AALTO UNIVERSITY
School of Science
Product Sustainability AAN-C2007

Life cycle report

Fairy lights

Task 3

Team 8
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Milla
Tanguy
Déborah
Samuli
Elodie

Abstract

The purpose of this work was to make a life cycle analysis of fairy lights, as part of the *Product Sustainability* course. Based on our calculations and estimations, our task was to design a new greener and more sustainable version of the product, and to perform the same LCA analysis in order to compare them. In addition to different internet sources, we used GRANTA EduPack, SimaPro, and OpenLCA to perform our calculations.

According to our LCA analysis, the most impactful parts of our product were the steel leaves that covered the LED lights on our garland, the batteries, and the PCB (Printed Circuit Board). The worst impacts were human toxicity, with and without cancer effects, and freshwater ecotoxicity. Based on these findings, we changed some materials to make our product greener and also more durable to increase the lifespan.

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Functional unit definition

We choose the following functional unit to make our Life Cycle Assessment:

"Enlighten during 400 hours"

The functional unit represents the average time of use for one garland during its average lifetime.

Green solutions and improvements

Our goal was to make our product, fairy lights, more sustainable and build a greener version. We made a LCA analysis using different tools and also studied all the materials individually. According to these findings we made some material changes and new greener solutions (see Table 1).

Classic fairy light	**Green version**
Batteries (3xAA)	Mains operated
Battery case	-
PCB	*No changes*
Screws	-
Cable (Wire & Wire sheats (PVC))	Halogen-free electric wire (Polypropylene (PP)) 2 m more length & 1 mm more thickness
Steel leaves	Wicker leaves
LED lights	*No changes*
Label & instructions	All printed to the packaging if possible
PET packaging box	Recycled cardboard

Table 1. Changes in materials and solutions

1. From batteries to mains operated

To reduce waste and the environmental cost of heavy metal extraction, we decided to change the batteries to a mains operated system. Even though some batteries are rechargeable, they still need to be changed at some point and need to be recycled separately. In Finland, most used batteries are alkaline batteries which are non-rechargeable [1]. Different metals used in batteries like lithium, nickel, cobalt, graphite, manganese, zinc, and potassium are creating different issues due to mining, environmental destruction, and pollution [2]. Due to this change we no more need the battery case or screws but we need to add some length to the cable to get enough reach.

2. From PVC to PP cable

To make our product more recyclable and having less impacts, we decided to change PVC (polyvinyl chloride) cable to halogen-free PP (polypropylene) cable. PP is 100% recyclable and contains carbon and hydrogen. It is manufactured without any dangerous emissions where PVC on the other hand is manufactured with the addition of a plethora of toxic additives [3]. Halogen-free cable also increases fire safety because they do not emit toxic gases in case on fire [4].

In addition to making our product more durable we wanted to add a little bit more thickness to our cable to protect it from physical damage, hence improving the lifespan of the fairy lights.

3. From steel to wicker leaves

The leds of the garland were covered with a fancy leaf looking steel structure. The steel leaves were shown to be the second most impactful component of the fairy light (LCA). We used Granta Edupack to search for alternative materials to replace the Copper coated stainless steel. Beyond the production impact of steel leaves, they are mechanically vulnerable to physical damage as we tested the durability when taking our product apart. The first solution of embedding the led into bulk translucent leaves would solve this problem. Granta Edupack allowed us to narrow the choice of suitable materials by establishing several criteria in terms of mechanical, optical, sustainable and safety criteria (see Diagram 1). From this diagram, we deducted that the most suitable material is PVC elastomer shore A75 [A.3]

