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Life Cycle Assessment of Indoor Residential Lighting

for Australia and New Zealand

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SUMMARY

I. INTRODUCTION

This study evaluates the potential environmental impacts of Incandescent Lamps, Compact Fluorescent Lamps (CFL), Light Emitting Diode (LED) for indoor residential lighting in Australia and New Zealand. For each country, the two main objectives of this research are: (1) to evaluate the environmental benefits of switching to LED lamps compared to incandescent or CFL lamps and (2) to highlight where efforts should be focused and what is the best strategy for further lighting system developments (increasing efficacy, lifetime, reuse, or recycling, ...).

Life Cycle Assessment (LCA) is a methodology aiming to evaluate the potential environmental impacts over the complete life cycle of a product, e.g. extraction of raw materials, manufacturing, packaging, transportation, energy consumption and End of Life. It has been widely used in studies to evaluate the potential impacts of lighting systems and gives the most comprehensive view when evaluating lamp performance. However, lighting systems' LCAs often use different methods, data sources, assumptions or simplifications, which leads to different results and interpretations.

The means of electricity production consumed during the use phase is one of the most impacting parameters for the lighting systems LCAs. For this study, we distinguish two main means of producing electricity: fossil fuels (Australia) and renewables (New Zealand). The recent improvement of Light-Emitting Diodes (LED) in terms of lifetime, efficacy and energy consumption led to a large variety of LED products available on the market. These products differ by their parameters but also by the quality of their manufacturing. When solely looking to reduce the energy consumption, LED lamps prove to be a fair choice thanks to their high efficacy. However, in the context of climate changes and a progressive decarbonisation of our energy production means, it is interesting to evaluate how the lamp replacement strategy is influenced by both the recent improvement of LED lamps and the local electricity mix. A Life Cycle Assessment has been conducted to address this issue and to evaluate which lamp should be preferred from an environmental point of view for each country.

II. Life Cycle assessment (LCA)

A. Life Cycle Assessment Method

An LCA is a scientific methodology that enables researchers to quantify the environmental and sustainability impacts across a range of impact categories for a product over its entire life cycle. An LCA characterizes and quantifies the inputs, outputs, and environmental impacts for a specific product or system at each life-cycle stage (ISO, 2006). The general procedure for conducting a life-cycle analysis is defined by the International Organization for Standards (ISO) 14000 series. The main phases of an LCA according to the ISO guidelines are goal, scope, and boundary definition; life-cycle inventory (LCI) analysis; life-cycle impact assessment; and interpretation.

B. Life cycle assessment stages

The impact inventories are broken down into five life cycle stages, which are (1) raw material production, (2) manufacture, (3) distribution, (4) use / consumption and (5) end-of-life.

The LCA work in this report is subdivided into these stages, with each of them being briefly described below.

1. Raw Material Production

Most products are made up of multiple components, and nearly all require some form of packaging material to protect them during transit to the final customer. This first stage of the life cycle accounts for the emissions and resource usage associated with the production of the various raw materials that go into the final product, and their transportation to the point of manufacture. If a component or item of packaging is made from recycled materials, it is acceptable to adjust the impacts associated with its production accordingly.

2. Manufacturing/Production

The manufacturing stage starts when all raw materials listed above, are delivered to the point of production, and accounts for the energies used and emissions associated with manufacturing the final product. For some products, the manufacturing impacts are dominated by energy usage, while, for others, the emissions during manufacturing are the most important.

3. Transport/Distribution

The distribution stage covers the transportation of the product from its point of production to its point of installation and use. There might be a tendency when thinking about an LCA to believe that a detailed transport model will be required. However, for many products, transport and distribution form a small part of the overall environmental footprint. Impacts from distribution tend to be much more significant when the product needs to be refrigerated during transit, which obviously isn’t the case for lighting systems.

4. Use

The use/consumption stage of a product is usually relatively straightforward to define, though it is important that a consistent basis is chosen when comparing different products. For luminaire systems, the use stage is associated with the consumption of electricity to produce light.

