DREEM

Designing useR centric E-kickscooters & business models for Enhancing interModality

DELIVERABLE NUMBER: **D16 (D4.1)**
DELIVERABLE TITLE: **LCA and end-of life report**

Deliverable due date: 31/01/2022
Submission date: M14 - 30/03/2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007085. The sole responsibility for the content of this document lies with the DREEM project and does not necessarily reflect the opinion of neither CINEA nor the European Commission.

DELIVERABLE INFORMATION

Deliverable Number:	D16 (4.1)
Deliverable Title	LCA and end-of life report
Work Package Number	WP4
Work Package Title	Environmental impact & circular economy
Lead Organization	PUNCH TORINO
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Reviewers	Pier Luigi Piccinini
Nature	Demonstrator
Dissemination Level	PU -Public
Deliverable Date	M14 - (30/03/2022)
Draft Number	1
Version history	Rev 0 – First issue
Version Number	0

PROJECT CONTRACTUAL DETAILS:

Project Title	Designing useR centric E-kickscooters & business models for Enhancing interModality
Project Acronym	DREEM
Grant Agreement No.	101007085
Project Start Date	01-02-2021
Project End Date	31-01-2023
Duration	24 months
Supplementary notes:	This document is only for use among the Partners of DREEM

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ABSTRACT

The aim of the WP4 is to increase DREEM Kickscooter sustainability by applying Circular Economy business model to the entire product life-cycle.

What is important to realize in this first task is to verify if LCA methodology that already exists can be applied to electric kickscooters. During WP2 initial phases (vehicle development and design), an analysis of all kickscooter components has been done in order to identify all materials used in the preparation of DREEM vehicles. The first step is to create a first design, production and end of life process release and study it with LCA and repeat the study at each new release: 1) set the goal and scope of the assessment, 2) include relevant cycle stages and 3) set appropriate boundaries.

CONTENTS

1. GOAL AND SCOPE

The aim of the analysis is to evaluate the environmental impact from the production until the end of life (from cradle to grave) of the DREEM e-kickscooter. Due to the complexity of kickscooter architecture, as a first step, LCA analysis has been focused only to the electric hub motor designed and developed during the WP2.
Subsequently same LCA methodology will be applied to the most relevant on-board systems, such as the battery pack.
Figure 1 represents the system boundaries of the process implemented.

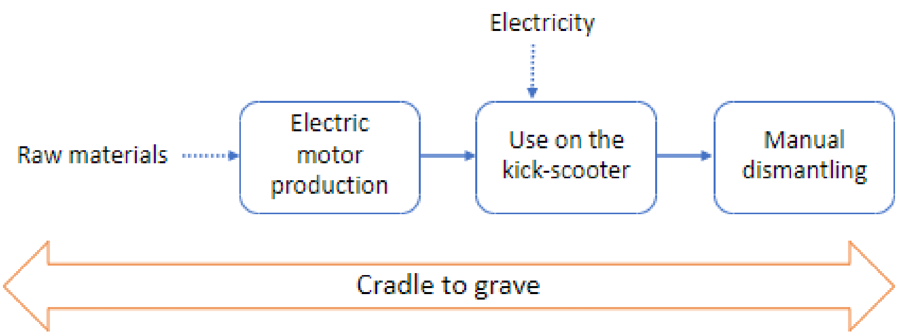

Fig. 1 – System boundaries of the analysis

For this analysis, a Life Cycle Assessment method is applied, using the software *OpenLCA v.1.11* and the database *ecoinvent v.3.7*. The Functional Unit defined is 1 p*km (person-kilometer). In order to evaluate and quantify the impacts of the production of the raw materials, production of the motor, use and dismantling of the motor, *ReCiPe 2016 Midpoint (H)* is selected as Impact Assessment method and all the impact categories available in this method are considered in this study.

In addition, a sensitivity analysis is carried out to evaluate the effect of different motor weights on the environmental impact.

1.1 ASSUMPTIONS

Some assumptions are defined with the aim to simplify the modeling process. The motor life expectancy on a kickscooter application is estimated at 20,000 km. Considering that an e-kickscooter is approved for carrying only one passenger at a time, the total life expectancy of each motor is 20,000 p*km.

