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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ABBREVIATIONS

Abbreviations	Descriptions
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
AND	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
BEV	Battery Electric Vehicle
BMS	Battery Management System
Cd	Cadmium
CE	European Conformity
CIT	International Rail Transport Committee
CPA	Statistical Classification of Products by Activity
CPT	Cordless Power Tools
CRM	Critical Raw Materials
DC	Direct Current
DG	Directorate General
DoC	Declaration of Conformity
DOD	Depth of Discharge
EC	European Commission
ECHA	European Chemicals Agency
ED	Ecodesign Directive
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
ESS	Electrical Energy Storage Systems
EU	European Union
EV	Electric Vehicle
FU	Functional Unit
GER	gross energy requirement
GWP	Global warming potential
HEV	Hybrid Electric Vehicle
Hg	Mercury
HREEs	Heavy rate earth elements
IATA	International Air Transport Association
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
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCO	Lithium-ion Cobalt Oxide
LFP	Lithium-Ion Phosphate
LIB	Lithium ion battery

Li-Cap	Lithium-ion Capacitor
LLCC	Least Life Cycle Cost
LMNO	Lithium-Ion Manganese Nickel Oxide
LMO	Lithium-Ion Manganese Oxide
LREEs	Light rare earth elements
LTO	Lithium-Ion Titanate Oxide
LVD	Low Voltage equipment
MEErP	Methodology for Ecodesign of Energy related Products
NACE	Statistical Classification of Economic Activity
NCA	Lithium Nickel Cobalt Aluminium
NiCd	Nickel-Cadmium
NiMh	Nickel-Metal hydride
NMC	Lithium-ion Nickel Manganese Cobalt Oxide
OCV	Open Circuit Voltage
Pb	Lead
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PCM	Protection Circuit Module
PEF	Product Environmental Footprint
PEm	Primary energy for manufacturing
PEr	Primary energy for recycling
PGMs	Platinum Group metals
PHEV	Plug-in Hybrid Electric Vehicle
PRODCOM	Production Communautaire
PTC	Positive Thermal Coefficient
PV	Photovoltaic
RE	Round-trip efficiency
REACH	Regulation on the registration, evaluation, authorisation and rustication of chemicals
RID	International Carriage of Dangerous Goods by Rail
RoHS	Restriction of hazardous substances
RRR	Recyclability, Recoverability, Reusability
SOC	State of Charge
SVHC	Substances of Very High Concern
TMS	Thermal Management System
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UPS	Uninterruptible Power Supply
vPvB	Very persistent and very bio accumulative
WEEE	Waste electrical and electronic equipment
WVTA	Whole Vehicle Type-Approval System

Use of text background colours

Blue: draft text

Yellow: text requires attention to be commented

Green: text changed in the last update (not used in this version)

List of Figures:

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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 analysed in previous tasks. The purpose is also to provide in Task 7-2 and Task 7-3an understanding 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 can then be compared with the Business-as-Usual scenario.

SUMMARY OF TASK 7

This is a draft version for discussion in the first stakeholder meeting on 2nd of May.

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 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. Stakeholders are invited to supply both position papers on proposed policy and detailed comments/inputs on the proposals. A possible extension of the scope beyond what has been analysed in Tasks 3 to 6 is discussed and position papers on this are welcome.

Note that due to time constraints Tasks 7 was elaborated parallel with Tasks 5 and 6; this will be improved in a new update published after collecting input[2] from the stakeholder meeting (2/5) and written feedback on Tasks 6.

7.1. Policy Analysis

Aim of Task 7.1:

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

7.1.1. Scoping of possible policy requirements and key definitions

Objective:

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

[2] https://ecodesignbatteries.eu/documents

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

Proposal:

Note: Text hereafter is draft and indicative, do not comment. It is not possible to elaborate this section before concluding on the subsequent policy options.

In line with Task 1 the proposed scope is 'high energy rechargeable batteries of high specific energy with lithium 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 7.1.4.

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. 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.

7.1.2. Use phase product performance parameters to consider in policy

Objective:

This section describes the potential requirements and their parameters to consider for policy measures to improve the battery in the use phase, especially those related to the battery life time.

7.1.2.1. Minimum battery pack/system life time 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 life time of batteries into a second life application is a straightforward approach to reduce its carbon footprint and also economic value along the life cycle.

Hence the main objective of this proposal is to reduce the carbon footprint per functional unit as modelled in Task 5 by warranting its projected useful life time. 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. The rationales to propose those minimum requirements were:

- Preference was given to shorter life test with increased thresholds, e.g. 90 % instead of 80 %, because this can shorten laboratory and market surveillance testing.
- They are in line with the Business as Usual scenario performance(Task 5) because several aspects of the improvement options of Task 6 are still based on few data available and own assumptions. Hence in a later policy Tier only, those requirements could be raised when more data and validation becomes available.
- They are in line but already little more ambitious as warranty claims currently offered.
- The shorter life times are still in line with their new defined ‘functional Energy Efficiency Index (fEEI)’, see later section 7.1.3.3. It refers to the kWh stored over its life time relative to the embodied primary or gross energy requirement (GER) for manufacturing.

Table 7-1 Life time related performance parameters for a fist Tier to support with policy

	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 [%]	96	96	96	96	96	96	96
Self-discharge (@STC) [%]	2	2	2	2	2	2	2

In order to support the previous life time assumptions, the following technical parameters are important to consider:

- Capacity, expressed in Ah as is common practice for batteries.

- Energy expressed in kWh, the functional unit in this study. 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, of importance of the carbon footprint during use phase.

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.

An important criterion for batteries is also calendar life, however it is hardly covered by test standards. 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.

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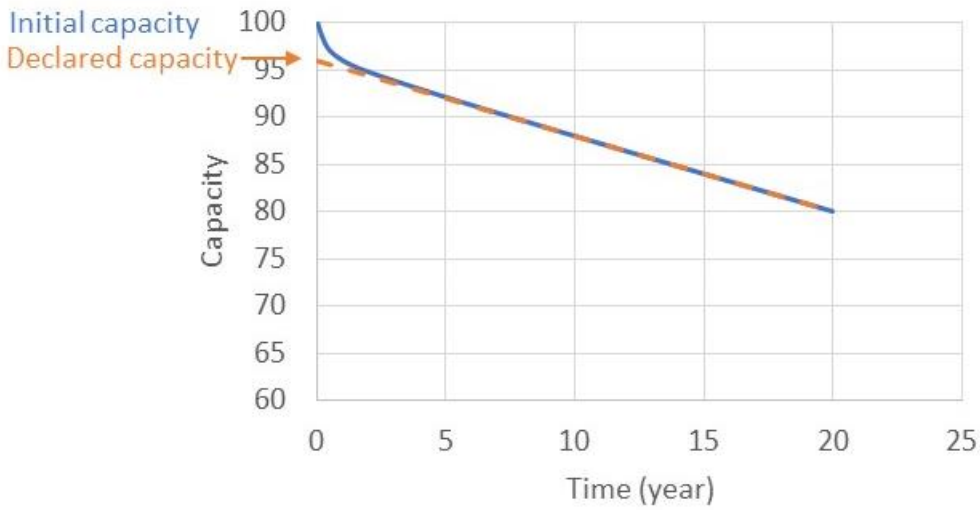

Figure 7-1: Concept of initial capacity and declared capacity based on an exemplary ageing curve for batteries.

Note that when defining requirements it should 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 standardisation mandate to CEN and CENELEC. Transitional test method 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 this is essential to characterise requirements properly.

- When proposing potential criteria it is possible to consider different levels of the study 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) and 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/module/packs brought on the market for the intended application (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, 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 Task1 and summarised in the annex to this document.

Table 7-2 Proposal for cycle-life performance requirements

Application	Maximum capacity fade (relative to the declared value)	Maximum internal resistance increase (relative to the declare value)	Minimum round trip energy efficiency	Standards
PC BEV	90 % @ 750 cycles	30 % @ 750 cycles	92 % @ 750 cycles	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
PC PHEV	90 % @ 1000 cycles	30 % @ 1000 cycles	92 % @ 1000 cycles	ISO 12405-4:2018 Cycle-life test according to Dynamic discharge application
Trucks BEV	90 % @ 1000 cycles	30 % @ 1000 cycles	92 % @ 1000 cycles	standard to be developed
Trucks PHEV	90 % @ 1500 cycles	30 % @ 1500 cycles	92 % @ 1500 cycles	standard to be developed

ESS	90 % @ 2000 cycles	30 % @ 2000 cycles	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.

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 need in the chapter about 'Requirements for traceable battery information', 7.1.3.2.

Proposal for a minimum battery pack/system warranty:

As discussed in the rationale this is not only related to real life warranty on previous requirements but also to the calendar life warranty. For calendar life herein half of the economic application lifetime is proposed for the calender life warranty. The proposal is in Table 7-3. For the functional unit health check the previous criteria are recommended to apply, see Table 7-2.

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

Application	Calendar life[3] warranty (whatever reached first)	Total Functional Unit[4] kWh warranty (whatever reached first)	
PC BEV	10 years	Declared capacity[kW]x750h	
PC PHEV	10 years	Declared capacity[kW]x1000h	
Trucks BEV	10 years	Declared capacity[kW]x1000h	
Trucks PHEV	10 years	Declared capacity[kW]x1500h	
ESS	12 years	Declared capacity[kW]x2000h	

Timing of policy measure:

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

[4] Total energy stored measured at the output over its life time (see also BMS proposal)

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 must be defined before thresholds can be determined. Also, the mentioned two standards do not cover all test requirements.

Challenges and standardisation needs:

Test cycles must be in line with test standards which are defined for each application, see Annex to Task 1. (Stakeholders please also comment on Annex 1 of 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 including calendar life) for BC1&2. IEC 62620 covers also many test requirements. The other standards are too limited for the study scope. Also calendar life tests are often lacking although both cycle life and calendar life tests are necessary to cover the ageing behaviour.

To be further elaborated.

7.1.2.2. Maximum auxiliary power consumption of the battery system

Rationale:

When using a battery system, insight in the auxiliary power consumption might also be needed. 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.

Proposal:

For the auxiliary power need a maximum value expressed in $W/kWh_{declared\ capacity}$ battery system is proposed. The test method must be developed.

– Auxiliary power, i.e. ≤ TBD $W/kWh_{battery}$.

For the cooling & heating need a similar threshold is needed. To allow comparison between energy cost and lifetime gain, a method needs to be developed to estimate the annual energy need. A maximum threshold value expressed in kWh/kWh battery system is proposed:

– Cooling & heating need, i.e. ≤ TBD $kWh_{yearly\ need}/kWh_{declared\ capacity}$.

Challenges:

It appeared that the auxiliary power need and the heating & cooling need is not covered by standards for the battery levels in the scope of the study.

7.1.2.3. Items 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/packs. The no load losses in battery application systems are usually attributed to power electronics, which are out of the scope. Alternatively, both possible losses, auxiliary power and cooling& heating loss have been directly proposed to be measured and capped.

7.1.3. Policy measures on sustainability

Objective:

This section describes the potential policy criteria on sustainability to improve the whole life cycle product performance apart from the use phase performance, such as: recycling, re-use, repurposing, material efficiency, etc. They are different from the previous section that was related to the use phase.

7.1.3.1. Requirements for battery management

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.
- Support life time 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.

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

- 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 and humidity statistics. The following data must be logged: ambient temperature, ambient humidity, 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 (§7.1.3.2).
- alternatively: battery temperature and humidity profile, logged at least daily including average and maximum value;
- 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.
- alternatively: load (discharge) and charge profile of each battery pack/module/cell.

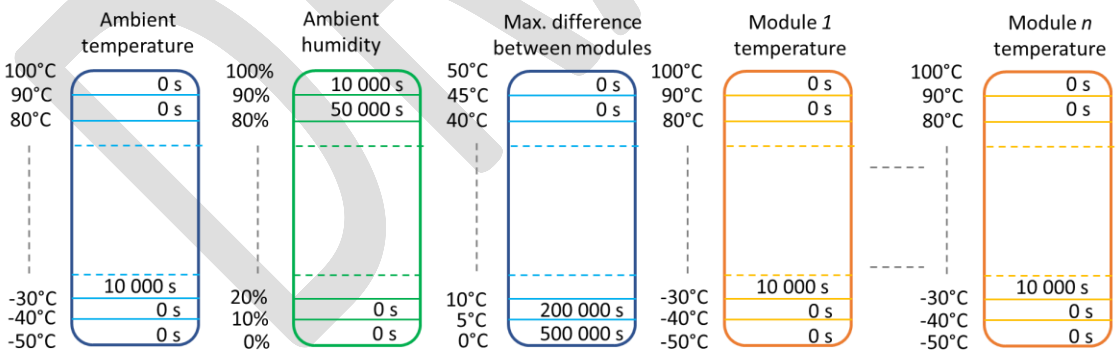

Figure 7-2: Temperature and humidity statistics with help of storing data in a cumulative fashion, counting the time spent in a range of intervals.

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 and date.

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 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 a the 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 standardization needs:

Related to partially open data:

The format for data access, and test protocols would need to be developed. 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. 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.

To allow access to the open data a diagnostics connector on each BMS must be standardised. The data transmission should go over CAN, a widely used communication standard. The 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. 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.

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

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. Key challenges cover health & 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 update of the BMS:

In case that firmware can be uploaded to the BMS, 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.

7.1.3.2. Requirements for battery information

Rationale:

To allow repair, reuse, remanufacturing and repurposing but also recycling of batteries in all cases 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 origin and its life is required.

Batteries have a calendar life and hence the date of manufacturing matters. Also it could provide end users with standardized and comparable expected life time 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.

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 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.

It can also be used to promote responsible sourcing, e.g. of cobalt because the concern about responsible sourcing of cobalt contained in batteries and in vehicles is rising among various stakeholders, including the public.

Encouraging the emergence of a circular economy for batteries and their constituent materials in the EU can be supported introducing voluntary 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.

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 traceable battery information.

Proposal:

The proposal is that the 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 data on a server which the manufacturer or supplier bears the responsibility of updating, e.g. such as the European Product Database for Energy Labelling (EPREL[5]), in three levels of:

Level 1: Public part (no access restriction):

- battery manufacturer
- manufacturing place and date
- battery type, and chemistry
- design capacity and declared capacity
- 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)
- C-rate of cycle-life test
- temperature range when in use (min, max, optimal)

[5] 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

- temperature (min and max) that the battery can withstand not in use
- battery 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 belo 80 and 70 %
- results from test requirements in this study:
    - Calendar life warranty period.
    - Battery efficiency information.
    - Power
    - Energy efficiency
    - Internal battery cell and pack (if applicable) resistance
    - Cycle life test standard and remaining capacity
    - Auxiliary power need
    - Cooling & heating need
- 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
- provide end users with standardized and comparable life time information, stimulate market competition and avoid overstated performance claims
- carbon footprint information in CO2eq including primary energy in MJ and kWh electricity used during manufacturing, see specific criteria proposed in section 7.1.3.3.
- % of recycled materials used in the cathode and anode material (further definitions might be needed), including 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.

Level 2: Data available to third party accredited professionals:

- 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):

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

Timing:

From 2022 onwards.

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.

There might be standards needed for traceability of information, 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 Figure.

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

Figure 7-3: Marking subjects in IEC 62620 for industrial lithium batteries.

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.

7.1.3.3. 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 1000 times, see capacity EEI in Table 7-4. 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 life time 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 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 7-4. EVs are therefore game changers to use renewables however similarly they are enabling technology 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.

	GWP [kgCO2eq/FU(kWh)]				GWP [kgCO2eq/cap.(kWh)]	GWP [kgCO2eq/kg product]	functional EEI (%)	capacity EEI (ratio)
Base Case	prod.+ distr.	use	EOL	total	production +distribution	production +distribution	FU(MJ)/ GER(MJ) prod. + distr.	capacity(MJ) /GER(MJ) prod. + distr.
Business As Usual (Task 5)								
1 PC BEV	0,214	0,077	-0,041	0,249	108	14,164	86,14%	585
2 PC BEV	0,182	0,077	-0,035	0,224	108	14,171	100,99%	585
3 PHEV	0,131	0,076	-0,026	0,181	147	13,957	135,16%	829
4 Truck BEV	0,086	0,056	-0,016	0,125	115	13,442	210,22%	637
5 Truck PHEV	0,063	0,057	-0,013	0,107	146	13,942	281,63%	828
6 res. ESS	0,061	0,036	-0,011	0,085	155	12,089	286,87%	890
7 comm. ESS	0,048	0,035	-0,009	0,075	155	12,089	358,58%	890
High Energy Density Option								
1 PC BEV	0,189	0,077	-0,037	0,23	96	14,662	98,63%	511
2 PC BEV	0,162	0,077	-0,031	0,207	96	14,671	115,62%	511
3 PHEV	0,103	0,076	-0,021	0,159	116	14,247	172,31%	650
4 Truck BEV	0,076	0,055	-0,014	0,117	101	13,763	240,66%	557
5 Truck PHEV	0,05	0,057	-0,01	0,096	116	14,229	359,09%	650
6 res. ESS	0,049	0,035	-0,009	0,075	124	12,249	360,33%	709
7 comm. ESS	0,039	0,035	-0,007	0,067	124	12,249	450,42%	709
Long Life Time Option								
1 PC BEV	0,187	0,077	-0,036	0,227	108	14,164	98,70%	585
2 PC BEV	0,159	0,077	-0,031	0,205	108	14,171	115,71%	585
3 PHEV	0,131	0,076	-0,026	0,181	147	13,957	135,16%	829
4 Truck BEV	0,074	0,055	-0,014	0,115	115	13,442	243,07%	637
5 Truck PHEV	0,063	0,057	-0,013	0,107	146	13,942	281,63%	828
6 res. ESS	0,055	0,036	-0,01	0,081	155	12,089	315,55%	890
7 comm. ESS	0,044	0,035	-0,008	0,072	155	12,089	394,44%	890

Table 7-4: Overview of carbon footprint, improvement options (excl. green energy) and primary energy results from Task 6

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 CO2 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.

