H2020 Work Programme "Smart, green and integrated transport"

GV-06-2017 – Physical integration of hybrid and electric vehicle batteries at pack level aiming at increased energy density and efficiency

D7.3 – Comparative LCA

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This document summarizes the results obtained following LCA methodology for the evaluation of the iModBatt battery pack and its reuse in three use cases: two electric vehicles and one stationary application. This study allows to identify the main environmental impact origins and to provide some sustainable improvement ways.

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Document History

Date	Version	Name	Changes
07/09/2020	1	Laurine Le Coadou (RSC)	Version 1
09/04/2021	2	Iosu Cendoya (CID)	Overall review

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1 Introduction

Nowadays, lithium ion batteries already dominate the consumer portable electronic, telecommunications market and hybrid and electric vehicles (HEV, EV) due to their higher power and energy density. The wide deployment of lithium ion batteries in the automotive industry is closely linked to an increase of a huge amount of battery packs (BP) to recycle, which raises the question of improvement of the modularity and recyclability of the BP. Modular BP design already exists for specialty applications with excellent performance and cost efficiency which leads to higher ambition with its spread in EV application.

In that context, the iModBatt project aims to design and manufacture, with the minimum environmental impact, a high energy density modular BP, which is flexible enough to be used in automotive and small stationary applications. This BP will be suitable for industrial automated assembly with an easy disassembly design, to make possible the shift from primary applications to secondary ones, and to facilitate the BP recyclability or parts replacement if necessary.

Environmental improvement of the lithium-ion BP from its design with specific eco-design recommendations until its manufacturing is of high concern in this project, which justifies the entire work package dedicated to that purpose (WP7). The aim of this deliverable 7.3 is to perform a comparative Life Cycle Assessment (LCA) analysis by quantifying environmental impacts of the Li-ion battery pack developed in iModBatt project in several applications in order to enhance its lifetime in comparison to the one-time use of the iModBatt battery pack.

The LCA methodology is framed by ISO 14040-44 [1-2] standards, ILCD handbook [3], and more recently, by the European Product Environmental Footprint (PEF) [4]. Those methodologies are the most recognized method to evaluate environmental impacts all along a product life cycle.

The LCA methodology consists of four phases (Figure 1 ; [1]):

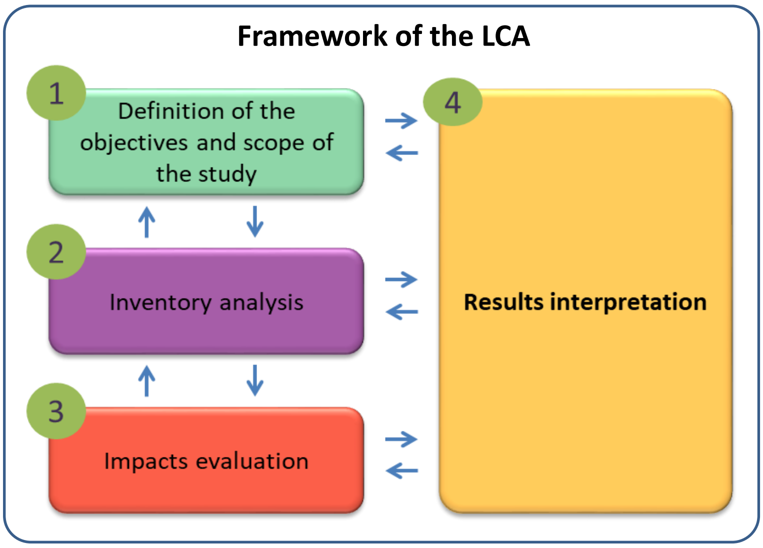


Figure 1. Framework of the life cycle assessment adapted from [1]

1. Objective and scope definition: aim of the LCA is defined and the central assumptions and system choices in the assessment are described.

2. The Life Cycle Inventory (LCI): collecting all inputs (resources…) and outputs (emissions…) of the system.
3. The Life Cycle Impact Assessment (LCIA) phase: these emissions and resource data are translated into indicators in order to evaluate the potential environmental impacts associated. This calculation is based on factors that represent the predicted contribution to an impact per unit emission or resource consumption. These factors are generally calculated using models.
4. The Interpretation phase: outcome is interpreted in accordance with the aim defined in the goal and scope of the study in order to evaluate the significance of the potential environmental impact of the system.

The present report has been prepared in accordance with the methodological stipulations of the standards cited above [1-4].

2 Work performed

2.1 Goal, definition and scope of the study

2.1.1 Goal

The two major objectives of this LCA are to:

- Evaluate the environmental impacts linked to the reuse of the iModBatt modules in several applications already described in deliverable 7.2, i.e. Renault Zoe, e.GO Life and a stationary application designed by TYVA.
- Compare those environmental impacts with the ones quantified in the reference scenario, i.e. one use of the iModBatt BP in Renault Zoe with no reuse of the iModBatt modules in several applications.

The global objective of this LCA is to underline the capability of this innovative modular battery pack to be easily reused in less demanding applications. First applications are automotive applications with a first use in a Renault Zoe car and, after its dismantling and customization if necessary, a second use phase in an e.GO Life 60 and finally a third use phase in a stationary application. Then, instead of having only one use phase of the BP [baseline scenario], the innovative scenario has three distinct use phases using the same modules from one application to another. The whole flow chart of both scenarios is exposed in Figure 2 below.

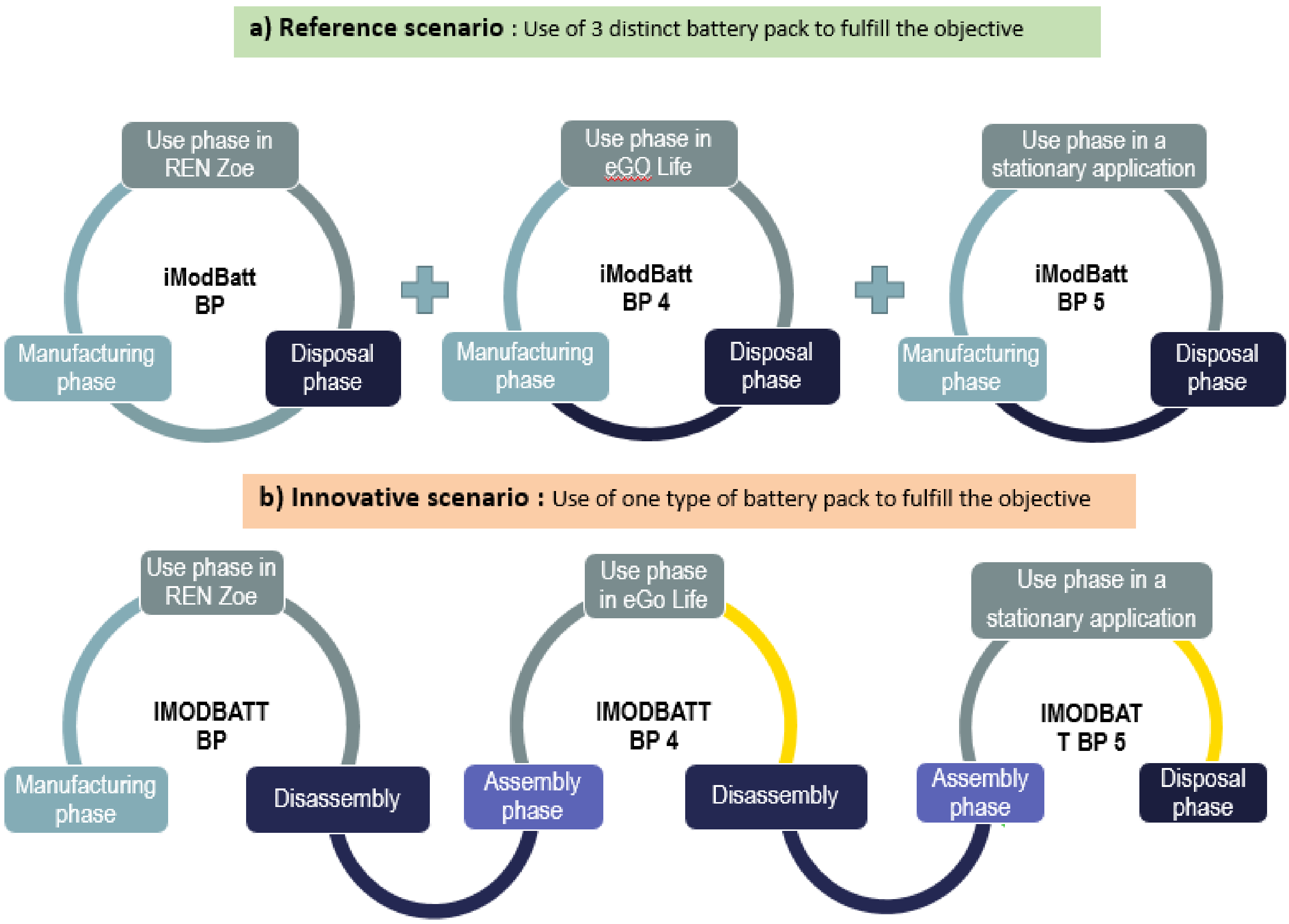
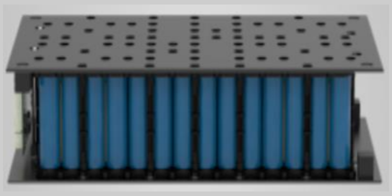
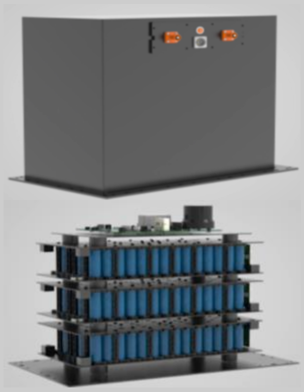


Figure 2. Flowchart of the life cycle of the BP in a) reference scenario and in b) innovative scenario

In order to fulfill the objectives, the following li-ion modules were assessed :

	iModBatt Module (cooling attached on top) *for iModBatt BP* (REN)	**iModBatt Module II** *for iModBatt BP 4 & BP 5 (EGO & TYVA)*
		
Nominal voltage Initial capacity	25,2 V 1,73 kWh	25,2 V 1,73 kWh
Number of cells Weight	98 9,2 kg	98 7,6 kg

The following li-ion battery packs were assessed :

	iModBatt BP *used in Renault Zoe Q90 ZE 40*	**iModbatt BP 4** *used in e.GO Life 60*	**iModBatt BP 5** *used in TYVA stationnary application*
			
Nominal voltage Initial capacity	327,6 V 45,0 kWh	327,6 V 21,5 kWh	75,6 V 5,2 kWh
Numbre of modules Weight Energetic density	26 320,5 kg* 140,2 Wh/kg	13 156,1 kg 137,7 Wh/kg	3 30,8 kg 168,2 Wh/kg

**Side bumpers of the vehicle included*

Please note that the baseline scenarios as detailed in the deliverable D7.2 are not taken into account as the reference scenario in the final LCA. In fact, it was decided to exclude those data from the scope of the comparative LCA due to a lack of information from the partner regarding the manufacturing of the cells, which represent the higher environmental impacts at the battery pack level. This decision was taken in order to lower the uncertainties linked to the final LCA and its main conclusions. The reference scenario used in this deliverable is detailed in Figure 2 and consist of a unique use of each BP in a unique use phase.

2.1.2 Functional unit

The functional unit provides a clear, full and definitive description of the product or service being investigated, enabling subsequent results to be interpreted correctly (all the inputs and outputs are related to this reference).

Here, the function of the high specific energy rechargeable batteries used in mobile applications is to supply electrical current at a desired voltage range. In order to take into account, the potential benefit linked with the increase of the lifetime of the battery pack initially manufactured, the functional units considered here are:

"Use of three Li-ion battery packs : first of 45 kWh in a Renault Zoe for 160 000 km, second of 21,5 kWh in an e.Go Life 60 for 80 000 cycles and third of 5,2 kWh in a stationary application designed by TYVA for 500 charging cycles"
"Use of two Li-ion battery packs : first of 45 kWh in a Renault Zoe for 160 000 km and second of 5,2 kWh in a stationary application designed by TYVA for 500 charging cycles"

The reference flow is the amount of product needed to fulfil the defined function; it is measured as kg of battery per kWh of the total energy required by the application over its service life. All quantitative input and output data are collected in the study in relation to this reference flow. The best-case scenario with no defective modules between two use phases was considered (Table 1). The influence of this factor will be studied with a sensitive analysis in section 3.2.3.

Table 1. Main parameters of the 2 main scenarios assessed

Scenario	Details
Reference 1	2 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP 5 (5,2 kWh)*
Innovative 1	1 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP (5,2 kWh)*
Reference 2	3 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP 4 (21,5 kWh) + 8,67 BP 5 (5,2 kWh)*
Innovative 2	1 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP (21,5 kWH) + 8,67 BP (5,2 kWh)*

2.1.3 System boundaries

The assessment considered the Li-ion battery pack all along its life cycle from its manufacturing step until its end of life and or its reuse. All the impacts associated to the electric vehicle were omitted of the calculation and considered as out of the scope of the objective of the study. The system boundaries for the modelling of each battery pack is detailed in Figure 3.

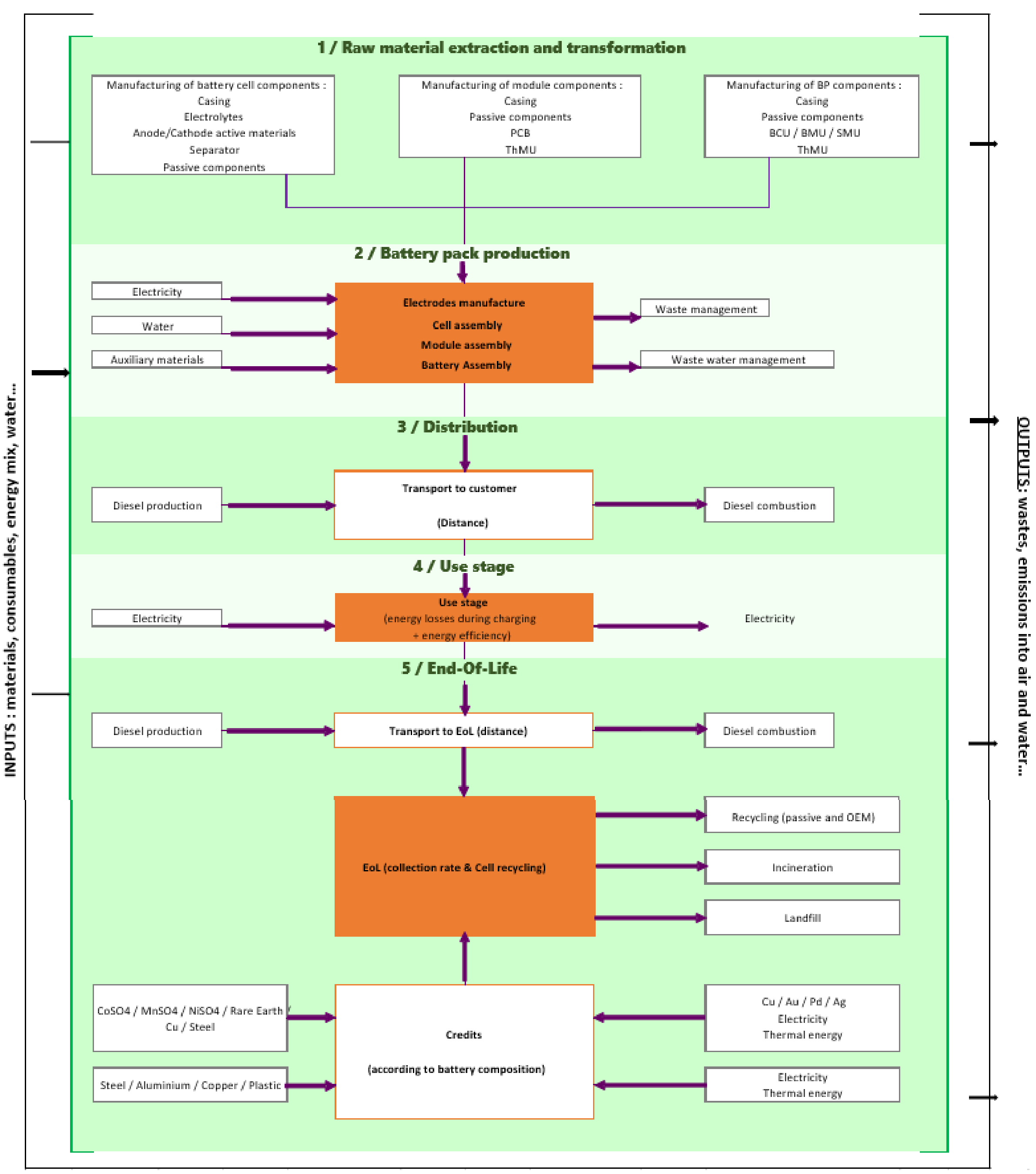


Figure 3. General boundary of the modelling of each BP.

As it can be seen in the figure below, for each battery pack, the global life cycle is divided into five main steps including following sub-steps:

1- Raw materials extraction and transformation: Includes mining and pre-processing, up to the manufacturing of cells and batteries components (active materials, separator, electrolyte, casings, active and passive battery components) and electric/electronic components.

2- Products production: cell, module and battery pack manufacturing. Please note that the manufacturing of the EV is out of the scope of the study.

3- Distribution of the BP: distribution of the BP incremented in the EV to consumer and collection prior to end of life.

4- Use stage: Electricity usage during use phase. Energy losses of the battery pack during its use in EV and during charging are taken into account.

5- End-Of-Life: Collection, dismantling until cell level and recycling. Please note that this step could be replace by a step of reuse after dissasembly until module level and reuse. That will be the case in the innovative scenario.

2.1.4 Excluded life cycle stages, cut-off and assumptions

No major step or component was totally omitted from the battery pack lifecycles. Nonetheless, due to the high number of battery components and the complexity of the linked processes, some components were neglected based on the cut-off rule of 0,5% w/w for all impact categories based on environmental significance.

According to the ISO 14 044 standard, some categories of operations may be excluded from the system with the condition that this is clearly stated. The categories not considered in the modelling are listed below:

- Consumption of packaging from raw materials or others inputs components due to lack of data.
- Machinery manufacturing and production buildings, because we considered that it is a stabilized operation of each system (impacts are amortised throughout their period of use).
- Detailed transport operation for raw materials, the product distribution or end of life since its impact has been shown to be negligible [4].
- Some secondary data not available from partners were estimated using literature data: manufacturing of cell, estimation of losses during the use phase, recycling of the cells using pyrometallurgical and hydrometallurgical treatments… All those data will be further detailed in the inventory analysis in the part below.

2.2 Methodological choices

2.2.1 Calculation methods

According to ILCD guidelines and the PEF methodology, the LCA considers midpoint environmental indicators presented in Table 2. Environmental impacts are assessed for the thirteen following indicators.

All those indicators are PEFCR aligned for the quantification of environmental impacts for E-mobility (e.g., e-bikes, ELV, PHEV, cars, bus/trucks) – excluding charging unit. Rescoll used the following LCA software “GaBi 9.2 Professional” from Thinkstep.

