Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1

TASK 7 Report

Policy Scenario Analysis

VITO, Fraunhofer, Viegand Maagøe

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Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

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Project website: https://ecodesignbatteries.eu/

Version history:

Version 1: Draft for discussion in the stakeholder meeting of 2/5/2019

Version 2: Updated version taking into account the written feedback from the stakeholders and those of the stakeholder meeting.

Main changes in the policy analysis are:

- In the carbon footprint requirements some recommendations are added to review/simplify the PEFCR to be used.
- Separate information requirements are added for battery cells to be used in the intended application.
- The information requirements are split in a list with information about batteries and cells to be stored in a European database, and in traceability of battery modules and packs to be stored with help of a public-private initiative.
- The minimum warranty has been better clarified.
- The proposed Recyclability index is renamed to R-R-R-R index, since it sustains all phases of repair, re-use, repurpose and recycle.
- In the other minimum battery pack design and construction requirements a requirement has been added to provide a vehicle-to-grid (V2G) and complementary vehicle-to-test (V2test) interface.

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ABBREVIATIONS

Abbreviations	Descriptions
AC	Alternating current
AD	Acidification
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
Ah	Ampere-hour
Al	Aluminum
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
AS	Application service energy
BAT	Best Available Technologies
BAU	Business As Usual
BC	Base case
BEV	Battery Electric Vehicle
BJB	Battery junction box
BMS	Battery Management System
BNAT	Best Not-yet Available Technologies
BOM	Bill-of-Materials
C	Capacity
CAPEX	Capital Expenditure
Cd	Cadmium
CE	European Conformity
CED	Cumulative energy demand
CF	Characterisation Factor
CIT	International Rail Transport Committee
CMC	Carbon methyl cellulose
C_n	Rated capacity
CNT	Carbon nanotube
Co	Cobalt
CPA	Statistical Classification of Products by Activity
CPE	Composite polymer electrolytes
CPT	Cordless Power Tools
CRM	Critical Raw Materials
DC	Direct Current
DEC	Diethyl carbonate
DG	Directorate General
DMC	Dimethyl carbonate
DoC	Declaration of Conformity
DOD	Depth of Discharge
E	Energy
EC	European Commission
EC	Ethylene carbonate
ECHA	European Chemicals Agency
ED	Ecodesign Directive

Abbreviations	Descriptions
EDLC	Electrical Double-Layer Capacitor
EEI	Energy efficiency index
EGDME	1, 2-dimethoxyethane or ethylene glycol dimethyl ether
ELR	Energy Labelling Regulation
ELV	End of Life of Vehicles
EMC	Ethyl Methyl Carbonate
EOL	End-of-Life
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EPTA	European Power Tool Association
eq.	equivalent
E_{Rated}	Rated energy
ESS	Electrical Energy Storage Systems
EU	European Union
EU-28	28 Member States of the European Union
EUP	Eutrophication
EV	Electric vehicle
FC	Full cycle
Fe	Iron
FESS	Flywheel energy storage systems
FTP	Federal Test Procedure
FU	Functional Unit
GER	Gross Energy Requirements
GHG	Greenhous Gases
GVW	Gross vehicle weight
GWP	Global warming potential
HDT	Heavy-duty truck
HDTU	Heavy-duty tractor unit
HE	High-energy
HEV	Hybrid Electric Vehicle
Hg	Mercury
HMa	Heavy metals to air
HMw	Heavy metals to water
HREEs	Heavy rate earth elements
HV	High-voltage
I	Current
IATA	International Air Transport Association
ICEV	Internal combustion engine vehicles
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IM	Implementing Measure
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
ISO	International Organization for Standardization
I_t	Reference test current
JRC	Joint Research Centre

Abbreviations	Descriptions
kWh	Kilowatt hour
LCA	Life Cycle Assessment
L_{Cal}	Calendar life
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LCO	Lithium-ion Cobalt Oxide
LCOE	Levelized Cost Of Energy
LCV	Light commercial vehicles
L_{Cyc}	Cycle life
LFP	Lithium-Ion Phosphate
Li	Lithium
LIB	Lithium ion battery
Li-Cap	Lithium-ion Capacitor
LiFSI	Lithium bis(fluorosulfonyl) imide
LiPF6	Lithium Hexaflurophosphate
LLCC	Least Life Cycle Costs
LMNO	Lithium-Ion Manganese Nickel Oxide
LMO	Lithium Manganese Oxide
LMP	Lithium-Metal-Polymer
LREEs	Light rare earth elements
LTO	Lithium-Ion Titanate Oxide
LVD	Low Voltage equipment
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy-using Products
Mn	Manganese
NACE	Statistical Classification of Economic Activity
$NaNiCl_2$	Sodium nickel chloride
NaS	Sodium-sulphur
nC	C-rate
NCA	Lithium Nickel Cobalt Aluminium
NCM	Lithium Nickel Manganese Cobalt Oxide
NEDC	New European Driving Cycle
Ni	Nickel
NiCd	Nickel-Cadmium
NiMH	Nickel-metal hydride
NMC	Lithium-ion Nickel Manganese Cobalt Oxide
NPV	Net Present Value
OCV	Open Circuit Voltage
OPEX	Operational expenditure
P	Phosphor
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
Pb	Lead-acid
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PC	Passenger car

Abbreviations	Descriptions
PC	Propylene Carbonate
PCM	Protection Circuit Module
PCR	Product Category Rules
PE	Polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PEm	Primary energy for manufacturing
PEM-FC	Proton exchange membrane fuel cell
PEr	Primary energy for recycling
PGMs	Platinum Group metals
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
POP	Persistent Organic Pollutants
PP	Polypropylene
PRODCOM	Production Communautaire
PTC	Positive Thermal Coefficient
PV	Photovoltaic
PVD	Physical vapour deposition
PVDF	Polyvinylidene fluoride
PWF	Present Worth Factor
Q_{FU}	Quantity of functional units
R	Internal resistance
R&D	Research and Development
RE	Round-trip efficiency
REACH	Regulation on the registration, evaluation, authorisation and rustication of chemicals
RFB	Redox-flow battery
RID	International Carriage of Dangerous Goods by Rail
RoHS	Restriction of hazardous substances
RRR	Recyclability, Recoverability, Reusability
RT	Room temperature
SASLAB	Sustainability Assessment of Second Life Application of Automotive Batteries
Sb	Antimony
SBR	Styrene-Butadiene Rubber
SD	Self-discharge
SEI	Solid-electrolyte interphase
Si	Silicon
SOC	State of Charge
SOH	State of Health
SOH_{cap}	Capacity degradation
SPE	Solid polymer electrolyte
SVHC	Substances of Very High Concern
T	Time
TIM	Thermal interfacial material
TMS	Thermal Management System
TOC	Total Cost of Ownership

Abbreviations	Descriptions
TRL	Technology Readiness Level
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UPS	Uninterruptible Power Supply
V	Voltage
VAT	Value Added Tax
VKT	Vehicle kilometres travelled
V_L	Voltage limits
V_{OC}	Open circuit voltage
VOC	Volatile Organic Compounds
vPvB	Very persistent and very bio accumulative
V_R	Rated voltage
WEEE	Waste electrical and electronic equipment
WLTP	Worldwide Harmonized Light Vehicle Test Procedure
WVTA	Whole Vehicle Type-Approval System
ZrO2	Zirconium Oxide
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e. V.
η_E	Energy efficiency
η_V	Voltaic efficiency

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7. Task 7: Policy Scenario Analysis

AIM OF TASK 7

This task identifies and discusses in Task 7.1 policy options aimed at reducing the impacts on the environment as analysed in previous tasks. It provides in Task 7.2 and Task 7.3 an analysis of the impacts of future scenarios in line with policy measures that could be introduced at EU level. This is a key task as it combines the results of the previous tasks. It discusses potential Ecodesign and/or Energy Labelling Regulation policy measures, and it is aimed at providing an analytical basis in support of the Ecodesign decision-making process. Therefore, a set of quantitative scenarios is defined. To this end, a stock model has been developed to estimate environmental and economic impacts according to future stocks and to different improvement scenarios. The outcomes of the expected improvement are compared with a Business-as-Usual scenario.

SUMMARY OF TASK 7

This document describes a set of policy options for battery systems, packs and cells within the scope proposed in Task 1, i.e. high energy rechargeable batteries of high specific energy with lithium chemistries for e-mobility and stationary energy storage batteries excluding power electronics and heat or cool supply systems. The environmental impact improvement and the key parameters to do this were previously discussed in Task 6, while this Task 7 discusses how they can potentially be converted into policy. For defining policy measures this task is built on previous work done by JRC[1] on 'Standards for the performance assessment of electric vehicle batteries (2018)'. Relative to the proposed policy options this task also analyses and models impact scenarios. This is a reviewed version elaborated after consulting stakeholders in a meeting and collecting feedback in writing. A summary of stakeholder positions with regards to the proposed policy is included as a support to the subsequent policy making process.

Be aware that in parallel to this study the EC hosts a website that provides the latest information for the related regulation making process and that information included in this report can be outdated, therefore please consult also:

https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053_en

Please consult the EC website for a summary on proposed policy and expected impact.

7.1. Policy Analysis

Aim of Task 7.1:

The aim is to identify policy options considering the outcomes of all previous tasks.

[1] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC113420/kjna29371enn.pdf

7.1.1. Scoping of possible policy requirements and key definitions

Objective:

This section describes the prospective boundaries or 'battery' definitions to address the eco-design performance improvement from this study. The proposed policy measures themselves and potential legislative instruments to be used are discussed in subsequent sections.

Proposal:

In line with Task 1 the proposed scope is 'high energy rechargeable batteries of high specific energy with solid lithium cathode chemistries for e-mobility and stationary energy storage (if any)'.

High specific energy is hereby defined by a gravimetric energy density 'typically' above 100 Wh/kg at cell level.

High capacity means that a total battery system capacity between 2 and 1000 kWh.

(see Task 1 for more details).

This does not include power electronics neither heat or cool supply systems for thermal management which can be part of what the study defined as a battery *application* system.

Note that a scope extension for certain of the proposed policy measures will be discussed in a later section 7.1.3.

Terms and definitions can be in line with IEC/ISO standards (see Task 1); however there is still a lack of clear definitions regarding some material efficiency issues. The following definitions are proposed for the terms repair, reuse, remanufacture and repurposing. They are in line with the draft standards on material efficiency under preparation as part of request (M/543) to develop horizontal, generic standards for future product publications covering a specific energy-related product (ErP) or group of related ErPs.

Note: A new complementary study is launched to explore the extension of the scope and to work as technology neutral as possible in formulating the scope of any future regulation. For this consult the project website: https://ecodesignbatteries.eu/planning

7.1.2. Proposed requirements to consider in policy measures

Note that this section is independent of the later policy instruments to be used and several aspects could be implemented under the scope of other legislation e.g.: Battery Directive, ELV Directive, UNECE Regulation, etc. This will need to be considered in a later stage of policy making. For more information on this please consult the website of the European Commission: https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053_en

Requirements are proposed on the following topics:

– Minimum battery pack/system lifetime
– Battery management systems
– Providing information about batteries and cells to be stored in a European database
– Traceability of battery modules and packs to be stored with help of a public-private initiative
– Carbon footprint information and considering the option for a threshold

- Minimum battery pack design and construction to support reusability/recyclability/recoverability.
- A ‘R-R-R-R’ index that follows from previous subject supporting all phases of repair, re-use, repurpose and recycle.
- Hardware requirements for a BMS open data diagnostics connector and for Vehicle to Grid and Vehicle to Test mode DC interface.

At the end of the section policy requirements are discussed that were considered but not proposed.

7.1.2.1. Minimum battery pack/system lifetime requirements

Rationale:

The switch from fossil-fuelled vehicles to battery-based vehicles should win the trust of the European public. The same applies to batteries that are used in stationary applications linked to the electricity grid such as storage of PV energy in households. To gain this trust, it must be demonstrated that the batteries have a long service life and that energy waste is minimised. High upfront cost and lack of confidence can be important barriers hindering the uptake of e-mobility solutions and of domestic/community energy storage solutions. Additionally, prolonging the lifetime of batteries into a second life application is an intuitive approach to reduce its carbon footprint and also economic value along the life cycle provided that the battery is prepared for this change.

Hence the main objective of requirements is to reduce the carbon footprint per functional unit as modelled in Task 5 by warranting its projected useful lifetime. The rationale is clear: it serves to ensure that those products at least perform as they were assumed in previous tasks for the base case in a first Tier (see timing), see Table 7-1.

Table 7-1 Battery pack/system Lifetime related performance data from previous Tasks

	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
Service life of battery (Tbat) [y]	14.40	13.43	10.67	8.04	5.33	17.02	17.02
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
Self-discharge (@STC) [%]	2	2	2	2	2	2	2

In order to support the previous lifetime and related performance assumptions, the following technical parameters are important to consider:

- Capacity, expressed in Ah as is common practice for batteries.
- Energy expressed in kWh. From the energy also the study's base criterion (100 Wh/kg at cell level) can be examined.
- Power capability, especially of importance for power intensive applications like PHEV cars, since power capability can be limiting before the capacity decrease limits the battery use in such an application.
- Energetic efficiency, expressed as a percentage, of importance for the carbon footprint during use phase. It is the ratio of discharge and charge energy. The value is influenced by power profile for charging and discharging, cut-off voltage and temperature. The method has thus to be described.

The last two parameters are closely related to the internal ohmic resistance of the battery. That is why an additional requirement can be imposed on resistance. Internal ohmic resistance was also recommended in the EU funded H2020 Everlasting project[2], see Deliverable 'D8.7 – White Paper 04: Definition of SOH' (5/2018)'.

[2] https://everlasting-project.eu/results/deliverables-reports/

An important criterion for batteries is calendar life. Batteries age over time despite that they are not used. However it is hardly covered by test standards: only one standard prescribes such a test (see the Appendix to Task 1). At 25°C a calendar life test takes the time of the envisaged application, so at least 13 years. Increasing the temperature reduces the test time but the predictability is subject of debate. Moreover, by reducing the SOC during periods of rest, the battery ageing can be slowed down. This allows for intelligent control. Since calendar life ageing is a main source of battery deterioration, while test methods with threshold values are difficult to envisage, an alternative approach is prerequisite, which we propose to be a warranty by the manufacturer. The manufacturer declares and warrants a calendar life before which the battery has a capacity fade of less than 20% of the declared capacity. This capacity is not necessarily the initial capacity of the battery. In this way the effect of a possible quick initial capacity fade before entering a steady capacity reduction over time can be taken into account by setting the declared capacity lower than the initial capacity. This is elucidated by Figure 7-1. In future new ownership models for passenger cars will appear that increase their utilisation. The maximum number of cycles will be reached in a shorter time-span, reducing the influence of calendar life on ageing.

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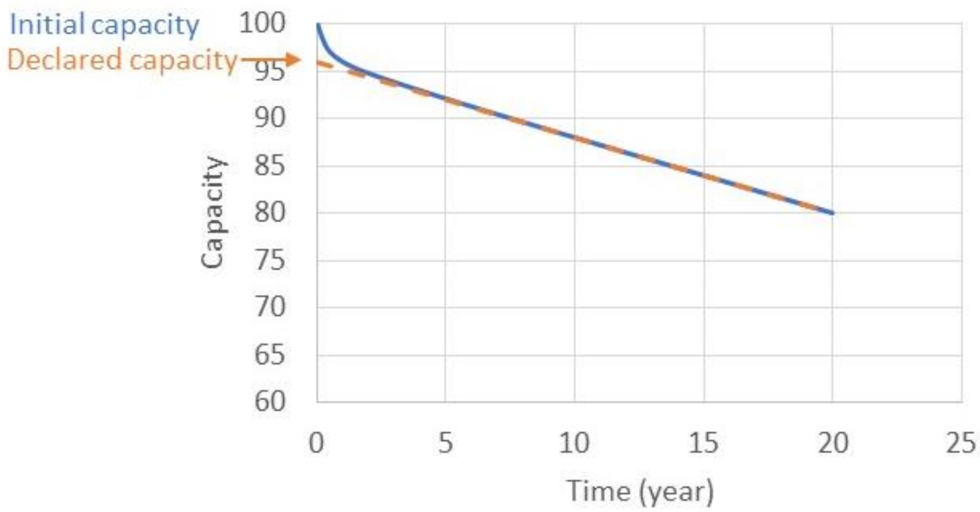

Figure 7-1: Concept of initial capacity and declared capacity based on an exemplary ageing curve for batteries.

When defining the requirements, see Table 7-2, the following aspects were taking into account:

- Preference was given to shorter lifetime test period with increased thresholds, e.g. 90 % instead of 80 % of declared capacity, because this can shorten laboratory and market surveillance testing.
- They are in the parameters of the Business as Usual scenario in Task 5. They are however not the Task 6 options because they were based on own assumptions which is too weak to provide a threshold. Hence in a later policy Tier only, those requirements could be raised when more data and validation becomes available.
- They are in line with but more ambitious than warranty claims currently offered.
- The relative short lifetime test period used to set requirements are still in line with their new defined ‘functional Energy Efficiency Index (fEEI)’, see later section 7.1.2.4. It

refers to the kWh stored over its lifetime relative to the embodied primary or gross energy requirement (GER) for manufacturing.

Note that when defining requirements it should also be considered that:

- The calendar life warranty depends on the application.
- With both e-mobility and stationary energy storage in scope, the study scope covers a wide range of applications, such as battery-powered passenger cars and trucks, their plug-in vehicle variants, and also grid stabilization support and home batteries. This is described in task 5 with the selection of base cases. The subjects listed for which requirements are needed, must have test methods related to the requirements in available standards or, in the absence of them, be included in standards. This can be a new European standard or an extension of current standards. Both approaches fall under a future standardisation mandate to CEN and CENELEC[3]. Transitional test methods may be established until the needed harmonised standards have been developed. Since the wide range of applications imposes different requirements on lifespan, a good understanding of them is essential to characterise requirements properly.
- When proposing potential criteria, it is possible to consider different levels of the battery scope: cells, modules, packs and battery system (see also figure 8 in task 1). This excludes power electronics and heating + cooling system (in the study defined as battery *application* system), which is outside the study boundary. The focus is on Li-ion.

Proposal:

Proposal for maximum capacity fade, internal resistance increase and round-trip efficiency for battery systems/modules/packs brought on the market for the intended applications (see Scope Task 1):

The proposed values are based on ensuring that at 50 % of the cycle-life performance can be proven under applicable laboratory test conditions, e.g. 90 % at 750 cycles instead of 80 % remaining capacity at 1500 cycles. The cycles are based on the base case values, see Table 7-1. The standards refer to the applicable standards as given in the Annex to Task 1 and summarised in annex A at the end of this document.

[3] Standardisation mandates, like for product groups in ecodesign are found here: https://ec.europa.eu/growth/tools-databases/mandates/index.cfm

Table 7-2 Proposal for minimum cycle-life performance or state of health compliance test for battery systems/packs depending on their declared application(s). A type test for batteries introduced on the European market.

Application	**Remaining capacity** (relative to the declared value)	**Maximum internal resistance increase**	**Minimum round-trip energy efficiency**	**Standards** (provisional -see notes on review)
PC BEV	90 % @ 750 cycles	30 % @ 750 cycles	90 % @ 750 cycles	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
PC PHEV	90 % @ 1000 cycles	30 % @ 1000 cycles	90 % @ 1000 cycles	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
Trucks BEV	90 % @ 1000 cycles	30 % @ 1000 cycles	90 % @ 1000 cycles	Standard to be developed
Trucks PHEV	90 % @ 1500 cycles	30 % @ 1500 cycles	90 % @ 1500 cycles	Standard to be developed
ESS	90 % @ 2000 cycles	NA	94 % @ 2000 cycles	IEC 61427-2 Cycle-life test according to declared application(s)

The threshold value is defined for each test standard separately since both the ageing procedure and the measurement prescription of each test topic is dissimilar. This does not allow direct comparisons of results between different standards. Research is necessary before setting the values. At the moment it is a conceptual proposal. The values should be verifiable, therefore the manufacturer must prescribe a test method so that the conformity with the threshold values can be measured. The installed heat or cool supply systems for thermal management can be used for the test if necessary.

For cars and trucks no public data was found that could be traced to specific batteries (see also the Task 3 report). However, as can be concluded from the EU funded H2020 Everlasting project, Deliverable D8.7 – White Paper 04: Definition of SOH' (5/2018), apart from capacity fade, internal resistance increase is also an important state of health (SOH) parameter, see Table 7-2.

The Battery Test Centre of ITP Renewables in Australia has set up a public test for stationary batteries, as proposed in Table 7-2. They published very recently (June 2019) a monitoring study on batteries used for ESS[4]. From this publication It can be concluded that apart from capacity fade, round trip efficiency fade is an important state of health (SOH) parameter for the intended application, see Table 7-2. In the study, they applied constant current charge and discharge test cycles of approximately 3 h each. This is not following the mentioned standard in Table 7-2. It represents an accelerated test cycle, but within the allowed limits of the products. A round-trip efficiency of 85 to 95% was found based on 11 battery types.

The test prescriptions in the given standards involve information that must be provided by the manufacturer like declared capacity, the applied discharge rate and charge rate, the ratio between maximum allowed battery power (W) and battery energy (Wh), the DOD in the cycle-life test and the power capability at 80% and 20% SOC. It is proposed here to cover this information demand in the chapter about 'Requirements for providing information on batteries and cells', 7.1.2.3.

Since the proposal is a type test a quality management system is needed to ensure the conformity of all produced battery systems/packs of identical type.

Proposal for a minimum battery pack/system warranty per product:

As discussed in the rationale the warranty is not only related to cycle-life warranty by previous requirements but also to the calendar life warranty. A battery should be able to offer a minimum throughput of energy, but it ages also over time when not being used. Therefore a warranty period should take both aspects into account. A calendar life warranty has to be given for half of the economic application lifetime. The minimum warranted values are based Table 7-2 and the difference with 100% is doubled in value. The proposal is in As given in the rationale, the cycle-life test threshold and the warrantee requirement are necessary to create a firm base of the functional unit used in the calculation of the carbon footprint indicator. Only if a manufacturer shows a better result of the cycle-life test and gives a better warranty than the proposed minimum, he can use the improved lifetime in the calculation of the functional unit, leading to a lower value of the carbon footprint indicator (see §7.1.2.5).

Timing of policy measure:

Should take effect as soon as possible, e.g. 2021.

A second Tier with more ambitious requirements could be considered later in time, e.g. from 2025 onwards.

For all other battery levels and applications new standards and test methods, at least transitional methods, must be defined before thresholds can be determined. Also, the mentioned two standards do not cover all test requirements.

[4] http://batterytestcentre.com.au/wp-content/uploads/2017/07/Battery-Testing-Report-6-June-2019.pdf

Table 7-3.

As given in the rationale, the cycle-life test threshold and the warrantee requirement are necessary to create a firm base of the functional unit used in the calculation of the carbon footprint indicator. Only if a manufacturer shows a better result of the cycle-life test and gives a better warranty than the proposed minimum, he can use the improved lifetime in the calculation of the functional unit, leading to a lower value of the carbon footprint indicator (see §7.1.2.5).

Timing of policy measure:

Should take effect as soon as possible, e.g. 2021.

A second Tier with more ambitious requirements could be considered later in time, e.g. from 2025 onwards.

For all other battery levels and applications new standards and test methods, at least transitional methods, must be defined before thresholds can be determined. Also, the mentioned two standards do not cover all test requirements.

Table 7-3 Proposal for minimum battery pack/system warranty

Application	**Warranty period**	(whatever reached first)	**Minimum warranty**				**Methods**
	Calendar life[5] warranty	Exceedance of minimum warranted amount of stored energy during the lifetime	Minimum energy that can be stored over life time in kWh	Remaining capacity (relative to the declared value)	Maximum internal resistance increase	Minimum round-trip energy efficiency	Standards (provisional -see notes on review)
PC BEV	10 years	See prescription at the right	Declared capacity [kWh]x750	80%	60%	80%	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
PC PHEV	10 years	See prescription at the right	Declared capacity [kWh]x1000	80%	60%	80%	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
Trucks BEV	10 years	See prescription at the right	Declared capacity [kWh]x1000	80%	60%	80%	Standard to be developed
Trucks PHEV	10 years	See prescription at the right	Declared capacity [kWh]x1500	80%	60%	80%	Standard to be developed
ESS	12 years	See prescription at the right	Declared capacity [kWh]x2000	80%	NA	88%	IEC 61427-2 Cycle-life test according to declared application(s)

[5] Measured from the manufacturing time (see information proposal)

Challenges and standardisation needs:

See the identified gaps as given in the Annex on standardisation to Task 1. It appeared that for most applications and battery levels no standards are available for the test requirements in this study. The standard IEC 62620 for industrial Li-ion batteries (from cell to system level) can be taken as a valid base. However, for energy efficiency, no reference method is available. The cycle-life test in IEC 62620 seems too different from the envisaged applications (too much DOD and too few cycles). Furthermore, it allows more capacity loss (60% remaining capacity) than is acceptable in most of those applications. Only once the test requirements have agreed test methods, the threshold values can be determined after a measurement campaign.

Test cycles must be in line with test standards which are defined for each application, see Annex to Task 1. In brief, only two standards appear to cover a substantial part of the test requirements but for a limited amount of base cases (BC1, 2 and 3): IEC 62660-1 and ISO 12405-4. DOE-INL/EXT-15-34184 (2015) covers the same number of topics (and includes calendar life) for BC1 and BC2. IEC 62620 covers also many test =requirements. The other standards are too limited for the study scope. Calendar life tests are often lacking although both cycle life and calendar life tests are necessary to cover the ageing behaviour. The test profiles for cycle life tests for the EV applications take around 3 h per cycle. This leads to a total test time of around 100 days for PC BEV and 130 days for BC PHEV. This seems acceptable given the long lifetime expectations aimed for in these applications.

Another concern is the experienced difference between ageing according to ISO 12405-4 and in real use situations. The technical research done in UN IWG EVE (battery durability) and the recommendation of this expert group, i.e. on deterioration factors on vehicle level, must be considered.

The standard for stationary on-grid applications, IEC 61427-2 has unfortunately no clear end of life criteria (to be negotiated between vendor and battery user). On the other side, the standard is strict in the applicable power levels. Scaling of the battery system and power level is not possible. Moreover, one cycle takes 24 h, with approximately half of the time the battery being in idle mode in discharged condition. This leads to a many-year test duration. An accelerated test method seems obligatory, like prescribed in IEC 62620 for industrial batteries with C-rates of C/5 to 1C, but also in ISO 18243 for electrically propelled mopeds and motorcycles where a continuously repeated 1C discharge rate is applied as test cycle. The Danish Technological Institute has developed more realistic and workable tests – in particular for residential systems. If another test method is used, then also a new test method for round-trip efficiency has to be worked out.

7.1.2.2. Requirements for battery management systems

Rationale:

Related to BMS with partially open data

A BMS with partially open data has multiple benefits:

- Create consumer confidence to invest in such applications, allowing feedback on the battery status including ageing.
- Increase the residual value of electric vehicles, ESSs and their battery packs by the reduced risk thanks to partially open information on the use history.

- Support lifetime warranty and claims (see other policy).
- Support transparency of battery information for used cars.
- Reduce repair costs.
- Enhance second-hand applications for e-mobility in less demanding applications (remanufacturing).
- Enhance second life applications for a different application (repurposing).
- Extend battery lifetime by aforementioned possibilities and therefore reduce the carbon footprint per functional unit.
- Provide individual product information that is complementary to the list of information about batteries and cells, which is discussed in subsequent section 7.1.2.3.

In general, extending the lifetime of EV battery application through for example re-purposing, 2nd hand applications, etc. may offer environmental and economic benefits as well as reducing the need for primary resources. The criterion will create the conditions for a more efficient management of batteries after 1st life. The information will help in understanding the condition of the batteries.

Related to firmware updates for BMS

Since the BMS designed for an EV application would probably not be suitable for a second use application, the possibility of uploading adapted firmware must be considered. This avoids the exchange of the BMS and the effort in re-attaching every single voltage measurement wire. If the battery is not changed physically, it also does not necessarily need to undergo UN 38.3 testing. However, this assumes that the firmware update has no considerable impact on the safety performance. It must be proven that the update does not change the battery's response to different stressors and abuse. This testing is a requirement in the regulations on transporting lithium batteries. All batteries to be transported must be tested. Tests at lower level e.g. cell tests although modules are transported, are not accepted. Since several tests involve the BMS on the battery, replacing the BMS automatically means that the UN38.3 tests must be redone, which is expensive.

Proposal:

Requirements for partially open data:

Requirements on data storage, and access to the data stored in the BMS to facilitate the determination of the State of Health (SoH). State of health includes several aspects and cannot be reduced to one figure. This would have to be e.g. the average of some ageing phenomena or the minimum of them. There is no consensus on this. To evaluate the possibility for second life applications it enough data should be available. This will create new business models. For specific applications a single health indicator is the state of function that e.g. expresses the remaining driving range. This is based on a combination of ageing phenomena like power fade and capacity decrease [6].

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[6] https://everlasting-project.eu/wp-content/uploads/2018/05/EVERLASTING_D8.7_final_20180531.pdf

Battery ageing is path dependent and thus statistics cannot lead to a perfect ageing estimation[7][8]. Still, they are good indicators but only within the same battery type population and knowing for that type what are the most prominent ageing factors. This cannot be generalised to all batteries.

The data stored during the life of the battery in the BMS may include the following parameters (at battery system, battery pack and module level):

- State of health-related information:
    - the (remaining) capacity, both in Ah and kWh, for each module in a battery pack. The relation between module number and physical location inside the pack must be specified and made publicly available.
    - and/or capacity fade;
    - internal resistance in mΩ for each module in a pack
    - and/or its increase;
    - remaining power capability and/or power fade;
    - actual cooling demand;
    - remaining efficiency and/or efficiency reduction;
    - self-discharge information and/or its evolution;
    - additional indicators like information from advanced measurement methods such as electrochemical impedance measurement.
- Lifetime information:
    - calendar age including manufacturing date and start of service
    - energy throughput and capacity throughput;
    - number of normal charges and fast charges;
    - overall kilometres (pack level) and the average kilometres per charge;
    - temperature statistics. The following data must be logged: ambient temperature, module temperature, maximum instantaneous temperature difference between modules in a battery pack. This data is stored in a cumulative fashion, counting the time spent in a range of intervals. Proposed as counter is a 32 bit integer representing seconds spent in each interval. Figure 7-2 shows the proposed principle. The position of the modules in the battery system must be known. It is proposed to include this in the information requirement (§7.1.2.3).

[7] Z. Ma et al, Investigation of path dependence in commercial lithium-ion cells for pure electric bus applications: Aging mechanism identification, Journal of Power Sources 274, 2015

[8] M. Dubarry et al, Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Path Dependence of Battery Degradation, ECS 165, 2018

- negative events during lifetime (over-voltage, under-voltage, close situations to over-voltage and under-voltage, low temperature charging, high temperature charging and discharging, overtemperature, long periods of empty battery, long periods of fully charged battery).
- errors from BMS
- number of balancing actions on cells in a module
- statistics on the battery use, such as the time being in a certain voltage interval and/or SOC, the time being at a certain power level, the time being at a certain charge rate level. This must be implemented in the same way as proposed for the battery temperature above.

