill/missing/fugitive, in %	33%	33%		5%		19%	29%	64%	55%	29%	45%
268	TOTAL	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
269	EoL recyclability****, (click& select: 'best', '>avg', 'avg' (basecase); '< avg'.; 'worst')	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**
		0%	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*

For this product group many materials were not available in the EcoReport tool (as explained in section 5.1.3.1 regarding the modelling of extra materials). The following table gives an overview of the different material fractions in % of the total mass per BC.

Table 22: Overview of the material fractions of the Base Cases [% of the total mass] (calculated by the EcoReport tool)

Material category	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
1 - Bulk Plastics	3.70	3.70	4.60	3.80	4.60	6.40	6.40
2 - Tec Plastics	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - Ferro	7.40	7.40	7.00	6.60	7.00	15.90	15.90
4 - Non-ferro	36.60	36.60	39.50	38.20	39.50	34.20	34.20
5 - Coating	0.00	0.00	0.60	0.00	0.60	0.00	0.00
6 - Electronics	1.00	1.00	1.30	1.10	1.30	1.60	1.60
7a - Misc., excl. refrigerant & Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Continuation of Table 22: Overview of the material fractions of the Base Cases [% of the total mass] (calculated by the EcoReport tool)

Material category	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
7b - refrigerant	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 - Extra	51.20	51.20	47.00	50.40	47.00	42.00	42.00
9 - Auxiliaries	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The extra materials form the biggest fraction of the total mass. Because they form the biggest fraction and the extra materials are very specific for this product group, the EOL scenario for the extra materials have been changed as follows:

- The default recycling rate of 60 % for extra materials has been lowered to an amount that would result in a total mass fraction that goes to recycling of at least 50 %, so it corresponds with the minimum recycling efficiency set in the Batteries Directive 2006/66/EC.
- A minimal recycling rate of 4 % for extra materials was applied, which corresponds with the fraction of cobalt and nickel that is recycled in a BAU situation based on a recycling rate of 16 % for cobalt as well as nickel and a recycling rate of 0 % for manganese, lithium and graphite (see section 4.2.4.3. in Task 4 on recycling); i.e. 4 % = 16 % * amount of Co and Ni / total amount of Co, Ni, Mn, Li and graphite.
- The default assumption that 1 % of the extra materials goes to reuse and 0 % to heat recovery is kept.
- The remaining EOL mass fraction is divided over incineration and landfill in the same ratio as the default MEErP EOL scenario for extra materials, which is 10 % going to incineration and 29 % to landfill. Thus ¼ of the remaining EOL mass fraction goes to incineration and ¾ to landfill.

Based on the above, Table 23 presents the EOL scenarios that has been applied to the extra materials in each base case and the total fraction that is being recycled.

Table 23: Overview of the EOL scenario of the extra materials and the total mass fraction that goes to recycling per base case

EOL mass fraction to	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Reuse [%]	1	1	1	1	1	1	1
Heat recovery [%]	0	0	0	0	0	0	0
Recycling [%]	14	14	9	13	9	4	4
Incineration [%]	21	21	23	22	23	24	24
Landfill(/missing/fugitive) [%]	64	64	68	65	68	71	71
Total mass fraction that goes to recycling [%]	50.2	50.2	50.5	50.2	50.5	51.4	51.4

The benefits of recycling are in the MEErP EcoReport tool calculated as a percentage of the impacts from production. For the material category ‘Extra’ (and all other categories), MEErP assumes that the benefits of recycling are 40 % of the impacts from the production. In other words, if the impact of the production of the extra materials equals 1 kg CO_2 eq in the impact category global warming, than the benefits attributed to the recycling of the same amount of extra materials in the impact category global warming are: 1*recycling rate*0.4 kg CO_2 eq.

After the extra materials, the second biggest material fraction is the non-ferro metals. For ferro and non-ferro metals the default assumptions are 94 % recycling, 1 % reuse, and 5 % landfilled/missing/fugitive at EOL.

5.2. Subtask 5.2 – Base Case environmental impact assessment

AIM OF SUBTASK 5.2:

The environmental Life Cycle Assessment (LCA) per BC are determined with the EcoReport 2014 tool in MEErP format for the life cycle stages:

- Raw materials use and manufacturing,
- Distribution,
- Use phase,
- End-of-Life (EOL).

The following subsections give the LCA results per BC. The last subsection of this subtask presents the Critical Raw Material (CRM) indicators for the BCs.

Based on the LCA results of all BCs, one can conclude that **the production phase has the biggest contribution** on the total life cycle impact in all impact categories. When looking into the production phase in more detail for the xEV BCs, the following points are notable:

- The cathode active material gives the biggest contribution across the different impact categories considered in the MEErP. This is more perceptible for the BEV BCs (1, 2 and 4) than the PHEV and ESS BCs.
- The contribution of the auxiliary materials in the impact categories water (process and cooling) and eutrophication is high, which caused by the use of n-Methylpyrolidone (NMP).
- The battery application system packaging gives a high contribution in hazardous waste due to the amount of Waste Electrical and Electronic Equipment (WEEE).

5.2.1. EcoReport LCA results BC1 – passenger car BEV with a higher battery capacity

Table 24 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a battery electric vehicle passenger car with a higher battery capacity. Figure 1 is a graphical presentation of the LCA results of BC1.

Table 24: EcoReport LCA results per FU of for BC1 PC BEV HIGH

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EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

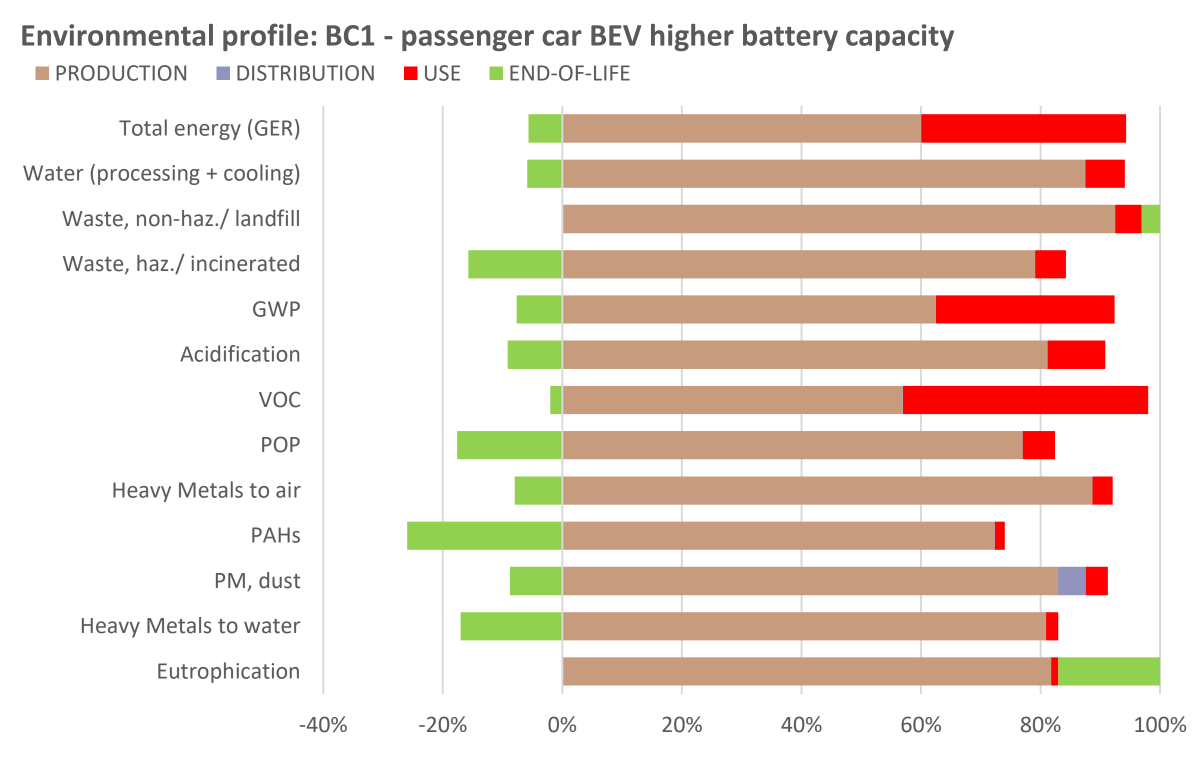
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC1 passenger car with higher battery capacity

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC1 passenger car with higher battery capacity	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.51**		**0.00**	0.28	0.23	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**1.03**		**0.00**	0.05	0.98	0.00	**0.00**
4	Non-ferro	g			**5.10**		**0.00**	0.26	4.85	0.00	**0.00**
5	Coating	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
6	Electronics	g			**0.15**		**0.00**	0.07	0.07	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**7.14**		**0.00**	6.07	1.07	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**13.93**		**0.00**	6.73	7.20	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	2.31	1.55	**3.85**	**0.01**	**2.20**	0.08	-0.45		**5.69**
12	of which, electricity (in primary MJ)	MJ	0.50	1.49	1.99	0.00	2.18	0.00	-0.04		4.13
13	Water (process)	ltr	1.34	0.00	**1.34**	**0.00**	**0.01**	0.00	-0.09		**1.26**
14	Water (cooling)	ltr	0.04	0.09	0.13	0.00	0.10	0.00	-0.01		0.22
15	Waste, non-haz./ landfill	g	28.35	1.11	**29.45**	**0.00**	**1.41**	3.69	-2.71		**31.85**
16	Waste, hazardous/ incinerated	g	0.60	0.02	**0.62**	**0.00**	**0.04**	0.00	-0.12		**0.54**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.13	0.07	**0.20**	**0.00**	**0.09**	0.00	-0.02		**0.27**
18	Acidification, emissions	g SO2 eq.	3.46	0.30	**3.76**	**0.00**	**0.45**	0.02	-0.45		**3.78**
19	Volatile Organic Compounds (VOC)	g	0.04	0.03	**0.07**	**0.00**	**0.05**	0.00	0.00		**0.11**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.07	0.01	**0.08**	**0.00**	**0.01**	0.00	-0.02		**0.07**
21	Heavy Metals	mg Ni eq.	0.76	0.03	**0.79**	**0.00**	**0.03**	0.01	-0.08		**0.75**
22	PAHs	mg Ni eq.	0.38	0.00	**0.38**	**0.00**	**0.01**	0.00	-0.14		**0.25**
23	Particulate Matter (PM, dust)	g	0.24	0.01	**0.25**	**0.01**	**0.01**	0.01	-0.04		**0.25**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.62	0.01	**0.62**	**0.00**	**0.02**	0.00	-0.13		**0.51**
25	Eutrophication	g PO4	0.09	0.00	**0.10**	**0.00**	**0.00**	0.03	-0.01		**0.12**

Figure 1: Relative contribution of the life cycle stages per FU of BC1 PC BEV HIGH based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC1 per impact category.

Table 25: Results for raw materials used in the production phase per FU of BC1 PC BEV HIGH based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X <10%

Materials	weight	GER	water (p + c)	haz. waste	non-haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	23%	27%	37%	0%	71%	36%	75%	61%	27%	70%	4%	48%	47%	56%
Cathode, other materials	7%	7%	2%	0%	1%	7%	2%	2%	5%	1%	15%	6%	3%	2%
Cell anode	24%	14%	1%	0%	1%	9%	11%	8%	7%	10%	3%	4%	19%	8%
Cell electrolyte	11%	4%	3%	0%	10%	3%	1%	6%	1%	3%	0%	2%	0%	3%
Cell separator	2%	1%	1%	0%	0%	1%	0%	0%	1%	0%	3%	1%	1%	0%
Auxillary materials		16%	50%	0%	7%	14%	3%	22%	10%	11%	2%	12%	1%	31%
Cell packaging	8%	7%	0%	0%	1%	7%	2%	0%	8%	1%	21%	8%	5%	0%
Module	5%	5%	1%	0%	1%	4%	1%	0%	7%	1%	9%	5%	2%	0%
System - BMS	4%	3%	2%	40%	2%	3%	3%	0%	9%	2%	0%	1%	7%	0%
System - thermal man.	4%	4%	0%	0%	1%	4%	1%	0%	5%	0%	13%	4%	3%	0%
System packaging	12%	12%	3%	60%	4%	12%	3%	0%	20%	1%	30%	9%	11%	0%

5.2.2. EcoReport LCA results BC2 – passenger car BEV with a lower battery capacity

Table 26 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a battery electric vehicle passenger car with a lower battery capacity. Figure 2 is a graphical presentation of the LCA results of BC2.