Table 2. List of relevant indicators for the evaluation of environmental impacts

Impact category	Abbreviation	Unit
Climate change	GWP	Kg $CO_{2\ \acute{e}q.}$
Characterizes the warming increasing of the troposphere due to anthropogenic greenhouse gases e.g. from the burning of fossil fuels. Recommended default LCIA method : Baseline model of 100 years of the IPCC (based on IPCC 2013)		
Ozone depletion	OP	Kg CFC-11 $_{\acute{e}q}$
Characterizes the reduction of ozone concentration in the stratosphere due to emissions such as CFCs. Recommended default LCIA method : Steady-state ODPs 1999 as in WMO assessment		
Human toxicity, cancer	Tox.Canc	CTUh
Characterizes the toxic potential of organic and inorganic substances with carcinogenic effects for humans. Recommended default LCIA method : USETox model (Rosenbaum et al, 2008)		
Human toxicity, non-cancer	Tox.Non.Canc	CTUh
Characterizes the toxic potential of organic and inorganic substances with non-carcinogenic effects for humans. Recommended default LCIA method : USETox model (Rosenbaum et al, 2008)		
Photochemical ozone formation, human health	POCP	Kg NMVOC $_{\acute{e}q}$
Characterizes the formation of ground-level ozone by the sun inducing the photochemical reaction of nitrogen oxides with hydrocarbons and volatile organic compounds. Recommended default LCIA method : LOTOS-EUROS model (Van Zelm et al, 2008).		
Acidification	AP	Mol H+ $_{\acute{e}q}$
Characterizes the increase in pH of precipitation (acid rain) due to the emission of acidifying gases such as SO_2 and NO_x. Recommended default LCIA method : Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)		
Eutrophication, terrestrial	EPT	Mol N $_{\acute{e}q}$
Characterize the excess of nutrients in water and soil from phosphorus and nitrogenous substances used in agriculture, combustion processes and effluents (green algae effect). Recommended default LCIA method : EUTREND model (Struijs et al, 2009b).		
Eutrophication, freshwater	EPW	kg P $_{eq}$
Characterize the excess of nutrients in water and soil from phosphorus and nitrogenous substances used in agriculture, combustion processes and effluents (green algae effect). Recommended default LCIA method : EUTREND model (Struijs et al, 2009b).		
Eutrophication, marine	EPM	kg N eq
Characterize the excess of nutrients in water and soil from phosphorus and nitrogenous substances used in agriculture, combustion processes and effluents (green algae effect). Recommended default LCIA method : EUTREND model (Struijs et al, 2009b).		
Ecotoxicity, freshwater	EcoTox	CTU_e
Characterizes the toxic potential of organic and inorganic substances on a fraction of aquatic species. Recommended default LCIA method : USEtox model, (Rosenbaum et al, 2008)		
Water use	W	m^3 world $_{\acute{e}q}$
Characterizes the risk of depletion of the water resource. Recommended default LCIA method : Available Water Remaining (AWARE) Boulay et al. 2016		
Resource use, minerals and metals	ADP-energy	Kg Sb $_{\acute{e}q}$
Characterizes the risk of depletion of a mineral, fossil, non-renewable resource. Recommended default LCIA method : CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.		
Resource use, fossils	ADP-fossil	MJ
Characterizes the risk of depletion of a mineral, fossil, non-renewable resource. Recommended default LCIA method : CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.		

In this deliverable, a special focus will be done regarding the following indicators : GWP, ODP, POCP, AP, EP and ADP as it was the case in previous deliverable D.7.2.

2.2.2 Life cycle inventory/modelling

(i) Generality

Primary data were preferentially collected from consortium members (REN, EGO, TYVA, ACC). When primary data were not available, secondary data have been used from databases as PE or Ecoinvent Database or from literature review. For confidentiality reason, all the quantitative flows from RESCOLL internal database are not detailed in this report.

(ii) Chemicals modelling

When a chemical was not available in the database, the following methodology was used:

- Life cycle inventory from the literature (manufacturers web sites, industrial reports, patents, scientific publications and other reliable sources…) to collect inputs (raw materials, energy, water, consumables, transports…) and outputs (wastes, emissions into air and water) at industrial scale.
- In the case no data relative to industrial processes has been found, the process is created by Rescoll using its internal methodology from the stoichiometric equation of the theoretical synthesis.
- If both of the previous points could not be applied, substitution data from current database can be used in order to reconcile missing inventory data if the manufacturing process is similar and the choice of substitution well justified.

(iii) Transports modelling

When transport phase are modeled such as for distribution or collection of the product, the modelled processes are selected according to the type of transport identified. When no data are available, road and rail supply is considered in a 1/6 ratio. Only the distances are adjusted according to the data available during the life cycle inventory.

(iv) Modelling methodology of end-of-life steps

The methodology used for recycling modeling follows ILCD handbook recommendations for a study corresponding to the situation A. Life cycle inventory modelling is attributional, which means that it describes the current recycling industrial situation, and not as intended it develops (which would correspond to a consequential modeling). The recycling of end of life components is considered as a multifunctionality case. Indeed the production of material which will be recycled at end of life will have two functions: function into the battery and function after recycling. Multifunctionality will be treated according to the recommendations of the ILCD handbook with the following priorities:

1. Subdivision (Figure 4),
2. Extension of the system (Figure 5),
3. Allocation (Figure 6).

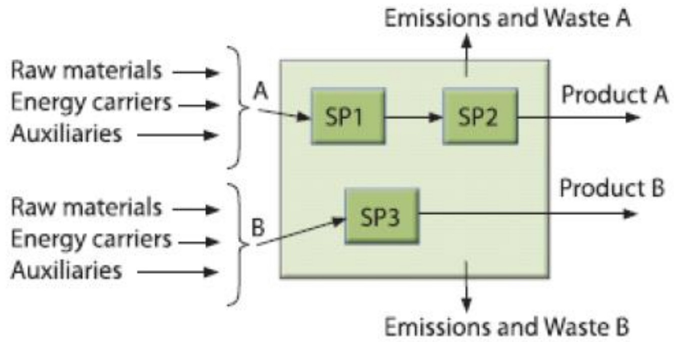


Figure 4. Subdivision (from [1])

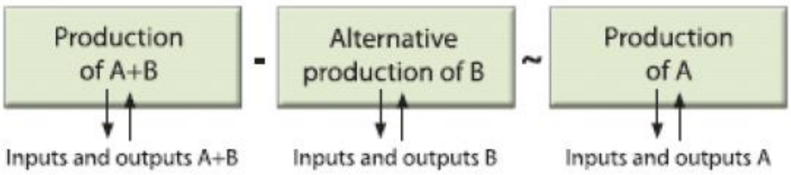


Figure 5. Extension of the system (from [1])

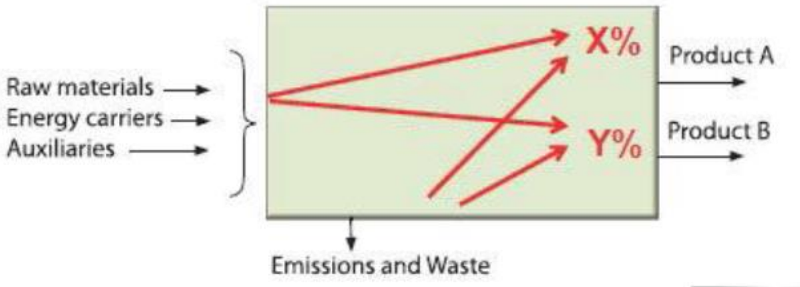


Figure 6. Allocation (from [1])

2.3 Inventory analysis

As a reminder the inventory data is the result of exchanges with consortium members (primary data). In the case where data were not available, due to confidentiality reasons for example, secondary data were collected from literature.

The inventory analysis will be presented in the sub-parts below following the category illustrated in Figure 7.

Figure 7. Sub-sets modelled for the LCA of reference scenario: one use in REN Zoe EV.

2.3.1 iModBatt battery pack manufacturing

Three types of battery pack were developped in iModBatt in order to comply with the 3 types of use phases targeted in this project :

1- iModbatt BP for Renault Zoe use (Figure 8)

2- iModbatt BP for eGO Life 60 use (Figure 9)

3- iModbatt BP for stationnary application for greedy home self consumption (Figure 10)

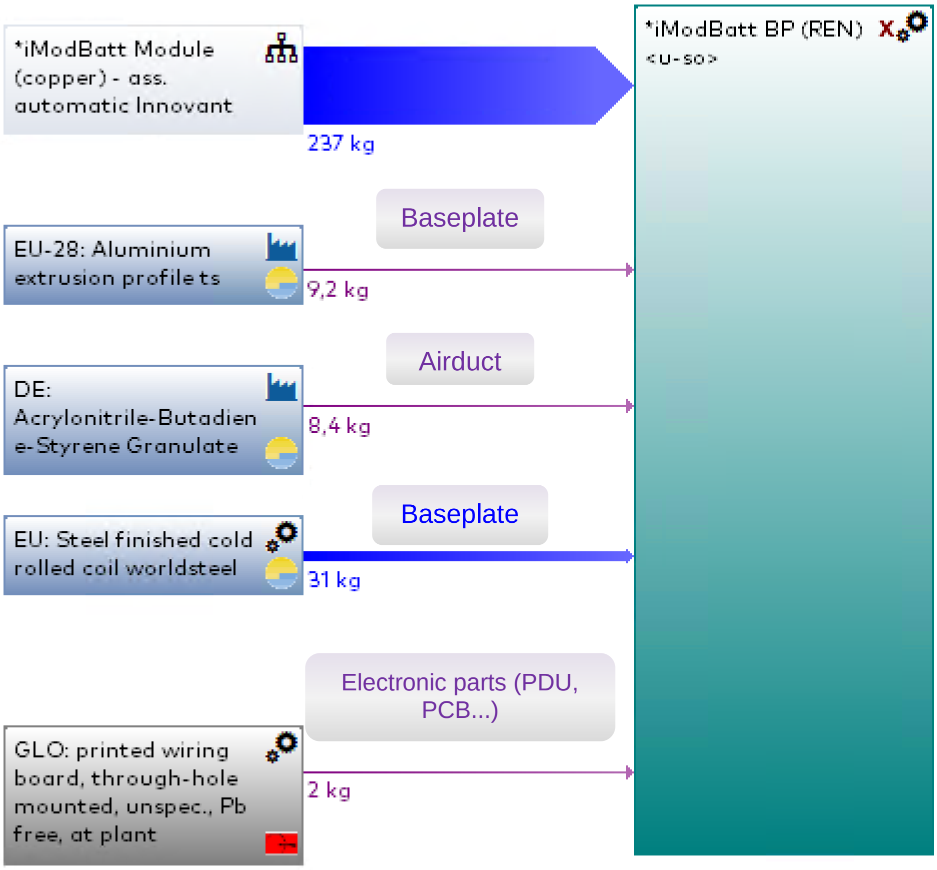


Figure 8. ICV of the manufacturing of the iModBatt BP used in Renault Zoe

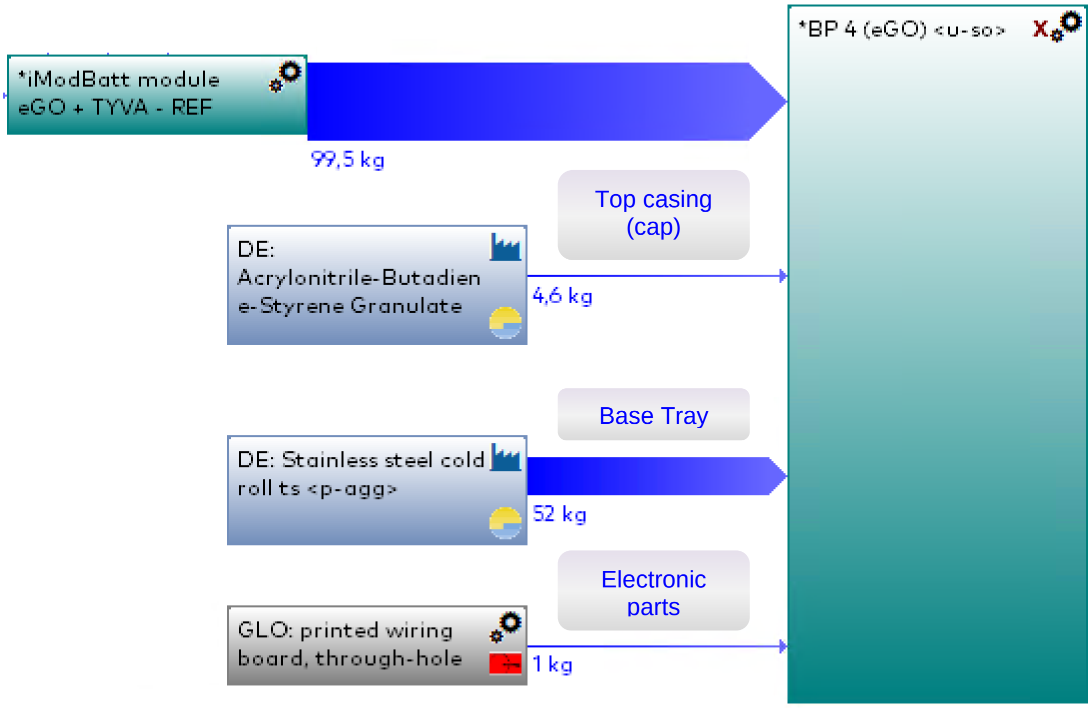


Figure 9. ICV of the manufacturing of the iModBatt BP used in EGO Life 60

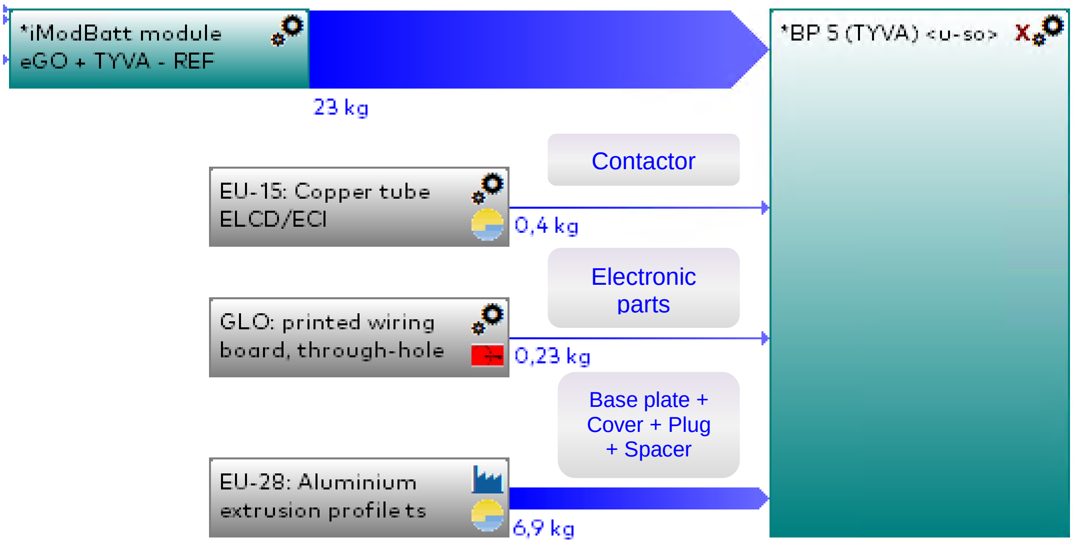


Figure 10. ICV of the manufacturing of the iModBatt BP used in a stationary application

The assembly of the three BPs is mostly manual and electric energy was considered negligible at the BP-scale. Only the electricity used for the assembly at the module-level was taken into account in the modelling (see Figure 11 and Figure 12).

2.3.1.1 Manufacturing of the modules

Two types of modules described in 2.1.1 have been modelled, first one is used in the BP used in Renault Zoe (Figure 8), the other is used in BP 4 (used in eGO Life 60) and in BP 5 (used in stationary application) (Figure 12). The ICVs are described in the figures below.

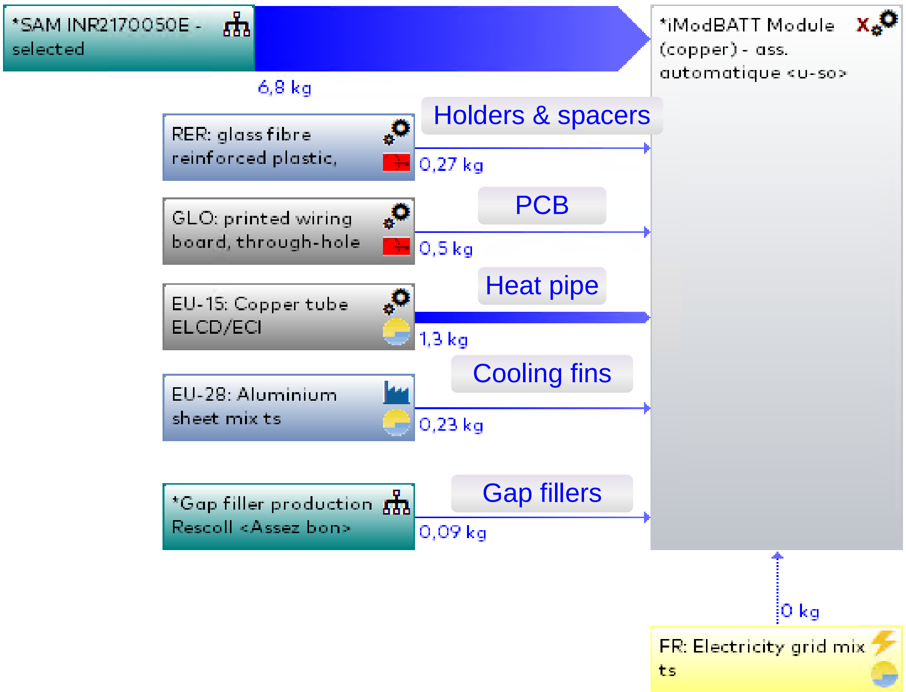


Figure 11. ICV of the manufacturing of the iModBatt module used in the BP used in Renault Zoe

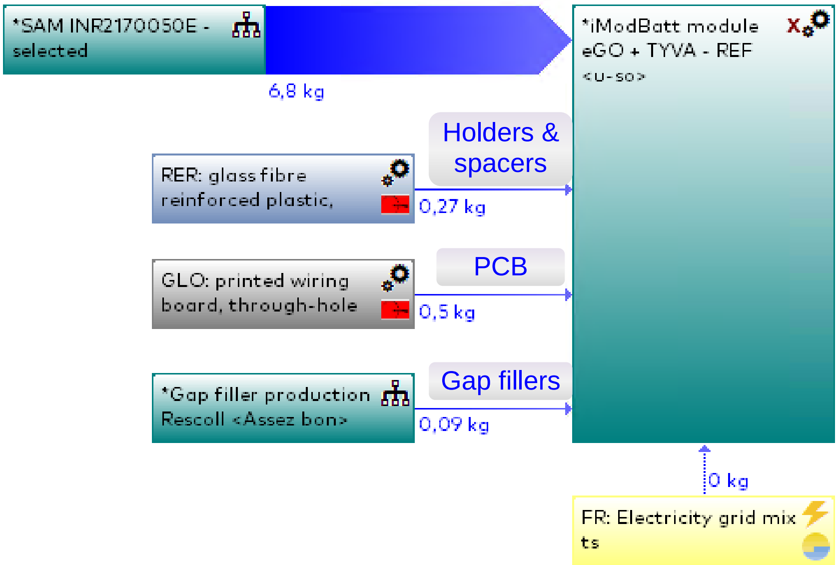


Figure 12. ICV of the manufacturing of the iModBatt module II used in the BP for eGO and TYVA applications.