5. End of Life (EoL)

The final stage of a life cycle is ‘end-of-life’, reflects what happens when the product is no longer required. It is far from straightforward to define what is within and without the system boundary at end-of-life, but some rules of thumb can be applied. As well as accounting for the product itself, the end-of-life stage needs to take into account all components, including the packaging. That being said, aspects such as the handling of transportation vehicles at their end-of-life are usually not explicitly included, as those impacts (together with, for example, the original production impacts) are rolled into the tonne-kilometre impacts associated with transportation during their service life.

There is also the question of whether to give a process credit for any end-of-life recycling. If a cardboard box is recycled at its end of life, this will reduce the need to use virgin pulp. However, if the reduce impact associated with using recycled cardboard for the packaging was already accounted for, this might constitute double-counting.

C. DATABASE, CALCULATION METHOD AND IMPACT CATEGORIES

1. Database: Ecoinvent 3.6

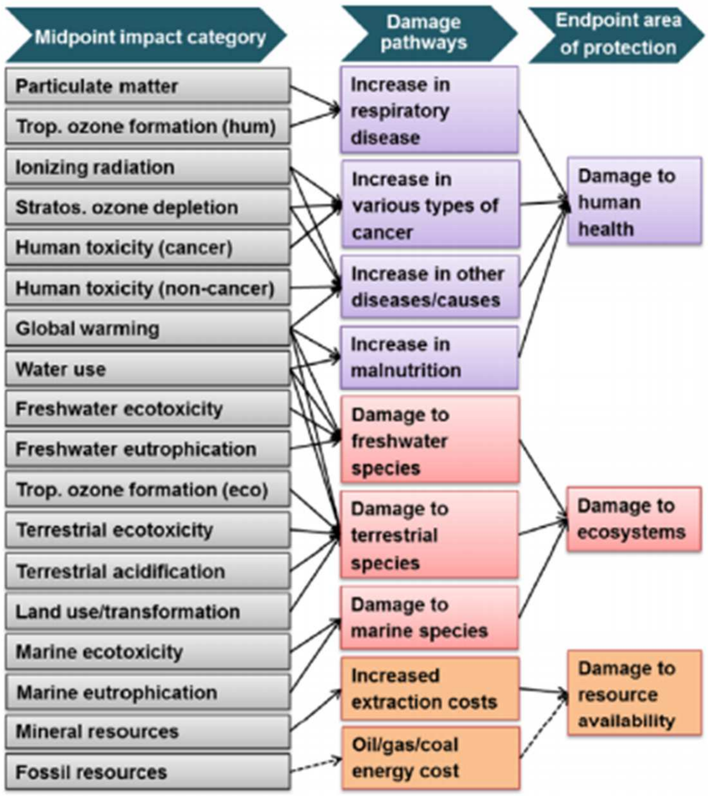
Ecoinvent has established itself as global leader in creating life cycle inventory databases. Their databases help companies manufacture products with reduced environmental impacts, policy makers implement new policies, and consumers adopt more environmentally friendly behaviour. The Ecoinvent LCI data can be used for life cycle assessment, life cycle management, carbon footprint assessment, water footprint assessment, environmental performance monitoring, product design and eco-design (DfE) or Environmental Product Declarations (EPD). For this report, we use data from Ecoinvent v3.6 (the latest available database).

2. Impact Assessment Method and Impact Categories

ReCiPe 2016 is an updated and extended version of ReCiPe 2008. Like its predecessor, ReCiPe 2016 includes both midpoint (problem oriented) and endpoint (damage oriented) impact categories, available for three different perspectives (individualist (I), hierarchist (H), and egalitarian (E)). The characterization factors are representative for the global scale, instead of the European scale as it was done in ReCiPe 2008. There are two mainstream approaches to derive characterisation factors, i.e. at midpoint level and at endpoint level. ReCiPe calculates:

- 18 midpoint indicators
- 3 endpoint indicators

Each midpoint indicator focus on a single environmental problem, for example climate change or acidification. Endpoint indicators show the environmental impact on three higher aggregation levels, being the 1) effect on human health, 2) biodiversity and 3) resource scarcity. Converting midpoints to endpoints simplifies the interpretation of the LCIA results. However, with each aggregation step, uncertainty in the results increases. For this study, only midpoint indicators on a hierarchist (H) perspective have been used. The figure below provides an overview of the structure of ReCiPe.



