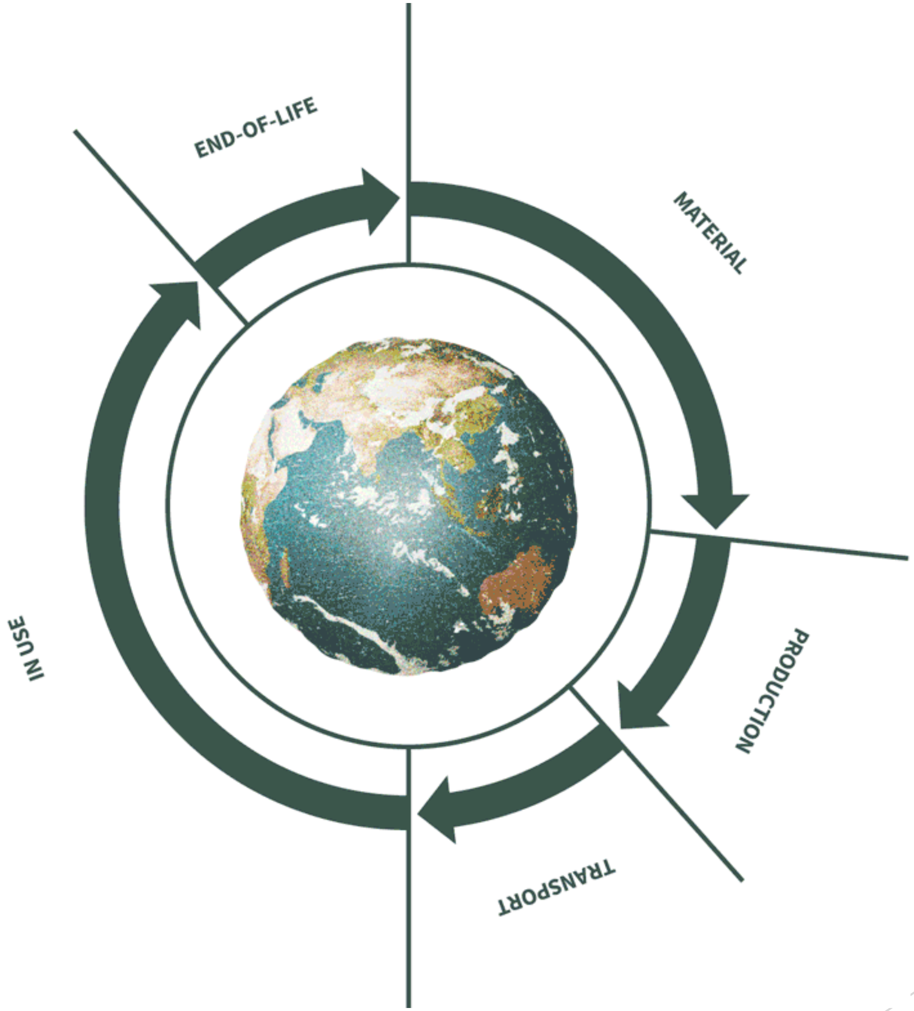
Life Cycle Assessment of LED luminaire and impact on lighting installation

Keywords

- Life Cycle Assessment;
- Lighting;
- Energy efficiency;
- LED luminaire



Abstract

- In the presented study the Life Cycle Assessment of a LED suspended luminaire manufactured in Romania was performed, with the use of One Click LCA software. The results of the calculations show that the main environmental impact of the LED luminaire is generated by the operational energy use (96.046 % percent of the total global warming potential fossil kg CO2e). The environmental impact at the manufacturing stage is determined mainly by the aluminum, found in higher percentage in the LED luminaire body, fixing clips, LED module and LED driver. The analysis was extended for a lighting installation composed of the studied LED suspended luminaire. The analysis was extended for a lighting installation composed of the studied LED suspended luminaire.

Introduction

- The Life Cycle Assessment (LCA) for a product or a building enables the quantification of their impact on the environment, for the selected lifetime period. The LCA is performed considering all of the stages in the development, operation and disassemble of the product or building: product, assembly, use and end-of life stage.

- The building sector represents one of the most important sector for improvement in reducing the CO_2 emissions and climate mitigation. The CO_2 emissions account for 20 ÷ 55 % for the used materials and 45 ÷ 80 % for the operation stage, both depending on the construction standard. As stated in, a focus on better construction and better use of buildings could lead to up to 42 % reduction in the energy consumption, 35 % reduction of greenhouse gas emissions, 30 % reduction in water consumption and can reduce significantly the extraction of new materials.

- The aim of this paper is to perform the life cycle assessment for an LED suspended luminaire and, through it, to determine the luminaire environmental impacts. The second goal is to determine the operational energy needed for the lighting installation through the simulation of the lighting system, to reduce the operational energy using the simulation and subsequently to calculate the environmental impacts for the lighting installation.

II. Materials and methods

- **2.1 Goal and purpose of the LCA**
  - The objective of the work is to investigate a selected LED suspended luminaire during its entire life cycle taking into consideration the manufacture, operation and end-of-life stages. Life cycle assessment was performed in accordance with the EN 15804+A2, ISO 14025 and ISO 21930 recommendations, using the One Click LCA software.

- Analysis includes product stage (A1-A3), transportation to the site and installation (A4-A5), use stage (B1–B6) and end-of-life stage (C1–C4) [29]. Global warming potential is expressed in kilogram of equivalent emissions of CO_2 within the system boundary "Cradle to Grave" with functional unit of the LED luminaire. As reference year was selected 2021 and stages considered in the analysis are shown in the Table 1.

Table 1. Life cycle diagram from cradle to grave considered for the LED suspended luminaire

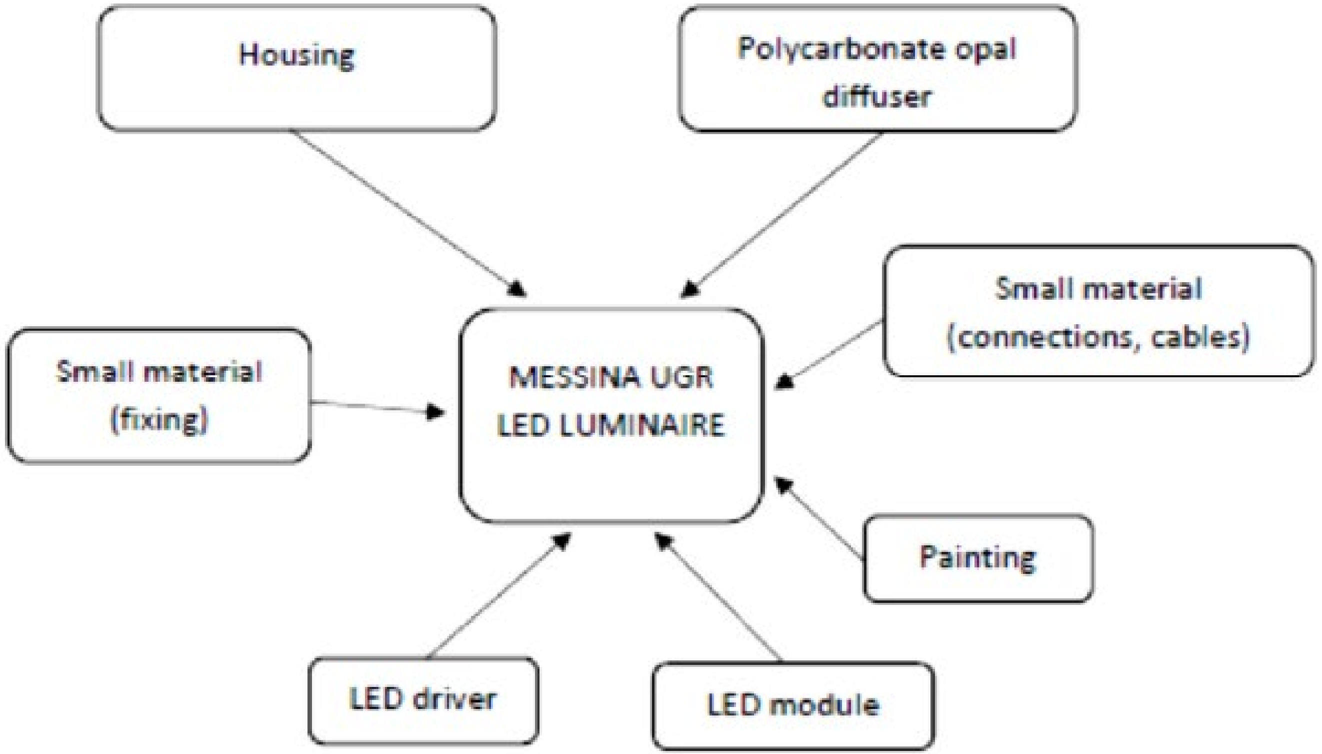
Product stage			Assembly stage		Use stage							End of life stage			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
Raw materials	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction /demolition	Transport	Waste processing	Disposal