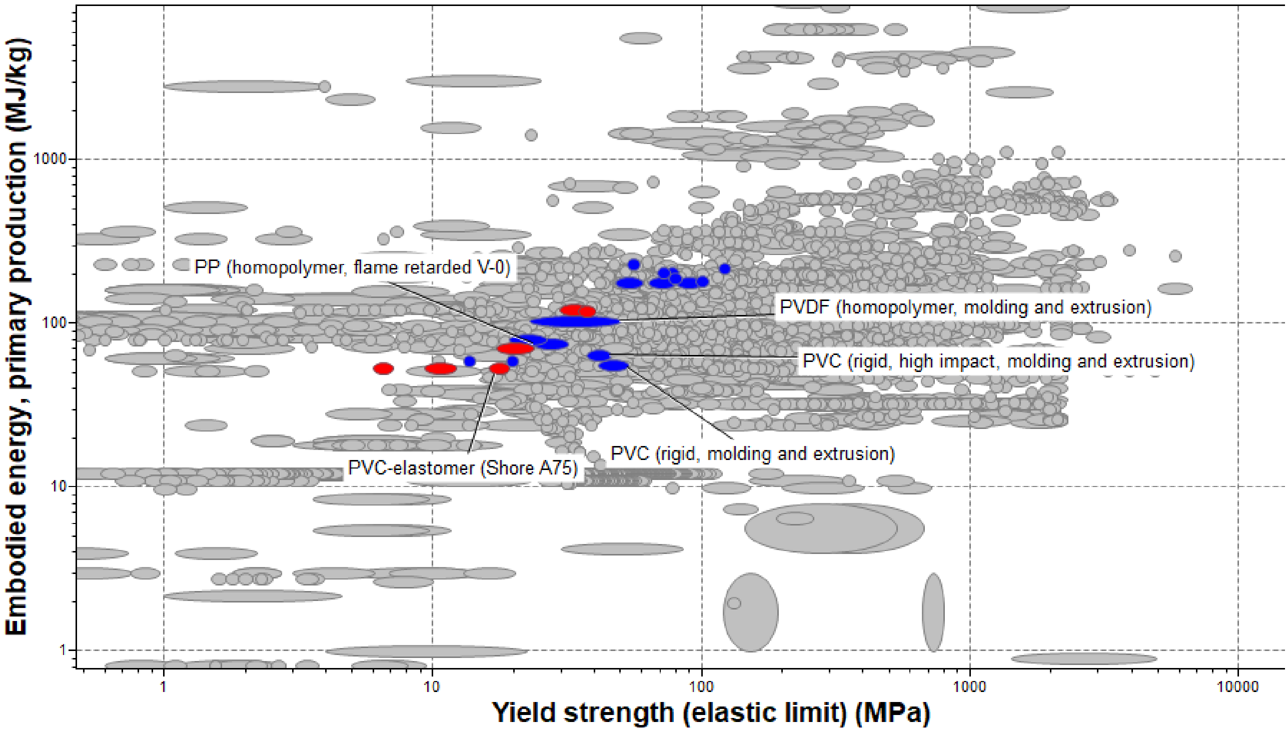

Diagram 1. Comparing different options for plastic leaves solution

The second solution is bio-based and it uses already existing wicker balls (see Figure 1). Wicker balls have a quite high resistance to physical damage. They also exhibit a natural design that enhances the perception of an eco-friendly product, which is good from a marketing point of view.

Figure 1. Wicker balls

To decide and to be sure to make the greenest possible decision, we made a comparison of the environmental impacts of the steel, PVC and wicker leaves (see Diagram 2). The wicker balls solution was by far the least impactful, so we decided to pick this one for our product. We add two more wicker balls to enable the customer to replace it in case of damage rather than throw away the fairy light.