Relationship between LCI parameters (left), midpoint indicators (centre) and endpoint indicators (right) in ReCiPe 2016.

3. Midpoint impacts indicators

Each midpoint impact indicator used in this study are detailed in this section:

a) *Climate Change*

The increase in greenhouse gas (GHG) concentration, resulting in potential increase in global average surface temperature. The characterization factor of climate change is the global warming potential, based on IPCC 2013 report. For the Individualist perspective 20 years times horizon was used, for Hierarchist 100 years and for Egalitarian 1000 years. Climate carbon feedbacks are included for non-CO2 GHGs in the Hierarchist perspective. The unit is kg CO2 equivalents.

b) *Ozone Depletion*

The characterization factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). The unit is kg CFC-11 equivalents.

c) *Ionizing radiation*

The regular releases of radioactive material which can have carcinogenetic and hereditary effects. The characterization factor of ionizing radiation accounts for the level of exposure for the global population. The unit is kBq Cobalt-60 equivalents to air.

d) Photochemical ozone formation

The characterization factor is determined from the change in intake rate of ozone due to change in emission of precursors (NOx and NMVOC). The unit of ecosystem ozone formation potential is kg NOx equivalents.

e) *Fine particulate matter formation*

The health issues related to increase respiration of very small particles. The characterization factor of particulate matter formation is the intake fraction of PM2.5. The unit is kg PM2.5 equivalents.

f) *Terrestrial acidification*

The emissions which increase acidity (lower PH) of water and soils. The most common form of deposition is acid rain but dry and cloud deposition also occur. The characterization factor for terrestrial acidification is Acidification Potential (AP) derived using the emission weighted world average fate factor of SO2. The unit is kg SO2 equivalents.

g) *Freshwater eutrophication*

The excessive biological activity of organisms due to over-nutrification. The characterization factor of freshwater eutrophication accounts for the environmental persistence (fate) of the emission of Phosphorus (P) containing nutrients. The unit is kg P to freshwater equivalents.

h) *Marine eutrophication*

The excessive biological activity of organisms due to over-nutrification The characterization factor of marine eutrophication accounts for the environmental persistence (fate) of the emission of Nitrogen (N) containing nutrients. The unit is kg N to marine equivalents.

i) *Human toxicity and ecotoxicity*

The effects to individual human health that can lead to disease or death and the impacts on whole ecosystems that can decrease production and/or decrease biodiversity. The characterization factor of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The unit is kg 1,4-dichlorobenzeen (1,4-DCB) emitted.

j) *Land use*

The amount of land transformed or occupied for a certain time. The alteration to habitats, particularly for threatened and endangered species. The unit is m2.

k) *Mineral resource scarcity*

Use of minerals, ores, etc based on relative scarcity and overall consumption. The characterization factor for mineral resource scarcity is the surplus ore potential. The unit is kg Copper (Cu) equivalents.

l) *Fossil resource scarcity*

Similar to mineral resource scarcity except it’s based on energy content, not mass. The characterization factor of fossil resource scarcity is the fossil fuel potential, based on the higher heating value. The unit is kg oil equivalents.

m) *Water use*

The factor for the water use is the amount of fresh water consumption. The unit is m3 water consumed.

III. LIFE-CYCLE INVENTORY (LCI)

A. LAMPS STUDIED

The following lighting systems have been chosen in order to identify which one has the least environmental impacts, focusing on most common indoor residential lighting lamps.