For all the phases of the life cycle, secondary data (obtained from suppliers) are preferentially used. However, when data are difficult to be obtained, datasets from the *ecoinvent* database are also applied.

The transportation of the motor from its production location in Slovenia to the kickscooter assembly plant in Italy is not included in the analysis.
For modelling the use phase, as the product is assumed to be used in European cities, an average European energy mix is considered for the electricity production.

2. LIFE CYCLE INVENTORY ANALYSIS

OpenLCA software is applied to model and evaluate the life cycle of the electric motor with *ecoinvent 3.7* database. Based on the system boundaries (Figures 1) and on the assumptions previously explained, three different phases are modeled.

2.1 PRODUCTION OF THE ELECTRIC MOTOR

A new *production process* has been created starting from a reference dataset already present in the database.
This dataset describes the production of an electric motor suitable for an electric scooter. The entries are given on a function of kg of device. The dataset is based on direct inspection of existing commercial devices of current technology. The dataset takes as input the various materials and energy resources required for the electric motor production. The dataset returns the electric motor and production waste materials as by-products.

The electric motor BOM (Bill of Materials) including material type and mass for all parts or sub-components, as shown in Figure 2, has been used for populating the inputs chart as well as the energy consumption required during serial production operations, as reported in Figure 3.

Component	Material	Mass [g]
Rotor housing	Aluminium	**382**
Rotor		**370**
Ring	Steel	227
Magnet (120x1,1)	NdFeB	132
Cage	Pa6	11
Stator		**1441**
Segment (3x)		901
SMC Segment (6x)	Somaloy (SMC)	136 x 6
Coil (3x)	Cu	21 x 3
Insulation (3x)	Pa6	7,3 x 3
Epoksi (3x)	epoxy	16 x 3
Shaft	Steel	243
Bearing 6003	Steel	40
stator holder	Aluminium	208
Hall sesnsors	/	1
Cover 1 (disk) with semering		**198**
Cover 1 (disk)	Aluminium	193
Semering	rubber	5
Cover 2 with bearing and circlip		**200**
Cover 2	Aluminium	160
Bearing 6003	Steel	40
Circlip	Steel	**1**
Semering	rubber	**5**
Bolt (12x)	Steel	**21**
TFM motor		**2618**

Fig. 2 – Electric motor BOM

Operation	Energy consumption [kWh/motor]
Stamping process (stator + rotor lamination)	0,112
Stator insulation overmolding	0,107
Magnet impression in rotor pack	0,082
Rotor 1 cavity overmolding	0,183
Stator winding + stator assembly line	0,785
End assembly line + EOL testing	0,735
Total:	**2,005**

Fig. 3 – Energy consumption for motor assembly operations

All data is collected for a device of approximately 2.6 kg.

The following assumptions have been also considered for inputs/outputs definition:

- *Aluminum* and *Copper* scrap has been estimated as 20% of consumed raw materials
- *Iron* scrap has been estimated as 9.75% of total electric motor weight
- *Polyphenylene sulfide* (present in the original process) has been maintained in place of *Pa6*, as materials are similar

- Permanent magnet production process has been used to simulate *NdFeB* alloy
- Plastic waste has been calculated as 5% of input *Pa6*

Hence, the entire process has been parametrized in function of the motor weight, as shown in Figure 4. The electricity consumption has been divided in two different parts: one fixed amount and the other one dependent on motor mass, based on the type of operations during the motor assembly.

Figure 5 shows, instead, the model graph of the production process.