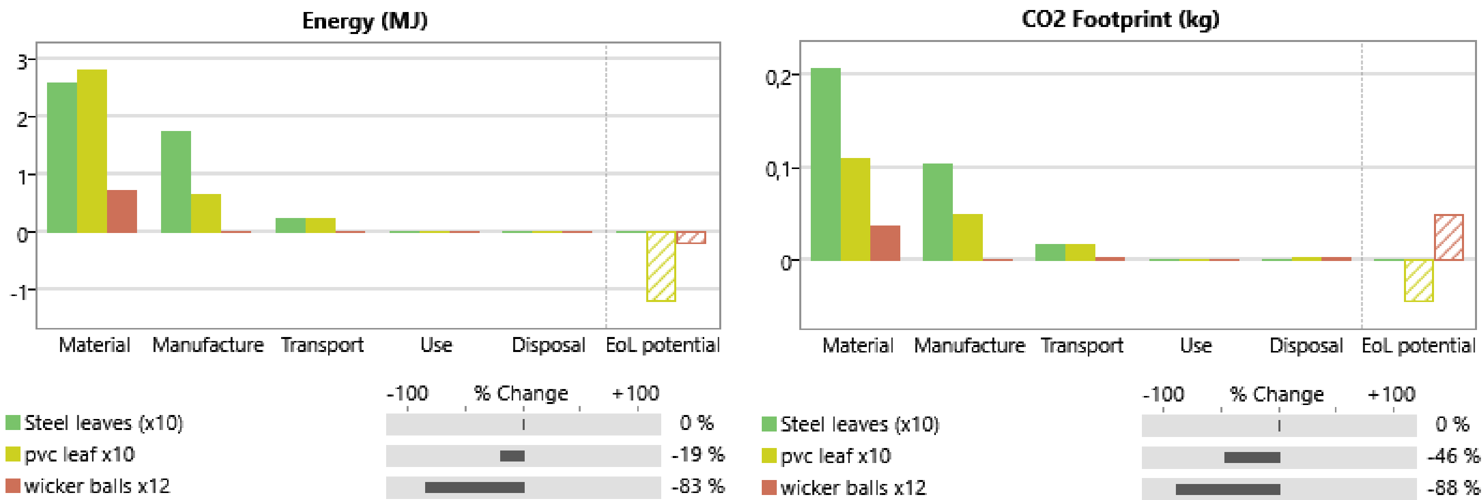

Diagram 2. Comparison between the steel, PVC and wicker leaves solutions

4. From PVC to recycled cardboard box

To reduce waste and excess materials we decided to have all the instructions and needed information printed on the packaging if possible. To comply with EU regulations we need to include relevant documents like the EU Declaration of Conformity and safety instructions [5]. With the packaging we decided to change the soft PVC box to recycled cardboard to have a more durable packaging. Even though plastic is more efficient to manufacture and produces less waste during the process than cardboard [6] we estimated that we can increase the lifetime of our product with the cardboard packaging because they are better for storing. Furthermore, the packaging should give a sustainable image of the product, which is necessary to advertise the fairy light as a green product. We made a comparison for the production of the PVC packaging [A.1] and the cardboard packaging [A.2] (see

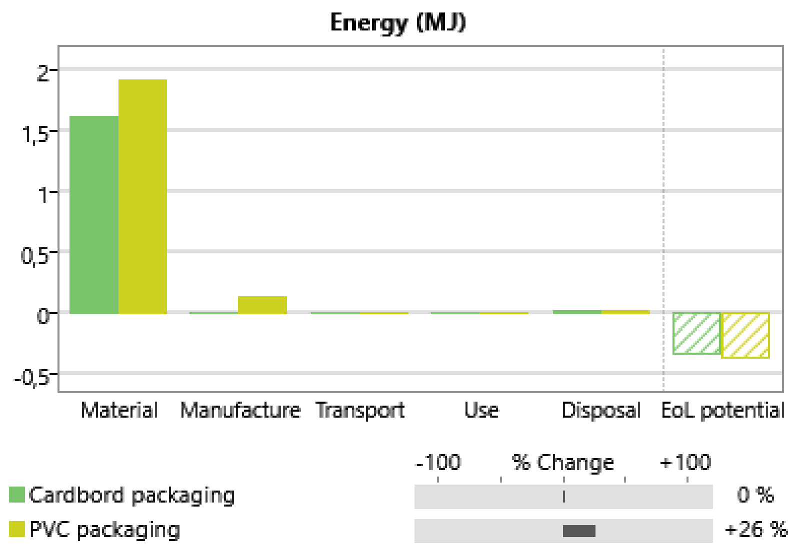

Diagram 3.)

Diagram 3. Comparison between PVC and cardboard packaging

The environmental impacts are slightly in favor of the cardboard. Most importantly cardboard will provide a stronger packaging and it is biodegradable. Considering the advantages the cardboard packaging solution is adopted.