Compact fluorescent lamp (CFL):

Compact Fluorescent Lamps (CFLs) were first developed in response to the oil supply shortages in the 1970's. The technology is based on a miniature-sized version of the linear fluorescent system - a ballast and a lamp. The CFL can have the lamp and ballast either packaged together (integrally ballasted) or sold separately (dedicated CFL luminaire). Like linear fluorescent lamps, CFLs contain a small amount of mercury in the arc tube which is recoverable, but only if the CFL is disposed of correctly (i.e., gathered and reprocessed at a recycling plant). Currently, it is estimated that 95% of mercury-containing lamps are sent to landfill in Australia. In Australia, the maximum allowed mercury for CFLs is 2.5mg for lamps less than 30W and 5mg above 30W. For New Zealand, it is 5mg for all lamps.

In Australia, CFL sales previously significantly increased thanks to a greater public awareness of energy costs and acceptance of the technology. Recently sales have been declining fast, in both Australia and New Zealand, as LEDs became available.

Incandescent

Originally invented in the 1880's, this lamp type continues to hold a dominant position in the domestic lighting sector in some countries. Improvements in efficacy were made over the years, however more than 95% of the power used by the lamp is radiated in the infrared (i.e., non- visible) spectrum. Incandescent lamps work by heating a metal filament to the point that it is so hot, it burns "white" and emits light. The system is extremely simple and does not require a ballast to operate or control the lamp.

Light-emitting Diode:

There are three common methods by which LEDs produce white-light. First is the phosphor- conversion approach, in which blue or UV-light LED pumps light into a phosphor which down-converts the light to be a more distributed spectrum resembling white-light. Second, there can be discrete colour-mixing LEDs, which blend together the light of discrete-colour LEDs to create white-light. Third, there is a hybrid approach in which phosphor- converting LEDs and discrete colour LEDs are combined to create the desired light emission.

The LED considered in this study is a phosphor conversion LED as it is the most common LED available on the market for indoor lighting purpose. LEDs are considered as an ultra-efficient lighting system. They can actually easily reach an efficacy higher than 100lm/W and the lifetime claimed by manufacturers have significantly increased over the past years, from 10000h for the first LED lamps to over 25000h. The manufacturing process also has been improved, reducing the global amount of materials and energy needed. Projections aim for over 200lm/w efficacy and 50000h lifetime for next years[1].

[1] U.S. Department of Energy, (2016), Multi-Year Program Plan

B. PERFORMANCE PARAMETERS

All lamps studied are described in Table 1. They are all meant to be used for indoor lighting, especially residential lighting. They are all A19 bulbs which represent the size and the shape of the lamp. The "A" refers to the overall shape of the bulb. An "A" bulb has the classic light bulb shape, commonly compared to an upside-down pear. The two digits refer to the bulb's diameter.

In order to assess the constant evolution of LED technology, 3 models of LED lamps are studied. LED O represent the "Old" LED with low lifetime and LED N represent the "New" LED available on the market with a longer lifetime and higher efficacy. The CFL and the incandescent lamp are classic A19 lamps used in residential lighting:

- LED O: A19 LED Lamp in 2012 (95lm/w efficacy and 10,000h lifetime)
- LED N1: A19 LED in 2017 with an improved manufacturing process (134lm/W efficacy and 15000h lifetime)
- LED N2: A19 LED in 2017 with an improved manufacturing process (134lm/W efficacy and 25000h lifetime)
- Incandescent: A19 60W general lighting service incandescent lamp
- CFL: A19 15 W integrally-ballast CFL

The power consumption and efficacy have been adapted to produce a similar lumen output for each lamp. The lamps compared are switching viable and provide a similar enlightenment to the room.

	Power Consumption (W)	Lumen Output (lm)	Efficacy (lm/W)	Lamp Lifetime (h)
Incandescent	60	900	15	1,500
CFL	15	1,020	68	10,000
LED O	11	1,045	95	10,000
LED N1	8	1,072	134	15,000
LED N2	8	1,072	134	25,000

Table 1: Performance parameter of lamps

C. LIFETIME OF LED LAMPS

The average rate life of LED lamps is generally defined as L70B50 or L80B50 (Chart 1). L70 indicates the lumen maintenance meaning that the LED will produce 70% of the initial light output at the end of the rate life. B50 indicates that 50% of a large group of lamps will failed at the end of the rate lifetime.