Proposal:

Requirement on carbon footprint information:

Carbon footprint calculated according to the Product Environmental Footprint Category Rules (PEFCR[6]) 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.

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[7]. This can be for done by installing a battery ESS on the production plant itself to cope with variable supply of renewables[8] and preferably second life EV batteries that return to plant before remanufacturing.

Carbon footprint (gCO2eq/kWh) should be calculated both; first relative to the minimum functional unit based on the product warranty and also relative to the specified average life time 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.

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

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

[8] 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

It is recommended to evaluate the option two 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 however were already involved in the Product Environmental Footprint Category Rules (PEFCR[9]) 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, ..)?
- 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?
- 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.

Today the PEFCR are only elaborated for mobile application batteries with high energy density, if the scope is broadened (see 7.1.4) it will require new PEFCR.

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

7.1.3.4. Other minimum battery pack design and construction requirements to support reusability/recyclability/recoverability

Rationale:

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

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
- 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.

Proposal:

Introduce a new minimum recyclability index wherein at least the following aspects are considered:

- Mandatory use of technical design features of the product (battery) that enable assembly/disassembly, e.g. reversible joints, joints that can be fastened/unfastened.
    - It is understood that the battery construction is compromise between safety and dismantlability.
    - The physical features must increase the possibility of (partly) automated dismantling, so to reduce the current very manual effort.
    - Use of standardised tools for disassembly in a bonus/malus system.
- Time lapsed digital photo record showing disassembly
- 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 in a bonus/malus system
- Calculate the amount of material that can be recycled

A recyclability index standard will need to be elaborated and a gradual increasing minimum index will need to be introduced.

Timing and threshold:

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:

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. For niche markets (e.g. specific garden equipment), this might be a cost burden and there is not benefit in the economy of scale for recycling. Therefore, this policy measure might not be recommendable for a large scope of potential applications.

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. In view of this it should also be evaluated if this proposal is not redundant with current practices and other Regulation.

7.1.4. 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 keep 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 kW 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 are: high temperature sodium-based batteries, being sodium sulphur battery and sodium-nickel, Lithium-sulphur batteries.
- Stationary batteries suitable for residential grid energy storage systems other than Lithium chemistries with low energy density; examples are: vanadium redox flow batteries, zinc bromine 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 however still additional environmental impact by extending scope. 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 200000 items sold per year because the capacity of these batteries is low per application (e.g. < 2 kW).

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.
- Create administrative overhead for niche battery applications: see previous argumentations, this also applies to large companies selling products for niche applications.
- Other policy tools might sometimes be more suitable: For example, large grid scale energy storage systems can be constructed under the Machinery Directive

(2006/42/EC) and might therefore require other policy instruments if one wants to address them. Those products are also sold in a business-to-business environment which have other information needs. Therefore, technologies such as high temperature batteries such as flow batteries, lithium metal polymer batteries, etc. 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[10].
    - 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 as.
    - Extending the scope will involve a larger set of stakeholders and therefore complicate reaching a consensus (if possible at all) and likely postpone taking policy measures.
    - 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.

Stakeholders please comment (will also be discussed in the meeting):

- Do you agree?
- If you disagree:
    - Should this be done by a full supplementary Task 3-6 Study?
    - Should a more pragmatic approach be followed based dedicated stakeholder enquiry (for example Table 7-5)?

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

- If needed, please provide proposals. In all this, keep in mind that the Ecodesign also enables Voluntary Agreements with manufacturing associations (please contact the EC services for that).

Table 7-5: Concept format on scoping enquiry (to be decided later)

	Policy measure 1	Policy measure 2				
Battery technology 1	Pro: .. Contra: .. Modifications needed: ..					
Battery technology 2						

To be discussed in a final review after concluding on those in the primary scope of this study.

7.1.5. Needs for standardization mandates to implement the proposed policy

Objective:

The proposed policy measures must be covered by methods in standards.

Proposal:

Note: this section will be updated after concluding on the policy proposal, including Annex 1 of Task 1.

The proposed policy measures lead to considerable methods that are not covered by existing standards. These need an implementation by a European standardisation mandate.

Standardisation need for performance requirements:

See Annex 1 of Task 1 or the annex for a summary in this document: 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, auxiliary power and cooling& heating need 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). Also, it allows more capacity loss 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.

It is proposed that first the lacking methods for the PC BEV& PHEV cells and PC BEV& PHEV battery systems are implemented.

Standardisation need for requirements on partially open data from BMS:

The format for data access, and test protocols would need to be developed. 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. 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. 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.

To allow access to the open data a diagnostics connector on each BMS must be standardised. The data transmission should go over CAN, a widely used communication standard. The 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. 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.

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

7.1.6. Summary of stakeholder positions

Objective:

This section contains an overview and summary of the stakeholder positions that will be added based on position papers collected after the second stakeholder meeting.

Stakeholders are invited to send us position papers before 21st of May.

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**: the products placed on the EU market have the same level of performance as the Base Case defined in Task 4
- **High Energy Density Scenario**: from year 2022, new batteries placed on the market are high energy density batteries, according to Task 6 assumptions
- **Extended lifetime scenario:** from year 2022, new batteries placed on the market are re-used, according to Task 6 assumptions

In addition, based on the outcome of Task 6 report and on Task 7-1, different electricity mix will be considered for the production of the batteries, since manufacturers can supply their battery systems plants with various electricity mix, ranging from almost no carbon electricity (e.g. green electricity or even from nuclear power plant) to very carbon-intensive electricity. Therefore, a low / middle and high carbon scenario for the battery production will be considered in the production phase of battery systems, see more details in Table 7-8.

Table 7-6 provides an overview of all scenarios covered in this report.

Table 7-6: Overview of the scenarios

		Design options		
		BAU	**High Energy Density**	**Extended Lifetime**
Electricity in the production phase	**Low Carbon**	BAU_lowC	HighDensity_lowC	ExtendedLifetime_lowC
	Middle Carbon	BAU	HighDensity	ExtendedLifetime
	High Carbon	BAU_highC	HighDensity_highC	ExtendedLifetime_highC

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	-	- 82.92	- 33.77	- 17.11	-	9 636	7 931	566	- 585
1	High Energy Density	80	14	521	140	1 200	700	5.32	79.21	43.66	11.85	13.94	-	- 75.25	- 41.04	- 11.85	-	8 387	7 931	566	- 540
1	Extended Lifetime	80	18	609	206	1 200	840	9.56	87.28	35.92	17.11	14.44	-	- 82.92	- 33.77	- 17.11	-	9 636	9 086	566	- 585
2	BAU	40	13	304	206	600	700	4.78	43.64	17.96	8.56	7.22	-	- 41.46	- 16.88	- 8.56	-	4 820	4 650	358	- 291
2	High Energy Density	40	13	261	140	600	700	2.66	39.61	21.83	5.93	6.97	-	- 37.63	- 20.52	- 5.93	-	4 201	4 650	358	- 270
2	Extended Lifetime	40	17	304	206	600	840	4.78	43.64	17.96	8.56	7.22	-	- 41.46	- 16.88	- 8.56	-	4 820	5 328	358	- 291
3	BAU	12	11	126	254	180	700	1.25	15.89	3.41	2.59	2.01	-	- 15.10	- 3.21	- 2.59	-	2 120	2 643	240	- 179
3	High Energy Density	12	11	98	185	180	700	0.85	12.54	3.83	3.55	1.67	-	- 11.91	- 3.60	- 3.55	-	1 653	2 643	240	- 142
3	Extended Lifetime	12	11	126	254	180	840	1.25	15.89	3.41	2.59	2.01	-	- 15.10	- 3.21	- 2.59	-	2 120	2 643	240	- 179
4	BAU	30	8	256	220	450	400	2.77	36.45	9.99	1.89	4.70	-	- 34.62	- 9.39	- 1.89	-	3 883	5 751	719	- 202
4	High Energy Density	30	8	221	129	450	400	1.23	31.08	12.10	6.54	4.45	-	- 29.52	- 11.37	- 6.54	-	3 395	5 751	719	- 186
4	Extended Lifetime	30	10	256	220	450	480	2.77	36.45	9.99	1.89	4.70	-	- 34.62	- 9.39	- 1.89	-	3 883	6 650	719	- 202
5	BAU	20	5	210	212	300	400	2.09	26.49	5.69	4.31	3.36	-	- 25.17	- 5.35	- 4.31	-	3 534	6 864	1 373	- 299
5	High Energy Density	20	5	163	185	300	400	1.42	20.90	6.38	5.92	2.78	-	- 19.85	- 5.99	- 5.92	-	2 754	6 864	1 373	- 236
5	Extended Lifetime	20	5	210	212	300	480	2.09	26.49	5.69	4.31	3.36	-	- 25.17	- 5.35	- 4.31	-	3 534	6 864	1 373	- 299
6	BAU	10	17	128	683	150	100	0.29	14.48	1.16	0.16	1.16	-	- 13.76	- 1.09	- 0.16	-	1 855	2 340	138	- 74
6	High Energy Density	10	17	101	499	150	100	0.12	11.05	1.35	3.81	1.05	-	- 10.50	- 1.27	- 3.81	-	1 481	2 340	138	- 62
6	Extended Lifetime	10	19	128	683	150	120	0.29	14.48	1.16	0.16	1.16	-	- 13.76	- 1.09	- 0.16	-	1 855	2 574	138	- 74
7	BAU	10	17	128	683	150	100	0.29	14.48	1.16	0.16	1.16	-	- 13.76	- 1.09	- 0.16	-	1 855	2 926	172	- 74
7	High Energy Density	10	17	101	499	150	100	0.12	11.05	1.35	3.81	1.05	-	- 10.50	- 1.27	- 3.81	-	1 481	2 926	172	- 62
7	Extended Lifetime	10	19	128	683	150	120	0.29	14.48	1.16	0.16	1.16	-	- 13.76	- 1.09	- 0.16	-	1 855	3 218	172	- 74

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 7-4.

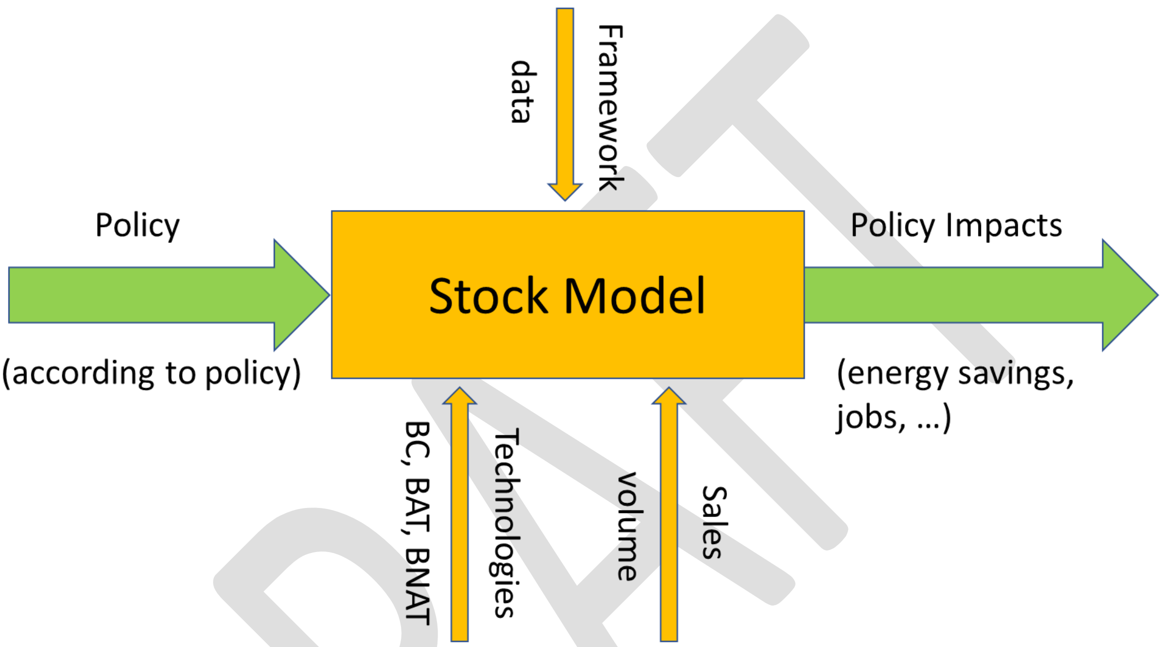

Figure 7-4: Simplified overview of the model (Source: Fraunhofer ISI)

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[11] 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.[12] The average assumption corresponds to the EU average (see PRIMES).

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

[12] 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

- Figures related to electricity prices (see Table 7-9): based on PRIMES[13] 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[14]	[kgCO2eq/kWh]	0.00	0.00	0.00	0.00	0.00	0.00
GHG Emission	Medium	[kgCO2eq/kWh]	0.38	0.36	0.34	0.32	0.30	0.28
GHG Emission	High[15]	[kgCO2eq/kWh]	1.28	1.28	1.28	1.28	1.28	1.28

Table 7-9: Electricity prices

Parameter	Scenario	Unit	2020	2025	2030	2035	2040	2045
Price	Low[16]	[c€/MWh]	9.55	9.80	10.00	10.20	10.15	9.95
Price	Medium[17]	[c€/MWh]	19.10	19.60	20.00	20.40	20.30	19.90
Price	High[18]	[c€/MWh]	28.65	29.40	30.00	30.60	30.45	29.85

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

Variable name and unit	Value	Source
WholeMargin[19] [-]		
Jobs Industry ([1/mln euros revenue]		
Jobs Install [1/mln euros revenue]		
Jobs Maint [1/mln euros revenue]		
Jobs Recycling [1/mln euros revenue]		
Jobs Energy Companies [1/mln euros energy]		

Question 2: Do you have figures for Table 7-10 ?

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.

13 reference scenario for the EU electricity mix in EU

14 only used in the production phase

15 only used in the production phase

16 -50% compared to the medium scenario

17 based on PRIMES (reference year: 2015)

18 +50% compared to the medium scenario

19 margin in the sector

- 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 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 backcasting the sales for the period prior 2010, considering the commercial lifetime of a battery. An overview of the stock figures is provided in Table 7-11 and Figure 7-5. Table 7-12 shows the stock figures expressed in number of battery systems.

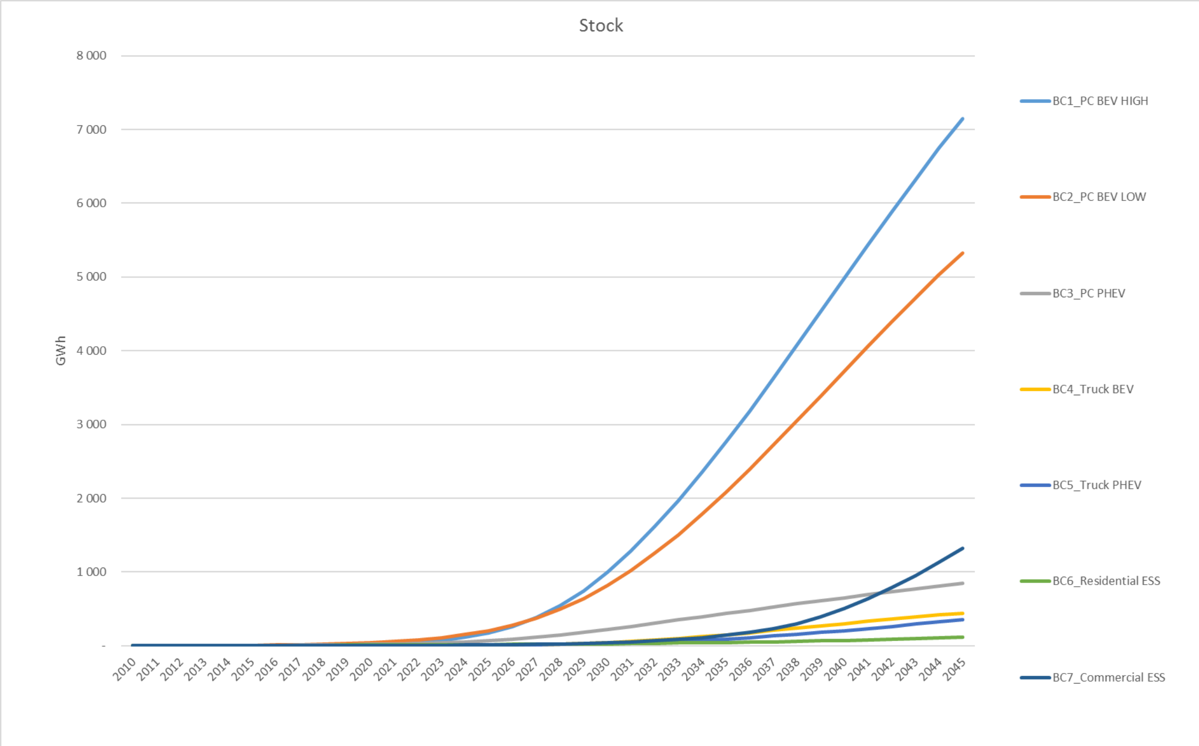

Figure 7-5: Forecast battery capacity stock for the EU market (medium sales scenario)

Table 7-11: 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

Table 7-12: Forecast battery stock for the EU market (medium sales scenario) expressed in number of battery systems

Stock [1000 of 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 7-6 and Table 7-13 provide an overview of the evolution of the sales over time (based on the findings from the Task 2 report). Please note, that due 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 7-14 shows the sales figures expressed in number of battery systems.