Table 26: EcoReport LCA results per FU of for BC2 PC BEV LOW

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EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

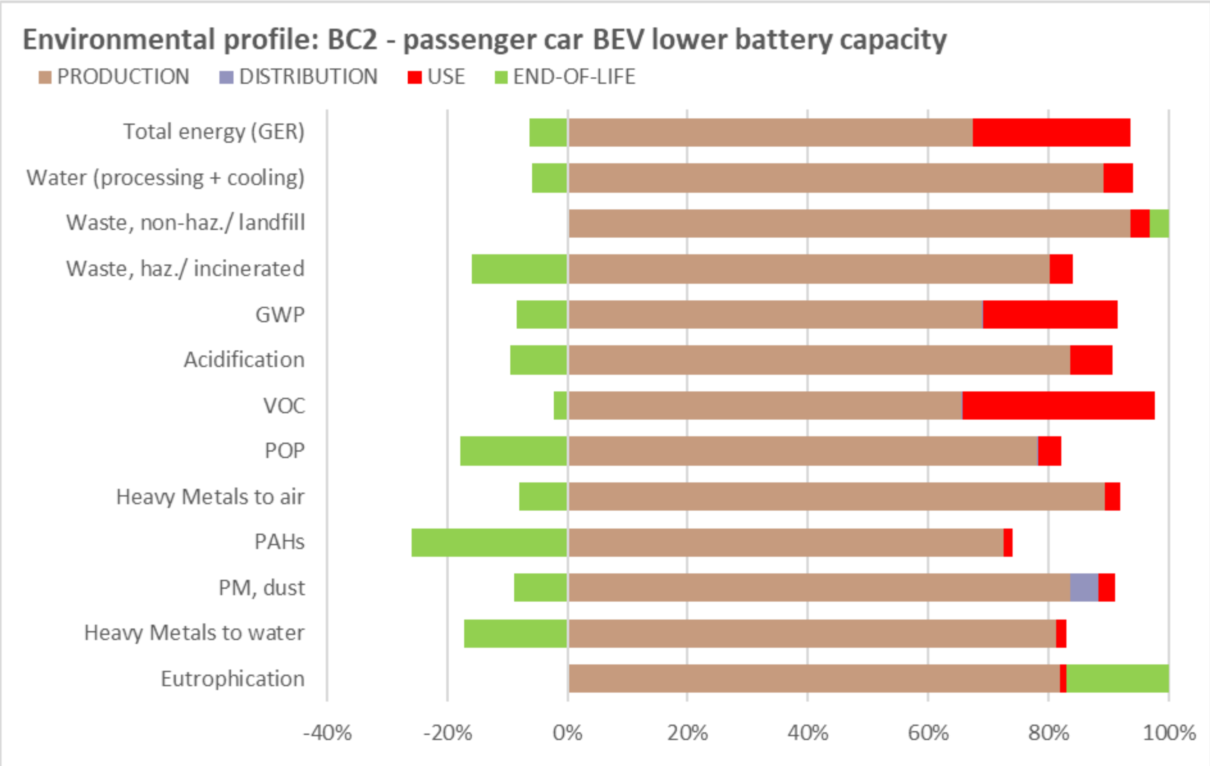
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC2: passenger car with lower battery capacity

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC2: passenger car with lower battery capacity	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.76**		**0.00**	0.42	0.34	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**1.52**		**0.00**	0.08	1.44	0.00	**0.00**
4	Non-ferro	g			**7.54**		**0.00**	0.38	7.16	0.00	**0.00**
5	Coating	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
6	Electronics	g			**0.22**		**0.00**	0.11	0.11	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**10.54**		**0.00**	8.96	1.58	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**20.58**		**0.00**	9.94	10.64	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	3.41	2.28	**5.69**	**0.01**	**2.21**	0.12	-0.66		**7.37**
12	of which, electricity (in primary MJ)	MJ	0.73	2.20	2.93	0.00	2.18	0.00	-0.06		5.06
13	Water (process)	ltr	1.97	0.00	**1.98**	**0.00**	**0.02**	0.00	-0.14		**1.86**
14	Water (cooling)	ltr	0.06	0.14	0.20	0.00	0.10	0.00	-0.01		0.29
15	Waste, non-haz./ landfill	g	41.88	1.63	**43.51**	**0.01**	**1.54**	5.45	-4.00		**46.51**
16	Waste, hazardous/ incinerated	g	0.88	0.03	**0.92**	**0.00**	**0.04**	0.00	-0.18		**0.78**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.19	0.10	**0.29**	**0.00**	**0.09**	0.00	-0.04		**0.35**
18	Acidification, emissions	g SO2 eq.	5.11	0.44	**5.55**	**0.00**	**0.46**	0.03	-0.66		**5.39**
19	Volatile Organic Compounds (VOC)	g	0.05	0.05	**0.10**	**0.00**	**0.05**	0.00	0.00		**0.15**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.11	0.01	**0.12**	**0.00**	**0.01**	0.00	-0.03		**0.10**
21	Heavy Metals	mg Ni eq.	1.12	0.04	**1.16**	**0.00**	**0.03**	0.02	-0.12		**1.09**
22	PAHs	mg Ni eq.	0.56	0.01	**0.57**	**0.00**	**0.01**	0.00	-0.20		**0.37**
23	Particulate Matter (PM, dust)	g	0.35	0.02	**0.37**	**0.02**	**0.01**	0.02	-0.06		**0.36**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.91	0.01	**0.92**	**0.00**	**0.02**	0.00	-0.20		**0.75**
25	Eutrophication	g PO4	0.14	0.00	**0.14**	**0.00**	**0.00**	0.04	-0.01		**0.17**

Figure 2: Relative contribution of the life cycle stages per FU of BC2 PC BEV HIGH based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC2 per impact category.

Table 27: Results for raw materials used in the production phase per FU of BC2 PC BEV LOW based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X <10%

Materials	weight	GER	water (p + c)	haz. waste	non-haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	23%	27%	37%	0%	71%	36%	75%	61%	27%	70%	4%	48%	47%	56%
Cathode, other materials	7%	7%	2%	0%	1%	7%	2%	2%	5%	1%	15%	6%	3%	2%
Cell anode	24%	14%	1%	0%	1%	9%	11%	8%	7%	10%	3%	4%	19%	8%
Cell electrolyte	11%	4%	3%	0%	10%	3%	1%	6%	1%	3%	0%	2%	0%	3%
Cell seperator	2%	1%	1%	0%	0%	1%	0%	0%	1%	0%	3%	1%	1%	0%
Auxillary materials		16%	50%	0%	7%	14%	3%	22%	10%	11%	2%	12%	1%	31%
Cell packaging	8%	7%	0%	0%	1%	7%	2%	0%	8%	1%	21%	8%	5%	0%
Module	5%	5%	1%	0%	1%	4%	1%	0%	7%	1%	9%	5%	2%	0%
System - BMS	4%	3%	2%	40%	2%	3%	3%	0%	9%	2%	0%	1%	7%	0%
System - thermal man.	4%	4%	0%	0%	1%	4%	1%	0%	5%	0%	13%	4%	3%	0%
System packaging	12%	12%	3%	60%	4%	12%	3%	0%	20%	1%	30%	9%	11%	0%

5.2.3. EcoReport LCA results BC3 – passenger car PHEV

Table 28 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a plug-in hybrid vehicle passenger car. Figure 1 is a graphical presentation of the LCA results of BC3.

Table 28: EcoReport LCA results per FU of for BC3 PC PHEV

Version 3.06 VHK for European Commission 2011,
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Document subject to a legal notice (see below)

EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

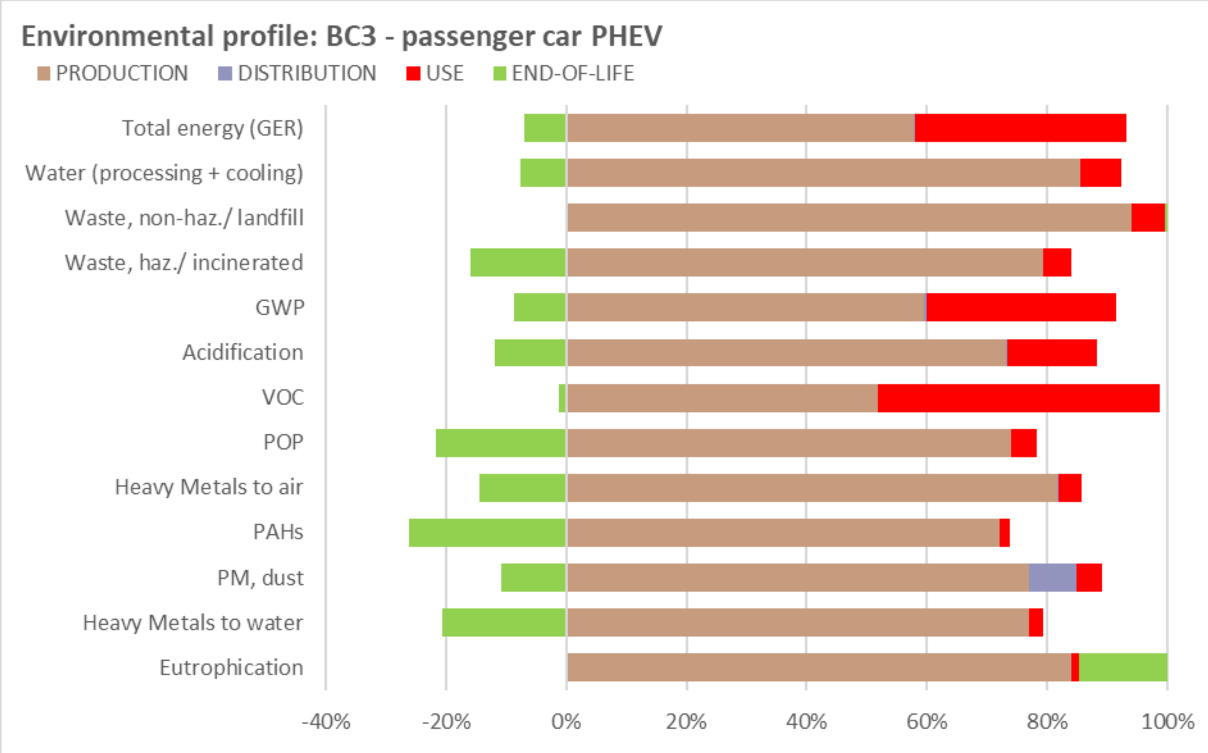
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC3: passenger car PHEV

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC3: passenger car PHEV	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.59**		**0.00**	0.32	0.26	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**0.89**		**0.00**	0.04	0.85	0.00	**0.00**
4	Non-ferro	g			**5.07**		**0.00**	0.25	4.82	0.00	**0.00**
5	Coating	g			**0.08**		**0.00**	0.00	0.08	0.00	**0.00**
6	Electronics	g			**0.17**		**0.00**	0.08	0.09	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**6.02**		**0.00**	5.42	0.60	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**12.82**		**0.00**	6.13	6.69	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	2.19	1.44	**3.63**	**0.01**	**2.20**	0.07	-0.50		**5.41**
12	of which, electricity (in primary MJ)	MJ	0.56	1.38	**1.94**	**0.00**	**2.18**	0.00	-0.11		**4.02**
13	Water (process)	ltr	1.09	0.00	**1.09**	**0.00**	**0.01**	0.00	-0.06		**1.04**
14	Water (cooling)	ltr	0.19	0.09	**0.28**	**0.00**	**0.10**	0.00	-0.06		**0.32**
15	Waste, non-haz./ landfill	g	21.38	1.08	**22.45**	**0.01**	**1.34**	2.59	-2.51		**23.87**
16	Waste, hazardous/ incinerated	g	0.69	0.02	**0.71**	**0.00**	**0.04**	0.00	-0.14		**0.61**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.11	0.06	**0.18**	**0.00**	**0.09**	0.00	-0.03		**0.25**
18	Acidification, emissions	g SO2 eq.	1.83	0.28	**2.11**	**0.00**	**0.43**	0.01	-0.35		**2.20**
19	Volatile Organic Compounds (VOC)	g	0.02	0.03	**0.05**	**0.00**	**0.05**	0.00	0.00		**0.10**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.10	0.01	**0.10**	**0.00**	**0.01**	0.00	-0.03		**0.08**
21	Heavy Metals	mg Ni eq.	0.56	0.03	**0.59**	**0.00**	**0.03**	0.01	-0.11		**0.51**
22	PAHs	mg Ni eq.	0.39	0.00	**0.39**	**0.00**	**0.01**	0.00	-0.14		**0.26**
23	Particulate Matter (PM, dust)	g	0.17	0.01	**0.19**	**0.02**	**0.01**	0.01	-0.03		**0.19**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.43	0.01	**0.44**	**0.00**	**0.01**	0.00	-0.12		**0.34**
25	Eutrophication	g PO4	0.07	0.00	**0.07**	**0.00**	**0.00**	0.02	-0.01		**0.08**

Figure 3: Relative contribution of the life cycle stages per FU of BC3 PC PHEV based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC3 per impact category.

Table 29: Results for raw materials used in the production phase per FU of BC3 PC PHEV based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X <10%

Materials	weight	GER	water (p + c)	haz. waste	non-haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	20%	15%	24%	0%	56%	21%	48%	46%	9%	36%	2%	30%	24%	34%
Cathode, other materials	6%	6%	2%	0%	1%	6%	2%	3%	3%	1%	11%	7%	4%	2%
Cell anode	20%	11%	1%	0%	1%	8%	16%	9%	4%	10%	2%	4%	20%	8%
Cell electrolyte	12%	4%	3%	0%	12%	3%	1%	9%	1%	3%	0%	3%	0%	4%
Cell separator	2%	2%	1%	0%	0%	1%	0%	0%	1%	0%	3%	1%	1%	0%
Auxillary materials		15%	50%	0%	9%	14%	5%	30%	7%	14%	2%	15%	2%	39%
Cell packaging	10%	19%	13%	1%	9%	18%	12%	2%	39%	29%	23%	12%	11%	11%
Module	5%	5%	1%	0%	2%	5%	2%	0%	5%	1%	10%	7%	3%	0%
System - BMS	5%	4%	3%	39%	3%	3%	6%	0%	8%	4%	0%	1%	12%	0%
System - thermal man.	5%	5%	0%	0%	1%	5%	2%	0%	5%	0%	14%	6%	5%	0%
System packaging	15%	15%	4%	59%	6%	15%	6%	1%	18%	2%	33%	14%	18%	0%

5.2.4. EcoReport LCA results BC4 – truck BEV

Table 30 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a battery electric vehicle truck. Figure 4 is a graphical presentation of the LCA results of BC4.