- Coupling to the information about traceability of battery modules and packs:
  - It is proposed to allow the traceability of battery modules and packs (§ 7.1.2.4). The BMS can accelerate the traceability by storing the module IDs of the modules attached to the BMS and if applicable the battery pack ID if one BMS is in the pack.

A complementary source of back up information for the case the BMS would fail is recommended. The proposed traceability of battery modules and packs (§ 7.1.2.4) may be used for this back-up possibility.

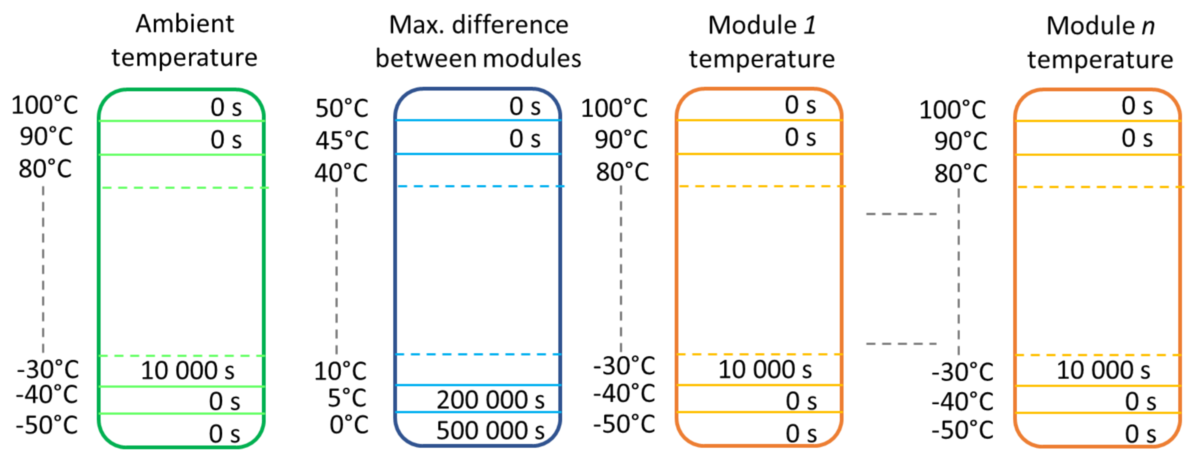

Figure 7-2: Temperature statistics with help of storing data in a cumulative fashion during the lifetime, counting the time spent in a range of intervals.

General information on the battery can be in the open data of BMS instead of in a central database. The advantage is that the necessary information on the battery remains attached to it whereas no agreement on a central system is needed. This information could be:

- design capacity
- minimal, nominal and maximum voltage, maybe temperature dependent
- original power capability and limits, maybe temperature dependent
- capacity threshold at which the cell is considered exhausted
- C-rate of cycle-life test

- battery type, and chemistry
- battery manufacturer
- manufacturing place.
- carbon footprint information and reference to the list of information about batteries and cells (see 7.1.2.3).

If partially open data by the BMS is not possible, alternatively an additional electronics board can be required that logs the proposed statistics and keeps the needed data.

The overall objective is to enable the determination of the state of health of a used battery as well as sufficient reference information, for the purpose of repair, reuse, remanufacture, reconditioning, or recycling.

Requirement on diagnostics connector:

To allow access to the open data a diagnostics connector on each BMS must be present. The data transmission should go over CAN, a widely used communication standard. In vehicles open data is standardised via the OBD connector and OBD protocol, the open data from the BMS must be reachable over the OBD connector. Only after dismantling an EV the diagnostics connector will be used. In other applications than EVs, the diagnostics connector on the BMS is the only way of access.

Requirement on BMS update possibilities:

It is possible that the BMS cannot suitably work after repurposing the battery. This can be related to the SOC determination algorithms but also due to the cell balancing strategy. In these cases, the hardware can be correct but the firmware not. A requirement or a bonus for the upgradability of the BMS is needed by possibility of a firmware update allowing the BMS to work satisfactory after the repurposing operation. An additional advantage can be that no new UN 38.3 test is needed since the battery did not change physically (see previous explanation).

Timing:

The timing is one to one related to the standardisation need, typically this will take 2 to 4 years to develop.

Challenges and standardisation needs:

Related to partially open data:

The format for data access, and test protocols would need to be developed. A major challenge may be the stakeholders' agreement regarding the parameters to be disclosed, the format and the protocol are also many factors can impact the SoH.

Apart from the data a more general uncertainty on SOH exists. No clear definition of SOH is available and it is differently used over applications and manufacturers. Battery degradation is a combination of phenomena as capacity fade, power fade, efficiency reduction and rise in cooling demand. A more elaborate approach to tackle SOH is therefore needed than only referring to capacity fade, what is the most used method. Even if SOH only refers to capacity fade then still the calculation method has to be clarified since the nominal capacity can be taken or the capacity related to the needed power.

New methods to determine the SOH of a battery are under development, e.g. by analysing the change in electrochemical impedance spectrum response. This may be a methodology that cannot be performed by the BMS in interaction with the battery load, but that is executed off-line.

For the individual parameters a similar uncertainty exists, e.g. for the efficiency information a representative standard should provide objective information that allows to be a benchmark.

In principle an open versus a closed BMS system should not entail extra product cost, nevertheless a closed system can be part of the business model of the manufacturer to create revenue from services and repair.

Related to supporting second life applications through an open BMS system:

While there is a number of potential benefits to reusing, remanufacturing and repurposing EV batteries, there are also a number of challenges that needs to be considered when introducing such aspects in ecodesign regulation. Key challenges cover health and safety concerns, regulatory and technical ones, which are highlighted along the proposed criteria. This includes battery liability from the original producer to second use distributor.

Related to the diagnostics connector on the BMS:

The proposed diagnostics connector on each BMS must be standardised. It gives access to the open data. The CAN IDs to request the required information must be standardised. Since in vehicles open data is standardised via the OBD connector and OBD protocol, the open data from the BMS must be reachable over the OBD connector.

Related to the update of the BMS:

In case that BMS firmware can be updated, it must be ensured that the functional safety is not endangered. Several solutions are possible: the algorithms have to be outside the safety critical processing area, only parameters are updated within restrained limits, or the new firmware is developed conform functional safety design.

Related to using the BMS to source some important battery data:

A possible concern is the link between warranty and information registration in the BMS. The registration of lifetime information can be an invitation to have the system manipulate this information, so as to avoid warranty claims. Also, if the battery management system breaks down, the battery owner will no longer have the data necessary for a warranty claim. Likely also a certified print out and/or a kind of back up of the data will need to be supplied with the battery at the time of purchase. The information about declared capacity and test method is also stored in the proposed European database with battery information (§7.1.2.3). The lifetime information may be periodically stored in the proposed battery traceability set-up (§7.1.2.4).

7.1.2.3. Requirements for providing information about batteries and cells

Rationale:

To allow repair, reuse, remanufacturing and repurposing but also recycling of batteries data and information about the battery is required. The current information requirement involves the battery capacity, the collection symbol and an indication of the battery type (Li, Pb or Ni). Recycling with a high material recovery rate needs more information to sort batteries. For the lifetime extension possibilities still more information about the battery is required.

This section deals with information that can be included per model or type and not per individual battery to reduce the amount of database entries. Individual battery information should be stored in the open BMS proposal in previous section 7.1.2.2. In the next section requirements are proposed to track individual battery modules and packs.

The battery information can provide end users with standardized and comparable expected lifetime information, stimulate market competition and avoid overstated performance claims.

Battery information is also essential for a repair, e.g. to replace a defected battery pack in a car. It is also part of the car type approval. The newly formed worldwide Platform for Accelerating the Circular Economy (PACE), as an outcome of Davos 2015, has already identified the issues on battery collection, repurposing and recycling as one of their first projects[9], stating the importance of this information.

EV batteries come in a variety of chemistries and forms. Whilst there are some differences in content, the material composition of the various lithium ion battery (LIB) chemistries that currently dominate the marketplace are generally quite similar with the exception of the active materials for the cathode (i.e. Cobalt, Nickel and other active materials). Therefore, traceable information on type level can play an important role in a circular economy approach for EV and ESS batteries.

It will facilitate the End-of-Life (EoL) treatment for sustainable collection-sorting-recycling, which can be better performed based on the available composition information at all product levels. The information seems useful for metal recycling to maximise substance reclamation, avoid the contamination of the waste streams, minimise downcycling issues and metal losses by compositionally closing the recycling loops. The data should also deliver the information likely needed for efficient recycling, or better sorting battery pack or modules for 2nd life applications and potentially a larger repair market.

Encouraging the emergence of a circular economy for batteries and their constituent materials in the EU can be supported introducing mandatory requirements for provision of information about recycled content for certain materials including CRM. Assessing CRM availability in stocks is an important objective of pillar 1 of the European Battery Alliance, thus, it could be important to declare their indicative quantities (or indicative range of quantities) in products put on the market.

[9] https://www.acceleratecirculareconomy.org/global-battery-alliance-index

The policy measures on product performance and on partially open data from the BMS is dependent on some essential manufacturer dependent parameters. These must be included in the list of information about batteries and cells.

For the purpose of battery system and cell information, the European product database for energy labelling (EPREL) could be used. Encouragement in this direction is found by a similar implementation [10,11].

For cells brought on the market separate requirements are formulated to support vehicle and ESS battery system manufacturers to source cells suitable for their systems.

Proposal for battery systems, packs and modules:

The proposal is that the individual battery should carry at all levels (battery system, battery pack and module) a bar code, QR code or similar with an EAN number and serial number.

This code provides access to European database with information on batteries and cells, which the manufacturer or supplier bears the responsibility of updating, e.g. such as the European Product Database for Energy Labelling (EPREL[12]), in three levels of:

Level 1: Public part (no access restriction):

- carbon footprint information in CO_2eq including primary energy in MJ and kWh electricity used during manufacturing, see specific criteria proposed in section 7.1.2.4, including the capacity Energy Efficiency Index (cEEI) which refers to the ratio of declared storage capacity relative to the embodied primary gross energy requirement (GER) for manufacturing (see also later section 7.1.2.4).
- battery manufacturer
- battery type, and chemistry
- design capacity and declared capacity
- conditions to derive the above-mentioned capacities such as the C-rate and ambient temperature.
- minimal, nominal and maximum voltage, with temperature range
- original power capability and limits, maybe temperature dependent
- capacity threshold at which the cell is considered exhausted (for electrical vehicles batteries only)
- temperature range when in use (min, max, optimal)
- temperature (min and max) that the battery can withstand not in use

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[10] https://www.idtechex.com/research/articles/all-ev-batteries-born-after-august-2018-in-china-will-have-unique-ids-00015455.asp

[11] https://uk.reuters.com/article/us-china-autos-batteries/china-launches-pilot-ev-battery-recycling-schemes-idUKKBN1KF375

[12] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/european-product-database-energy-labelling_en

- battery lifetime expressed in cycles that followed from the type test proposed in Table 7-2 and the test method used to obtain this value.
- the estimation by the manufacturer of minimum number of cycles that the battery can withstand until end of life including its criterion like a remaining capacity of 80 or 70% of the declared capacity.
- provide end users with standardized and comparable lifetime information, stimulate market competition and avoid overstated performance claims.
- Percentage of recycled materials used in the cathode and anode material
- A reference to a recycling method that can be used.
- if found appropriate, the proposed criteria related to recyclability (dismantling, labelling and declaration of materials) could be combined and transformed into an aggregated requirement or index like a R-R-R-R index (§7.1.2.6).

Level 2: Data available to third party accredited professionals:

- C-rate of cycle-life test
- results from test requirements in this study:
  - Calendar life warranty period.
  - Battery efficiency information.
  - Power
  - Energy efficiency
  - Internal battery cell, module and pack (if applicable) resistance
  - Cycle life test standard and remaining capacity that followed from this test
- information needed to perform and to interpret the test requirements, such as:
  - the applied discharge rate and charge rate
  - the ratio between maximum allowed battery power (W) and battery energy (Wh)
  - the DOD in the cycle-life test
  - the power capability at 80% and 20% SOC
- information need following from partially open data from BMS:
  - The link between module number and its physical position in the battery system
- The physical position of each cell inside the battery module shall be made available and traceable to the BMS open data (see 7.1.2.2).
- The composition by means of standardised composition categories (e.g. NMC, LTO etc.), that facilitate identification of the main chemistry of the battery, and the substances contained.
- The precise content of critical raw materials (e.g. cobalt, natural graphite) as well as other important raw materials (e.g. lithium, nickel).

- Repair information including:
    - exploded diagrams of the battery system/pack (showing the location of battery cells);
    - disassembly sequences;
    - type and number of fastening technique(s) to be unlocked;
    - tool(s) required;
    - warnings if delicate disassembly operations are involved (risk of damaging a part).
    - Amount of cells used and lay out.
- Dismantling information for recyclers in the form of, safety instructions, a tools list and a time laps video to show how a product can be dismantled for recycling (<5 minutes).
- Repair information.

Level 3: Compliance part (Information available for market surveillance authorities only, protected access for intellectual property reasons):

- Detailed assembly drawing and material list.
- Test reports proving compliance with the requirements in the proposed regulation.

Proposal for requirements on suitable battery cell type information

Level 1: Public part (no access restriction):

- carbon footprint information in CO_2eq including primary energy in MJ and kWh electricity used during manufacturing, see specific criteria proposed in section 7.1.2.4, including the capacity Energy Efficiency Index (cEEI) which refers to the ratio of declared storage capacity relative to the embodied primary gross energy requirement (GER) for manufacturing (see also later section 7.1.2.4).
- battery cell manufacturer
- battery cell type, and chemistry
- design capacity and declared capacity
- minimal, nominal and maximum voltage, with temperature range
- original power capability and limits, maybe temperature dependent
- temperature range when in use (min, max, optimal)
- temperature (min and max) that the battery can withstand not in use
- battery cell lifetime expressed in cycles and the reference test used for this statement, including for electric vehicles the minimum number of cycles the battery can withstand before SOH drops below 80 and 70 %.
- % of recycled materials used in the cathode and anode material, including a reference to a recycling method that can be used.

Level 2: Data available to third party accredited professionals:

- C-rate of cycle-life test
- results from test requirements in this study:
  - Calendar life warranty period.
  - Battery efficiency information.
  - Power
  - Energy efficiency
  - Internal battery cell resistance
  - Cycle life test standard and remaining capacity
- information needed to perform and to interpret the test requirements, such as:
  - the applied discharge rate and charge rate
  - the ratio between maximum allowed battery power (W) and battery energy (Wh)
  - the DOD in the cycle-life test
  - the power capability at 80% and 20% SOC
- The composition by means of standardised composition categories (e.g. NMC, LTO etc.), that facilitate identification of the main chemistry of the battery cell, and the substances contained.
- The precise content of critical raw materials (e.g. cobalt, natural graphite) as well as other important raw materials (e.g. lithium, nickel).

Level 3: Compliance part (Information available for market surveillance authorities only, protected access for intellectual property reasons):

- Test reports proving compliance with the requirements in the proposed regulation.

Timing:

From 2021 onwards on declared suitable cells for the intended application.

From 2022 onwards on battery systems, packs and modules.

Challenges and standardization needs:

For recycled content it relies on a credible traceability system throughout the value chain and existing volumes for recycled materials, neither of which are available at present. No traceability system for recycled materials is currently operational in the context of eco-design implementing measures. This topic is a core theme of the traceable battery information of next section (§ 7.1.2.4).

There might be standards needed for the traceability, an analysis might be needed in a later review. As the battery manufacturer (final assemblers) is not the point of the supply chain where the origin of the materials is easily traceable, the criteria need to address the upstream phases of the supply chain.

Facilitating access to high-voltage and/or potentially corrosive battery components by untrained personnel conflicts with safety objectives.

The proposed contents differ from other product groups so far in the European product database for energy labelling (EPREL) and the database might need to be reworked or extended for the proposed content.

Requiring to detailed information on battery pack design might compromise or conflict intellectual property rights and harm the competitive advantage of the inventor.

The marking of batteries can be supported by future (updates of) standards. Several standards cover the topic: in IEC TC 21 the international standard titled Secondary batteries: Marking symbols for identification of their chemistry (IEC 62902) has been developed. It obliges to indicate whether the battery is lithium, lead or nickel based including a background colour for fast identification. In IEC SC21A a standard on environmental aspects of portable batteries is proposed, IEC 63218. It contains a similar identification of the battery type, but with a two-digit extension that represents the anodic and cathodic chemistry like iron-based or cobalt-based cathode. In the same commission another standard with an elaborate battery marking requirement has been developed, being IEC 62620: Secondary lithium cells and batteries for use in industrial applications. The marking subjects are represented in the next table.

Table 7-4: Marking subjects in IEC 62620 for industrial lithium batteries.

Making information	Cell	Battery system	
		Tested unit	
		Module or Battery pack	Battery system
Secondary (rechargeable) Li or Li-ion	R	R	R
Polarity	R	R	R
Date of manufacture (which may be in code)* (see note1)	V	V	V
Name or identification of manufacturer or supplier	R	R	R* (see note2)
Rated capacity	R	R	R* (see note3)
Calculated rated capacity* (see note4)	-	-	R
Method for calculating rated capacity* (see note4)	-	-	R
Nominal Voltage	R	R	R
Watt-hour* (see note5)	V	V	V
appropriate caution statement (Including disposal instructions)	R	R	R
Cell designation as specified in 5.2	R	-	-
Battery designation as specified in 5.4*	-	R	R

As starting point several reference documents could be used:

i. IEC 62902: Secondary batteries: Marking symbols for identification of their chemistry,

ii. the newly proposed standard on environmental aspects of portable batteries IEC 63218 that contains a two-digit extension to declare the main cathode and anode material.

iii. Guideline for Recycle Marking on Li-ion Batteries for the Japanese Market [8]. In the latest one it is recommended to industry to add a two-digit code to the logo for LIB chemistries to specify, with the first digit, the metal predominantly found (by mass) in the cathode (such as Co, Mn, Ni, or Fe), and whether tin or phosphorous exceeding a specified threshold are contained in the battery.

iv. IEC 62620: Secondary lithium cells and batteries for use in industrial applications. This standard contains an elaborate battery marking including the main anode and cathode material as an alphabetic code.

The issue raised in 7.1.2.2 on SOH has to be elaborated further within standardisation.

The proposed Recyclability index is based on criteria related to recyclability (dismantling, labelling and declaration of materials). They can be combined and transformed into an aggregated requirement or index. A wider scope in addition to recycling is possible by considering multiple 2nd life options, i.e. reuse, repair and purposing. This index and the criteria must be worked out within standardisation.

7.1.2.4. Requirements on the traceability of battery modules and packs

Rationale:

The previous section dealt with information that can be included per model or type and not per individual battery. This allowed to extend a European database with information that is essential for battery repair, EOL treatment and the cycle-life test on battery systems. Also the provision of information about recycled content for certain materials including CRM was proposed as part of the battery type information.

In the public debate on Li-ion batteries emphasis is laid on the labour conditions in the extraction of the raw materials needed for these batteries, including child labour, health and safety hazards[13][14]. In the Netherlands companies must be able to prove that products are free from child labour (‘Wet zorgplicht kinderarbeid’). Materials may also come from conflict zones, as covered by the Conflict Minerals Regulation[15] for tin, tungsten, tantalum and gold. For several materials like diamond auditing schemes and material traceability has been set-up by private initiatives, like a diamond passport based on block chain technology[16]. The ITRI Tin Supply Chain Initiative (iTSCi) tracks and traces tin from mines, processors and exporters in African countries by allocating tracing numbers to each bag and storing them in a database.[17] For EV manufacturers responsibly mined lithium and cobalt is a discerning selling offer, setting up transparent supply chains including NGOs[18]. The automotive manufacturer’s partnership

[13] Reported by Amnesty International in ‘This is what we die for’, https://www.amnesty.org/en/documents/afr62/3183/2016/en/

[14] https://drivesustainability.org/raw-materials/

[15] https://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/regulation-explained/

[16] https://www.tracr.com/

[17] https://www.chainpoint.com/our-customers/itsci/

[18] https://sonomotors.com/en/sion/battery/

Drive Sustainability together with the Responsible Minerals Initiative (RMI) have analysed 37 automotive materials on environmental, social and governance issues. For the battery these are cobalt, graphite, lithium and nickel.[19]

Tracing the raw materials can be set further to tracing battery modules and packs. This promotes the statistics on and implementation of Li-ion battery recycling in Europe. It may help reducing illegal traffic of batteries at EOL to other continents. Inappropriate recycling over there leads to severe health risks. The Global Battery Alliance is setting up a passport for batteries[20] to address these challenges.

For the lifetime extension possibilities, the needed information about the battery's life was proposed to be stored in the proposal on partially open BMS data in section 7.1.2.2. In that section an information back-up possibility was suggested by using the set-up of traceability of battery modules and packs.

In China already a traceability system started. The "traceability management platform" covers the entire lifecycle of batteries from production to recycling, clarifying who is responsible for handling and recycling spent batteries and establishing a formal monitoring system.[21][22]

The issues in this Rationale go beyond the Ecodesign framework. However, the European Commission considers to broaden the scope of battery regulation to sustainable batteries. This initiative is in parallel to the Task7 report.[23]

Proposal for battery systems, packs and modules:

The proposal is that battery modules and packs have an individual serial number that is linked to a database system that tracks the battery modules and packs that come on the European internal market. This database can be a public-private cooperation. This database has to be linked to material databases for ethical mining. The suitability of initiatives from the European Battery Alliance and the Global Battery Alliance should be examined. The serial number is apart from the EAN number proposed in § 7.1.2.3. In § 7.1.2.2 it was required to encode these serial numbers also in the attached BMS to accelerate battery identification.

Timing of policy measure:

This policy measure is supported by public-private initiatives. The timing is therefore less in own hands. A target date of 2023 seems feasible.

Challenges and standardisation needs:

A large challenge exists since both auditing schemes and databases for traceability must be developed. Nevertheless, examples for several materials like diamonds and gold exist. Labour circumstances are part of ISO standardisation progress. However, the proposal goes much further than raw materials since it includes the battery modules and packs.

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19 https://drivesustainability.org/wp-content/uploads/2018/07/Material-Change_VF.pdf

20 https://www.weforum.org/projects/global-battery-alliance

21 https://chargedevs.com/newswire/china-developing-battery-tracking-system-to-manage-recycling/

22 https://www.reuters.com/article/us-china-batteries-recycling/china-puts-responsibility-for-battery-recycling-on-makers-of-electric-vehicles-idUSKCN1GA0MG

23 https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053_en

7.1.2.5. Specific requirements for carbon footprint information and considering the option for a threshold

Rationale:

Task 6 showed that manufacturing a battery requires far more energy compared to its storage capacity, typically 500 to 900 times, see capacity EEI in Table 7-5. Herein the newly defined capacity Energy Efficiency Index (cEEI) refers to the ratio of declared storage capacity relative to the embodied primary or gross energy requirement (GER) for manufacturing. Therefore embodied energy and its carbon footprint cannot be neglected. It is also possible to define a 'functional Energy Efficiency Index (fEEI)' which refers to the ratio between functional unit or kWh stored over its lifetime relative to the embodied primary or gross energy requirement (GER) for manufacturing. For the Base Case 1 BEV modelled in Task 5 this fEEI was below 100 %, which means that the primary energy source in such a car is for the production of the battery and not the energy supplied during use. Task 4 also illustrated in Figure 21 that electricity takes a large share in the carbon footprint and this opens the opportunity to use low carbon electricity, this green electricity in battery manufacturing is likely the most important improvement option but not yet included in Table 7-5. EVs are therefore game changers to use renewables. However, similarly they are able to propel cars with lignite and hard coal. Therefore, requiring more accurate information on carbon footprint is recommended and on the long term even a threshold could be considered.

This carbon footprint information will help to promote "cleaner" BEV and might be a useful benchmarking between car manufacturers. This information could in future also support a car label based on an LCA carbon footprint replacing the current tail pipe CO_2 emission approach, tax incentives or green procurement.

When considering a carbon footprint information requirement, it is also useful to ask complementary information on electricity used for manufacturing, this can simplify market surveillance.

Table 7-5: Overview of carbon footprint, improvement options (excl. green energy) and primary energy results from Task 6.

	GWP [kg CO2 eq/FU (kWh)]				GWP [kg CO2 eq/cap. (kWh)]	GWP [kg CO2 eq/kg product]	functional EEI [%] *FU [MJ]/GER [MJ]*	capacity EEI [ratio] *GER [MJ]/capacity [MJ]*
Base case	Prod. + distr.	Use	EOL	TOTAL	Prod. + distr.	Prod. + distr.	Prod. + distr.	Prod. + distr.
Business As Usual (Task 5)								
1 PC BEV-HIGH	0.214	0.094	-0.026	0.282	108	14.164	86.14	585
2 PC BEV-LOW	0.183	0.094	-0.022	0.255	108	14.190	100.88	586
3 PC PHEV	0.131	0.094	-0.019	0.206	147	14.021	134.69	832
4 Truck BEV	0.086	0.073	-0.011	0.148	115	13.442	210.22	637
5 Truck PHEV	0.063	0.074	-0.009	0.128	146	13.942	281.63	828
6 res. ESS	0.061	0.053	-0.008	0.106	155	12.089	286.87	890
7 comm. ESS	0.048	0.053	-0.006	0.095	155	12.089	358.58	890
Reduction of active and passive materials design option (Task 6)								
1 PC BEV-HIGH	0.190	0.094	-0.023	0.261	96	14.667	98.60	511
2 PC BEV-LOW	0.162	0.094	-0.020	0.236	96	14.699	115.44	512
3 PC PHEV	0.104	0.094	-0.015	0.183	117	14.340	171.45	653
4 Truck BEV	0.076	0.073	-0.009	0.139	101	13.769	240.58	557
5 Truck PHEV	0.050	0.074	-0.007	0.117	116	14.238	358.91	650
6 res. ESS	0.049	0.053	-0.006	0.096	124	12.257	360.15	709
7 comm. ESS	0.039	0.053	-0.005	0.087	124	12.257	450.19	709
Extended lifetime design option (Task 6)								
1 PC BEV-HIGH	0.187	0.094	-0.023	0.258	108	14.164	98.70	585
2 PC BEV-LOW	0.159	0.094	-0.019	0.234	108	14.190	115.59	586
3 PC PHEV	0.131	0.094	-0.019	0.206	147	14.021	134.69	832
4 Truck BEV	0.074	0.068	-0.009	0.132	115	13.442	243.07	637
5 Truck PHEV	0.063	0.074	-0.009	0.128	146	13.942	281.63	828
6 res. ESS	0.061	0.053	-0.008	0.106	155	12.089	286.87	890
7 comm. ESS	0.048	0.053	-0.006	0.095	155	12.089	358.58	890
Combined design option								
1 PC BEV-HIGH	0.165	0.094	-0.020	0.239	96	14.667	112.98	511
2 PC BEV-LOW	0.141	0.094	-0.017	0.218	96	14.699	132.28	512
3 PC PHEV	0.104	0.094	-0.015	0.183	117	14.340	171.45	653
4 Truck BEV	0.065	0.068	-0.008	0.125	101	13.769	278.17	557
5 Truck PHEV	0.050	0.074	-0.007	0.117	116	14.238	358.91	650
6 res. ESS	0.049	0.053	-0.006	0.096	124	12.257	360.15	709
7 comm. ESS	0.039	0.053	-0.005	0.087	124	12.257	450.19	709

Proposal:

Requirement on carbon footprint information:

Carbon footprint calculated according to the Product Environmental Footprint Category Rules (PEFCR[24]) for high specific energy rechargeable batteries for mobile applications. The carbon footprint is therefore part of a life cycle approach, and the PEF, among other impact categories, defines how to calculate the GWP. The PEFCR has also defined a representative product (the average product sold in EU), for different types of batteries, including for EV. It provides the calculations of the corresponding benchmark, including the Global Warming Potential (GWP). It also includes LCI data for lithium batteries.

Also to be provided are the calculated Primary Energy (MJ) and the share of electricity (MJ) according to the PEFCR and compatible with the MEErP.

[24] PEFCR available at http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Batteries.pdf

When the PEFCR carbon footprint calculation is not based on the local electricity mix, a warranty should be provided that the low carbon electricity (if any) has been supplied based on hourly net metering[25]. Country specific residual electricity grid mix could be considered for the production this would encourage battery manufacturers to seek clean (provided it is additional) electricity supply, thus putting pressure on member states to increase their investment in renewable power generation. This can be for done by installing a battery ESS on the production plant itself to cope with variable supply of renewables[26] and preferably second life EV batteries that return to plant before remanufacturing. Also information could be provided more specific on the share of renewable energy used in the electricity mix.

Carbon footprint (gCO_2eq/kWh) should be calculated both; first relative to the minimum functional unit based on the product warranty and also relative to the specified average lifetime based on laboratory tests and the applicable test cycles from EN standards.

Potential (long term) minimum carbon footprint threshold:

It is not recommended to put a minimum carbon footprint threshold in the short term, because there are several challenges to be addressed for the carbon footprint information first (see later section).

Thresholder and timing:

Carbon footprint Information requirements for all lithium cells should start from 2021.

Carbon footprint Information for packs and systems should start from 2022.

It is recommended to reconsider the option to set a minimum threshold on carbon footprint 2 years after that this information is made available based on the information provided by the manufacturers.

Challenges and standardisation needs:

So far, such a product related carbon footprint requirement has not yet been implemented in European product regulation before and it cannot build on lessons learnt. Therefore, it will need a close follow up and a gradual implementation is recommended with the focus on a few primary applications first to learn from and extending the scope afterwards. Note however that some battery manufacturers were already involved in the Product Environmental Footprint Category Rules (PEFCR[27]) for high specific energy rechargeable batteries for mobile applications and therefore they should already have knowledge and competences to provide this type of information.

The carbon footprint improvement potential does heavily rely on carbon footprint of electricity and therefore the following issues needs to be further defined:

- Which electricity mix-emission factor will be used (EU, country, local production, etc.)?
- If the electricity mix is considered at country level, there could also be issues of conflict and competitiveness among EU member states, in case manufacturing is in the EU.
- Emission factors change as the electricity mix change over time, how this effect will be captured?

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[25] This excludes Electricity Guaranties of Origin that are based on annual green energy production

[26] Likely in a circular economy approach these are second life EV batteries that return to the plant and are used in grid ESS before remanufacturing

[27] PEFCR available at http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Batteries.pdf

- if there is energy generation in-house of a manufacturing plant will this be accounted and how?
- Today much of the manufacturing is outside the EU and therefore its carbon footprint reduction does not contribute to the EU 2030 targets.

The PEFCR method can be exhaustive and elaborate work, while only the carbon footprint is needed. Hence a simplification could be considered that focuses on the most dominant manufacturing stages and simplifies less relevant components. For the PEFCR, primary Life Cycle Inventory (LCI) data is an important issue as well as the verification of this data. Carrying out an LCA with this data remains complex and there is a risk this may end up in the use of non-accurate and non-quality assured LCI data using several proxies and assumptions which can result in inaccuracy, creative accounting methods and circumvention. A close follow up of the PEFCR applicability will be needed. The PEFCR methodology is compatible with ISO 14040/44 but reduces the flexibility of the standard and does therefore not automatically provide a global level of playing field for ISO 14040/44 compliant data.