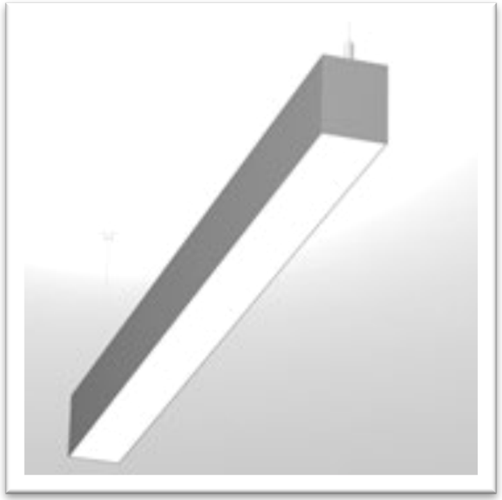
2.2 Inventory analysis

- The life cycle inventory includes, at first, the quantification of materials, transport, manufacturing processes and energy consumptions at the product and assembly stage. The use stage takes into consideration the operational energy and the water consumption. The end-of-life stage represents deconstruction, transportation to the place of the waste processing and finally recycling, reusing or landfilling. The luminaire selected for the study has the characteristics presented in Table 2.

Functional unit	LED suspended luminaire
Producer	V.E.M. Proiect Lighting, Almalux
Installation	Suspended
Luminaire luminous flux	3950 lm
Correlated colour temperature	4000 K
LED module luminous efficacy	166 lm/W
Luminaire luminous efficacy	94 lm/W
Electrical installed power	42 W
Electrical product protection class	IP 43
R_{UGL} index	<19
Mechanical protection degree	IK 02
Architecture	Aluminium painted with polyurethane powders by polymerization in the oven at 180°C, UV stabilized (unalterable)
Optics	Micro-prismatic
Ambient temperature	-20 ... +40 °C
IEC protection class	Safety class I
Lumen depreciation	L90F10 at 65°C > 60.000 h

- The luminaire emits a luminous flux of 3950 lm, at 4000 K, with a luminous efficacy of 94 lm/W. With a reduced glare (R_{UGL}<19) it ensures the workplace lighting according with EN 12464-1:2021 [30] standard prescriptions. It is designed to be used in office, educational rooms, residential and shopping centres with an electrical product protection class of IP 43. It can be installed also in environments with dust and humidity levels above average.
- The LED suspended luminaire is comprised, as seen in next figure, of an aluminium LED housing painted with polyurethane powders, a driver power supply with electric protection, a LED linear module with electronic control system, a polycarbonate opal diffuser, small materials used for connection and fixing (electrical cables, connection plugs, screws).
- The LED aluminium housing is manufactured from aluminium extruded profile, which has excellent thermal and electrical conductivity properties. It plays an important part in the dissipating and transferring of heat from the LED array. Also, it is 100 % recyclable and a corrosion-free material. The aluminium extrusion process is performed by heating the aluminium and applying force to it, with the use of a hydraulic ram placed within a shaped opening in the die. After the extrusion process is finalized, the output aluminium will be cooled, straightened, quenched, and then cut.





LED suspended luminaire: a) components of the luminaire; b) picture of the luminaire

- The polycarbonate opal diffuser, with high transparent properties and micro-structured prismatic surface, enables the radial emission of light from the optical light source, which has been fed into the diffuser in axial direction. The micro-structured prismatic surface allows the LED light source to achieve lower R_{UGL} values ($R_{UGL} \leq 19$), making the light source ideal for office areas, educational rooms and environments with computer screens, in accordance with EN 12464-1:2021. The polycarbonate is manufactured through chemical reactions between BPA and $COCl_2$. The BPA can be replaced by other diols to enhance or alter the physical properties. The manufacturing process includes operation such as drying, dosing, extrusion, die, calibration and cooling, cutting [40].

- The flow diagram of the LED suspended luminaire is presented in the next slide.

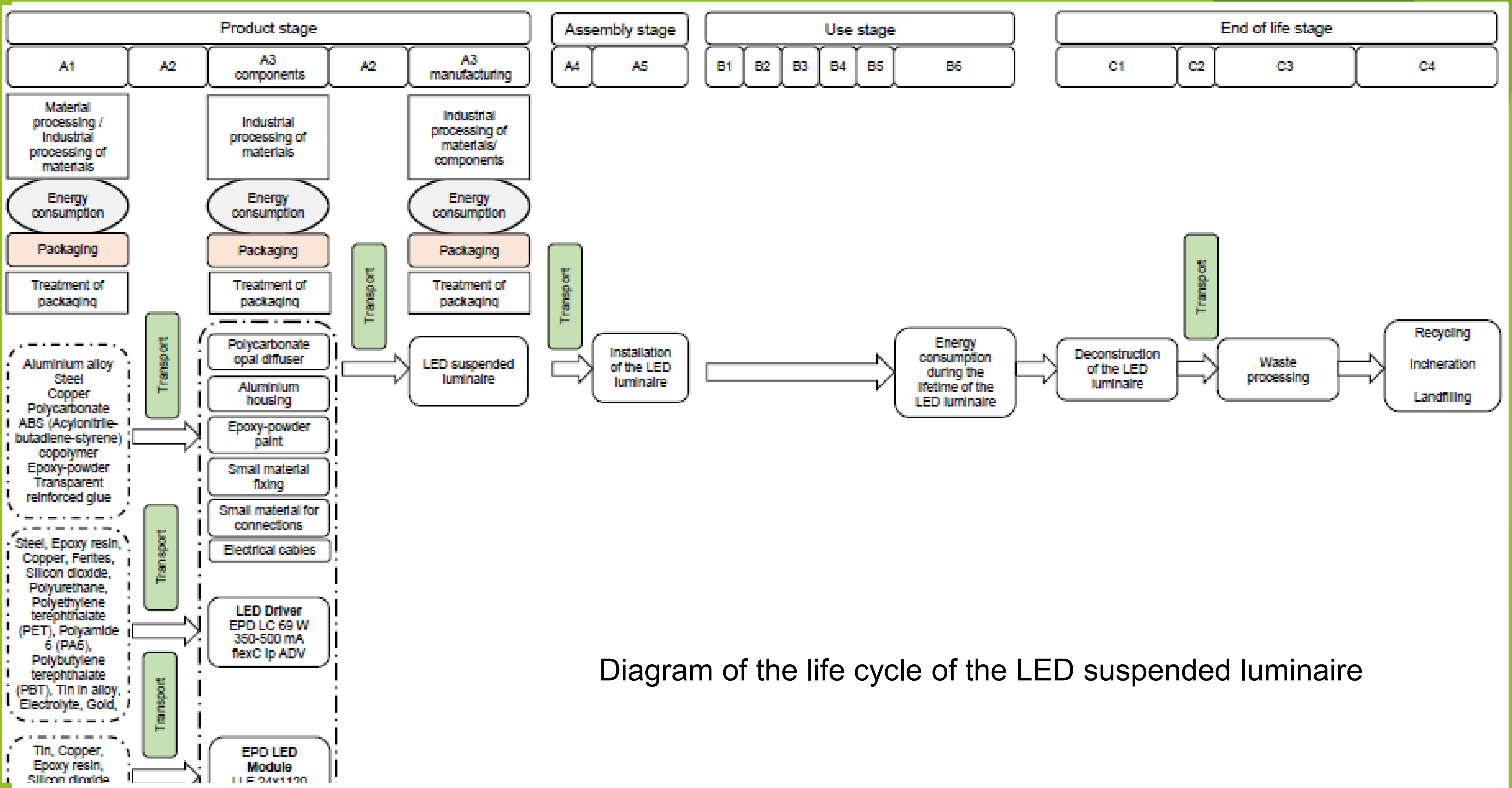


Diagram of the life cycle of the LED suspended luminaire

A. Product stage

- At the product stage the information regarding the product raw materials is provided by the manufacturer - detail information about the product components and their functions (materials, weights, manufacturing processes, origin, transport method and distances, energy consumptions). The materials are quantified in kg, as presented in Table 3. For the LED luminaire, a lifetime period of 20 years was considered.

- For each component, data points were selected from the One Click LCA database. The database contains more than 150,000 data points, each with specific technical description. In this way, impacts can be estimated for each of the component.

- Information about transportation methods and distances was also provided by manufactures for the reference year of 2021. The luminaire components are transported from different parts of Romania and Europe to the factory located in Bucharest. The transport of the components was performed via lorry (16 ÷ 32 metric ton, euro 5), and the considered distances are presented in Table 3. Packaging is also considered for each component. As precise data was unavailable, packaging is considered mainly as cardboard, regarded as approximately 10 % of the product components weight, similar to other studies.