Table 30: EcoReport LCA results per FU of for BC4 Truck BEV

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

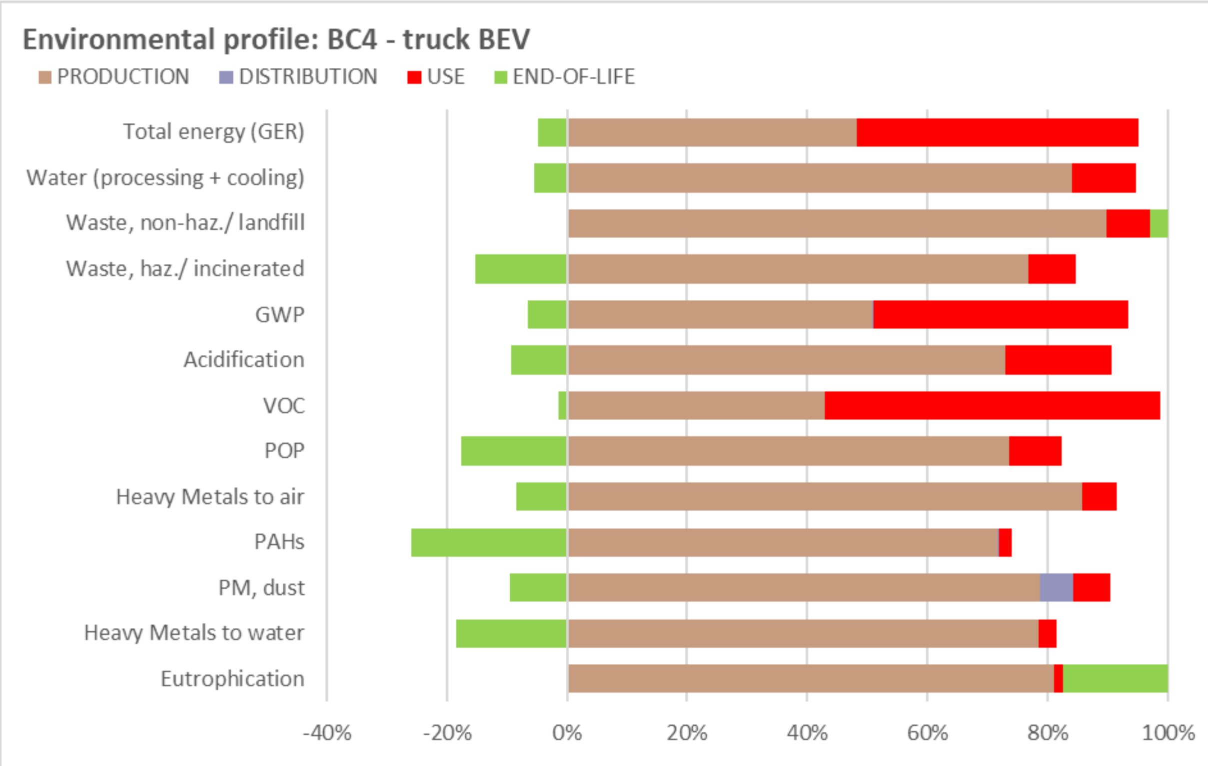
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC4: truck BEV

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC4: truck BEV	2018	vito

Nr	Life Cycle phases --> Resources Use and Emissions	unit	PRODUCTION Material	PRODUCTION Manuf.	PRODUCTION Total	DISTRI-BUTION	USE	END-OF-LIFE Disposal	END-OF-LIFE Recycl.	END-OF-LIFE Stock	TOTAL
	Materials	**unit**									
1	Bulk Plastics	g			**0.25**		**0.00**	0.13	0.11	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**0.43**		**0.00**	0.02	0.41	0.00	**0.00**
4	Non-ferro	g			**2.49**		**0.00**	0.12	2.37	0.00	**0.00**
5	Coating	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
6	Electronics	g			**0.07**		**0.00**	0.03	0.03	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**3.29**		**0.00**	2.83	0.46	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**6.52**		**0.00**	3.14	3.38	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	1.03	0.72	**1.75**	**0.00**	**1.71**	0.03	-0.21		**3.29**
12	of which, electricity (in primary MJ)	MJ	0.19	0.70	0.89	0.00	1.70	0.00	-0.02		2.57
13	Water (process)	ltr	0.58	0.00	**0.58**	**0.00**	**0.01**	0.00	-0.04		**0.55**
14	Water (cooling)	ltr	0.02	0.04	0.06	0.00	0.08	0.00	0.00		0.14
15	Waste, non-haz./ landfill	g	11.73	0.52	**12.25**	**0.00**	**0.99**	1.52	-1.13		**13.63**
16	Waste, hazardous/ incinerated	g	0.28	0.01	**0.29**	**0.00**	**0.03**	0.00	-0.06		**0.26**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.06	0.03	**0.09**	**0.00**	**0.07**	0.00	-0.01		**0.15**
18	Acidification, emissions	g SO2 eq.	1.24	0.14	**1.38**	**0.00**	**0.33**	0.01	-0.19		**1.53**
19	Volatile Organic Compounds (VOC)	g	0.01	0.02	**0.03**	**0.00**	**0.04**	0.00	0.00		**0.07**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.03	0.00	**0.04**	**0.00**	**0.00**	0.00	-0.01		**0.03**
21	Heavy Metals	mg Ni eq.	0.28	0.01	**0.29**	**0.00**	**0.02**	0.00	-0.03		**0.28**
22	PAHs	mg Ni eq.	0.18	0.00	**0.19**	**0.00**	**0.01**	0.00	-0.07		**0.12**
23	Particulate Matter (PM, dust)	g	0.10	0.01	**0.10**	**0.01**	**0.01**	0.00	-0.02		**0.10**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.25	0.00	**0.26**	**0.00**	**0.01**	0.00	-0.06		**0.21**
25	Eutrophication	g PO4	0.04	0.00	**0.04**	**0.00**	**0.00**	0.01	0.00		**0.05**

Figure 4: Relative contribution of the life cycle stages per FU of BC4 Truck BEV based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC4 per impact category.

Table 31: Results for raw materials used in the production phase per FU of BC4 Truck BEV based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X < 10%

Materials	weight	GER	water (p + c)	haz. waste	haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	21%	21%	32%	0%	66%	29%	66%	53%	21%	62%	3%	39%	37%	48%
Cathode, other materials	7%	8%	2%	0%	2%	8%	2%	3%	5%	2%	15%	8%	4%	3%
Cell anode	24%	14%	1%	0%	1%	10%	15%	9%	7%	13%	2%	5%	22%	9%
Cell electrolyte	12%	4%	4%	0%	12%	4%	1%	8%	2%	4%	0%	3%	0%	4%
Cell seperator	2%	1%	1%	0%	0%	1%	0%	0%	1%	0%	2%	1%	1%	0%
Auxillary materials		16%	54%	0%	8%	15%	4%	26%	10%	14%	2%	14%	1%	36%
Cell packaging	9%	9%	0%	0%	2%	9%	3%	0%	9%	1%	24%	9%	7%	0%
Module	5%	5%	1%	0%	2%	5%	1%	0%	8%	1%	10%	6%	3%	0%
System - BMS	4%	3%	2%	40%	2%	3%	4%	0%	10%	3%	0%	1%	8%	0%
System - thermal man.	4%	4%	0%	0%	1%	4%	1%	0%	6%	0%	12%	4%	3%	0%
System packaging	12%	13%	4%	60%	5%	13%	4%	0%	21%	1%	29%	10%	13%	0%

5.2.5. EcoReport LCA results BC5 – truck PHEV

Table 32 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a plug-in hybrid vehicle truck. Figure 5 is a graphical presentation of the LCA results of BC5.

Table 32: EcoReport LCA results per FU of for BC5 Truck PHEV

Version 3.06 VHK for European Commission 2011,
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Document subject to a legal notice (see below)

EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

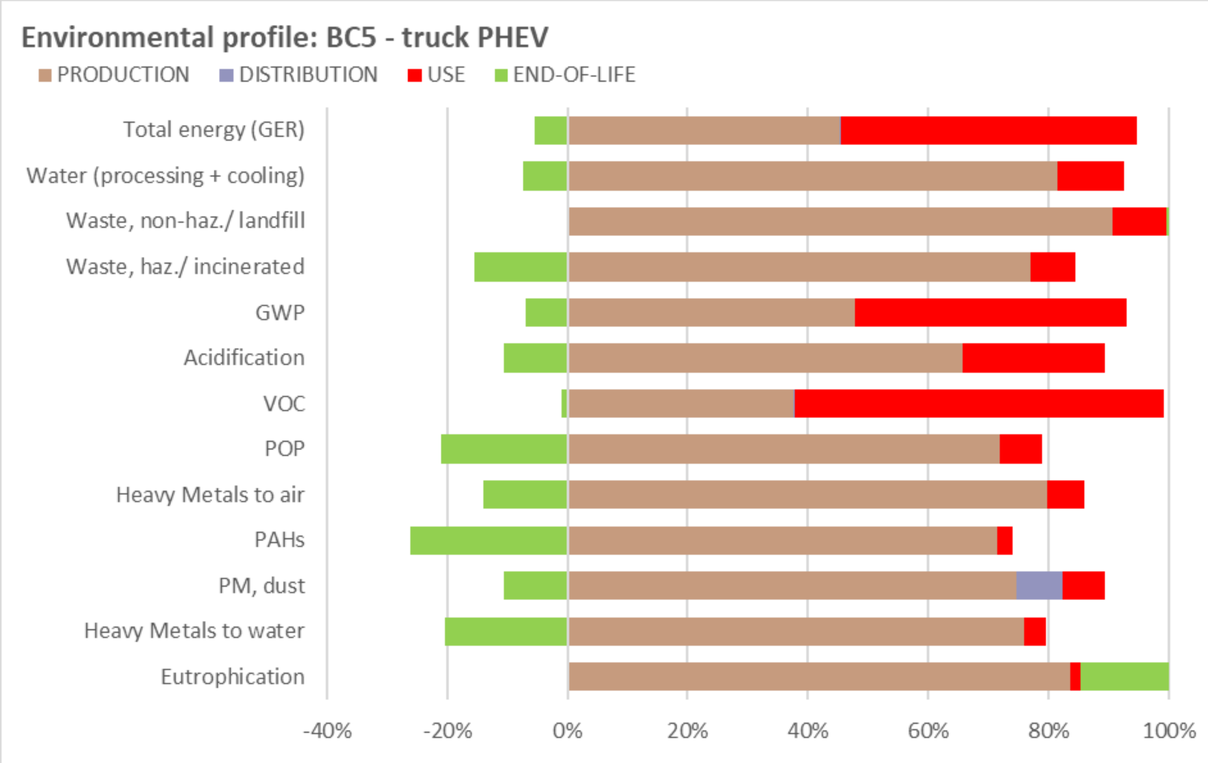
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC5: Truck PHEV

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC5: Truck PHEV	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.26**		**0.00**	0.14	0.12	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**0.40**		**0.00**	0.02	0.38	0.00	**0.00**
4	Non-ferro	g			**2.24**		**0.00**	0.11	2.13	0.00	**0.00**
5	Coating	g			**0.04**		**0.00**	0.00	0.03	0.00	**0.00**
6	Electronics	g			**0.07**		**0.00**	0.04	0.04	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**2.66**		**0.00**	2.39	0.27	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**5.66**		**0.00**	2.71	2.96	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	0.97	0.64	**1.60**	**0.00**	**1.74**	0.03	-0.22		**3.16**
12	of which, electricity (in primary MJ)	MJ	0.25	0.61	0.86	0.00	1.73	0.00	-0.05		2.54
13	Water (process)	ltr	0.48	0.00	**0.48**	**0.00**	**0.00**	0.00	-0.03		**0.46**
14	Water (cooling)	ltr	0.08	0.04	0.12	0.00	0.08	0.00	-0.03		0.17
15	Waste, non-haz./ landfill	g	9.44	0.47	**9.91**	**0.00**	**0.99**	1.14	-1.11		**10.94**
16	Waste, hazardous/ incinerated	g	0.31	0.01	**0.32**	**0.00**	**0.03**	0.00	-0.06		**0.28**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.05	0.03	**0.08**	**0.00**	**0.07**	0.00	-0.01		**0.14**
18	Acidification, emissions	g SO2 eq.	0.81	0.12	**0.93**	**0.00**	**0.34**	0.00	-0.15		**1.12**
19	Volatile Organic Compounds (VOC)	g	0.01	0.01	**0.02**	**0.00**	**0.04**	0.00	0.00		**0.06**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.04	0.00	**0.05**	**0.00**	**0.00**	0.00	-0.01		**0.04**
21	Heavy Metals	mg Ni eq.	0.25	0.01	**0.26**	**0.00**	**0.02**	0.00	-0.05		**0.23**
22	PAHs	mg Ni eq.	0.17	0.00	**0.17**	**0.00**	**0.01**	0.00	-0.06		**0.12**
23	Particulate Matter (PM, dust)	g	0.08	0.01	**0.08**	**0.01**	**0.01**	0.00	-0.02		**0.09**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.19	0.00	**0.19**	**0.00**	**0.01**	0.00	-0.05		**0.15**
25	Eutrophication	g PO4	0.03	0.00	**0.03**	**0.00**	**0.00**	0.01	0.00		**0.04**

Figure 5: Relative contribution of the life cycle stages per FU of BC5 Truck PHEV based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC5 per impact category.