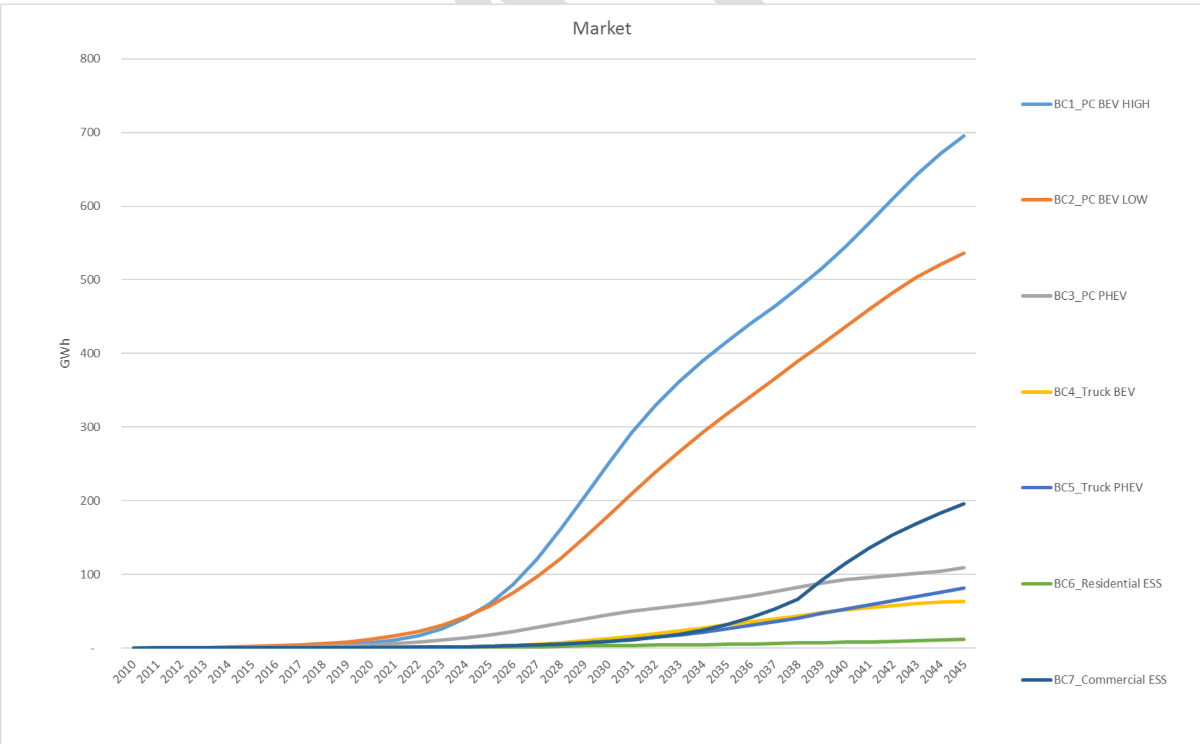

Figure 7-6: Forecast battery capacity sales for the EU market (medium sales scenario)

Table 7-13: 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	5	18	46	66	93	109
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	140	498	858	1 178	1 485
Total stationary application	0	1	2	4	12	37	123	208
Total all application	0	5	26	144	510	896	1 301	1 693

Table 7-14: Forecast battery sales for the EU market (medium sales scenario) expressed in number of battery systems

Sales [1000 of 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	28	95	383	1 501	3 793	5 526	7 711	9 069
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	31	158	803	3 877	12 308	21 038	29 785	37 358
Total stationary application	8	104	187	426	1 212	3 730	12 299	20 798
Total all application	39	262	989	4 304	13 520	24 768	42 084	58 156

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 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 impact. 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: material and manufacturing
- Use phase
- EoL: End of Life

7.2.1.1. Electricity consumption

Figure 7-7 and Table 7-15 show the electricity consumption of the battery systems in the production phase. The best improvement potential is seen in HighDensity scenarios until 2040. However afterwards the ExtendedLifetime scenarios show a better impact, reducing the energy consumption by 16.2% (36648 GWh/year) in 2045, compared to the BAU scenario. The lowC and highC scenarios have the same impact as the scenarios with medium GHG electricity supply in the production phase.

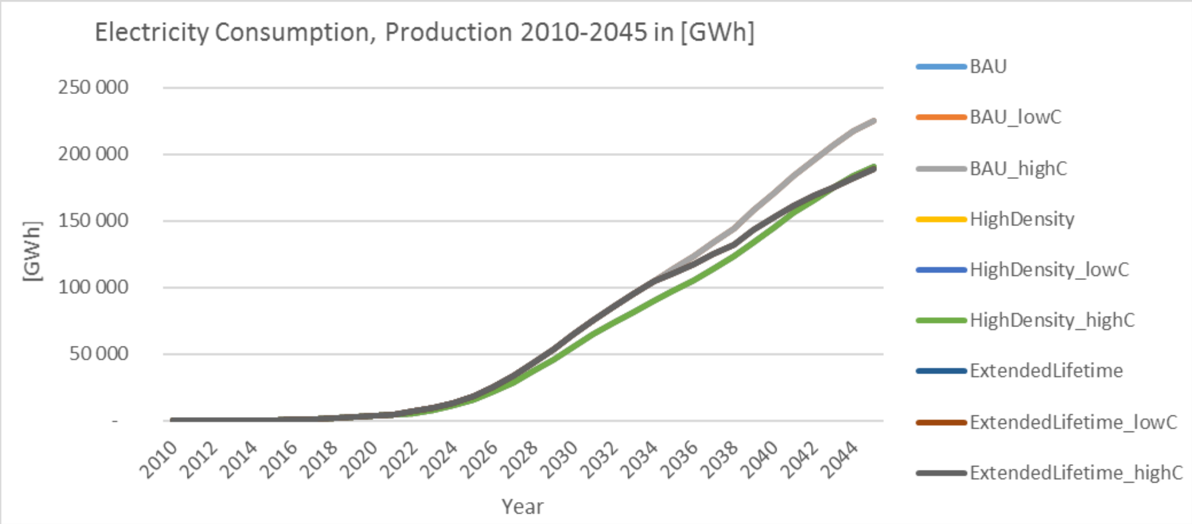

Figure 7-7: Electricity consumption in GWh/year for the production phase (EU-28 battery system stock)

Table 7-15: Electricity consumption in GWh/year for the production phase (EU-28 battery system stock)

Electricity Consumption, in [GWh]								
Electricity Consumption, in	2010	2015	2020	2025	2030	2035	2040	2045
BAU	75	721	3 529	18 673	64 907	114 171	171 187	225 694
BAU_lowC	75	721	3 529	18 673	64 907	114 171	171 187	225 694
BAU_highC	75	721	3 529	18 673	64 907	114 171	171 187	225 694
HighDensity	75	721	3 529	15 886	55 527	97 600	145 304	190 982
HighDensity_lowC	75	721	3 529	15 886	55 527	97 600	145 304	190 982
HighDensity_highC	75	721	3 529	15 886	55 527	97 600	145 304	190 982
ExtendedLifetime	75	721	3 529	18 673	64 791	111 092	153 335	189 046
ExtendedLifetime_lowC	75	721	3 529	18 673	64 791	111 092	153 335	189 046
ExtendedLifetime_highC	75	721	3 529	18 673	64 791	111 092	153 335	189 046
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 2 786	- 9 381	- 16 571	- 25 883	- 34 712
HighDensity_lowC	-	-	-	- 2 786	- 9 381	- 16 571	- 25 883	- 34 712
HighDensity_highC	-	-	-	- 2 786	- 9 381	- 16 571	- 25 883	- 34 712
ExtendedLifetime	-	-	-	-	- 116	- 3 079	- 17 853	- 36 648
ExtendedLifetime_lowC	-	-	-	-	- 116	- 3 079	- 17 853	- 36 648
ExtendedLifetime_highC	-	-	-	-	- 116	- 3 079	- 17 853	- 36 648
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-14.9%	-14.5%	-14.5%	-15.1%	-15.4%
HighDensity_lowC	0.0%	0.0%	0.0%	-14.9%	-14.5%	-14.5%	-15.1%	-15.4%
HighDensity_highC	0.0%	0.0%	0.0%	-14.9%	-14.5%	-14.5%	-15.1%	-15.4%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.4%	-16.2%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.4%	-16.2%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.4%	-16.2%

Electricity consumption for the use phase is illustrated in Figure 7-8. As visible in this figure, the electricity losses in all battery systems will reach around 180 000 GWh/a in 2045 and will be the same for all the analysed scenarios.

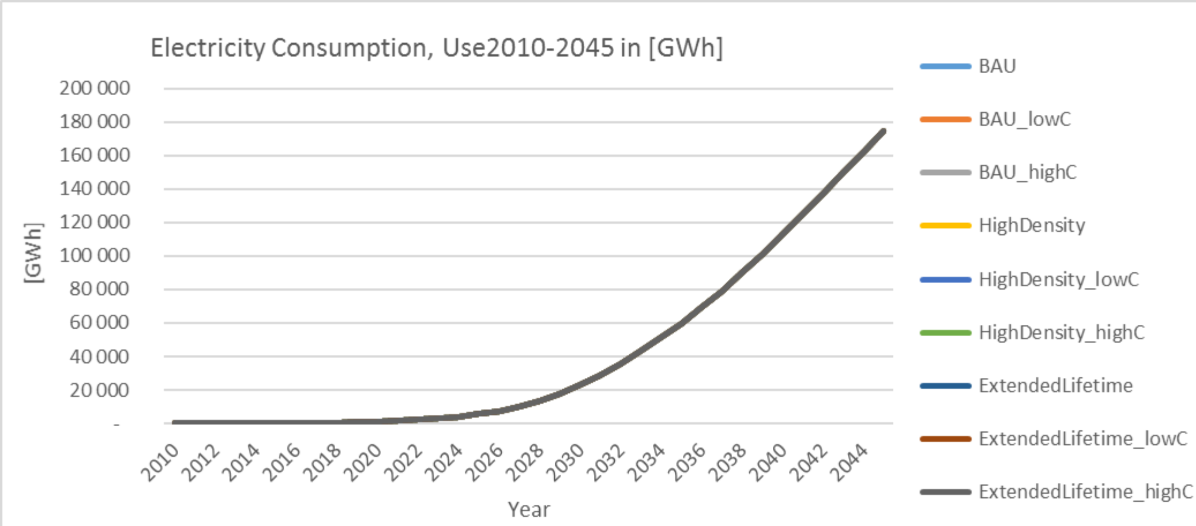

Figure 7-8: Electricity consumption in GWh/year for the use phase (EU-28 battery system stock)

The evolution of electricity consumption is also analysed for the EoL phase and the results are shown in Figure 7-9 and Table 7-16. Until 2025 the electricity consumption in all scenarios is the same. In 2045, the ExtendedLifetime scenarios will have the best impact, decreasing the electricity consumptions by 33.9% compared to the BAU scenario.

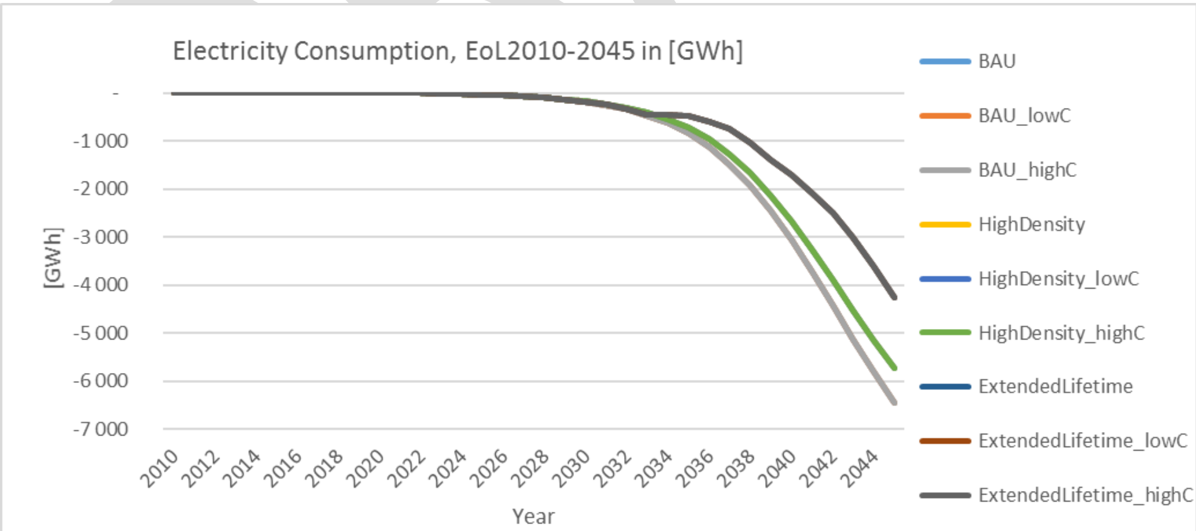

Figure 7-9: Electricity consumption in GWh/year for the EoL phase (EU-28 battery system stock)

Table 7-16: Electricity consumption in GWh/year for the EoL phase (EU-28 battery system stock)

Electricity Consumption, in [GWh]								
Electricity Consumption, in	2010	2015	2020	2025	2030	2035	2040	2045
BAU	- 6	- 6	- 6	- 34	- 187	- 847	- 3 056	- 6 446
BAU_lowC	- 6	- 6	- 6	- 34	- 187	- 847	- 3 056	- 6 446
BAU_highC	- 6	- 6	- 6	- 34	- 187	- 847	- 3 056	- 6 446
HighDensity	- 6	- 6	- 6	- 34	- 176	- 725	- 2 674	- 5 719
HighDensity_lowC	- 6	- 6	- 6	- 34	- 176	- 725	- 2 674	- 5 719
HighDensity_highC	- 6	- 6	- 6	- 34	- 176	- 725	- 2 674	- 5 719
ExtendedLifetime	- 6	- 6	- 6	- 34	- 179	- 472	- 1 718	- 4 264
ExtendedLifetime_lowC	- 6	- 6	- 6	- 34	- 179	- 472	- 1 718	- 4 264
ExtendedLifetime_highC	- 6	- 6	- 6	- 34	- 179	- 472	- 1 718	- 4 264
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	-	11	122	382	727
HighDensity_lowC	-	-	-	-	11	122	382	727
HighDensity_highC	-	-	-	-	11	122	382	727
ExtendedLifetime	-	-	-	-	9	375	1 337	2 182
ExtendedLifetime_lowC	-	-	-	-	9	375	1 337	2 182
ExtendedLifetime_highC	-	-	-	-	9	375	1 337	2 182
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
HighDensity_lowC	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
HighDensity_highC	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%

As summary, Figure 7-10 and Table 7-17 show the electricity consumptions of the battery systems on the EU market, considering all phases of the products.

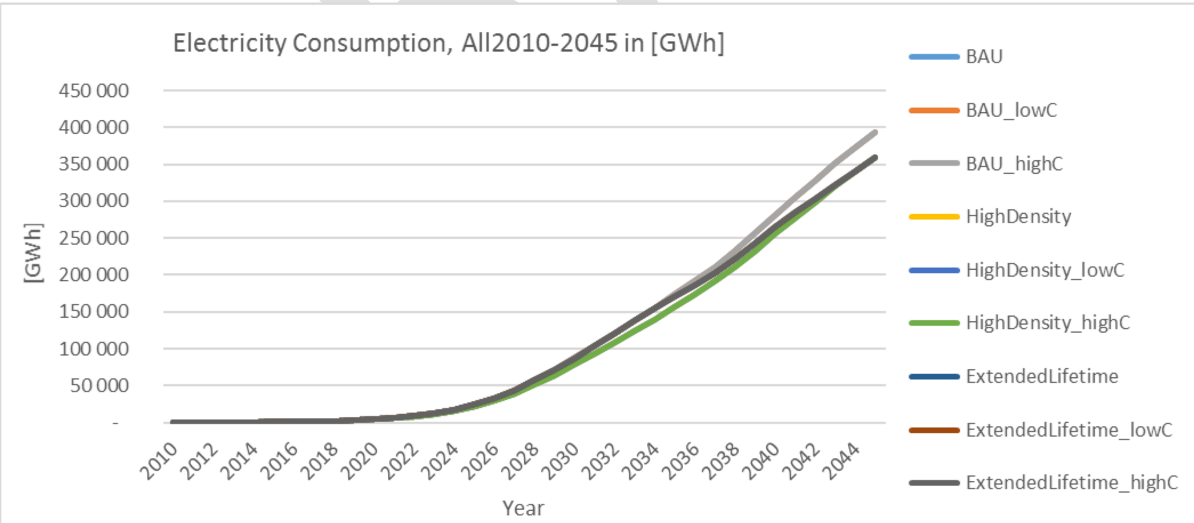

Figure 7-10: Electricity consumption in GWh/year for all phases (EU-28 battery system stock)

Table 7-17: Electricity consumption in GWh/year for all phases (EU-28 battery system stock)

Electricity Consumption, in [GWh]								
Electricity Consumption, in	2010	2015	2020	2025	2030	2035	2040	2045
BAU	169	971	4 618	24 196	87 700	173 139	280 856	393 544
BAU_lowC	169	971	4 618	24 196	87 700	173 139	280 856	393 544
BAU_highC	169	971	4 618	24 196	87 700	173 139	280 856	393 544
HighDensity	169	971	4 618	21 410	78 331	156 689	255 354	359 559
HighDensity_lowC	169	971	4 618	21 410	78 331	156 689	255 354	359 559
HighDensity_highC	169	971	4 618	21 410	78 331	156 689	255 354	359 559
ExtendedLifetime	169	971	4 618	24 196	87 593	170 435	264 340	359 078
ExtendedLifetime_lowC	169	971	4 618	24 196	87 593	170 435	264 340	359 078
ExtendedLifetime_highC	169	971	4 618	24 196	87 593	170 435	264 340	359 078
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 2 786	- 9 370	- 16 449	- 25 502	- 33 984
HighDensity_lowC	-	-	-	- 2 786	- 9 370	- 16 449	- 25 502	- 33 984
HighDensity_highC	-	-	-	- 2 786	- 9 370	- 16 449	- 25 502	- 33 984
ExtendedLifetime	-	-	-	-	- 108	- 2 704	- 16 515	- 34 465
ExtendedLifetime_lowC	-	-	-	-	- 108	- 2 704	- 16 515	- 34 465
ExtendedLifetime_highC	-	-	-	-	- 108	- 2 704	- 16 515	- 34 465
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-11.5%	-10.7%	-9.5%	-9.1%	-8.6%
HighDensity_lowC	0.0%	0.0%	0.0%	-11.5%	-10.7%	-9.5%	-9.1%	-8.6%
HighDensity_highC	0.0%	0.0%	0.0%	-11.5%	-10.7%	-9.5%	-9.1%	-8.6%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.1%	-1.6%	-5.9%	-8.8%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.1%	-1.6%	-5.9%	-8.8%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.1%	-1.6%	-5.9%	-8.8%

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.