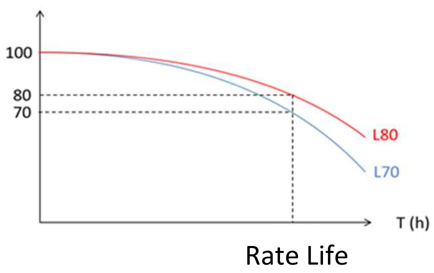


Chart 1: Lumen maintenance of LED

When some manufacturers claim rate life over 40,000h, there are several factors that can reduce it like the temperature management which can induce a risk of failure for some components of the lamp.

Moreover, the individual perception of lumen depreciation can lead some user to replace LED lamps because they feel like the enlightenment is too low for the room even if the rated lifetime has not been reached. For these reasons, the actual lifetime of a LED is difficult to evaluate precisely in the real usage condition. This is why several LED lamps with various lifetime have been assessed. It will help to evaluate the impacts of lifetime shorter than the one announced by manufacturers.

D. Material Inventories and manufacturing

The material and manufacturing data for CFL, LED and Incandescent Lamp have been collected by the US Department of Energy[2] and have been updated drawing upon more recent data[3] to reflect improvements in the manufacturing process among over the last years. All detailed inventories are available in Annex D.

E. Transport

Regarding the transportation stage, the following hypothesis have been made:

H1: All lamps are produced in China. Production site is Datang (currently producing 1/3 of world goods consumption).

H3: The travel distance over land between China and Australia or New Zealand is 1000km by road.

H4: The travel distance over sea between China and Sydney is calculated between Shanghai and Sydney (**9,658 km** by transoceanic ship) and the distance over sea between China and New Zealand (Auckland) is **10,000km**[4]

F. Use Stage

Use stage is known as the most impacting stage in LCA of lighting system, this is why the electricity mix of the country where the lamp is used is preponderant when assessing environmental impacts. In order to distinguish the impact of electricity mix on the LCA result, both Australia and New Zealand have been considered in this study. The Australian electricity is mostly generated by fossil fuels (84.3%) while it is mostly generated by renewables (82.4%) in New Zealand.

2016-17	GWh	(per cent)
Fossil fuels	217,562	84.3
Black coal	118,272	45.8
Brown coal	43,558	16.9
Gas	5,046	19.6
Oil	5,273	2.0
Renewables	40,455	15.7
Hydro	16,285	6.3
Wind	12,597	4.9
Bioenergy	3,501	1.4
Solar PV	8,072	3.1
Total	**258,017**	**100**

Table 2: Australian electricity generation, by fuel type (2016-2017)

Source: Department of the Environment and Energy (2018) *Australian Energy Statistics*, Table O https://www.energy.gov.au/sites/default/files/australian_energy_update_2018.pdf

[2] Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products Part 2: LED Manufacturing and Performance

[3] Luth Richter, Jessika & Tähkämö, Leena & Dalhammar, Carl. (2019). *Trade-offs with longer lifetimes? The case of LED lamps considering product development and energy contexts*. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.03.331

[4] Distances calculated with https://sea-distances.org/

2016-17	GWh	(per cent)
Hydro	25,330	58.5
Geothermal	7,439	17.2
Biogas	263	0.6
Wood	303	0.7
Wind	2,233	5.2
Solar	126	0.3
Oil	4	0.01
Coal	2,119	4.9
Gas	5,466	12.6
Waste Heat	51	0.1
Total	**43,333**	**100**

Table 3: New Zealand electricity generation, by fuel type (2019)
Source: Data tables for electricity from Ministry of business, innovation & employment of New Zealand, table 2 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

G. End of Life (EoL)

Regarding the recovery and recycling of materials, there is a lack of information in the public domain about the materials used in the manufacturing of LEDs which are reused or recycled. If these materials were recovered, processed and then reused, it would reduce the potential impacts of the manufacturing phase. However, in this version of the study, we are assuming that only new materials are used at all stages of the LCA process, thus providing a conservative estimate of the impacts. In other words, to the extent that materials are recovered and recycled, the environmental impacts will be less than those reported in this study.