Recycling instructions

The changes made to our product do not affect its status as an electrical device, so the same recyclability regulations and standards still apply after the changes. In the EU region, the recycling and recovery of electronic devices are regulated with directives, the most significant being WEEE [7]. As the producer of our product (Marksjöld) states, they try to recover the used products and work with third-party recycling companies to recover all recyclable materials from the products [8]. The EU region enforces electronic device producers to take care of the costs of their product's waste management and recycling [9]. Consumers are encouraged to return electronic devices into collection sites if no other specific instructions are given to the product recycling. We will write this and other end of life instructions on the box in order to influence the customer into having the best behaviour.

What is excluded

As the alternative solutions on PCB (wire-wrap and point-to-point construction) are old-fashioned and do not bring any major benefits [10], we chose to not change anything on the current PCB solution.

The PCB in our product is already quite small (~10cm^2), so optimizing the size does not bring any significant benefits.

We also decided to leave the LEDs in our product as-is, because LEDs are currently one of the most efficient ways of producing lighting [11]. LED power consumption is small in comparison with the traditional light bulbs. Also LEDs' energy consumption is already really well optimized and has a rather low impact compared to fairy light manufacturing processes. Therefore we excluded the energy consumption from our LCA analysis. The LED size is also suitable for this kind of product, so there was no need to change that either. In addition, they also last significantly longer than traditional light bulbs, so it is also better in this case.

Inventory Analysis

Inventories are presented in Annex 5 and 6. The main assumptions that we made are:

- Battery cells lifetime enable to enlight during 100 hours
- A fairy light enlights 400 hours during its average lifetime
- The classic fairy light was manufactured in China and thus, transported for around 6000 km
- The green version would be manufactured in Finland to have less transport and to use finnish electricity
- A 32 tons truck can transport 4902 fairy lights
- In the two cases, we choose the Netherlands waste scenario.

Impact Assessment

In our LCA calculations we did impact analysis for each part in our original and green product. We found out that the steel leaves, batteries, and PCB were the most impactful components and the worst impacts were human toxicity, with and without cancer effects, and freshwater ecotoxicity. We decided to take the steel leaves as our main focus when designing the green version. We changed some parts and materials as presented above. In our final comparison we compared PVC and willow solutions (see Diagram 4).

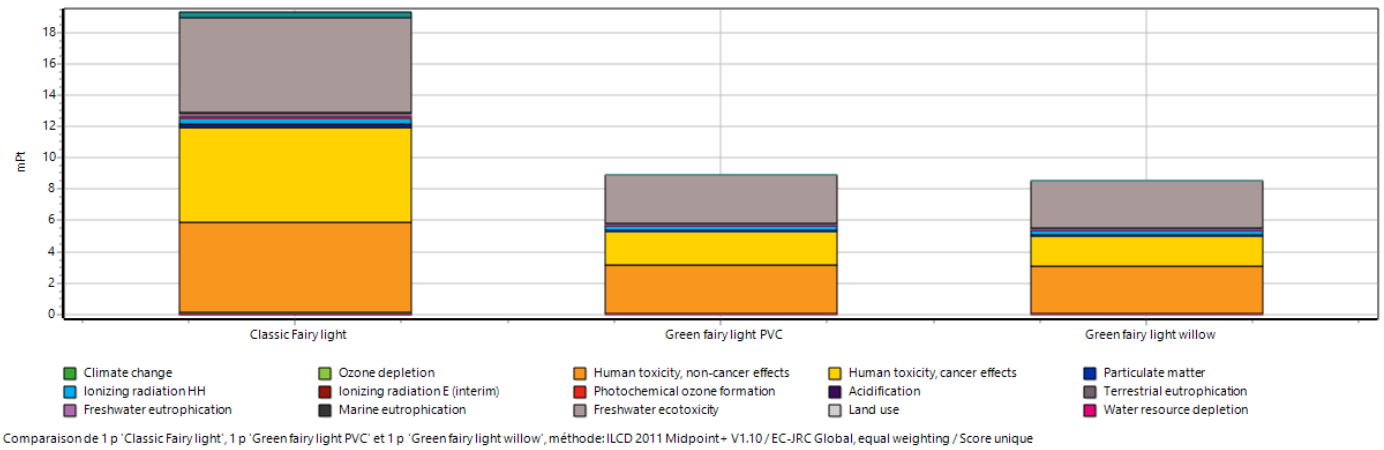

Diagram 4. Comparison of classic fairy light with PVC and willow leaves solution

Depending if we want to keep the original design of the leaves, PVC leaves are the greener solution. Wicker ball is an even greener solution if the design is not really important.