Table 33: Results for raw materials used in the production phase per FU of BC5 Truck PHEV based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X <10%

Materials	weight	GER	water (p + c)	haz. waste	haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	20%	15%	24%	0%	56%	21%	48%	46%	9%	36%	2%	30%	24%	34%
Cathode, other materials	6%	6%	2%	0%	1%	6%	2%	3%	3%	1%	11%	7%	4%	2%
Cell anode	20%	11%	1%	0%	1%	8%	16%	9%	4%	10%	2%	4%	20%	8%
Cell electrolyte	12%	4%	3%	0%	12%	3%	1%	9%	1%	3%	0%	3%	0%	4%
Cell seperator	2%	2%	1%	0%	0%	1%	0%	0%	1%	0%	3%	1%	1%	0%
Auxillary materials		15%	50%	0%	9%	14%	5%	30%	7%	14%	2%	15%	2%	39%
Cell packaging	10%	19%	13%	1%	9%	18%	12%	2%	39%	29%	23%	12%	11%	11%
Module	5%	5%	1%	0%	2%	5%	2%	0%	5%	1%	10%	7%	3%	0%
System - BMS	5%	4%	3%	39%	3%	3%	6%	0%	8%	4%	0%	1%	12%	0%
System - thermal man.	5%	5%	0%	0%	1%	5%	2%	0%	5%	0%	14%	6%	5%	0%
System packaging	15%	15%	4%	59%	6%	15%	6%	1%	18%	2%	33%	14%	18%	0%

5.2.6. EcoReport LCA results BC6 – residential ESS

Table 34 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a residential energy storage system. Figure 6 is a graphical presentation of the LCA results of BC6.

Table 34: EcoReport LCA results per FU of for BC6 residential ESS

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

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EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

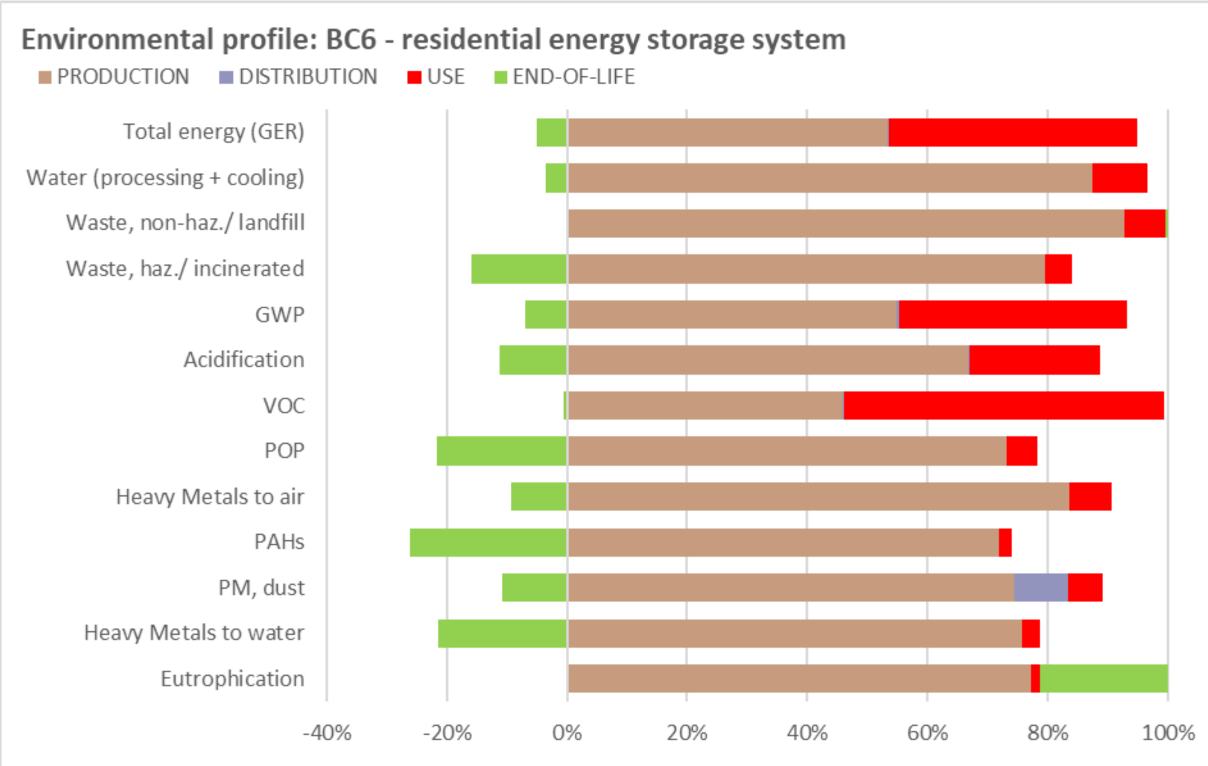
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC6: residential ESS

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC6: residential ESS	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.41**		**0.00**	0.23	0.19	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**1.02**		**0.00**	0.05	0.97	0.00	**0.00**
4	Non-ferro	g			**2.19**		**0.00**	0.11	2.08	0.00	**0.00**
5	Coating	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
6	Electronics	g			**0.10**		**0.00**	0.05	0.05	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**2.68**		**0.00**	2.55	0.13	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**6.40**		**0.00**	2.98	3.41	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	0.87	0.73	**1.60**	**0.01**	**1.24**	0.03	-0.18		**2.69**
12	of which, electricity (in primary MJ)	MJ	0.14	0.69	0.83	0.00	1.23	0.00	-0.01		2.06
13	Water (process)	ltr	0.49	0.00	**0.49**	**0.00**	**0.00**	0.00	-0.02		**0.48**
14	Water (cooling)	ltr	0.03	0.05	0.08	0.00	0.06	0.00	0.00		0.13
15	Waste, non-haz./ landfill	g	9.18	0.57	**9.75**	**0.00**	**0.73**	1.11	-1.08		**10.51**
16	Waste, hazardous/ incinerated	g	0.41	0.01	**0.42**	**0.00**	**0.02**	0.00	-0.09		**0.36**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.04	0.03	**0.08**	**0.00**	**0.05**	0.00	-0.01		**0.12**
18	Acidification, emissions	g SO2 eq.	0.59	0.14	**0.73**	**0.00**	**0.24**	0.00	-0.13		**0.85**
19	Volatile Organic Compounds (VOC)	g	0.01	0.01	**0.02**	**0.00**	**0.03**	0.00	0.00		**0.05**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.04	0.00	**0.05**	**0.00**	**0.00**	0.00	-0.01		**0.04**
21	Heavy Metals	mg Ni eq.	0.15	0.01	**0.17**	**0.00**	**0.01**	0.00	-0.02		**0.16**
22	PAHs	mg Ni eq.	0.16	0.00	**0.16**	**0.00**	**0.00**	0.00	-0.06		**0.11**
23	Particulate Matter (PM, dust)	g	0.07	0.01	**0.07**	**0.01**	**0.01**	0.00	-0.01		**0.08**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.18	0.00	**0.19**	**0.00**	**0.01**	0.00	-0.05		**0.14**
25	Eutrophication	g PO4	0.03	0.00	**0.03**	**0.00**	**0.00**	0.01	0.00		**0.03**

Figure 6: Relative contribution of the life cycle stages per FU of BC6 residential ESS based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC6 per impact category.

Table 35: Results for raw materials used in the production phase per FU of BC6 residential ESS based on the EcoReport LCA results

Contribution to impact category	X > 50%	25% < X < 50%	10% < X < 25%	X <10%

Materials	weight	GER	water (p + c)	haz. waste	haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	16%	10%	20%	0%	47%	14%	34%	30%	6%	33%	1%	18%	15%	28%
Cathode, other materials	6%	7%	2%	0%	2%	7%	3%	3%	3%	2%	13%	8%	4%	3%
Cell anode	19%	13%	1%	0%	1%	10%	24%	11%	4%	18%	2%	5%	24%	10%
Cell electrolyte	12%	5%	4%	0%	14%	4%	1%	12%	1%	6%	0%	4%	1%	5%
Cell seperator	2%	1%	1%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%
Auxillary materials		19%	61%	0%	10%	19%	7%	41%	8%	25%	2%	20%	2%	52%
Cell packaging	10%	13%	0%	0%	2%	14%	8%	1%	7%	2%	35%	16%	13%	0%
Module	5%	6%	1%	0%	2%	6%	3%	0%	6%	2%	12%	9%	4%	0%
System - BMS	5%	4%	3%	33%	3%	4%	9%	0%	9%	7%	1%	2%	14%	0%
System - thermal man.	5%	7%	0%	0%	2%	7%	3%	0%	5%	1%	17%	8%	6%	0%
System packaging	20%	14%	8%	66%	17%	15%	6%	1%	50%	4%	16%	11%	18%	1%

5.2.7. EcoReport LCA results BC7 – commercial ESS

Table 36 provides the environmental impact results in absolute values for 1 kWh delivered by a battery system in a residential energy storage system. Figure 7 is a graphical presentation of the LCA results of BC7.

Table 36: EcoReport LCA results per FU of for BC7 commercial ESS

Version 3.06 VHK for European Commission 2011,
modified by IZM for european commission 2014

Document subject to a legal notice (see below)

EcoReport 2014: OUTPUTS
Assessment of Environmental Impact

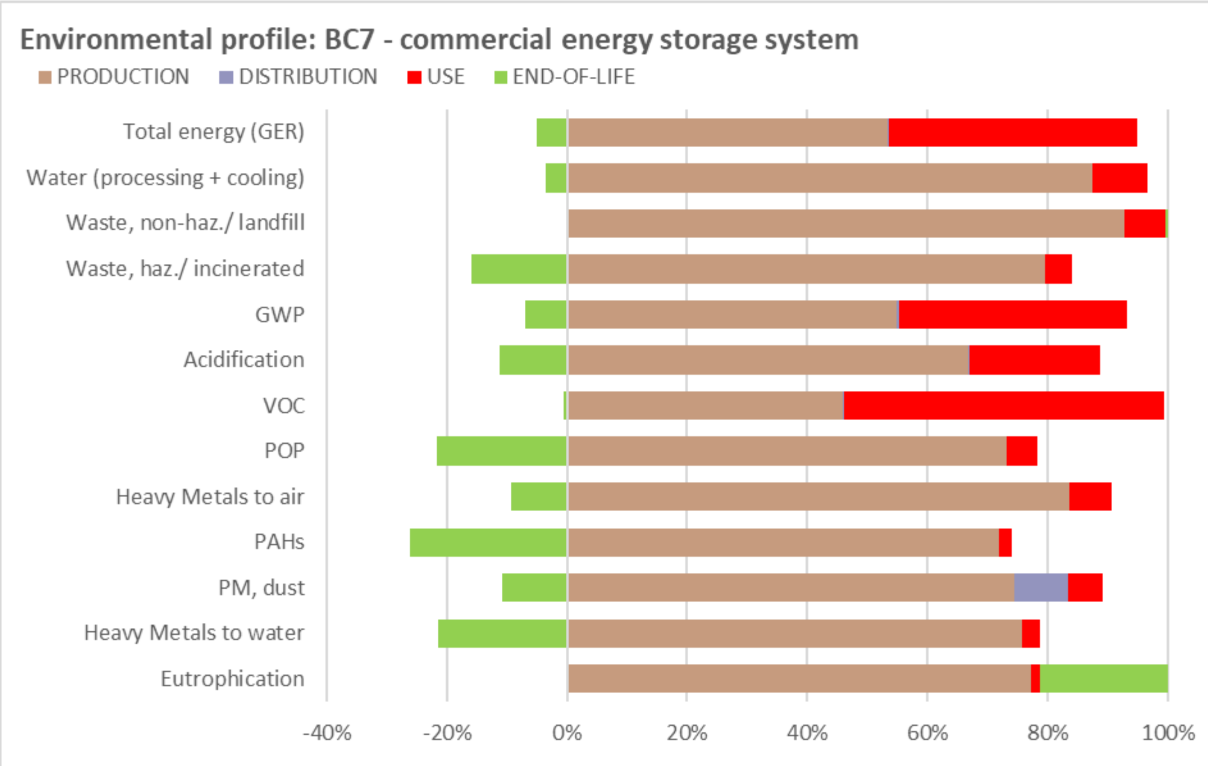
ECO-DESIGN OF ENERGY-RELATED PRODUCTS

Life Cycle Impact (per FU) of Batteries - BC7: commercial ESS

Nr	Life cycle Impact per product:	Reference year	Author
	Batteries - BC7: commercial ESS	2018	vito

Nr	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock	
	Materials	**unit**									
1	Bulk Plastics	g			**0.41**		**0.00**	0.23	0.19	0.00	**0.00**
2	TecPlastics	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
3	Ferro	g			**1.02**		**0.00**	0.05	0.97	0.00	**0.00**
4	Non-ferro	g			**2.19**		**0.00**	0.11	2.08	0.00	**0.00**
5	Coating	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
6	Electronics	g			**0.10**		**0.00**	0.05	0.05	0.00	**0.00**
7	Misc.	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
8	Extra	g			**2.68**		**0.00**	2.55	0.13	0.00	**0.00**
9	Auxiliaries	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
10	Refrigerant	g			**0.00**		**0.00**	0.00	0.00	0.00	**0.00**
	Total weight	g			**6.40**		**0.00**	2.98	3.41	0.00	**0.00**
	Other Resources & Waste							debet	credit		
11	Total Energy (GER)	MJ	0.87	0.73	**1.60**	**0.01**	**1.24**	0.03	-0.18		**2.69**
12	of which, electricity (in primary MJ)	MJ	0.14	0.69	0.83	0.00	1.23	0.00	-0.01		2.06
13	Water (process)	ltr	0.49	0.00	**0.49**	**0.00**	**0.00**	0.00	-0.02		**0.48**
14	Water (cooling)	ltr	0.03	0.05	0.08	0.00	0.06	0.00	0.00		0.13
15	Waste, non-haz./ landfill	g	9.18	0.57	**9.75**	**0.00**	**0.73**	1.11	-1.08		**10.51**
16	Waste, hazardous/ incinerated	g	0.41	0.01	**0.42**	**0.00**	**0.02**	0.00	-0.09		**0.36**
	Emissions (Air)										
17	Greenhouse Gases in GWP100	kg CO2 eq.	0.04	0.03	**0.08**	**0.00**	**0.05**	0.00	-0.01		**0.12**
18	Acidification, emissions	g SO2 eq.	0.59	0.14	**0.73**	**0.00**	**0.24**	0.00	-0.13		**0.85**
19	Volatile Organic Compounds (VOC)	g	0.01	0.01	**0.02**	**0.00**	**0.03**	0.00	0.00		**0.05**
20	Persistent Organic Pollutants (POP)	ng i-Teq	0.04	0.00	**0.05**	**0.00**	**0.00**	0.00	-0.01		**0.04**
21	Heavy Metals	mg Ni eq.	0.15	0.01	**0.17**	**0.00**	**0.01**	0.00	-0.02		**0.16**
22	PAHs	mg Ni eq.	0.16	0.00	**0.16**	**0.00**	**0.00**	0.00	-0.06		**0.11**
23	Particulate Matter (PM, dust)	g	0.07	0.01	**0.07**	**0.01**	**0.01**	0.00	-0.01		**0.08**
	Emissions (Water)										
24	Heavy Metals	mg Hg/20	0.18	0.00	**0.19**	**0.00**	**0.01**	0.00	-0.05		**0.14**
25	Eutrophication	g PO4	0.03	0.00	**0.03**	**0.00**	**0.00**	0.01	0.00		**0.03**

Figure 7: Relative contribution of the life cycle stages per FU of BC7 commercial ESS based on the EcoReport LCA results



The table below shows the relative contribution to the impact caused by the raw materials of the different battery system components in BC7 per impact category.