Inputs/Outputs: electric motor production, for e-kickscooter_items

Inputs

Flow	Category	Amount	Unit	Costs...	Uncertainty	Avoided ...	Provider	Data qual...	Descrip...
aluminium scrap, new	242:Manufacture of ...	-0.0720*weight	kg	-0.06...	lognorm...		alumini...	(2; 4; 4; 4...	Product...
aluminium, cast alloy	242:Manufacture of ...	0.3602*weight	kg		lognorm...		market...	(2; 4; 4; 4...	Based ...
copper scrap, sorted, press...	38:Waste collection, ...	-0.0048*weight	kg	-0.09...	lognorm...		copper...	(2; 4; 4; 4...	Product...
copper, cathode	072:Mining of non-f...	0.0241*weight	kg		lognorm...		market...	(2; 4; 4; 4...	Based ...
electricity, medium voltage	351:Electric power g...	0.1537*weight	kWh		lognorm...		market...		Energy ...
electricity, medium voltage	351:Electric power g...	1.60230	kWh		lognorm...		market...	(2; 4; 4; 4...	Energy ...
epoxy resin, liquid	201:Manufacture of ...	0.0183*weight	kg		none		market...		
iron scrap, unsorted	383:Materials recove...	-0.0975*weight	kg	-0.01...	lognorm...		iron sc...	(2; 4; 4; 4...	Product...
iron sinter	241:Manufacture of ...	0.3117*weight	kg		none		market...		
permanent magnet, for ele...	242:Manufacture of ...	0.0504*weight	kg		none		market...		
polyphenylene sulfide	201:Manufacture of ...	0.0126*weight	kg		lognorm...		market...	(2; 4; 4; 4...	Based ...
steel, low-alloyed, hot rolled	241:Manufacture of ...	0.1318*weight	kg		lognorm...		market...	(2; 4; 4; 4...	Based ...

Outputs

Flow	Category	Amount	Unit	Costs/Re...	Uncertainty	Avoided ...	Provider	Data qual...	Descrip...
electric motor, for kickscoo...	**0:DREEM electric ...**	**1.00000**	**Item(s)**		**none**				
used electric motor	0:DREEM electric mo...	1.00000	Item(s)		none				
waste plastic, industrial electr...	382:Waste treatmen...	0.0006*weig...	kg		lognorm...		market...	(2; 4; 4; 4...	Product...

Fig. 4 – Production process inputs and outputs

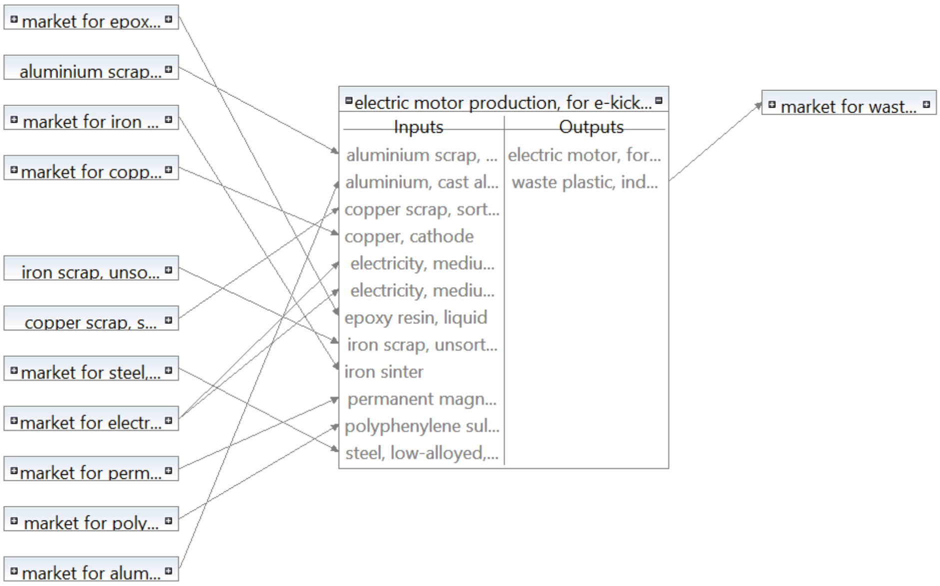

Fig. 5 – Production process flow

2.2 USE OF THE ELECTRIC MOTOR

The electric motor requires electricity during the use phase. The energy consumption, provided by supplier for a motor of 2.6 kg, has been rated at an average of 20 Wh/km on the kickscooter driving cycle. This energy consumption is driven primarily by user's mass and driving cycle profile. Secondary drivers are tire rolling resistance and electric motor energy efficiency profile.

For the sensitivity analysis, it has been considered that heavier electric motors, if properly designed, are more energy efficient, due to more copper material and possibility to use lower density of magnetic field.

Considering this efficiency increase, it has been assumed that final energy demand can decrease of 2% with 0.5 kg of added material, and additional 1% for further 0.5 kg (thus, 3% of less energy required for 1 kg-heavier motor).