For the carbon footprint calculation of the batteries to be more accurate, simple to verify/elaborate and trustworthy, the following points could to be improved/reviewed:

- Data from background processes should be disaggregated to provide more accuracy and robustness to the carbon footprint calculation.
- More company-specific PEF values for key products along the value chain could be made be publicly available, in particular in the upstream processes. In a future regulation, this information will enable all actors to undertake PEF assessments.
- The LCA databases necessary to undertake the PEFs are not all publicly accessible and free of use.
- The complexity of the PEF could be reduced by focusing on CO_2 hotspots to have a realistic and practical implementation and enforcement of the regulation and could be a benefit for market surveillance. Hereby
- Nevertheless, some other significant impact categories might be maintained for a check that this is no disproportionate negative impact. For example, a low carbon footprint should not permit a higher water footprint.
- The carbon footprint indicator is the carbon footprint per functional unit. Since the functional unit is based on the envisaged lifetime of the battery, the lifetime has to be embedded by a cycle-life test and a warranty (7.1.2.1). Only if a manufacturer shows a better result of the cycle-life test and gives a better warranty than the proposed minimum, he can use the improved lifetime in the calculation of the functional unit, leading to a lower value of the carbon footprint indicator.
- It is also worth considering a functional unit change to per storage capacity because this decouples the information to be provided when the product comes on the market from the use phase which is complex because this depends on the application dependent lifetime. This means that carbon footprint information would focus on the cell production step only. Given that the minimum life time warranty requirements are likely to be included, this is an overlapping requirement (see requirements in 7.1.2.1).
- If the scope of the study is extended to other batteries, that do not necessarily have a similar lifetime as the Li-ion batteries under current focus, the functional unit change

leads to incomparable results and maybe false optimism for certain battery chemistries.

- Focusing exclusively on the production phase eliminates the geographical and temporal uncertainty on the carbon intensity of the electricity used during the use phase for charging batteries. Finally the recycling route at the end of life is also not a priori known when batteries are brought on the market. Focusing on the cell manufacturing and its storage capacity as a functional unit, avoids the complexity that from creative accounting based on assumptions on the use and end of life of batteries.

The PEFCR have been only elaborated for mobile application batteries with high energy density, if the scope is broadened (see 7.1.3) to Energy Storage Systems(ESS) it will require new PEFCR.

Effective carbon footprint market surveillance can be a challenge and further research might be needed to elaborate verification procedures.

7.1.2.6. Other minimum battery pack design and construction requirements to support reusability/recyclability/recoverability including a R-R-R-R index

Rationale:

A design with harmonized physical requirements has multiple benefits:

- simplify recycling at the end of life
- create a more competitive market and level of playing field for OEM, repair, upgrade, recyclers and reuse
- Support 2nd life applications/ownership, e.g. as a second hand car or into another applications
- create consumer confidence by having a second source supplier (multiple vendors), which avoids a vendor lock in effects and/or provides a second supplier to repair the car in case of bankruptcy

Modular design can help in the safety during disassembly by streamlining procedures and training for the personnel involved in recycling/reuse.

For 2nd life applications and consumer confidence it is important that an independent workshop can verify the state of health of a battery.

It should be noted that all vehicles have already such a recycling information system in place, called IDIS[28]. Hence what is discussed hereafter are more particular requirements that differ from ICE vehicles.

The proposed ‘R-R-R-R’ index could be connected to taxes, levies and subventions.

When considering policy also the Battery Directive (2006/66/EC), which is currently under review and the end-of-life vehicles (ELV) Directive (2000/53/EC) should be considered to avoid any overlap or contradiction.

[28] https://www.idis2.com/discover.php

Proposal:

Mandatory adding dismantling information to an open access database such as IDIS[28], it should be at least demonstrated how cells can be removed from packs/systems with common tools.

A mandatory DC charging/discharging interface that supports vehicle-to-grid mode (V2G) and a vehicle-to-test mode (V2test) to verify the performance and information criteria previously proposed in this study is likely the most important issue to warrant a long product lifetime.

Introduce a R-R-R-R index (derived from repair, re-use, repurpose and recycle) wherein at least the following aspects are considered:

- Use of technical design features of the product (battery) that enable assembly/disassembly, e.g. reversible joints, joints that can be fastened/unfastened.
- Standardised interfaces for hardware and software including connectors in a bonus/malus system
- Standardised thermal interface in a bonus/malus system
- Standardised dimensions and connections in an open multi-vendor system in a bonus/malus system
- Use of standard cell formats that fit in different applications in a bonus/malus system
- Use of multi-vendor modular battery packs
- Calculation of the amount of material that can be recycled

Timing and threshold:

The mandatory requirements can be introduced only at earliest after 2022 to allow manufacturers to update the software to allow V2G and V2test mode DC interfaces. Vehicles with battery packs below 10 kWh that have not yet a DC interface could be temporarily exempted.

It is recommended to start developing a standard for two main applications before introduction (see next paragraph). It is also recommended to introduce this requirement first for vehicle applications due to the size of the market volume and they are familiar with the concept due to Directive 2005/64/EC.

Challenges and standardization needs:

Most vehicles today have DC mode charging, hence adding a V2G and V2test mode is probably a software issue, to be verified are safety features involved. It is recommended to develop a standard or harmonized method for this, this will develop a larger economy of scale for car workshops (mostly SMEs) that can run the test mode.

This new concept to be developed should also fit to the Directive 2005/64/EC on the type-approval of motor vehicles with regard to their usability, recyclability and recoverability wherein Annex I states that:

> 1. Vehicles belonging to category M and those belonging to category N shall be so constructed as to be:
>
> — reusable and/or recyclable to a minimum of 85 % by mass, and
>
> — reusable and/or recoverable to a minimum of 95 % by mass.

> 2. For the purposes of type-approval, the manufacturer shall submit a data presentation form duly completed, established in accordance with Annex A to the standard ISO 22628: 2002. It shall include the materials breakdown. It shall be accompanied by a listing of the dismantled component parts, declared by the manufacturer with respect to the dismantling stage, and the process he recommends for their treatment.
>
> 3. For the application of points 1 and 2, the manufacturer shall demonstrate to the satisfaction of the approval authority that the reference vehicles meet the requirements. The calculation method prescribed in Annex B to the standard ISO 22628: 2002 shall apply.

This work to develop a recycling index can built on the ISO 22628:2002 on ‘Road vehicles -- Recyclability and recoverability - Calculation method’ but also IEC/TR 62635:2012 on ‘Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment’. A key challenge will lie on the data(base) on recycling rates of materials to be used for the calculation. The data will need to be the most recent and appropriate, it has to be representative, it could come from waste data reporting, from modelling, etc. CEN/CENELEC JTC 10 on ‘Material Efficiency Aspects for Ecodesign’ also deals with source of data for recyclability calculations but does not come to final data sources. This data needs to be agreed by the sector.

Some construction requirements could potentially be sourced from ANSI/CAN/UL 1974 on the repurposing of batteries.

For residential stationary energy storage applications, a similar standard and method could be developed.

On the negative side is that EV batteries are a relative new market and setting such strong reusability/recyclability/recoverability requirements could hamper innovation. A too detailed requirement might also limit the possible design options and compromise the new development of optimal vehicle considering customer usage, driving distance and cost. For niche markets (e.g. specific garden equipment), this might be a cost burden and there is not a benefit in the economy of scale for re-use. Therefore, this policy measure might not be recommendable for a large scope of potential applications.

Second sourcing of battery packs for EVs might result in lower performance and in worst cases can lead to safety issues. For example many historic safety failures in portable electronics (mobiles and laptops) often were associated with second source batteries. Lithium battery cells for electrical vehicles neither for ESS are not simple exchangeable components.

Note that car manufacturers already have a long-standing track record in providing service and repair manuals with software support, e.g. with a database to link their Vehicle Identification Number (VIN) to all parts numbers and step by step manuals for repair. Car manufacturers already provide digital Information on disassembly/dismantling is via IDIS[29]. Therefore the proposed policy herein might be redundant and superficial.

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[29] https://www.idis2.com/#

7.1.2.7. Policy requirements considered but not proposed

Minimum initial energy efficiency

This is not considered because it is redundant with energy efficiency threshold after the cycle-life test. Hence there is no evidence that setting such requirements can have an additional impact.

Minimum gravimetric energy density for e-mobility (Wh/kg)

This is not considered because the market for e-mobility today covers already high gravimetric density as an important design parameter and there is no evidence that setting a minimum requirement will be useful to influence the market.

Minimum self-discharge (loss at storage) [% SoC/time]

It is a relatively easy test. However, it is not recognized as a problem for the lithium batteries cells and packs. The no-load losses in battery application systems are usually attributed to power electronics, which are out of the scope.

Maximum auxiliary power consumption of the battery management system

When using a battery system, insight in the auxiliary power consumption might also be needed, especially the Battery Management System (BMS). If the BMS power is drained from the battery it can lead to a problematic self-discharge: the consumption of the BMS can be too high to bridge standstill periods. This applies to both BMSs that are powered from the main battery and that those powered from an external source such as an auxiliary battery. Despite this demand, no solid base was found in a threshold value. A large variation seems to exist ranging from 10 $W/kWh_{battery}$ down to a fraction of a watt. The standards do not prescribe a measurement methodology, complicated by the many possible BMS topologies and by the power going to cell balancing.

Maximum auxiliary power for heating and cooling

Auxiliary power for heating and cooling is left out of the scope of this proposal because for vehicles this is redundant requirement with WLTP driving range and for LiB in residential storage systems it was not identified as a relevant issue [30].

Requiring all environmental impact parameters instead of focusing on carbon footprint

The previous section proposed to focus on carbon footprint based on the PEFCR, however also other environmental impact parameters are included in the PEFCR and in principle they could be included in the data information requirements, but it was not proposed because:

- It would complicate market surveillance;
- It was not the primary optimization parameter of the study in Task 6
- Most of these parameters relate to local emissions and impact that can be addressed by local factory regulations. This could therefore result in a requirement that all imported battery cells in accordance to the related European environmental regulations or have locally similar manufacturing standards in place, i.e. the Industrial

[30] Up to our knowledge the LiB system for residential ESS only the Tesla Powerwall has heating-cooling systems added It might become an issue when considering other high temperature chemistries.

Emissions Directive (Directive 2010/75/EU) and the European Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)((EC) No 1907/2006). Because most of the cells are manufactured today outside the EU this would jeopardize the supply and for this type of products it was not judged realistic for the time being.

7.1.3. Recommendations on opportunities to extend the scope of policy measures

Aim: Several NGOs asked frequently to broaden the scope of technologies and applications addressed in this study, despite that manufacturers and their association insisted in keeping the focus in e-mobility first. Hereafter we discuss briefly the possibilities and considerations based in the lessons learned from Tasks 2-6.

Potential options to consider are:

- Lithium e-mobility batteries below 2 kWh that are proposed to be exempted, e.g. those for electric bicycles, garden tools, cordless power tools, cordless home appliances, etc.
- Stationary batteries suitable for residential grid energy storage systems other than Lithium chemistries with high energy density; examples include: high temperature sodium-based batteries and lithium-sulphur batteries.
- Stationary batteries suitable for residential grid energy storage systems other than lithium chemistries with low energy density; examples include: Sodium batteries, nickel metal hydride and lead acid batteries.

Opportunities and challenges to consider a scope extension are:

Opportunities:

- In principle often, a scope extension can close loopholes in regulation because with the scope proposed batteries can still be brought on the market declared for use in other applications. Nevertheless, for vehicles due to their type approval process such a risk for a loophole in the regulation is likely non existing.
- A broader scope could create a level of playing field with other competing battery technology, e.g. sodium batteries.
- Finally, Task 2 clearly identified the proposed scope of vehicles by far as the largest in volume and thus impact. Off course, by extending the scope an additional environmental impact is reached. The main rationale for the proposed scope was the large total EU volume in tonnes of material expected on the market for e-mobility (see Task 2). Other applications and their technologies were not expected to have similar impact despite that they often exceed the threshold of 200.000 items sold per year because the capacity of these batteries is low per application (e.g. < 2 kWh).

Challenges:

- The standards on which the policy proposals rely are for LiB vehicle and grid energy storage applications. For other applications they are mostly missing. It would be better to develop them before considering the policy, this is a time-consuming process that should be outweighed compared to the impact.

- Impact on Small and Medium-sized Enterprises (SMEs) and innovation: The advent of low-cost lithium batteries will likely trigger new application. Much policy measures proposed will bring extra work and administration to SMEs and will jeopardize innovation in Europe because it will be more attractive to develop and market the products first elsewhere without this additional work and requirements.
- Creation of administrative overhead for niche battery applications: see previous argumentations, this also applies to large companies selling products for niche applications.
- Other policy tools that target ‘industrial installations’ instead of ‘consumer products’ might sometimes be more suitable. For example, large grid scale energy storage systems with redox-flow batteries can be constructed onsite whereby parts of the battery system, such as pumps and controllers, can be procured from different suppliers. The battery system is herein not a priori sold or brought on the market as a product but it is an installed system under the direct responsibility of the owner. In this case the Machinery Directive (2006/42/EC) might be a policy tool to consider, despite that it has currently a different scope (e.g. safety).
- Small battery packs (< 2 kWh) in cordless power tools or bicycles are already repaired for replacement in small workshops and their batteries are collected under the WEEE Directive. This market could likely more benefit from policy supporting (affordable) training and a quality label.
- Lack of data and evidence: For carbon footprint of some new or niche battery technologies the LCI data and/or PEFCR are not yet sufficiently available.
- Delay of policy measures:
    - Looking to all other potential applications at the level of detail done in Tasks 3-6 including modelling the use phase will be magnitudes more work and take several more years. For example, a vacuum cleaner can have such a battery as well and it will require to model properly the load cycle in Task 3 which can already become a point of discussion on itself[31].
    - Related to the previous concern, any life cycle analysis requires a well-defined and agreed functional unit (see Task 1). As already mentioned in Task 1 UPS applications have a different functional unit meaning that the whore approach from Task 3 to 6 will differ, moreover there are several UPS that have safety requirements, e.g. in a nuclear power plant. Also, when considering for example portable cordless power tools (PCT), their main requirement to substitute the nuisance of a power cord without excessive weight and cost to the product which is completely different.
    - Extending the scope will involve a larger set of stakeholders and therefore complicate reaching a agreement (if possible at all) and likely postpone taking policy measures.

[31] https://uk.reuters.com/article/uk-eu-dyson-court-energy/dyson-wins-fight-against-eu-energy-labelling-rules-idUKKCN1ND1NM

  - The proposed policy is new in its kind and it might be wiser to learn first from some key applications and consider extending it to other applications in a second tier.

Conclusion:

We do not recommend to extend or review the scope relative to the proposal in Task 1 apart from:

- Considering other battery chemistries that can be used for residential energy storage where high energy density is not a driver and other chemistries can be found on the market that could provide unfair competition to batteries in the proposed scope if not included.
- Considering smaller e-mobility applications such as scooters etc., where the market may increase more than expected.

Note: a complementary study has been launched among others to investigate this scope extension, it will also look to other applications and chemistries.

7.1.4. Summary of stakeholder positions

Objective:

This section contains an overview and summary of the stakeholder positions.

Overview of stakeholder positions:

General remarks on the scope of a regulation:

Several stakeholders commented that any future regulation should be cross-checked for overlaps/consistency/conflict with:

- The Battery Directive (2006/66/EC) for what matters recycling, and which is currently under review. In addition, it is mentioned that guidelines are developed on setting modular fees in the context of Extended Producer Responsibility (EPR) largely based on circular economy principles.
- The end-of-life vehicles (ELV) Directive 2000/53/EC and its implementation, for what matters recycling of vehicles.
- The UNECE Regulations[32], for what matters performance of electric vehicles.
- The European Conflict Minerals Regulation that will start on 1 January 2021 (Regulation (EU) 2017/821).

All position papers and/or related comments received are included in separate 'Annex on stakeholder positions' hereafter is a summary.

[32] https://ec.europa.eu/growth/sectors/automotive/legislation/unece_en

Positions related to minimum battery pack/system lifetime requirements:

The Danish Energy Agency suggested to consider a labelling type requirement to foster competition on warranty extent. There is an overall welcome to such requirements from the European Consumer Organisations (ANEC/BEUC), other comments received are of technical nature and to avoid overlap/conflict with upcoming UNECE Regulation for vehicles.

RECHARGE opposes to warranty as being not part of ecodesign.

The Danish Energy Agency utters doubts on the usefulness of IEC 61427-2. It has already developed more realistic and workable tests – in particular for residential systems.

Positions related to maximum auxiliary power consumption of the battery system:

Danish Energy Agency suggested to leave out requirements for auxiliary power requirements for automotive applications, because vehicles have already other incentives and it is redundant with WLTP tests. This is also supported by ECOS, an NGO on environmental standards, because vehicle manufacturers have already a strong incentive to improve the overall vehicle efficiency. Also, no technical information has been provided, meaning that setting a requirement would be difficult.

Positions related to requirements for battery management systems:

There is an overall welcome to such requirements from the European Consumer Organisations (ANEC/BEUC), other comments received are of technical nature. Also, ECOS very much support these requirements regarding the availability of data.

ECOS and RECHARGE ask for a single SOH value.

ACEA mentions that even with a lot of data battery ageing cannot be correctly derived. Too much information, especially about humidity, was prescribed.

The Danish Energy Agency expresses a concern in a possible manipulation of lifetime related information registered in a BMS.

Positions related to requirements for battery information:

There is an overall welcome to such requirements from the European Consumer Organisations (ANEC/BEUC), other comments received are of technical nature.

ACEA, the car manufacturers association, noted that sustainable sourcing is already part of OEMs sourcing strategy, see https://drivesustainability.org/.

Positions related to specific requirements for carbon footprint information and considering the option for a threshold

There is an overall welcome to such requirements from the European Consumer Organisations.

In February 2019 RECHARGE, the European Advanced Rechargeable and Lithium Batteries association, stated in their position paper that CO_2eq content of finished e-mobility batteries should be used as a criterion to discriminate across products placed on the EU market.

Both RECHARGE, battery manufacturers, and ACEA, car manufacturers, do not support using the existing PEFCR for calculating the carbon footprint. RECHARGE experienced that the PEF today faces some issues and limitations, especially when it comes to reliable, meaningful and auditable data. ACEA prefers the use of ISO 14040&14044 standards on LCA analysis to guarantee a global level playing field.

ECOS provided useful technical inputs also suggesting that the PEFCR needs to be reviewed for the purpose. Amongst others they argue that the metric used for the carbon footprint standard should be based on gram CO_2eq/cap(kWh) and not gram CO_2eq/FU(kWh) as in the PEFCR. This will better reflect the carbon footprint when they are brought on the market and focus on the production step only and will also eliminate the geographical and temporal uncertainty on the carbon intensity of the electricity used during the use phase.

ECOS welcomes the proposed Recyclability index and wants to broaden it to second life application possibilities.

Positions related to other minimum battery pack design and construction requirements to support reusability/recyclability/recoverability:

ACEA, the car manufacturers association, noted that recyclability as part of the ELV directive is already common practice and recycling information is sourced through the broadly used International Dismantling Information System, see https://www.idis2.com/.

The European Portable Battery Association, EPBA, stated that circular economy principles concerning discussions concerning reusability, reparability and recyclability proposed in this study would not apply to portable primary and rechargeable batteries. The application of these circular economy principles can differ subject to the battery type, what can work for a large industrial rechargeable battery does not necessarily work for a small consumer battery.

ECOS asked to rename the proposed recyclability index to reflect more the wider scope, i.e. reuse, repair, repurposing and recycling. This is implemented by naming it R-R-R-R index.

Positions related to recommendations on opportunities to extend the scope of policy measures:

The European Portable Battery Association, EPBA, states that any inclusion of portable primary and/or rechargeable batteries would require a separate discussion.

APPlia, the association of home appliances, strongly advised not the extend neither to review the scope relative to Task 1. They argue that that portable batteries below 2 kWh are already subject to regulation under the WEEE Directive (e.g. collection), they often have already their own Eco-design product regulation and there are no standards to underpin policy measures.

The Recharge battery manufacturers association agreed that there is no need to extend the scope and suggest to wait for output of this exercise before considering extending the scope.

ANEC/BEUC consumer organizations encourage investigating a scope extension.

Helmholtz Institute of Ulm (HIU) and the Institute for Technology Assessment and System Analysis (ITAS); both research organizations, asked to study much more applications and battery chemistries.

Note that the EC has launched an open public consultation on a potential regulatory intervention related to this study, see:

https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053/public-consultation_en

Hence for the latest state of play consult the EC website on related policy:
https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-5951053_en

7.2. Scenario Analysis (unit stock/sale & environmental)

Aim of Task 7.2:

Subtask 7.2 establishes the scenarios according to the design options described in Task 6 and the policy measures described in subtask 7.1, so far this is possible. To this end, the analyses on the previous tasks have been extended to the defined scenarios in comparison with the Business-as-Usual (BAU) Scenario and the Best Available Technology (BAT) Scenario.

7.2.1. Introduction to Scenario Analysis

Different scenarios have been drawn up to illustrate quantitatively the improvements mainly in terms of sustainability that can be achieved at the EU level by 2045 with suitable Ecodesign policy actions against the Business-as-Usual scenario. Taking into account the time needed to elaborate and implement any regulation, the regulation is assumed to enter into force in 2022 under the scenario.

The reference case and main technical improvement option scenarios based on the findings of Task 6 are defined as follows:

- **BAU scenario**: no additional EU regulation. The products placed on the EU market have the same level of performance as the Base Case defined in Task 4
- **Reduction of materials (RedMat):** From year 2022, new batteries placed on the market are batteries with less passive and active materials than in the BAU scenario (see Task 6 assumptions)
- **Extended lifetime (ExtLifeTime):** From year 2022, new batteries placed on the market are batteries, which are used longer (if applicable), according to Task 6 assumptions
- **Combination of reduction of materials and extended lifetime (RedMat_ExtLifetime):** From year 2022, new batteries placed on the market are batteries which have less materials and are used longer (if applicable), based on Task 6 assumptions
- **RedMat_ExtLifeTime_GHG_Info**: same as RedMat_ExtLifetime, but in addition, information on carbon footprint is required. In this scenario, it is assumed, that the EU market will be driven by batteries with low carbon footprint in the production phase and that in total, 30% of the customers will buy the battery for the lowest GHG emissions.[33] Accordingly, in this scenario, the electricity mix in the production phase corresponds to 70% of the EU average electricity mix and 30% of the most decarbonised electricity mix.[34]
- **RedMat_ExtLifeTime_GHG_Low**: same as RedMat_ExtLifetime, but in addition, the GHG emissions related to electricity consumption during the production phase are the lowest and correspond to the low GHG emission scenario (see Table 7-8). The scenario highlights the contribution of the decarbonisation of the production phase of batteries to the overall GHG emissions during the whole lifecycle of a battery.
- **RedMat_ExtLifeTime_Recycling**: same as RedMat_ExtLifetime, but in addition, the recycling of CRM is improved.
- **BAT:** reflects a combination of all quantifiable improvement options: reduction of passive and active materials, extended lifetime, reduced GHG footprint with the most

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33 this is a rough estimate

34 see "low" and "medium" scenarios in Table 7-8

decarbonised electricity mix during the battery production phase as well as improved recycling at EoL.

Table 7-6 presents an overview of the scenarios covered in this task as well as the associated policies. In some cases, the impact of the policies cannot be quantified, due to a lack of data or a lack of concrete requirements.

Table 7-6: Overview of the scenarios and associated policies

Policy Measures	**General comment**	**Extended lifetime**	**Reduction of material**	**RedMax_ExtLifetime**	**RedMat_ExtLifeTime_GHG_Info**	**RedMat_ExtLifeTime_GHG_Low**	**RedMat_ExtLifeTime_Recycling**	**BAT**
Performance policy requirements								
Minimum battery pack/system lifetime requirements	quantifiable	XX		XX	XX	XX	XX	XX
Maximum auxiliary power consumption of the battery system	Not quantified	-	-	-	-	-	-	(X)
Policy measures on sustainability								
Requirements for battery management	Impact difficult to quantify	X	-	X	X	X	X	X
Requirements for battery information	Improve recycling and lifetime	X		X	X	X	XX	X
Specific requirements for carbon footprint information and considering the option for a threshold	Quantifiable	-	X	-	X	XX	-	XX
Other minimum battery pack design and construction requirements to support reusability/recyclability/recoverability	Quantifiable	-	--		-	-	XX	XX

XX: strong and large impact, X: moderate impact, (X): some impact, - : no / very small impact

Table 7-7 provides an overview of the main assumptions of new products placed on the market from 2022 for each product Base Case and scenario. The figures are derived from the results of Tasks 4, 5 and 6 and cover following parameters of a battery system:

- nominal capacity in kWh
- service lifetime in year
- total weight of a battery system in kg
- purchase costs in € / kWh capacity
- CAPEX for decommissioning in € / battery system
- OPEX for replacement in € / service
- weight of CRM, in kg / battery system. Cobalt, Graphite, Nickel, Manganese and Lithium were taken into account here
- weight of CRM recycled, in kg / battery system. This figure is negative, since the demand for CRM decreases due to recycling
- electricity consumption, in kWh/battery system, for each life stage of a battery system: raw material / production / transport, use and EoL. For the use phase, the electricity consumption is also calculated on a yearly basis.

Table 7-7: Main assumptions on the battery systems, according to Base Case and Design Option

					Cost			CRM - Weight / battery system					Recycling CRM - Weight / battery system					Electricity consumption			
		Nominal Capacity	Service Lifetime	Total weight of a battery system	Cost	CAPEX for decomissioning	OPEX replace battery	Cobalt	Graphite	Nickel	Manganese	Lithium	Cobalt	Graphite	Nickel	Manganese	Lithium	For raw materials, transport and production	Use stage	Use stage / year (=yearly losses)	EoL
Base Case	Tech Level	[kWh]	[year]	[kg]	[EURO/kWh]	[EUR/unit]	[EURO/service]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kWh]	[kWh]	[kWh/a]	[kWh]
1	BAU	80	14	609	206	1 200	700	9.56	87.28	35.92	17.11	14.44	- 1.53	-	- 5.75	-	-	9 640	9 756	697	- 197
1	RedMat	80	14	521	140	1 200	700	5.32	79.21	43.66	11.85	13.94	- 0.85	-	- 6.99	-	-	8 403	9 756	697	- 203
1	ExtLifeTime	80	18	609	206	1 200	840	9.56	87.28	35.92	17.11	14.44	- 1.53	-	- 5.75	-	-	9 640	11 178	621	- 197
1	RedMat_ExtLifeTime	80	18	521	140	1 200	840	5.32	79.21	43.66	11.85	13.94	- 0.85	-	- 6.99	-	-	8 403	11 178	621	- 203
1	RedMat_ExtLifeTime_Footprint	80	18	521	140	1 200	840	5.32	79.21	43.66	11.85	13.94	- 0.85	-	- 6.99	-	-	8 403	11 178	621	- 203
1	RedMat_ExtLifeTime_Recycling	80	18	521	140	1 200	840	5.32	79.21	43.66	11.85	13.94	- 4.48	-	- 36.00	- 9.97	- 11.14	8 403	11 178	621	- 203
1	BAT	80	18	521	140	1 200	840	5.32	79.21	43.66	11.85	13.94	- 4.48	-	- 36.00	- 9.97	- 11.14	8 403	11 178	621	- 203
2	BAU	40	13	304	206	600	700	4.78	43.64	17.96	8.56	7.22	- 0.76	-	- 2.87	-	-	4 820	5 720	440	- 99
2	RedMat	40	13	261	140	600	700	2.66	39.61	21.83	5.93	6.97	- 0.43	-	- 3.49	-	-	4 201	5 720	440	- 101
2	ExtLifeTime	40	17	304	206	600	840	4.78	43.64	17.96	8.56	7.22	- 0.76	-	- 2.87	-	-	4 820	6 554	386	- 99
2	RedMat_ExtLifeTime	40	17	261	140	600	840	2.66	39.61	21.83	5.93	6.97	- 0.43	-	- 3.49	-	-	4 201	6 554	386	- 101
2	RedMat_ExtLifeTime_Footprint	40	17	261	140	600	840	2.66	39.61	21.83	5.93	7.22	- 0.43	-	- 3.49	-	-	4 201	6 554	386	- 101
2	RedMat_ExtLifeTime_Recycling	40	17	261	140	600	840	2.66	39.61	21.83	5.93	7.22	- 2.24	-	- 18.00	- 4.99	- 5.77	4 201	6 554	386	- 101
2	BAT	40	17	261	140	600	840	2.66	39.61	21.83	5.93	7.22	- 2.24	-	- 18.00	- 4.99	- 5.77	4 201	6 554	386	- 101
3	BAU	12	11	126	254	180	700	1.25	15.89	3.41	2.59	2.01	- 0.20	-	- 0.55	-	-	2 120	3 252	296	- 117
3	RedMat	12	11	98	185	180	700	0.85	12.54	3.83	3.55	1.67	- 0.14	-	- 0.61	-	-	1 653	3 252	296	- 91
3	ExtLifeTime	12	11	126	254	180	840	1.25	15.89	3.41	2.59	2.01	- 0.20	-	- 0.55	-	-	2 120	3 252	296	- 117
3	RedMat_ExtLifeTime	12	11	98	185	180	840	0.85	12.54	3.83	3.55	1.67	- 0.14	-	- 0.61	-	-	1 653	3 252	296	- 91
3	RedMat_ExtLifeTime_Footprint	12	11	98	185	180	840	0.85	12.54	3.83	3.55	1.67	- 0.14	-	- 0.61	-	-	1 653	3 252	296	- 91
3	RedMat_ExtLifeTime_Recycling	12	11	98	185	180	840	0.85	12.54	3.83	3.55	1.67	- 0.71	-	- 3.15	- 2.99	- 1.33	1 653	3 252	296	- 91
3	BAT	12	11	98	185	180	840	0.85	12.54	3.83	3.55	1.67	- 0.71	-	- 3.15	- 2.99	- 1.33	1 653	3 252	296	- 91
4	BAU	30	8	256	220	450	400	2.77	36.45	9.99	1.89	4.70	- 0.44	-	- 1.60	-	-	3 883	7 571	946	- 69
4	RedMat	30	8	221	129	450	400	1.23	31.08	12.10	6.54	4.45	- 0.20	-	- 1.94	-	-	3 395	7 571	946	- 68
4	ExtLifeTime	30	10	256	220	450	480	2.77	36.45	9.99	1.89	4.70	- 0.44	-	- 1.60	-	-	3 883	8 118	812	- 69
4	RedMat_ExtLifeTime	30	10	221	129	450	480	1.23	31.08	12.10	6.54	4.45	- 0.20	-	- 1.94	-	-	3 395	8 118	812	- 68
4	RedMat_ExtLifeTime_Footprint	30	10	221	129	450	480	1.23	31.08	12.10	6.54	4.45	- 0.20	-	- 1.94	-	-	3 395	8 118	812	- 68
4	RedMat_ExtLifeTime_Recycling	30	10	221	129	450	480	1.23	31.08	12.10	6.54	4.45	- 1.04	-	- 9.98	- 5.50	- 3.56	3 395	8 118	812	- 68
4	BAT	30	10	221	129	450	480	1.23	31.08	12.10	6.54	4.45	- 1.04	-	- 9.98	- 5.50	- 3.56	3 395	8 118	812	- 68
5	BAU	20	5	210	212	300	400	2.09	26.49	5.69	4.31	3.36	- 0.33	-	- 0.91	-	-	3 534	8 976	1 795	- 195
5	RedMat	20	5	163	185	300	400	1.42	20.90	6.38	5.92	2.78	- 0.23	-	- 1.02	-	-	2 754	8 976	1 795	- 152
5	ExtLifeTime	20	5	210	212	300	480	2.09	26.49	5.69	4.31	3.36	- 0.33	-	- 0.91	-	-	3 534	8 976	1 795	- 195
5	RedMat_ExtLifeTime	20	5	163	185	300	480	1.42	20.90	6.38	5.92	2.78	- 0.23	-	- 1.02	-	-	2 754	8 976	1 795	- 152
5	RedMat_ExtLifeTime_Footprint	20	5	163	185	300	480	1.42	20.90	6.38	5.92	2.78	- 0.23	-	- 1.02	-	-	2 754	8 976	1 795	- 152
5	RedMat_ExtLifeTime_Recycling	20	5	163	185	300	480	1.42	20.90	6.38	5.92	2.78	- 1.19	-	- 5.26	- 4.98	- 2.22	2 754	8 976	1 795	- 152
5	BAT	20	5	163	185	300	480	1.42	20.90	6.38	5.92	2.78	- 1.19	-	- 5.26	- 4.98	- 2.22	2 754	8 976	1 795	- 152
6	BAU	10	17	128	683	150	100	0.29	14.48	1.16	0.16	1.16	- 0.05	-	- 0.19	-	-	1 855	3 497	206	- 25
6	RedMat	10	17	101	499	150	100	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	3 497	206	- 20
6	ExtLifeTime	10	17	128	683	150	120	0.29	14.48	1.16	0.16	1.16	- 0.05	-	- 0.19	-	-	1 855	3 497	206	- 25
6	RedMat_ExtLifeTime	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	3 497	206	- 20
6	RedMat_ExtLifeTime_Footprint	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	3 497	206	- 20
6	RedMat_ExtLifeTime_Recycling	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.10	-	- 1.11	- 3.21	- 0.84	1 481	3 497	206	- 20
6	BAT	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.10	-	- 1.11	- 3.21	- 0.84	1 481	3 497	206	- 20
7	BAU	10	17	128	683	150	100	0.29	14.48	1.16	0.16	1.16	- 0.05	-	- 0.19	-	-	1 855	4 371	257	- 25
7	RedMat	10	17	101	499	150	100	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	4 371	257	- 20
7	ExtLifeTime	10	17	128	683	150	120	0.29	14.48	1.16	0.16	1.16	- 0.05	-	- 0.19	-	-	1 855	4 371	257	- 25
7	RedMat_ExtLifeTime	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	4 371	257	- 20
7	RedMat_ExtLifeTime_Footprint	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.02	-	- 0.22	-	-	1 481	4 371	257	- 20
7	RedMat_ExtLifeTime_Recycling	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.10	-	- 1.11	- 3.21	- 0.84	1 481	4 371	257	- 20
7	BAT	10	17	101	499	150	120	0.12	11.05	1.35	3.81	1.05	- 0.10	-	- 1.11	- 3.21	- 0.84	1 481	4 371	257	- 20

7.2.2. Policy scenarios

7.2.2.1. Approach

For the purpose of producing the quantified scenario impact analyses under subtask 7.2, an Excel based stock-model was developed for the battery system product group. The structure of the model is shown in Figure 7-3.