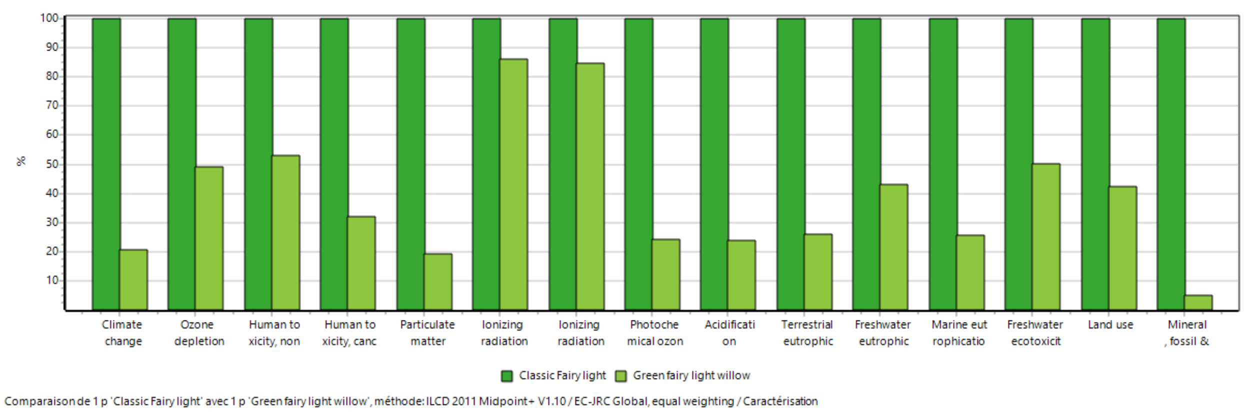

Diagram 5. Impact comparison of classic fairy light with PVC and willow leaves solution

It is here clearly visible that all impacts were reduced significantly with our greener version (see Diagram 5). Notably, climate change effects are only 1/5th of what they were: for the classic fairy light CO2 impact is 12kg CO2 emitted, while for the green version we manage to divide it by 5 with only 2,48 kgCO2 emitted. Toxicity is divided by three; indeed for the classic fairy light the Comparative Toxic Unit for humans (CTUh) is $1{,}12 * 10^{-6}$ CTUh while for the green version it is $3{,}6 * 10^{-7}$. Terrestrial eutrophication is divided by three with 0,127 molc N eq for the classic fairy light against 0,0329 molc N eq for the green version We achieved this by changing the two components that had the worst impact : steel leaves and batteries.

As a conclusion, we could say that sometimes small changes and better material choices can have a lot of impact. With our product, our goal was to propose a sustainable option to the customers and also guide them towards better sustainability and consumption behaviour.

Resources

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https://www.paristokierratys.fi/en/how-to-recycle/battery-family/allie-alkaline-battery/

[2] Francesca de la Torre. 2019. Batteries.
https://www.ethicalconsumer.org/energy/shopping-guide/batteries

[3] Megara. Polypropylene vs PVC.
https://megara.com.au/wp-content/uploads/2017/06/fact-sheet_pp-Vs-pvc.pdf

[4] Incore Cables. What are halogen-free cables.
https://www.incore-cables.com/what-are-halogen-free-cables/

[5] LightingEurope. 2019. Guidelines.
https://www.europeanlightingpriorities.eu/books/2/LE_ELR%20Guidelines.pdf

[6] Devitt Matthew. 2020. Plastic vs Cardboard Packaging: A Complex Choice.
https://theecobahn.com/packaging/plastic-vs-cardboard-packaging-a-complex-choice/

[7] Waste Electrical & Electronic Equipment (WEEE)
https://ec.europa.eu/environment/waste/weee/index_en.htm