2.3.1.2 Manufacturing of the cell: SAM INR 21700 50E

The modelling of the cell used in this project was done using the information gathered in deliverables D2.2 and exhaustive information communicated by the CEA in WP2 regarding the dismantling of the cell used in the iModBatt modules. The missing information was then estimated using the literature data and modelling of chemicals was performed using the RESCOLL internal methodology.

Flow chart of the ICV performed is presented in the flowchart below:

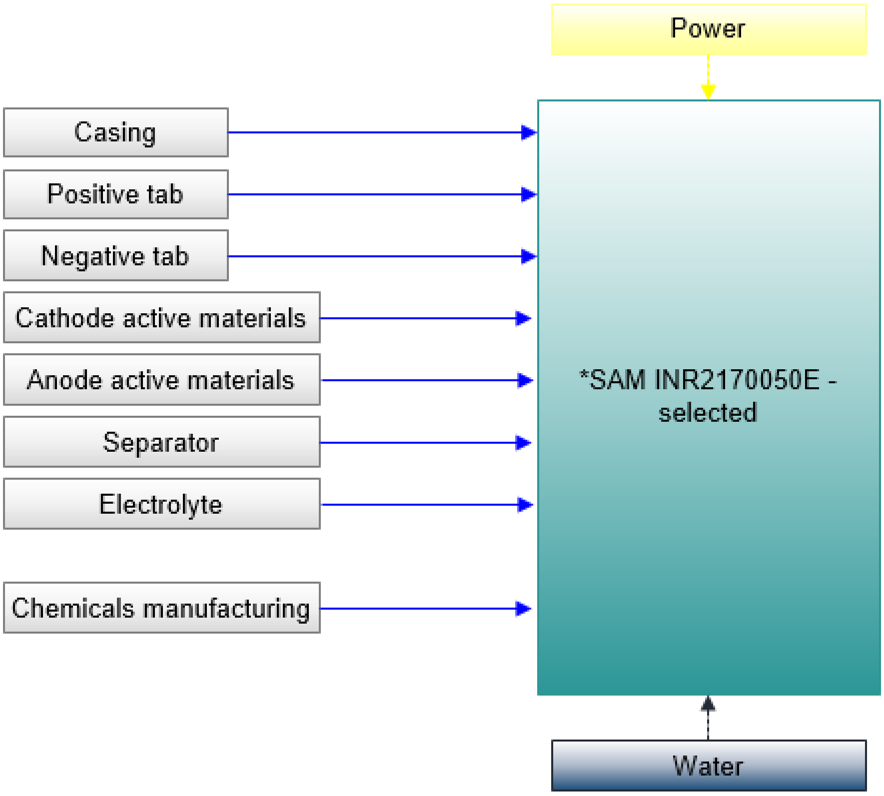
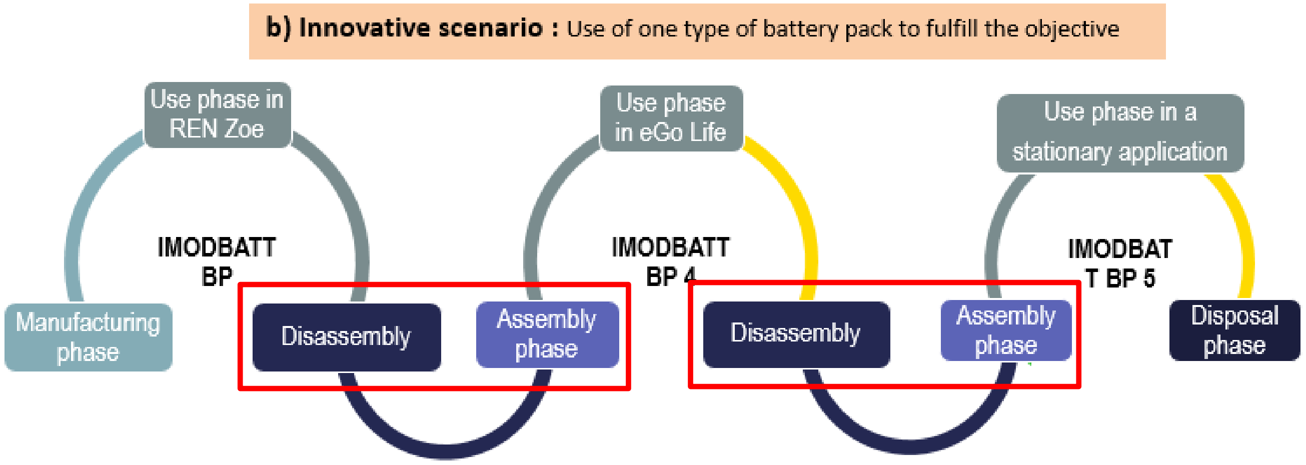


Figure 13. Information collected for the modelling of the cells used in iModBatt modules and BP.

2.3.2 iModBatt assembly and dismantling phases taken into account in the innovative scenario.

In the innovative scenarios, were the reuse of the first iModBatt BP is taken into account, two phases of dismantling and reassembly have to be taken into account between the 1^{st} and 2^{nd} use of the first BP and between the 2^{nd} and 3^{rd} BP.



62% w/w of the parts of the 1st iModBatt BP used in REN Zoe could be directly reuse in the 2nd iModBatt BP used in eGO Life 60 and in the 3rd iModBatt BP used in a stationnary application. Main parts that could be reused from an application to another are the modules and the electronic parts (PDU, BMS...).

2.3.3 iModBatt use phases

The energy consumption during the use stage of the battery is defined by the energy losses linked to the battery and charger efficiency during charge, discharge and storage. All those consumptions could not be directly measured during the project. Thus, it was decided to use the consumptions information linked to the reference battery pack already sold by Renault and eGO in order to have the most accurate consumption data linked to the use of a battery pack. Then, the data of the use phase are directly communicated by Renault and eGO and are compiled in the table below. Regarding the data used in the modelling for the stationary application for greedy home self-consumption, they are directly collected from a literature review performed by RESCOLL and a benchmark performed by TYVA. The conditions of use and consumptions used in the modelling are detailed in the table below.

BP	iModBatt BP	iModBatt BP 4	iModBatt BP 5
Initial capacity	41,1 kWh	21,5 kWh	5,2 kWh
Use condition	In REN Zoe in WLTP driving conditions	In e.GO Life 60 in WLTP driving conditions	In a stationnary application for greedy home self-consumption
Energy needed	15,8 kWh / 100km	15,5 kWh / 100 km	3,7 kWh / cycle
Lifetime	160 000 km (guarantee lifetime)	80 000 km (guarantee lifetime)	500 cycles
Total energy required for use phase (kWh)	**25 300**	**12 400**	**2 150**

The energetic process used in GaBi is the “electricity grid mix” in Europe (ENTSO) from the GaBi database. The data of this process is valid from 2016 to 2020. Details on the origin of the production of electricity in this dataset is shown in the figure below :

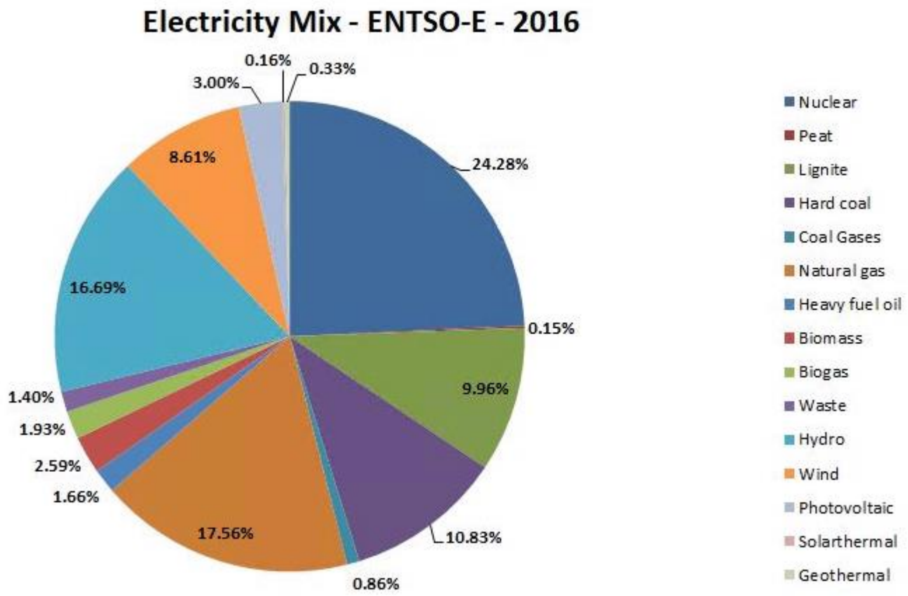


Figure 14. Details of the process used for the use phase "electricity grid mix" of Gabi database

2.3.4 iModBatt battery pack end-of-life

The end of life of a battery pack is composed of five distinct phases as described in the flowchart below.

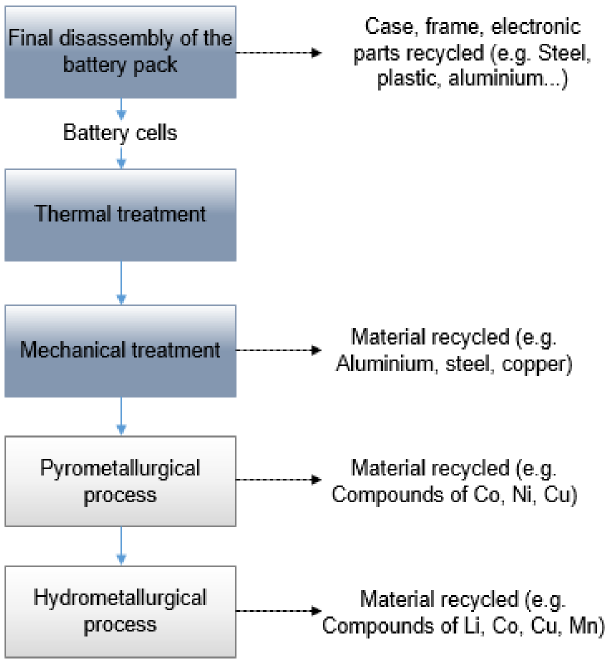


Figure 15. ICV of the end of life of the battery pack.

Data regarding the three first steps of the end of life (in blue in Figure 15) have been communicated directly by ACCUREC and are considered of good quality. Data regarding the two last steps, i.e. pyrometallurgical and hydrometallurgical process has been directly adapted from a report communicated by the Commission PEF Project regarding the PEFCR for high specific energy rechargeable batteries for mobile applications [5]. The recyclability of major materials used in the BP are given in the Table 3. This recyclability was used in the modelling of the end of life of each battery pack and was given by ACCUREC.

Table 3. Recyclability [%] of materials used in the BP of this project [data from ACCUREC]

Type of materials	% Recyclability	End of life process of the non-recyclable part [Database]
Aluminium	60	40% : Disposal, landfill [Ecoinvent]
Acrylonitrile-Butadiene-Styrene (ABS)	50	25% : Disposal, landfill [GaBi] 25% : Incineration [GaBi]
Steel	80	20% : Disposal, landfill [Ecoinvent]
Stainless-steel	80	20% : Disposal, landfill [Ecoinvent]
Copper	80	20% : Disposal, landfill [GaBi]
Electronic parts (PCB)	50	25% : Disposal, landfill [GaBi] 25% : Incineration [GaBi]

3 Results and discussion

3.1 Results at the BP-level

3.1.1 Environmental footprint of the reference scenario: one use of the iModBatt BP in Renault Zoe Q90 ZE 40.

Results regarding the use of one iModBatt BP in a Renault Zoe for 160 000 km is detailed in the figure below:

Table 4. Value of the impacts for each studied indicators for iModBatt BP in Renault.

Indicators	Total	Manufacturing	EoL	Use in Europe
AP [Mole of H+ eq.]	134	98,6	-0,114	35,3
Tox. Canc. [CTUh]	1,13E-05	9,23E-06	-5,87E-08	2,18E-06
GWP [kg CO2 eq.]	33597,1	23694,2	-6,856	9941
EcoTox [CTUe]	8,01E+06	2,56E+06	5,38E+06	7,51E+04
EP freshwater [kg P eq.]	2,45	2,42	0,00138	0,0254
EP Marine [kg N eq.]	60,8	55,9	-0,0144	4,94
EP terrestrial [Mole of N eq.]	204	152	-0,174	52,1
Tox. Non. Canc. [CTUh]	4,23E-04	3,47E-04	-7,63E-07	7,73E-05
ODP [kg CFC-11 eq.]	2,83E-04	2,84E-04	-4,25E-07	2,09E-10
POCP [kg NMVOC eq.]	58	43,7	-0,0632	14,4
ADP - energy [MJ]	5,89E+05	4,16E+05	1,81E+03	1,71E+05
ADP - resources [kg Sb eq.]	0,281	0,413	-0,135	0,00281
Water [m3 world equiv.]	4,53E+05	4,51E+05	-7,98E+01	2,09E+03

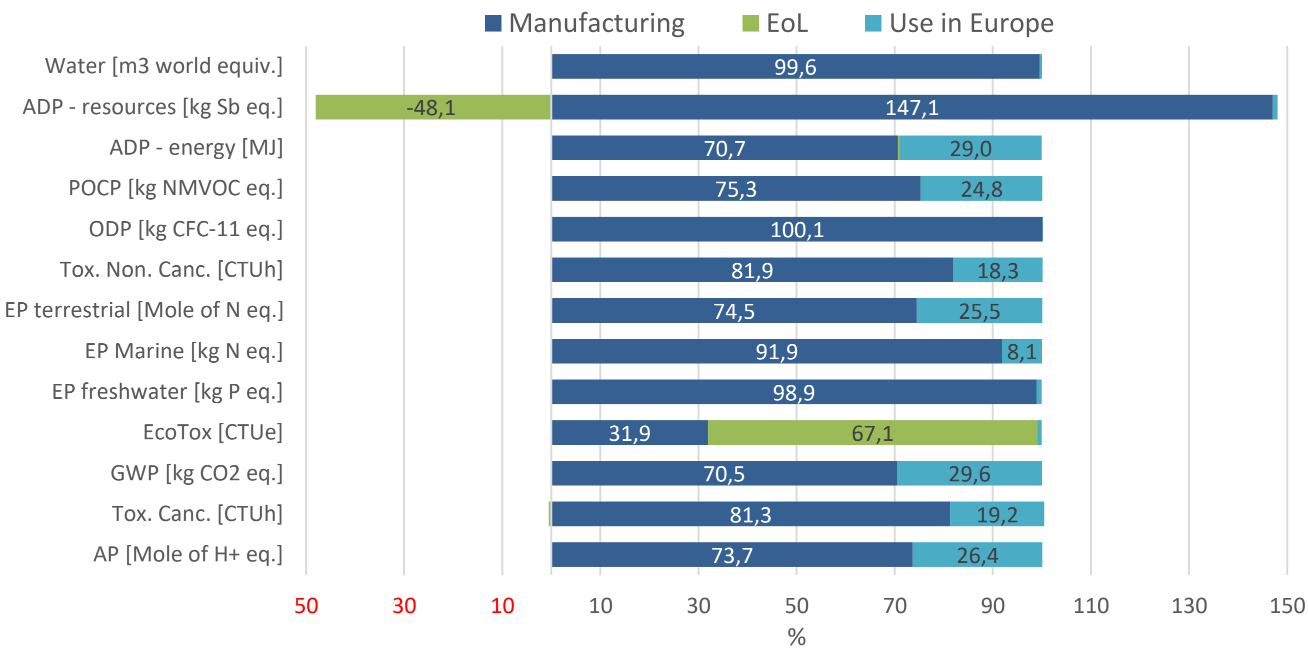


Figure 16. Impacts of the life cycle of the iModBatt BP used in Renault Zoe for 160 000 km.

It is interesting to underline that most of the indicators studied here (12/13) are directly impacted by the manufacturing phase with impacts bigger than 70 %. Only the Ecotox indicator is mostly impacted by the end-of-life of the BP. It is also interesting to note that the end of life of the BP has a positive impact on the resource depletion indicator due to the recycling of the major parts of the BP.

Details of the manufacturing phase and end-of-life phase of the lifecycle of the product according to indicator of interest are given in Figure 17.

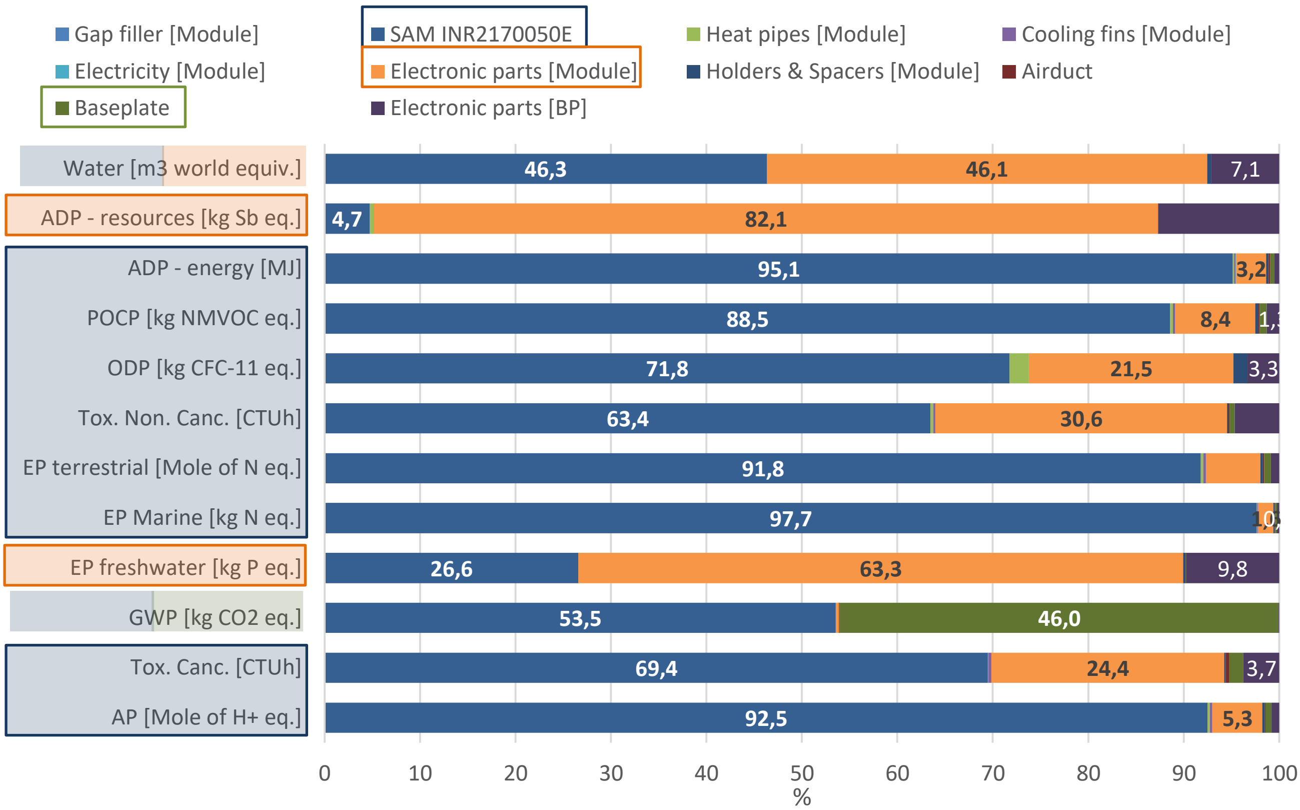


Figure 17. Impacts linked to the manufacturing phase of the iModBatt BP

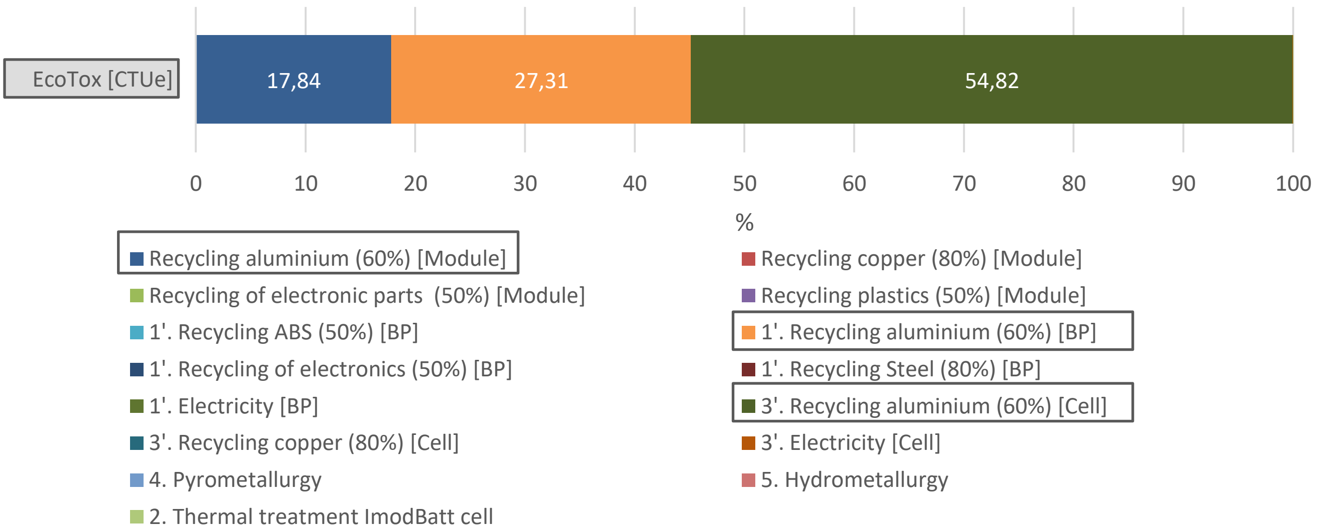


Figure 18. Impacts linked to the end-of-life phase of the iModBatt BP for Renault: focus on ecotoxicity