Raw material	Quantity [kg]	Transport distance [km]
Aluminium extruded profile (body)	1.93	193
Epoxy powder paint	0.04	1196
Aluminium extruded profile (fixing clips)	0.46	193
Polycarbonate cable connector 2p+n	0.005	542
ABS cable gland	0.005	19
Copper electric cable FY 0.5mm	0.05	11
Copper electric ground wire	0.1	11
Copper electric cable 3X0.5 mm	0.01	11
Polycarbonate opal dispenser	0.13	1881
Iron screws M4	0.01	591
ABS Plastic taps	0.08	19
ABS plastic clips	0.08	19
LED Module	0.07	1690
LED Driver	0.18	1690
Driver selector plug	0.001	1690
Paper adhesive label 50X32 mm	0.02	12

B. Transportation and assembly stage

- The LED luminaires are mainly transported as multiple products to the place of use in wooden pallets. The transport data, distances and method of transport were retrieved from the luminaire manufacturer. It was assumed, for the simulation, that the LED luminaire was transported internally in Romania via lorry (>32 metric ton, euro 5), with a covered distance of 400 km. The installation of the LED suspended luminaire takes into consideration the transport and the treatment of the package materials – wood pallets waste, polyethylene, and paperboard.

C. Use stage

- The operational energy use of the LED suspended luminaire is modelled based on the energy consumption and product lifetime. The lifetime of the LED luminaire is estimated for the study case, at 50,000 h (20 years). According with the manufacturer information, at the end of the operating life (60,000 h), the LED luminaire is expected to provide at least 90 % of the initial luminous flux, with 10 % led chips failing rate. There will be no luminaires replaced during the lifetime period.

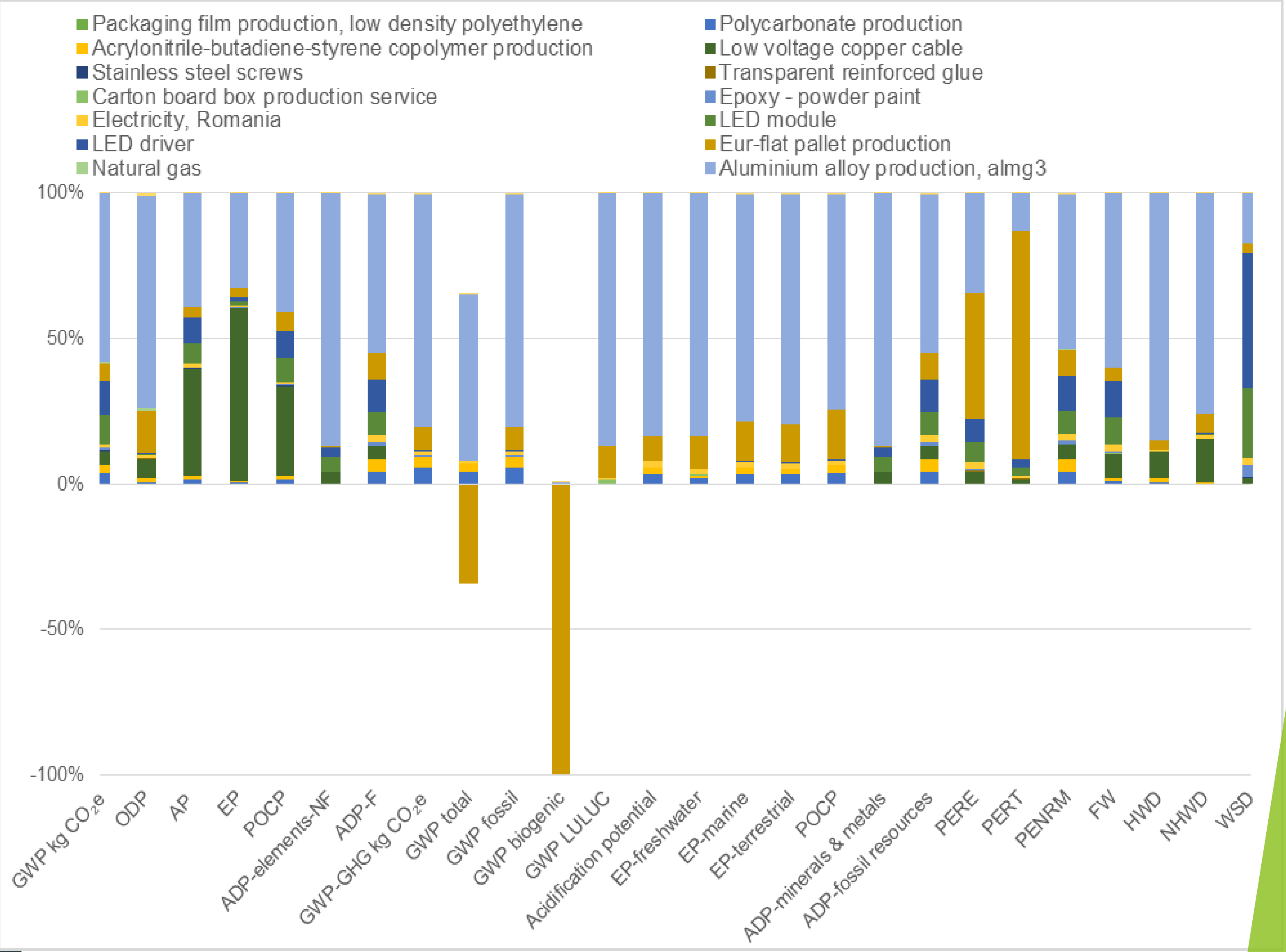
D. End of life stage

- The End-of-Life scenario is performed by taking into consideration the material split and their respective recycling rates. The LED luminaire is transported to the waste processing facility, where the equipment is dismantled. For the LED suspended luminaire, it is considered the treatment of aluminium scrap, used cable, waste plastic, electronics scrap, bulk iron and wastepaper.

- For the LED module and LED driver, according with the component manufacturer prescriptions, 70 % of the glass and the metal parts will be recycled. The plastics will be incinerated, and the remaining parts will be landfilled. [53,54]. The energy needed for the treatment of materials (ex. shredding processes) is included in the calculations.

Results and discussion

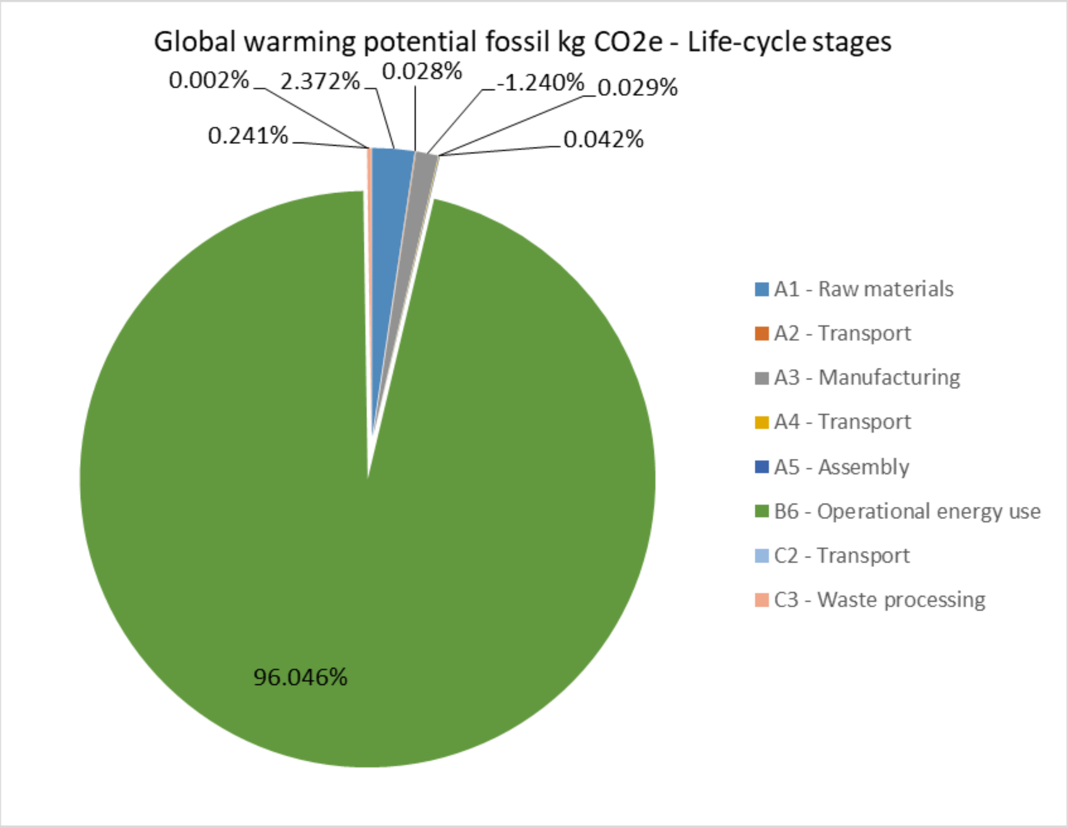
- The environmental impacts of the manufacturing stage of the LED suspended luminaire are presented in Figure 3. For each of the environmental impact categories, the resources involved in the manufacturing stage are divided by their impact percentage.