In the production phase (see Figure 7-11 and Table 7-18) the GHG Emissions are expected to decrease to 847 MtCO2/year for the scenario ExtendedLifetime_lowC in 2045, which is 98.7% less than the amount for BAU scenario.

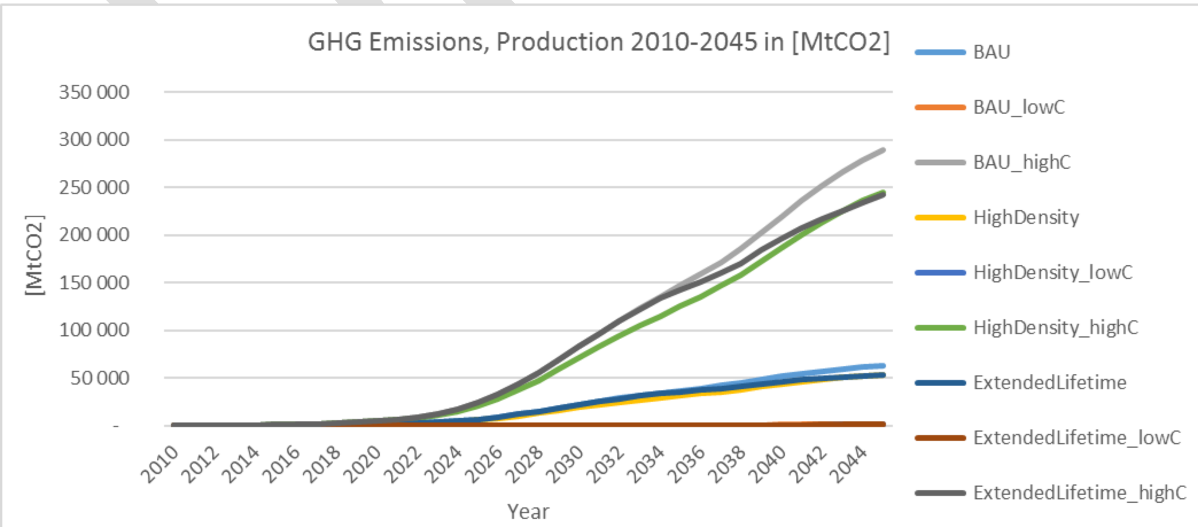

Figure 7-11: GHG emission (of the electricity consumption) in $MtCO_2$/year for the production phase (EU-28 battery system stock)

Table 7-18: GHG emission (of the electricity consumption) in MtCO2/year for the production phase (EU-28 battery system stock)

GHG, in [MtCO2]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	31	285	1 341	6 722	22 069	36 535	51 356	63 194
BAU_lowC	0	3	16	84	291	512	767	1 011
BAU_highC	97	926	4 532	23 979	83 352	146 615	219 833	289 828
HighDensity	31	285	1 341	5 719	18 879	31 232	43 591	53 475
HighDensity_lowC	0	3	16	71	249	437	651	856
HighDensity_highC	97	926	4 532	20 401	71 306	125 334	186 594	245 252
ExtendedLifetime	31	285	1 341	6 722	22 029	35 549	46 000	52 933
ExtendedLifetime_lowC	0	3	16	84	290	498	687	847
ExtendedLifetime_highC	97	926	4 532	23 979	83 203	142 660	196 907	242 766
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-31	-282	-1 325	-6 639	-21 778	-36 023	-50 589	-62 183
BAU_highC	66	641	3 191	17 257	61 283	110 080	168 477	226 634
HighDensity	-	-	-	-1 003	-3 189	-5 303	-7 765	-9 719
HighDensity_lowC	-31	-282	-1 325	-6 651	-21 820	-36 097	-50 705	-62 338
HighDensity_highC	66	641	3 191	13 679	49 237	88 799	135 238	182 058
ExtendedLifetime	-	-	-	-	-40	-985	-5 356	-10 261
ExtendedLifetime_lowC	-31	-282	-1 325	-6 639	-21 778	-36 037	-50 669	-62 347
ExtendedLifetime_highC	66	641	3 191	17 257	61 134	106 125	145 551	179 572
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	-98.9%	-98.9%	-98.8%	-98.8%	-98.7%	-98.6%	-98.5%	-98.4%
BAU_highC	213.2%	225.1%	237.9%	256.7%	277.7%	301.3%	328.1%	358.6%
HighDensity	0.0%	0.0%	0.0%	-14.9%	-14.5%	-14.5%	-15.1%	-15.4%
HighDensity_lowC	-98.9%	-98.9%	-98.8%	-98.9%	-98.9%	-98.8%	-98.7%	-98.6%
HighDensity_highC	213.2%	225.1%	237.9%	203.5%	223.1%	243.1%	263.3%	288.1%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.7%	-10.4%	-16.2%
ExtendedLifetime_lowC	-98.9%	-98.9%	-98.8%	-98.8%	-98.7%	-98.6%	-98.7%	-98.7%
ExtendedLifetime_highC	213.2%	225.1%	237.9%	256.7%	277.0%	290.5%	283.4%	284.2%

However, in the use phase (see Figure 7-12), the trend stays unchanged over time for all scenarios, since both, the electricity consumption (see Figure 7-8) and the EU electricity mix are the same far all scenarios.

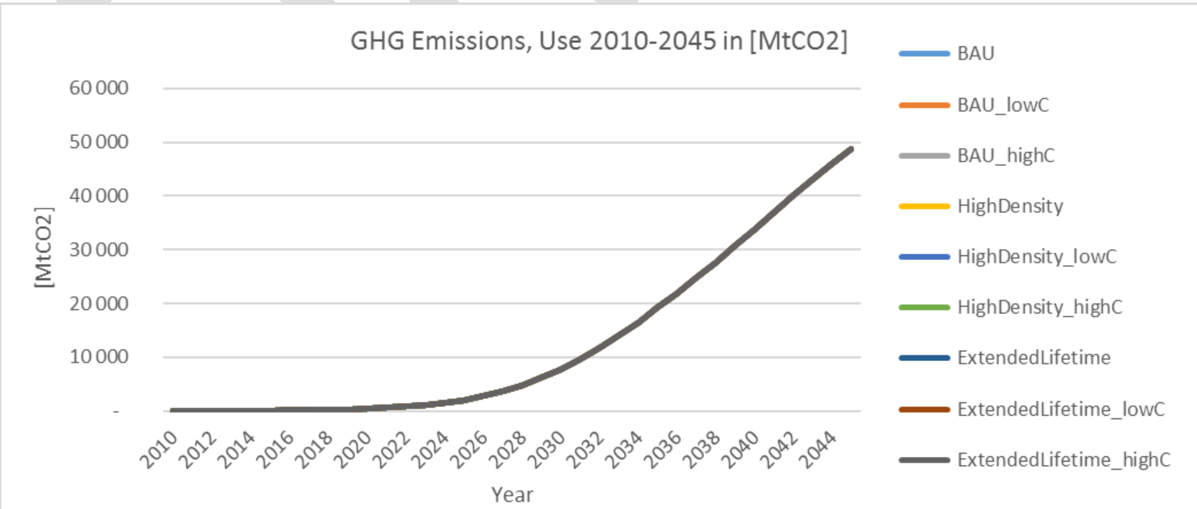

Figure 7-12: GHG emission (of the electricity consumption) in MtCO2/year for the use phase (EU-28 battery system stock)

The evolution in terms of GHG Emissions is also compared for the EoL phase in Figure 7-13 and Table 7-19, the figures are based on the EU emission of the electricity mix. The ExtendedLifetime scenarios show the best improvement potential in terms of GHG emissions.

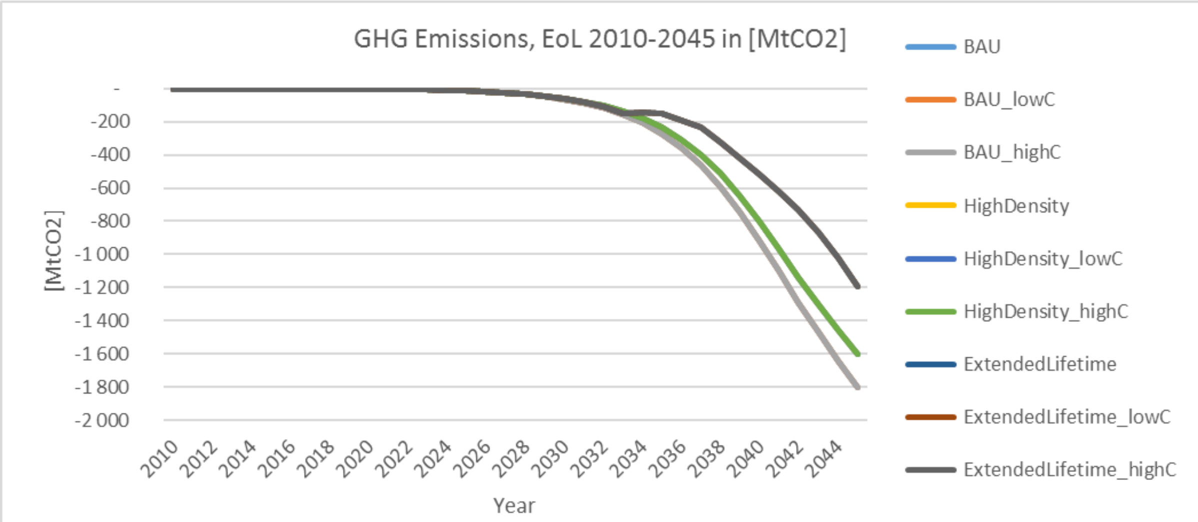

Figure 7-13: GHG emission (of the electricity consumption) in MtCO2/year for the EoL phase (EU-28 battery system stock)

Table 7-19: GHG emission (of the electricity consumption) in MtCO2/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	- 2	- 2	- 2	- 12	- 64	- 271	- 917	- 1 805
BAU_lowC	- 2	- 2	- 2	- 12	- 64	- 271	- 917	- 1 805
BAU_highC	- 2	- 2	- 2	- 12	- 64	- 271	- 917	- 1 805
HighDensity	- 2	- 2	- 2	- 12	- 60	- 232	- 802	- 1 601
HighDensity_lowC	- 2	- 2	- 2	- 12	- 60	- 232	- 802	- 1 601
HighDensity_highC	- 2	- 2	- 2	- 12	- 60	- 232	- 802	- 1 601
ExtendedLifetime	- 2	- 2	- 2	- 12	- 61	- 151	- 516	- 1 194
ExtendedLifetime_lowC	- 2	- 2	- 2	- 12	- 61	- 151	- 516	- 1 194
ExtendedLifetime_highC	- 2	- 2	- 2	- 12	- 61	- 151	- 516	- 1 194
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	-	4	39	115	204
HighDensity_lowC	-	-	-	-	4	39	115	204
HighDensity_highC	-	-	-	-	4	39	115	204
ExtendedLifetime	-	-	-	-	3	120	401	611
ExtendedLifetime_lowC	-	-	-	-	3	120	401	611
ExtendedLifetime_highC	-	-	-	-	3	120	401	611
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
HighDensity_lowC	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
HighDensity_highC	0.0%	0.0%	0.0%	0.0%	-5.9%	-14.4%	-12.5%	-11.3%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-4.6%	-44.3%	-43.8%	-33.9%

Figure 7-14 and Table 7-20 show the GHG emissions for all phases of the battery systems in the EU. In the BAU scenario, the overall GHG emission will increase up to 110 192 Mt/a, assuming the average EU electricity mix in all phases of a battery system. The GHG impact can be reduced by 56% with a low carbon electricity mix for the production phase. Assuming a high carbon electricity mix in the production, the BAU scenario would increase the GHG emissions by 205%.

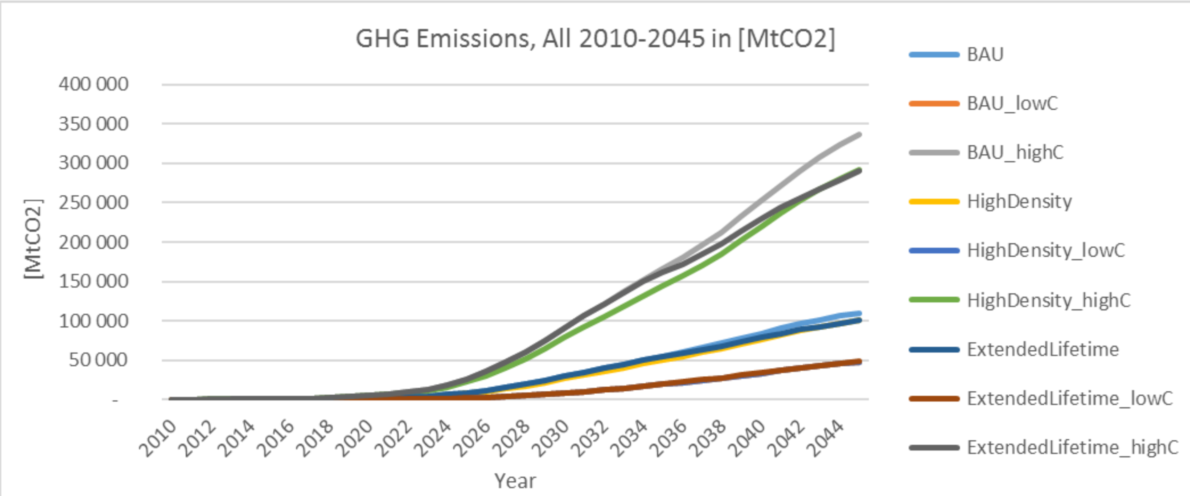

Figure 7-14: GHG emission (of the electricity consumption) in MtCO2/year for all phases (EU-28 battery system stock)

Table 7-20: GHG emission (of the electricity consumption) in MtCO2/year for all phases (EU-28 battery system stock)

GHG, in [MtCO2]								
GHG, in [MtCO2]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	69	384	1 755	8 711	29 818	55 404	84 257	110 192
BAU_lowC	39	102	429	2 072	8 040	19 381	33 668	48 009
BAU_highC	135	1 025	4 946	25 967	91 101	165 484	252 733	336 826
HighDensity	69	384	1 755	7 708	26 632	50 141	76 606	100 677
HighDensity_lowC	39	102	429	2 060	8 002	19 346	33 666	48 058
HighDensity_highC	135	1 025	4 946	22 389	79 059	144 243	219 609	292 454
ExtendedLifetime	69	384	1 755	8 711	29 781	54 539	79 302	100 542
ExtendedLifetime_lowC	39	102	429	2 072	8 043	19 488	33 989	48 456
ExtendedLifetime_highC	135	1 025	4 946	25 967	90 955	161 650	230 209	290 375
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	- 31	- 282	- 1 325	- 6 639	- 21 778	- 36 023	- 50 589	- 62 183
BAU_highC	66	641	3 191	17 257	61 283	110 080	168 477	226 634
HighDensity	-	-	-	- 1 003	- 3 186	- 5 264	- 7 650	- 9 516
HighDensity_lowC	- 31	- 282	- 1 325	- 6 651	- 21 816	- 36 058	- 50 590	- 62 135
HighDensity_highC	66	641	3 191	13 679	49 241	88 839	135 353	182 262
ExtendedLifetime	-	-	-	-	- 37	- 865	- 4 955	- 9 650
ExtendedLifetime_lowC	- 31	- 282	- 1 325	- 6 639	- 21 775	- 35 917	- 50 268	- 61 736
ExtendedLifetime_highC	66	641	3 191	17 257	61 137	106 246	145 952	180 183
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	-44.2%	-73.4%	-75.5%	-76.2%	-73.0%	-65.0%	-60.0%	-56.4%
BAU_highC	95.2%	167.2%	181.9%	198.1%	205.5%	198.7%	200.0%	205.7%
HighDensity	0.0%	0.0%	0.0%	-11.5%	-10.7%	-9.5%	-9.1%	-8.6%
HighDensity_lowC	-44.2%	-73.4%	-75.5%	-76.4%	-73.2%	-65.1%	-60.0%	-56.4%
HighDensity_highC	95.2%	167.2%	181.9%	157.0%	165.1%	160.3%	160.6%	165.4%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.1%	-1.6%	-5.9%	-8.8%
ExtendedLifetime_lowC	-44.2%	-73.4%	-75.5%	-76.2%	-73.0%	-64.8%	-59.7%	-56.0%
ExtendedLifetime_highC	95.2%	167.2%	181.9%	198.1%	205.0%	191.8%	173.2%	163.5%

7.2.1.3. Cobalt demand

Figure 7-15 and Table 7-21 show the Cobalt demand in the production phase of the battery systems. In the BAU scenarios, the yearly Cobalt demand will rise up to 177 kt/a for the EU market in 2045. This demand could be reduced by 44% in the HighDensity scenarios. A similar trend is seen in the analysis for all phases (see Figure 7-16 and Table 7-22).