As a conclusion, majority of the impacts are due to the manufacturing phase (12/13 indicators) and are linked to:

- The manufacturing of the cell (9 / 13 indicators)
- The manufacturing of the electronic parts of the iModBatt module (2,5 / 13 indicators)
- The manufacturing of the baseplate (made of aluminium and steel) (0,5 / 13 indicators)

The ecotoxicity indicator is mainly impacted by the end-of-life phase of the BP and more precisely by the end-of-life of aluminium in a landfill (40% and 60% is recycled).

It is also interested to note that the use phase represents around 20-30% of the impacts of 7 indicators. It could be interesting to perform a sensitive analysis on the impact of the geographical zone where the car is used. This will be studied in part 3.1.4. It is also interested to note that the energy used for the assembly of the module is negligible for all the indicator as the main components of the BP as majority of the BP are linked to the type of cell used and the weight of the electronic parts at the module-level.

3.1.2 Environmental footprint of the reference scenario: one use of the iModBatt BP in eGO Life 60.

Results regarding the use of one iModBatt BP in a eGO Life 60 for 80 000 km is detailed in the figure below:

Table 5. Value of the impacts for each studied indicators for iModBatt BP in eGo.

Indicators	Total	Manufacturing	EoL	Use in Europe
AP [Mole of H+ eq.]	67,1	49,9	-0,1	17,3
Tox. Canc. [CTUh]	8,3E-05	8,2E-05	-8,0E-09	1,1E-06
GWP [kg CO2 eq.]	145,6	98,0	3,2	44,7
EcoTox [CTUe]	2,8E+06	1,3E+06	1,5E+06	3,7E+04
EP freshwater [kg P eq.]	1,2	1,2	0,0	0,0
EP Marine [kg N eq.]	30,4	28,0	0,0	2,4
EP terrestrial [Mole of N eq.]	102,0	76,6	-0,2	25,5
Tox. Non. Canc. [CTUh]	2,1E-04	1,7E-04	-9,4E-07	3,8E-05
ODP [kg CFC-11 eq.]	1,4E-04	1,4E-04	-6,3E-07	1,0E-10
POCP [kg NMVOC eq.]	28,9	21,9	-0,1	7,0
ADP - energy [MJ]	2,9E+05	2,1E+05	2,4E+01	8,4E+04
ADP - resources [kg Sb eq.]	1,2E-01	2,1E-01	-9,6E-02	1,4E-03
Water [m3 world equiv.]	2,3E+05	2,3E+05	-2,1E+02	1,0E+03

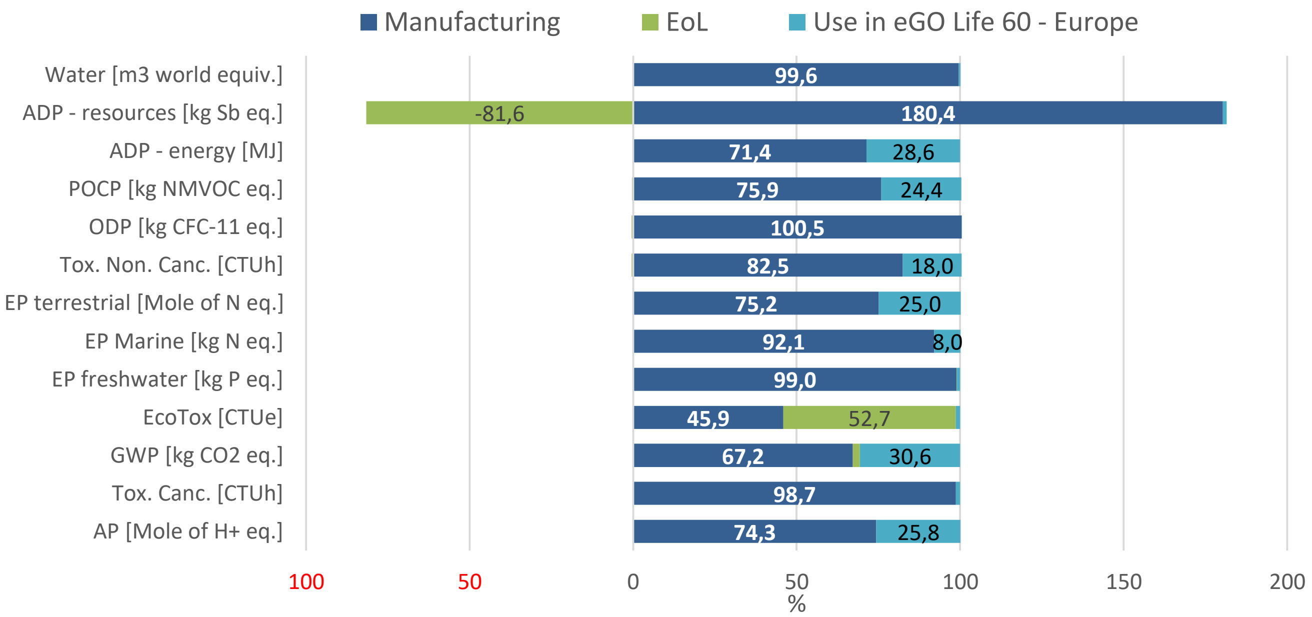


Figure 19. Impacts of the life cycle of the iModBatt BP used in eGo Life 60 for 80 000 km.

As for the iModBatt BP used in Renault Zoe, the manufacturing phase of the BP is the most impactful with 12 indicators over 13. The ecotoxicity indicator is also mainly impacted by the end of life of the BP. Details of those two phases of the lifecycle of the product filtered on the indicator of interest are given in Figure 20 and Figure 21.

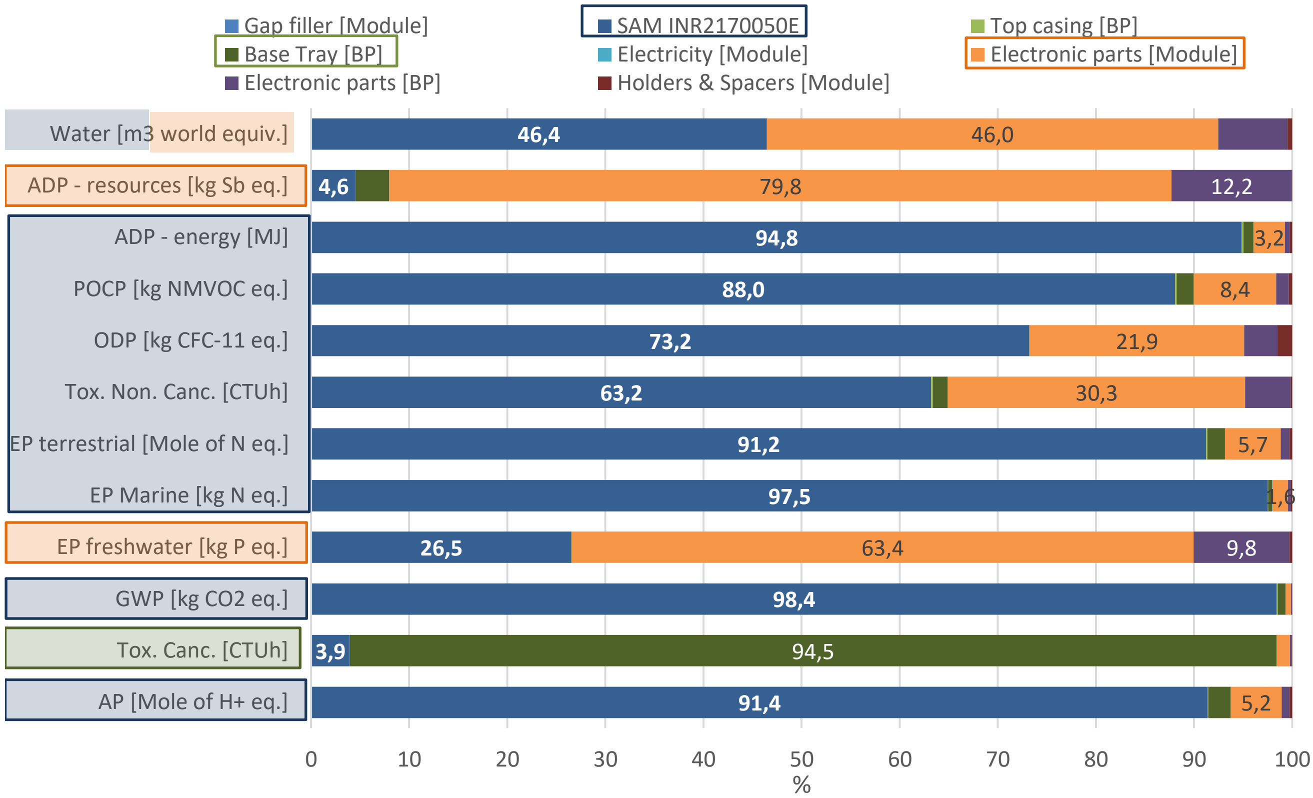


Figure 20. Impacts linked to the manufacturing phase of the iModBatt BP for eGo use.

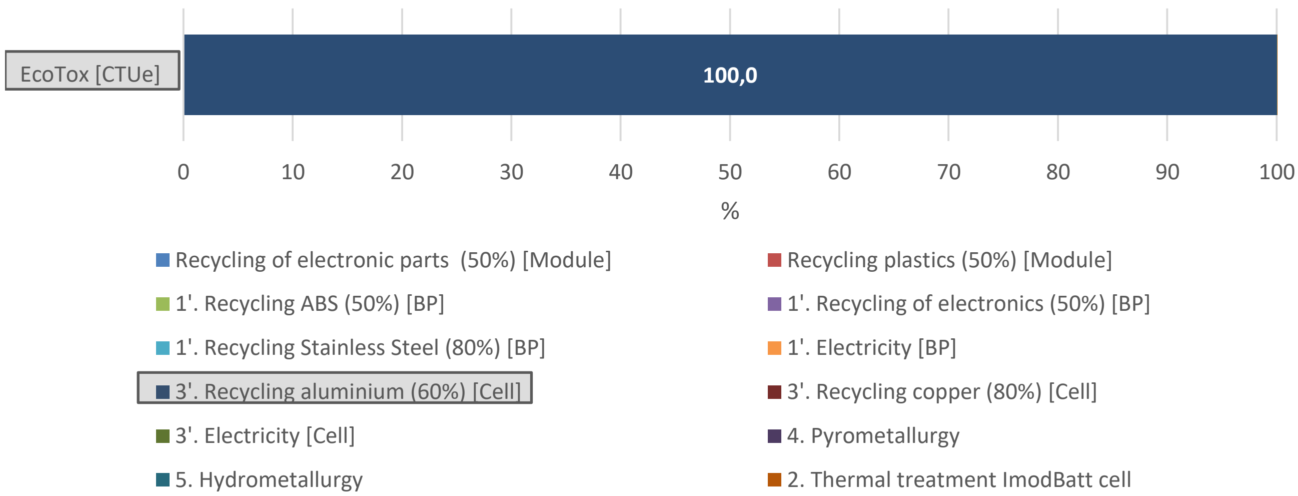


Figure 21. Impacts linked to the end-of-life phase of the iModBatt BP for eGo: focus on ecotoxicity

As a conclusion, majority of the impacts are due to the manufacturing phase (12/13 indicators) and are linked to:

- The manufacturing of the cell (8,5 / 13 indicators)
- The manufacturing of the electronic parts of the iModBatt module (2,5 / 13 indicators)
- The manufacturing of the baseplate (made of stainless steel) (1 / 13 indicators)

It is interesting to note that during this phase, the impacted indicator are not the same as the iModBatt BP use for Renault due to the change of materials of the baseplate: in eGo, the base tray, made of stainless steel, impacts directly the indicator Tox. Canc. Whereas in Renault, the baseplate, made of aluminium, impacts directly the GWP indicator.

The ecotoxicity indicator is mainly impacted by the end-of-life phase of the BP and more precisely by the end-of-life of aluminium originating from the cells as co-products of the mechanical treatment of the cells. This waste of aluminium is treated in a landfill (40%) and 60% is recycled. This is the same origin as the BP used for Renault.

It is also interested to note that, as for the BP used in Renault Zoe, the use phase represents around 20-30% of the impacts of 6 indicators. It could be interesting to perform a sensitive analysis on the impact of the geographical zone where the car is used. This will be studied in part 3.1.4. It is also interested to note that the energy used for the assembly of the module is negligible for all the indicator as the main components of the BP as majority of the impacts of the BP are linked to the type of cell used and the weight of the electronic parts at the module-level.

3.1.3 Environmental footprint of the reference scenario: one use of the iModBatt BP in a stationary application.

Results regarding the use of one iModBatt BP in a stationary application for 500 cycles is detailed in the figure below:

Table 6. Value of the impacts for each studied indicators for iModBatt BP in a stationary application

Indicators	Total	Manufacturing	EoL	Use in Europe
AP [Mole of H+ eq.]	14,4	11,5	-0,1	3,0
Tox. Canc. [CTUh]	1,2E-06	1,1E-06	-2,2E-08	1,9E-07
GWP [kg CO2 eq.]	31,1	22,5	0,8	7,7
EcoTox [CTUe]	1,7E+06	3,0E+05	1,4E+06	6,4E+03
EP freshwater [kg P eq.]	2,8E-01	2,8E-01	9,4E-05	2,2E-03
EP Marine [kg N eq.]	6,9E+00	6,5E+00	-1,5E-02	4,2E-01
EP terrestrial [Mole of N eq.]	22,0	17,8	-0,2	4,4
Tox. Non. Canc. [CTUh]	4,7E-05	4,0E-05	-3,6E-07	6,6E-06
ODP [kg CFC-11 eq.]	3,2E-05	3,2E-05	-1,3E-07	1,8E-11
POCP [kg NMVOC eq.]	6,3	5,1	-4,8E-02	1,2
ADP - energy [MJ]	6,3E+04	4,8E+04	-1,6E+02	1,5E+04
ADP - resources [kg Sb eq.]	2,5E-02	4,7E-02	-2,3E-02	2,4E-04
Water [m3 world equiv.]	5,2E+04	5,2E+04	-3,7E+01	1,8E+02

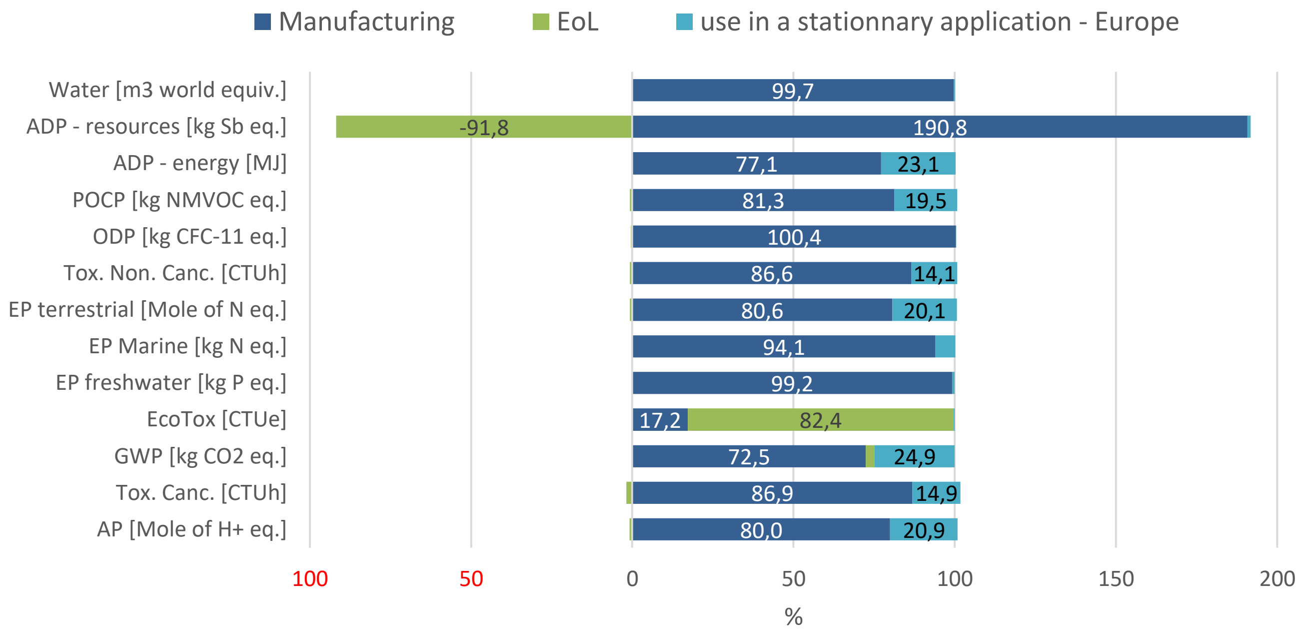


Figure 22. Impacts of the life cycle of the iModBatt BP used in a stationary application for 500 cycles.