This motor efficiency trend has been included into the *OpenLCA* process by parametrizing the electricity consumption in function of the motor mass, as follows:

$$Efficiency = 2.04 \times mass^2 - 15.701 \times mass + 127.12$$

Finally, as the e-kickscooter is supposed to be used in European cities, the average EU energy mix available in *ecoinvent 3.7* is considered for the electricity production ("market group for electricity, low voltage | electricity, low voltage | Cutoff, U").

2.3 END OF LIFE: MANUAL DISMANTLING OF THE ELECTRIC MOTOR

A separate process has been created to model the end-of-life phase where the electric motor is assumed to be manually dismantled. In this step – as shown in Figure 6 – the output of the previous flow "use of electric motor", described above, becomes an input of the process. The impact of a manual treatment facility for waste electric and electronic equipment is also considered.

Among the outputs, the treatment of used motor materials is included as a waste flow.

Inputs/Outputs: electric motor manual dismantling, EoL

Inputs

Flow	Category	Amount	Unit	..	Uncertai...	Avoided...	Provider	Data
manual treatment facility...	410:Construction ...	4E-7*weigh...	Item(s)		lognor...		market for manual treatment facility,...	
use of electric motor	0:DREEM electric ...	1.00000	p*km		none		use of electric motor	

Outputs

Flow	Category	Amount	Unit	.	Uncertai...	Avoided...	Provider
electric motor EoL	**0:DREEM electric...**	**1.00000**	**p*km**		**none**		
used electric motor	0:DREEM electric ...	5.00000E-5	Item(s)		none		treatment of used motor for e-kickscooter, ..

Fig. 6 – End-of-life process inputs and outputs

This final end-of-life process is eventually used to create the *product system* and the respective *model graph*, shown in Figure 7. The model graph shows the complete supply chain and the respective linkages.

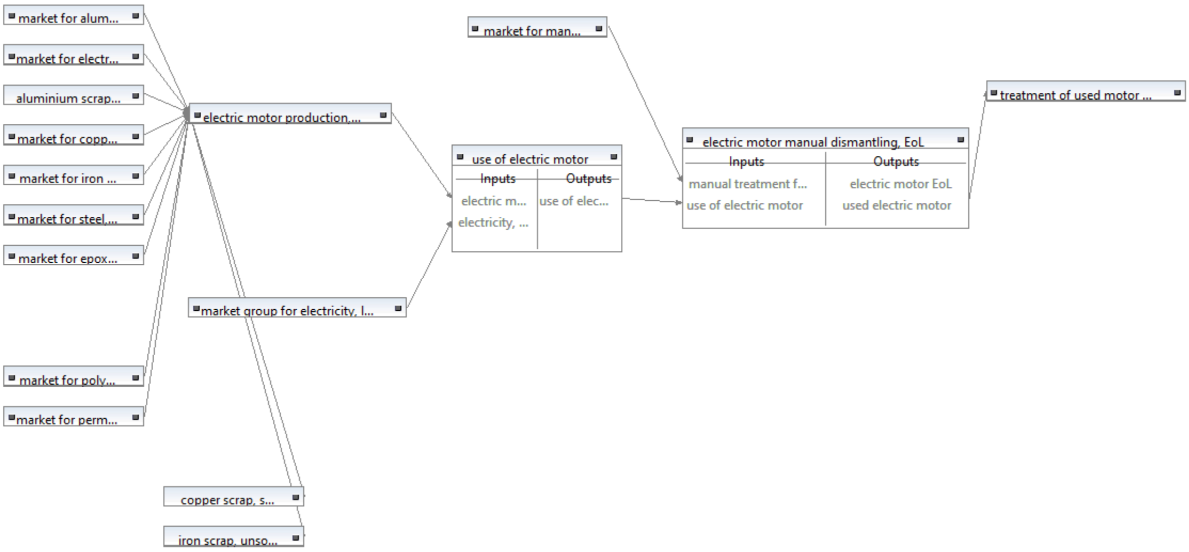

Fig. 7 – Model graph of the entire LCA process

3. LIFE CYCLE IMPACT ASSESSMENT

The Life Cycle Impact Assessment is divided in two different parts. The first part contains the results for an electric motor with a mass of 2.6 kg. Subsequently, the results of a sensitivity analysis comparing different motor weights – as reported in Table 1 – will be presented.