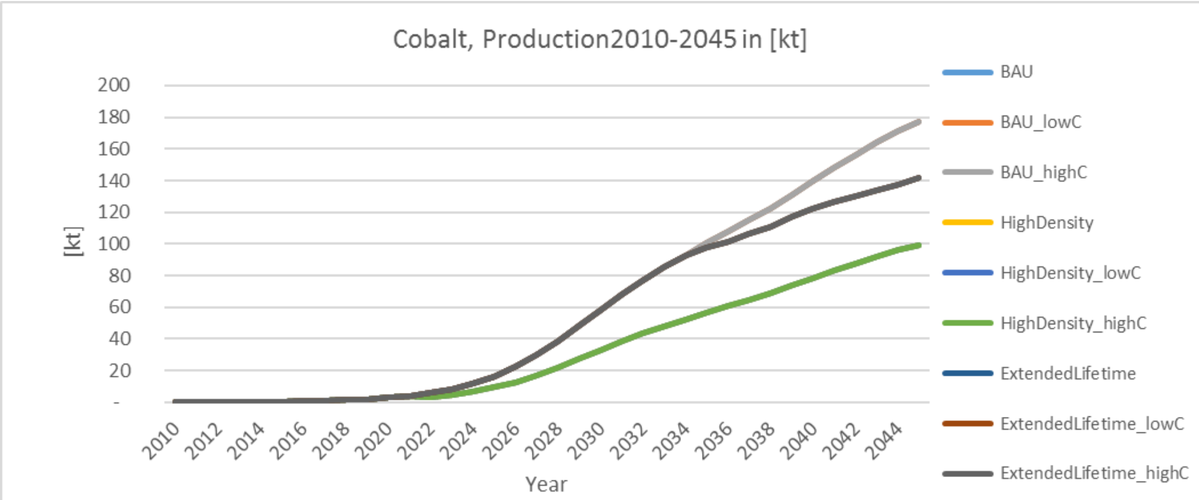

Figure 7-15: Cobalt demand in kt/year for the production phase (EU-28 battery system stock)

Table 7-21: Cobalt demand in kt/year for the production phase (EU-28 battery system stock)

Cobalt, in [kt]								
Cobalt, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	3	16	58	100	139	177
BAU_lowC	0	0	3	16	58	100	139	177
BAU_highC	0	0	3	16	58	100	139	177
HighDensity	0	0	3	9	33	56	78	99
HighDensity_lowC	0	0	3	9	33	56	78	99
HighDensity_highC	0	0	3	9	33	56	78	99
ExtendedLifetime	0	0	3	16	58	97	122	142
ExtendedLifetime_lowC	0	0	3	16	58	97	122	142
ExtendedLifetime_highC	0	0	3	16	58	97	122	142
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 7	- 25	- 44	- 61	- 78
HighDensity_lowC	-	-	-	- 7	- 25	- 44	- 61	- 78
HighDensity_highC	-	-	-	- 7	- 25	- 44	- 61	- 78
ExtendedLifetime	-	-	-	-	- 0	- 3	- 17	- 35
ExtendedLifetime_lowC	-	-	-	-	- 0	- 3	- 17	- 35
ExtendedLifetime_highC	-	-	-	-	- 0	- 3	- 17	- 35
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-43.1%	-43.5%	-43.8%	-43.9%	-43.9%
HighDensity_lowC	0.0%	0.0%	0.0%	-43.1%	-43.5%	-43.8%	-43.9%	-43.9%
HighDensity_highC	0.0%	0.0%	0.0%	-43.1%	-43.5%	-43.8%	-43.9%	-43.9%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.9%	-12.2%	-20.0%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.9%	-12.2%	-20.0%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.9%	-12.2%	-20.0%

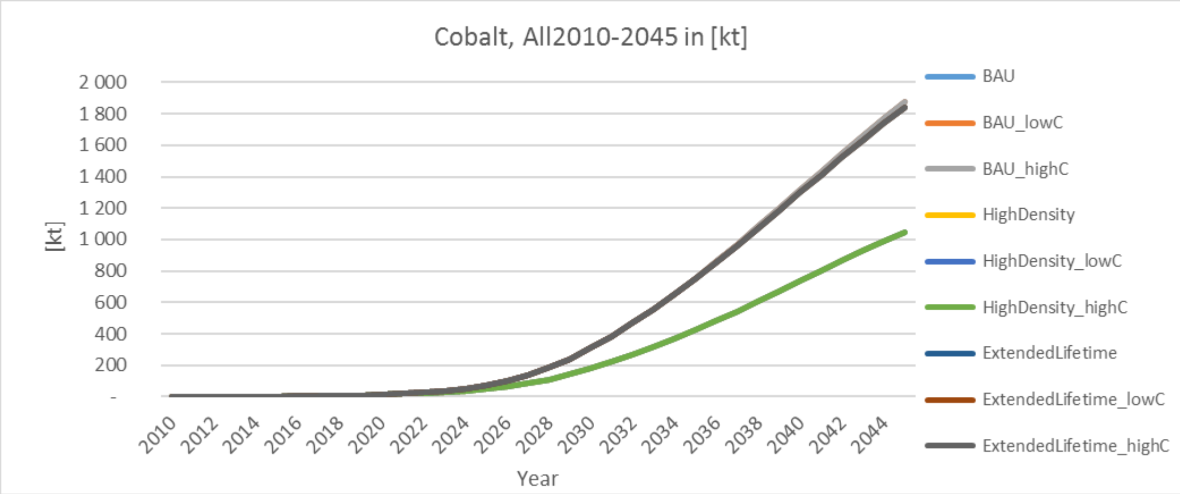

Figure 7-16: Cobalt demand in kt/year for all phases (EU-28 battery system stock)

Table 7-22: Cobalt demand in kt/year for all phases (EU-28 battery system stock)

Cobalt, in [kt]								
Cobalt, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	12	71	307	753	1 314	1 876
BAU_lowC	0	2	12	71	307	753	1 314	1 876
BAU_highC	0	2	12	71	307	753	1 314	1 876
HighDensity	0	2	12	46	178	424	737	1 050
HighDensity_lowC	0	2	12	46	178	424	737	1 050
HighDensity_highC	0	2	12	46	178	424	737	1 050
ExtendedLifetime	0	2	12	71	307	750	1 297	1 840
ExtendedLifetime_lowC	0	2	12	71	307	750	1 297	1 840
ExtendedLifetime_highC	0	2	12	71	307	750	1 297	1 840
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 25	- 129	- 329	- 576	- 826
HighDensity_lowC	-	-	-	- 25	- 129	- 329	- 576	- 826
HighDensity_highC	-	-	-	- 25	- 129	- 329	- 576	- 826
ExtendedLifetime	-	-	-	-	- 0	- 3	- 17	- 35
ExtendedLifetime_lowC	-	-	-	-	- 0	- 3	- 17	- 35
ExtendedLifetime_highC	-	-	-	-	- 0	- 3	- 17	- 35
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-35.3%	-42.0%	-43.7%	-43.9%	-44.0%
HighDensity_lowC	0.0%	0.0%	0.0%	-35.3%	-42.0%	-43.7%	-43.9%	-44.0%
HighDensity_highC	0.0%	0.0%	0.0%	-35.3%	-42.0%	-43.7%	-43.9%	-44.0%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.9%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.9%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.9%

7.2.1.4. Graphite demand

The evolution of the Graphite demand in the battery systems over time is shown for the production phase in Figure 7-15 and Table 7-23 and for all phases in Figure 7-18 and Table 7-24.

The demand for Graphite is expected to rise up to 1951 kt/y in 2045 in the BAU scenarios.

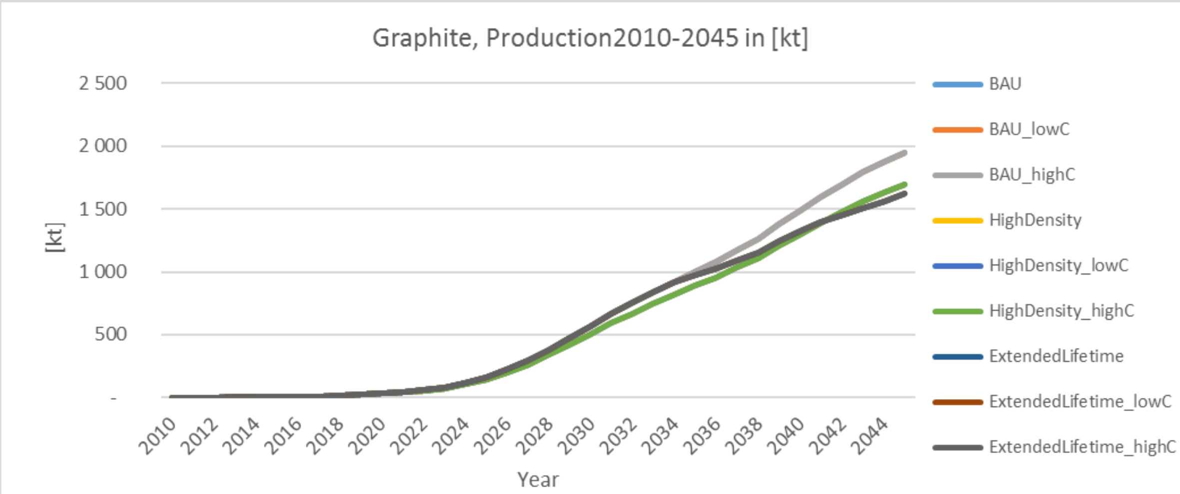

Figure 7-17: Graphite demand in kt/year for the production phase (EU-28 battery system stock)

Table 7-23: Graphite demand in kt/year for the production phase (EU-28 battery system stock)

Graphite, in [kt]								
Graphite, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	6	30	163	571	1 004	1 487	1 951
BAU_lowC	1	6	30	163	571	1 004	1 487	1 951
BAU_highC	1	6	30	163	571	1 004	1 487	1 951
HighDensity	1	6	30	144	507	888	1 300	1 696
HighDensity_lowC	1	6	30	144	507	888	1 300	1 696
HighDensity_highC	1	6	30	144	507	888	1 300	1 696
ExtendedLifetime	1	6	30	163	570	976	1 326	1 619
ExtendedLifetime_lowC	1	6	30	163	570	976	1 326	1 619
ExtendedLifetime_highC	1	6	30	163	570	976	1 326	1 619
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	-19	-64	-116	-188	-255
HighDensity_lowC	-	-	-	-19	-64	-116	-188	-255
HighDensity_highC	-	-	-	-19	-64	-116	-188	-255
ExtendedLifetime	-	-	-	-	-1	-28	-161	-332
ExtendedLifetime_lowC	-	-	-	-	-1	-28	-161	-332
ExtendedLifetime_highC	-	-	-	-	-1	-28	-161	-332
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-11.8%	-11.3%	-11.5%	-12.6%	-13.1%
HighDensity_lowC	0.0%	0.0%	0.0%	-11.8%	-11.3%	-11.5%	-12.6%	-13.1%
HighDensity_highC	0.0%	0.0%	0.0%	-11.8%	-11.3%	-11.5%	-12.6%	-13.1%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.8%	-10.8%	-17.0%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.8%	-10.8%	-17.0%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.8%	-10.8%	-17.0%

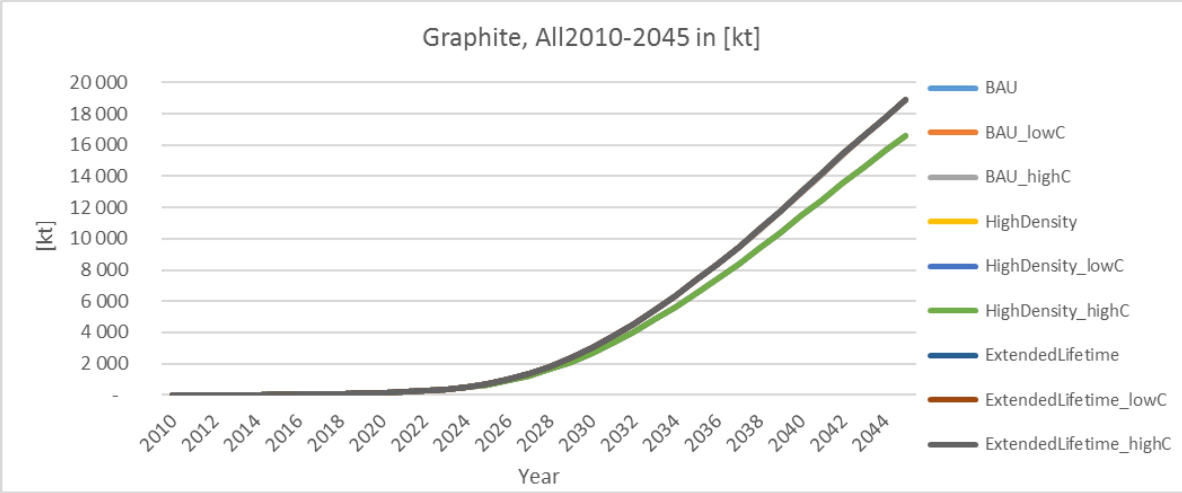

Figure 7-18: Graphite demand in kt/year for all phases (EU-28 battery system stock)

Table 7-24: Graphite demand in kt/year for all phases (EU-28 battery system stock)

Graphite, in [kt]								
Graphite, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	7	28	135	724	3 014	7 337	12 948	18 945
BAU_lowC	7	28	135	724	3 014	7 337	12 948	18 945
BAU_highC	7	28	135	724	3 014	7 337	12 948	18 945
HighDensity	7	28	135	654	2 680	6 510	11 439	16 623
HighDensity_lowC	7	28	135	654	2 680	6 510	11 439	16 623
HighDensity_highC	7	28	135	654	2 680	6 510	11 439	16 623
ExtendedLifetime	7	28	135	724	3 014	7 363	12 979	18 927
ExtendedLifetime_lowC	7	28	135	724	3 014	7 363	12 979	18 927
ExtendedLifetime_highC	7	28	135	724	3 014	7 363	12 979	18 927
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 70	- 334	- 827	- 1 509	- 2 323
HighDensity_lowC	-	-	-	- 70	- 334	- 827	- 1 509	- 2 323
HighDensity_highC	-	-	-	- 70	- 334	- 827	- 1 509	- 2 323
ExtendedLifetime	-	-	-	-	0	26	31	- 18
ExtendedLifetime_lowC	-	-	-	-	0	26	31	- 18
ExtendedLifetime_highC	-	-	-	-	0	26	31	- 18
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-9.7%	-11.1%	-11.3%	-11.7%	-12.3%
HighDensity_lowC	0.0%	0.0%	0.0%	-9.7%	-11.1%	-11.3%	-11.7%	-12.3%
HighDensity_highC	0.0%	0.0%	0.0%	-9.7%	-11.1%	-11.3%	-11.7%	-12.3%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	-0.1%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	-0.1%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	-0.1%

7.2.1.5. Nickel demand

Figure 7-19 and Table 7-25 illustrate the Nickel demand in the battery systems for the production phase. Regarding the production phase, the Nickel demand in the ExtendedLifetime scenarios is expected to be the lowest (514 kt/a) compared to the BAU scenario (647 kt/a) in 2045.