As for the iModBatt BP used in Renault Zoe, the manufacturing phase of the BP is the more impactful with 12 indicators over 13. The ecotoxicity indicator is also mainly impacted by the end of life of the BP. Details of the manufacturing phase filtered on the indicator of interest is given in Figure 23.

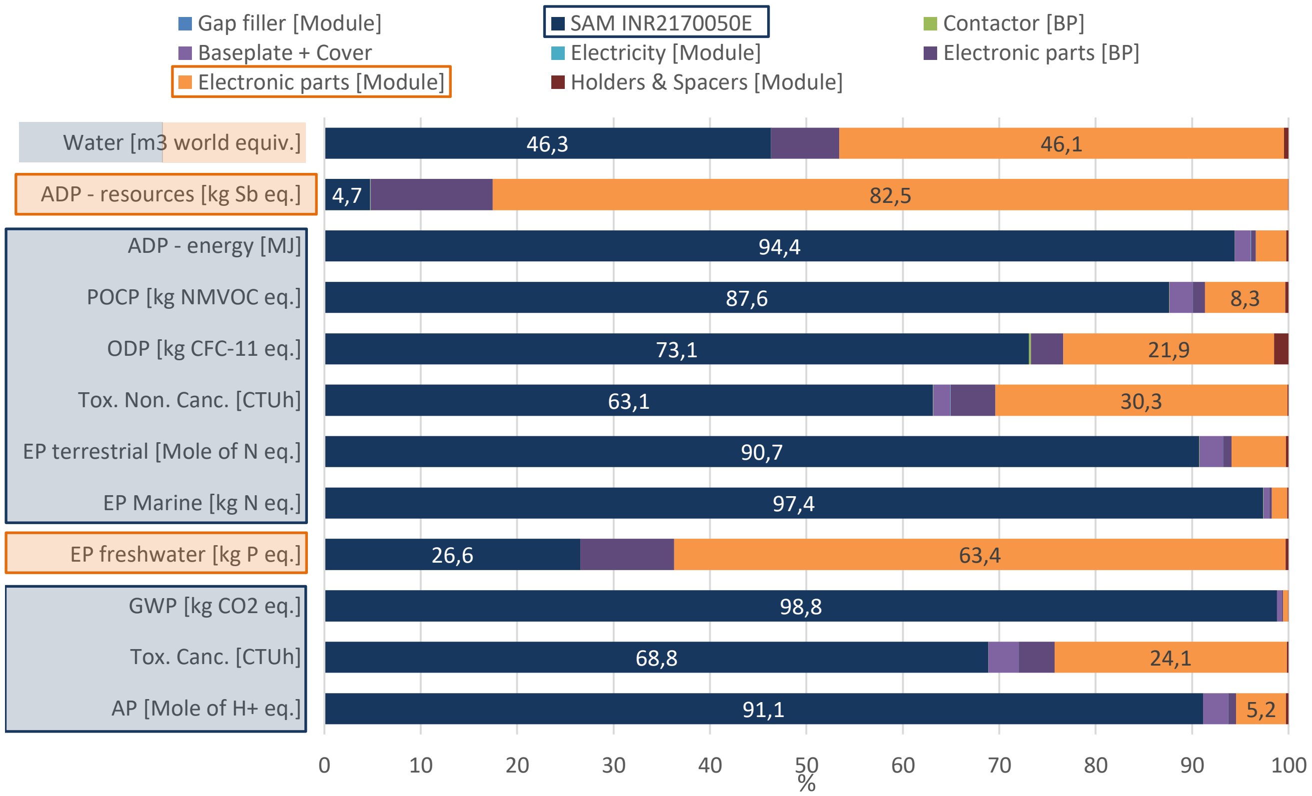


Figure 23. Impacts linked to the manufacturing phase of the iModBatt BP for use in a stationary application.

As a conclusion, most impacts are due to the manufacturing phase (12/13 indicators) and are linked to:

- The manufacturing of the cell (9,5 / 13 indicators)
- The manufacturing of the electronic parts of the iModBatt module (2,5 / 13 indicators)

It is interesting to note that the material of the baseplate is not one of the sources of the impact on the indicator, mainly due to a very low weight compared to the weight used in the BP used for automotive application.

The ecotoxicity indicator is mainly impacted by the end-of-life phase of the BP and more precisely by the end-of-life of aluminium originating from the cells as co-products of the mechanical treatment of the cells and from the baseplate. This waste of aluminium is treated in a landfill (40%) and 60% is recycled. This is the same origin as the BP used for Renault and eGO.

It is also interesting to note that, as for the BP used in Renault Zoe and in eGO Life 60, the use phase represents around 20-30% of the impacts of 7 indicators. It could be useful to perform a sensitive analysis on the impact of the geographical zone where the device is used. This will be studied in part 3.1.4. It is also interested to note that the energy used for the assembly of the module is negligible for all the indicator as the main components of the BP since majority of the impacts of the BP are linked to the type of cell used and the weight of the electronic parts at the module-level.

3.1.4 Sensitive analysis

The sensitive analysis that seemed relevant at the beginning of the project was described as follows:

1. At the module scale, the impact of the automatic assembly compared to the manual assembly.
2. At the battery pack scale, the impact of different choices of materials for the top casing or baseplate for example.
3. At the battery pack scale, the study of the influence of the use phase area on the environmental impacts.

The two first sensitive analysis seems finally less relevant due to the low environmental impacts linked to the energetic processes during the manufacturing phase and the type of materials used at the battery pack level for each identified needs: Renault (Figure 17), eGO (Figure 20) and stationary application (Figure 23).

Finally, only the third sensitive analysis seems relevant and will be studied in this part of the report. Three area of use of the BP will be studied and are described in the table below. The studied area were chosen depending on the type of electricity production sources diversity and countries available in the software at the time of the modelling. Details on the electricity production sources are given in the figure below.

Table 7. Sensitive analysis performed at the BP-level: Use area influence

Scenario	Details
Reference	Use of the three BP in Europe: Nuclear (24,28%), Natural gas (17,56%), coal gases (16,69%)…
Zone 1	Use of the three BP in India: Hard coal (64,01%)…
Zone 2	Use of the three BP in USA : Natural gas (32,85%); Hard coal (29,38%); Nuclear (19,46%)…

The three selected areas have the particularity of having very diverse sources of production of electricity.

The global comparison of the environmental impacts linked to the use of each BP in the 3 areas of use selected are given in the figures of 3.1.4.1 per BP.

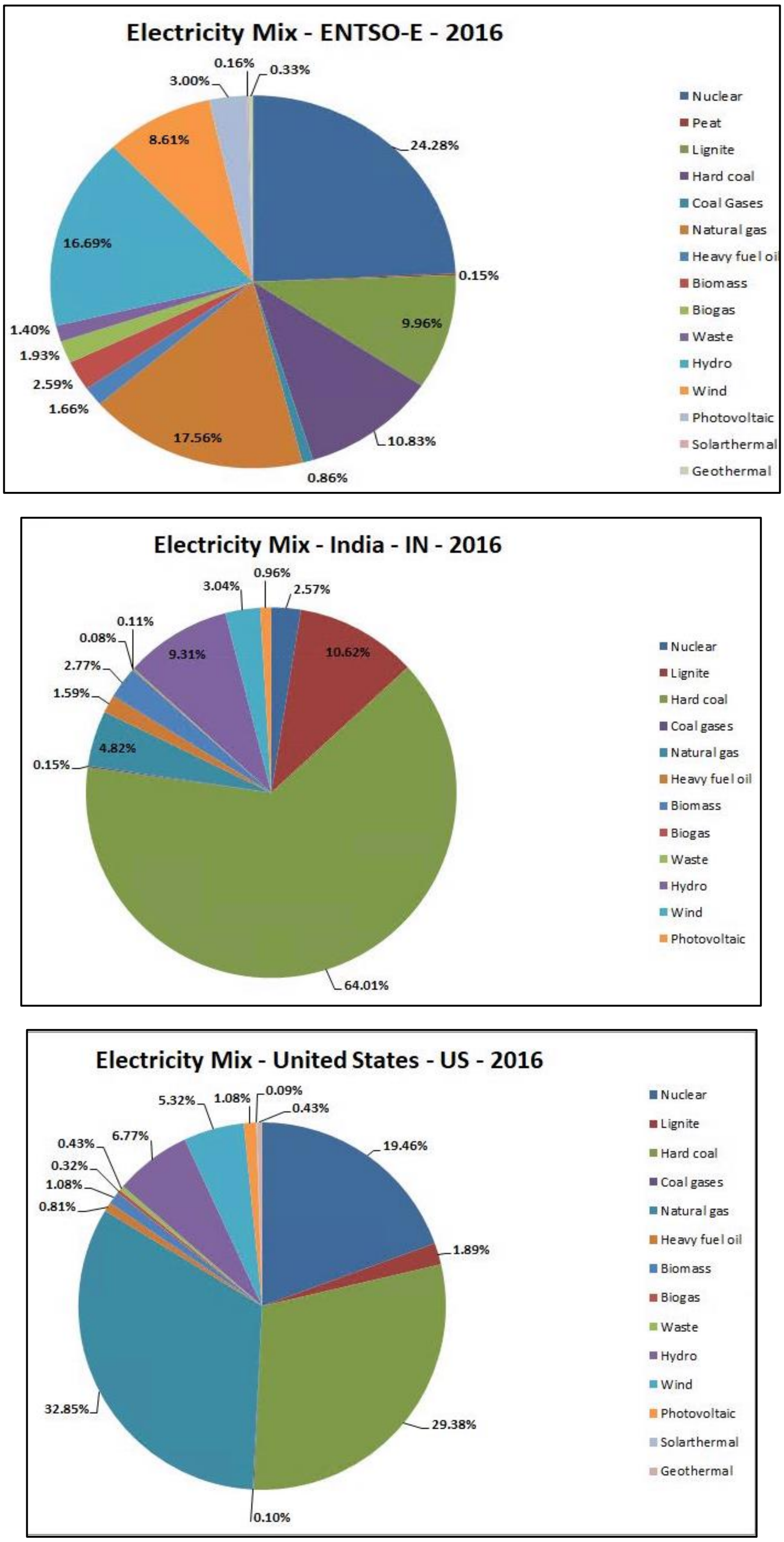


Figure 24. Description of the processes used for the production of electricity [GaBi database]

3.1.4.1 Impact of the use area of the BP in a Zoe, Renault.

The global comparison of the environmental impacts linked to the use of one iModBatt BP in a Renault Zoe for 160 000 km in Europe, India and the United States of America are given in Figure 25.

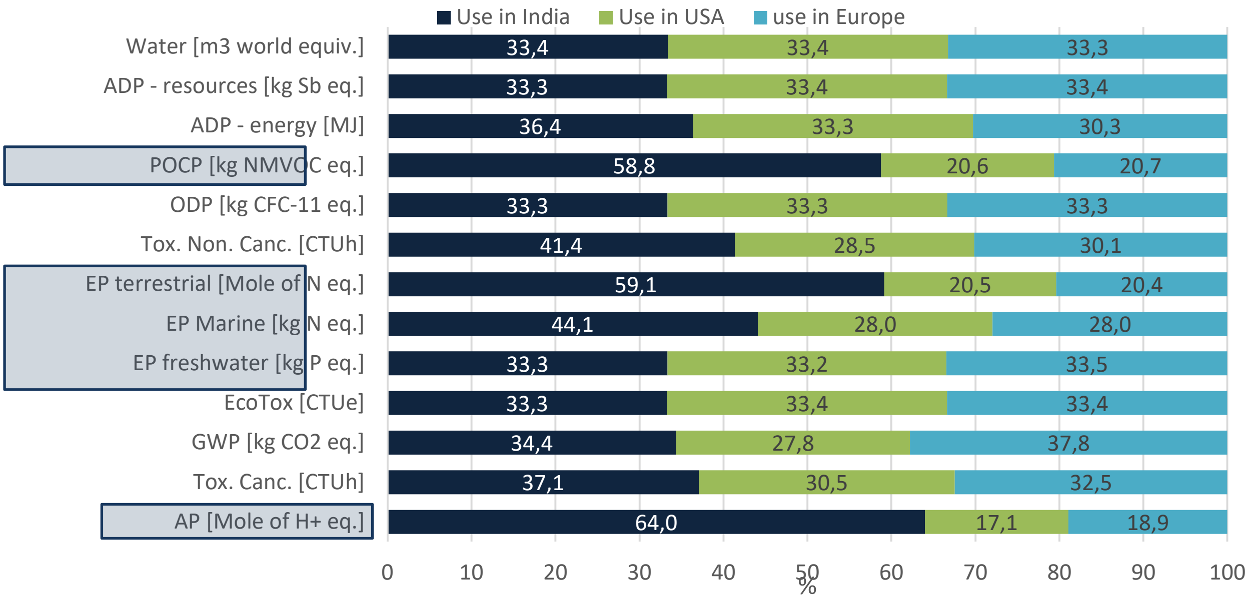


Figure 25. Impacts of the life cycle of the iModBatt BP used in Renault Zoe for 160 000 km in Europe, India and the USA

It is interesting to see that depending on the use area and then the type of electricity production technology, the environmental impacts are not the same for 4 indicators such as POCP, AP, Tox. Non. Canc. And EP (terrestrial and marine) with higher impacts regarding the use of the BP in India. On the other hand, impacts linked to the use of the BP in Europe or in the USA are in the same order of magnitude. It could be interesting to see if this increase of impacts is also noticeable at the life cycle level of the BP. The detailed impacts per life cycle phase are given in the figures below for the use of the BP in India.

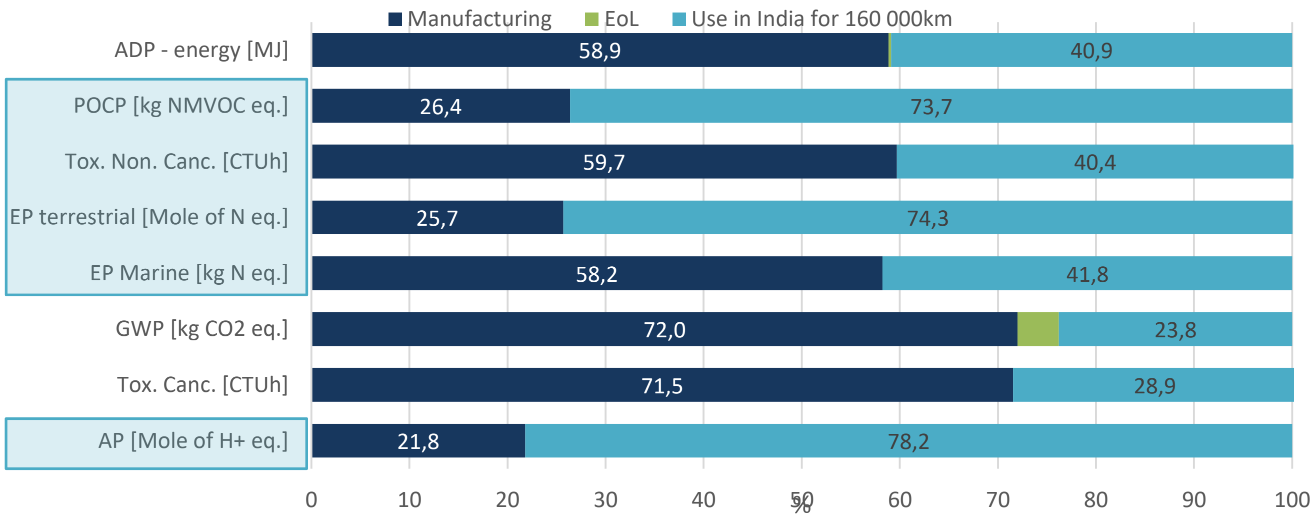


Figure 26. Impacts of the life cycle of the iModBatt BP used in Renault Zoe for 160 000 km in India (detailed)

The repartition of the impacts is compared to the one obtained for the use of the BP in Europe for 160 000 km (Figure 16). It is obvious that, for the indicators that were already impacted by the use phase of the reference scenario, the impacts are increased by 2 to 5 when the same BP is used for 160 000 km (Table 8).

Table 8. Evolution of the impacts related to the indicators linked to the use phase of the BP

Indicators	Proportion of the impacts linked to the use phase (%)		Increase of the proportion of the impacts allocated to the use phase
	Reference scenario	Use of the BP in India	
AP [Mole of H+ eq.]	**26,4 %**	78,2 %	X 3
Tox. Canc. [CTUh]	**19,2 %**	28,9 %	X 1,5
GWP [kg CO2 eq.]	**29,6 %**	23,8 %	X 0,8
EP Marine [kg N eq.]	**8,1 %**	41,8 %	X 5,2
EP terrestrial [Mole of N eq.]	**25,5 %**	74,3 %	X 2,9
Tox. Non. Canc. [CTUh]	**18,3 %**	40,4 %	X 2,2
POCP [kg NMVOC eq.]	**24,8 %**	73,7 %	X 3,0
ADP - energy [MJ]	**29,0 %**	40,9 %	X 1,4

It is interesting to note that the indicators ADP – energy, GWP and Tox. Canc. are in the same order of magnitude than the reference scenario.

3.1.4.2 Impact of the use area of the BP in a Life 60, eGO.

For eGo, the conclusions regarding the impacts linked to the use area of the BP are the same as the ones underlined for Renault in Figure 25, with a non-negligible difference for 4 indicators such as POCP, AP, Tox. Non. Canc. and EP (terrestrial and marine) with higher impacts regarding the use of the BP in India. On the other hand, impacts linked to the use of the BP in Europe or in the USA are in the same order of magnitude. Details of the impacts per life cycle phase is given in the figure below for the use of the BP in India.

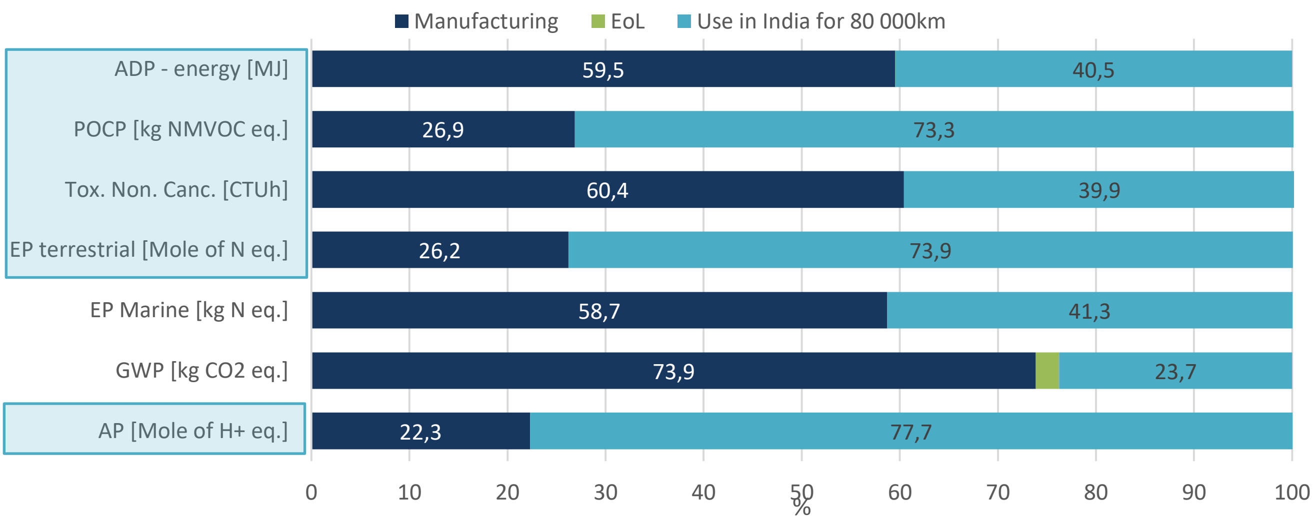


Figure 27. Impacts of the life cycle of the iModBatt BP used in eGo Life 60 for 80 000 km in India (detailed)

The repartition of the impacts is compared to the one obtained for the use of the BP in Europe for 80 000 km (Figure 19). It is obvious that, for the indicators that were already impacted by the use phase of the reference scenario, the impacts are increased by 2 to 5 when the same BP is used for 80 000 km (Table 9).