The end of life scenario for both packaging and lamp are available in Annex D. Materials considered for lamp recycling are glass and waste electronic equipment. All other materials are considered landfilled.

Packaging landfill/recycling ratio came from the *National Waste Report 2018*, developed by the Australian Government. It is estimated that 95% of lamps are landfilled in Australia and New Zealand as recycling schemes currently do not target these products.

H. Functional Unit

The functional unit is defined as the quantified performance of a product system, which will be used as a reference unit. The most coherent functional unit applicable to a lighting system is currently the Mega lumen hour (**Mlm.h**). It consists of equalizing the lumen output during a defined length of time before comparing the potential environmental impacts of lamps.

	Inc.	CFL	LED O	LED N1	LED N2
Power Consumption (W)	60	15	11	8	8
Lumen Output (lm)	900	1,020	1,045	1,072	1,072
Efficacy (lm/W)	15	68	95	134	134
Lamp Lifetime (h)	1,500	10,000	10,000	15,000	25,000
Total Lumen Output (Mlm.h)	1.35	10.2	10.45	16.08	26.8
Consumption during the lifetime (kWh)	90	150	110	120	200
Weight (kg)	0.0782	0.234	0.176	0.047	0.047

Table 4: Data Calculation for LCA

First, the total lumen output, the consumption during the whole lifetime and the weight of each system have been calculated (Table 4). The total consumption is used to evaluate the potential impacts of the use stage; the weight is used for the transport stage, and the total lumen output is used to define the reference flow. The reference flow is defined by "*the measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit*" (ISO 14040:2006).

Functional Unit	Inc.	CFL	LED O	LED N1	LED N2
Lamp Unit	1	1	1	1	1
26.8 Mlm.h	19.9	2.63	2.56	1.67	1

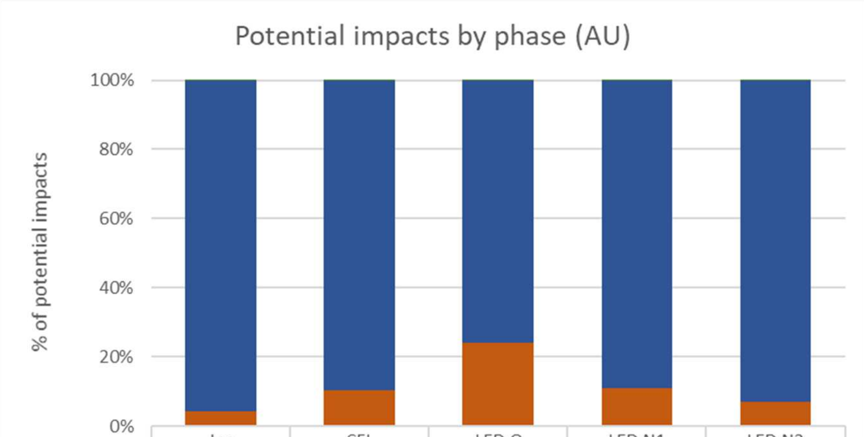
Table 5: Reference flow

The functional unit (26.8 Mlm.h) is given by LED N2 lamp which have the biggest total lumen output during its lifetime. The chosen value for the functional unit won't impact the result but, by choosing the highest one, the reference flow will be higher than 1. The reference flow represents the number of lamps needed to reach the total lifetime lumen output of LED N2.