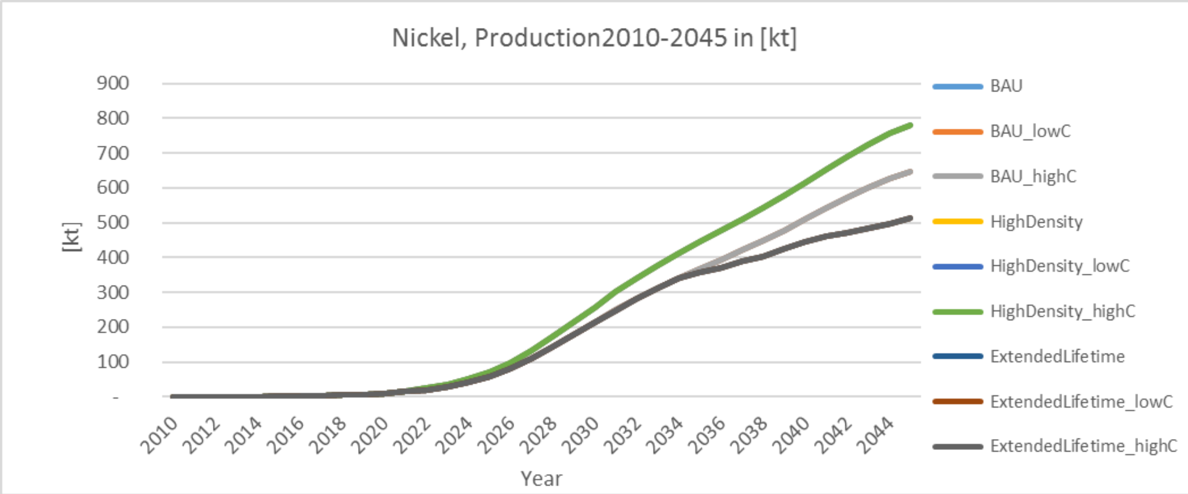

Figure 7-19: Nickel demand in kt/year for the production phase (EU-28 battery system stock)

Table 7-25: Nickel demand in kt/year for the production phase (EU-28 battery system stock)

Nickel, in [kt]								
Nickel, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	10	59	214	368	510	647
BAU_lowC	0	2	10	59	214	368	510	647
BAU_highC	0	2	10	59	214	368	510	647
HighDensity	0	2	10	72	258	445	615	781
HighDensity_lowC	0	2	10	72	258	445	615	781
HighDensity_highC	0	2	10	72	258	445	615	781
ExtendedLifetime	0	2	10	59	213	357	446	514
ExtendedLifetime_lowC	0	2	10	59	213	357	446	514
ExtendedLifetime_highC	0	2	10	59	213	357	446	514
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	12	45	77	105	133
HighDensity_lowC	-	-	-	12	45	77	105	133
HighDensity_highC	-	-	-	12	45	77	105	133
ExtendedLifetime	-	-	-	-	- 0	- 11	- 64	- 133
ExtendedLifetime_lowC	-	-	-	-	- 0	- 11	- 64	- 133
ExtendedLifetime_highC	-	-	-	-	- 0	- 11	- 64	- 133
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	20.6%	20.8%	20.9%	20.7%	20.6%
HighDensity_lowC	0.0%	0.0%	0.0%	20.6%	20.8%	20.9%	20.7%	20.6%
HighDensity_highC	0.0%	0.0%	0.0%	20.6%	20.8%	20.9%	20.7%	20.6%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.1%	-3.0%	-12.5%	-20.6%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.1%	-3.0%	-12.5%	-20.6%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.1%	-3.0%	-12.5%	-20.6%

An overview of the results, taking into account all phases of the battery systems, is provided in Figure 7-20 and in Table 7-26.

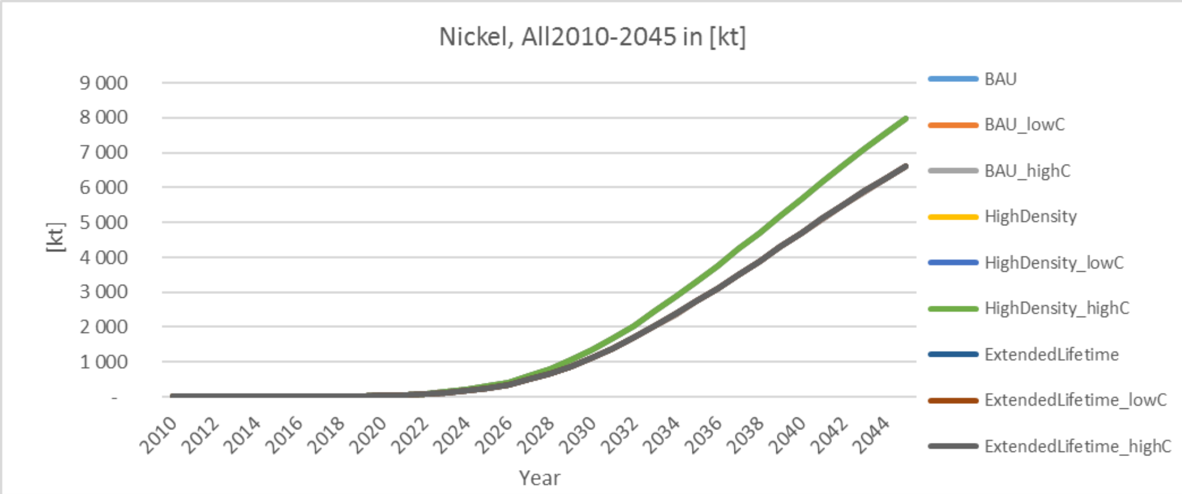

Figure 7-20: Nickel demand in kt/year for all phases (EU-28 battery system stock)

Table 7-26: Nickel demand in kt/year for all phases (EU-28 battery system stock)

Nickel, in [kt]								
Nickel, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	7	43	256	1 116	2 732	4 701	6 608
BAU_lowC	1	7	43	256	1 116	2 732	4 701	6 608
BAU_highC	1	7	43	256	1 116	2 732	4 701	6 608
HighDensity	1	7	43	300	1 342	3 304	5 684	7 987
HighDensity_lowC	1	7	43	300	1 342	3 304	5 684	7 987
HighDensity_highC	1	7	43	300	1 342	3 304	5 684	7 987
ExtendedLifetime	1	7	43	256	1 116	2 743	4 714	6 599
ExtendedLifetime_lowC	1	7	43	256	1 116	2 743	4 714	6 599
ExtendedLifetime_highC	1	7	43	256	1 116	2 743	4 714	6 599
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	43	226	571	983	1 379
HighDensity_lowC	-	-	-	43	226	571	983	1 379
HighDensity_highC	-	-	-	43	226	571	983	1 379
ExtendedLifetime	-	-	-	-	0	10	13	- 9
ExtendedLifetime_lowC	-	-	-	-	0	10	13	- 9
ExtendedLifetime_highC	-	-	-	-	0	10	13	- 9
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	17.0%	20.2%	20.9%	20.9%	20.9%
HighDensity_lowC	0.0%	0.0%	0.0%	17.0%	20.2%	20.9%	20.9%	20.9%
HighDensity_highC	0.0%	0.0%	0.0%	17.0%	20.2%	20.9%	20.9%	20.9%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.3%	-0.1%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.3%	-0.1%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.3%	-0.1%

7.2.1.6. Manganese demand

Figure 7-21 and Figure 7-22 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 7-27 and Table 7-28.

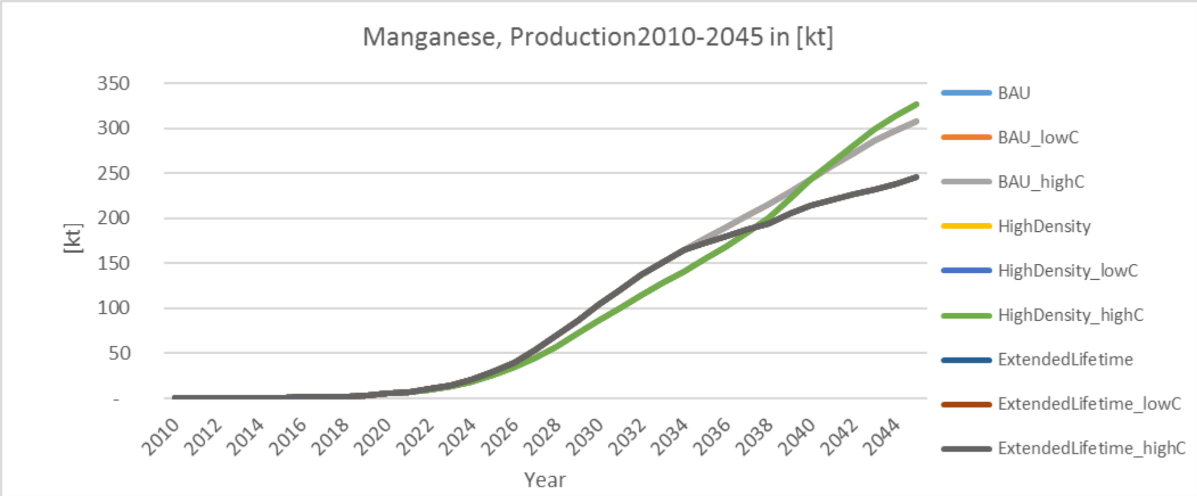

Figure 7-21: Manganese demand in kt/year for the production phase (EU-28 battery system stock)

Table 7-27: Manganese demand in kt/year for the production phase (EU-28 battery system stock)

Manganese, in [kt]								
Manganese, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	1	5	29	104	178	244	308
BAU_lowC	0	1	5	29	104	178	244	308
BAU_highC	0	1	5	29	104	178	244	308
HighDensity	0	1	5	25	87	154	243	327
HighDensity_lowC	0	1	5	25	87	154	243	327
HighDensity_highC	0	1	5	25	87	154	243	327
ExtendedLifetime	0	1	5	29	104	173	214	246
ExtendedLifetime_lowC	0	1	5	29	104	173	214	246
ExtendedLifetime_highC	0	1	5	29	104	173	214	246
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 4	- 18	- 23	- 1	19
HighDensity_lowC	-	-	-	- 4	- 18	- 23	- 1	19
HighDensity_highC	-	-	-	- 4	- 18	- 23	- 1	19
ExtendedLifetime	-	-	-	-	- 0	- 5	- 29	- 62
ExtendedLifetime_lowC	-	-	-	-	- 0	- 5	- 29	- 62
ExtendedLifetime_highC	-	-	-	-	- 0	- 5	- 29	- 62
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-14.0%	-17.0%	-13.0%	-0.4%	6.1%
HighDensity_lowC	0.0%	0.0%	0.0%	-14.0%	-17.0%	-13.0%	-0.4%	6.1%
HighDensity_highC	0.0%	0.0%	0.0%	-14.0%	-17.0%	-13.0%	-0.4%	6.1%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.8%	-12.1%	-20.2%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.8%	-12.1%	-20.2%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.1%	-2.8%	-12.1%	-20.2%

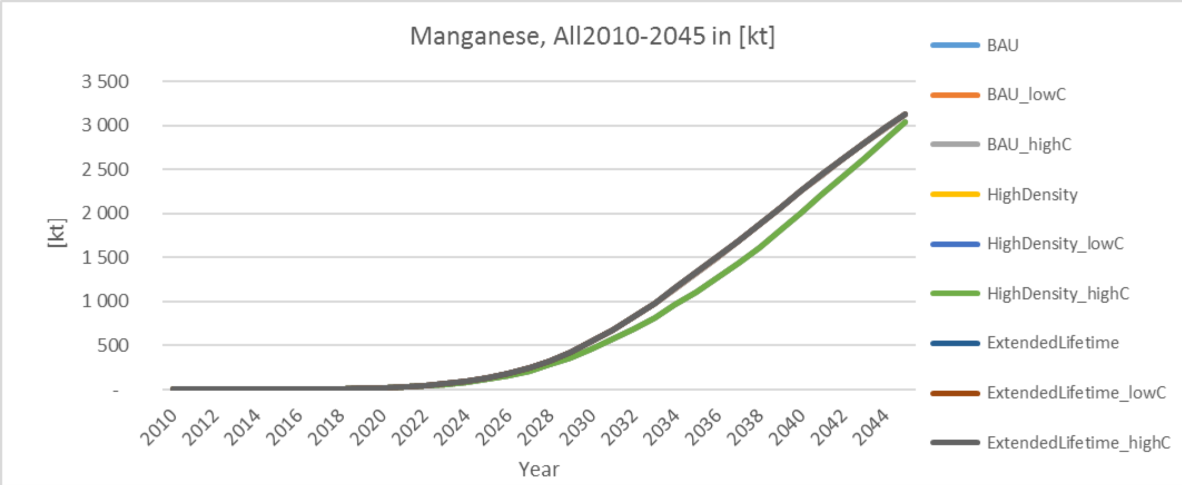

Figure 7-22: Manganese demand in kt/year for all phases (EU-28 battery system stock)

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

Manganese, in [kt]								
Manganese, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	3	21	127	547	1 322	2 250	3 131
BAU_lowC	1	3	21	127	547	1 322	2 250	3 131
BAU_highC	1	3	21	127	547	1 322	2 250	3 131
HighDensity	1	3	21	114	460	1 112	2 008	3 039
HighDensity_lowC	1	3	21	114	460	1 112	2 008	3 039
HighDensity_highC	1	3	21	114	460	1 112	2 008	3 039
ExtendedLifetime	1	3	21	127	547	1 328	2 258	3 130
ExtendedLifetime_lowC	1	3	21	127	547	1 328	2 258	3 130
ExtendedLifetime_highC	1	3	21	127	547	1 328	2 258	3 130
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 13	- 86	- 210	- 242	- 92
HighDensity_lowC	-	-	-	- 13	- 86	- 210	- 242	- 92
HighDensity_highC	-	-	-	- 13	- 86	- 210	- 242	- 92
ExtendedLifetime	-	-	-	-	0	6	8	- 1
ExtendedLifetime_lowC	-	-	-	-	0	6	8	- 1
ExtendedLifetime_highC	-	-	-	-	0	6	8	- 1
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-10.5%	-15.8%	-15.9%	-10.8%	-2.9%
HighDensity_lowC	0.0%	0.0%	0.0%	-10.5%	-15.8%	-15.9%	-10.8%	-2.9%
HighDensity_highC	0.0%	0.0%	0.0%	-10.5%	-15.8%	-15.9%	-10.8%	-2.9%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%	0.0%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%	0.0%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%	0.0%

7.2.1.7. Lithium demand

As shown in Figure 7-23, 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 HighDensity scenarios, the demand is reduced by 5% compared to the BAU scenario. However, for the ExtendedLifetime scenarios this amount decreases to -20.5% in 2045 (see Table 7-29).

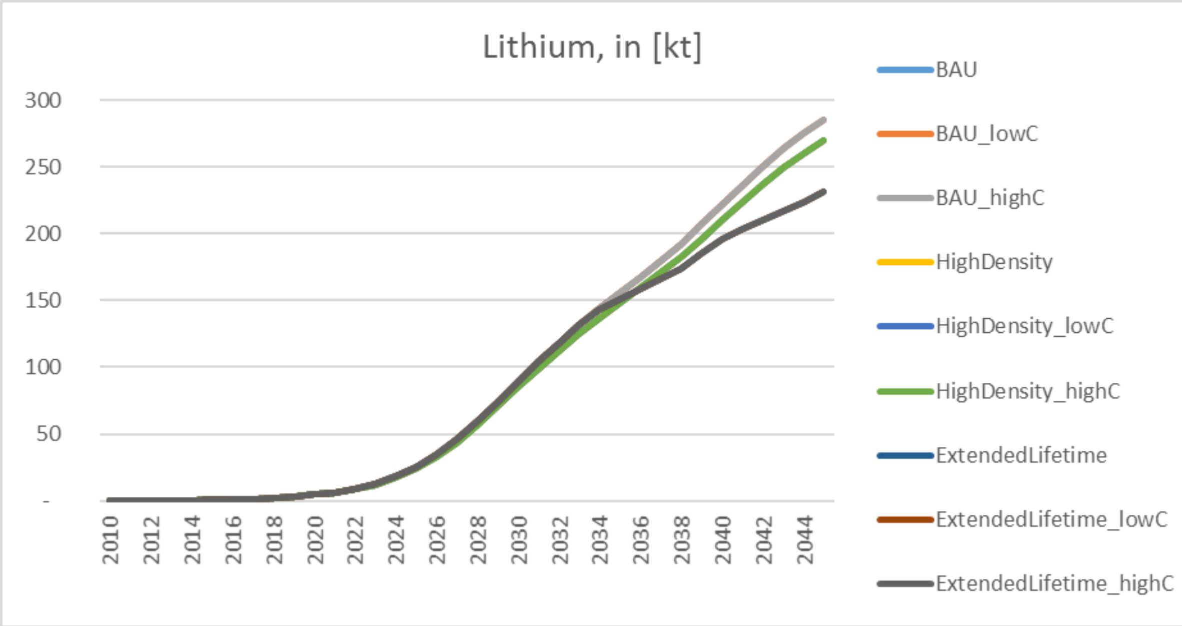

Figure 7-23: Lithium demand in kt/year for the production phase (EU-28 battery system stock)

Table 7-29: Lithium demand in kt/year for the production phase (EU-28 battery system stock)

Lithium, in [kt]								
Lithium, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	1	4	25	90	156	222	285
BAU_lowC	0	1	4	25	90	156	222	285
BAU_highC	0	1	4	25	90	156	222	285
HighDensity	0	1	4	24	85	148	210	270
HighDensity_lowC	0	1	4	24	85	148	210	270
HighDensity_highC	0	1	4	24	85	148	210	270
ExtendedLifetime	0	1	4	25	90	151	196	231
ExtendedLifetime_lowC	0	1	4	25	90	151	196	231
ExtendedLifetime_highC	0	1	4	25	90	151	196	231
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 1	- 4	- 8	- 12	- 16
HighDensity_lowC	-	-	-	- 1	- 4	- 8	- 12	- 16
HighDensity_highC	-	-	-	- 1	- 4	- 8	- 12	- 16
ExtendedLifetime	-	-	-	-	- 0	- 5	- 26	- 54
ExtendedLifetime_lowC	-	-	-	-	- 0	- 5	- 26	- 54
ExtendedLifetime_highC	-	-	-	-	- 0	- 5	- 26	- 54
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-5.4%	-4.9%	-4.9%	-5.3%	-5.5%
HighDensity_lowC	0.0%	0.0%	0.0%	-5.4%	-4.9%	-4.9%	-5.3%	-5.5%
HighDensity_highC	0.0%	0.0%	0.0%	-5.4%	-4.9%	-4.9%	-5.3%	-5.5%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.9%	-11.7%	-18.9%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.9%	-11.7%	-18.9%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.9%	-11.7%	-18.9%

Lithium demand has been also analysed for all phases and the results are presented in Figure 7-24 and Table 7-30.