Table 9. Evolution of the impacts related to the indicators linked to the use phase of the BP

Indicators	Proportion of the impacts linked to the use phase (%)		Increase of the proportion of the impacts allocated to the use phase
	Reference scenario	Use of the BP in India	
AP [Mole of H+ eq.]	**25,8 %**	77,7 %	X 3
GWP [kg CO2 eq.]	**30,6 %**	23,7 %	X 0,8
EP Marine [kg N eq.]	**8,0 %**	41,3 %	X 5,2
EP terrestrial [Mole of N eq.]	**25,0 %**	73,9 %	X 3,0
Tox. Non. Canc. [CTUh]	**18,0 %**	39,9 %	X 2,2
POCP [kg NMVOC eq.]	**24,4 %**	73,3 %	X 3,0
ADP - energy [MJ]	**28,6 %**	40,5 %	X 1,4

It is interesting to note that, as for the BP used in a Renault zoe, the indicators ADP – energy and GWP are in the same order of magnitude than the reference scenario. Here the indicator Tox. Canc. is not a relevant indicator linked to the use phase since majority of the impacts are linked to the manufacturing phase for the reference scenario.

3.1.4.3 Impact of the use area of the BP in a stationary application

For the stationary application, the conclusions regarding the impacts linked to the use area of the BP are the same as the ones underlined for Renault in Figure 25 and hence for eGo, with a non-negligible difference for 4 indicators such as POCP, AP, Tox. Non. Canc. And EP (terrestrial and marine) with higher impacts regarding the use of the BP in India. On the other hand, impacts linked to the use of the BP in Europe or in the USA are in the same order of magnitude. Details of the impacts per life cycle phase is given in the figure below for the use of the BP in India.

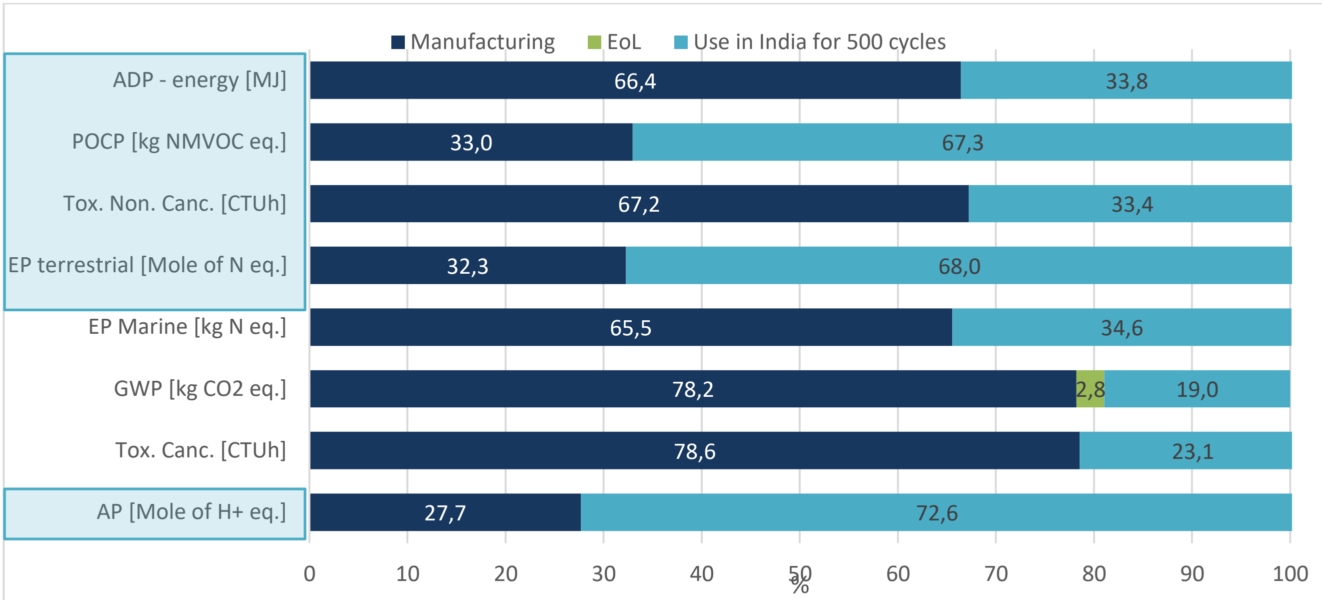


Figure 28. Impacts of the life cycle of the iModBatt BP used in a stationary application

The repartition of the impacts is compared to the one obtained for the use of the BP in Europe for 500 cycles (Figure 22). It is obvious that, for the indicators that were already impacted by the use phase of the reference scenario, the impacts are increased by 2 to 5 when the same BP is used for 500 cycles in India (Table 10).

Table 10. Evolution of the impacts related to the indicators linked to the use phase of the BP

Indicators	Proportion of the impacts linked to the use phase (%)		Increase of the proportion of the impacts allocated to the use phase
	Reference scenario	Use of the BP in India	
AP [Mole of H+ eq.]	**20,9 %**	72,6 %	X 3,5
Tox. Canc. [CTUh]	**14,9 %**	23,1 %	X 1,6
GWP [kg CO2 eq.]	**24,9 %**	19,0 %	X 0,8
EP Marine [kg N eq.]	**6,1 %**	34,6 %	X 5,7
EP terrestrial [Mole of N eq.]	**20,1 %**	68,0 %	X 3,4
Tox. Non. Canc. [CTUh]	**14,1 %**	33,4 %	X 2,4
POCP [kg NMVOC eq.]	**19,5 %**	67,3 %	X 3,5
ADP - energy [MJ]	**23,1 %**	33,8 %	X 1,5

It is interesting to note that, as for the BP used in a Renault zoe, the indicators ADP – energy and GWP are in the same order of magnitude than the reference scenario. All the impacts are a bit higher than the ones quantified for the BP used in a Zoe and a Life 6.0.

3.1.4.4 Conclusion of the sensitive analysis at the BP-level.

As a conclusion for this sensitive analysis performed at the BP-level for one use of the BP in two automotive applications and one stationary application, the area of use has a relevant impact on the following indicators : POCP, EP and AP. Most of the impacts for these indicators are directly linked to the use phase (between 60-75%) and not to the manufacturing phase as it is the case for the reference scenarios detailed in 3.1.1, 0 and 3.1.3 (between 20-30%). This influence of the geographical area is directly use to the type of processes used for the production of electricity with a dominant part in India produced from hard coal. In Europe and the USA, electricity is mainly generated from nuclear energy and natural gas.

3.2 Results on the increase of the lifetime of the battery pack

The LCA performed at the BP-level for the three BP studied in iModBatt seems to all focus on the same conclusions: most of the impacts are linked to the manufacturing phase (12/13 indicators) and more precisely to the manufacturing of the cells used in modules and BP and to the manufacturing of the electronic parts of the iModBatt module. Consequently, the better perspective to have a better performance regarding the environmental impacts is to increase the lifetime of those BP, in order to lower the initial impacts identified at the BP-level. The influence of this increase of the lifetime of the modular BP manufactured in this project will be studied in the present part of the report.

As a reminder, the studied scenarios along with the chapters of the report are detailed in the table below:

Table 11. Main parameters of the 2 main scenarios assessed

Part of this report	Scenario	Details
0	Reference 1	2 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP 5 (5,2 kWh)*
	Innovative 1	1 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP (5,2 kWh)*
3.2.2	Reference 2	3 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP 4 (21,5 kWh) + 8,67 BP 5 (5,2 kWh)*
	Innovative 2	1 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP (21,5 kWh) + 8,67 BP (5,2 kWh)*

3.2.1 Comparative assessment of the environmental impact of reference and innovative scenario 1.

First, the environmental impacts linked to the reuse of the iModBatt BP in two distinct applications (automotive and stationary application) will be detailed in the table and figure below.

Table 12. Value of the impacts for each studied indicators for the two scenario: REF 1 & INN 1

Indicators	Total	INN 1	REF 1	Impact difference (%)
AP [Mole of H+ eq.]	420	161	259	-37,8
Tox. Canc. [CTUh]	3,52E-05	1,31E-05	2,21E-05	-40,7
GWP [kg CO2 eq.]	932	365,3	566,5	-35,5
EcoTox [CTUe]	4,02E+07	1,73E+07	2,28E+07	-24,1
EP freshwater [kg P eq.]	7,35	2,46	4,89	-49,7
EP Marine [kg N eq.]	185	64,6	120	-46,2
EP terrestrial [Mole of N eq.]	640	244	395	-38,2
Tox. Non. Canc. [CTUh]	1,31E-03	4,83E-04	8,27E-04	-41,6
ODP [kg CFC-11 eq.]	8,44E-04	2,83E-04	5,61E-04	-49,6
POCP [kg NMVOC eq.]	181	69,1	112	-38,3
ADP - energy [MJ]	1,85E+06	7,17E+05	1,13E+06	-36,5
ADP - resources [kg Sb eq.]	0,68	0,18	0,50	-63,3
Water [m3 world equiv.]	1,36E+06	4,54E+05	9,05E+05	-49,8

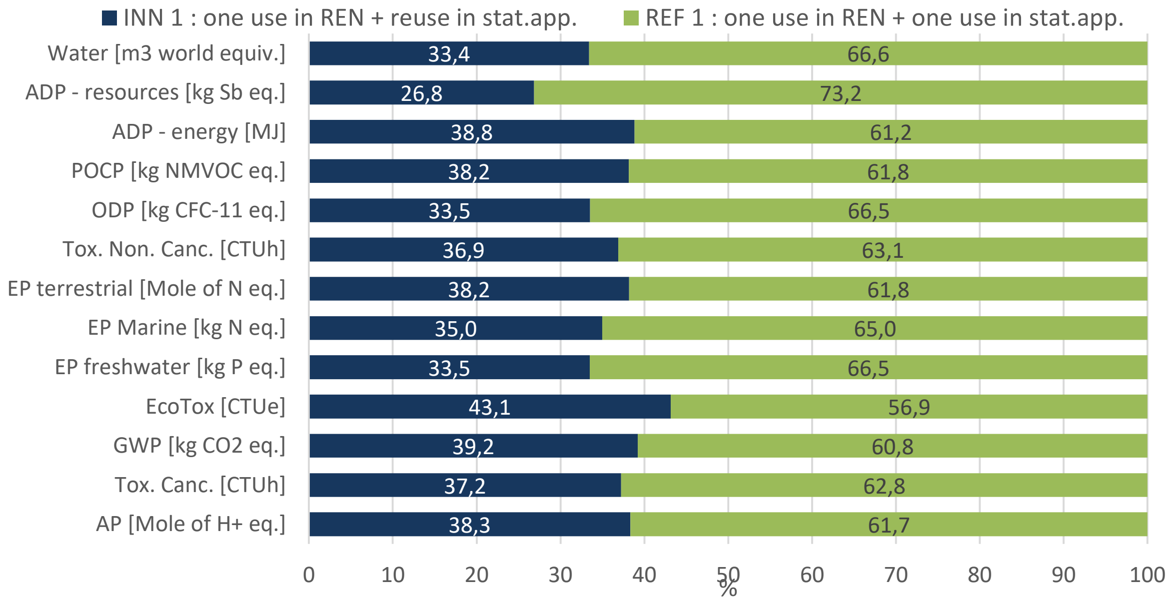


Figure 29. Comparison of the impacts linked to INN 1 & REF 1 scenarios

As it can be seen in Figure 29, the reference scenario 1 has the highest impacts for each indicators studied with impacts in the range 60-75%. Only the indicator Ecotox seems to be impacted equally by both scenarios with impacts in the range 43-57%, which is considered in the uncertainties of the methodology. It is interesting to go into details for each scenario in order to be able to better understand environmental impacts along with life cycle phases of the BP. The results will be compared in the following parts per scenario.

3.2.1.1 Results linked to reference scenario 1.

Environmental impacts quantified for the REF 1 scenario are equally distributed between the life cycle of the iModBatt BP used in Zoe and the life cycle of the iModBatt BP used in the stationary application (Figure 30).

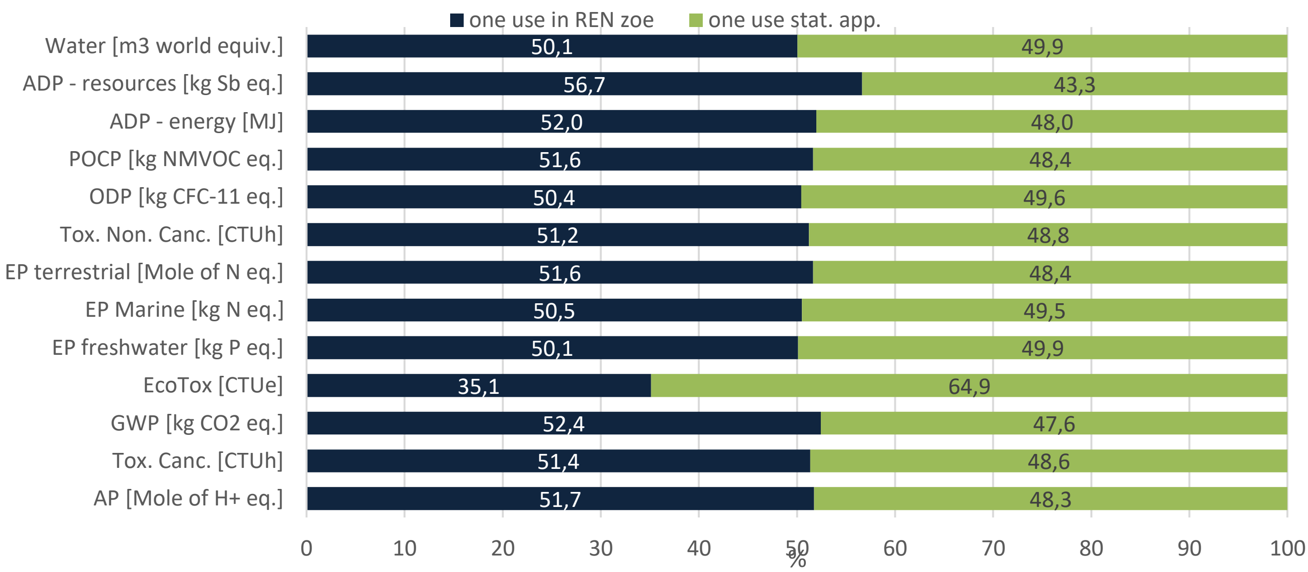


Figure 30. Environmental impacts repartition in the REF 1 scenario

This results is quite understandable since we consider here the life cycle of 1 iModBatt BP used in Zoe Renault and the life cycle of 8,7 iModBatt BP used in a stationary application. Hence, the same number of cell is manufactured for the two scenarios included in REF 1 scenario. Only the Ecotox indicator is more impacted by the life cycle of the BP used in a stationary application as previously underlined in 3.1.3 due to the end of life of aluminium.

3.2.1.2 Results linked to innovative scenario 1.

For the INN 1 scenario, most of the impacts are linked to the first use of the iModBatt BP in Zoe Renault within the range 82% - 230%. As shown in the section 3.1.1, most of the impact linked to the first use of the BP is originated from the manufacturing phase and more precisely by the manufactuing of the cells and the elctronic parts at the module-level of the BP.

Only the Ecotox indicator is the only one to be mainly impacted by the reuse of the BP in a stationnary application and the end of life of the BP with 70% of the impact linked to this phase. Finally, it is interesting to see that the indicator ADP – resources linked to the depletion of resources is impacted in a positive way by the reuse of the iModBatt BP in a stationnary application and the end of life of materials during the dismantling phase and end of life of the BP. Focus on those two indicators will be done in this section in order to better understand their origin during the reuse phase of the BP in a stationnary application (Figure 32). It is interesting to underline that most of impacts linked to EcoTox and ADP resources originated both from the end of life of the iModBatt BP with the recycling of most parts and more precisely of aluminium for the Ecotox indicator. This repartition is in line with the interpretation performed at the BP-level in 3.1.3.