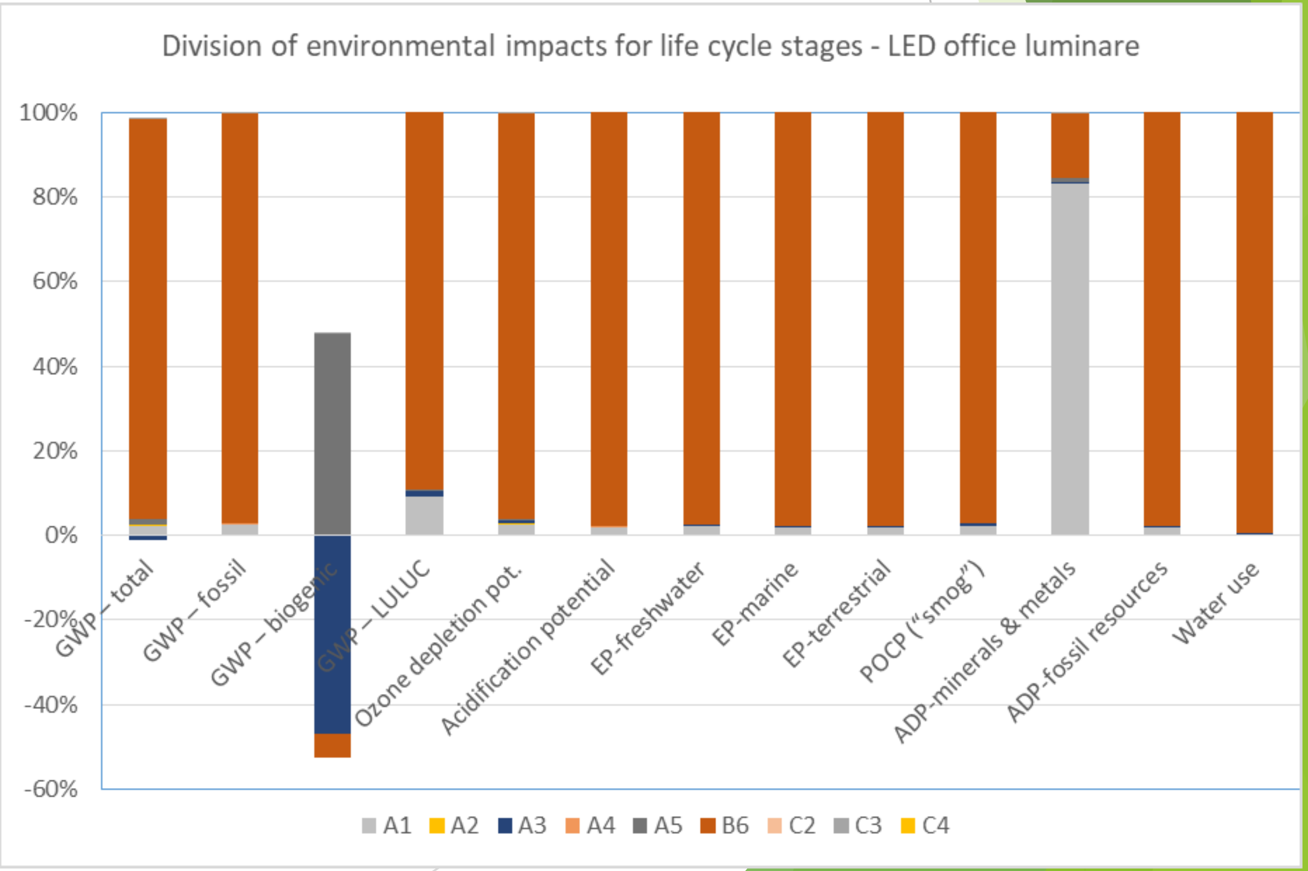


Environmental impact of the manufacturing stage of the LED suspended luminaire

- The aluminium parts used for the luminaire body, fixing clips, as well as in the LED module and LED driver, account for approx. 15 ÷ 75 % of the environmental impacts. The environmental impacts of the LED driver are more predominant especially on the ozone depletion and eutrophication potential. As presented also in studies [39,40], the components of the LED module and LED driver that have the highest environmental impact are electrolyte capacitors, steel, glass diodes.

- Figure 4 shows the environmental impact indicators of the LED luminaire for the product, assembly, use and end of life stages, including the energy consumption during the 50,000-h lifetime operation.





Environmental impacts for the LED suspended luminaire

Module	GWP[1]	ODP[2]	AP[3]	EP[4]	ADP-elements[5]	ADP-fossil fuels[6]	REPE[7]	NRE[8]	HW[9]	NHW[10]
A1	25.3	0.00000087	0.2	0.087	0.0084	298.31	37.05	305.8	3.56	40.76
A2	0.22	0.000000041	0.00045	0.000092	0.0000056	3.38	0.047	3.38	0.0034	0.26
A3	2.1006	1.7798E-07	0.010166	0.003421	0.00003105	39.41	145.1941	39.55	0.1361708	3.5936
A4	0.33	0.000000062	0.00068	0.00014	0.0000065	5.15	0.068	5.15	0.0052	0.54
A5	0.34301	1.76668E-08	0.0023884	0.00112097	8.43634E-05	4.7444	2.036788	4.8226	0.0416136	0.759132
B6	747.8	0.000024	5.2	1.24	0.00156	15961.4	3537.4	15961.4	32.8	1399
C2	0.018	3.3E-09	0.000036	0.0000074	0.00000031	0.28	0.0035	0.28	0.00027	0.03
C3	1.89142	4.49307E-08	0.00283628	0.001177433	1.34181E-05	5.65323	0.602015	5.65323	0	0

[1]Global Warming Potential [kg CO_2eq]; [2]Ozone Depletion Potential [kg CFC11eq]; [3]Acidification Potential [kg SO_2eq]; [4]Eutrophication Potential [kg PO_4e]; [5]Abiotic Depletion Potential (ADP-elements) for non-fossil resources [kg Sbeq]; [6]Abiotic Depletion Potential (ADP-fossil fuels) for fossil resources [MJ]; [7]Total use of renewable primary energy [MJ]; [8]Total use of non-renewable primary energy [MJ]; [9]Hazardous waste disposed [kg]; [10]Non hazardous waste disposed [kg].

- From Figure 4 and Table 4 it can be observed that the electrical energy used for the operation of the LED suspended luminaire, throughout the entire lifetime, represents the main environmental impact contributor in the majority of the categories. Because of this reason and taking into consideration that the LED luminaire can be dimmed, with considerably reduction of the electrical energy use, an LCA of a lighting installation was considered for evaluation.

Illuminance simulation and life cycle impact assessment for a lighting installation

- A simulation is performed to establish the LCA for the lighting installation for different educational rooms, by implementing the solution with the studied LED suspended luminaire and by considering the natural light contribution. In the simulation, only the LED suspended luminaires contribution is taken into consideration, without the daylight sensors and electrical cables. For the simulation, the educational rooms from of the Building Services Engineering Faculty, Technical University of Cluj-Napoca were selected. They have the same configuration, as it usually happens in educational buildings.

Lighting installation simulation: a) location of the educational rooms of Building Services Engineering Faculty, Technical University of Cluj-Napoca; b) educational room selected for simulation

- The selected educational room has approximately 48 m^2, with three equal windows covering a wall, each of the windows having the dimensions of 2.45 m x 1.4 m (height 1.4 m). The room surfaces have a reflection factor of 20/50/70. The task area was set at 0.75 m. For the simulation, the 42 W LED suspended luminaire is used. The simulations are performed using DIALux Evo 11 software, in accordance with EN 12464-1:2021 standard prescriptions.

- At first, the number of the luminaires needed in the room and the luminous characteristics were established, without considering the natural light contribution. Table 5 presents the luminous characteristics at the working plane (0.75 m height) determined by using 9 LED suspended luminaires in the room.