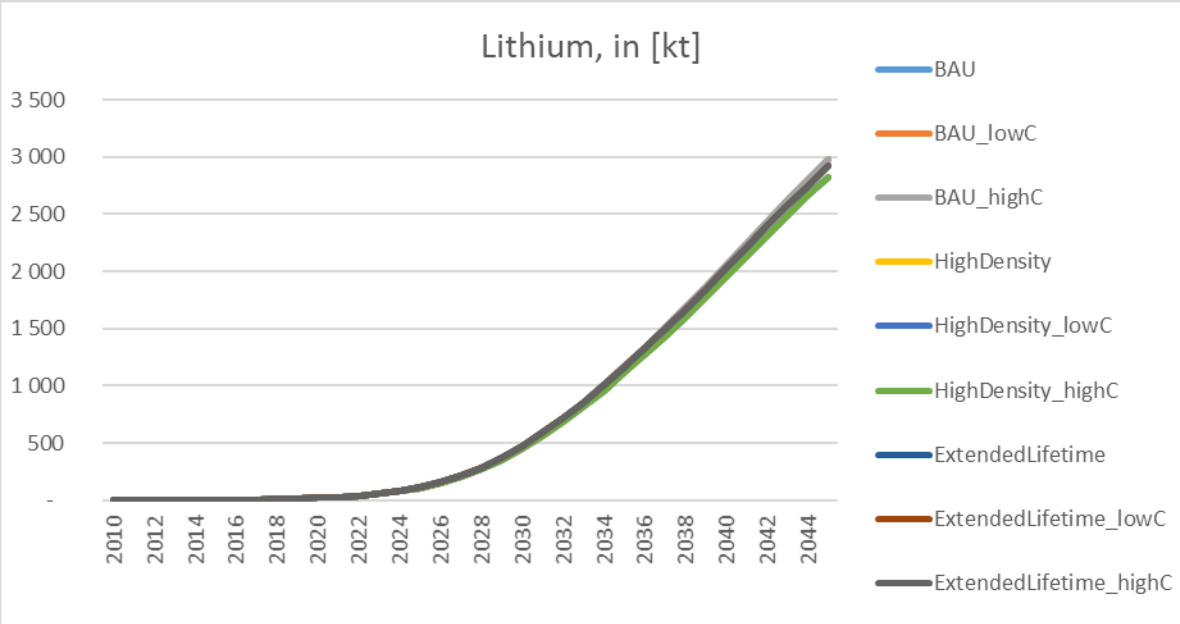

Figure 7-24: Lithium demand in kt/year for all phases (EU-28 battery system stock)

Table 7-30: Lithium demand in kt/year for all phases (EU-28 battery system stock)

Lithium, in [kt]								
Lithium, in [kt]	2010	2015	2020	2025	2030	2035	2040	2045
BAU	1	4	19	111	474	1 163	2 052	2 975
BAU_lowC	1	4	19	111	474	1 163	2 052	2 975
BAU_highC	1	4	19	111	474	1 163	2 052	2 975
HighDensity	1	4	19	106	451	1 107	1 952	2 827
HighDensity_lowC	1	4	19	106	451	1 107	1 952	2 827
HighDensity_highC	1	4	19	106	451	1 107	1 952	2 827
ExtendedLifetime	1	4	19	111	474	1 158	2 026	2 921
ExtendedLifetime_lowC	1	4	19	111	474	1 158	2 026	2 921
ExtendedLifetime_highC	1	4	19	111	474	1 158	2 026	2 921
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 5	- 23	- 56	- 100	- 148
HighDensity_lowC	-	-	-	- 5	- 23	- 56	- 100	- 148
HighDensity_highC	-	-	-	- 5	- 23	- 56	- 100	- 148
ExtendedLifetime	-	-	-	-	- 0	- 5	- 26	- 54
ExtendedLifetime_lowC	-	-	-	-	- 0	- 5	- 26	- 54
ExtendedLifetime_highC	-	-	-	-	- 0	- 5	- 26	- 54
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-4.5%	-4.9%	-4.8%	-4.9%	-5.0%
HighDensity_lowC	0.0%	0.0%	0.0%	-4.5%	-4.9%	-4.8%	-4.9%	-5.0%
HighDensity_highC	0.0%	0.0%	0.0%	-4.5%	-4.9%	-4.8%	-4.9%	-5.0%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.8%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.8%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	-1.3%	-1.8%

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 7-25 and Table 7-31. According to the figures, the expenditure for the BAU increases to 510 € bln. by 2045. The HighDensity scenarios however is expected to reduce the expenditure by 26.4% in 2045, making it the cheapest scenario. Furthermore, Figure 7-26-Figure 7-28 and Table 7-32-Table 7-33 show the details of the costs positions according to the scenarios until 2045.

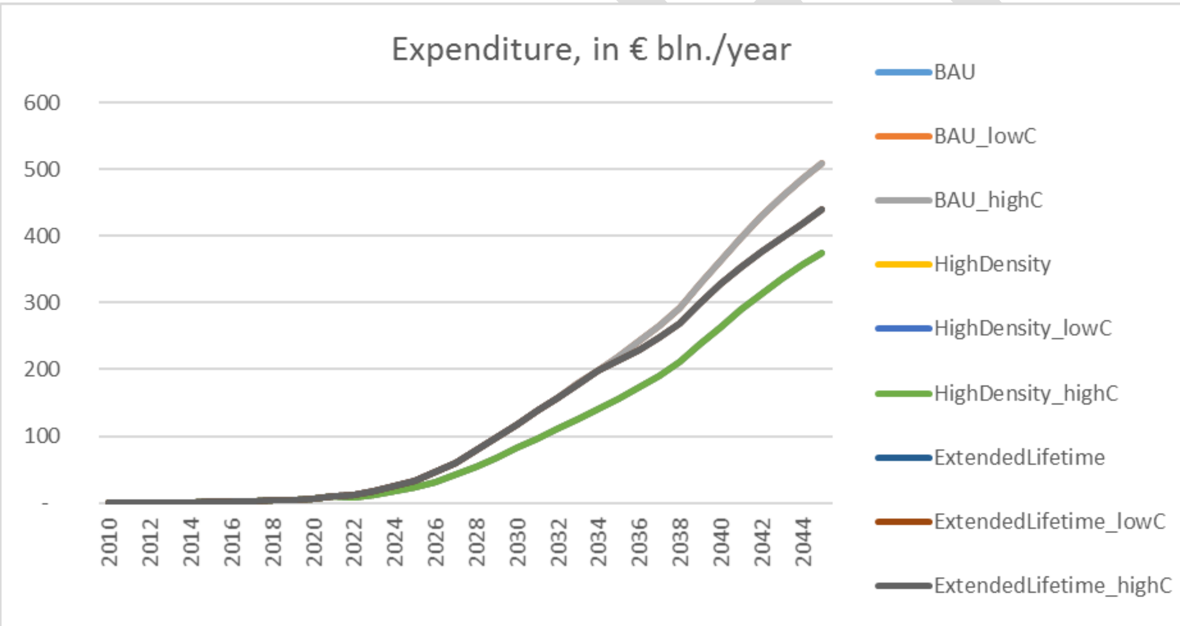

Figure 7-25: Total expenditure in € bln. /year (EU-28 battery system stock)

Table 7-31: Total expenditure in € bln. /year (EU-28 battery system stock)

Expenditure, in € bln./year								
Expenditure, in € bln./year	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	7	34	118	219	364	510
BAU_lowC	0	2	7	34	118	219	364	510
BAU_highC	0	2	7	34	118	219	364	510
HighDensity	0	2	7	24	83	156	264	375
HighDensity_lowC	0	2	7	24	83	156	264	375
HighDensity_highC	0	2	7	24	83	156	264	375
ExtendedLifetime	0	2	7	34	117	213	328	439
ExtendedLifetime_lowC	0	2	7	34	117	213	328	439
ExtendedLifetime_highC	0	2	7	34	117	213	328	439
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 10	- 35	- 63	- 100	- 135
HighDensity_lowC	-	-	-	- 10	- 35	- 63	- 100	- 135
HighDensity_highC	-	-	-	- 10	- 35	- 63	- 100	- 135
ExtendedLifetime	-	-	-	- 0	- 0	- 6	- 36	- 70
ExtendedLifetime_lowC	-	-	-	- 0	- 0	- 6	- 36	- 70
ExtendedLifetime_highC	-	-	-	- 0	- 0	- 6	- 36	- 70
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-29.9%	-29.9%	-28.9%	-27.4%	-26.4%
HighDensity_lowC	0.0%	0.0%	0.0%	-29.9%	-29.9%	-28.9%	-27.4%	-26.4%
HighDensity_highC	0.0%	0.0%	0.0%	-29.9%	-29.9%	-28.9%	-27.4%	-26.4%
ExtendedLifetime	0.0%	0.0%	0.0%	-0.1%	-0.3%	-2.8%	-9.9%	-13.8%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	-0.1%	-0.3%	-2.8%	-9.9%	-13.8%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	-0.1%	-0.3%	-2.8%	-9.9%	-13.8%

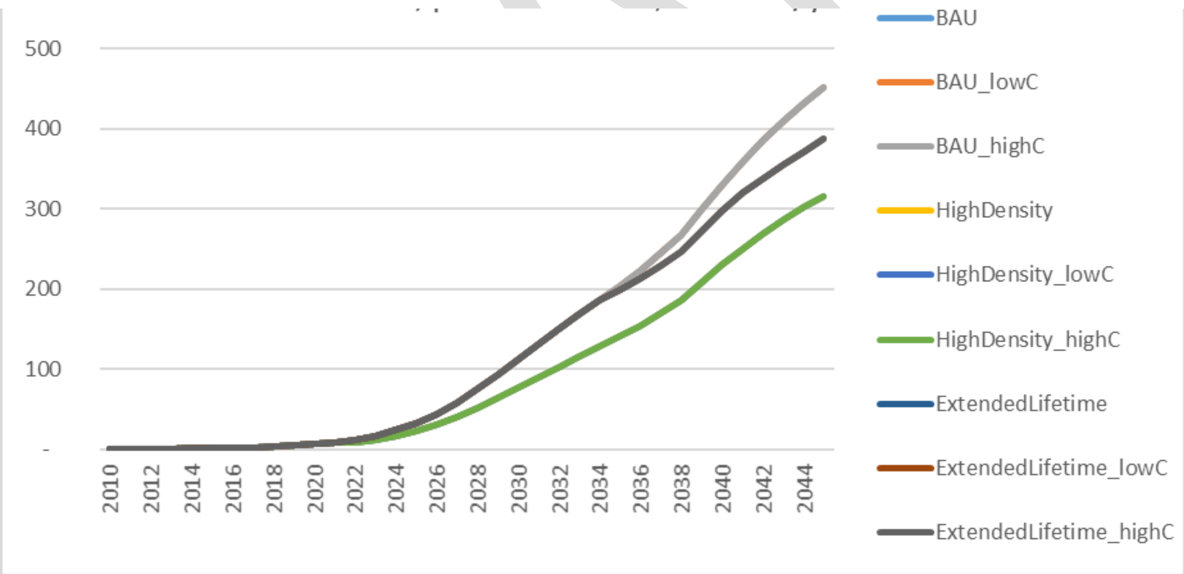

Figure 7-26: Purchase costs in € bln. /year (EU-28 battery system stock)

Table 7-32: Purchase costs in € bln. /year (EU-28 battery system stock)

of that, purchase costs, in € bln./year								
of that, purchase costs, in €	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	2	6	32	113	204	329	451
BAU_lowC	0	2	6	32	113	204	329	451
BAU_highC	0	2	6	32	113	204	329	451
HighDensity	0	2	6	22	77	141	230	316
HighDensity_lowC	0	2	6	22	77	141	230	316
HighDensity_highC	0	2	6	22	77	141	230	316
ExtendedLifetime	0	2	6	32	112	199	298	387
ExtendedLifetime_lowC	0	2	6	32	112	199	298	387
ExtendedLifetime_highC	0	2	6	32	112	199	298	387
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	- 10	- 35	- 63	- 100	- 135
HighDensity_lowC	-	-	-	- 10	- 35	- 63	- 100	- 135
HighDensity_highC	-	-	-	- 10	- 35	- 63	- 100	- 135
ExtendedLifetime	-	-	-	-	- 0	- 5	- 32	- 64
ExtendedLifetime_lowC	-	-	-	-	- 0	- 5	- 32	- 64
ExtendedLifetime_highC	-	-	-	-	- 0	- 5	- 32	- 64
Relative difference to BAU								
BAU	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	-30.9%	-31.3%	-31.0%	-30.2%	-29.9%
HighDensity_lowC	0.0%	0.0%	0.0%	-30.9%	-31.3%	-31.0%	-30.2%	-29.9%
HighDensity_highC	0.0%	0.0%	0.0%	-30.9%	-31.3%	-31.0%	-30.2%	-29.9%
ExtendedLifetime	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.6%	-9.6%	-14.2%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.6%	-9.6%	-14.2%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	0.0%	-0.2%	-2.6%	-9.6%	-14.2%

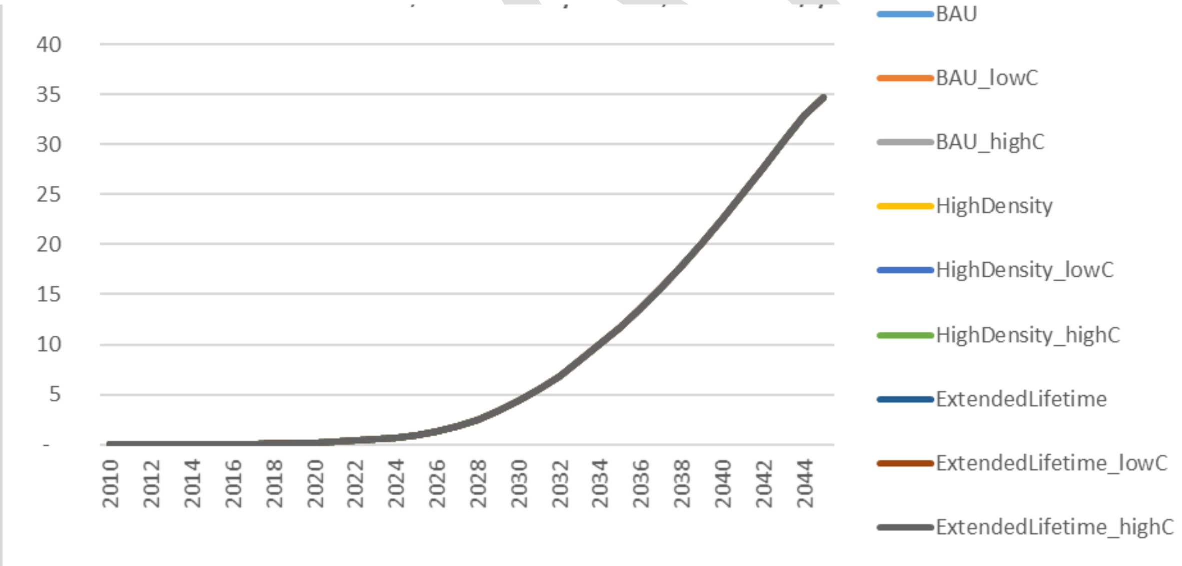

Figure 7-27: Electricity costs (use phase only) in € bln. /year (EU-28 battery system stock)

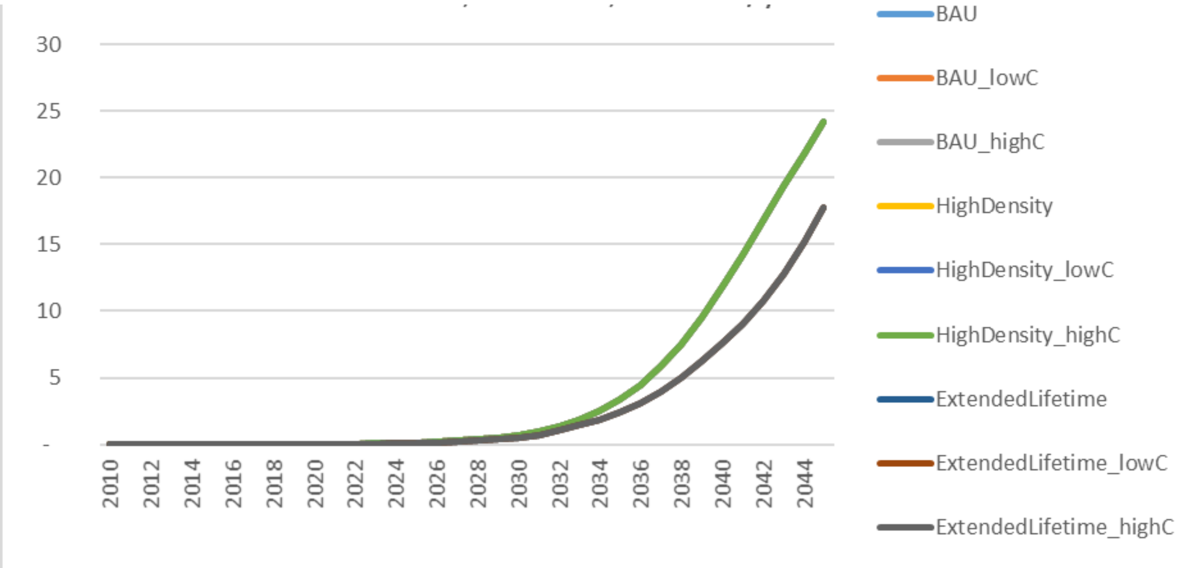

Figure 7-28: EoL costs in € bln. /year (EU-28 battery system stock)