Scenario	Identification	Electric motor mass
1	baseline	2.6 kg
2	+0.5 kg	3.1 kg
3	+1 kg	3.6 kg

Tab. 1 – Scenarios evaluated in the sensitivity analysis

3.1 ELECTRIC MOTOR LCA

For the first scenario (2.6kg-mass electric motor), for almost all the impact categories, the use phase accounts for the greatest share of the impacts (Table 2). The exceptions are Mineral resource scarcity and Marine eutrophication.

Impact Category	Production	Use	EoL	Total	Unit
Fine particulate matter formation	9,76%	89,83%	0,42%	0,288	kg PM2.5 eq
Fossil resource scarcity	5,85%	93,87%	0,28%	48,237	kg oil eq
Freshwater ecotoxicity	25,18%	74,63%	0,18%	23,439	kg 1,4-DCB
Freshwater eutrophication	4,66%	95,25%	0,09%	0,176	kg P eq
Global warming	6,73%	92,95%	0,33%	182,023	kg CO2 eq
Human carcinogenic toxicity	22,63%	76,33%	1,04%	17,561	kg 1,4-DCB
Human non-carcinogenic toxicity	18,10%	81,51%	0,39%	198,249	kg 1,4-DCB
Ionizing radiation	1,36%	98,62%	0,02%	85,758	kBq Co-60 eq
Land use	17,09%	80,23%	2,67%	5,371	m2a crop eq
Marine ecotoxicity	24,78%	75,02%	0,20%	29,316	kg 1,4-DCB
Marine eutrophication	72,37%	27,56%	0,07%	0,043	kg N eq
Mineral resource scarcity	84,19%	15,36%	0,45%	1,782	kg Cu eq
Ozone formation, Human health	9,67%	89,74%	0,59%	0,348	kg NOx eq
Ozone formation, Terrestrial ecosystems	9,73%	89,67%	0,61%	0,351	kg NOx eq
Stratospheric ozone depletion	6,23%	93,56%	0,21%	0,000	kg CFC11 eq
Terrestrial acidification	9,04%	90,43%	0,54%	0,703	kg SO2 eq
Terrestrial ecotoxicity	22,33%	76,95%	0,71%	224,381	kg 1,4-DCB
Water consumption	4,92%	94,92%	0,16%	3,010	m3

Tab. 2 – Results for an electric motor of 2.6 kg

A relevant impact category to be evaluated more in detail is Global Warming. This category is impacted at almost 93% by the use phase, mainly driven by those markets whit a significant electricity production share from high GHG emission-intensive sources (i.e. lignite and hard coal), such as Germany or Poland.

For what concerns the production phase, accounting for 6.7% of the entire process, hard coal mine operations, permanent magnet production and electricity production are among the Top 5 contributions showed in Figure 8. However, it is not easy to identify real major contributors, as the carbon impact seems to be evenly distributed across all process operations.

For a more detailed picture, the list of all operations with an impact higher than 1% is reported in Figure 9.

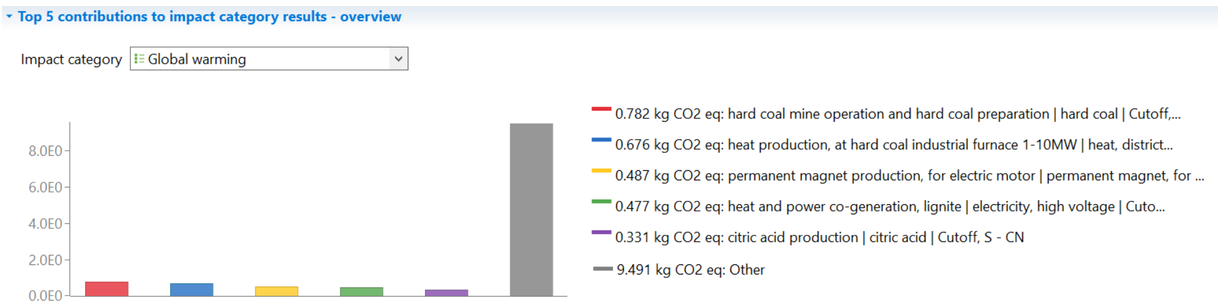

Fig. 8 – Production process Top 5 contributions to global warming

Impact analysis: ReCiPe 2016 Midpoint (H)