Eav	Emax	Emin	Emin/Emax
lx	lx	lx	
511	660	343	0.67

DIALux Evo 11 simulation illuminance levels at work plane level

- Next, using the natural daylight calculation feature of DIALux Evo 11, a series of simulations have been performed. The software calculates the required illuminance level at the work plane, while taking into consideration the natural daylight and, when required, the artificial light from the LED luminaires. This is performed while considering the implementation of a daylight sensor inside each of the rooms considered for the studies. The quantity of daylight transmitted into the room through the room windows can be assessed annual, daily, and hourly. [63,64].

- Four cases are considered:

1). Educational room 109 without artificial control;

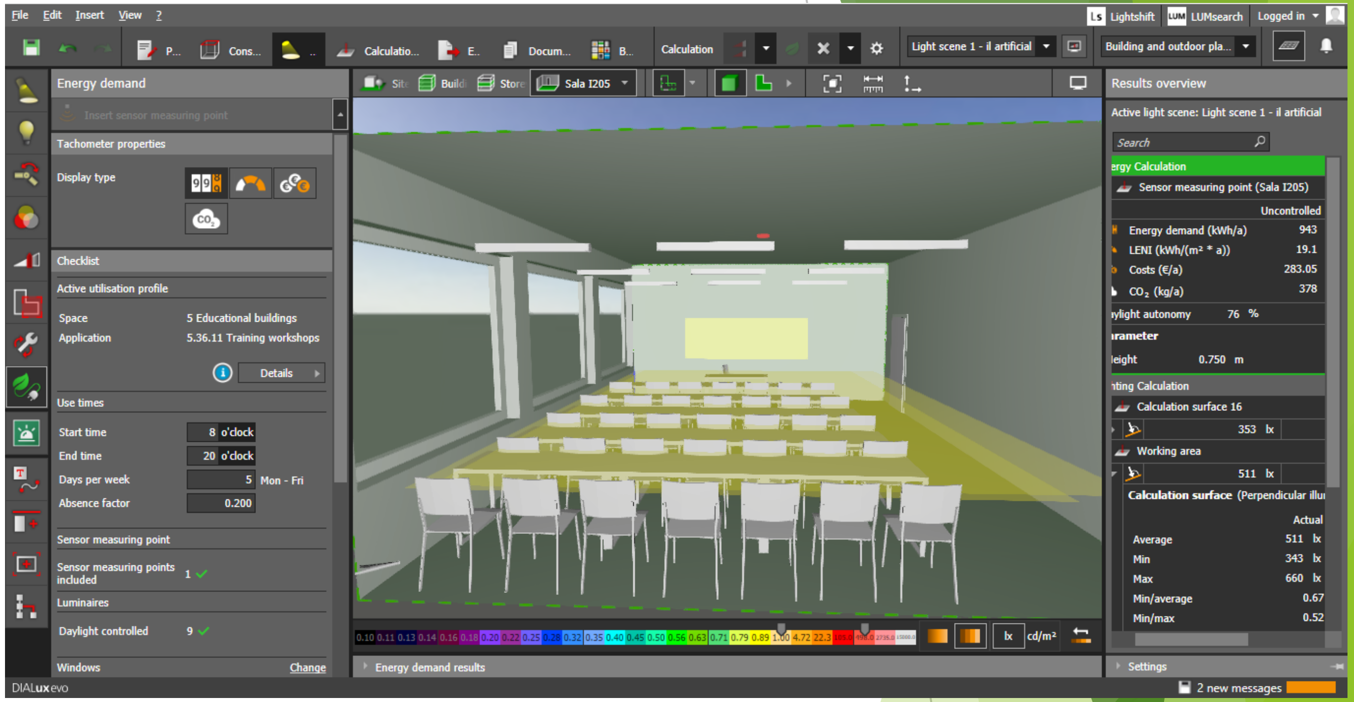
2). Educational room 109, situated at the 1st floor of the Faculty of Building Services Engineering, facing Southeast (with an angle of 27° from South towards East);

3). Educational room 107, situated at the 1st floor of the Faculty of Building Services Engineering, facing Southwest (with an angle of 62° from South towards West);

4). Educational room 205, situated at the 2nd floor of the Faculty of Building Services Engineering, facing Northwest (with an angle of 27° from North towards East).

Building Services Engineering Faculty, Technical University of Cluj-Napoca:

a) 1st floor – Educational rooms 109, 107; b) 2nd floor – Educational room 205

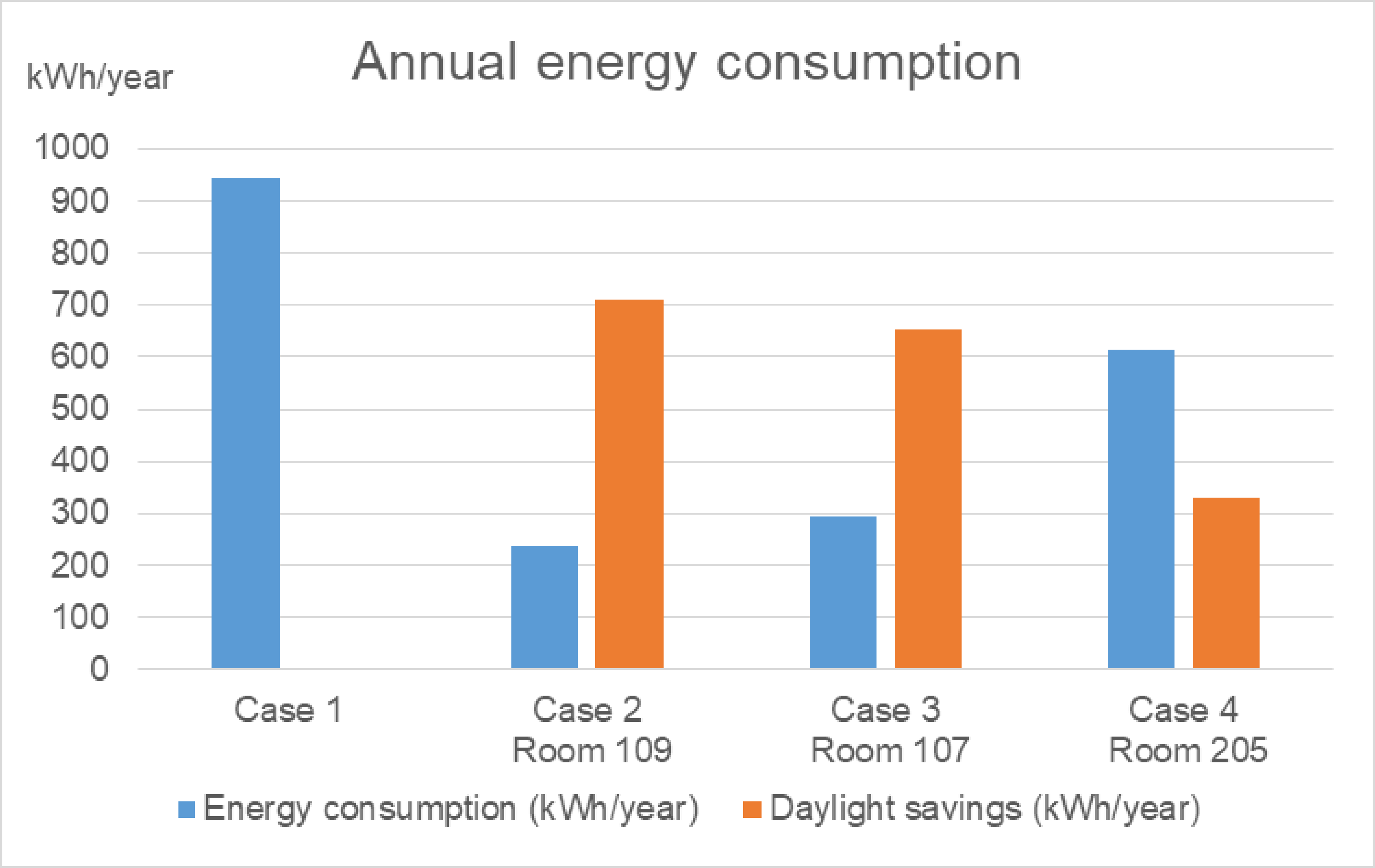


Natural daylight simulation:

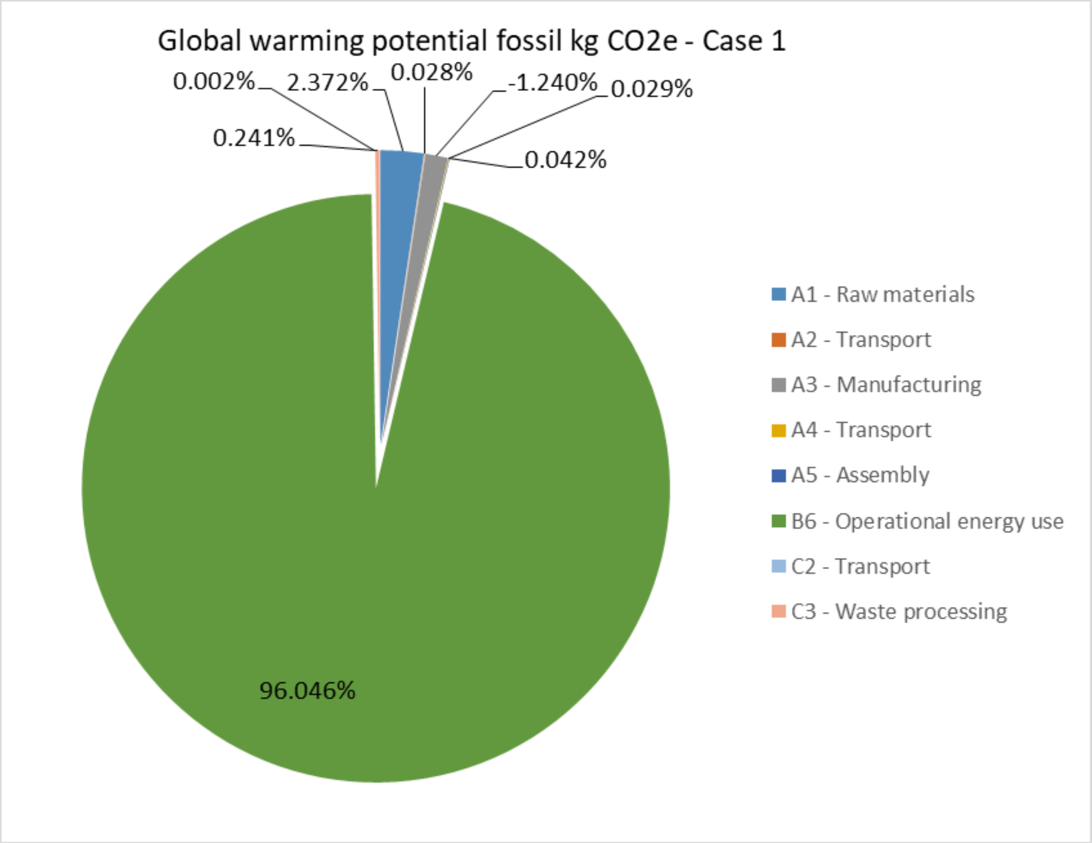
a) annual, daily, and hourly overview of the energy demand results

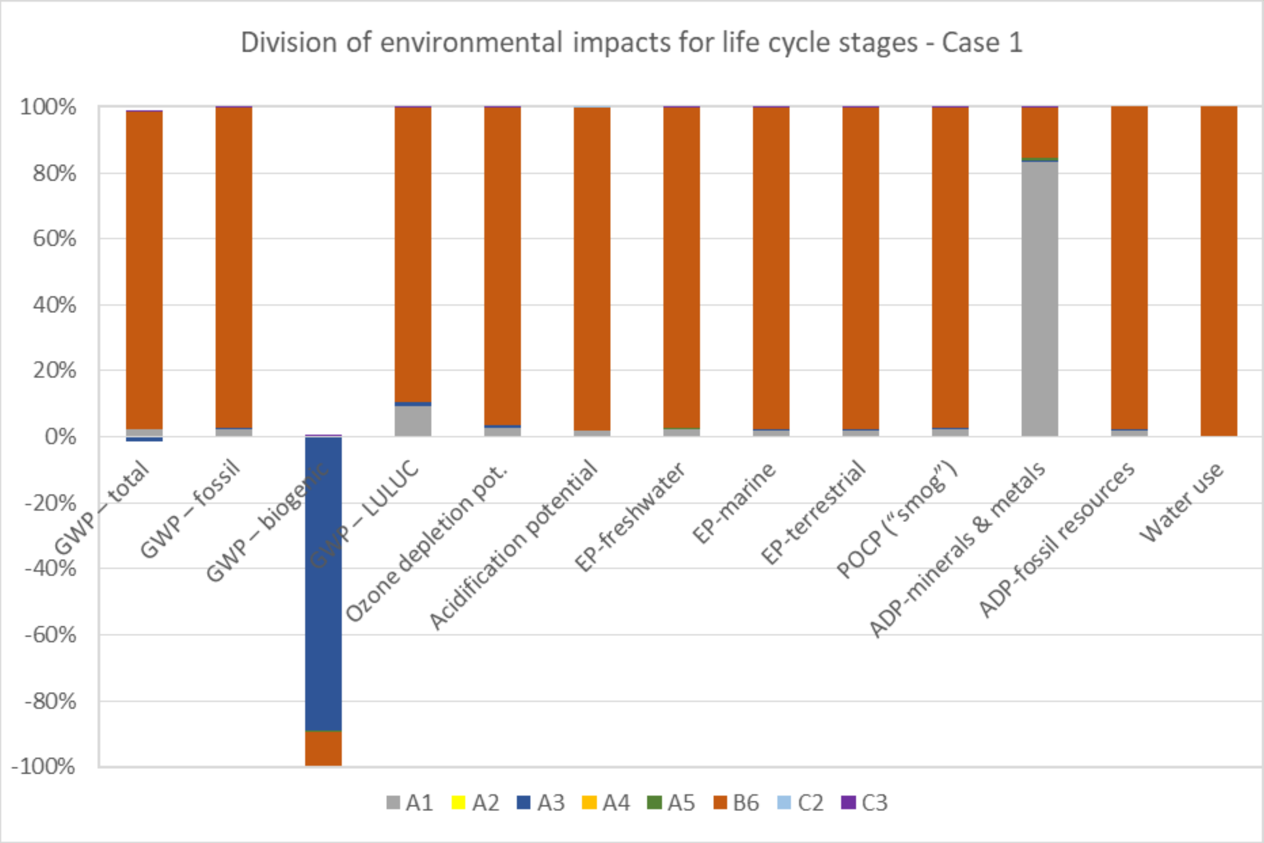
b) DIALux Evo 11 simulation for the educational room 109

- The annual energy consumption considering the analysed four cases is detailed in Figure 8. The daylight autonomy represents the saving potential of daylight control for the installed lighting system. The percentage varies from 35 % - for the educational room with windows facing Northwest (educational room 205), 69 % - for the educational room with windows facing Southwest (educational room 107), to 75% - for the educational room with windows facing Southeast (educational room 109).