Table 7-33: EoL costs in € bln. /year (EU-28 battery system stock)

of that,EoL costs, in € bln./year								
of that,EoL costs, in € bln./y	2010	2015	2020	2025	2030	2035	2040	2045
BAU	0	0	0	0	1	3	12	24
BAU_lowC	0	0	0	0	1	3	12	24
BAU_highC	0	0	0	0	1	3	12	24
HighDensity	0	0	0	0	1	3	12	24
HighDensity_lowC	0	0	0	0	1	3	12	24
HighDensity_highC	0	0	0	0	1	3	12	24
ExtendedLifetime	0	0	0	0	1	2	8	18
ExtendedLifetime_lowC	0	0	0	0	1	2	8	18
ExtendedLifetime_highC	0	0	0	0	1	2	8	18
Absolute difference to BAU								
BAU	-	-	-	-	-	-	-	-
BAU_lowC	-	-	-	-	-	-	-	-
BAU_highC	-	-	-	-	-	-	-	-
HighDensity	-	-	-	-	-	-	-	-
HighDensity_lowC	-	-	-	-	-	-	-	-
HighDensity_highC	-	-	-	-	-	-	-	-
ExtendedLifetime	-	-	-	- 0	- 0	- 1	- 4	- 6
ExtendedLifetime_lowC	-	-	-	- 0	- 0	- 1	- 4	- 6
ExtendedLifetime_highC	-	-	-	- 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%
BAU_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAU_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity_lowC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HighDensity_highC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ExtendedLifetime	0.0%	0.0%	0.0%	-22.7%	-26.0%	-27.8%	-36.0%	-26.4%
ExtendedLifetime_lowC	0.0%	0.0%	0.0%	-22.7%	-26.0%	-27.8%	-36.0%	-26.4%
ExtendedLifetime_highC	0.0%	0.0%	0.0%	-22.7%	-26.0%	-27.8%	-36.0%	-26.4%

7.2.3. Overview

A summary of the main impacts of the different scenarios are presented in *Table 7-34,* showing the figures for 2045.

Table 7-34: Overview of the main impacts in 2045 (EU-28 battery system stock)

Criteria			MAIN IMPACTS IN YEAR 2045								
			1	2	3	4	5	6	7	8	9
			BAU	BAU_lowC	BAU_highC	HighDensity	HighDensity_lowC	HighDensity_highC	ExtendedLifetime	ExtendedLifetime_lowC	ExtendedLifetime_highC
ENVIRONMENT											
	Electricity Consumption	[GWh]	393 544	393 544	393 544	359 559	359 559	359 559	359 078	359 078	359 078
	GHG	[MtCO2]	110 192	48 009	336 826	100 677	48 058	292 454	100 542	48 456	290 375
RESSOURCE											
	Cobalt	[kt]	1 876	1 876	1 876	1 050	1 050	1 050	1 840	1 840	1 840
	Graphite	[kt]	18 945	18 945	18 945	16 623	16 623	16 623	18 927	18 927	18 927
	Nickel	[kt]	6 608	6 608	6 608	7 987	7 987	7 987	6 599	6 599	6 599
	Manganese	[kt]	3 131	3 131	3 131	3 039	3 039	3 039	3 130	3 130	3 130
	Lithium	[kt]	2 975	2 975	2 975	2 827	2 827	2 827	2 921	2 921	2 921
CONSUMER											
EU totals	Expenditure	€ bln./year	510	510	510	375	375	375	439	439	439
	of that, purchase costs	€ bln./year	451	451	451	316	316	316	387	387	387
	of that,EoL costs	€ bln./year	24	24	24	24	24	24	18	18	18
	of that, electricity costs	€ bln./year	35	35	35	35	35	35	35	35	35
Per product sold	Sales (regulated)	000 000	57	57	57	57	57	57	51	51	51
	Product price	€	7 948	7 948	7 948	5 575	5 575	5 575	7 587	7 587	7 587

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. This sensitivity analysis 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.

7.3.1. Stock volumes

In this section, the battery sales for the EU market for low and high sale scenarios are considered and the assumptions[20] are presented in Table 7-36-Table 7-37.

[20] based on the stock scenarios (low and high) elaborated in Task 2

Table 7-35: Forecast battery 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	37	158	539	1 361	2 556	3 852
BC3_PC PHEV	3	5	16	60	180	404	714	1 090
BC4_Truck BEV	0	0	0	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	73	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	85	398	1 557	4 054	7 532	11 305
Stock [1000 of 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	920	3 946	13 478	34 030	63 896	96 305
BC3_PC PHEV	250	417	1 373	4 981	15 040	33 686	59 460	90 806
BC4_Truck BEV	7	7	9	105	572	2 145	5 258	8 827
BC5_Truck PHEV	8	8	45	284	928	2 307	4 783	8 604
BC6_Residential ESS	108	435	861	1 383	2 014	2 987	4 356	6 129
BC7_Commercial ESS	30	112	367	1 159	2 708	4 953	11 137	25 297
Total mobile application	272	591	2 574	11 141	39 451	98 406	181 577	274 688
Total stationary application	138	547	1 228	2 543	4 722	7 941	15 493	31 427
Total all application	411	1 137	3 802	13 684	44 173	106 346	197 069	306 115

Table 7-36: Forecast battery 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	325	431	549
BC2_PC BEV LOW	0	2	10	39	112	218	319	407
BC3_PC PHEV	0	1	4	15	38	71	112	157
BC4_Truck BEV	0	0	- 0	1	5	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	21	103	345	642	916	1 196
Total stationary application	0	1	2	4	5	10	23	46
Total all application	0	5	22	107	350	652	939	1 242
Sales [1000 of battery systems]	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**
BC1_PC BEV HIGH	0	8	87	591	2 306	4 062	5 388	6 865
BC2_PC BEV LOW	1	52	239	963	2 809	5 453	7 969	10 169
BC3_PC PHEV	28	95	317	1 224	3 158	5 884	9 313	13 090
BC4_Truck BEV	1	1	- 7	35	165	520	986	1 370
BC5_Truck PHEV	2	2	22	94	271	622	1 223	2 088
BC6_Residential ESS	6	79	88	115	221	322	416	573
BC7_Commercial ESS	2	25	80	238	303	698	1 884	4 050
Total mobile application	31	158	658	2 906	8 709	16 542	24 880	33 581
Total stationary application	8	104	168	352	524	1 019	2 300	4 622
Total all application	39	262	825	3 259	9 233	17 561	27 180	38 203

Table 7-37: Forecast 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	41	255	1 096	2 796	4 890	6 801
BC3_PC PHEV	3	5	18	79	262	472	592	611
BC4_Truck BEV	0	0	2	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	80	556	2 710	7 060	12 357	17 250
Total stationary application	1	5	13	29	87	291	997	2 560
Total all application	5	18	93	585	2 796	7 351	13 354	19 810
Stock [1000 of battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	1	16	228	2 495	15 468	42 768	76 404	108 598
BC2_PC BEV LOW	7	143	1 029	6 381	27 401	69 888	122 245	170 037
BC3_PC PHEV	250	417	1 504	6 609	21 867	39 343	49 304	50 941
BC4_Truck BEV	7	7	55	430	2 417	7 785	14 838	20 695
BC5_Truck PHEV	8	8	48	424	2 055	6 883	15 898	26 437
BC6_Residential ESS	108	435	910	1 749	3 274	5 921	10 101	16 503
BC7_Commercial ESS	30	112	356	1 167	5 382	23 185	89 573	239 473
Total mobile application	272	591	2 864	16 340	69 209	166 666	278 689	376 709
Total stationary application	138	547	1 266	2 916	8 656	29 105	99 674	255 975
Total all application	411	1 137	4 130	19 255	77 865	195 772	378 363	632 684

Table 7-38: Forecast battery 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	508	658	841
BC2_PC BEV LOW	0	2	14	75	247	418	554	665
BC3_PC PHEV	0	1	5	21	53	62	73	61
BC4_Truck BEV	0	0	1	4	21	48	74	87
BC5_Truck PHEV	0	0	1	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	28	176	650	1 075	1 440	1 774
Total stationary application	0	1	2	5	19	64	223	370
Total all application	0	5	30	181	669	1 140	1 663	2 144
Sales [1000 of battery systems]	2010	2015	2020	2025	2030	2035	2040	2045
BC1_PC BEV HIGH	0	8	88	907	3 953	6 349	8 229	10 512
BC2_PC BEV LOW	1	52	348	1 873	6 164	10 448	13 855	16 622
BC3_PC PHEV	28	95	448	1 778	4 427	5 168	6 109	5 048
BC4_Truck BEV	1	1	39	136	695	1 587	2 458	2 889
BC5_Truck PHEV	2	2	26	155	667	1 983	4 039	6 064
BC6_Residential ESS	6	79	137	215	455	732	1 156	1 872
BC7_Commercial ESS	2	25	68	285	1 445	5 709	21 143	35 102
Total mobile application	31	158	948	4 849	15 907	25 535	34 691	41 135
Total stationary application	8	104	206	500	1 901	6 441	22 298	36 973
Total all application	39	262	1 153	5 349	17 807	31 976	56 989	78 108

Table 7-39 and Table 7-40 respectively present an overview of the main impacts of the low and high sales scenarios for battery systems in 2045.

*Table 7-39: Overview of the main impacts in 2045 (EU-28 battery system stock) – **low sales scenario***

Criteria			MAIN IMPACTS IN YEAR 2045								
			1	2	3	4	5	6	7	8	9
			BAU	BAU_lowC	BAU_highC	HighDensity	HighDensity_lowC	HighDensity_highC	ExtendedLifetime	ExtendedLifetime_lowC	ExtendedLifetime_highC
ENVIRONMENT											
	Electricity Consumption	[GWh]	275 288	275 288	275 288	251 610	251 610	251 610	251 078	251 078	251 078
	GHG	[MtCO2]	77 081	32 836	238 337	70 451	32 878	207 389	70 302	33 167	205 644
RESSOURCE											
	Cobalt	[kt]	1 434	1 434	1 434	812	812	812	1 409	1 409	1 409
	Graphite	[kt]	13 581	13 581	13 581	12 020	12 020	12 020	13 575	13 575	13 575
	Nickel	[kt]	5 021	5 021	5 021	6 063	6 063	6 063	5 018	5 018	5 018
	Manganese	[kt]	2 452	2 452	2 452	2 077	2 077	2 077	2 454	2 454	2 454
	Lithium	[kt]	2 212	2 212	2 212	2 099	2 099	2 099	2 174	2 174	2 174
CONSUMER											
EU totals	Expenditure	€ bln./year	323	323	323	237	237	237	274	274	274
	of that, purchase costs	€ bln./year	282	282	282	195	195	195	237	237	237
	of that,EoL costs	€ bln./year	18	18	18	18	18	18	14	14	14
	of that, electricity costs	€ bln./year	24	24	24	24	24	24	24	24	24
Per product sold	Sales (regulated)	000 000	36	36	36	36	36	36	33	33	33
	Product price	€	7 715	7 715	7 715	5 344	5 344	5 344	7 265	7 265	7 265

*Table 7-40: Overview of the main impacts in 2045 (EU-28 battery system stock) – **high sales scenario***

Criteria			MAIN IMPACTS IN YEAR 2045								
			1	2	3	4	5	6	7	8	9
			BAU	BAU_lowC	BAU_highC	HighDensity	HighDensity_lowC	HighDensity_highC	ExtendedLifetime	ExtendedLifetime_lowC	ExtendedLifetime_highC
ENVIRONMENT											
	Electricity Consumption	[GWh]	511 799	511 799	511 799	467 509	467 509	467 509	467 079	467 079	467 079
	GHG	[MtCO2]	143 304	63 183	435 315	130 902	63 237	377 519	130 782	63 745	375 106
RESSOURCE											
	Cobalt	[kt]	2 317	2 317	2 317	1 287	1 287	1 287	2 272	2 272	2 272
	Graphite	[kt]	24 310	24 310	24 310	21 225	21 225	21 225	24 279	24 279	24 279
	Nickel	[kt]	8 196	8 196	8 196	9 911	9 911	9 911	8 180	8 180	8 180
	Manganese	[kt]	3 809	3 809	3 809	4 001	4 001	4 001	3 807	3 807	3 807
	Lithium	[kt]	3 738	3 738	3 738	3 556	3 556	3 556	3 669	3 669	3 669
CONSUMER											
EU totals	Expenditure	€ bln./year	696	696	696	513	513	513	604	604	604
	of that, purchase costs	€ bln./year	620	620	620	437	437	437	537	537	537
	of that,EoL costs	€ bln./year	30	30	30	30	30	30	22	22	22
	of that, electricity costs	€ bln./year	46	46	46	46	46	46	46	46	46
Per product sold	Sales (regulated)	000 000	77	77	77	77	77	77	69	69	69
	Product price	€	8 059	8 059	8 059	5 685	5 685	5 685	7 739	7 739	7 739

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 7-41 (low electricity price) and Table 7-42 (high electricity price). Regarding the sales and stock volumes, the medium scenario was considered.

Table 7-41: Overview of the main impacts in 2045 (EU-28 battery system stock) ***– low electricity price scenario***

Criteria			MAIN IMPACTS IN YEAR 2045								
			1	2	3	4	5	6	7	8	9
			BAU	BAU_lowC	BAU_highC	HighDensity	HighDensity_lowC	HighDensity_highC	ExtendedLifetime	ExtendedLifetime_lowC	ExtendedLifetime_highC
ENVIRONMENT											
	Electricity Consumption	[GWh]	393 544	393 544	393 544	359 559	359 559	359 559	359 078	359 078	359 078
	GHG	[MtCO2]	110 192	48 009	336 826	100 677	48 058	292 454	100 542	48 456	290 375
RESSOURCE											
	Cobalt	[kt]	1 876	1 876	1 876	1 050	1 050	1 050	1 840	1 840	1 840
	Graphite	[kt]	18 945	18 945	18 945	16 623	16 623	16 623	18 927	18 927	18 927
	Nickel	[kt]	6 608	6 608	6 608	7 987	7 987	7 987	6 599	6 599	6 599
	Manganese	[kt]	3 131	3 131	3 131	3 039	3 039	3 039	3 130	3 130	3 130
	Lithium	[kt]	2 975	2 975	2 975	2 827	2 827	2 827	2 921	2 921	2 921
CONSUMER											
EU totals	Expenditure	€ bln./year	492	492	492	358	358	358	422	422	422
	of that, purchase costs	€ bln./year	451	451	451	316	316	316	387	387	387
	of that,EoL costs	€ bln./year	24	24	24	24	24	24	18	18	18
	of that, electricity costs	€ bln./year	17	17	17	17	17	17	17	17	17
Per product sold	Sales (regulated)	000 000	57	57	57	57	57	57	51	51	51
	Product price	€	7 948	7 948	7 948	5 575	5 575	5 575	7 587	7 587	7 587

Table 7-42: Overview of the main impacts in 2045 (EU-28 battery system stock) – ***high electricity price scenario***

Criteria			MAIN IMPACTS IN YEAR 2045								
			1	2	3	4	5	6	7	8	9
			BAU	BAU_lowC	BAU_highC	HighDensity	HighDensity_lowC	HighDensity_highC	ExtendedLifetime	ExtendedLifetime_lowC	ExtendedLifetime_highC
ENVIRONMENT											
	Electricity Consumption	[GWh]	393 544	393 544	393 544	359 559	359 559	359 559	359 078	359 078	359 078
	GHG	[MtCO2]	110 192	48 009	336 826	100 677	48 058	292 454	100 542	48 456	290 375
RESSOURCE											
	Cobalt	[kt]	1 876	1 876	1 876	1 050	1 050	1 050	1 840	1 840	1 840
	Graphite	[kt]	18 945	18 945	18 945	16 623	16 623	16 623	18 927	18 927	18 927
	Nickel	[kt]	6 608	6 608	6 608	7 987	7 987	7 987	6 599	6 599	6 599
	Manganese	[kt]	3 131	3 131	3 131	3 039	3 039	3 039	3 130	3 130	3 130
	Lithium	[kt]	2 975	2 975	2 975	2 827	2 827	2 827	2 921	2 921	2 921
CONSUMER											
EU totals	Expenditure	€ bln./year	527	527	527	392	392	392	457	457	457
	of that, purchase costs	€ bln./year	451	451	451	316	316	316	387	387	387
	of that,EoL costs	€ bln./year	24	24	24	24	24	24	18	18	18
	of that, electricity costs	€ bln./year	52	52	52	52	52	52	52	52	52
Per product sold	Sales (regulated)	000 000	57	57	57	57	57	57	51	51	51
	Product price	€	7 948	7 948	7 948	5 575	5 575	5 575	7 587	7 587	7 587

7.4. References

ANNEX.........................Battery Requirements Covered In Current Standards

Table 7-43: 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.