Subgroup by processes ☑ Don't show < 1 %

Name	Category	Impact result	Unit
Global warming		12.24296	kg CO2 eq
P hard coal mine operation and hard coal preparation | hard coal | Cutoff, U	051:Mining of hard coal / ...	0.78232	kg CO2 eq
P heat production, at hard coal industrial furnace 1-10MW | heat, district or	353:Steam and air conditio...	0.67566	kg CO2 eq
P permanent magnet production, for electric motor | permanent magnet, fo	242:Manufacture of basic ...	0.48701	kg CO2 eq
P heat and power co-generation, lignite | electricity, high voltage | Cutoff, U	351:Electric power generati...	0.47657	kg CO2 eq
P citric acid production | citric acid | Cutoff, S - CN	201:Manufacture of basic c...	0.33078	kg CO2 eq
P aluminium production, primary, liquid, prebake | aluminium, primary, liqu	242:Manufacture of basic ...	0.31193	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.28981	kg CO2 eq
P electricity production, natural gas, conventional power plant | electricity, h	351:Electric power generati...	0.24963	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.23044	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.21943	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.17323	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.17033	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - RoW	351:Electric power generati...	0.15315	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.15074	kg CO2 eq
P pig iron production | pig iron | Cutoff, U - RoW	241:Manufacture of basic i...	0.14411	kg CO2 eq
P electricity production, lignite | electricity, high voltage | Cutoff, U - AU	351:Electric power generati...	0.13889	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.13394	kg CO2 eq
P electricity production, hard coal | electricity, high voltage | Cutoff, U - CN-	351:Electric power generati...	0.12598	kg CO2 eq

Fig. 9 – List of most impacting contributions of production process

3.2 SENSITIVITY ANALYSIS

A *project* is applied to compare the three scenarios of life cycle for different motor weights. Final results for all the impact categories are showed in Table 3.

Same results are also plotted in a bar graph (Figure 10), that compares the impact of the different scenarios on each category in terms of relative percentage.

Impact Category	baseline	+0.5 kg	+1 kg	Unit
Fine particulate matter formation	0,2877	0,2876	0,2901	kg PM2.5 eq
Fossil resource scarcity	48,2373	47,8672	47,9591	kg oil eq
Freshwater ecotoxicity	23,4389	24,2184	25,1762	kg 1,4-DCB
Freshwater eutrophication	0,1761	0,1742	0,1739	kg P eq
Global warming	182,0230	180,9640	181,6310	kg CO2 eq
Human carcinogenic toxicity	17,5611	18,0743	18,7241	kg 1,4-DCB
Human non-carcinogenic toxicity	198,2490	201,8560	207,1120	kg 1,4-DCB
Ionizing radiation	85,7585	84,2280	83,5603	kBq Co-60 eq
Land use	5,3709	5,4854	5,6439	m2a crop eq
Marine ecotoxicity	29,3160	30,2662	31,4407	kg 1,4-DCB
Marine eutrophication	0,0434	0,0492	0,0551	kg N eq
Mineral resource scarcity	1,7817	2,0641	2,3493	kg Cu eq
Ozone formation, Human health	0,3476	0,3480	0,3514	kg NOx eq
Ozone formation, Terrestrial ecosystems	0,3515	0,3518	0,3554	kg NOx eq
Stratospheric ozone depletion	0,0001	0,0001	0,0001	kg CFC11 eq
Terrestrial acidification	0,7035	0,7020	0,7070	kg SO2 eq
Terrestrial ecotoxicity	224,3810	230,7420	238,8650	kg 1,4-DCB
Water consumption	3,0095	2,9791	2,9779	m3