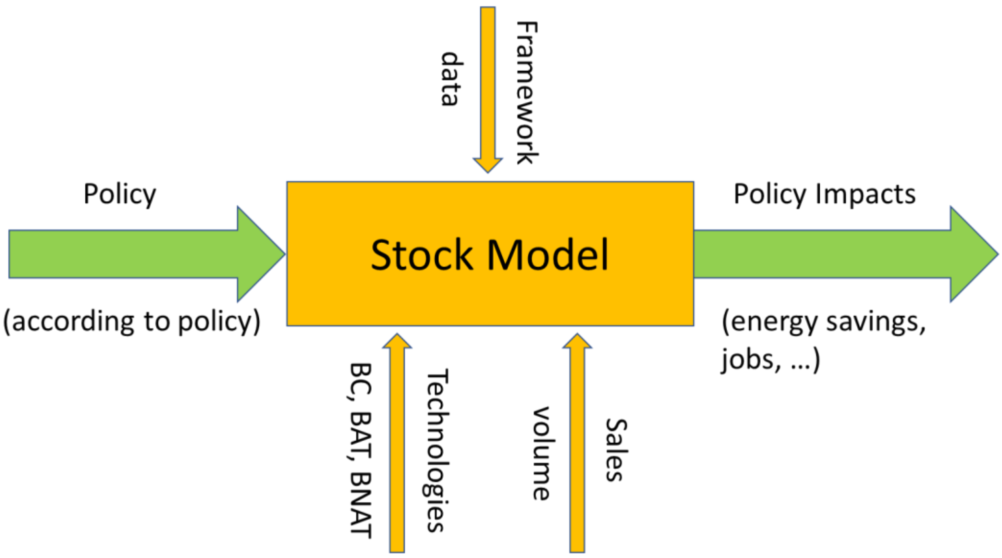

Figure 7-3: Simplified overview of the model (Source: Fraunhofer ISI)

With:

- Technologies and policies: an overview of the main data for each Base Case according to the level of technology considered was provided in Table 7-7.
- Figures related to GHG emissions of electricity (see Table 7-8): based on PRIMES[35] for the medium scenario, it applies for the use phase and the EoL.
  With regard to the production phase, the GHG emission factor applicable to a battery system that will be placed on the EU market depends on the manufacturers' electricity supplier along the value chain. Therefore, a range between a low-carbon electricity mix and a high-carbon electricity mix has been considered here.[36] The average assumption corresponds to the EU average (see PRIMES).

[35] reference scenario for the EU electricity mix in EU

[36] To determine this range, the GWP impact of the available high voltage electricity generating technologies within the ecoinvent LCI database (version 3.4) were calculated within SimaPro (version 8.52). The power generator with the highest GWP impact is electricity production from lignite and the one with the lowest is run-of-river hydroelectricity. The impact was increased with 5% in order to include the losses when transforming high voltage electricity to medium voltage electricity.

- Figures related to electricity prices (see Table 7-9): based on PRIMES[37] for the medium scenario. For a sensitivity analysis, +50% and -50% are applied.
- Socio-economical figures from the battery sector (see Table 7-10).

Table 7-8: GHG emissions related to electricity

Parameter	Scenario	Unit	2020	2025	2030	2035	2040	2045
GHG Emission	Low[38]	[$kgCO_{2eq}$/kWh]	0.00	0.00	0.00	0.00	0.00	0.00
GHG Emission	Medium	[$kgCO_{2eq}$/kWh]	0.38	0.36	0.34	0.32	0.30	0.28
GHG Emission	High[39]	[$kgCO_{2eq}$/kWh]	1.28	1.28	1.28	1.28	1.28	1.28

Important remark: the figures in Table 7-8 do not match to those presented in Task 5 report. This is due to the fact, that Task 5 report uses figures from the EcoReport 2014 tool.

Table 7-9: Electricity prices

Parameter	Scenario	Unit	2020	2025	2030	2035	2040	2045
Price	Low[40]	[c€/MWh]	7.80	8.05	8.20	8.45	8.40	8.35
Price	Medium[41]	[c€/MWh]	15.60	16.10	16.40	16.90	16.80	16.70
Price	High[42]	[c€/MWh]	23.40	24.15	24.60	25.35	25.20	25.05

Table 7-10: Socio-economical figures from the battery sector

Variable name and unit	Value	Source
Jobs direct [full time equ./GWh]	125	Based on Task 2
Jobs Indirect [full time equ./GWh]	300	Based on Task 2

In addition, several recycling rates have been considered for the CRM during the EOL phase (see Table 7-11, taken from Task 4 report, see section 4.2.4.3, table 13 for the different sources of the recycling rates).

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[37] reference scenario for the EU electricity mix in EU

[38] only used in the production phase

[39] only used in the production phase

[40] -50% compared to the medium scenario

[41] based on PRIMES (reference year: 2015) as average of electricity prices for households and industry, see also Task 5

[42] +50% compared to the medium scenario

Table 7-11: EOL recycling rates [%] (EV battery specific data)

Scenario	Cobalt	Graphite	Nickel	Mangan-ese	Lithium
BAU	16.00	0.00	16.00	0.00	0.00
Improved: 65% collection rate + combination of pyrometallurgical & hydrometallurgical processes	61.10	0.00	61.75	0.00	37.05
Ambitious: 85% collection rate + purely hydrometallurgical process	84.15	0.00	82.45	84.15	79.90

- Sales and stock:

The model is a simplified stock model, wherein:

Equation 1

$$stock_{BC_i,y} = \sum_{j=y-lifetime_i+1}^{y} sales_{BC_i,j}$$

Equation 2

$$stock_{batteries,y} = \sum_{i=1}^{7} stock_{BC_i,y}$$

Where:

- Y = year
- lifetime = lifetime of the BC
- BC = Base Case
- i = index of the BC

Also, sales figures can be calculated based on stock figures:

Equation 3

$$sales_{BC_i,y} = stock_{BC_i,y} - stock_{BCi,y-1} + sales_{BC_i,y-litetime+1}$$

The market volume consists in the stock increase and in the replacement of old products, which have reached the technical lifetime.

Due to the long technical lifetime of the products considered (around 20 years for some battery systems), it is important to run the model and to analyse the results over a long period. Since policy options discussed in this task will address the sales market (new products) and not the stock, the effect of such new policy options will not be perceptible from the first year and thus requires the scenario analysis to cover the time window of 2019-2045.

The Task 7 stock figures are the same as in Task 2. In addition, the historical data had to be estimated by back casting the sales for the period prior 2010, considering the commercial lifetime of a battery. An overview of the stock figures is provided in Table 7-12 and Figure 7-4. Table 7-13 shows the stock figures expressed in number of battery systems.[43]

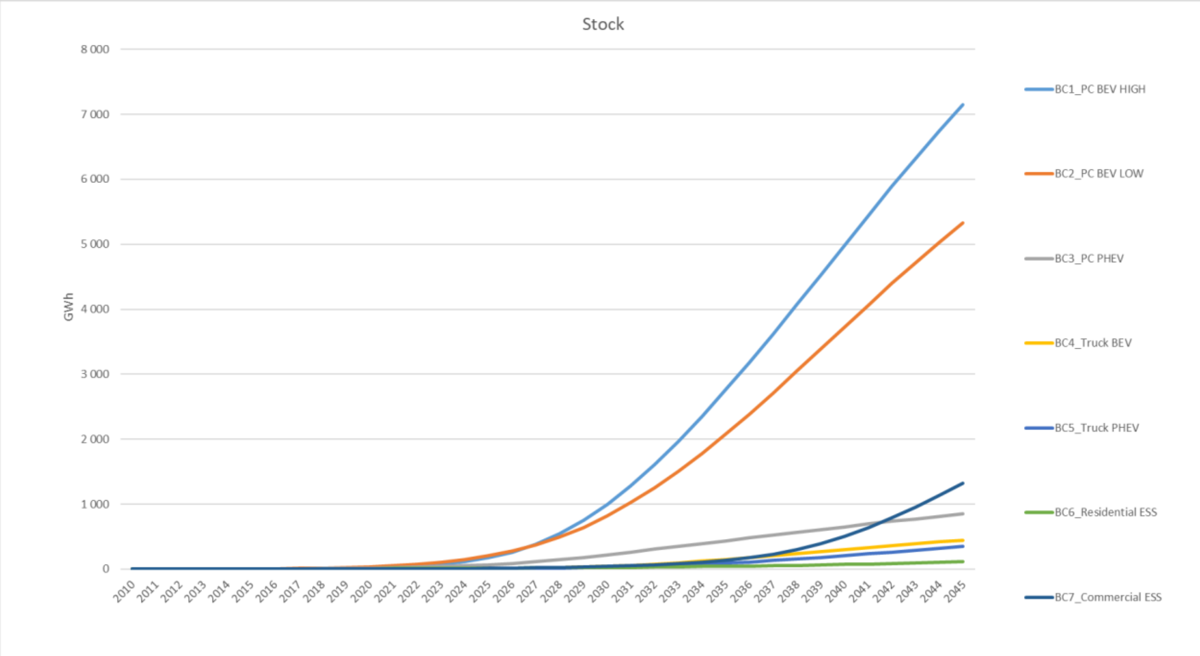

Figure 7-4: Forecast battery capacity stock for the EU market (medium sales scenario)

Table 7-12: Forecast battery capacity stock for the EU market (medium sales scenario)

Stock [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	18	173	996	2 760	4 983	7 150
BC2_PC BEV LOW	0	6	39	207	818	2 078	3 723	5 327
BC3_PC PHEV	3	5	17	70	221	438	653	850
BC4_Truck BEV	0	0	1	8	45	149	301	443
BC5_Truck PHEV	0	0	1	7	30	92	207	350
BC6_Residential ESS	1	4	9	16	26	45	72	113
BC7_Commercial ESS	0	1	4	12	40	141	504	1 324
Total mobile application	4	12	76	464	2 110	5 518	9 867	14 120
Total stationary application	1	5	12	27	67	185	576	1 437
Total all application	5	18	89	491	2 177	5 703	10 443	15 557

[43] Not in number of applications. For Basecase 7 (commercial ESS), there are 30 000 battery systems with 10 kWh nominal capacity.

Table 7-13: Forecast battery stock for the EU market (medium sales scenario) expressed in number of battery systems

Stock [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	1	16	227	2 160	12 450	34 503	62 292	89 372
BC2_PC BEV LOW	7	143	974	5 164	20 440	51 959	93 070	133 171
BC3_PC PHEV	250	417	1 439	5 795	18 454	36 515	54 382	70 873
BC4_Truck BEV	7	7	32	268	1 494	4 965	10 048	14 761
BC5_Truck PHEV	8	8	46	354	1 492	4 595	10 341	17 521
BC6_Residential ESS	108	435	886	1 566	2 644	4 454	7 228	11 316
BC7_Commercial ESS	30	112	361	1 163	4 045	14 069	50 355	132 385
Total mobile application	272	591	2 719	13 740	54 330	132 536	230 133	325 698
Total stationary application	138	547	1 247	2 729	6 689	18 523	57 583	143 701
Total all application	411	1 137	3 966	16 470	61 019	151 059	287 716	469 399

Figure 7-5 and Table 7-14 provide an overview of the evolution of the sales over time (based on the findings from the Task 2 report). Please note that due to the simplified approach of the Task 7 stock model (see Equation 3), the sales in Task 7 cannot match to the figures provided in Task 2. Table 7-15 shows the sales figures expressed in number of battery systems.

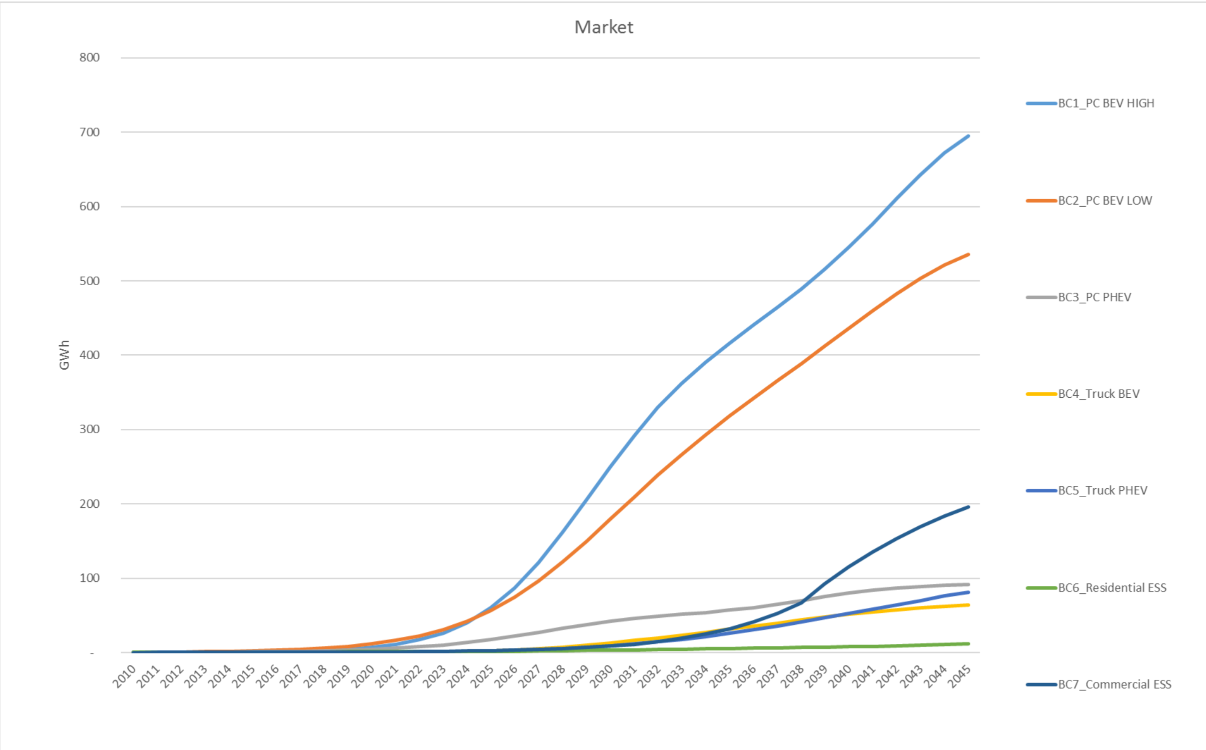

Figure 7-5: Forecast battery capacity sales for the EU market (medium sales scenario)

Table 7-14: Forecast battery capacity sales for the EU market (medium sales scenario)

Sales [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	7	60	250	416	545	695
BC2_PC BEV LOW	0	2	12	57	179	318	436	536
BC3_PC PHEV	0	1	4	17	43	57	80	91
BC4_Truck BEV	0	0	0	3	13	32	52	64
BC5_Truck PHEV	0	0	0	2	9	26	53	82
BC6_Residential ESS	0	1	1	2	3	5	8	12
BC7_Commercial ESS	0	0	1	3	9	32	115	196
Total mobile application	0	4	24	139	495	849	1 166	1 468
Total stationary application	0	1	2	4	12	37	123	208
Total all application	0	5	26	143	507	886	1 289	1 676

Table 7-15: Forecast battery sales for the EU market (medium sales scenario) expressed in number of battery systems

Sales [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	8	87	749	3 129	5 206	6 809	8 688
BC2_PC BEV LOW	1	52	293	1 418	4 487	7 950	10 912	13 395
BC3_PC PHEV	23	90	369	1 445	3 560	4 750	6 687	7 618
BC4_Truck BEV	1	1	16	86	430	1 054	1 722	2 130
BC5_Truck PHEV	2	2	24	125	469	1 303	2 631	4 076
BC6_Residential ESS	6	79	113	165	338	527	786	1 222
BC7_Commercial ESS	2	25	74	261	874	3 203	11 513	19 576
Total mobile application	26	153	790	3 821	12 076	20 263	28 761	35 907
Total stationary application	8	104	187	426	1 212	3 730	12 299	20 798
Total all application	34	257	976	4 248	13 288	23 993	41 060	56 705

At the end of this task report, a sensitivity analysis is carried out. It covers low / high sales scenarios (see 7.3.1) as well as low / high energy price scenarios (see 7.3.2).

7.2.1. Environmental impacts

For most of the products covered by an Ecodesign preparatory study, the energy consumption during the use phase of the product is the most important environmental impacting life cycle stage. Task 5 and Task 6 showed for battery systems a more complex situation. Therefore, beside the electricity consumption and the GHG emissions, the demand of CRM will be analysed here. Furthermore, for most of the environmental impacts, figures are presented according to the three main phases of the product:

- Production: raw materials use and manufacturing
- Use phase
- EoL: End of Life

7.2.1.1. Electricity consumption

Figure 7-6[44] shows the electricity consumption of the battery systems in the production phase[45]. The best improvement potential is seen in the RedMat_ExtLifeTime scenarios as well as in the BAT scenario. All achieve a reduction of the energy consumption by 29.3% (159 656 GWh/year) in 2045, compared to the BAU scenario (225 721 GWh/year).

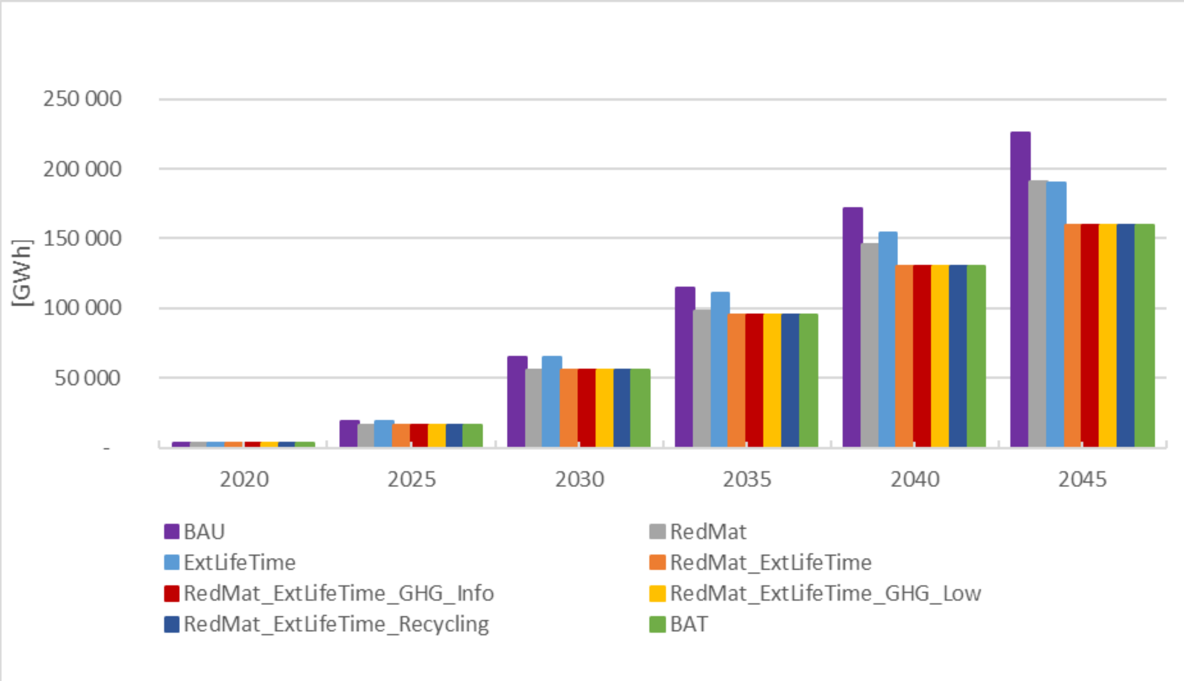

Figure 7-6: Electricity consumption in GWh/year for the production phase (EU-28 battery system stock)

[44] see also Table 7-28 in Annex

[45] Within the EcoReport tool there are two primary energy related environmental indicators: the Gross Energy Requirement (GER, in MJ) and the part of the GER that is used in form of electricity (also in MJ). The environmental impact of primary energy depends on the energy source. As mentioned in the MEErP 2011 methodological report part 1 (p. 94): the electricity use is an auxiliary parameter which "should not be perceived as a form of energy that in itself would have a higher or lower reduction priority that the GER. However, it is an important auxiliary parameter, as it not only creates the link with efficiency of power generation but also with a host of other parameters (emissions, waste, water use) that are relevant". Within the production of li-ion batteries, large amounts of electricity is used e.g. to prepare cathode active materials (when precursors are added to the lithium source) and for the electrode, cell forming and battery assembly (see table 8 and 10 of Task 5 report). In the EcoReport, the electricity part of the GER is given for the 55 common materials. For the added extra materials the study team has made rough estimates on the electricity part of the GER as good as possible, despite the limitations within LCA software to extract the amount of electricity in primary energy along the complete production chain. Considering all this, the study team found it important to include to electricity consumption in the production stage.

Electricity consumption in the use phase is illustrated in Figure 7-7. As visible in this figure, the electricity losses in all battery systems will exceed 200 000 GWh/a in 2045 This is in a similar range as the electricity consumption required for the production of the batteries.

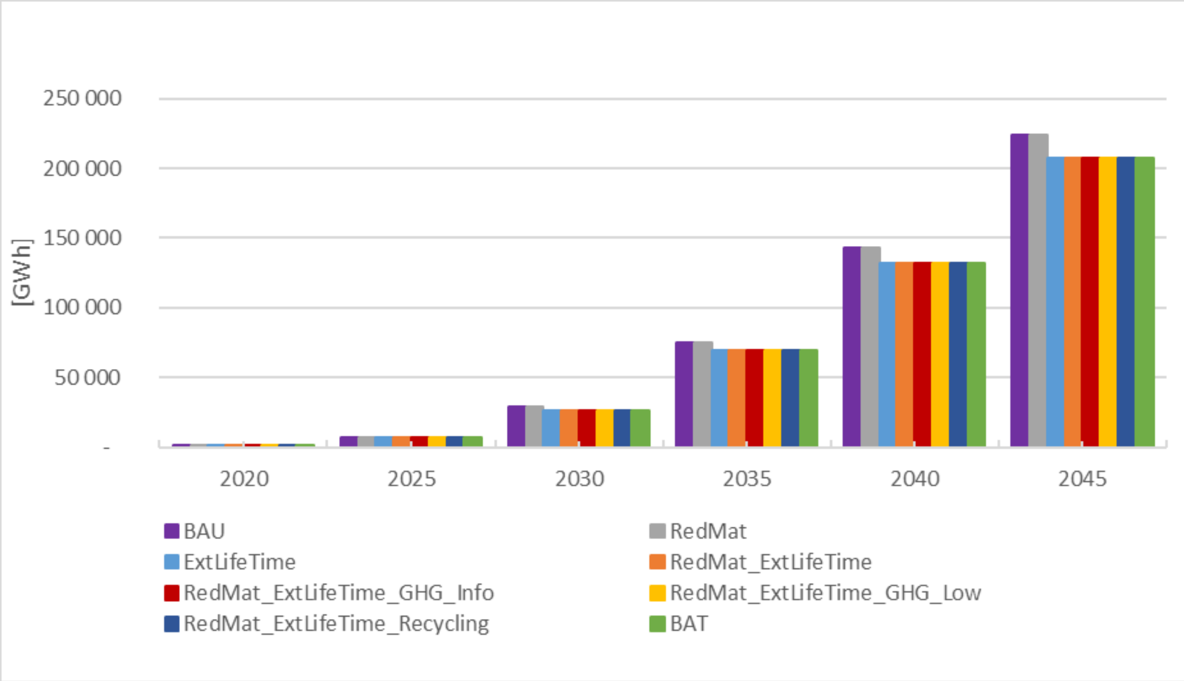

Figure 7-7: Electricity consumption in GWh/year for the use phase (EU-28 battery system stock)

The evolution of electricity consumption is also analysed for the EOL phase and the results are shown in Figure 7-8[46]. Until 2027, the electricity consumption in all scenarios is the same, since only batteries placed on the market after 2022 will be affected by the EOL measures when their technical lifetime will be reached.[47] In 2045, the BAU scenario will have the best impact, decreasing the electricity consumptions in the EOL phase by 2 724 GWh.

[46] see also Table 7-29 in Annex

[47] Basecase 5 has the shortest technical lifetime: 5 years.

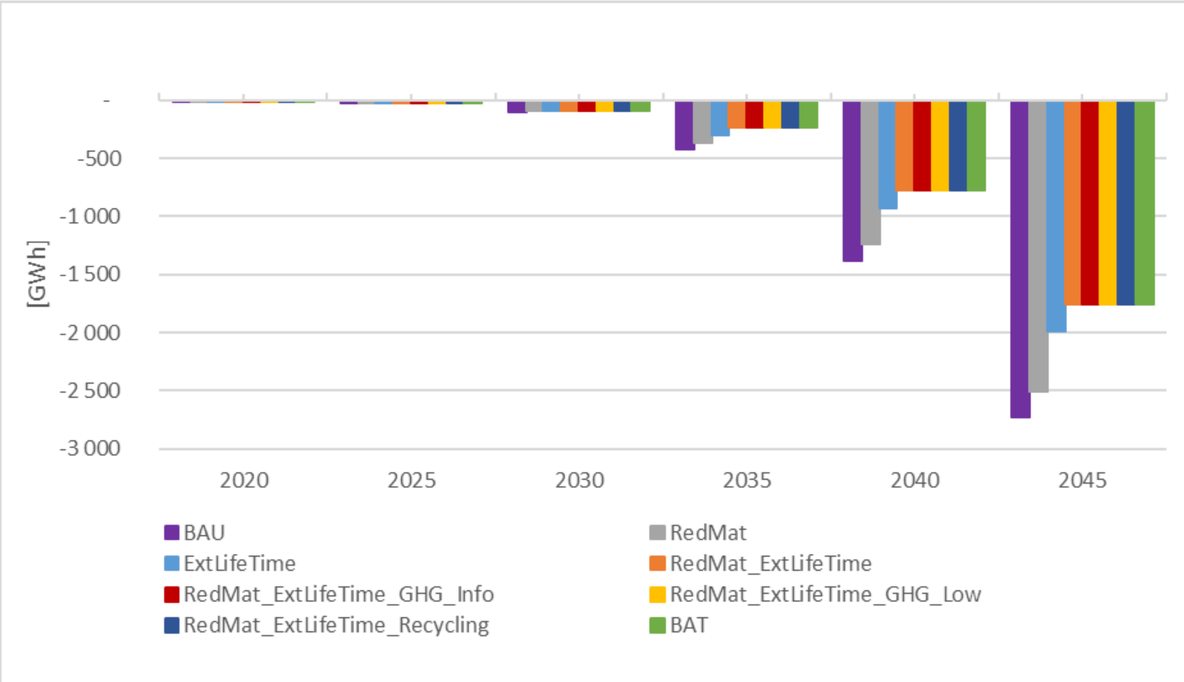

Figure 7-8: Electricity consumption in GWh/year for the EOL phase (EU-28 battery system stock)[48]

As summary, Figure 7-9[49] shows the electricity consumptions of the battery systems on the EU market in year 2045, considering all phases of the products. In general, the scenarios combining an extended lifetime and the reduction of material have the same impact on the electricity consumption: they have the potential to reduce it by 18.2% in year 2045 compared to the BAU scenario. Based on the previous tables and figures, the electricity consumption in the production and the use phase are similar, while the contribution in the EOL phase is negligible.