Table 37: Results for raw materials used in the production phase per FU of BC7 commercial ESS based on the EcoReport LCA results

Contribution to impact category: X > 50% | 25% < X < 50% | 10% < X < 25% | X <10%

Materials	weight	GER	water (p + c)	haz. waste	haz. waste	GWP	AD	VOC	POP	HMa	PAH	PM	HMw	EUP
Cathode active material	16%	10%	20%	0%	47%	14%	34%	30%	6%	33%	1%	18%	15%	28%
Cathode, other materials	6%	7%	2%	0%	2%	7%	3%	3%	3%	2%	13%	8%	4%	3%
Cell anode	19%	13%	1%	0%	1%	10%	24%	11%	4%	18%	2%	5%	24%	10%
Cell electrolyte	12%	5%	4%	0%	14%	4%	1%	12%	1%	6%	0%	4%	1%	5%
Cell seperator	2%	1%	1%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%
Auxillary materials		19%	61%	0%	10%	19%	7%	41%	8%	25%	2%	20%	2%	52%
Cell packaging	10%	13%	0%	0%	2%	14%	8%	1%	7%	2%	35%	16%	13%	0%
Module	5%	6%	1%	0%	2%	6%	3%	0%	6%	2%	12%	9%	4%	0%
System - BMS	5%	4%	3%	33%	3%	4%	9%	0%	9%	7%	1%	2%	14%	0%
System - thermal man.	5%	7%	0%	0%	2%	7%	3%	0%	5%	1%	17%	8%	6%	0%
System packaging	20%	14%	8%	66%	17%	15%	6%	1%	50%	4%	16%	11%	18%	1%

5.2.8. Critical Raw Materials

The Critical Raw Material (CRM) indicator in this preparatory study is calculated according to MEErP 2011. There are 14 CRMs listed in the MEErP methodology, however the number of CRMs for the EU has increased to 27 in 2017[12]. There are two raw materials within battery systems that are seen as CRMs: i.e. cobalt and natural graphite. Lithium, manganese, and nickel are also used in battery systems, but are still assessed as non-critical raw materials (non-CRMs) by the EC[13]. Although the latter three materials are not yet seen as critical, the three are included in this assessment as the criticality threshold can be passed when the demand for the three materials increases.

The CRM indicator in the EcoReport tool is calculated by multiplying the weight of a CRM (in kg) with a material specific characterisation factor (CF) with the unit kg antimony (Sb) equivalent per kg CRM. The CFs are calculated with the following formula provided in the MEErP methodology report part 2:

- CF [kg Sb eq./kg CRM] = 451 / (A * B * C * (1 – D))

  In which: A = the EU consumption [ton/yr]
  B = the import dependency rate [%]
  C = the substitutability supply risk [%]
  D = the recycling rate [%]

The number 451 is the result of (A * B * C1 * (1 – D)) of the reference material antimony. However, this value is based on figures dating from 2006-2007 and the EU consumption, substitutability supply risk and recycling rate of antimony have changed much. When using data from the 2017 CRM Factsheets of the EC (Deloitte, et al. 2017) for A, B and C, and additional sources for the recycling rate D, the multiplication for antimony will result in 13 392. Because of the big difference between 451 and 13 392, the study team of this preparatory study decided to use the updated figure to determine the CRM indicator of all the other (non-)CRMs within this study. Thus changing the formula into:

- CF [kg Sb eq./kg CRM] = 13 392 / (A * B * C * (1 – D))

The data used to calculate the updated and additional CFs (European Commision 2017, Deloitte, et al. 2017, and see also footnote 14) and the resulting CFs are given in the table below.

[12] http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

[13] https://publications.europa.eu/en/publication-detail/-/publication/6f1e28a7-98fb-11e7-b92d-01aa75ed71a1/language-en

Table 38: Input values for and result of the calculation of the updated and additional CRM characterisation factors

	EU consumption (A) [ton/yr]	Import dependency rate (B) [%]	Substitutability supply risk (C) [%]	Recycling rate (D) [%] [14]	A*B*C*(1 – D)	Characteri-sation factor (kg Sb eq./kg)
Antimony (CRM)	18 000	100	93	20	13 392.0	1.00
Cobalt (CRM)	30 000	32	100	68	3072.0	4.36
Lithium (non-CRM)	4 200	86	91	0	3 286.9	4.07
Manganese (non-CRM)	1 400 000	89	100	53	585 620.0	0.02
Natural graphite (CRM)	91 000	99	97	3	84 765.7	0.16
Nickel (non-CRM)	300 000	59	96	58	71 366.4	0.19

Table 39 gives the overview of the CRM indicators for all BCs, calculated with the CFs in Table 38. The share of the CRM indictor of each material in the CRM indicator of the total battery system are also included in Table 39. In addition, the weight of the total battery system and of the (non-)CRM are also given per FU in absolute figures and relative numbers for the individual materials, based on the total numbers of batteries needed in application and including replacements.

[14] In the (non-)CRM factsheets of the EC not all recycling rates are included (though the recycling input rate (EOL-RIR) are presented for each material, also known as the recycled content). The recycling rates presented here are general rates i.e. not specific for EV batteries as CRM characterisation factors need to be applicable for every type of product group not only for EV batteries. To determine the recycling rates the following sources were used:

- Antimony (UNEP 2011, Dupont, et al. 2016)
- Cobalt (UNEP 2011, Deloitte, et al. 2017)
- Lithium (UNEP 2011)
- Manganese (UNEP 2011)
- Natural graphite (Deloitte, et al. 2017)
- Nickel (Ellingsen and Hung 2018, UNEP 2011)

Table 39: Overview of the critical raw materials per FU per BC

		BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Total battery appl. system(s)	Weight [g/FU]	13.93	20.58	12.82	6.52	5.66	6.40	6.40
	CRM indicator	$2.82 \cdot 10^{-3}$	$4.17 \cdot 10^{-3}$	$1.74 \cdot 10^{-3}$	$1.01 \cdot 10^{-3}$	$7.67 \cdot 10^{-4}$	$4.44 \cdot 10^{-4}$	$4.44 \cdot 10^{-4}$
Cobalt	Weight [g/FU]	0.22	0.32	0.13	0.07	0.06	0.01	0.01
	[%]	1.57	1.57	0.99	1.08	0.99	0.23	0.23
	CRM indicator	$9.54 \cdot 10^{-4}$	$1.41 \cdot 10^{-3}$	$5.56 \cdot 10^{-4}$	$3.08 \cdot 10^{-4}$	$2.46 \cdot 10^{-4}$	$6.37 \cdot 10^{-5}$	$6.37 \cdot 10^{-5}$
	[%]	33.82	33.82	32.00	30.38	32.00	14.35	14.35
Lithium	Weight [g/FU]	0.34	0.50	0.21	0.12	0.09	0.06	0.06
	[%]	2.44	2.44	1.67	1.91	1.67	0.98	0.98
	CRM indicator	$1.39 \cdot 10^{-3}$	$2.05 \cdot 10^{-3}$	$8.70 \cdot 10^{-4}$	$5.09 \cdot 10^{-4}$	$3.84 \cdot 10^{-4}$	$2.55 \cdot 10^{-4}$	$2.55 \cdot 10^{-4}$
	[%]	49.19	49.19	50.08	50.27	50.08	57.38	57.38
Manganese	Weight [g/FU]	0.39	0.58	0.26	0.05	0.12	0.01	0.01
	[%]	2.81	2.81	2.05	0.74	2.05	0.12	0.12
	CRM indicator	$8.96 \cdot 10^{-6}$	$1.32 \cdot 10^{-5}$	$6.02 \cdot 10^{-6}$	$1.10 \cdot 10^{-6}$	$2.66 \cdot 10^{-6}$	$1.80 \cdot 10^{-7}$	$1.80 \cdot 10^{-7}$
	[%]	0.32	0.32	0.35	0.11	0.35	0.04	0.04
Natural graphite	Weight [g/FU]	2.00	2.95	1.62	0.93	0.72	0.72	0.72
	[%]	14.34	14.34	12.61	14.25	12.61	11.32	11.32
	CRM indicator	$3.16 \cdot 10^{-4}$	$4.66 \cdot 10^{-4}$	$2.56 \cdot 10^{-4}$	$1.47 \cdot 10^{-4}$	$1.13 \cdot 10^{-4}$	$1.14 \cdot 10^{-4}$	$1.14 \cdot 10^{-4}$
	[%]	11.20	11.20	14.70	14.51	12.61	25.78	25.78
Nickel	Weight [g/FU]	0.82	1.21	0.27	0.25	0.12	0.06	0.06
	[%]	5.90	5.90	2.07	3.91	2.07	0.91	0.91
	CRM indicator	$1.54 \cdot 10^{-4}$	$2.28 \cdot 10^{-4}$	$4.99 \cdot 10^{-5}$	$4.78 \cdot 10^{-5}$	$2.20 \cdot 10^{-5}$	$1.09 \cdot 10^{-6}$	$1.09 \cdot 10^{-6}$
	[%]	5.47	5.47	2.87	4.72	2.87	2.45	2.45

Based on Table 39 it can be concluded that for the CRM in EV batteries lithium and cobalt are the biggest contributors to the CRM indicator for the EV base cases (BC1 to 5) and for the ESS base cases (BC 6 and 7) lithium and natural graphite. This is because cobalt and lithium have high CRM characterisation factors compared to the other materials. The high CF of cobalt is caused by the import dependency and for lithium because it is not being recycled. The amount of cobalt (and manganese) is much lower in the ESS base cases compared to the EV base cases, which causes the shift from cobalt to natural graphite of becoming the second biggest contributor to the CRM indicator for BC 6 and 7.

5.3. Subtask 5.3 – Base Case Life Cycle Costs

AIM OF SUBTASK 5.3:

The Life Cycle Costs (LCC) and Levelized Cost Of Energy (LCOE) for the consumer are calculated per BC, for more background information on LCC and LCOE see section 5.1.2.1. Given the complexity of the LCC and LCOE calculation, a separate calculation spreadsheet was created instead of using the EcoReport tool. But for the calculation of the societal LCC the EcoReport is used, as the societal LCC are linked to the emissions to air calculated with the EcoReport. Section 5.3.1 presents the LCC and LCOE results of all base cases and section 5.3.2 the LCC for society.

5.3.1. LCC and LCOE results of all Base Cases

An overview of all the assumptions made to calculate the LCC and LCOE is given Table 40. Data has been sourced from previous sections. The LCC and LCOE results of all BCs are summarised in Table 41. The calculation details per year are given in the next sub-sections per BC.

Table 40: Overview of the assumed parameters for the LCC and LCOE of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Economic lifetime of application (Tapp) [yr]	13	14	13	14	12	20	20
Application service energy (AS) [kWh/Tapp]	43 680	29 568	19 656	940 800	890 400	40 000	120 x 10^6
Service life of battery (Tbat) [y]	14.40	13.43	10.67	8.04	5.33	17.02	17.02
Nominal battery system capacity [kWh]	80	40	12	30	20	10	10
Number of batteries in the application [-]	1	1	1	12	8	1	3 000
Number of battery application systems per Tapp (Ass) [-]	1	2	2	2	3	2	2
Average efficiency of battery system [%]	92	92	92	92	92	92	92
Charger efficiency [%]	85	85	85	92	92	98	98
Brake energy recovery [%]	20	20	20	12	6	n.a.	n.a.

Continuation of Table 40: Overview of the assumed parameters for the LCC and LCOE of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Thermal management efficiency [%]	99	99	99	99	99	99	99
Self-discharge (@STC) [%]	2	2	2	2	2	2	2
Electricity cost (incl. VAT) [EUR/kWh][15]	0.213	0.213	0.213	0.101	0.101	0.213	0.101
Discount rate [%]	4	4	4	4	4	4	4
Discount rate electricity [%]	0	0	0	0	0	0	0
CAPEX battery system cost per declared initial capacity [EUR/kWh]	206	206	254	220	212	683	683
OPEX battery system replacement [EUR/service]	700	700	700	400	400	100	100
CAPEX decommissioning battery system at EOL [EUR]	1 200	600	180	450	300	150	150

Table 41: Overview of the life cycle costing results of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
LCOE or LCC per FU [EUR/kWh]	0.461	0.547	0.377	0.177	0.125	0.293	0.278
LCC total for all batteries in application per Tapp [EUR/appl.]	20 152	16 179	7 401	166 397	111 511	11 723	33 328 317

[15] For the commercial sector, costs are typically without VAT.