Tab. 3 – Results for different motor weight scenarios

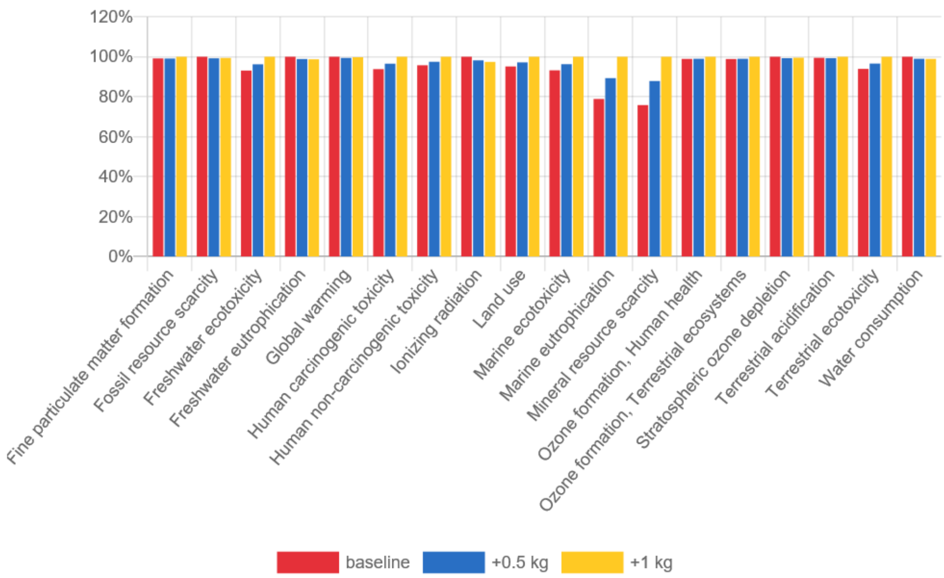

Fig. 10 – Comparison of results from different weight scenarios

Looking in more detail at Global Warming category, Figure 11 shows the impact of each phase for the three scenarios analyzed.

It can be observed that there is no significant difference in the total impact between the three weight options, since the amount of CO2eq saved during the use phase with a higher efficiency motor is compensated by the more emissions required to produce a heavier motor.

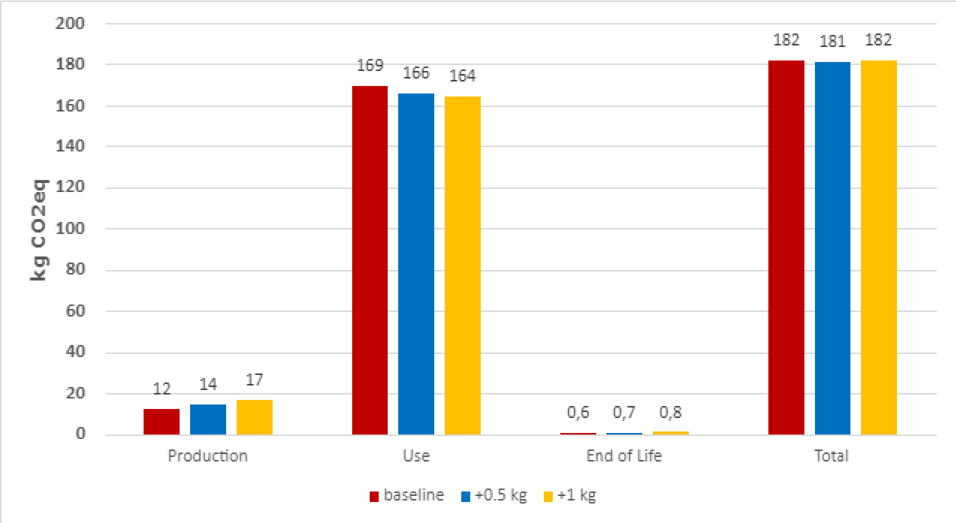

Fig. 11 – Impact on global warming of different weight scenarios

4. INTERPRETATION OF RESULTS

The results obtained show that, for almost all impact categories, the hotspot of the entire life cycle is the use phase. Specifically for the Global Warming, it accounts for almost 93% of the total impact. As the main contributor is the electricity production, the results may vary when considering a local and more specific energy mix, instead of the average European mix taken in account in this analysis.

The sensitivity analysis results show that the comparison between different electric motor weights is not straightforward and final conclusions can depend on which impact category is considered.

For most of the categories, the difference between the three scenarios can be considered almost negligible. For example, scenario n.2 (3.1kg-mass electric motor), that has the least impact in terms of Global Warming, shows only 1 kg of CO2eq reduction during the entire life cycle, since a higher efficiency during the use phase is compensated by a more carbon-intensive process to produce a motor with higher mass.

On the other hand, there are few categories where the impact of a heavier motor is more significant, such as Marine eutrophication or Mineral resource scarcity, where the total impact is up to 25% higher by adding 1 kg of materials to the electric motor.

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