[48] The MEErP EcoReport tool considers incineration and landfilling as impacting processes during EOL and recycling, reuse and energy recovery as beneficial processes. The benefits of recycling, reuse and energy recovery are calculated as a (fixed) percentage of the impacts from production, i.e. 40 %, 75 %, and 30 % respectively. For instance: if the production impact of a certain plastic material is 1 MJ electricity of primary energy and the (MEErP default) recycling, reuse and energy recovery rate are 29 %, 1 % and 15 % respectively, than the benefits due to recycling, reuse and energy recovery during EOL = (0.4 * 0.29 + 0.75 * 0.01 + 0.3 * 0.15) * 1 = 0.91 MJ. In case the impact from electricity used at the incineration and landfilling of the remaining fraction of that plastic material is smaller than 0.91 MJ, than it would result in a negative value (i.e. benefit) for the EOL phase. If it is bigger than 0.91 MJ than it would result in a positive value, i.e. an impact.

[49] see also Table 7-30 in Annex

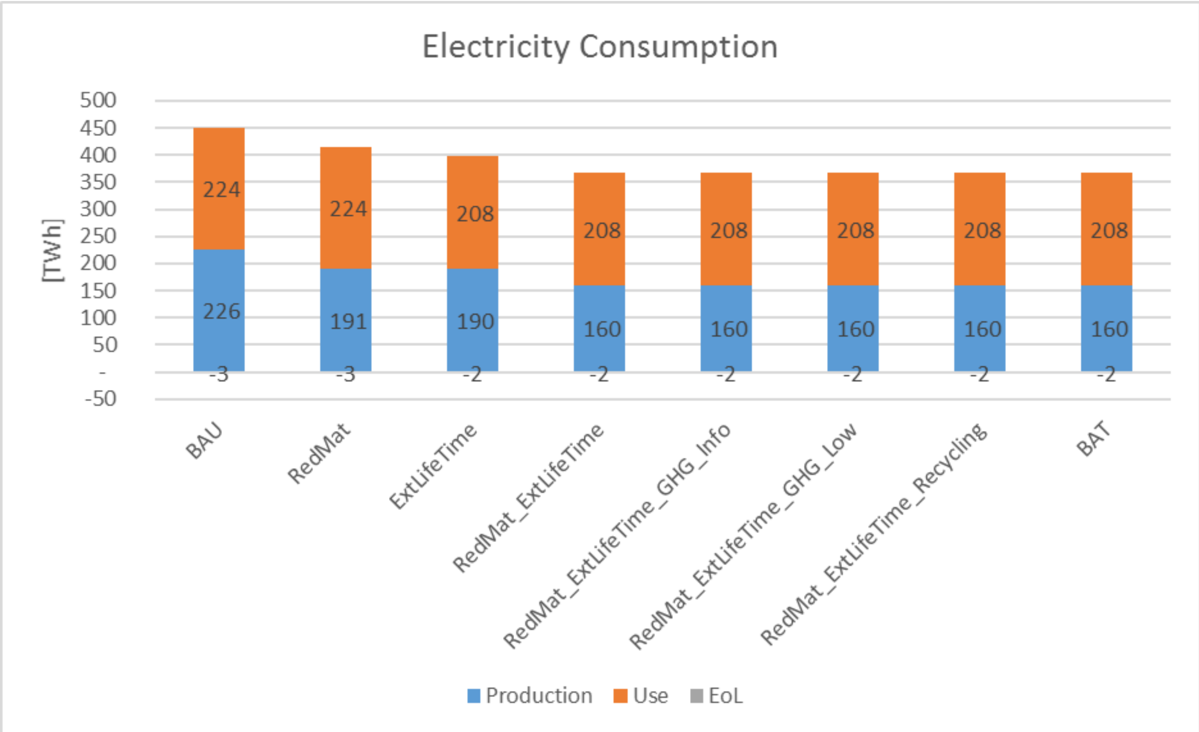

Figure 7-9: Electricity consumption in TWh/year for all phases in 2045 (EU-28 battery system stock)

7.2.1.2. GHG emissions

The results of the GHG emissions analysis in different phases of the battery systems are presented in this section.

Looking at the production phase (see Figure 7-10)[50], the best way to reduce the GHG emissions related to the electricity consumptions is through the electricity mix. The best scenarios are RedMat_ExtLifeTime_GHG_Low and BAT, emitting only 1 $MtCO_2$/year in 2045, which is 98.9% below the BAU level. RedMat_ExtLifeTime_GHG_Info is the next best scenario, with 50% reduction compared to the BAU scenario.

50 see also Table 7-31 in Annex

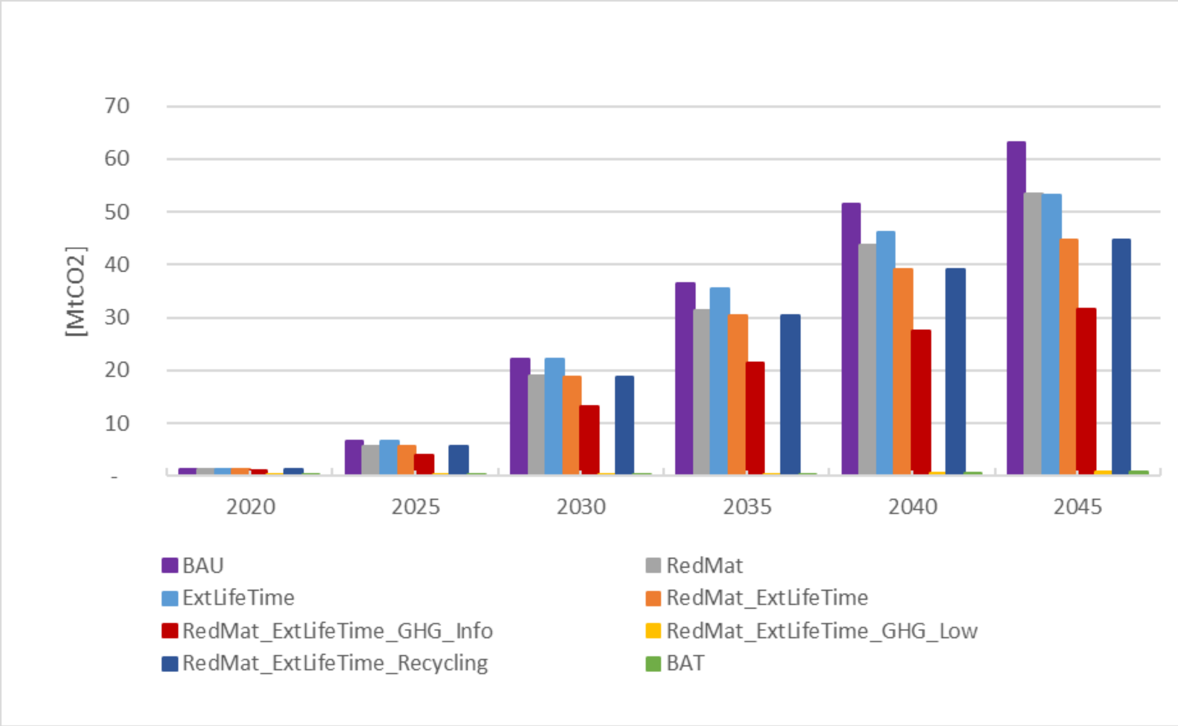

Figure 7-10: GHG emission (of the electricity consumption) in $MtCO_2$/year for the production phase (EU-28 battery system stock)

However, in the use phase (see Figure 7-11), where the same electricity mix (EU average) is assumed for all scenarios, the ranking of the scenarios is the same as for GHG emissions in the use phase (see Figure 7-7).

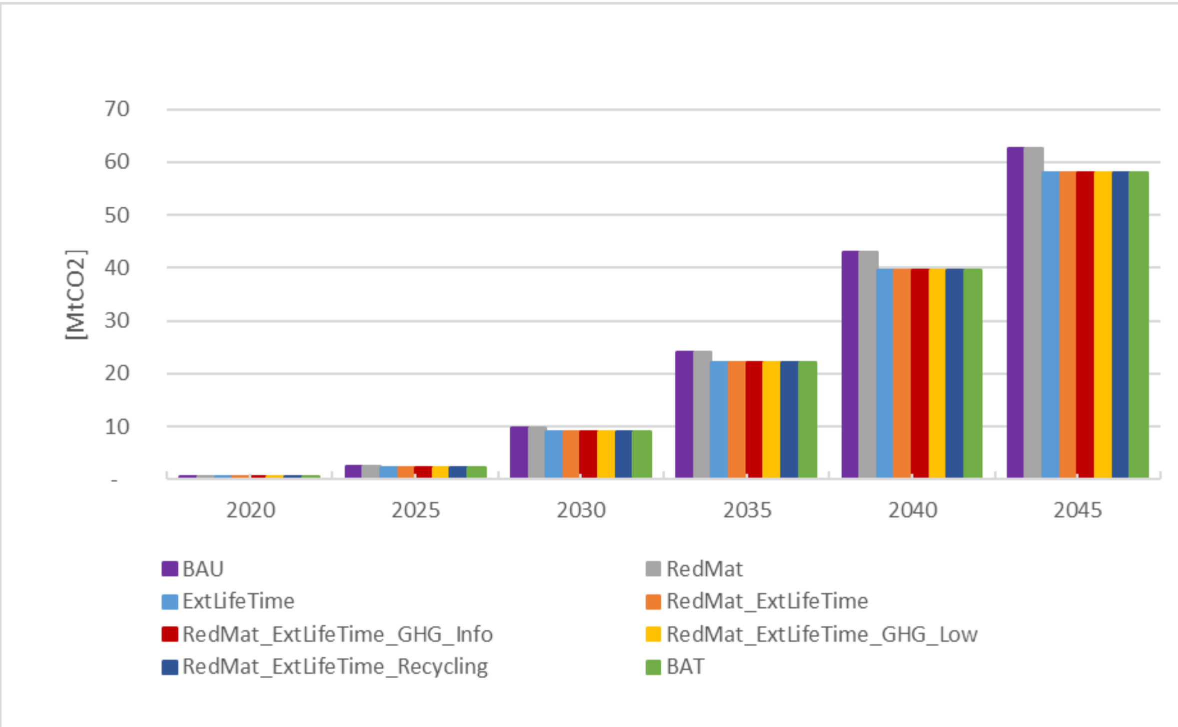

Figure 7-11: GHG emission (of the electricity consumption) in $MtCO_2$/year for the use phase (EU-28 battery system stock)

The evolution in terms of GHG Emissions is also compared for the EOL phase, see Figure 7-12[51]. The GHG figures are calculated on the basis of GHG emissions of an average kWh electricity in the EU and on the electricity consumptions (see Figure 7-8).

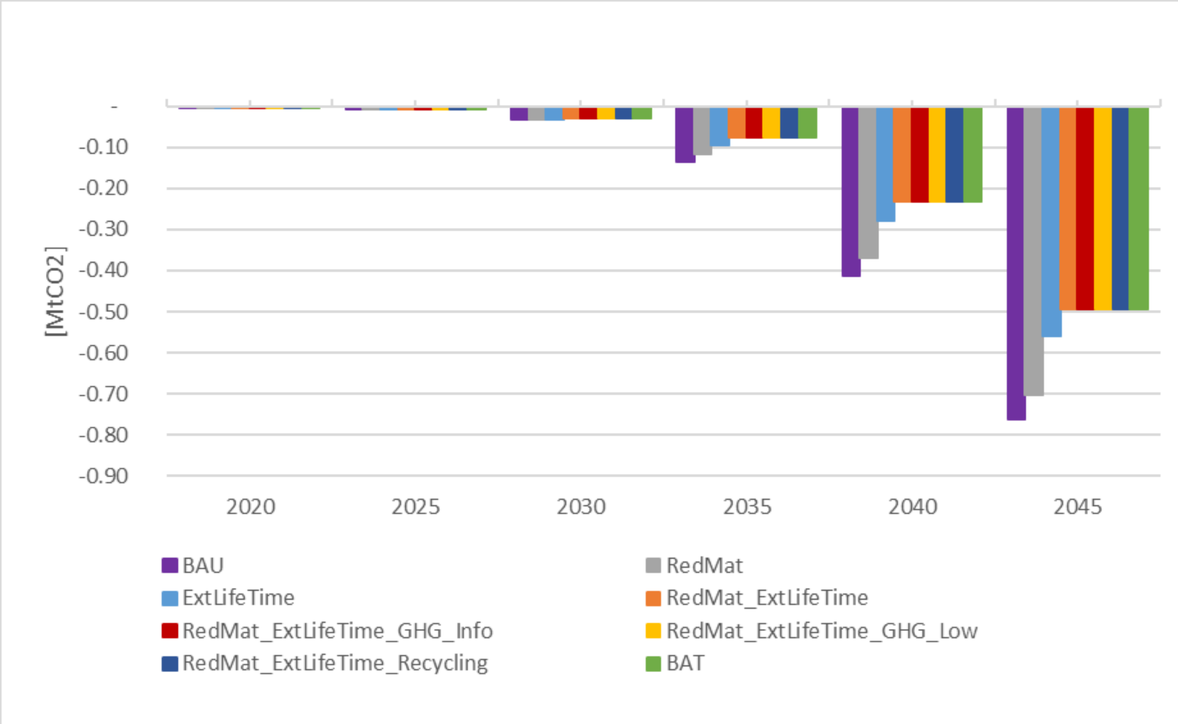

Figure 7-12: GHG emission (of the electricity consumption) in $MtCO_2$/year for the EOL phase (EU-28 battery system stock)

Figure 7-13[52] shows the GHG emissions for all phases and for battery systems in the EU in 2045. In the BAU scenario, the overall GHG emissions *are expected to* increase up to 125 $MtCO_{2eq}$/a, by 2045 assuming the average EU electricity mix for all phases of a battery system. The GHG emissions can be reduced by 53.3% in RedMat_ExtLifeTime scenarios[53] using low carbon electricity mix during the production phase.

[51] see also Table 7-32 in Annex

[52] see also Table 7-33 in Annex

[53] RedMat_ExtLifeTime_GHG_Low and BAT

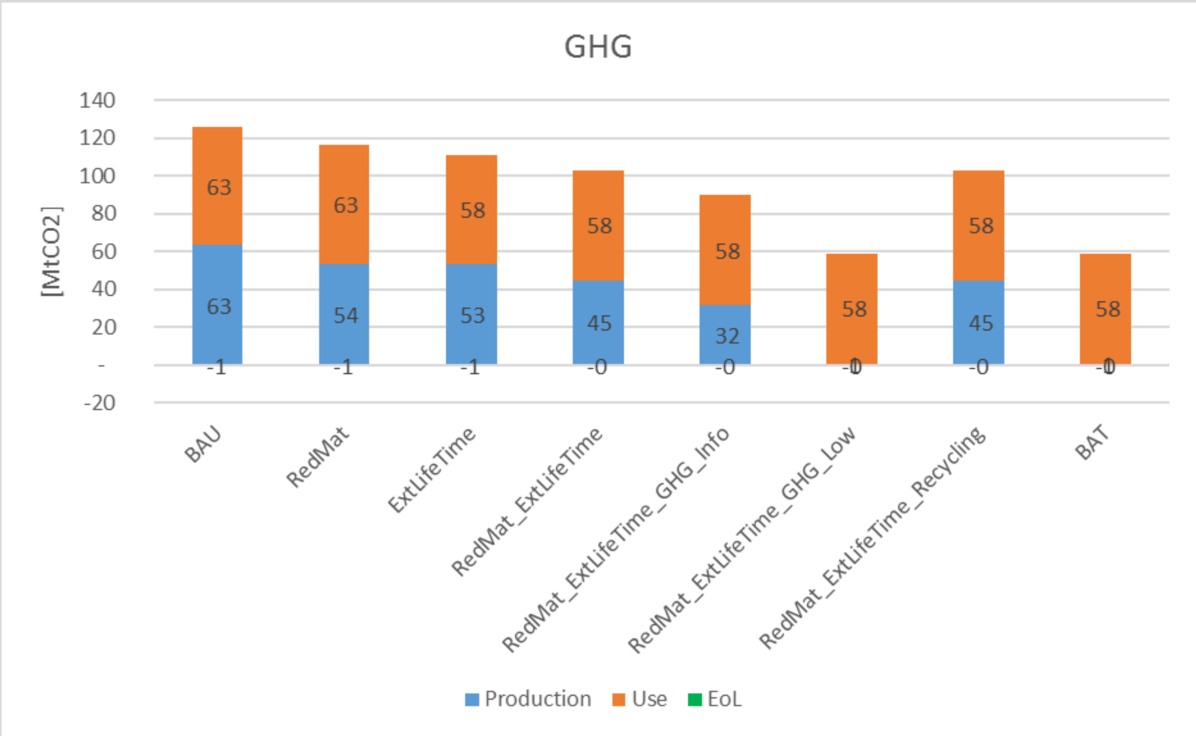

Figure 7-13: GHG emission (of the electricity consumption) in $MtCO_2$/year for all phases in 2045 (EU-28 battery system stock)

7.2.1.3. Cobalt demand

Figure 7-14[54] shows the Cobalt demand in the production phase of the battery systems. In the BAU scenario, the yearly Cobalt demand will rise up to 177 kt/a for the EU market in 2045. This demand could be reduced by 55% in the RedMat_ExtLifeTime scenarios as well as in the BAT scenario. A similar analysis for all phases shows the highest potential reduction in the Cobalt demand for RedMat_ExtLifeTime_Recycling and BAT scenarios (see Figure 7-15[55]).

[54] see also Table 7-34 in Annex

[55] see also Table 7-35 in Annex

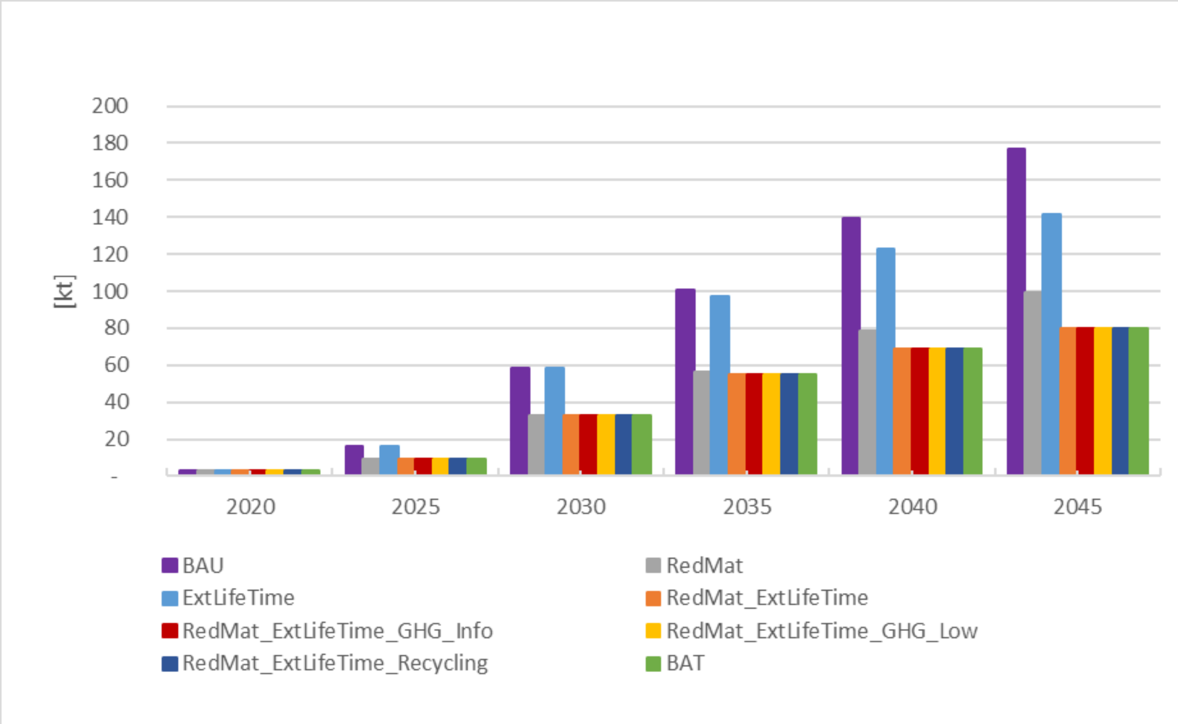

Figure 7-14: Cobalt demand in kt/year for the production phase (EU-28 battery system stock)

The following figure *(*Figure 7-15*)* shows the amount of cobalt used in batteries by product phase:

- *Production*: quantity required for the manufacture of new batteries.
- *U*se: total quantity used by all batteries in service on the market
- *EoL*: quantity recovered at the end of a battery's life. This quantity depends on the demand for the production (when the batteries have been put on the market) and the recycling rate. The figure is negative, since the amount of recycled cobalt decreases the

The sum indicates year by year the amount of cobalt mobilised for all batteries on the EU market.

For comparison, in 2016 global cobalt production was 126 kt with the largest supply (55%) coming from the Democratic Republic of the Congo. In turn, the EU production of cobalt was estimated at 2,3 kt sourced from Finland[56]. As a conclusion, significant more cobalt mining will be needed to satisfy the forecasted demand in this study and it will be essential to recycle all possible cobalt. Today most cobalt is obtained as a co- and by-product of copper (46 %) and nickel (39 %) mining, which is beneficial to reduce the environmental impact per kt due to synergies in production. An increased demand might however change this in future.

[56] JRC (2018) Technical Report: 'Cobalt: demand-supply balances in the transition to electric mobility', ISBN 978-92-79-94311-9

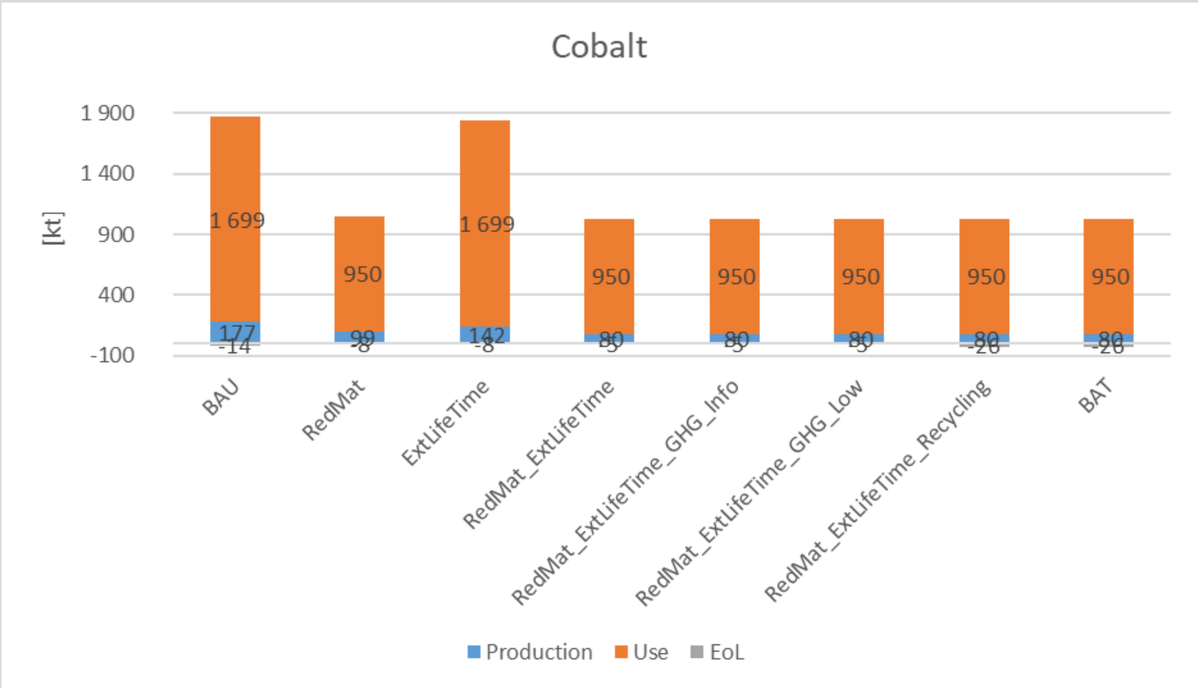

Figure 7-15: Cobalt demand in kt/year for all phases in 2045 (EU-28 battery system stock)

7.2.1.4. Graphite demand

The evolution of the Graphite demand for the battery systems over time is shown for the production phase in Figure 7-16[57] and for all phases in Figure 7-17.

The demand for Graphite is expected to rise up to 1 951 kt/y in 2045 in the BAU scenario. The RedMat_ExtLifeTime scenarios as well as the BAT scenario will reduce the demand by 28.3% in 2045.

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57 see also Table 7-36 in Annex

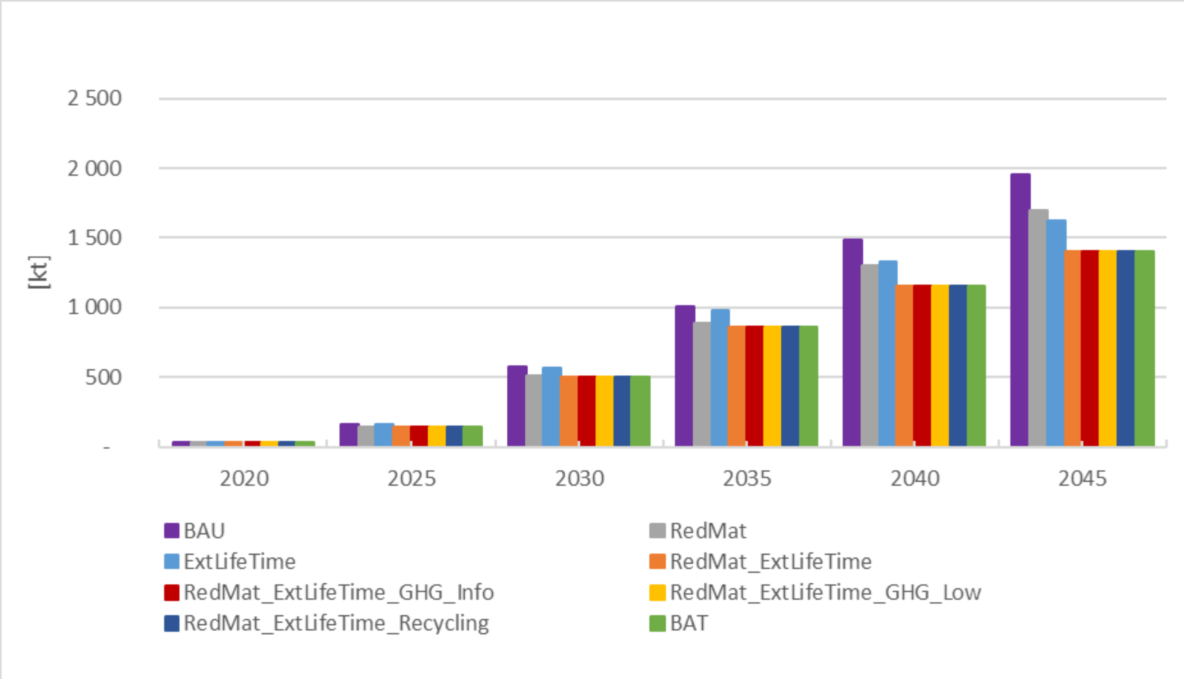

Figure 7-16: Graphite demand in kt/year for the production phase (EU-28 battery system stock)

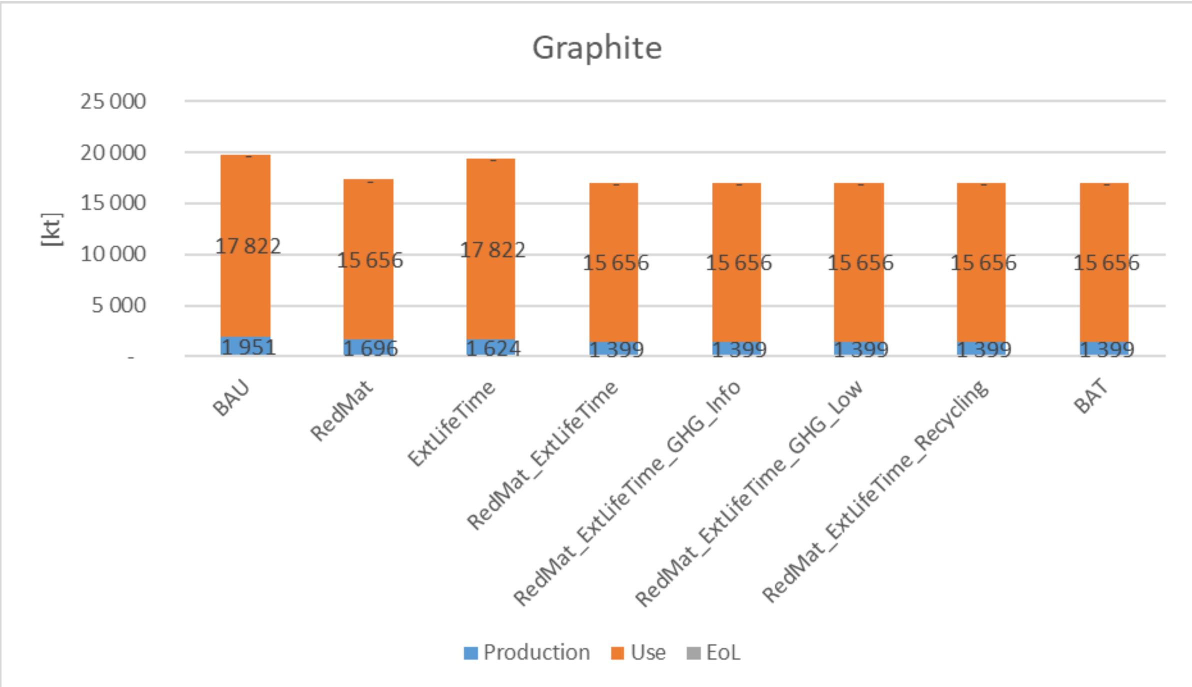

Figure 7-17: Graphite demand in kt/year for all phases (EU-28 battery system stock)

7.2.1.5. Nickel demand

Figure 7-18[58] illustrates the nickel demand in the battery systems for the production phase. Here, the nickel demand in the ExtLifeTime scenario is expected to be the lowest (514 kt/a) compared to the BAU scenario (647 kt/a) in 2045. An increase of 20.6% of the nickel demand is expected in the RedMat scenario. The other scenarios have a similar level of nickel demand as in the BAU scenario.