5.3.1.1. Detailed LCC results BC1 – passenger car BEV with a higher battery capacity

Table 42: Details of the Life Cycle Cost calculation per year for BC1 – PC BEV HIGH

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	16 480 €	700 €	173.16 €	17 353.16 €	292.2	520.8
	2	0.925	1.000			173.16 €	173.16 €	292.2	520.8
	3	0.889	1.000			173.16 €	173.16 €	292.2	520.8
	4	0.855	1.000			173.16 €	173.16 €	292.2	520.8
	5	0.822	1.000			173.16 €	173.16 €	292.2	520.8
	6	0.790	1.000			173.16 €	173.16 €	292.2	520.8
	7	0.760	1.000			173.16 €	173.16 €	292.2	520.8
	8	0.731	1.000			173.16 €	173.16 €	292.2	520.8
	9	0.703	1.000			173.16 €	173.16 €	292.2	520.8
	10	0.676	1.000			173.16 €	173.16 €	292.2	520.8
	11	0.650	1.000			173.16 €	173.16 €	292.2	520.8
	12	0.625	1.000			173.16 €	173.16 €	292.2	520.8
EOL	13	0.601	1.000	1 200 €		173.16 €	893.85 €	292.2	520.8
Total				17 680 €	700 €	2 251.12 €	20 151.81 €	3 798.3	6 770.4

5.3.1.2. Detailed LCC results BC2 – passenger car BEV with a lower battery capacity

Table 43: Details of the Life Cycle Cost calculation per year for BC2 – PC BEV LOW

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	8 240 €	700 €	108.85 €	9 048.85 €	183.7	327.4
	2	0.925	1.000			108.85 €	108.85 €	183.7	327.4
	3	0.889	1.000			108.85 €	108.85 €	183.7	327.4
	4	0.855	1.000			108.85 €	108.85 €	183.7	327.4
	5	0.822	1.000			108.85 €	108.85 €	183.7	327.4
	6	0.790	1.000			108.85 €	108.85 €	183.7	327.4
	7	0.760	1.000			108.85 €	108.85 €	183.7	327.4
	8	0.731	1.000			108.85 €	108.85 €	183.7	327.4
	9	0.703	1.000			108.85 €	108.85 €	183.7	327.4
	10	0.676	1.000			108.85 €	108.85 €	183.7	327.4
	11	0.650	1.000			108.85 €	108.85 €	183.7	327.4
	12	0.625	1.000			108.85 €	108.85 €	183.7	327.4
O&M	13	0.601	1.000	8 240 €	700 €	108.85 €	5 477.98 €	183.7	327.4
EOL	14	0.577	1.000	600 €		108.85 €	455.33 €	183.7	327.4
Total				17 080 €	1 400 €	1 523.84 €	16 179.46 €	2 571.1	4 583.0

5.3.1.3. Detailed LCC results BC3 – passenger car PHEV

Table 44: Details of the Life Cycle Cost calculation per year for BC3 – PC PHEV

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	3 048 €	700 €	77.92 €	3 825.92 €	131.5	234.4
	2	0.925	1.000			77.92 €	77.92 €	131.5	234.4
	3	0.889	1.000			77.92 €	77.92 €	131.5	234.4
	4	0.855	1.000			77.92 €	77.92 €	131.5	234.4
	5	0.822	1.000			77.92 €	77.92 €	131.5	234.4
	6	0.790	1.000			77.92 €	77.92 €	131.5	234.4
	7	0.760	1.000			77.92 €	77.92 €	131.5	234.4
	8	0.731	1.000			77.92 €	77.92 €	131.5	234.4
	9	0.703	1.000			77.92 €	77.92 €	131.5	234.4
O&M	10	0.676	1.000	3 048 €	700 €	77.92 €	2 609.94 €	131.5	234.4
	11	0.650	1.000			77.92 €	77.92 €	131.5	234.4
	12	0.625	1.000			77.92 €	77.92 €	131.5	234.4
EOL	13	0.601	1.000	180 €		77.92 €	186.03 €	131.5	234.4
Total				6 276 €	1 400 €	1 013.01 €	7 401.12 €	1709.2	3 046.7

5.3.1.4. Detailed LCC results BC4 – truck BEV

Table 45: Details of the Life Cycle Cost calculation per year for BC4 – Truck BEV

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	79 200 €	4 800 €	1 278.61 €	85 278.61 €	5 843.5	6 816.0
	2	0.925	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	3	0.889	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	4	0.855	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	5	0.822	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	6	0.790	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	7	0.760	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
O&M	8	0.731	1.000	79 200 €	4 800 €	1 278.61 €	62 656.58 €	5 843.5	6 816.0
	9	0.703	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	10	0.676	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	11	0.650	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	12	0.625	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
	13	0.601	1.000			1 278.61 €	1 278.61 €	5 843.5	6 816.0
EOL	14	0.577	1.000	5 400 €		1 278.61 €	4 396.97 €	5 843.5	6 816.0
Total				163 800 €	9 600 €	17 900.50 €	166 396.84 €	81 808.7	95 424.0

5.3.1.5. Detailed LCC results BC5 – truck PHEV

Table 46: Details of the Life Cycle Cost calculation per year for BC5 – Truck PHEV

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	33 920 €	3 200 €	1 442.10 €	38 562.10 €	6 452.2	7 826.0
	2	0.925	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
	3	0.889	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
	4	0.855	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
O&M	5	0.822	1.000	33 920 €	3 200 €	1 442.10 €	31 952.03 €	6 452.2	7 826.0
	6	0.790	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
	7	0.760	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
	8	0.731	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
	9	0.703	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
O&M	10	0.676	1.000	33 920 €	3 200 €	1 442.10 €	26 519.04 €	6 452.2	7 826.0
	11	0.650	1.000			1 442.10 €	1 442.10 €	6 452.2	7 826.0
EOL	12	0.625	1.000	2 400 €		1 442.10 €	2 941.13 €	6 452.2	7 826.0
Total				104 160 €	9 600 €	17 305.15 €	111 511.06 €	77 426.1	93 912.0

5.3.1.6. Detailed LCC results BC6 – residential ESS

Table 47: Details of the Life Cycle Cost calculation per year for BC6 – residential ESS

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	6 830 €	100 €	58.34 €	6 988.34 €	173.9	100.0
	2	0.925	1.000			58.34 €	58.34 €	173.9	100.0
	3	0.889	1.000			58.34 €	58.34 €	173.9	100.0
	4	0.855	1.000			58.34 €	58.34 €	173.9	100.0
	5	0.822	1.000			58.34 €	58.34 €	173.9	100.0
	6	0.790	1.000			58.34 €	58.34 €	173.9	100.0
	7	0.760	1.000			58.34 €	58.34 €	173.9	100.0
	8	0.731	1.000			58.34 €	58.34 €	173.9	100.0
	9	0.703	1.000			58.34 €	58.34 €	173.9	100.0
	10	0.676	1.000			58.34 €	58.34 €	173.9	100.0
	11	0.650	1.000			58.34 €	58.34 €	173.9	100.0
	12	0.625	1.000			58.34 €	58.34 €	173.9	100.0
	13	0.601	1.000			58.34 €	58.34 €	173.9	100.0
	14	0.577	1.000			58.34 €	58.34 €	173.9	100.0
	15	0.555	1.000			58.34 €	58.34 €	173.9	100.0
	16	0.534	1.000			58.34 €	58.34 €	173.9	100.0
O&M	17	0.513	1.000	6 830 €	100 €	58.34 €	3 616.02 €	173.9	100.0
	18	0.494	1.000			58.34 €	58.34 €	173.9	100.0
	19	0.475	1.000			58.34 €	58.34 €	173.9	100.0
EOL	20	0.456	1.000	150 €		58.34 €	126.80 €	173.9	100.0
Total				13 810 €	200 €	1 167 €	11 723 €	3478.3	2000.0

5.3.1.7. Detailed LCC results BC7 – commercial ESS

Table 48: Details of the Life Cycle Cost calculation per year for BC7 – commercial ESS

Event	Year	Other PWF ratio	Elec. PWF ratio	CAPEX [euro]	Other OPEX [euro]	Electricity OPEX [euro]	NPV OPEX+CAPEX [euro/yr]	Direct losses elec. per year [kWh]	Indirect losses elec. per year [kWh]
purchase EV	1	1.000	1.000	20 490 000 €	300 000 €	82 996 €	20 872 996 €	521 739	300 000
	2	0.925	1.000			82 996 €	82 996 €	521 739	300 000
	3	0.889	1.000			82 996 €	82 996 €	521 739	300 000
	4	0.855	1.000			82 996 €	82 996 €	521 739	300 000
	5	0.822	1.000			82 996 €	82 996 €	521 739	300 000
	6	0.790	1.000			82 996 €	82 996 €	521 739	300 000
	7	0.760	1.000			82 996 €	82 996 €	521 739	300 000
	8	0.731	1.000			82 996 €	82 996 €	521 739	300 000
	9	0.703	1.000			82 996 €	82 996 €	521 739	300 000
	10	0.676	1.000			82 996 €	82 996 €	521 739	300 000
	11	0.650	1.000			82 996 €	82 996 €	521 739	300 000
	12	0.625	1.000			82 996 €	82 996 €	521 739	300 000
	13	0.601	1.000			82 996 €	82 996 €	521 739	300 000
	14	0.577	1.000			82 996 €	82 996 €	521 739	300 000
	15	0.555	1.000			82 996 €	82 996 €	521 739	300 000
	16	0.534	1.000			82 996 €	82 996 €	521 739	300 000
O&M	17	0.513	1.000	20 490 000 €	300 000 €	82 996 €	10 756 025 €	521 739	300 000
	18	0.494	1.000			82 996 €	82 996 €	521 739	300 000
	19	0.475	1.000			82 996 €	82 996 €	521 739	300 000
EOL	20	0.456	1.000	450 000 €		82 996 €	288 370 €	521 739	300 000
Total				41 430 000 €	600 000 €	1 659 913 €	33 328 317 €	10 434 783	6 000 000

5.3.2. Life Cycle Costs for society of all Base Cases

Societal LCC are costs for marginal external damages. Within the EcoReport, these costs are only calculated for the emissions to air by multiplying the emissions mass calculated in the EcoReport with fixed rates of external marginal costs to society (see Table 49).

Table 49: External marginal costs to society rates within EcoReport 2014 (main sources mentioned in the MEErP 2011 Methodology part 1: CO2 ETS trading price 1.1.2011, EEA 2011)

Emissions to air	Unit	EUR/unit
Greenhouse gases in GWP100 (GHG)	kg CO2 eq.	0.014
Acidification potential (AP)	g SO2 eq.	0.0085
Volatile organic compounds (VOC)	g	0.00076
Persistent Organic Pollutants (POP)	ng i-Teq	0.000027
Heavy metals: other (HM1)	mg Ni eq.	0.000175
Heavy metals: stainless steel, CRT, bitumen (HM2)	mg Ni eq.	0.00004
Heavy metals: electricity, copper (HM3)	mg Ni eq.	0.0003
Polycyclic aromatic hydrocarbons (PAH)	mg Ni eq.	0.001279
Particulate matter (PM)	g	0.01546

The societal LCC results of all BCs are summarised in Table 50. The calculation details per life cycle phase and impact categories are given in the next sub-sections per BC.

Table 50: Overview of the societal life cycle costing results (marginal external damages) of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Societal LCC per FU [EUR/kWh]	0.050	0.072	0.034	0.021	0.017	0.013	0.013
Societal LCC total for all batteries in application per Tapp [EUR/appl.]	2 189	2 119	663	19 924	14 830	531	1 582 515

5.3.2.1. Detailed societal LCC results BC1 – passenger car BEV with a higher battery capacity

Table 51: Details of the societal Life Cycle Cost (marginal external damages) calculation per FU for BC1 – PC BEV HIGH

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.20	0.003	0.09	0.001	0.02	0.000	0.32	0.004
AP	g SO2 eq.	3.76	0.032	0.45	0.004	0.47	0.004	4.68	0.040
VOC	g	0.07	0.000	0.05	0.000	0.00	0.000	0.12	0.000
POP	ng i-Teq	0.08	0.000	0.01	0.000	0.02	0.000	0.11	0.000
HM1	mg Ni eq.	0.79	0.000	0.01	0.000	0.09	0.000	0.89	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.02	0.000	0.00	0.000	0.02	0.000
PAH	mg Ni eq.	0.38	0.000	0.01	0.000	0.14	0.000	0.53	0.001
PM	g	0.26	0.004	0.01	0.000	0.05	0.001	0.32	0.005
Total			0.039		0.005		0.005		0.050

5.3.2.2. Detailed societal LCC results BC2 – passenger car BEV with a lower battery capacity

Table 52: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC2 – PC BEV LOW

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.29	0.004	0.09	0.001	0.04	0.001	0.42	0.006
AP	g SO2 eq.	5.56	0.047	0.46	0.004	0.69	0.006	6.71	0.057
VOC	g	0.10	0.000	0.05	0.000	0.00	0.000	0.15	0.000
POP	ng i-Teq	0.12	0.000	0.01	0.000	0.03	0.000	0.16	0.000
HM1	mg Ni eq.	1.16	0.000	0.01	0.000	0.14	0.000	1.31	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.02	0.000	0.00	0.000	0.02	0.000
PAH	mg Ni eq.	0.57	0.001	0.01	0.000	0.20	0.000	0.78	0.001
PM	g	0.39	0.006	0.01	0.000	0.08	0.001	0.47	0.007
Total			0.058		0.006		0.008		0.072