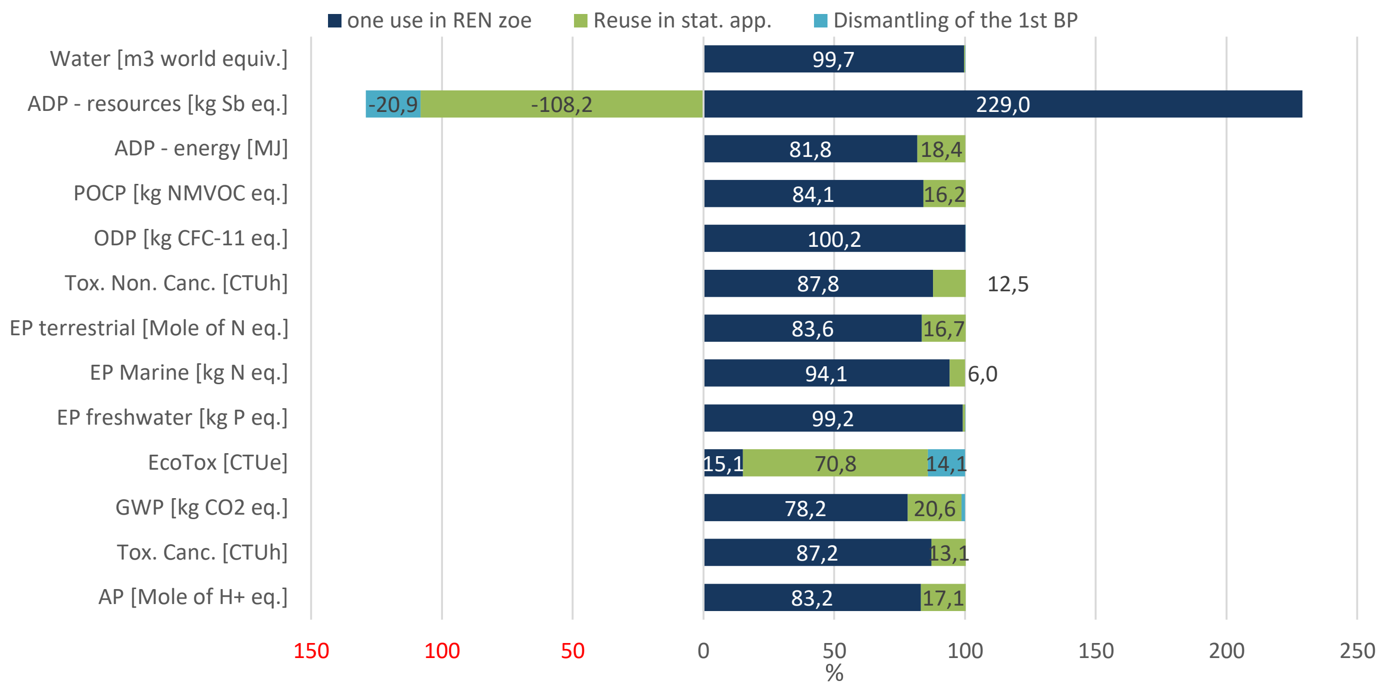


Figure 31. Environmental impacts repartition in the INN 1 scenario

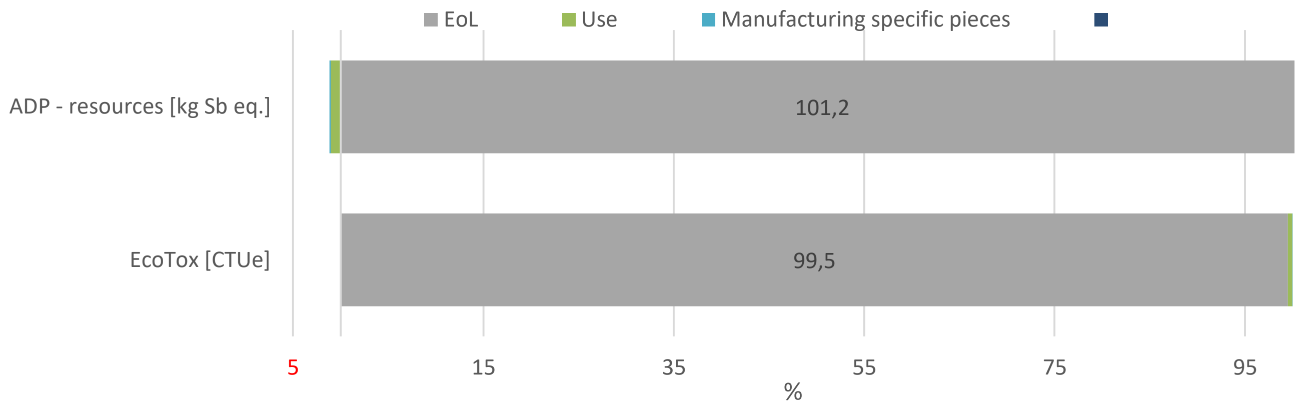


Figure 32. Environmental impacts focused on ADP - resources and EcoTox indicators during the reuse of the stat. app.

As a conclusion, the reuse of the iModBatt BP in two applications (one automotive and one stationary) permits to lower significantly the environmental impacts by eliminating the second manufacturing phase of the BP used in a stationary application. It is interesting to note that this improvement is not clearly established regarding the Ecotox indicator due to origin of the impact linked to the end of life of aluminium used in the cells and in the BP.

3.2.2 Comparative assessment of the environmental impact of reference and innovative scenario 2.

Finally, the environmental impacts linked to the reuse of the iModBatt BP in three distinct applications (two automotive and one stationary application) will be detailed in the table and figure below.

Table 13. Value of the impacts for each studied indicators for the two scenario: REF 2 & INN 2

Indicators	Total	INN 2	REF 2	Impact differences (%)
AP [Mole of H+ eq.]	590	198	393	-49,6
Tox. Canc. [CTUh]	3,57E-04	1,70E-04	1,88E-04	-9,6
GWP [kg CO2 eq.]	1311	456,3	858	-46,8
EcoTox [CTUe]	4,58E+07	1,74E+07	2,84E+07	-38,7
EP freshwater [kg P eq.]	9,82	2,49	7,33	-66,0
EP Marine [kg N eq.]	251	69,7	181	-61,5
EP terrestrial [Mole of N eq.]	897	298	599	-50,3
Tox. Non. Canc. [CTUh]	1,81E-03	5,63E-04	1,25E-03	-55,0
ODP [kg CFC-11 eq.]	1,12E-03	2,83E-04	8,38E-04	-66,2
POCP [kg NMVOC eq.]	254	83,7	170	-50,8
ADP - energy [MJ]	2,61E+06	8,88E+05	1,72E+06	-48,4
ADP - resources [kg Sb eq.]	0,93	0,20	0,73	-73,1
Water [m3 world equiv.]	1,81E+06	4,56E+05	1,36E+06	-66,5

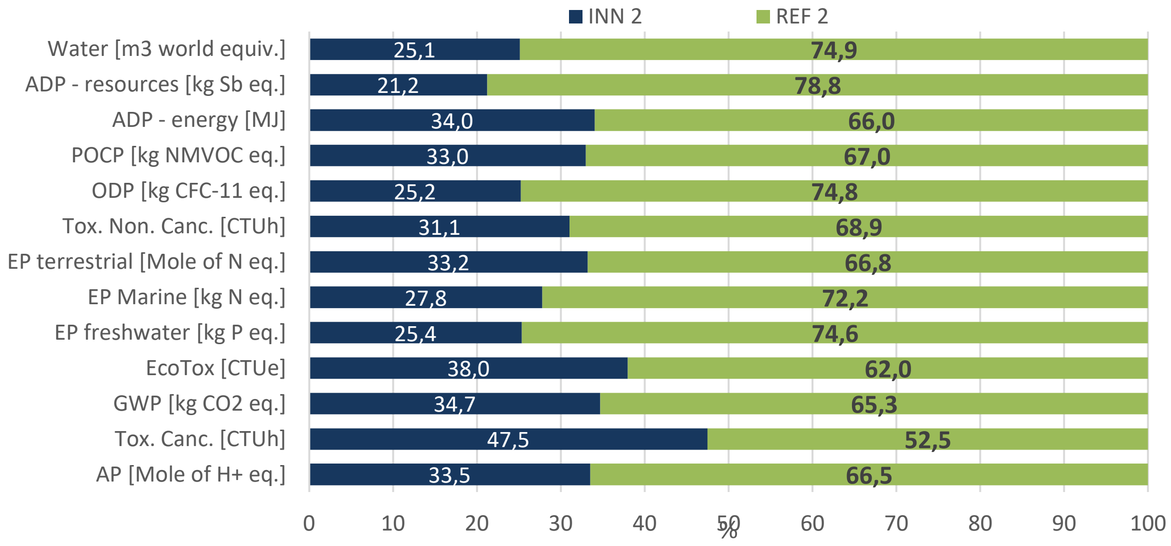


Figure 33. Comparison of the impacts linked to INN 2 & REF 2 scenarios

As it can be seen in Figure 33, the reference scenario 2 has the highest impacts for each indicators studied with impacts in the range 60-80%. Only the indicator Tox. Canc. seems to be impacted equally by both scenarios with impacts in the range 47-53%, which is considered in the uncertainties of the methodology. It is interesting to go into details for each scenarios in order to be able to better understand environmental impacts along with life cycle phases of the BP. The results will be compared in the following parts per scenario.

3.2.2.1 Results linked to reference scenario 2.

Environmental impacts quantified for the REF 2 scenario are equally distributed for most of the indicators between the life cycle of the iModBatt BP used in Zoe, the life cycle of the iModBatt BP used in Life 6.0 and the life cycle of the iModBatt BP used in the stationary application (Figure 34).

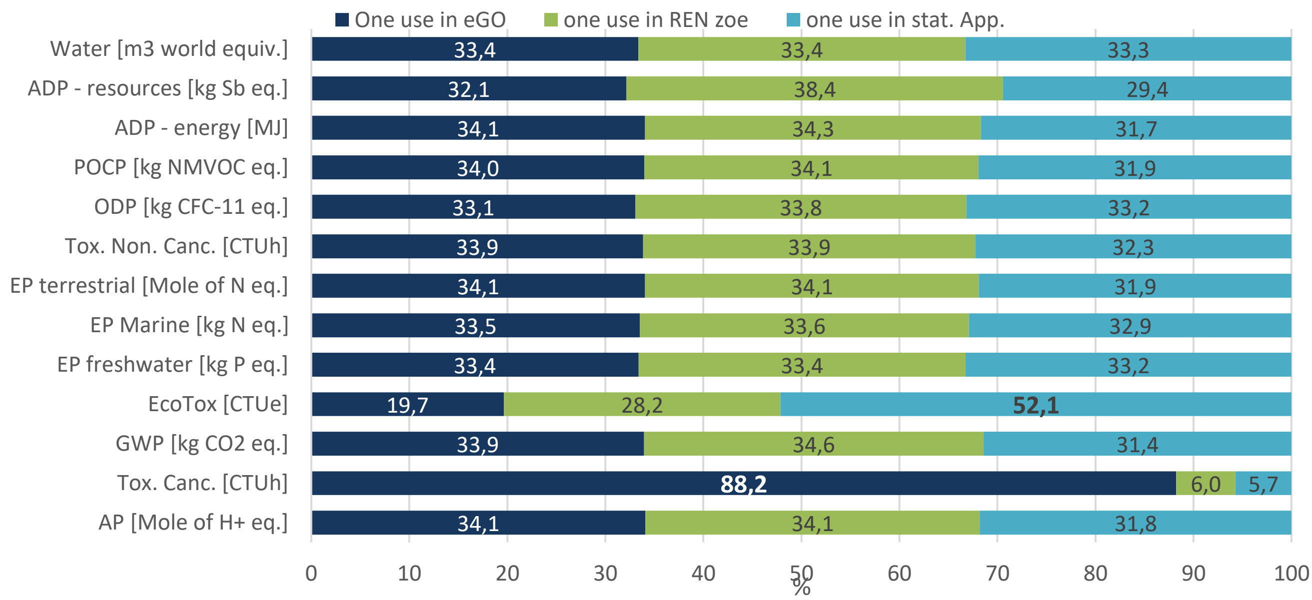


Figure 34. Environmental impacts repartition in the REF 2 scenario

This results is quite understandable and close to the results obtained in 3.2.1.1 since we consider here the life cycle of 1 iModBatt BP used in Zoe Renault, of 2 iModBatt BP used in eGO Life 6.0 and of 8,7 iModBatt BP used in a stationary application. Hence, the same number of cell is manufactured for the three scenarios included in REF 2 scenario. Only the Ecotox indicator is more impacted by the life cycle of the BP used in a stationary application and the Tox Canc. Indicator is more impacted by the life cycle of the BP used in eGO Life 6.0. These trends were already observed in 3.1.3 due to the end of life of aluminium and in 0 due to the manufacturing of the baseplate (made of stainless steel).

3.2.2.2 Results linked to innovative scenario 2.

For the INN 2 scenario, majority of the impacts for most of the inficators are linked to the first use of the iModBatt BP in Zoe Renault and are within the range 60% - 210%. As shown in the section 3.1.1, most of the impact linked to the first use of the BP is originated from the manufacturing phase and more precisely by the manufactuing of the cells and the electronic parts at the module-level of the BP.

Only two indicators, i.e. Ecotox and Tox. Canc. are the only ones to be mainly impacted by the reuse of the BP in a stationnary application and the end of life of the BP (70% of the impact) and to the reuse of the BP in the eGO Life 6.0 (92%) respectively. Finally, it is interesting to see that the indicator ADP – resources linked to the depletion of resources is impacted in a positive way by the reuse of the iModBatt BP in a stationnary application and the end of life of materials during the dismantling phase and the final end of life of the BP as already observed in 3.2.1.2.

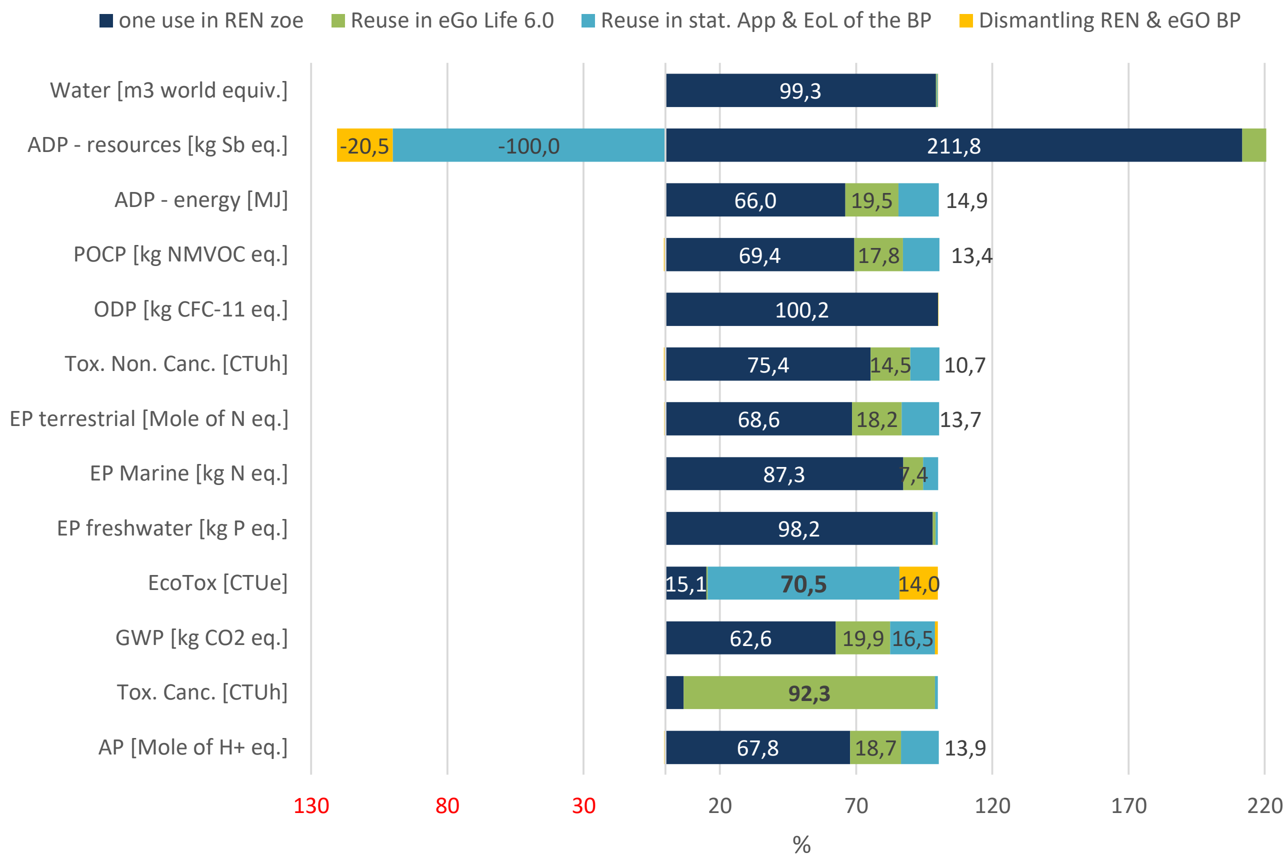


Figure 35. Environmental impacts repartition in the INN 2 scenario

Focus on the indicator Ecotox has already been done in section 3.2.1.2 of this report. The impact originated from the end of life of the BP with the recycling process of aluminium. Focus on the Tox. Canc. Indicator is done in the figure below in order to better understand their origin during the reuse phase of the BP in an eGO Life 6.0 (Figure 36). It is interesting to underline that most of impacts linked to this indicator originates from the manufacturing of the base tray of the eGO BP as previously seen at the BP-level in 0.

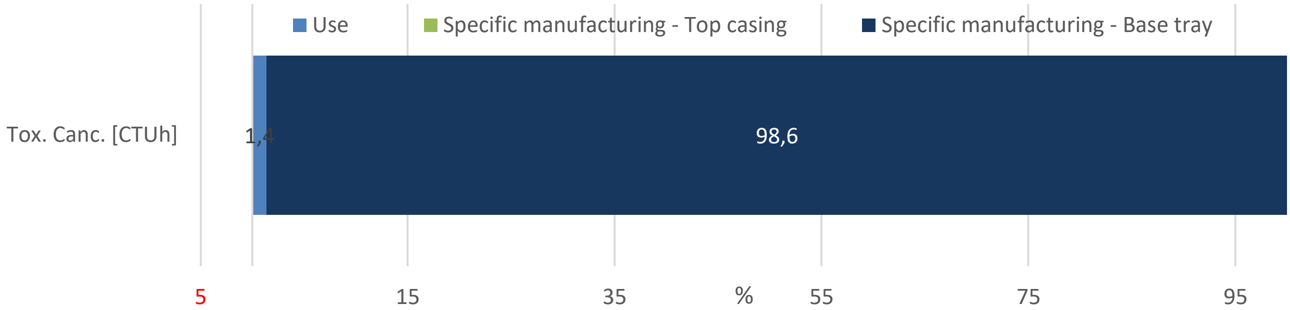


Figure 36. Environmental impacts focused on Tox. Canc. Indicator during the reuse of the BP in eGO Life 6.0.

As a conclusion, the reuse of the iModBatt BP in three applications (two automotive and one stationary) permits to lower significantly the environmental impacts by eliminating the two manufacturing phase of the BP used in an eGo Life 6.0 and in a stationary application. It is interesting to note that this improvement is not clearly established regarding the Tox. Canc. indicator due to the origin of the impact linked to the specific manufacturing of the base tray made of stainless-steel of the BP used in and eGO Life 6.0 application.

3.2.3 Sensitive analysis

Regarding the results obtained in section 3.2, the most relevant sensitive analysis regarding the study of the increase of the lifetime of the battery seems to be related with the chosen reuse factor between two applications. In those LCA, this factor was chosen equal to 100%, meaning that all the modules used in a previous application could be entirely reuse in a second application with no loss of modules. Then, it could be interesting here to study the influence of this factor on the environmental impacts generated by the reuse of BP in two or three applications. Then the sensitive analysis that will be performed here are stated in the table below.

Table 14. Sensitive analysis performed at the BP reuse-level : influence of the factor of reuse

Scenario	Factor of reuse	Details
REF 1	None	2 distinct BP for 2 distinct use phases
INN 1	100 %	1 BP for 2 distinct use phases *26 modules reused over 26*
Sensitive analysis 1	70 %	1 BP for 2 distinct use phases *18,2 modules reused over 26*
REF 2	None	3 distinct BP for 3 distinct use phases
INN 2	100 %	1 BP for 3 distinct use phases *26 modules reused over 26*
Sensitive analysis 2	70 %	1 BP for 3 distinct use phases *18,2 modules reused over 26*

Results for the first sensitive analysis could be found in the figures below.

When environmental impacts generated for the scenario INN 1 and SA 1 are compared; it seems that there are distributed fairly between both. Impacts are all in the range of the uncertainties of the calculation methodologies (45-55%) (Figure 37). Only the ADP-resources indicator seems to be more impacted by the scenario with 70% of reuse of the module with impacts equal to 60%. This is directly linked to the fact that new modules need to be manufactured at each reuse phase which required to extract more raw materials.