[8] Markslojd - About us
https://markslojd.com/en-fi/markets/se/help/about-us

[9] Extended Producer Responsibility (EPR)
https://ec.europa.eu/environment/archives/waste/eu_guidance/introduction.html

[10] PCB
https://en.wikipedia.org/wiki/Printed_circuit_board

[11] LED
https://en.wikipedia.org/wiki/Light-emitting_diode

Annexes

[Annex 1] : Original packaging

The original packaging is made of PVC shore 85 and it is 30% recycled for the end of life. Its weight is 21.1g and it comes with a paper instruction manual weighing 13.2g.
The impact of this solution is the following one :

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	1,92	93,2	0,0646	86,1
Manufacture	0,127	6,2	0,00956	12,7
Transport	0	0,0	0	0,0
Use	0	0,0	0	0,0
Disposal	0,0119	0,6	0,000833	1,1
Total (for first life)	**2,06**	**100**	**0,075**	**100**
End of life potential	-0,363		-0,00971	

[Annex 2] : Cardboard packaging

The cardboard packaging weighs 30g, it is 30% recycled after disposal and the instructions are printed on it (no need for the paper one).
The impact of this solution is the following one :

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	1,63	99,0	0,0429	97,4
Manufacture	0,00386	0,2	0,000296	0,7
Transport	0	0,0	0	0,0
Use	0	0,0	0	0,0
Disposal	0,012	0,7	0,00084	1,9
Total (for first life)	**1,64**	**100**	**0,0441**	**100**
End of life potential	-0,327		-0,000455	

[Annex 3]: PVC elastomer solution

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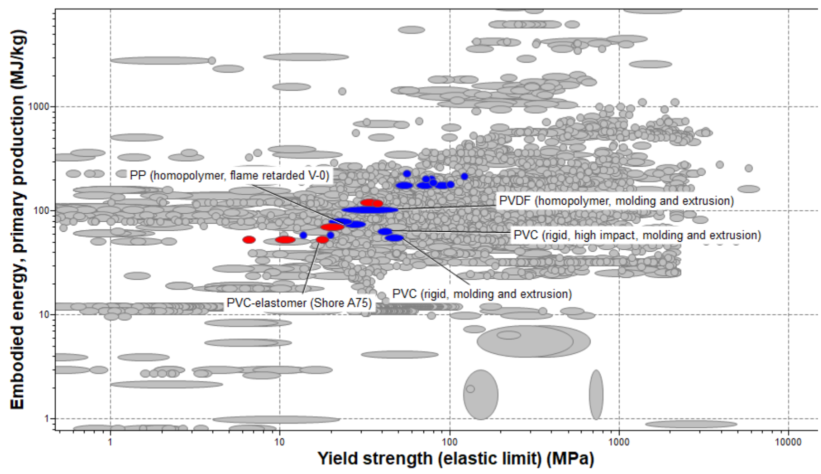
We require a low environmental impact material fitting the following criteria :

- optical properties : translucent or transparent
- mechanical properties : high elastic limit, low brittleness
- safety : not flammable
- sustainability : recyclable material
- cost : avoiding expensive materials

The different materials matched the criteria :



The most suitable material is elastomer PVC shore A75 (flame retarded) because its texture is not vulnerable to scratches which makes it more durable. After volumic characteristics consideration, the model of using 39.2g of material for manufacturing 10 leaves appears to be convenient (approximately 3cm x 2cm x 0.5 cm leaves). The hauling conditions are the same as for steel leaves and 60% of end of life recycling is assumed.
The impact of this solution is the following one :

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	2,8	75,8	0,109	62,2
Manufacture	0,654	17,7	0,0491	28,0
Transport	0,22	6,0	0,0158	9,0
Use	0	0,0	0	0,0
Disposal	0,0195	0,5	0,00137	0,8
Total (for first life)	**3,69**	**100**	**0,175**	**100**
End of life potential	-1,17		-0,0434	

[Annex 4] : Wicker balls

60g of wood for 12 led cases (with 2 spare ones). This material can be produced locally with willow, thus reducing hauling to 400km. A 60% recovery ratio for incinerating is assumed.
The impact of this solution is the following one :