5.3.2.3. Detailed societal LCC results BC3 – passenger car PHEV

Table 53: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC3 – PC PHEV

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.18	0.003	0.09	0.001	0.03	0.000	0.30	0.004
AP	g SO2 eq.	2.11	0.018	0.43	0.004	0.36	0.003	2.90	0.025
VOC	g	0.05	0.000	0.05	0.000	0.00	0.000	0.10	0.000
POP	ng i-Teq	0.10	0.000	0.01	0.000	0.03	0.000	0.14	0.000
HM1	mg Ni eq.	0.59	0.000	0.01	0.000	0.11	0.000	0.71	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.02	0.000	0.00	0.000	0.02	0.000
PAH	mg Ni eq.	0.39	0.001	0.01	0.000	0.14	0.000	0.55	0.001
PM	g	0.20	0.003	0.01	0.000	0.04	0.001	0.26	0.004
Total			0.024		0.005		0.004		0.034

5.3.2.4. Detailed societal LCC results BC4 – truck BEV

Table 54: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC4 – Truck BEV

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.09	0.001	0.07	0.001	0.01	0.000	0.17	0.002
AP	g SO2 eq.	1.38	0.012	0.33	0.003	0.19	0.002	1.90	0.016
VOC	g	0.03	0.000	0.04	0.000	0.00	0.000	0.07	0.000
POP	ng i-Teq	0.04	0.000	0.00	0.000	0.01	0.000	0.05	0.000
HM1	mg Ni eq.	0.29	0.000	0.00	0.000	0.04	0.000	0.33	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.02	0.000	0.00	0.000	0.02	0.000
PAH	mg Ni eq.	0.19	0.000	0.01	0.000	0.07	0.000	0.26	0.000
PM	g	0.11	0.002	0.01	0.000	0.02	0.000	0.14	0.002
Total			0.015		0.004		0.002		0.021

5.3.2.5. Detailed societal LCC results BC5 – truck PHEV

Table 55: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC5 – Truck PHEV

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.08	0.001	0.07	0.001	0.01	0.000	0.16	0.002
AP	g SO2 eq.	0.93	0.008	0.34	0.003	0.16	0.001	1.43	0.012
VOC	g	0.02	0.000	0.04	0.000	0.00	0.000	0.06	0.000
POP	ng i-Teq	0.05	0.000	0.00	0.000	0.01	0.000	0.06	0.000
HM1	mg Ni eq.	0.26	0.000	0.00	0.000	0.05	0.000	0.31	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.02	0.000	0.00	0.000	0.02	0.000
PAH	mg Ni eq.	0.17	0.000	0.01	0.000	0.06	0.000	0.24	0.000
PM	g	0.09	0.001	0.01	0.000	0.02	0.000	0.12	0.002
Total			0.011		0.004		0.002		0.017

5.3.2.6. Detailed societal LCC results BC6 – residential ESS

Table 56: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC6 – residential ESS

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.08	0.001	0.05	0.001	0.01	0.000	0.14	0.002
AP	g SO2 eq.	0.73	0.006	0.24	0.002	0.13	0.001	1.10	0.009
VOC	g	0.02	0.000	0.03	0.000	0.00	0.000	0.05	0.000
POP	ng i-Teq	0.05	0.000	0.00	0.000	0.01	0.000	0.06	0.000
HM1	mg Ni eq.	0.17	0.000	0.00	0.000	0.02	0.000	0.19	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.01	0.000	0.00	0.000	0.01	0.000
PAH	mg Ni eq.	0.16	0.000	0.00	0.000	0.06	0.000	0.23	0.000
PM	g	0.08	0.001	0.01	0.000	0.02	0.000	0.10	0.002
Total			0.009		0.003		0.002		0.013

5.3.2.7. Detailed societal LCC results BC7 – commercial ESS

Table 57: Details of the societal Life Cycle Cost (marginal external damages) per FU for BC7 – commercial ESS

	Unit	Production & distrubution emissions mass [unit]	PPext [EUR]	Use phase emissions mass [unit]	OEext [EUR]	EoL emissions mass [unit]	EOLext [EUR]	TOTAL emissions mass [unit]	TOTAL LCext [EUR]
GHG	kg CO2 eq.	0.08	0.001	0.05	0.001	0.01	0.000	0.14	0.002
AP	g SO2 eq.	0.73	0.006	0.24	0.002	0.13	0.001	1.10	0.009
VOC	g	0.02	0.000	0.03	0.000	0.00	0.000	0.05	0.000
POP	ng i-Teq	0.05	0.000	0.00	0.000	0.01	0.000	0.06	0.000
HM1	mg Ni eq.	0.17	0.000	0.00	0.000	0.02	0.000	0.19	0.000
HM2	mg Ni eq.	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
HM3	mg Ni eq.	0.00	0.000	0.01	0.000	0.00	0.000	0.01	0.000
PAH	mg Ni eq.	0.16	0.000	0.00	0.000	0.06	0.000	0.23	0.000
PM	g	0.08	0.001	0.01	0.000	0.02	0.000	0.10	0.002
Total			0.009		0.003		0.002		0.013

5.4. Subtask 5.4 – EU totals

The stock and market data from section 5.1.2.3 are used to aggregate the data from subtask 5.2 (LCA) and 5.3 (LCC) to EU-28 level.

The total energy use due to direct and indirect losses is calculated per BC with the following formula:

- EU total energy use per year = stock [application units] * energy use per application [kWh/year]

  In which: the number of application units in stock was determined by dividing the installed capacity by the typical capacity of the application.

Table 58 shows the total energy use due to losses in the use stage per BC and all BCs calculated for the EU for the reference year 2018. The assessed battery systems in **EU-28 consumed in 2018 0.89 TWh**.

Table 58: EU total of the total energy use during use stage of the assessed battery application systems (reference year 2018)

	Installed capacity [GWh]	Nominal battery system capacity [kWh]	Stock [battery units]	Typical application capacity [kWh]	Stock [application units]	Energy use per application [kWh/year]	Total energy use for EU [TWh/yr]
BC1 – PC BEV HIGH	6.79	80	84 877	80	84 877	813	0.07
BC2 – PC BEV LOW	18.89	40	472 348	40	472 348	511	0.24
BC3 – PC PHEV	10.04	12	836 283	12	836 283	366	0.31
BC4 – Truck BEV	0.20	30	6 600	360	550	12 659	0.01
BC5 – Truck PHEV	0.16	20	8 000	160	1 000	14 278	0.01
BC6 – Resid. ESS	6.83	10	682 811	10	682 811	274	0.19
BC7 – Com. ESS	2.27	10	226 510	30 000	76	821 739	0.06
Total	45.17		2 317 428				0.89

The total Net Present Value of the annual LCC over the economic lifetime of the sold applications in 2018 is calculated per BC with the following formula:

- EU total NPV [EUR/yr] = sales [applications units] * LCC [EUR/appl.] / Tapp [yr]

  In which: the number of sold application units was determined by dividing the sold capacity by the typical capacity of the application.

The results of calculating the EU total NPV based on reference year 2018 are presented in Table 59 showing that the assessed battery systems in **EU-28 sums up to an NPV of the annual total LCC of the applications sold in 2018 of about 435 MEUR**.

Table 59: EU total of the total NPV of the annual life cycle costs of the assessed battery application systems over their economic lifetime (reference year 2018)

	Sold capacity [GWh]	Typical application capacity [kWh]	Sales [application units]	LCC [EUR/appl,]	Economic lifetime of application (Tapp) [yr]	Total NPV for EU [MEUR/yr]
BC1 – PC BEV HIGH	2.76	80	34 552	20 152	13	53.56
BC2 – PC BEV LOW	5.99	40	149 694	16 179	14	172.99
BC3 – PC PHEV	2.58	12	214 974	7 401	13	122.39
BC4 – Truck BEV	0.02	360	69	166 397	14	0.82
BC5 – Truck PHEV	0.03	160	200	111 511	12	1.86
BC6 – Resid. ESS	0.95	10	95 105	11 723	20	55.75
BC7 – Comm. ESS	0.50	30 000	17	33 328 317	20	27.75
Total	12.84					435.12

5.5. Comparison with the Product Environmental Footprint pilot

This section compares the results of the environmental LCA executed within this preparatory study with the EcoReport 2014 tool according to the MEErP format with the results of the Product Environmental Footprint (PEF) pilot on rechargeable batteries. The PEF method was developed by the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC), a Directorate General of the EC upon mandate of the EC Directorate General Environment (DG ENV). The PEF is a harmonised methodology for the calculation of the environmental performance of products (i.e. goods and/or services) from a life cycle perspective.

Annex B contains a comparison of the MEErP environmental impact categories with PEF environmental impact categories. Both methodologies apply different principles (e.g. regarding end-of-life). **The comparison included in this preparatory study is just to verify whether the order of magnitude of the results is in the same range.**

In the rechargeable batteries PEF pilot, the following four batteries were assessed: Li-ion in cordless power tools, Li-ion in ICT, NiMH in ICT, and Li-ion in e-mobility. Only the latter is comparable with two of the seven BCs within this preparatory study, i.e. BC1 and BC2 the BEV passenger car. The only impact category that is directly comparable (same environmental impact and expressed in a similar unit) is the impact category 'global warming' (see Annex B). **Only the impact caused in the production phase are compared, as the scenarios for the distribution, use phase, and EOL within the MEErP methodology are very different to the one in the PEF pilot.**

Table 60 gives an overview of the comparison. Although BC1 and BC2 have a higher battery weight than the PEF battery, the results per FU are lower for the two BCs in comparison with the PEF battery due to the higher amount of total energy delivered over the lifetime. But when looking at the distribution of the GWP impact in the production phase between the raw material acquisition and the manufacturing and the GWP impact per kg battery, the figures are comparable:

- The share between the raw materials and the manufacturing for the PEF is 63/37 % and for the BCs it is 66/34 %.
- The GWP results per kg battery is for the PEF pilot 13.7 kg CO_2 eq./kg and for the two BCs 14.14 kg CO_2 eq./kg.

Table 60: Overview of the comparison between the e-mobility Li-ion battery of the PEF pilot and BC1 – passenger car BEV.

	PEF e-mobility Li-ion	BC1 PC BEV HIGH	BC2 PC BEV LOW
Specifications			
Battery weight [kg]	225	609	304
Number of battery application systems per Tapp (Ass) [-]	1	1	2
Total energy delivered over the lifetime [kWh]	8 000	43 680	29 568
Conversion to unit analysis [kg/kWh]	0.028	0.014	0.021
GWP results production phase [kg CO_2 eq./FU[16]]	[17]		
Raw material acquisition	0.244 (63.4%)	0.129 (65.6%)	0.191 (65.6%)
Manufacturing of the product	0.141 (36.6%)	0.068 (34.3%)	0.100 (34.4%)
Total production phase	0.385	0.197	0.290
GWP results per kg battery application system [kg CO_2 eq./kg]	[18]		
Raw material acquisition	8.66	9.28	9.28
Manufacturing of the product	5.05	4.86	4.86
Total production phase	13.70	14.14	14.14

[16] Functional unit is defined in Task 1 as '1 kWh (kilowatt-hour) of the total output energy delivered over the service life by the battery system (measured in kWh)'

[17] The amounts of the PEF pilot are calculated based on the figures provided within the LCI excel PEF batteries; G version - April 2017 (received on 18/02/2018 by the project team from Recharge). By taking the shares of the life cycle stages, i.e. 45.1 % and 26.3 % (sheet 'Most relevant LCS'), and multiplying them with the total life cycle impact, i.e. 0.543 (sheet 'Benchmark').

[18] The amounts of the PEF pilot are calculated based on the calculated GWP results per FU (see footnote 17) and multiplying them with 8 000/225.

5.6. Comparison with other literature sources

A similar comparison to check whether the order of magnitude of the results is in the same range can be done with other literature. Based on Peters et al. paper review, the average GHG emissions for battery production across all chemistries are **110 kg CO_2 eq. per kWh of storage capacity**. The results for the different battery chemistries are presented in Figure 8 (Peters, et al. 2017). An overview of the GWP impact per kWh storage capacity and per kg battery of all BCs are given in Table 61, please bear in mind that the BCs are a conscious abstraction of the reality of complete battery application systems compiled of a mix of battery chemistries.