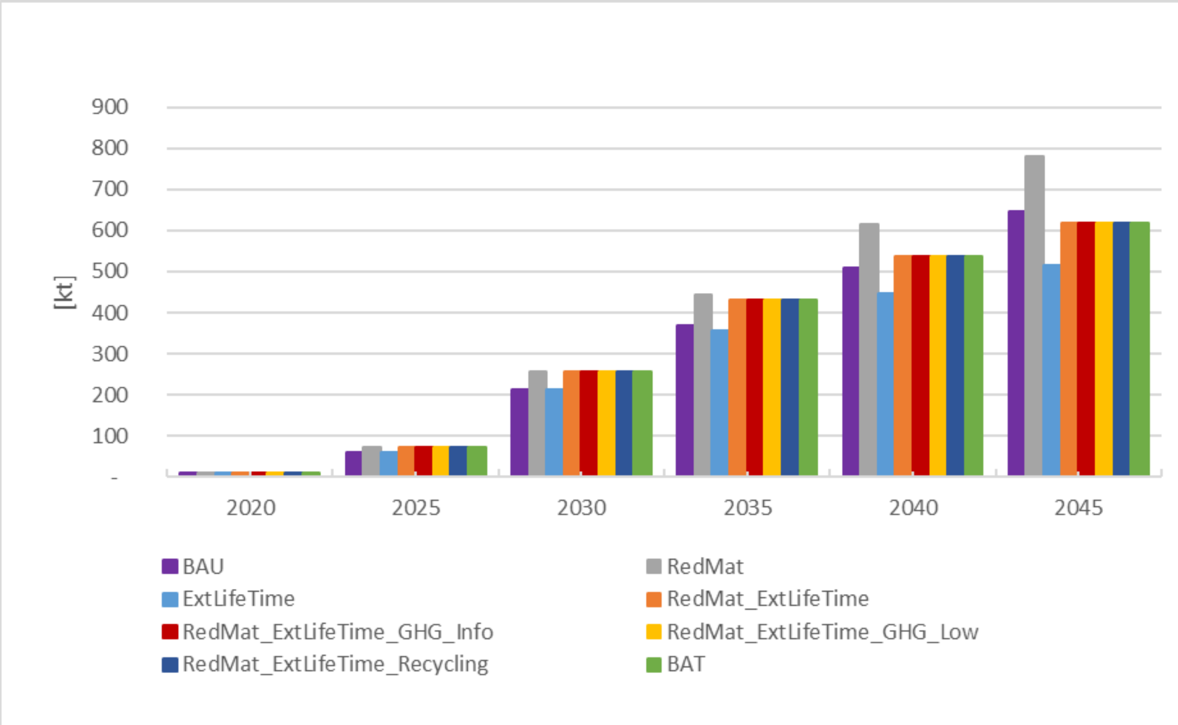

Figure 7-18: Nickel demand in kt/year for the production phase (EU-28 battery system stock)

An overview of the results, taking into account all phases of the battery systems, is provided in Figure 7-19[59].

For comparison, in 2018 global primary nickel demand was 2 293 kt mainly used in stainless steel alloys while supply was 2 193 kt[60].Clearly significant more nickel mining and/or recycling

[58] see also Table 7-38 in Annex

[59] see also Table 7-39 in Annex

[60] Glencore (2017) report:'Nickel: State of the market November 2017', https://www.glencore.com/dam/jcr:ac289c69-acb9-48c5-8224-de4ce48c2627/2017-11-MB-Ferroalloy-conference.pdf

will be needed to satisfy this forecasted demand. In the EU the largest operational Nickel mines are located in Finland, Greece and Spain[61].

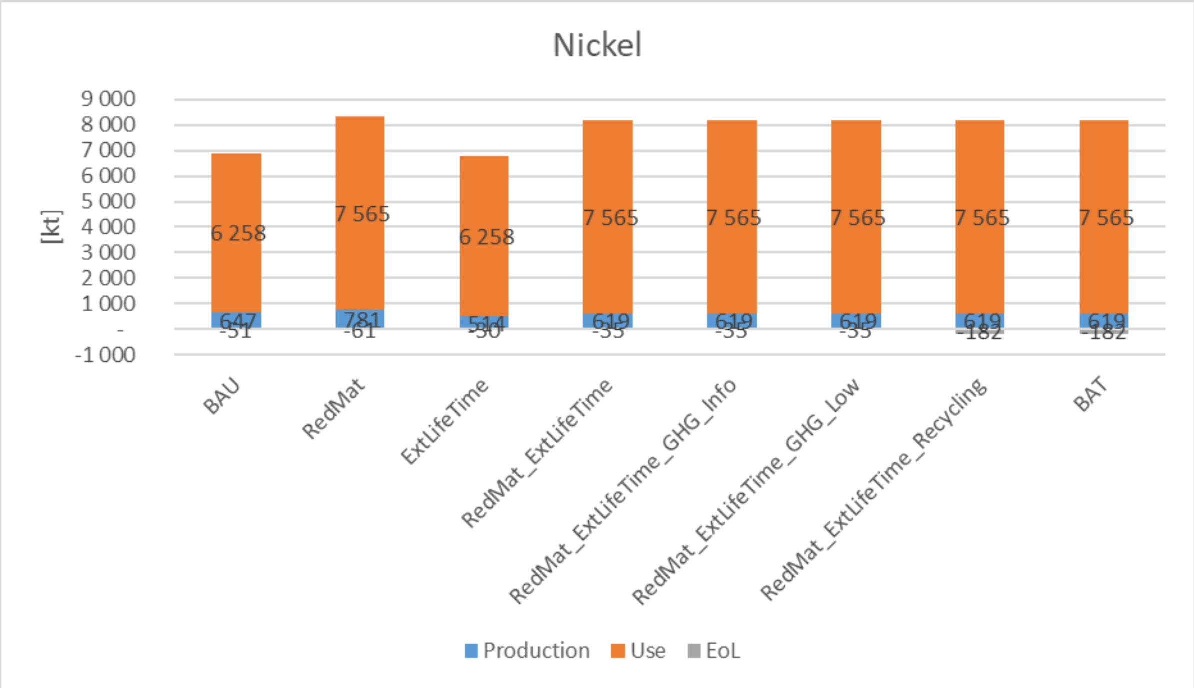

Figure 7-19: Nickel demand in kt/year for all phases (EU-28 battery system stock)

7.2.1.6. Manganese demand

Figure 7-20 and Figure 7-21 respectively illustrate the manganese demand in the production phase and all phases of the battery systems. The details of the results are shown in Table 7-40 and in Table 7-41 (see Annex).

61 http://www.euromines.org/mining-europe/production-mineral#Nickel

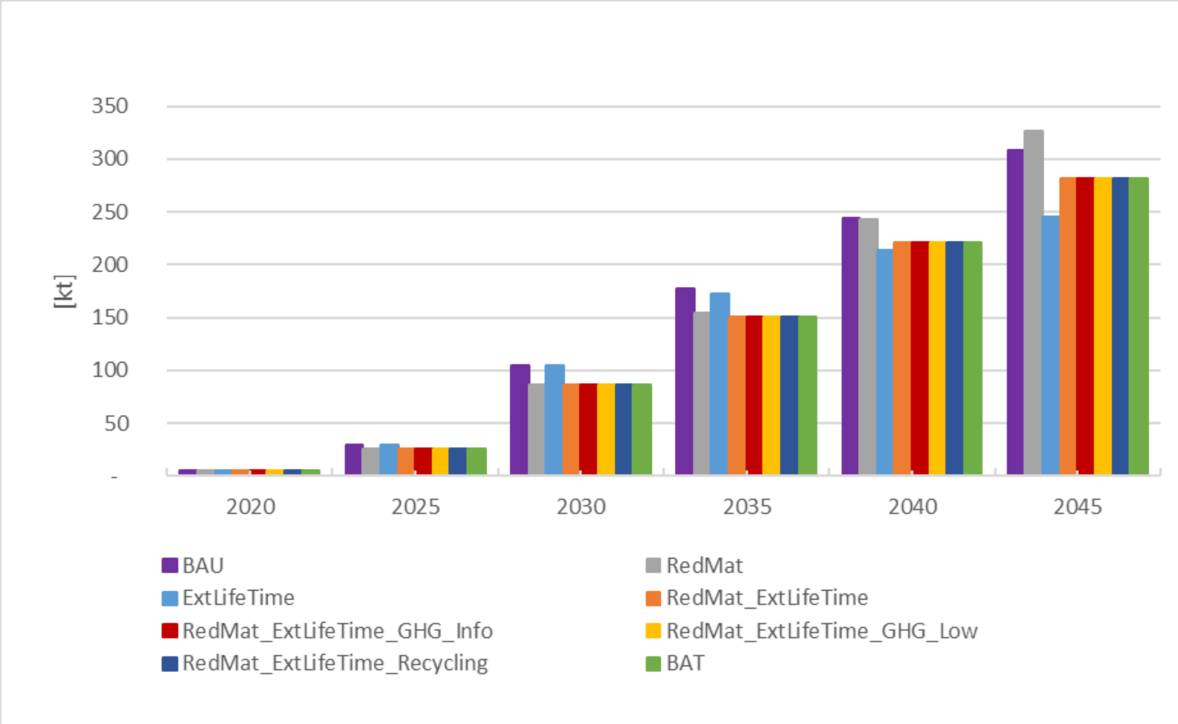

Figure 7-20: Manganese demand in kt/year for the production phase (EU-28 battery system stock)

By 2045, the ResdMat_ExtLifeTime_Recycling and BAT scenarios will reduced the total amount of Manganese by 7%, compared to BAU.

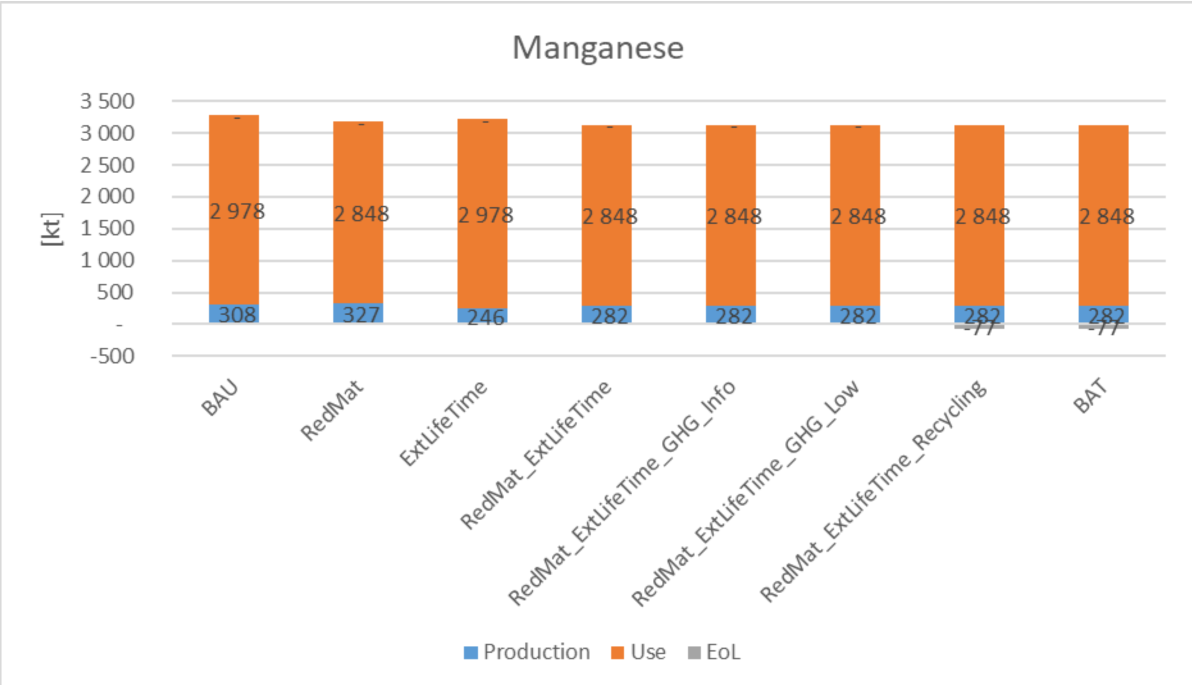

Figure 7-21: Manganese demand in kt/year for all phases in 2045 (EU-28 battery system stock)

The largest European mine for manganese is located in Bulgaria which produced 12 kT in 2016[62].

7.2.1.7. Lithium demand

As shown in Figure 7-22, the lithium demand in the production phase of the battery systems is expected to grow over the next decades, reaching 285 kt/a by 2045 in the BAU scenario. In the RedMat scenario, the demand will decrease by only 5.5% compared to the BAU scenario. However, the lithium demand is at its lowest level in the RedMat_ExtLifeTime, RedMat_ExtLifeTime_GHG_Info and RedMat_ExtLifeTime_GHG_Low scenarios, with a 23.6% decrease compared to the BAU scenario.[63]

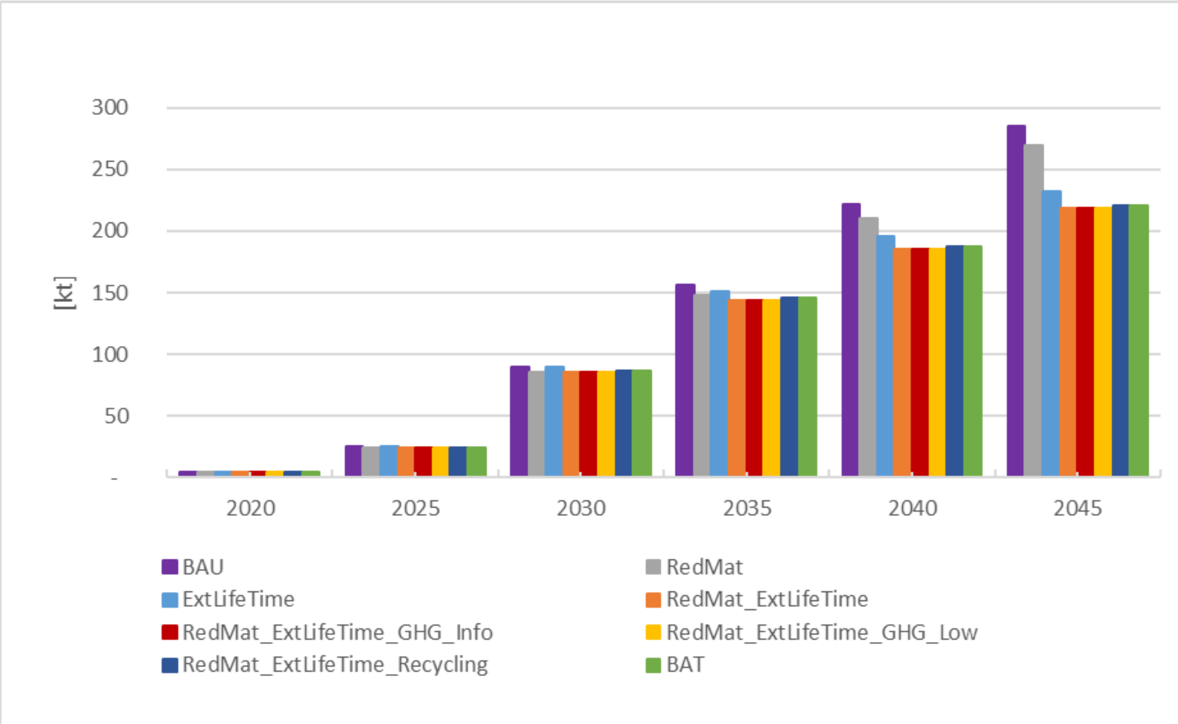

Figure 7-22: Lithium demand in kt/year for the production phase (EU-28 battery system stock)

The lithium demand has been also estimated for all phases and the results are presented in Figure 7-23.[64]

62 http://www.euromines.org/mining-europe/production-mineral#Manganese

63 see also Table 7-42 in Annex

64 see also Table 7-43 in Annex

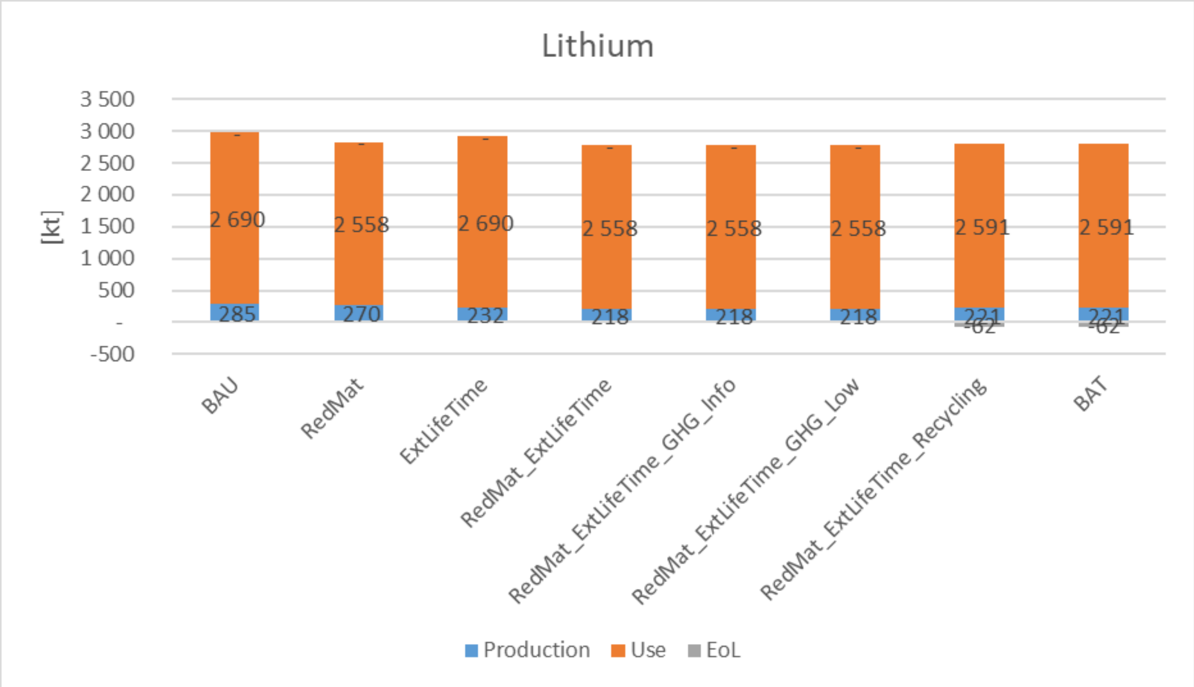

Figure 7-23: Lithium demand in kt/year for all phases in 2045 (EU-28 battery system stock)

7.2.2. Socio-economic impacts

In this section, socio-economic impacts are analysed according to the scenarios. The total expenditures include:

- the purchase costs: they are driven by the market sales and the purchase price of the battery systems.
- the running costs. In the model, only the electricity costs in the use phase were considered. They are expressed on a yearly basis until the technical lifetime of the battery system is reached.
- the EOL costs: including the replacement costs and the decommissioning costs.

The total expenditures in € bln./year are shown in Figure 7-24 and Figure 7-25. According to the figures, the expenditure for the BAU increases to 512 € bln. by 2045. The RedMat_ExtLifeTime scenarios and the BAT scenario however are expected to reduce the total expenditures by 36.2% in 2045, making them the cheapest scenarios. Furthermore, Figure 7-26, Figure 7-27 and Figure 7-28 show the details of the costs positions according to the scenarios until 2045.

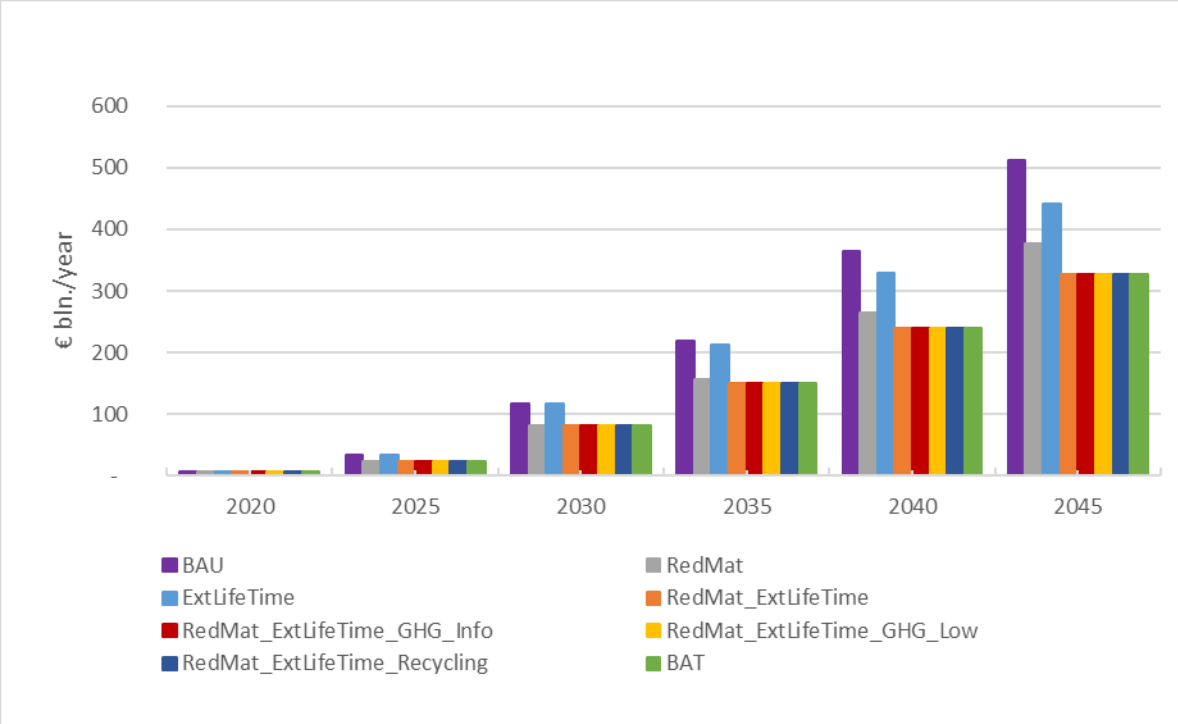

Figure 7-24: Total expenditure in € bln. /year (EU-28 battery system stock)

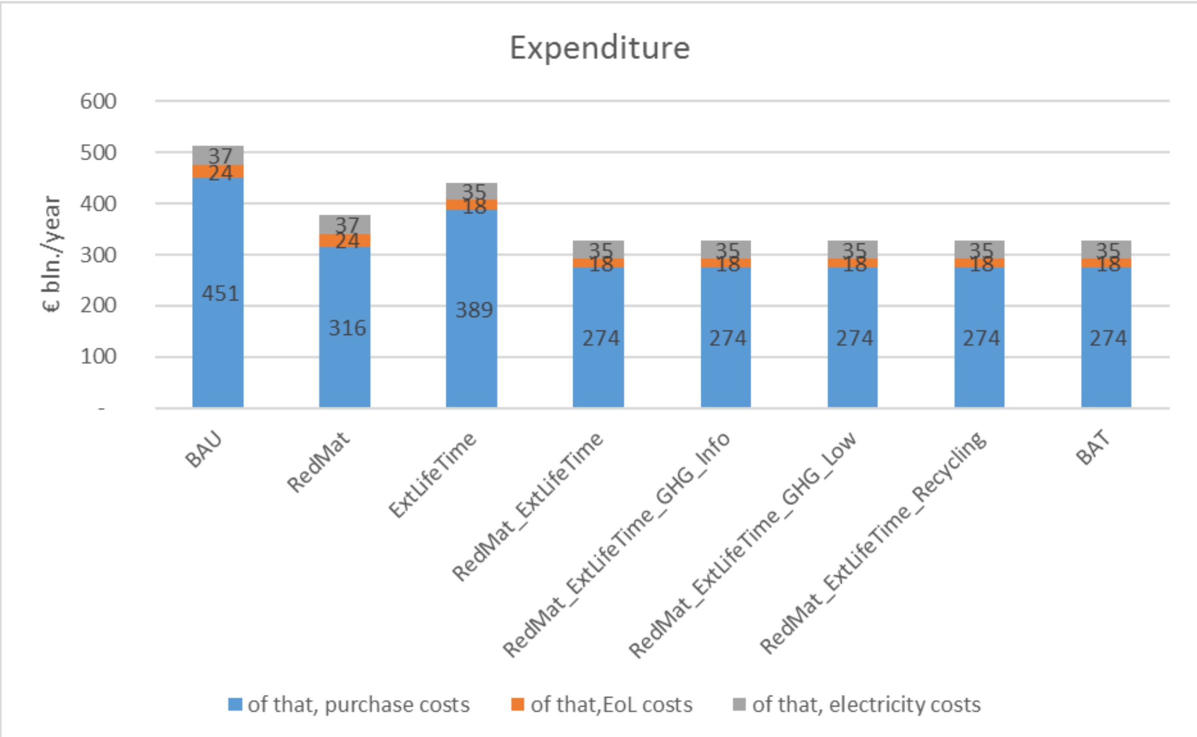

Figure 7-25: Total expenditure in € bln. /year in 2045 (EU-28 battery system stock)

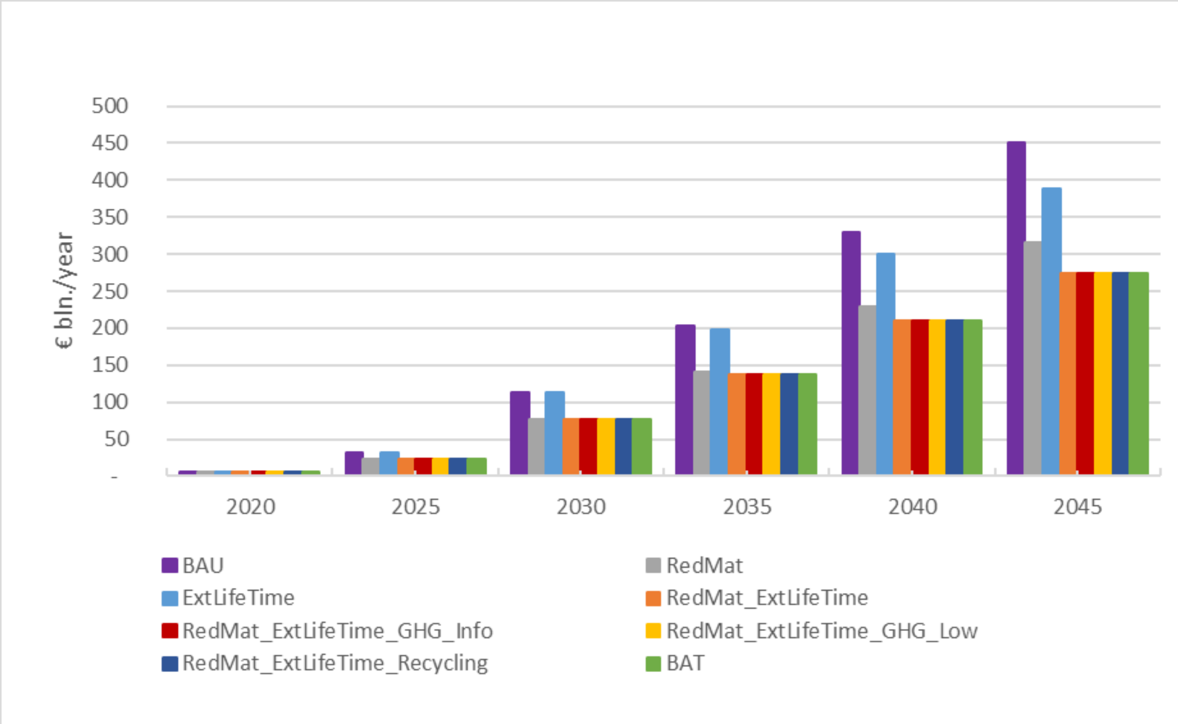

Figure 7-26: Purchase costs in € bln. /year (EU-28 battery system stock)

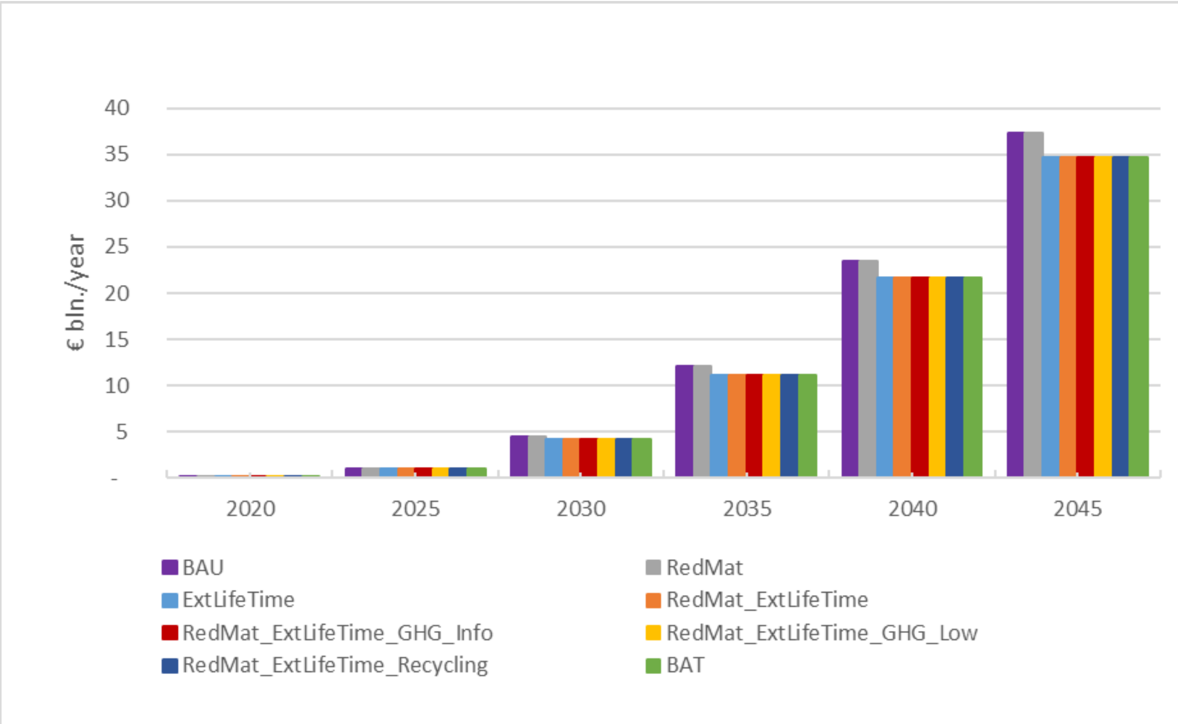

Figure 7-27: Electricity costs (use phase only) in € bln. /year (EU-28 battery system stock)

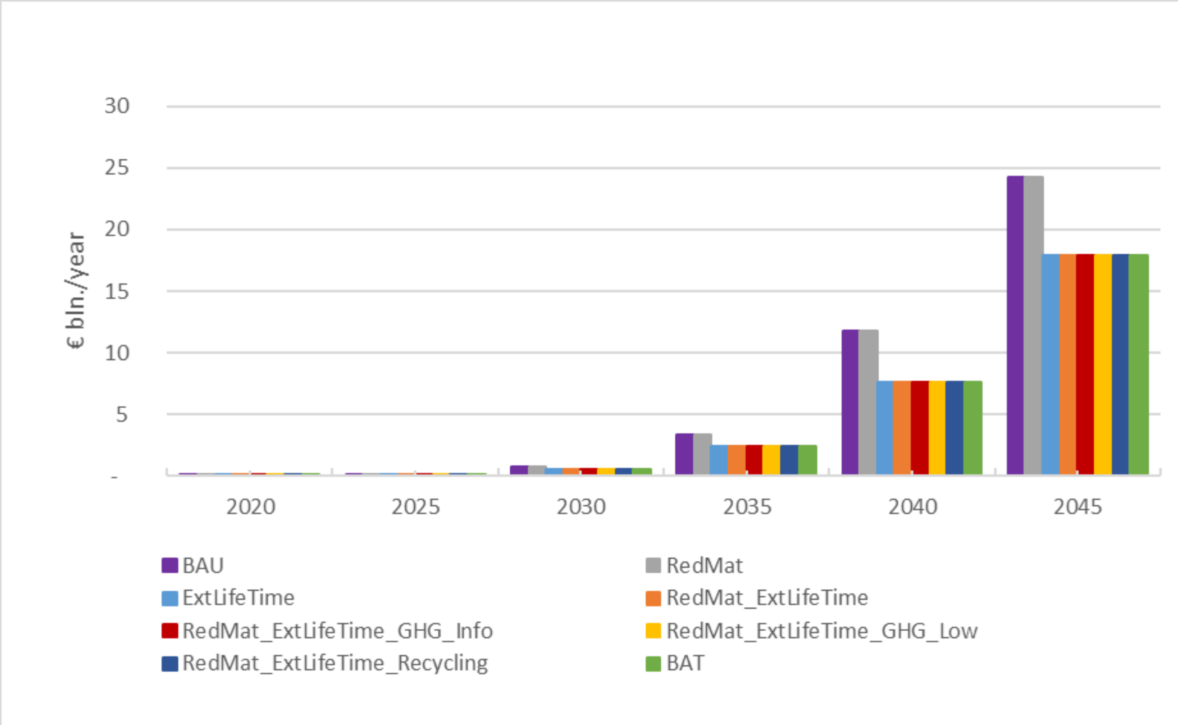

Figure 7-28: EOL costs in € bln. /year (EU-28 battery system stock)

7.2.3. Overview

A summary of the main impacts of the different scenarios is presented in Table 7-16, showing the figures for 2045.