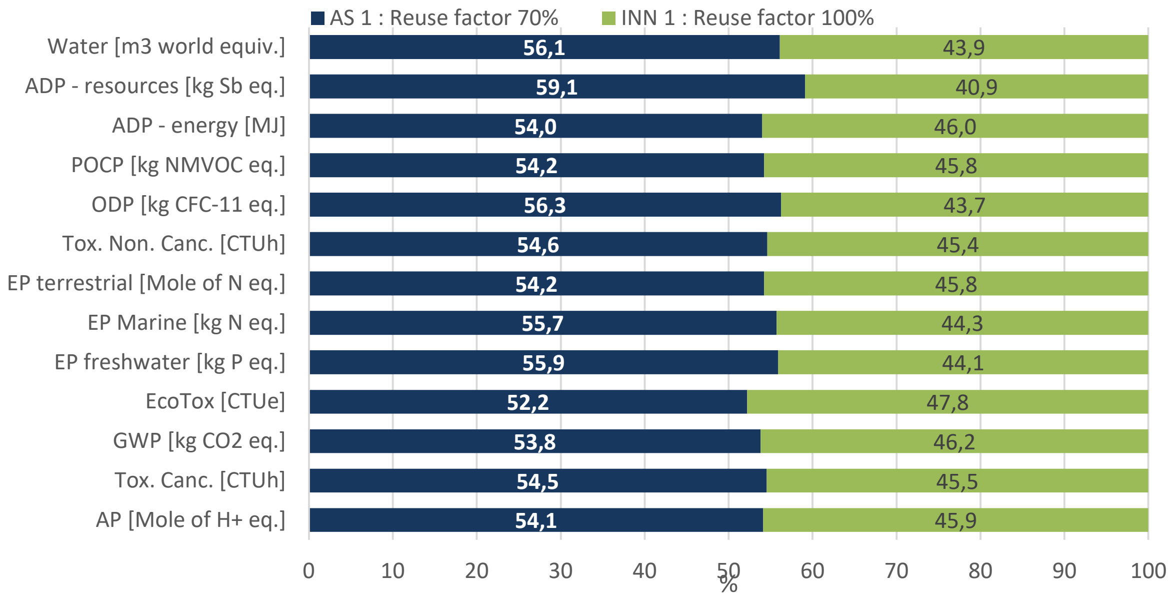


Figure 37. Impacts of the reuse factor of the module between one application to another.

Consequently, when we compare the environmental impacts generated by the AS 1 scenario to the reference scenario of this study (REF 1, with no reuse), most of the indicators still have bigger impacts when no reuse of the modules are performed (Figure 38).

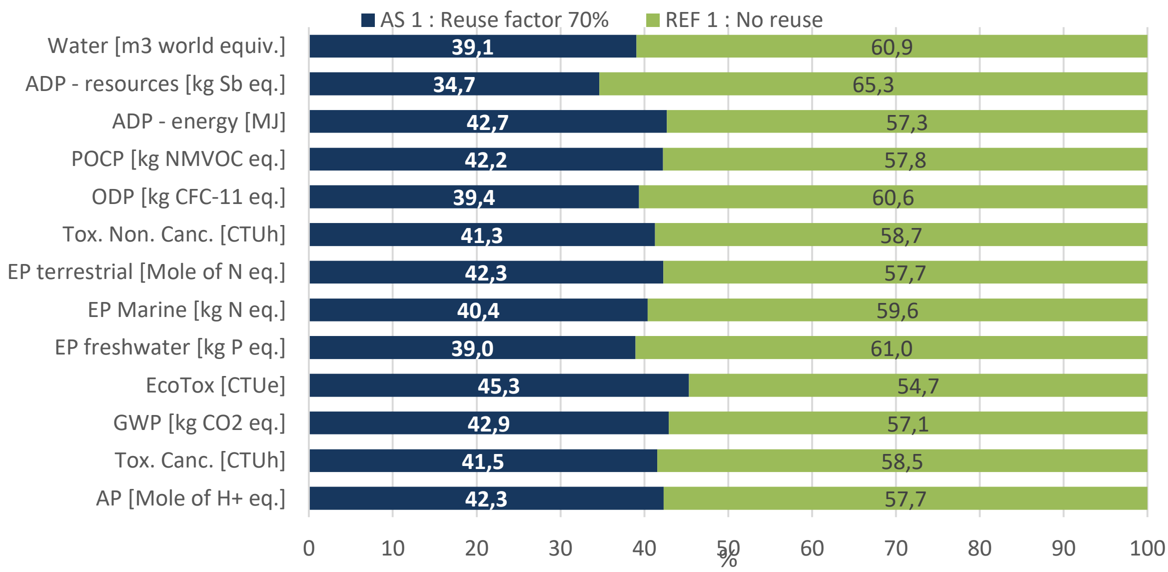


Figure 38. Comparison of the impacts between a scenario where 70% of modules could be reused (AS 1) in two applications and where none of the modules is reused (REF1)

Finally, results for the second sensitive analysis could be found in the figures below.

When environmental impacts generated for the scenario INN 2 and SA 2 are compared; it seems that there are distributed fairly between both for most of the indicators. Impacts are all in the range of the uncertainties of the calculation methodologies (45-55%) (Figure 39). Nevertheless, contrary to the scenario INN 1 and SA 1, five indicators seems to be more impacted by the scenario with 70% of reuse of the module with impacts equal to 60%. Those indicators are Water, ADP – resources, ODP, EP Marine and freshwater which are directly linked to the fact that new modules are manufactured at each reuse phase to replace the 30% that could not be reused. Moreover, it is understandable that more indicators are affected compared to the AS 1 scenario since there is one more reuse phase in an eGO Life 6.0, thus more extra modules need to be manufactured.

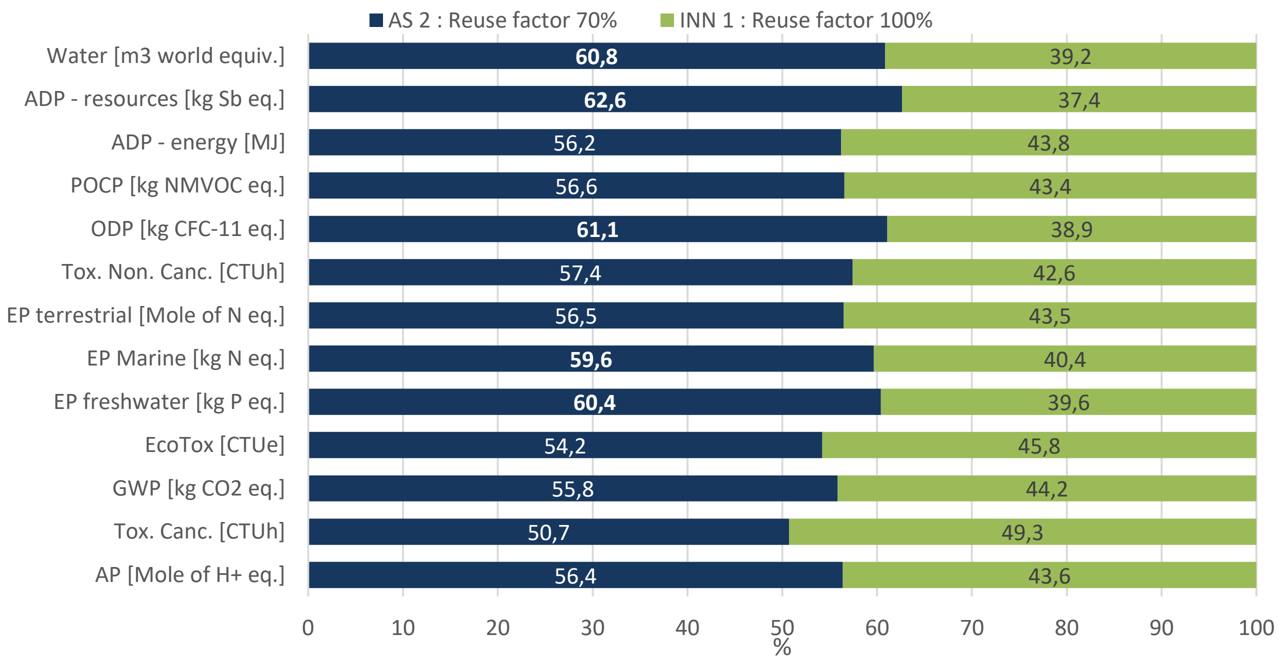


Figure 39. Impacts of the reuse factor of the module for a life cycle where three uses of the same BP are done.

Thus, it is interesting to see if these difference in the environmental impacts are also noticed at the reuse-BP scale when compared to a scenario where none of the modules are reused (REF 2). The results quantified are given in Figure 40. Most of the indicators have bigger impacts when none of the modules is reused compared to a scenario where 70% of the modules are reused. However, the impacts linked to the scenario AS 2 has increased by 10% (except for the Ecotox. Indicator) compared to the scenario INN 2 (see Figure 33).

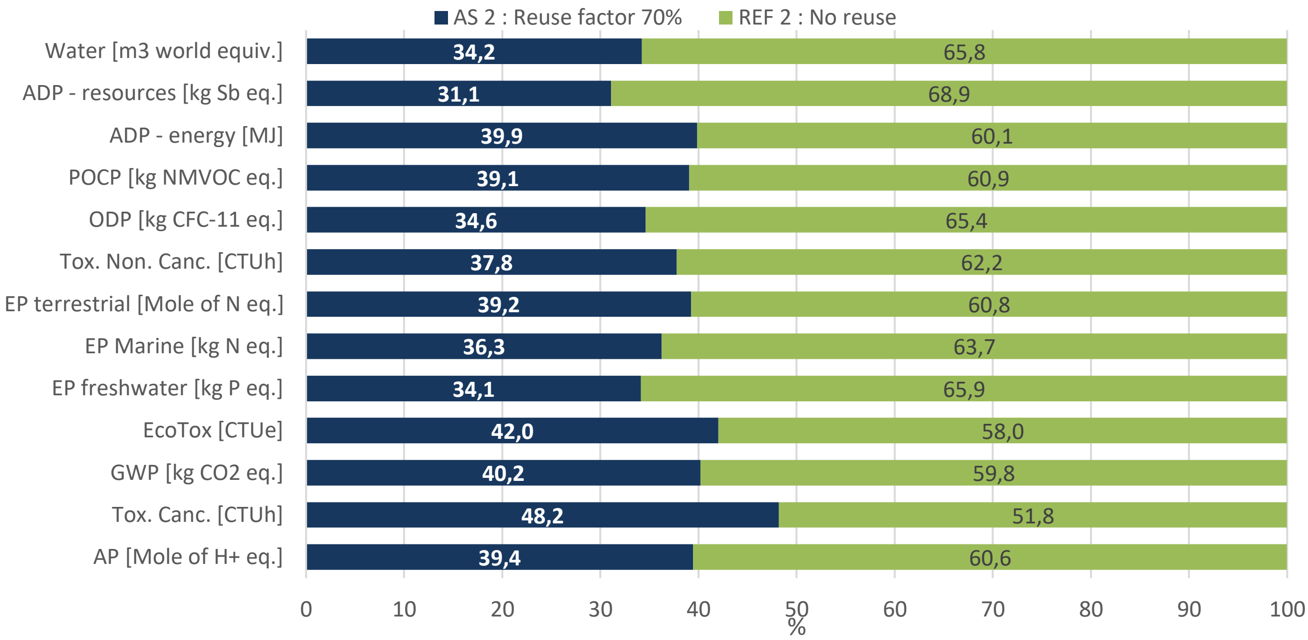


Figure 40. Comparison of the impacts between a scenario where 70% of modules could be reused (AS 2) in 3 applications and where none of the modules are reused (REF 2)

As a conclusion, the reuse factor of the modules have an influence on the environmental impacts quantified. It should be noted that the increase of the environmental impacts linked to the diminution of the reuse factor is negligible in front of the environmental impacts linked to the scenario where no reuse of the modules are performed. Even if only 70% of the modules could be reused after the first use phase of the BP, for one or two other applications, the environmental benefice is still higher than for a scenario where no reuse of the modules is performed.

4 Conclusions

The present report aims to:

(1) Evaluate the environmental impacts linked to the reuse of the iModBatt modules in several applications already described in deliverable 7.2, i.e. Renault Zoe, e.GO Life and a stationary application designed by TYVA.

(2) Compare those environmental impacts with the ones quantified in the reference scenario, i.e. one use of the iModBatt BP in Renault Zoe with no reuse of the iModBatt modules in several applications.

Two functional units are then established and defined as :

Scenario	Details
Reference 1	2 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP 5 (5,2 kWh)*
Innovative 1	1 BP for 2 distinct use phases *1 BP (45,0 kWh) + 8,67 BP (5,2 kWh)*
Reference 2	3 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP 4 (21,5 kWh) + 8,67 BP 5 (5,2 kWh)*
Innovative 2	1 BP for 3 distinct use phases *1 BP (45,0 kWh) + 2 BP (21,5 kWH) + 8,67 BP (5,2 kWh)*

The system boundaries for both scenarios are the whole life cycle of the iModBatt BP, from its manufacturing until its end of life. The inventory analysis is considered of good quality and based upon measured data given by partners. Since, no testing of the battery pack could be performed during the project, litterature data and data on comercial BP were considered for the three battery packs.

At the BP-level, it is interesting to note that majority of the impacts for most of the studied indicators are linked to the manufacturing phase of the BP whatever the use phase (Zoe Renault, eGO Life 6.0 or stationnary application). Most of the indicators are mostly impacted at the module-level with the manufacturing phase of the cells (8-9 / 13 indicators) and of the elctronic parts (2-3 / 13 indicators). This underlines the interest of extending the lifespan of the BP in order to lower the environmental impacts of this phase. For the three types of BP, the Ecotox indicator is mainly impacted by the end-of-life phase of the BP and more precisely by the end-of-life of aluminium in a landfill (40% and 60% is recycled) since the most of the BP are mainly composed of aluminium (Baseplates). Moreover, the energy used as the module-level for its assembly or disassembly is found negligible for all the studied indicators. Regarding the eGO BP and more precisely the manufacturing phase of the BP, a different indicator is impacted compared to the Renault BP. This is the Tox. Canc. Indicator which is directly linked to the base tray material (stainless steel) whereas aluminium is used in the Renault BP. This change of material is non negligible on the impact of this indicator. Regarding the stationary application BP, it is interesting to note that the material of the baseplate is not one the sources of the impact on one particular indicator mainly due to a very low weight compared to the one in the BP used for automotive applications. Finally, it is also interesting to note that the use phase represents around 20-30% of the impacts of 7 indicators which underline the interest of better understanding the impact of the geographical area where the BP is used.

At the reuse of the BP-level, most of the indicators have bigger impacts when no reuse of the modules from one application to another is done. This result is the same whether the BP is reused in one or two applications. This results is understandable since most of the origin of the impacts is linked to the manufacturing phase of the BP : The more BP is manufactured, the higher will be the environmental impacts.

Indicators	Impact difference (%)	
	One reuse phase INN 1 / REF 1	Two reuse phases INN 2 / REF 2
AP [Mole of H+ eq.]	-37,8	-49,6
Tox. Canc. [CTUh]	-40,7	-9,6
GWP [kg CO2 eq.]	-35,5	-46,8
EcoTox [CTUe]	-24,1	-38,7
EP freshwater [kg P eq.]	-49,7	-66,0
EP Marine [kg N eq.]	-46,2	-61,5
EP terrestrial [Mole of N eq.]	-38,2	-50,3
Tox. Non. Canc. [CTUh]	-41,6	-55,0
ODP [kg CFC-11 eq.]	-49,6	-66,2
POCP [kg NMVOC eq.]	-38,3	-50,8
ADP - energy [MJ]	-36,5	-48,4
ADP - resources [kg Sb eq.]	-63,3	-73,1
Water [m3 world equiv.]	-49,8	-66,5

Only the Ecotox indicator is equally impacted by both scenarios due to a majority of the impacts linked to the end of life of the BP which is the same for both scenarios whether the BP is reused or not and whether the number of applications considered. Finally, if the BP is reused in an eGO application before being reused in a stationary application, the Tox. Canc. will be equally impacted by both scenarios since the impact is linked to the manufacturing of the base tray of the eGo BP. As a conclusion, the reuse of the iModBatt BP in two or three applications (one or two automotive and one stationary) permits to lower significantly the environmental impacts by eliminating the second or third manufacturing phases of the BP used in an eGo Life 6.0 or in a stationary application. Thus, it could be interesting to study the influence of the reuse factor from one application to another. Here, the reuse factor was taken equal to 100%.

Finally, **two sensitive analysis were performed** in order to better understand the origin of the environmental impacts quantified along with the uncertainties linked to the processes selected in the modelling. The first one was performed at the BP-level, the second one at the reuse-level of the BP. At the BP-level, the geographical area of use of each BP was studied with use phases considered in India and in the USA. As a conclusion, the area of use has a relevant impact on the following indicators : POCP, EP and AP. Most of the impacts for these indicators are directly linked to the use phase (between 60-75%) and not to the manufacturing phase as it was the case for the reference scenarios. In the reference scenarios, the impacts linked to the use phase were in the range 20-30%. This influence of the geographical area of use of the BP is directly linked to the type of processes used for the production of electricity : in India, a dominant part is produced from hard coal in contrary to Europe and USA where the electricity is mainly generated from nuclear energy and natural gas. At the reuse BP-level, the influence of the reuse factor of modules between two applications was studied with a reuse factor equal to 70%, considered closer to reality. The results of this sensitive analysis was then compared to a scenario with a reuse factor equal to 100% and a scenario where no reuse of the modules was performed. Whether the reuse of the BP was done in two or three applications, the impacts remains bigger for the scenario where no reuse of the module is performed. Finally, it is interesting to note that the reuse factor of the modules have an influence on the environmental impacts quantified with bigger environmental impacts (+ 10%) for the majority of the indicators for the scenario with a reuse factor of 70% compared to the one with a reuse factor of 100%. Even if only 70% of the modules could be reused after the first use phase of the BP, for one or two other applications, the environmental benefice is still higher than for a scenario where no reuse of the modules is performed.

Regarding milestone linked to this Deliverable:

Table 15. MS linked to this Deliverable

MS	MS header	Related WPs	Est. Date (Month)	Description of executed activity
MS18	LCA of defined BP industrial handling process and means (final)	WP7	M36	The comparative LCA focused on the life cycle of iModBatt BP. Some partners were involved in this task for the data collection (REN, EGO, TYVA, ACC and RSC). The assessment allowed to highlight the main environmental impact origins and to provide some sustainable improvement ways.

5 References

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ANNEX I: literature review and benchmark for the use phase of the stationary application (RSC, TYVA).

Only BP configurations closed to the iModBatt BP for stationary application are shown here.

Ref	Objective of the study	Cell chemistry	Initial capacity (kWh)	Energy needed (kWh/cycle)	Average efficiency per cycle (%)	Lifetime
[6]	Energy storage systems that are considered as a suitable backup and balancing tool in a large scale energy grid.	LMO	2,71	1,90	70	5-10 years 2500 cycles
[7-8]	Use of second life Li-ion batteries from electric vehicles as stationary battery storage applications as an environmentally viable option to further decrease the en-vironmental impact of electric mobility by extending the battery lifetime while, at the same time, enabling an increased integration of RES into the grid.	LMO	16,5	-	-	5 years 2000 cycles
[9]	LCA of the 2nd use of a Li-ion battery for energy storage in buildings	LMO	13,3	12,0	90,2	1,8 years 660 cycles
[10]	LCA from the reuse of an LFP battery which can no longer be used in an EV, but still fulfills the requirements as an energy storage unit in a building in spain.	LFP	18		75	4 years 1500 cycles
iModBatt BP 5	TYVA : application stationnaire for greedy home self consumption	NMC	5,2	3,7	86	1 cycle per day 500 cycles