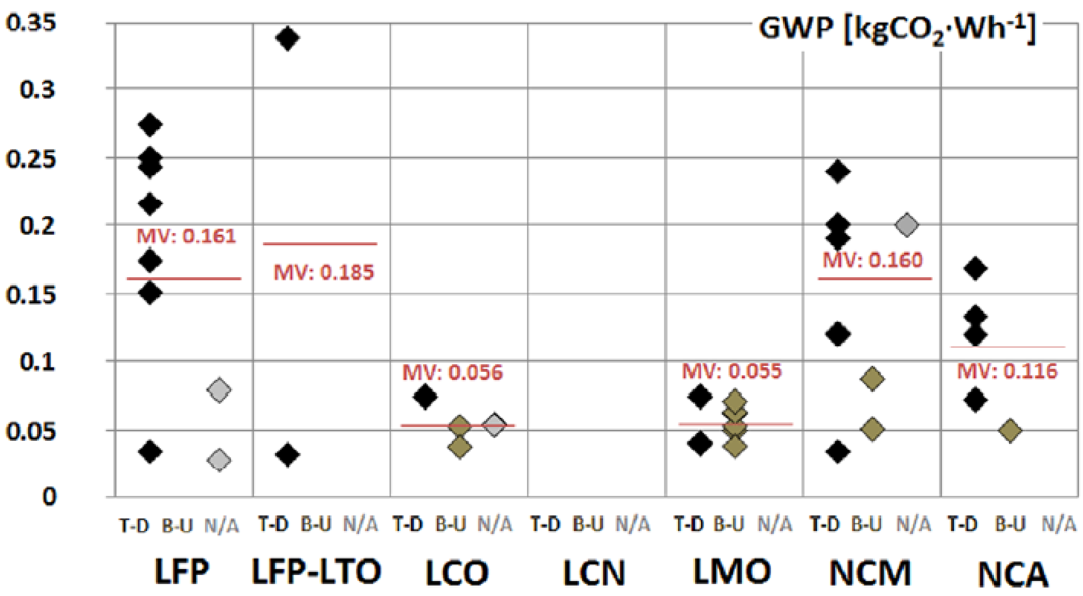


Figure 8: GWP results obtained for different battery chemistries. T-D: Top-Down modelling; B-U: Bottom-up; N/A: not given. MV: mean value (Peters, et al. 2017)

Table 61: Overview of the GWP impact [kg CO_2 eq.] per kWh storage capacity and kg battery of the Base Cases (based on the EcoReport calculations)

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
GWP results per kWh storage capacity [kg CO_2 eq./kWh]							
Raw material	70.57	70.57	93.98	72.75	93.98	89.35	89.35
Manufacturing	36.96	36.96	51.93	41.52	51.93	64.50	64.50
Total production	107.53	107.53	145.91	114.27	145.91	153.85	153.85
GWP results per kg battery application system [kg CO_2 eq./kg]							
Raw material	9.28	9.28	8.95	8.53	8.95	6.99	6.99
Manufacturing	4.86	4.86	4.94	4.87	4.94	5.04	5.04
Total production	14.14	14.14	13.89	13.40	13.89	12.03	12.03

In the recent study in support of the evaluation of the Battery Directive an amount of 26 kg CO_2 eq./kg battery is assumed as a upper range of values for Li-ion batteries (Trinomics, Öko-

Institut and EY 2018) which is almost twice as high as our calculated results. The study did not disclose the details of this assumption. A possible explanation of the big difference could be because of the comparison between cells (Battery Directive) and battery application systems (this study).

5.7. Conclusions

An environmental LCA and economic LCC assessment have been carried out for all seven BCs based on the BOM (see section 5.1.3.1.1 - 5.1.3.1.7, based on Task 4). A complete overview of the assumed parameters of the seven BCs is provided in Table 1.

Detailed results of the LCA and LCC assessments are included in section 5.2 and 5.3 respectively. Table below summarizes the life cycle impact per FU for all BCs.

Table 62: Concluding overview of the LCA and LCC results of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Total energy (GER) per FU [MJ/kWh]	5.69	7.37	5.41	3.29	3.16	2.69	2.19
Water (process + cooling) per FU [L/kWh]	1.26	1.86	1.04	0.55	0.46	0.48	0.37
Waste, non-haz./ landfill per FU [g/kWh]	31.85	46.51	23.87	13.63	10.94	10.51	8.17
Waste, haz./ incinerated per FU [g/kWh]	0.54	0.78	0.61	0.26	0.28	0.36	0.35
Greenhouse Gases in GWP100 per FU [kg CO2 eq./kWh]	0.27	0.35	0.25	0.15	0.14	0.12	0.10
Acidification, emissions per FU [g SO2 eq./kWh]	3.78	5.39	2.20	1.53	1.12	0.85	0.71
Volatile Organic Compounds (VOC) per FU [g/kWh]	0.11	0.15	0.10	0.07	0.06	0.05	0.04
Persistent Organic Pollutants (POP) per FU [ng i-Teq/kWh]	0.07	0.10	0.08	0.03	0.04	0.04	0.03
Heavy Metals to air per FU [mg Ni eq./kWh]	0.75	1.09	0.51	0.28	0.23	0.16	0.13
PAHs per FU [mg Ni eq./kWh]	0.25	0.37	0.26	0.12	0.12	0.11	0.11

Continuation of Table 62: Concluding overview of the LCA and LCC results of the Base Cases

	BC1 PC BEV HIGH	BC2 PC BEV LOW	BC3 PC PHEV	BC4 Truck BEV	BC5 Truck PHEV	BC6 Resid. ESS	BC7 Comm. ESS
Particulate Matter (PM, dust) per FU [g/kWh]	0.25	0.36	0.19	0.10	0.09	0.08	0.07
Heavy Metals to water per FU [mg Hg/20/kWh]	0.51	0.75	0.34	0.21	0.15	0.14	0.13
Eutrophication per FU [g PO4/kWh]	0.12	0.17	0.08	0.05	0.04	0.03	0.02
LCOE or LCC per FU [EUR/kWh]	0.461	0.547	0.377	0.177	0.125	0.293	0.278
LCC total for all batteries in application per Tapp [EUR/appl.]	20 152	16 179	7 401	166 397	111 511	11 723	33 328 317

The production phase has the biggest contribution on the total life cycle impact in all impact categories. When looking at the production phase in more detail, the cathode active material is noticeable as a big contributor to the environmental impact across different impact categories.

The xEV passenger car BCs result in a bigger environmental impact per kWh delivered over their lifetime in comparison with the truck and ESS BCs.

The BEV passenger car BCs have the highest LCOE and the truck BCs the lowest. However when looking at the total LCC the costs for the commercial ESS (BC7) stands out in comparison with the other BCs, due the big number of batteries in the commercial ESS application.

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Annex A: Materials added to the MEErP EcoReport tool

Due to the structure of the life cycle inventory, it is not possible to distinguish between process water and cooling water. The water input mentioned under process water is an input for both cooling and process water. It is also not possible to make a distinction between primary electric energy and feedstock.

Name material	Primairy Energy (MJ)	Electr energy (MJ)	feedstock	water proces	Water cool	waste haz	waste non	GWP	AD
New Materials production phase (category **'Extra'**)	MJ	MJ	MJ	L	L	g	g	kg CO2 eq.	g SO2 eq.
NCM622	253.17	113.93		190.62		0.46	7 447.29	19.17	1 070.60
NCM424	230.00	110.40		168.93		0.44	6 289.89	17.60	751.10
NCM111	254.44	124.68		196.19		0.47	6 168.18	19.42	669.03
NCM532	244.70	112.56		181.29		0.46	6 897.22	18.53	915.06
LMO	45.34	23.12		53.22		0.12	1 835.15	2.85	11.83
NCA	290.28	124.82		220.87		0.51	8 995.14	22.08	1 405.11
LFP	57.28	9.74		81.76		0.23	3 609.14	3.60	22.12
Carbon	81.67	0.00		2.21		0.02	76.87	1.87	9.85
PVDF	218.38	109.19		171.93		0.30	1 099.65	15.30	71.33
ZrO2	68.56	32.22		84.57		0.14	540.44	4.83	27.04
Graphite	81.67	0.00		2.21		0.02	76.87	1.87	9.85
CMC	88.66	26.60		55.62		0.17	364.92	3.48	21.81
LiPF6	76.99	19.25		83.79		0.66	11 949.90	6.24	35.38
LiFSI	324.36	129.74		377.25		0.62	13 052.61	21.57	199.60
EC (Ethylene carbonate)	41.46	7.05		16.03		0.02	153.20	1.62	5.89
DMC (Dimethyl carbonate)	58.40	10.51		20.29		0.04	206.10	2.21	8.34
EMC (Ethyl methyl carbonate)	58.40	10.51		20.29		0.04	206.10	2.21	8.34
PC (Propylene carbonate)	112.22	22.44		52.85		0.00	150.61	7.87	24.91
Hydrochloric acid	16.41	10.42		24.58		0.05	156.14	0.75	5.92
n-Methylpyrolidone (NMP)	137.80	37.21		283.26		0.14	588.01	7.10	32.13

Name material	VOC	POP	HMa	PAH	PM	HMw	EUP
New Materials production phase (category **'Extra'**)	g	ng i-Teq	mg Ni eq.	mg Ni eq.	g	mg Hg/20	mg PO4
NCM622	9.51	8.31	219.23	5.59	49.37	117.06	21 116.60
NCM424	8.41	6.72	160.78	4.92	42.73	79.96	16 131.82
NCM111	11.06	7.16	154.02	5.76	49.83	67.93	16 018.92
NCM532	9.02	7.56	191.02	5.33	46.33	98.62	18 785.00
LMO	0.76	0.61	8.83	0.95	2.44	1.12	1 395.56
NCA	9.96	10.07	283.14	6.24	55.63	156.50	26 768.56
LFP	1.36	1.25	16.29	1.54	4.56	9.09	4 302.12
Carbon	1.32	0.18	3.87	0.58	2.76	0.21	3 433.80
PVDF	2.47	4.69	36.71	3.23	28.34	2.80	6 993.95
ZrO2	1.47	1.13	18.90	1.93	10.01	1.56	2 778.68
Graphite	1.32	0.18	3.87	0.58	2.76	0.21	3 433.80
CMC	1.08	3.39	13.57	1.58	8.07	0.98	3 488.81
LiPF6	2.09	1.43	35.46	3.13	9.41	6.76	4 099.76
LiFSI	6.28	6.44	127.55	8.48	38.12	9.30	20 341.55
EC (Ethylene carbonate)	1.21	0.25	7.11	0.47	1.87	0.29	598.75
DMC (Dimethyl carbonate)	1.43	0.78	10.02	0.74	2.88	0.52	1 842.94
EMC (Ethyl methyl carbonate)	1.43	0.78	10.02	0.74	2.88	0.52	1 842.94
PC (Propylene carbonate)	4.19	0.08	6.86	0.11	7.72	0.08	625.25
Hydrochloric acid	0.22	0.21	6.68	0.42	1.02	0.86	580.76
n-Methylpyrolidone (NMP)	3.35	3.06	24.60	2.54	11.44	1.44	13 409.32

Annex B: Product environmental footprint compared to MEErP Ecoreport tool

The Product Environmental Footprint (PEF) method[19] was developed by the European Commission as part of the Single Market for Green Products Initiative[20]. The European Commission proposes the PEF method as a common way of measuring environmental performance of products. During several pilot projects[21], Product Environmental Footprint Category Rules (PEFCR) were developed for several product groups. One of these product groups was the product group of ‘Rechargeable batteries’.

In 2005, the Methodology for Ecodesign of Energy-using Products (MEEuP) was developed for assessing whether and which ecodesign requirements are appropriate for energy-using products under the Ecodesign Directive. Following the revision of the Ecodesign Directive and the extension of its scope to energy-related products in 2009, the Commission reviewed the effectiveness of the MEEuP with a view to extend it to energy-related products. The updated methodology MEErP has been endorsed by the Ecodesign Consultation Forum of 20 January 2012 and shall be used as basis for ecodesign and energy labelling preparatory studies. The MEErP methodology consists of seven tasks, of which Task 5 is on ‘Environment and Economics’. For MEErP assessments a reporting tool called EcoReport was developed that facilitates the necessary calculations to translate product-specific characteristics into environmental impact indicators per product.

This annex compares the impact categories used in the PEF methodology and the MEErP methodology (subtask 5.2 environmental impact assessment), which have both been developed to assess the environmental impact of products.

Environmental impact categories

PEF considers 16 environmental impact categories; MEErP considers 13 environmental impact categories. Table 63 gives an overview of the impact categories considered in both methodologies. Common impact categories are ‘Climate change’, ‘Particulate matter’, ‘Acidification’, ‘Eutrophication’ and ‘Water use’. Only the impact category climate change is expressed in a common unit.

[19] Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations

[20] http://ec.europa.eu/environment/eussd/smgp/index.htm

[21] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

Table 63: Impact categories considered in PEF and MEErP

PEF[22]		**MEErP**[23]	
Impact category	**Unit**	**Impact category**	**Unit**
Climate change	kg $CO_{2\ eq}$	Greenhouse Gases in GWP100	kg CO_2 eq.
Ozone depletion	kg CFC-11 $_{eq}$	/	/
Human toxicity, cancer	CTUh	/	/
Human toxicity, non-cancer	CTUh	/	/
Particulate matter	disease incidence	Particulate Matter (PM, dust)	g
Ionising radiation, human health	kBq $U^{235}{}_{eq}$	/	/
Photochemical ozone formation, human health	kg NMVOC $_{eq}$	/	/
Acidification	mol $H+_{eq}$	Acidification, emissions	g SO_2 eq.
Eutrophication, terrestrial	mol N $_{eq}$	/	/
Eutrophication, freshwater	kg P $_{eq}$	Eutrophication (water)	g PO_4
Eutrophication, marine	kg N $_{eq}$	/	/
Ecotoxicity, freshwater*	CTUe	/	/
Land use	• Dimensionless (pt) • kg biotic production • kg soil • m^3 water • m^3 groundwater	/	/

[22] Impact categories taken from 'Product Environmental Footprint Category Rules Guidance', European Commission, version 6.3 – May 2018.
[23] Impact categories taken from MEErP ecoreport tool version 2014.

PEF[22]		MEErP[23]	
Impact category	**Unit**	**Impact category**	**Unit**
Water use	m^3 world $_{eq}$	Process water and cooling water	ltr
Resource use, minerals and metals	kg Sb $_{eq}$	/	/
Resource use, fossils	MJ		
		Total energy	MJ
/	/	Waste, non-haz./ landfill	g
/	/	Waste, hazardous/ incinerated	g
/	/	Volatile Organic Compounds (VOC) to air	g
/	/	Persistent Organic Pollutants (POP) to air	ng i-Teq
/	/	Heavy metals to air	mg Ni eq.
/	/	PAHs to air	mg Ni eq.
/	/	Heavy metals to water	mg Hg/2O