Table 7-16: Overview of the main impacts in 2045 (EU-28 battery system stock)

			1	2	3	4	5	6	7	8
			BAU	RedMat	ExtLifeTime	RedMat_ExtLife Time	RedMat_ExtLife Time_GHG_Info	RedMat_ExtLife Time_GHG_Low	RedMat_ExtLife Time_Recycling	BAT
ENVIRONMENT										
	Electricity Consumption	[GWh]	446 616	412 233	395 234	365 498	365 498	365 498	365 498	365 498
	GHG	[MtCO2]	125	115	111	102	89	58	102	58
RESSOURCE										
	Cobalt	[kt]	1 685	942	1 690	946	946	946	925	925
	Graphite	[kt]	17 822	15 656	17 822	15 656	15 656	15 656	15 656	15 656
	Nickel	[kt]	6 208	7 504	6 229	7 529	7 529	7 529	7 383	7 383
	Manganese	[kt]	2 978	2 848	2 978	2 848	2 848	2 848	2 771	2 771
	Lithium	[kt]	2 690	2 558	2 690	2 558	2 558	2 558	2 529	2 529
CONSUMER										
EU totals	Expenditure	€ bln./year	512	378	441	327	327	327	327	327
	of that, purchase costs	€ bln./year	451	316	389	274	274	274	274	274
	of that,EoL costs	€ bln./year	24	24	18	18	18	18	18	18
	of that, electricity costs	€ bln./year	37	37	35	35	35	35	35	35
Per product sold	Sales (regulated)	000 000	57	57	51	51	51	51	51	51
	Product price	€	7 948	5 575	7 583	5 352	5 352	5 352	5 352	5 352
BUSINESS										
EU turnover	Manufacturers	€ bln./year	450.70	316.14	388.89	274.48	274.48	274.48	274.48	274.48
	Maintenance and EoL	€ bln./year	24.21	24.21	17.90	17.90	17.90	17.90	17.90	17.90
	Electricity Companies	€ bln./year	37.34	37.34	34.67	34.67	34.67	34.67	34.67	34.67
EMPLOYMENT										
Employment (jobs)	Manufacturers (direct jobs)	000	209.46	209.46	172.12	172.12	172.12	172.12	172.12	172.12
	Manufacturers (indirect jobs)	000	502.70	502.70	413.08	413.08	413.08	413.08	413.08	413.08
	TOTAL	000	712.16	712.16	585.20	585.20	585.20	585.20	585.20	585.20

7.3. Sensitivity analysis

Aim of Task 7.3:

The aim of the analysis in this section is to investigate the sensitivity of the main outcomes for changes in the main calculation parameters. The sensitivity analysis on the stock volumes (section 7.3.1) and electricity prices (section 7.3.2) is performed at scenario level.

This sensitivity analysis should also serve to compensate for weaknesses in the robustness of the reference scenarios and policy options due to uncertainties in the underlying data and assumptions.

The sensitivity analysis on the battery system service life (section 7.3.3) is done for the BAU on application level to complement the base case calculations of Task 5 and to see its effect on the life cycle impact of an application.

7.3.1. Stock volumes

In this section, the battery sales for the EU market for low and high sales scenarios are considered and the assumptions[65] are presented in Table 7-17 to Table 7-20.

Table 7-17: Forecast of battery systems stock for the EU market (low sales scenario), in capacity and in 1000' units

Stock [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	18	146	755	2 099	3 854	5 612
BC2_PC BEV LOW	0	6	39	158	539	1 361	2 556	3 852
BC3_PC PHEV	3	5	17	60	180	404	714	1 090
BC4_Truck BEV	0	0	1	3	17	64	158	265
BC5_Truck PHEV	0	0	1	6	19	46	96	172
BC6_Residential ESS	1	4	9	14	20	30	44	61
BC7_Commercial ESS	0	1	4	12	27	50	111	253
Total mobile application	4	12	76	372	1 510	3 975	7 377	10 990
Total stationary application	1	5	12	25	47	79	155	314
Total all application	5	18	89	398	1 557	4 054	7 532	11 305
Stock [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	1	16	227	1 825	9 433	26 237	48 180	70 146
BC2_PC BEV LOW	7	143	974	3 946	13 478	34 030	63 896	96 305
BC3_PC PHEV	250	417	1 439	4 981	15 040	33 686	59 460	90 806
BC4_Truck BEV	7	7	32	105	572	2 145	5 258	8 827
BC5_Truck PHEV	8	8	46	284	928	2 307	4 783	8 604
BC6_Residential ESS	108	435	886	1 383	2 014	2 987	4 356	6 129
BC7_Commercial ESS	30	112	361	1 159	2 708	4 953	11 137	25 297
Total mobile application	272	591	2 719	11 141	39 451	98 406	181 577	274 688
Total stationary application	138	547	1 247	2 543	4 722	7 941	15 493	31 427
Total all application	411	1 137	3 966	13 684	44 173	106 346	197 069	306 115

65 Based on the stock scenarios (low and high) elaborated in Task 2

Table 7-18: Forecast of battery systems sales for the EU market (low sales scenario), in capacity and in 1000' units

Sales [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	7	47	184	326	431	549
BC2_PC BEV LOW	0	2	12	39	112	213	319	407
BC3_PC PHEV	0	1	4	14	36	63	99	136
BC4_Truck BEV	0	0	0	1	4	16	30	41
BC5_Truck PHEV	0	0	0	2	5	12	24	42
BC6_Residential ESS	0	1	1	1	2	3	4	6
BC7_Commercial ESS	0	0	1	2	3	7	19	40
Total mobile application	0	4	24	103	342	630	902	1 176
Total stationary application	0	1	2	4	5	10	23	46
Total all application	0	5	26	106	347	641	925	1 222
Sales [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	8	87	591	2 306	4 073	5 388	6 865
BC2_PC BEV LOW	1	52	293	963	2 809	5 325	7 969	10 169
BC3_PC PHEV	23	90	369	1 168	2 981	5 284	8 210	11 367
BC4_Truck BEV	1	1	16	35	129	520	986	1 383
BC5_Truck PHEV	2	2	24	95	272	624	1 225	2 089
BC6_Residential ESS	6	79	113	115	221	322	416	573
BC7_Commercial ESS	2	25	74	238	303	698	1 884	4 050
Total mobile application	26	153	790	2 852	8 498	15 827	23 779	31 872
Total stationary application	8	104	187	352	524	1 019	2 300	4 622
Total all application	34	257	976	3 204	9 022	16 846	26 078	36 494

Table 7-19: Forecast of battery stock for the EU market (high sales scenario), in capacity and in 1000' units

Stock [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	18	200	1 237	3 421	6 112	8 688
BC2_PC BEV LOW	0	6	39	255	1 096	2 796	4 890	6 801
BC3_PC PHEV	3	5	17	79	262	472	592	611
BC4_Truck BEV	0	0	1	13	73	234	445	621
BC5_Truck PHEV	0	0	1	8	41	138	318	529
BC6_Residential ESS	1	4	9	17	33	59	101	165
BC7_Commercial ESS	0	1	4	12	54	232	896	2 395
Total mobile application	4	12	76	556	2 710	7 060	12 357	17 250
Total stationary application	1	5	12	29	87	291	997	2 560
Total all application	5	18	89	585	2 796	7 351	13 354	19 810
Stock [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	1	16	227	2 495	15 468	42 768	76 404	108 598
BC2_PC BEV LOW	7	143	974	6 381	27 401	69 888	122 245	170 037
BC3_PC PHEV	250	417	1 439	6 609	21 867	39 343	49 304	50 941
BC4_Truck BEV	7	7	32	430	2 417	7 785	14 838	20 695
BC5_Truck PHEV	8	8	46	424	2 055	6 883	15 898	26 437
BC6_Residential ESS	108	435	886	1 749	3 274	5 921	10 101	16 503
BC7_Commercial ESS	30	112	361	1 167	5 382	23 185	89 573	239 473
Total mobile application	272	591	2 719	16 340	69 209	166 666	278 689	376 709
Total stationary application	138	547	1 247	2 916	8 656	29 105	99 674	255 975
Total all application	411	1 137	3 966	19 255	77 865	195 772	378 363	632 684

Table 7-20: Forecast battery systems sales for the EU market (high sales scenario), in capacity and in 1000' units

Sales [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	1	7	73	316	507	658	841
BC2_PC BEV LOW	0	2	12	75	247	423	554	665
BC3_PC PHEV	0	1	4	21	50	51	62	46
BC4_Truck BEV	0	0	0	4	22	48	74	86
BC5_Truck PHEV	0	0	0	3	13	40	81	121
BC6_Residential ESS	0	1	1	2	5	7	12	19
BC7_Commercial ESS	0	0	1	3	14	57	211	351
Total mobile application	0	4	24	175	648	1 068	1 429	1 760
Total stationary application	0	1	2	5	19	64	223	370
Total all application	0	5	26	180	667	1 132	1 652	2 130
Sales [1,000 battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	8	87	907	3 953	6 338	8 229	10 512
BC2_PC BEV LOW	1	52	293	1 873	6 164	10 576	13 855	16 622
BC3_PC PHEV	23	90	369	1 722	4 140	4 216	5 163	3 870
BC4_Truck BEV	1	1	16	136	730	1 587	2 458	2 877
BC5_Truck PHEV	2	2	24	154	666	1 981	4 038	6 062
BC6_Residential ESS	6	79	113	215	455	732	1 156	1 872
BC7_Commercial ESS	2	25	74	285	1 445	5 709	21 143	35 102
Total mobile application	26	153	790	4 791	15 654	24 699	33 744	39 943
Total stationary application	8	104	187	500	1 901	6 441	22 298	36 973
Total all application	34	257	976	5 291	17 554	31 140	56 042	76 917

Table 7-21 and Table 7-22 respectively present an overview of the main impacts of the low and high sales scenarios for battery systems in 2045.

Table 7-21: Overview of the main impacts in 2045 (EU-28 battery system stock) – low sales scenario

			1	2	3	4	5	6	7	8
			BAU	RedMat	ExtLifeTime	RedMat_ExtLife Time	RedMat_ExtLife Time_GHG_Info	RedMat_ExtLife Time_GHG_Low	RedMat_ExtLife Time_Recycling	BAT
ENVIRONMENT										
	Electricity Consumption	[GWh]	308 274	284 317	271 436	250 779	250 779	250 779	250 779	250 779
	GHG	[MtCO2]	86	80	76	70	61	39	70	39
RESSOURCE										
	Cobalt	[kt]	1 286	728	1 290	730	730	730	715	715
	Graphite	[kt]	12 773	11 311	12 773	11 311	11 311	11 311	11 311	11 311
	Nickel	[kt]	4 697	5 673	4 713	5 692	5 692	5 692	5 591	5 591
	Manganese	[kt]	2 318	1 953	2 318	1 953	1 953	1 953	1 899	1 899
	Lithium	[kt]	1 998	1 897	1 998	1 897	1 897	1 897	1 878	1 878
CONSUMER										
EU totals	Expenditure	€ bln./year	325	238	274	202	202	202	202	202
	of that, purchase costs	€ bln./year	282	195	238	165	165	165	165	165
	of that,EoL costs	€ bln./year	18	18	14	14	14	14	14	14
	of that, electricity costs	€ bln./year	25	25	23	23	23	23	23	23
Per product sold	Sales (regulated)	000 000	36	36	33	33	33	33	33	33
	Product price	€	7 715	5 344	7 263	5 056	5 056	5 056	5 056	5 056
BUSINESS										
EU turnover	Manufacturers	€ bln./year	281.56	195.02	237.67	165.43	165.43	165.43	165.43	165.43
	Maintenance and EoL	€ bln./year	18.04	18.04	13.52	13.52	13.52	13.52	13.52	13.52
	Electricity Companies	€ bln./year	24.99	24.99	23.03	23.03	23.03	23.03	23.03	23.03
EMPLOYMENT										
Employment (jobs)	Manufacturers (direct jobs)	000	152.73	152.73	126.21	126.21	126.21	126.21	126.21	126.21
	Manufacturers (indirect jobs)	000	366.54	366.54	302.90	302.90	302.90	302.90	302.90	302.90
	TOTAL	000	519.27	519.27	429.10	429.10	429.10	429.10	429.10	429.10

Table 7-22: Overview of the main impacts in 2045 (EU-28 battery system stock) – high sales scenario

			1	2	3	4	5	6	7	8
			BAU	RedMat	ExtLifeTime	RedMat_ExtLife Time	RedMat_ExtLife Time_GHG_Info	RedMat_ExtLife Time_GHG_Low	RedMat_ExtLife Time_Recycling	BAT
ENVIRONMENT										
	Electricity Consumption	[GWh]	584 957	540 149	519 031	480 217	480 217	480 217	480 217	480 217
	GHG	[MtCO2]	164	151	145	134	118	78	134	78
RESSOURCE										
	Cobalt	[kt]	2 083	1 157	2 090	1 161	1 161	1 161	1 134	1 134
	Graphite	[kt]	22 871	20 001	22 871	20 001	20 001	20 001	20 001	20 001
	Nickel	[kt]	7 718	9 334	7 744	9 366	9 366	9 366	9 174	9 174
	Manganese	[kt]	3 638	3 743	3 638	3 743	3 743	3 743	3 644	3 644
	Lithium	[kt]	3 382	3 218	3 382	3 218	3 218	3 218	3 180	3 180
CONSUMER										
EU totals	Expenditure	€ bln./year	700	517	609	452	452	452	452	452
	of that, purchase costs	€ bln./year	620	437	540	384	384	384	384	384
	of that,EoL costs	€ bln./year	30	30	22	22	22	22	22	22
	of that, electricity costs	€ bln./year	50	50	46	46	46	46	46	46
Per product sold	Sales (regulated)	000 000	77	77	70	70	70	70	70	70
	Product price	€	8 059	5 685	7 733	5 491	5 491	5 491	5 491	5 491
BUSINESS										
EU turnover	Manufacturers	€ bln./year	619.83	437.25	540.10	383.53	383.53	383.53	383.53	383.53
	Maintenance and EoL	€ bln./year	30.38	30.38	22.28	22.28	22.28	22.28	22.28	22.28
	Electricity Companies	€ bln./year	49.69	49.69	46.31	46.31	46.31	46.31	46.31	46.31
EMPLOYMENT										
Employment (jobs)	Manufacturers (direct jobs)	000	266.19	266.19	218.03	218.03	218.03	218.03	218.03	218.03
	Manufacturers (indirect jobs)	000	638.86	638.86	523.26	523.26	523.26	523.26	523.26	523.26
	TOTAL	000	905.05	905.05	741.29	741.29	741.29	741.29	741.29	741.29

7.3.2. Electricity prices

In this section, electricity prices for the use phase are based on the low and high assumptions of Table 7-9. Using those assumptions, the scenarios are compared and presented in Table 7-23 (low electricity price) and Table 7-24 (high electricity price). Regarding the sales and stock volumes, the medium scenario was considered.

Table 7-23: Overview of the main impacts in 2045 (EU-28 battery system stock) **–** *low electricity price scenario*

			1	2	3	4	5	6	7	8
			BAU	RedMat	ExtLifeTime	RedMat_ExtLife Time	RedMat_ExtLife Time_GHG_Info	RedMat_ExtLife Time_GHG_Low	RedMat_ExtLife Time_Recycling	BAT
ENVIRONMENT										
	Electricity Consumption	[GWh]	446 616	412 233	395 234	365 498	365 498	365 498	365 498	365 498
	GHG	[MtCO2]	125	115	111	102	89	58	102	58
RESSOURCE										
	Cobalt	[kt]	1 685	942	1 690	946	946	946	925	925
	Graphite	[kt]	17 822	15 656	17 822	15 656	15 656	15 656	15 656	15 656
	Nickel	[kt]	6 208	7 504	6 229	7 529	7 529	7 529	7 383	7 383
	Manganese	[kt]	2 978	2 848	2 978	2 848	2 848	2 848	2 771	2 771
	Lithium	[kt]	2 690	2 558	2 690	2 558	2 558	2 558	2 529	2 529
CONSUMER										
EU totals	Expenditure	€ bln./year	494	359	424	310	310	310	310	310
	of that, purchase costs	€ bln./year	451	316	389	274	274	274	274	274
	of that,EoL costs	€ bln./year	24	24	18	18	18	18	18	18
	of that, electricity costs	€ bln./year	19	19	17	17	17	17	17	17
Per product sold	Sales (regulated)	000 000	57	57	51	51	51	51	51	51
	Product price	€	7 948	5 575	7 583	5 352	5 352	5 352	5 352	5 352
BUSINESS										
EU turnover	Manufacturers	€ bln./year	450.70	316.14	388.89	274.48	274.48	274.48	274.48	274.48
	Maintenance and EoL	€ bln./year	24.21	24.21	17.90	17.90	17.90	17.90	17.90	17.90
	Electricity Companies	€ bln./year	18.67	18.67	17.33	17.33	17.33	17.33	17.33	17.33
EMPLOYMENT										
Employment (jobs)	Manufacturers (direct jobs)	000	209.46	209.46	172.12	172.12	172.12	172.12	172.12	172.12
	Manufacturers (indirect jobs)	000	502.70	502.70	413.08	413.08	413.08	413.08	413.08	413.08
	TOTAL	000	712.16	712.16	585.20	585.20	585.20	585.20	585.20	585.20

Table 7-24: Overview of the main impacts in 2045 (EU-28 battery system stock) – high electricity price scenario

			1	2	3	4	5	6	7	8
			BAU	RedMat	ExtLifeTime	RedMat_ExtLife Time	RedMat_ExtLife Time_GHG_Info	RedMat_ExtLife Time_GHG_Low	RedMat_ExtLife Time_Recycling	BAT
ENVIRONMENT										
	Electricity Consumption	[GWh]	446 616	412 233	395 234	365 498	365 498	365 498	365 498	365 498
	GHG	[MtCO2]	125	115	111	102	89	58	102	58
RESSOURCE										
	Cobalt	[kt]	1 685	942	1 690	946	946	946	925	925
	Graphite	[kt]	17 822	15 656	17 822	15 656	15 656	15 656	15 656	15 656
	Nickel	[kt]	6 208	7 504	6 229	7 529	7 529	7 529	7 383	7 383
	Manganese	[kt]	2 978	2 848	2 978	2 848	2 848	2 848	2 771	2 771
	Lithium	[kt]	2 690	2 558	2 690	2 558	2 558	2 558	2 529	2 529
CONSUMER										
EU totals	Expenditure	€ bln./year	531	396	459	344	344	344	344	344
	of that, purchase costs	€ bln./year	451	316	389	274	274	274	274	274
	of that,EoL costs	€ bln./year	24	24	18	18	18	18	18	18
	of that, electricity costs	€ bln./year	56	56	52	52	52	52	52	52
Per product sold	Sales (regulated)	000 000	57	57	51	51	51	51	51	51
	Product price	€	7 948	5 575	7 583	5 352	5 352	5 352	5 352	5 352
BUSINESS										
EU turnover	Manufacturers	€ bln./year	450.70	316.14	388.89	274.48	274.48	274.48	274.48	274.48
	Maintenance and EoL	€ bln./year	24.21	24.21	17.90	17.90	17.90	17.90	17.90	17.90
	Electricity Companies	€ bln./year	56.02	56.02	52.00	52.00	52.00	52.00	52.00	52.00
EMPLOYMENT										
Employment (jobs)	Manufacturers (direct jobs)	000	209.46	209.46	172.12	172.12	172.12	172.12	172.12	172.12
	Manufacturers (indirect jobs)	000	502.70	502.70	413.08	413.08	413.08	413.08	413.08	413.08
	TOTAL	000	712.16	712.16	585.20	585.20	585.20	585.20	585.20	585.20

7.3.3. Service life of battery

In this section, the service lifetime of the battery (Tbat) [yr] is adjusted with -20 % and +20 % to represent the situation of a shorter and a longer battery lifetime. The formula that is used to calculate Tbat (see section 5.1.2.4 of Task 5 report) is an early approximation open to a significant margin of error depending on the specific Li-ion battery design. The parameters used to calculate Tbat were also under discussion by the stakeholders during the course of this preparatory study. Therefore, this sensitivity analysis considers Tbat as the variable parameter and not the underlying parameters nor the formula to show the effect of a shorter or longer battery lifetime, which will have an impact on the number of replacement battery application systems during the economic lifetime of the application.

Table 7-25: Overview of assumed Tbat

	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
Service life of battery (Tbat) [yr] - BAU	14.40	13.43	10.67	8.04	5.33	17.02	17.02
Service life of battery (Tbat - 20 %) [yr] - BAU-20%	11.52	10.75	8.53	6.43	4.26	13.62	13.62
Service life of battery (Tbat + 20 %) [yr] - BAU+20%	17.28	16.12	12.80	9.65	6.40	20.43	20.43

Table 7-26: Overview of the effect of a shorter or longer battery service lifetime on GWP, functional EEI and capacity EEI

	GWP [kg CO2 eq/FU (kWh)]				GWP [kg CO2 eq/cap. (kWh)]	GWP [kg CO2 eq/kg product]	functional EEI [%] *FU [MJ]/GER [MJ]*	capacity EEI [ratio] *GER [MJ]/capacity [MJ]*
Base case	Prod. + distr.	Use	EOL	TOTAL	Prod. + distr.	Prod. + distr.	Prod. + distr.	Prod. + distr.
Business As Usual (Task 5)								
1 PC BEV-HIGH	0.197	0.094	-0.024	0.268	108	14.164	93.32	585
2 PC BEV-LOW	0.292	0.095	-0.036	0.351	216	14.171	63.15	1 171
3 PC PHEV	0.179	0.094	-0.026	0.247	293	13.957	98.84	1 657
4 Truck BEV	0.088	0.073	-0.011	0.149	2 750	13.442	205.04	15 295
5 Truck PHEV	0.079	0.074	-0.011	0.142	3 514	13.942	223.99	19 876
6 res. ESS	0.077	0.053	-0.010	0.121	309	12.089	224.71	1 780
7 comm. ESS	0.077	0.053	-0.010	0.121	927 761	12.089	224.71	5 340 154
Sensitivity analysis - shorter lifetime (Tbat -20%)								
1 PC BEV-HIGH	0.395	0.094	-0.048	0.441	215	14.164	46.66	1 170
2 PC BEV-LOW	0.292	0.095	-0.036	0.351	216	14.171	63.15	1 171
3 PC PHEV	0.179	0.094	-0.026	0.247	293	13.957	98.84	1 657
4 Truck BEV	0.132	0.073	-0.017	0.188	4 126	13.442	136.69	22 942
5 Truck PHEV	0.079	0.074	-0.011	0.142	3 514	13.942	223.99	19 876
6 res. ESS	0.077	0.053	-0.010	0.121	309	12.089	224.71	1 780
7 comm. ESS	0.077	0.053	-0.010	0.121	927 761	12.089	224.71	5 340 154
Sensitivity analysis - longer lifetime (Tbat +20%)								
1 PC BEV-HIGH	0.197	0.094	-0.024	0.268	108	14.164	93.32	585
2 PC BEV-LOW	0.146	0.095	-0.018	0.223	108	14.171	126.30	585
3 PC PHEV	0.179	0.094	-0.026	0.247	293	13.957	98.84	1 657
4 Truck BEV	0.088	0.073	-0.011	0.149	2 750	13.442	205.04	15 295
5 Truck PHEV	0.053	0.074	-0.008	0.119	2 343	13.942	335.99	13 251
6 res. ESS	0.039	0.053	-0.005	0.087	155	12.089	449.43	890
7 comm. ESS	0.039	0.053	-0.005	0.087	463 881	12.089	449.43	2 670 077

Based on the table above, we see that:

- Tbat of -20% or +20% has no effect on BC3, as with all three Tbat the same number of replacements during Tapp (i.e 1 replacement) is still needed. However it can be questioned whether in case of a Tbat of + 20% the replacement will still occur in practice seeing the small differences with Tapp.For BC1 and B4 a shorter battery lifetime would have a negative effect, as an additional replacement would be needed in comparison with the BAU Tbat. A longer Tbat has no effect on BC1 and B4.
- For BC2, BC5, BC6 and B7 a longer Tbat would a positive effect, as a replacement less would be needed in comparison with the BAU Tbat. A shorter Tbat gives no difference for the four base cases compared to BAU.

ANNEX A Battery requirements covered in current standards

Table 7-27: Battery requirements covered in current standards for the discerned base cases. Also industrial batteries are added for information.

Base case		Level	Reference	Refined application		Capacity	Energy	Power	Energy efficiency	Resistance	Cycle life test	Calendar life test	Auxiliary power need	Cooling & heating need	**Conclusion**
BC1	*PC BEV high &*	Cell	IEC 62660-1: 2010	Cells for the propulsion of BEV		x	x	x	x	x	x				Many tests covered
			DOE-INL/EXT-15-34184(2015)	U.S. DOE Battery Test Manual for EV		x	x	x		x	x	x			Many tests covered, including Calendar life
& BC2	*PC BEV low*	Module	DOE-INL/EXT-15-34184(2015)	U.S. DOE Battery Test Manual for EV		x	x	x		x	x	x			Many tests covered, including Calendar life
			SAE J1798:2008	Performance Rating of EV Battery Modules		x	x	x		x					Limited number of tests
		Pack	ISO 12405-4: 2018	BEV& PHEV packs and system	{a}	x	x	x	x	x					Parameters covered, not ageing tests
			DOE-INL/EXT-15-34184(2015)	U.S. DOE Battery Test Manual for EV		x	x	x		x	x	x			Many tests covered, including Calendar life
		Battery system	ISO 12405-4: 2018	BEV& PHEV packs and system	{b}	x	x	x	x	x	x {c}				Many tests covered
			DOE-INL/EXT-15-34184(2015)	U.S. DOE Battery Test Manual for EV		x	x	x		x	x	x			Many tests covered, including Calendar life
		Batt.appl.system													
BC3	*PC PHEV*	Cell	DOE-INL/EXT-07-12536 (2008)	Battery test manual for PHEV				x	x	x	x	x			Few parameters covered, but calendar life included in ageing test
		Module	DOE-INL/EXT-07-12536 (2008)	Battery test manual for PHEV				x	x	x	x	x			Few parameters covered, but calendar life included in ageing test
		Pack	ISO 12405-4: 2018	BEV& PHEV packs and system	{a}	x	x	x	x	x					Parameters covered, not ageing tests
			DOE-INL/EXT-07-12536 (2008)	Battery test manual for PHEV				x	x	x	x	x			Few parameters covered, but calendar life included in ageing test
		Battery system	ISO 12405-4: 2018	BEV& PHEV packs and system	{b}	x	x	x	x	x	x {c}				Many tests covered
			DOE-INL/EXT-07-12536 (2008)	Battery test manual for PHEV				x	x	x	x	x			Few parameters covered, but calendar life included in ageing test
		Batt.appl.system													
BC4	*Truck BEV &*	Cell													
& BC5	*Truck PHEV*	Module													
		Pack													
		Battery system													
		Batt.appl.system													
BC6	*Residential ESS*	Cell													
		Module													
		Pack													
		Battery system	IEC 61427-2	PV energy storage / time shift	{d}				x		x {e}				Limited use: cycle life only
		Batt.appl.system													
BC7	*Grid ESS*	Cell													
		Module													
		Pack													
		Battery system	IEC 61427-2	Frequency regulation service	{d}				x		x {e}				Limited use: cycle life only
				Load-following service	„				x		x {e}				Limited use: cycle life only
				Peak-power shaving service	„				x		x {e}				Limited use: cycle life only
		Batt.appl.system	IEC 62933-2-1	All grid-connected services	{f}		x	x	x		x {g}		x		Few tests covered
	Industrial battery	Cell	IEC 62620	Energy (E; C/2)		x	x	x		x	x	x {h}			Many tests covered
				Medium rate discharge (M; <3.5C)		x	x	x		x	x	x {h}			„
				High rate discharge (H; >3.5C)		x	x	x		x	x	x {h}			„
		Module	„	„		„	„	„			„	„			„
		Pack	„	„		„	„	„			„	„			„
		Battery system	„	„		„	„	„			„	„			„
		Batt.appl.system													

{a} The standard discerns cells, packs and system. No module level. The pack has cell electronics but no BMS (called BCU).
{b} System included electronics like contacter and BMS, but also cooling device. The cooling device is not defined. Power electronics is excluded.
{c} Test profile is given but conditions like SOC window and test power are mainly left to the battery manufacturer. Only at system level with cooling applied.
{d} Includes battery support system such as cooling devices. Power electronics is excluded.
{e} Powers and periods are defined. Manufacturer can spread the power over a number of cells, modules or packs, to be defined by him.
{f} The services are divided in short duration (<1h), long duration (>1h; typically 24h) and back-up power. For the test topics in this table the test descriptions are identical.
{g} No test cycles are given in the standard. They are left to agreement between supplier and user. The manufacturer must show representative degradation data.
{h} Applicable for standby applications only.