Daylight energy savings compared with energy consumption for the studied cases

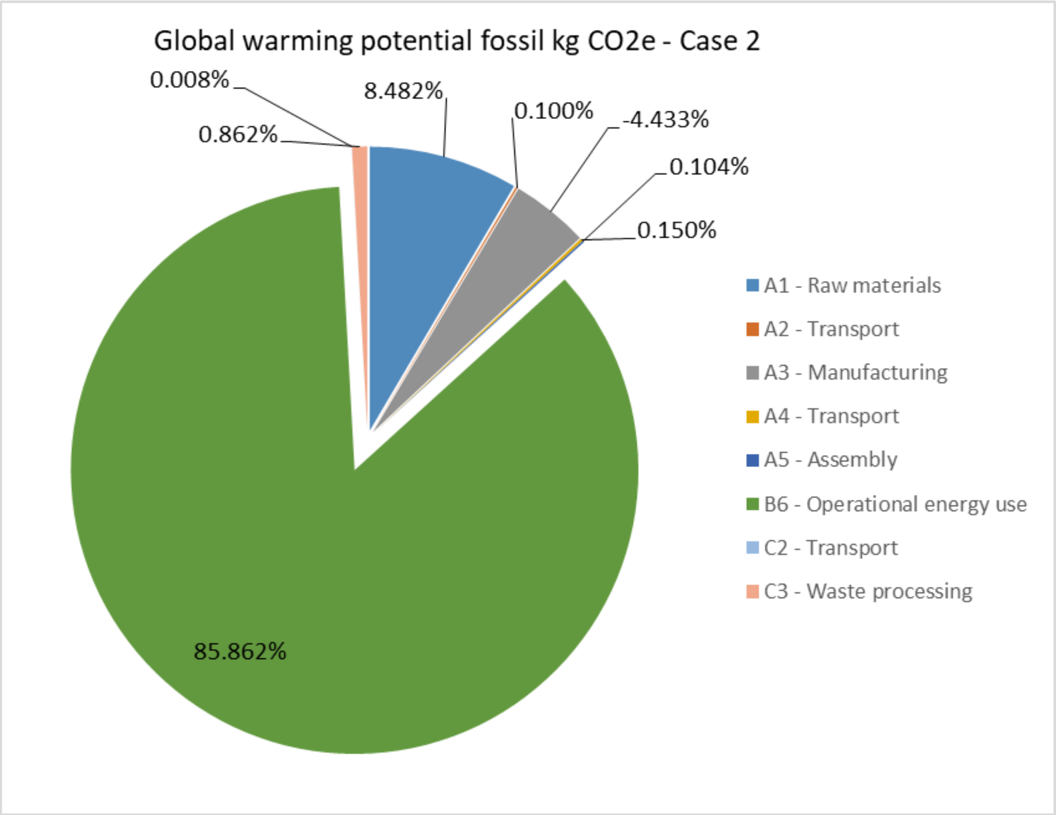


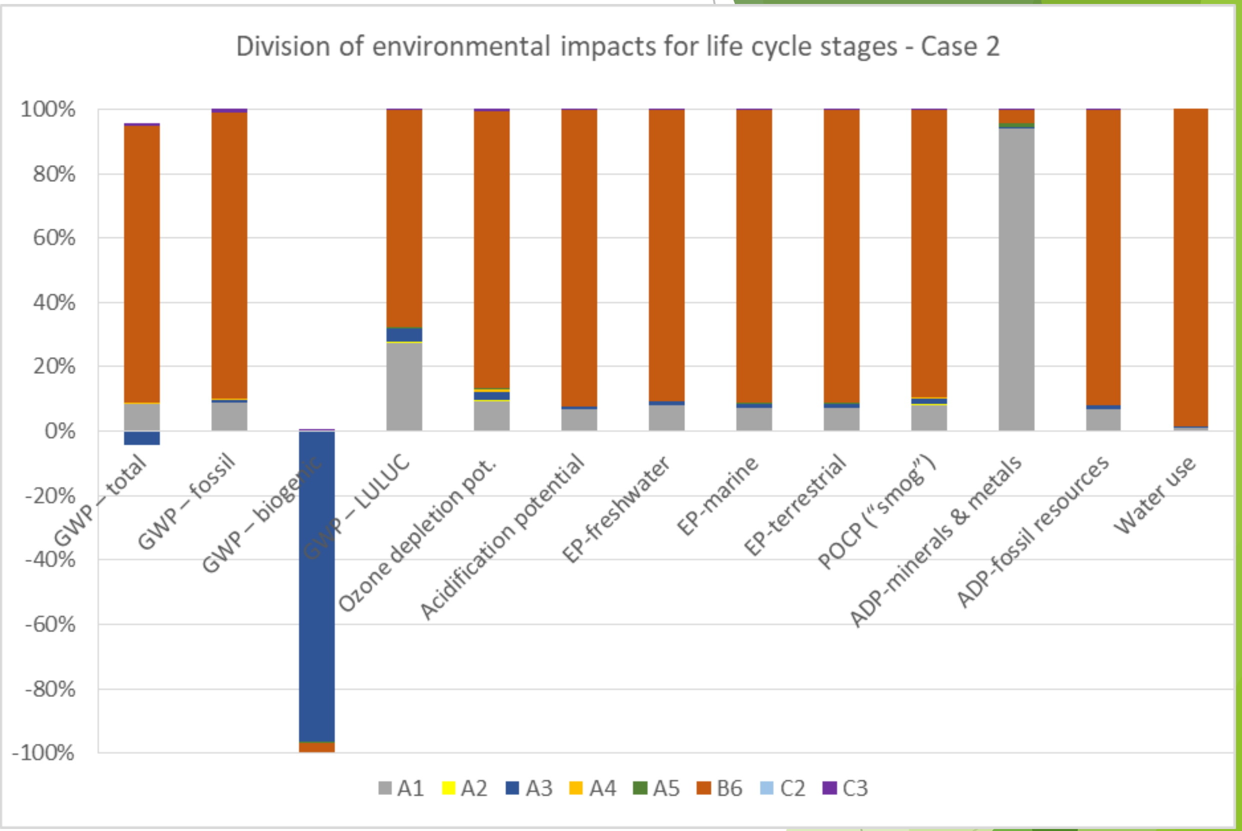


Case 1 - results of environmental impact indicators for the life cycle stages:

a) GWP-fossil

b) b) All analysed environmental impact indicators.

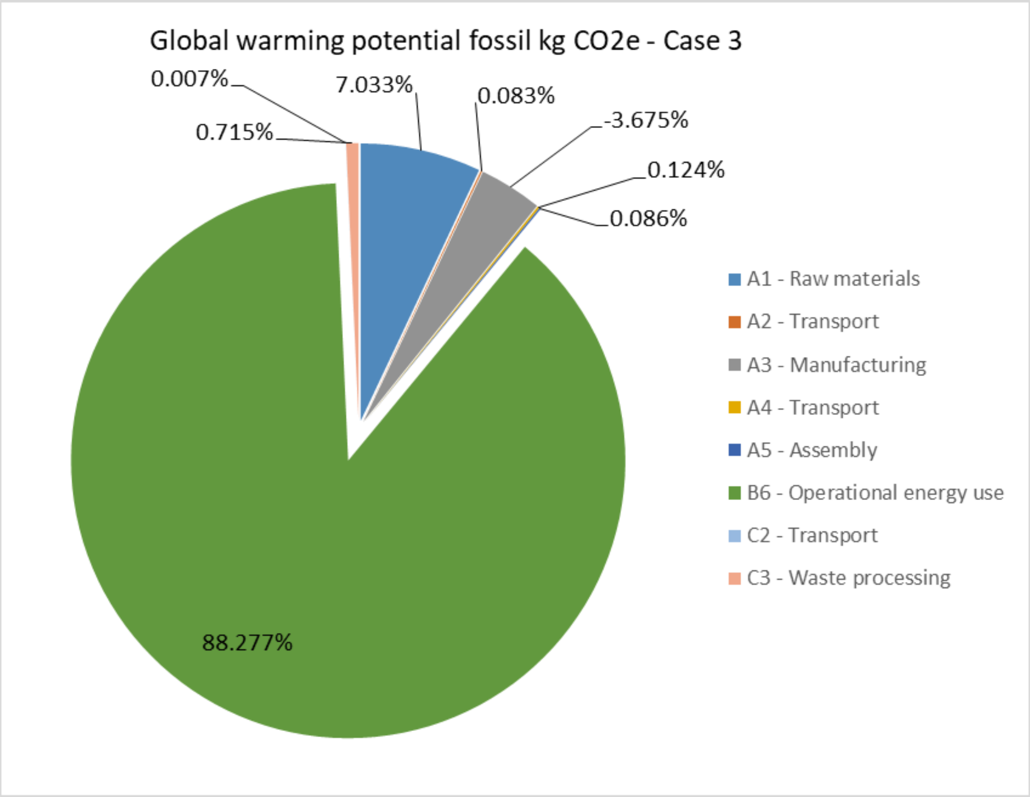


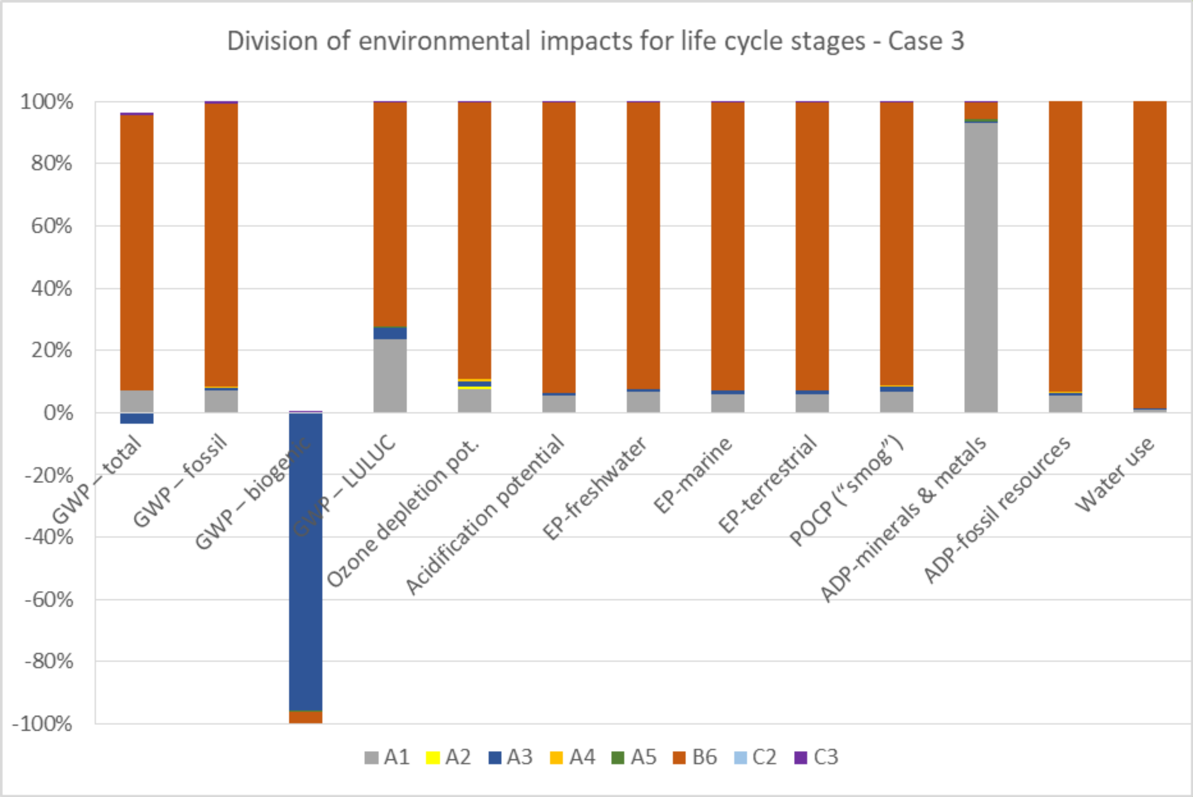


Case 2 - results of environmental impact indicators for the life cycle stages:

a) GWP-fossil

b) b) All analysed environmental impact indicators

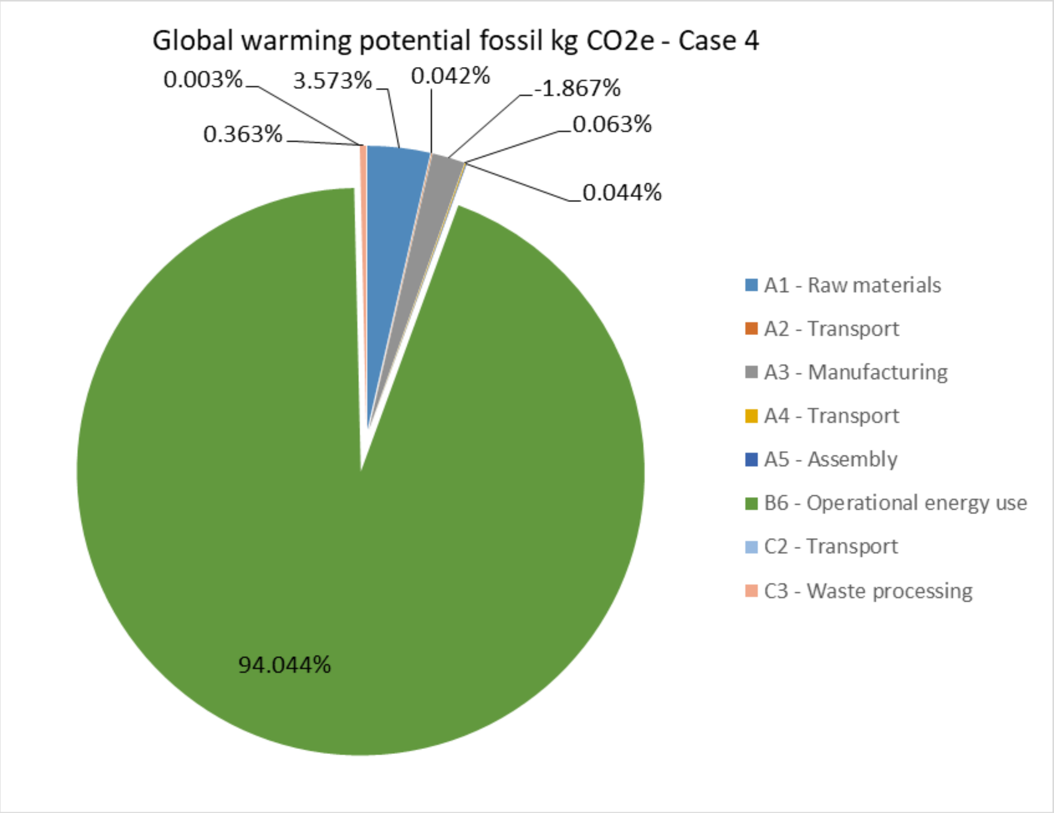


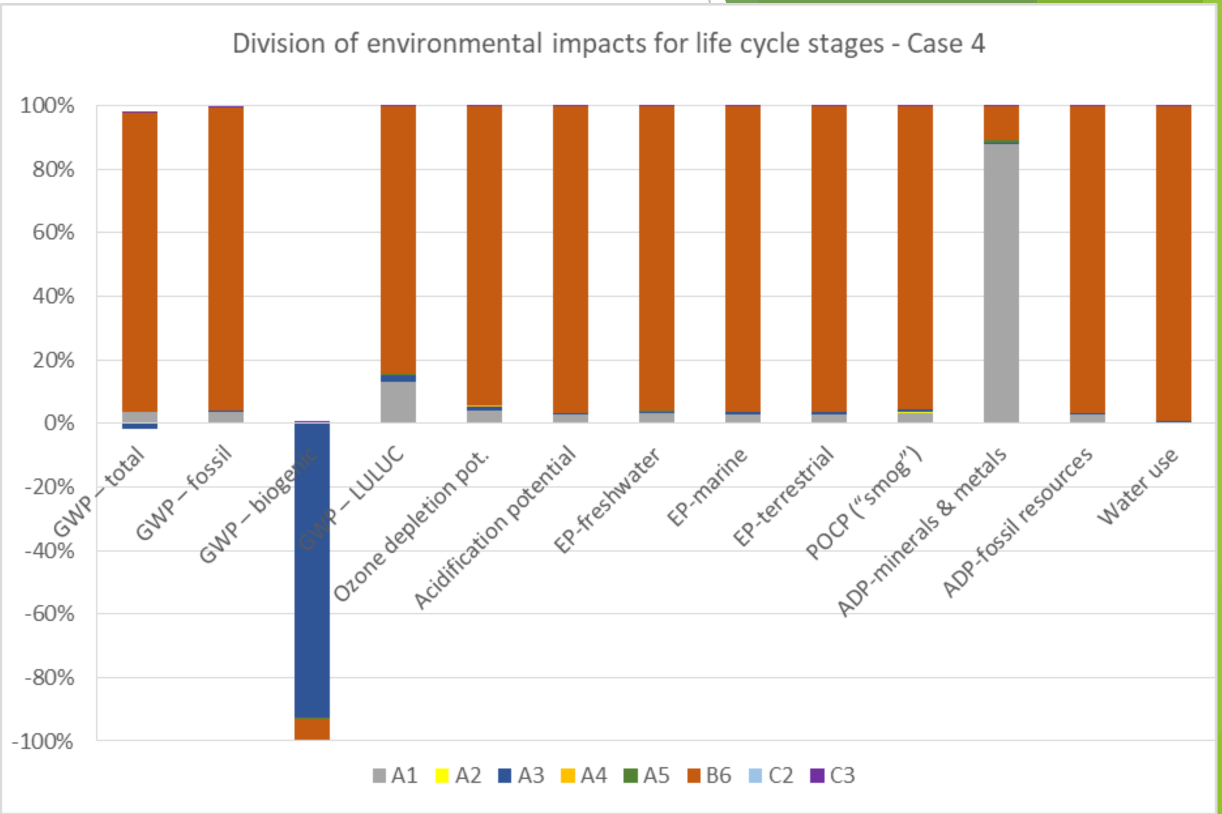


Case 3 - results of environmental impact indicators for the life cycle stages:

a) GWP-fossil

b) b) All analysed environmental impact indicators





Case 4 - results of environmental impact indicators for the life cycle stages:

a) GWP-fossil

b) b) All analysed environmental impact indicators

Discussion

- Manufacturing stage accounts for approx. **85%** of the life cycle impact. The high percentage is mainly due to aluminium housing, LED driver and LED module.
- The selected product LED suspended luminaire has a luminous efficacy of **94 lm/W**
- The regulations under the Ecodesign Law state the minimum luminous efficacy of **85 lm/W**
- **Integrated shading and lighting control** can generate energy savings up to **35%** during the cooling season
- The current available technologies are able to economically recover only around **55%** of the materials contained by LEDs, as stated in

Conclusion

- In the presented study a life cycle analysis of a LED suspended luminaire manufactured in Romania was performed. The input data - quantification of the materials, transport, operation and energy consumptions at the product stage and assembly stage, was received from the product manufacturer. Supplementary, information regarding the LED Module and LED Driver were retrieved from the EPDs of the component producer. The operational energy consumption was taken into consideration for a period of 20 years, taking also into account the electrical energy mix specific for Romania. The LCA calculation was performed using the One Click LCA software. The results show that the main contributor of the LED luminaire to the GWP-fossil expressed in kg CO_2e is the operational energy use with the share of 96.046%. The biggest effect on the environmental impact at the manufacturing stage of the LED luminaire is caused by the aluminium parts, LED module and LED driver.