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	0,731	94,2	0,0362	91,8
Manufacture	0	0,0	0	0,0
Transport	0,0226	2,9	0,00162	4,1
Use	0	0,0	0	0,0
Disposal	0,0228	2,9	0,0016	4,1
Total (for first life)	**0,776**	**100**	**0,0394**	**100**
End of life potential	-0,185		0,0496	

[Annex 5] : Inventory classic fairy lights

	Classic fairy light		
Battery	Battery cell, Li-ion {GLO}| market for | Alloc Def, S	156	g
	Electricity, medium voltage {CN}| market group for | Alloc Def, S	3200	Wh
Battery case	Polypropylene, granulate {GLO}| market for | Alloc Def, S	22,6	g
	Thermoforming of plastic sheets {GLO}| market for | Alloc Def, S	22,6	g
PCB	Printed wiring board, surface mounted, unspecified, Pb containing {G	2,1	g
Screws	Steel, low-alloyed {GLO}| market for | Alloc Def, S	0,5	g
	Metal working, average for steel product manufacturing {RoW}| proc	0,5	g
Cable	Polyvinylidenchloride, granulate {GLO}| market for | Alloc Def, S	8,5	g
	Electric connector, wire clamp {GLO}| market for | Alloc Def, S	10,1	g
	Thermoforming of plastic sheets {GLO}| market for | Alloc Def, S	8,5	g
Wire sheats	Polyvinylidenchloride, granulate {GLO}| market for | Alloc Def, S	5,7	g
	Thermoforming of plastic sheets {GLO}| market for | Alloc Def, S	5,7	g
Leaves	Steel, low-alloyed {GLO}| market for | Alloc Def, S	39,2	g
	Laser machining, metal, with CO2-laser, 2000W power {GLO}| marke	10	min
	Selective coat, copper sheet, black chrome {RoW}| selective coating,	12	cm²
LED	Light emitting diode {GLO}| market for | Alloc Def, S	2,2	g
Label & instructions	Kraft paper, bleached {GLO}| market for | Alloc Def, S	13	g
	Paper, melamine impregnated {GLO}| market for | Alloc Def, S	1	g
PET box	Polyethylene terephthalate, granulate, amorphous {GLO}| market for	21,1	g
	Extrusion of plastic sheets and thermoforming, inline {GLO}| market	21,1	g
Transport	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc	1,2	tkm

[Annex 6] : Inventory green fairy lights

	Green Fairy light		
Cable green version	Polyvinylidenchloride, granulate {GLO}| market for | Alloc Def, S	17	g
	Electric connector, wire clamp {GLO}| market for | Alloc Def, S	20,2	g
	Thermoforming of plastic sheets {GLO}| market for | Alloc Def, S	17	g
Wire sheats	Polyvinylidenchloride, granulate {GLO}| market for | Alloc Def, S	5,7	g
	Thermoforming of plastic sheets {GLO}| market for | Alloc Def, S	5,7	g
PCB	Printed wiring board, surface mounted, unspecified, Pb containing {GLO}| market for | Alloc Def, S	2,1	g
LED	Light emitting diode {GLO}| market for | Alloc Def, S	2,2	g
PVC leaves	Polyvinylidenchloride, granulate {GLO}| market for | Alloc Def, S	39,2	g
	Injection moulding {GLO}| market for | Alloc Def, S	39,2	g
	OR		
Willow leaves	Wood chips and particles, willow {DE}| willow production, short rotation coppice | Alloc Def, S	60	g
Cardboard box	Folding boxboard/chipboard {GLO}| market for | Alloc Def, S	21,1	g
	Printing ink, offset, without solvent, in 47.5% solution state {GLO}| market for | Alloc Def, S	1	g
Transport	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Def, U	0,122	kmt
Energie	Electricity, medium voltage {FI}| market for | Alloc Def, S	3,2	kWh
Waste scenario	Waste (waste scenario) {NL}| treatment of waste | Alloc Def, SWaste (waste scenario) {NL}| treatment of waste | Alloc Def, S		