ANNEX B Details of the scenarios

Table 7-28: Electricity consumption in GWh/year for the production phase (EU-28 battery system stock)

Electricity Consumption, in [GWh]

Electricity Consumption, in [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	75	721	3 530	18 675	64 918	114 188	171 209	225 721
RedMat	75	721	3 530	15 899	55 578	97 684	145 415	191 123
ExtLifeTime	75	721	3 530	18 675	64 801	111 108	153 890	189 627
RedMat_ExtLifeTime	75	721	3 530	15 899	55 476	94 999	130 315	159 656
RedMat_ExtLifeTime_GHG_Info	75	721	3 530	15 899	55 476	94 999	130 315	159 656
RedMat_ExtLifeTime_GHG_Low	75	721	3 530	15 899	55 476	94 999	130 315	159 656
RedMat_ExtLifeTime_Recycling	75	721	3 530	15 899	55 476	94 999	130 315	159 656
BAT	75	721	3 530	15 899	55 476	94 999	130 315	159 656
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 2 777	- 9 340	- 16 503	- 25 795	- 34 598
ExtLifeTime	-	-	-	-	- 116	- 3 079	- 17 319	- 36 094
RedMat_ExtLifeTime	-	-	-	- 2 777	- 9 441	- 19 189	- 40 894	- 66 065
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 2 777	- 9 441	- 19 189	- 40 894	- 66 065
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 2 777	- 9 441	- 19 189	- 40 894	- 66 065
RedMat_ExtLifeTime_Recycling	-	-	-	- 2 777	- 9 441	- 19 189	- 40 894	- 66 065
BAT	-	-	-	- 2 777	- 9 441	- 19 189	- 40 894	- 66 065
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-14.9%	-14.4%	-14.5%	-15.1%	-15.3%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.1%	-16.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
BAT	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%

Table 7-29: Electricity consumption in GWh/year for the EOL phase (EU-28 battery system stock)

Electricity Consumption, in [GWh]

Electricity Consumption, in [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	- 3	- 3	- 3	- 20	- 100	- 424	- 1 379	- 2 724
RedMat	- 3	- 3	- 3	- 20	- 93	- 364	- 1 235	- 2 508
ExtLifeTime	- 3	- 3	- 3	- 20	- 97	- 297	- 930	- 1 995
RedMat_ExtLifeTime	- 3	- 3	- 3	- 20	- 90	- 234	- 774	- 1 760
RedMat_ExtLifeTime_GHG_Info	- 3	- 3	- 3	- 20	- 90	- 234	- 774	- 1 760
RedMat_ExtLifeTime_GHG_Low	- 3	- 3	- 3	- 20	- 90	- 234	- 774	- 1 760
RedMat_ExtLifeTime_Recycling	- 3	- 3	- 3	- 20	- 90	- 234	- 774	- 1 760
BAT	- 3	- 3	- 3	- 20	- 90	- 234	- 774	- 1 760
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	-	7	60	145	216
ExtLifeTime	-	-	-	-	3	127	449	729
RedMat_ExtLifeTime	-	-	-	-	10	190	606	964
RedMat_ExtLifeTime_GHG_Info	-	-	-	-	10	190	606	964
RedMat_ExtLifeTime_GHG_Low	-	-	-	-	10	190	606	964
RedMat_ExtLifeTime_Recycling	-	-	-	-	10	190	606	964
BAT	-	-	-	-	10	190	606	964
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	0.0%	-7.2%	-14.1%	-10.5%	-7.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-2.9%	-30.0%	-32.6%	-26.8%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
BAT	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%

Table 7-30: Electricity consumption in GWh/year for all phases (EU-28 battery system stock)

Electricity Consumption, in [GWh]

Electricity Consumption, in [GWh]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	200	1 054	4 927	25 656	93 619	188 946	312 774	446 616
RedMat	200	1 054	4 927	22 880	84 287	172 502	287 125	412 233
ExtLifeTime	200	1 054	4 927	25 283	91 331	179 879	284 760	395 234
RedMat_ExtLifeTime	200	1 054	4 927	22 507	82 012	163 833	261 341	365 498
RedMat_ExtLifeTime_GHG_Info	200	1 054	4 927	22 507	82 012	163 833	261 341	365 498
RedMat_ExtLifeTime_GHG_Low	200	1 054	4 927	22 507	82 012	163 833	261 341	365 498
RedMat_ExtLifeTime_Recycling	200	1 054	4 927	22 507	82 012	163 833	261 341	365 498
BAT	200	1 054	4 927	22 507	82 012	163 833	261 341	365 498
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 2 777	- 9 333	- 16 444	- 25 650	- 34 382
ExtLifeTime	-	-	-	- 373	- 2 289	- 9 067	- 28 015	- 51 382
RedMat_ExtLifeTime	-	-	-	- 3 150	- 11 607	- 25 113	- 51 433	- 81 118
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 3 150	- 11 607	- 25 113	- 51 433	- 81 118
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 3 150	- 11 607	- 25 113	- 51 433	- 81 118
RedMat_ExtLifeTime_Recycling	-	-	-	- 3 150	- 11 607	- 25 113	- 51 433	- 81 118
BAT	-	-	-	- 3 150	- 11 607	- 25 113	- 51 433	- 81 118
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-10.8%	-10.0%	-8.7%	-8.2%	-7.7%
ExtLifeTime	0.0%	0.0%	0.0%	-1.5%	-2.4%	-4.8%	-9.0%	-11.5%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
BAT	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%

Table 7-31: GHG emission (of the electricity consumption) in $MtCO_2$/year for the production phase (EU-28 battery system stock)

GHG, in [MtCO2]

GHG, in [MtCO2]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	1	7	22	37	51	63
RedMat	0	0	1	6	19	31	44	54
ExtLifeTime	0	0	1	7	22	36	46	53
RedMat_ExtLifeTime	0	0	1	6	19	30	39	45
RedMat_ExtLifeTime_GHG_Info	0	0	1	3	10	15	20	23
RedMat_ExtLifeTime_GHG_Low	0	0	0	0	0	0	1	1
RedMat_ExtLifeTime_Recycling	0	0	1	6	19	30	39	45
BAT	0	0	0	0	0	0	1	1
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 1	- 3	- 5	- 8	- 10
ExtLifeTime	-	-	-	-	- 0	- 1	- 5	- 10
RedMat_ExtLifeTime	-	-	-	- 1	- 3	- 6	- 12	- 18
RedMat_ExtLifeTime_GHG_Info	- 0	- 0	- 1	- 4	- 13	- 21	- 32	- 40
RedMat_ExtLifeTime_GHG_Low	- 0	- 0	- 1	- 7	- 22	- 36	- 51	- 62
RedMat_ExtLifeTime_Recycling	-	-	-	- 1	- 3	- 6	- 12	- 18
BAT	- 0	- 0	- 1	- 7	- 22	- 36	- 51	- 62
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-14.9%	-14.4%	-14.5%	-15.1%	-15.3%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.1%	-16.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
RedMat_ExtLifeTime_GHG_Info	-49.5%	-49.4%	-49.4%	-56.9%	-56.7%	-57.8%	-61.4%	-64.1%
RedMat_ExtLifeTime_GHG_Low	-98.9%	-98.9%	-98.8%	-98.9%	-98.9%	-98.8%	-98.9%	-98.9%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-14.9%	-14.5%	-16.8%	-23.9%	-29.3%
BAT	-98.9%	-98.9%	-98.8%	-98.9%	-98.9%	-98.8%	-98.9%	-98.9%

Table 7-32: GHG emission (of the electricity consumption) in $MtCO_2$/year for the EOL phase (EU-28 battery system stock)

GHG, in [MtCO2]

GHG, in [MtCO2]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.14	- 0.41	- 0.76
RedMat	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.12	- 0.37	- 0.70
ExtLifeTime	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.09	- 0.28	- 0.56
RedMat_ExtLifeTime	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.07	- 0.23	- 0.49
RedMat_ExtLifeTime_GHG_Info	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.07	- 0.23	- 0.49
RedMat_ExtLifeTime_GHG_Low	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.07	- 0.23	- 0.49
RedMat_ExtLifeTime_Recycling	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.07	- 0.23	- 0.49
BAT	- 0.00	- 0.00	- 0.00	- 0.01	- 0.03	- 0.07	- 0.23	- 0.49
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	-	0.00	0.02	0.04	0.06
ExtLifeTime	-	-	-	-	0.00	0.04	0.13	0.20
RedMat_ExtLifeTime	-	-	-	-	0.00	0.06	0.18	0.27
RedMat_ExtLifeTime_GHG_Info	-	-	-	-	0.00	0.06	0.18	0.27
RedMat_ExtLifeTime_GHG_Low	-	-	-	-	0.00	0.06	0.18	0.27
RedMat_ExtLifeTime_Recycling	-	-	-	-	0.00	0.06	0.18	0.27
BAT	-	-	-	-	0.00	0.06	0.18	0.27
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	0.0%	-7.2%	-14.1%	-10.5%	-7.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-2.9%	-30.0%	-32.6%	-26.8%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%
BAT	0.0%	0.0%	0.0%	0.0%	-10.0%	-44.8%	-43.9%	-35.4%

Table 7-33: GHG emission (of the electricity consumption) in $MtCO_2$/year for all phases (EU-28 battery system stock)

GHG, in [MtCO2]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	2	9	32	60	94	125
RedMat	0	0	2	8	29	55	86	115
ExtLifeTime	0	0	2	9	31	58	85	111
RedMat_ExtLifeTime	0	0	2	8	28	52	78	102
RedMat_ExtLifeTime_GHG_Info	0	0	1	6	22	43	67	89
RedMat_ExtLifeTime_GHG_Low	0	0	1	2	9	22	40	58
RedMat_ExtLifeTime_Recycling	0	0	2	8	28	52	78	102
BAT	0	0	1	2	9	22	40	58
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 1	- 3	- 5	- 8	- 10
ExtLifeTime	-	-	-	- 0	- 1	- 3	- 8	- 14
RedMat_ExtLifeTime	-	-	-	- 1	- 4	- 8	- 15	- 23
RedMat_ExtLifeTime_GHG_Info	- 0	- 0	- 0	- 3	- 10	- 17	- 27	- 36
RedMat_ExtLifeTime_GHG_Low	- 0	- 0	- 1	- 7	- 23	- 38	- 54	- 67
RedMat_ExtLifeTime_Recycling	-	-	-	- 1	- 4	- 8	- 15	- 23
BAT	- 0	- 0	- 1	- 7	- 23	- 38	- 54	- 67
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-10.8%	-10.0%	-8.7%	-8.2%	-7.7%
ExtLifeTime	0.0%	0.0%	0.0%	-1.5%	-2.4%	-4.8%	-9.0%	-11.5%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
RedMat_ExtLifeTime_GHG_Info	-11.2%	-20.3%	-21.2%	-30.6%	-29.9%	-28.2%	-28.8%	-28.7%
RedMat_ExtLifeTime_GHG_Low	-37.2%	-67.6%	-70.8%	-73.5%	-70.9%	-62.9%	-57.5%	-53.3%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-12.3%	-12.4%	-13.3%	-16.4%	-18.2%
BAT	-37.2%	-67.6%	-70.8%	-73.5%	-70.9%	-62.9%	-57.5%	-53.3%

Table 7-34: Cobalt demand in kt/year for the production phase (EU-28 battery system stock)

Cobalt, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	3	16	58	100	139	177
RedMat	0	0	3	9	33	56	78	99
ExtLifeTime	0	0	3	16	58	97	123	142
RedMat_ExtLifeTime	0	0	3	9	33	55	69	80
RedMat_ExtLifeTime_GHG_Info	0	0	3	9	33	55	69	80
RedMat_ExtLifeTime_GHG_Low	0	0	3	9	33	55	69	80
RedMat_ExtLifeTime_Recycling	0	0	3	9	33	55	69	80
BAT	0	0	3	9	33	55	69	80
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 7	- 25	- 44	- 61	- 78
ExtLifeTime	-	-	-	-	- 0	- 3	- 17	- 35
RedMat_ExtLifeTime	-	-	-	- 7	- 25	- 46	- 70	- 97
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 7	- 25	- 46	- 70	- 97
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 7	- 25	- 46	- 70	- 97
RedMat_ExtLifeTime_Recycling	-	-	-	- 7	- 25	- 46	- 70	- 97
BAT	-	-	-	- 7	- 25	- 46	- 70	- 97
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-43.1%	-43.5%	-43.8%	-43.9%	-43.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.9%	-12.1%	-20.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-43.1%	-43.6%	-45.4%	-50.5%	-55.0%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-43.1%	-43.6%	-45.4%	-50.5%	-55.0%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-43.1%	-43.6%	-45.4%	-50.5%	-55.0%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-43.1%	-43.6%	-45.4%	-50.5%	-55.0%
BAT	0.0%	0.0%	0.0%	-43.1%	-43.6%	-45.4%	-50.5%	-55.0%

Table 7-35: Cobalt demand in kt/year for all phases (EU-28 battery system stock)

Cobalt, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	9	55	249	651	1 168	1 685
RedMat	0	2	9	37	145	367	656	942
ExtLifeTime	0	2	9	55	249	652	1 172	1 690
RedMat_ExtLifeTime	0	2	9	37	145	367	658	946
RedMat_ExtLifeTime_GHG_Info	0	2	9	37	145	367	658	946
RedMat_ExtLifeTime_GHG_Low	0	2	9	37	145	367	658	946
RedMat_ExtLifeTime_Recycling	0	2	9	37	145	366	650	925
BAT	0	2	9	37	145	366	650	925
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 18	- 104	- 284	- 512	- 742
ExtLifeTime	-	-	-	-	0	1	3	6
RedMat_ExtLifeTime	-	-	-	- 18	- 104	- 284	- 511	- 739
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 18	- 104	- 284	- 511	- 739
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 18	- 104	- 284	- 511	- 739
RedMat_ExtLifeTime_Recycling	-	-	-	- 18	- 104	- 285	- 518	- 760
BAT	-	-	-	- 18	- 104	- 285	- 518	- 760
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-33.0%	-41.7%	-43.6%	-43.9%	-44.1%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.3%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-33.0%	-41.7%	-43.6%	-43.7%	-43.9%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-33.0%	-41.7%	-43.6%	-43.7%	-43.9%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-33.0%	-41.7%	-43.6%	-43.7%	-43.9%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-33.0%	-41.8%	-43.8%	-44.3%	-45.1%
BAT	0.0%	0.0%	0.0%	-33.0%	-41.8%	-43.8%	-44.3%	-45.1%

Table 7-36: Graphite demand in kt/year for the production phase (EU-28 battery system stock)

Graphite, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	6	30	163	571	1 004	1 487	1 951
RedMat	1	6	30	144	507	888	1 300	1 696
ExtLifeTime	1	6	30	163	570	976	1 330	1 624
RedMat_ExtLifeTime	1	6	30	144	506	863	1 158	1 399
RedMat_ExtLifeTime_GHG_Info	1	6	30	144	506	863	1 158	1 399
RedMat_ExtLifeTime_GHG_Low	1	6	30	144	506	863	1 158	1 399
RedMat_ExtLifeTime_Recycling	1	6	30	144	506	863	1 158	1 399
BAT	1	6	30	144	506	863	1 158	1 399
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 19	- 64	- 116	- 188	- 255
ExtLifeTime	-	-	-	-	- 1	- 28	- 157	- 327
RedMat_ExtLifeTime	-	-	-	- 19	- 65	- 141	- 330	- 552
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 19	- 65	- 141	- 330	- 552
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 19	- 65	- 141	- 330	- 552
RedMat_ExtLifeTime_Recycling	-	-	-	- 19	- 65	- 141	- 330	- 552
BAT	-	-	-	- 19	- 65	- 141	- 330	- 552
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-11.8%	-11.3%	-11.5%	-12.6%	-13.1%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.8%	-10.6%	-16.8%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-11.8%	-11.4%	-14.0%	-22.2%	-28.3%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-11.8%	-11.4%	-14.0%	-22.2%	-28.3%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-11.8%	-11.4%	-14.0%	-22.2%	-28.3%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-11.8%	-11.4%	-14.0%	-22.2%	-28.3%
BAT	0.0%	0.0%	0.0%	-11.8%	-11.4%	-14.0%	-22.2%	-28.3%

Table 7-37: Graphite demand in kt/year for all phases (EU-28 battery system stock)

Graphite, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	7	23	106	565	2 463	6 430	11 837	17 822
RedMat	7	23	106	514	2 193	5 706	10 467	15 656
ExtLifeTime	7	23	106	565	2 463	6 430	11 837	17 822
RedMat_ExtLifeTime	7	23	106	514	2 193	5 706	10 467	15 656
RedMat_ExtLifeTime_GHG_Info	7	23	106	514	2 193	5 706	10 467	15 656
RedMat_ExtLifeTime_GHG_Low	7	23	106	514	2 193	5 706	10 467	15 656
RedMat_ExtLifeTime_Recycling	7	23	106	514	2 193	5 706	10 467	15 656
BAT	7	23	106	514	2 193	5 706	10 467	15 656
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
ExtLifeTime	-	-	-	-	-	-	-	-
RedMat_ExtLifeTime	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
RedMat_ExtLifeTime_Recycling	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
BAT	-	-	-	- 51	- 270	- 724	- 1 370	- 2 166
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%
BAT	0.0%	0.0%	0.0%	-9.0%	-11.0%	-11.3%	-11.6%	-12.2%

Table 7-38: Nickel demand in kt/year for the production phase (EU-28 battery system stock)

Nickel, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	10	59	214	368	510	647
RedMat	0	2	10	72	258	445	615	781
ExtLifeTime	0	2	10	59	213	357	446	514
RedMat_ExtLifeTime	0	2	10	72	258	432	538	619
RedMat_ExtLifeTime_GHG_Info	0	2	10	72	258	432	538	619
RedMat_ExtLifeTime_GHG_Low	0	2	10	72	258	432	538	619
RedMat_ExtLifeTime_Recycling	0	2	10	72	258	432	538	619
BAT	0	2	10	72	258	432	538	619
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	12	45	77	105	133
ExtLifeTime	-	-	-	-	- 0	- 11	- 63	- 133
RedMat_ExtLifeTime	-	-	-	12	44	63	28	- 28
RedMat_ExtLifeTime_GHG_Info	-	-	-	12	44	63	28	- 28
RedMat_ExtLifeTime_GHG_Low	-	-	-	12	44	63	28	- 28
RedMat_ExtLifeTime_Recycling	-	-	-	12	44	63	28	- 28
BAT	-	-	-	12	44	63	28	- 28
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	20.6%	20.8%	20.9%	20.7%	20.6%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.1%	-3.0%	-12.4%	-20.5%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	20.6%	20.7%	17.2%	5.6%	-4.3%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	20.6%	20.7%	17.2%	5.6%	-4.3%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	20.6%	20.7%	17.2%	5.6%	-4.3%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	20.6%	20.7%	17.2%	5.6%	-4.3%
BAT	0.0%	0.0%	0.0%	20.6%	20.7%	17.2%	5.6%	-4.3%

Table 7-39: Nickel demand in kt/year for all phases (EU-28 battery system stock)

Nickel, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	5	33	198	908	2 389	4 299	6 208
RedMat	1	5	33	229	1 089	2 889	5 198	7 504
ExtLifeTime	1	5	33	198	908	2 393	4 312	6 229
RedMat_ExtLifeTime	1	5	33	229	1 089	2 893	5 214	7 529
RedMat_ExtLifeTime_GHG_Info	1	5	33	229	1 089	2 893	5 214	7 529
RedMat_ExtLifeTime_GHG_Low	1	5	33	229	1 089	2 893	5 214	7 529
RedMat_ExtLifeTime_Recycling	1	5	33	229	1 088	2 886	5 169	7 383
BAT	1	5	33	229	1 088	2 886	5 169	7 383
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	31	181	499	900	1 296
ExtLifeTime	-	-	-	-	0	4	13	21
RedMat_ExtLifeTime	-	-	-	31	181	504	915	1 322
RedMat_ExtLifeTime_GHG_Info	-	-	-	31	181	504	915	1 322
RedMat_ExtLifeTime_GHG_Low	-	-	-	31	181	504	915	1 322
RedMat_ExtLifeTime_Recycling	-	-	-	31	181	497	871	1 175
BAT	-	-	-	31	181	497	871	1 175
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	15.8%	20.0%	20.9%	20.9%	20.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.3%	0.3%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	15.8%	20.0%	21.1%	21.3%	21.3%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	15.8%	20.0%	21.1%	21.3%	21.3%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	15.8%	20.0%	21.1%	21.3%	21.3%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	15.8%	19.9%	20.8%	20.3%	18.9%
BAT	0.0%	0.0%	0.0%	15.8%	19.9%	20.8%	20.3%	18.9%

Table 7-40: Manganese demand in kt/year for the production phase (EU-28 battery system stock)

Manganese, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	1	5	29	104	178	244	308
RedMat	0	1	5	25	87	154	243	327
ExtLifeTime	0	1	5	29	104	173	214	246
RedMat_ExtLifeTime	0	1	5	25	86	151	221	282
RedMat_ExtLifeTime_GHG_Info	0	1	5	25	86	151	221	282
RedMat_ExtLifeTime_GHG_Low	0	1	5	25	86	151	221	282
RedMat_ExtLifeTime_Recycling	0	1	5	25	86	151	221	282
BAT	0	1	5	25	86	151	221	282
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 4	- 18	- 23	- 1	19
ExtLifeTime	-	-	-	-	- 0	- 5	- 29	- 62
RedMat_ExtLifeTime	-	-	-	- 4	- 18	- 27	- 23	- 26
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 4	- 18	- 27	- 23	- 26
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 4	- 18	- 27	- 23	- 26
RedMat_ExtLifeTime_Recycling	-	-	-	- 4	- 18	- 27	- 23	- 26
BAT	-	-	-	- 4	- 18	- 27	- 23	- 26
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-14.0%	-17.0%	-13.0%	-0.4%	6.1%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.8%	-12.1%	-20.2%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-14.0%	-17.1%	-15.2%	-9.3%	-8.5%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-14.0%	-17.1%	-15.2%	-9.3%	-8.5%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-14.0%	-17.1%	-15.2%	-9.3%	-8.5%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-14.0%	-17.1%	-15.2%	-9.3%	-8.5%
BAT	0.0%	0.0%	0.0%	-14.0%	-17.1%	-15.2%	-9.3%	-8.5%

Table 7-41: Manganese demand in kt/year for all phases (EU-28 battery system stock)

Manganese, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	3	16	99	446	1 162	2 076	2 978
RedMat	1	3	16	89	378	975	1 829	2 848
ExtLifeTime	1	3	16	99	446	1 162	2 076	2 978
RedMat_ExtLifeTime	1	3	16	89	378	975	1 829	2 848
RedMat_ExtLifeTime_GHG_Info	1	3	16	89	378	975	1 829	2 848
RedMat_ExtLifeTime_GHG_Low	1	3	16	89	378	975	1 829	2 848
RedMat_ExtLifeTime_Recycling	1	3	16	89	377	967	1 798	2 771
BAT	1	3	16	89	377	967	1 798	2 771
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 9	- 68	- 187	- 246	- 130
ExtLifeTime	-	-	-	-	-	-	-	-
RedMat_ExtLifeTime	-	-	-	- 9	- 68	- 187	- 246	- 130
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 9	- 68	- 187	- 246	- 130
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 9	- 68	- 187	- 246	- 130
RedMat_ExtLifeTime_Recycling	-	-	-	- 9	- 69	- 195	- 277	- 207
BAT	-	-	-	- 9	- 69	- 195	- 277	- 207
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-9.4%	-15.3%	-16.1%	-11.9%	-4.4%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-9.4%	-15.3%	-16.1%	-11.9%	-4.4%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-9.4%	-15.3%	-16.1%	-11.9%	-4.4%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-9.4%	-15.3%	-16.1%	-11.9%	-4.4%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-9.4%	-15.5%	-16.8%	-13.4%	-7.0%
BAT	0.0%	0.0%	0.0%	-9.4%	-15.5%	-16.8%	-13.4%	-7.0%

Table 7-42: Lithium demand in kt/year for the production phase (EU-28 battery system stock)

Lithium, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	1	4	25	90	156	222	285
RedMat	0	1	4	24	85	148	210	270
ExtLifeTime	0	1	4	25	90	151	196	232
RedMat_ExtLifeTime	0	1	4	24	85	144	185	218
RedMat_ExtLifeTime_GHG_Info	0	1	4	24	85	144	185	218
RedMat_ExtLifeTime_GHG_Low	0	1	4	24	85	144	185	218
RedMat_ExtLifeTime_Recycling	0	1	4	24	86	146	188	221
BAT	0	1	4	24	86	146	188	221
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 1	- 4	- 8	- 12	- 16
ExtLifeTime	-	-	-	-	- 0	- 5	- 26	- 54
RedMat_ExtLifeTime	-	-	-	- 1	- 5	- 12	- 37	- 67
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 1	- 5	- 12	- 37	- 67
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 1	- 5	- 12	- 37	- 67
RedMat_ExtLifeTime_Recycling	-	-	-	- 1	- 3	- 10	- 34	- 65
BAT	-	-	-	- 1	- 3	- 10	- 34	- 65
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-5.4%	-4.9%	-4.9%	-5.3%	-5.5%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.9%	-11.6%	-18.8%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-5.4%	-5.1%	-7.7%	-16.5%	-23.6%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-5.4%	-5.1%	-7.7%	-16.5%	-23.6%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-5.4%	-5.1%	-7.7%	-16.5%	-23.6%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-4.0%	-3.8%	-6.5%	-15.4%	-22.7%
BAT	0.0%	0.0%	0.0%	-4.0%	-3.8%	-6.5%	-15.4%	-22.7%

Table 7-43: Lithium demand in kt/year for all phases (EU-28 battery system stock)

Lithium, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	3	15	86	384	1 007	1 830	2 690
RedMat	1	3	15	82	365	958	1 742	2 558
ExtLifeTime	1	3	15	86	384	1 007	1 830	2 690
RedMat_ExtLifeTime	1	3	15	82	365	958	1 742	2 558
RedMat_ExtLifeTime_GHG_Info	1	3	15	82	365	958	1 742	2 558
RedMat_ExtLifeTime_GHG_Low	1	3	15	82	365	958	1 742	2 558
RedMat_ExtLifeTime_Recycling	1	3	15	83	370	968	1 745	2 529
BAT	1	3	15	83	370	968	1 745	2 529
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 4	- 19	- 49	- 88	- 132
ExtLifeTime	-	-	-	-	-	-	-	-
RedMat_ExtLifeTime	-	-	-	- 4	- 19	- 49	- 88	- 132
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 4	- 19	- 49	- 88	- 132
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 4	- 19	- 49	- 88	- 132
RedMat_ExtLifeTime_Recycling	-	-	-	- 3	- 14	- 39	- 85	- 161
BAT	-	-	-	- 3	- 14	- 39	- 85	- 161
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-4.3%	-4.9%	-4.8%	-4.8%	-4.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-4.3%	-4.9%	-4.8%	-4.8%	-4.9%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-4.3%	-4.9%	-4.8%	-4.8%	-4.9%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-4.3%	-4.9%	-4.8%	-4.8%	-4.9%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-3.2%	-3.7%	-3.9%	-4.6%	-6.0%
BAT	0.0%	0.0%	0.0%	-3.2%	-3.7%	-3.9%	-4.6%	-6.0%

Table 7-44: Total expenditure in € bln. /year (EU-28 battery system stock)

Expenditure, in € bln./year	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	7	34	118	220	365	512
RedMat	0	2	7	24	83	156	265	378
ExtLifeTime	0	2	7	34	117	212	329	441
RedMat_ExtLifeTime	0	2	7	24	82	151	239	327
RedMat_ExtLifeTime_GHG_Info	0	2	7	24	82	151	239	327
RedMat_ExtLifeTime_GHG_Low	0	2	7	24	82	151	239	327
RedMat_ExtLifeTime_Recycling	0	2	7	24	82	151	239	327
BAT	0	2	7	24	82	151	239	327
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 10	- 35	- 63	- 100	- 135
ExtLifeTime	-	-	-	- 0	- 1	- 7	- 36	- 71
RedMat_ExtLifeTime	-	-	-	- 10	- 36	- 69	- 126	- 185
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 10	- 36	- 69	- 126	- 185
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 10	- 36	- 69	- 126	- 185
RedMat_ExtLifeTime_Recycling	-	-	-	- 10	- 36	- 69	- 126	- 185
BAT	-	-	-	- 10	- 36	- 69	- 126	- 185
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-29.9%	-29.9%	-28.8%	-27.3%	-26.3%
ExtLifeTime	0.0%	0.0%	0.0%	-0.3%	-0.6%	-3.3%	-9.8%	-13.8%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-30.1%	-30.4%	-31.3%	-34.4%	-36.2%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-30.1%	-30.4%	-31.3%	-34.4%	-36.2%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-30.1%	-30.4%	-31.3%	-34.4%	-36.2%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-30.1%	-30.4%	-31.3%	-34.4%	-36.2%
BAT	0.0%	0.0%	0.0%	-30.1%	-30.4%	-31.3%	-34.4%	-36.2%

Table 7-45: Purchase costs in € bln. /year (EU-28 battery system stock)

of that, purchase costs, in € bln./year	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	6	32	113	204	329	451
RedMat	0	2	6	22	77	141	230	316
ExtLifeTime	0	2	6	32	112	199	300	389
RedMat_ExtLifeTime	0	2	6	22	77	137	210	274
RedMat_ExtLifeTime_GHG_Info	0	2	6	22	77	137	210	274
RedMat_ExtLifeTime_GHG_Low	0	2	6	22	77	137	210	274
RedMat_ExtLifeTime_Recycling	0	2	6	22	77	137	210	274
BAT	0	2	6	22	77	137	210	274
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	- 10	- 35	- 63	- 100	- 135
ExtLifeTime	-	-	-	-	- 0	- 5	- 30	- 62
RedMat_ExtLifeTime	-	-	-	- 10	- 35	- 67	- 120	- 176
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 10	- 35	- 67	- 120	- 176
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 10	- 35	- 67	- 120	- 176
RedMat_ExtLifeTime_Recycling	-	-	-	- 10	- 35	- 67	- 120	- 176
BAT	-	-	-	- 10	- 35	- 67	- 120	- 176
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	-30.9%	-31.3%	-31.0%	-30.2%	-29.9%
ExtLifeTime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.6%	-9.0%	-13.7%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-30.9%	-31.4%	-32.7%	-36.3%	-39.1%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-30.9%	-31.4%	-32.7%	-36.3%	-39.1%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-30.9%	-31.4%	-32.7%	-36.3%	-39.1%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-30.9%	-31.4%	-32.7%	-36.3%	-39.1%
BAT	0.0%	0.0%	0.0%	-30.9%	-31.4%	-32.7%	-36.3%	-39.1%

Table 7-46: EOL costs in € bln. /year (EU-28 battery system stock)

of that,EoL costs, in € bln./year	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	0	0	1	3	12	24
RedMat	0	0	0	0	1	3	12	24
ExtLifeTime	0	0	0	0	1	2	8	18
RedMat_ExtLifeTime	0	0	0	0	1	2	8	18
RedMat_ExtLifeTime_GHG_Info	0	0	0	0	1	2	8	18
RedMat_ExtLifeTime_GHG_Low	0	0	0	0	1	2	8	18
RedMat_ExtLifeTime_Recycling	0	0	0	0	1	2	8	18
BAT	0	0	0	0	1	2	8	18
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
RedMat	-	-	-	-	-	-	-	-
ExtLifeTime	-	-	-	- 0	- 0	- 1	- 4	- 6
RedMat_ExtLifeTime	-	-	-	- 0	- 0	- 1	- 4	- 6
RedMat_ExtLifeTime_GHG_Info	-	-	-	- 0	- 0	- 1	- 4	- 6
RedMat_ExtLifeTime_GHG_Low	-	-	-	- 0	- 0	- 1	- 4	- 6
RedMat_ExtLifeTime_Recycling	-	-	-	- 0	- 0	- 1	- 4	- 6
BAT	-	-	-	- 0	- 0	- 1	- 4	- 6
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RedMat	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ExtLifeTime	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%
RedMat_ExtLifeTime	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%
RedMat_ExtLifeTime_GHG_Info	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%
RedMat_ExtLifeTime_GHG_Low	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%
RedMat_ExtLifeTime_Recycling	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%
BAT	0.0%	0.0%	0.0%	-22.7%	-25.6%	-27.5%	-35.7%	-26.1%