IV. Life-cycle Impact Assessment per Lamp Unit

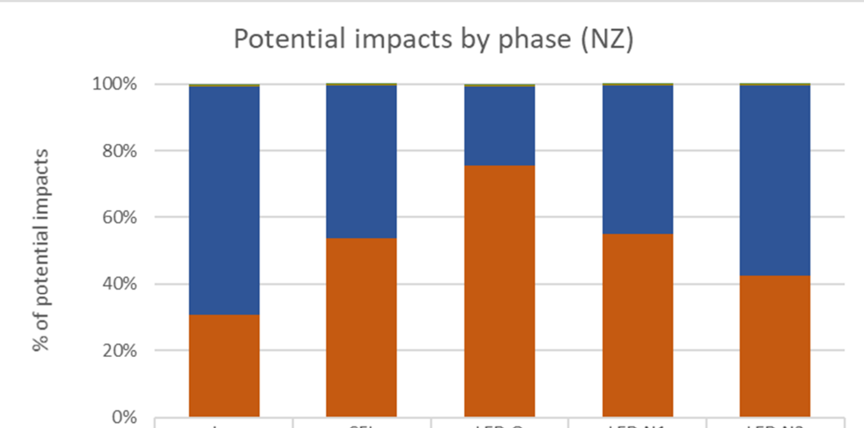
A. Impact Assessment by Stage Per Lamp Unit

The charts 2 and 3 below show the allocation of the potential impacts of each lamp among the lifecycle phases. The y-axis represents the percentage of the total potential impacts.



	Inc	CFL	LED O	LED N1	LED N2
End of life	0.07%	0.04%	0.16%	0.05%	0.03%
Transport	0.03%	0.05%	0.06%	0.05%	0.03%
Use	95.61%	89.44%	75.87%	88.90%	93.03%
Production	4.29%	10.47%	23.92%	11.00%	6.91%

Chart 2: Potential impact by phase – Australia



	Inc	CFL	LED O	LED N1	LED N2
End of life	0.48%	0.21%	0.49%	0.25%	0.19%
Transport	0.23%	0.28%	0.18%	0.26%	0.20%
Use	68.59%	45.90%	23.95%	44.51%	57.20%
Production	30.70%	53.61%	75.38%	54.98%	42.41%

Chart 3: Potential impact by phase - NZ

The use phase is the most impacting for all lamps used in Australia. It accounts for more than 75% of the potential environmental impacts (Chart 2). This is essentially due to the electricity being mostly generated by fossil fuel in Australia. When comparing the old LED models (LED O) with the most recent one (LED N1 and N2), the share of the potential impacts generated by the use phase are increasing. This is due to a less impacting manufacturing process associated to an increase of the global consumption during a longer lifetime (Table 4). The transport phase represents less than 0.1% of the potential impact and the end of life phase contributes from 0.03% to 0.16%.

LED O is the only lamp used in New Zealand (Chart 3) having a production phase significantly more impacting than the use phase (75% for production, 24% for use). It can be explained by a heavier production process and a short lifetime. By improving the production process, the lifetime and the efficacy, the impacts of the manufacturing phase for LED N1 and N2 are reduced respectively to 55% and 42% of the potential impacts. CFL and incandescent lamp's use phase represents respectively 46% and 68% of the potential impacts. Transport phase represents less than 0.1% of the potential impacts. The End of life phase contributes from 0.03% to 0.16%.

This first finding shows that depending on the country electricity mix, the effort should be oriented either towards a less impacting production process (LED O for New Zealand); or towards a higher efficacy (reduced energy consumption) or the development of renewable energy (reduced electricity production impact) in Australia. The higher the proportion of renewables in the electricity mix, the lower is the impact of the use stage for each lamp.

Manufacturing or Raw Material production stage is the second most impacting stage (except for LED O in New Zealand). Globally, this can be explained by the amount of exhaustible primary resources or materials needed for the manufacturing of the lamp and the energy needed to reach and transform these materials.

A detailed Life Cycle Inventory Analysis of each lamp by stage is available in Annex A.

B. IMPACT ASSESSMENT BY MATERIAL PER LAMP UNIT

The following charts show the detailed repartition of the potential impacts by material and process for each lamp. Charts for both Australia and New Zealand, and for all lamps are available in Annex B. All processes and materials contributing to less than 0.5% of the potential total impact have been included in the "Other" category (truncation = 0.5%).

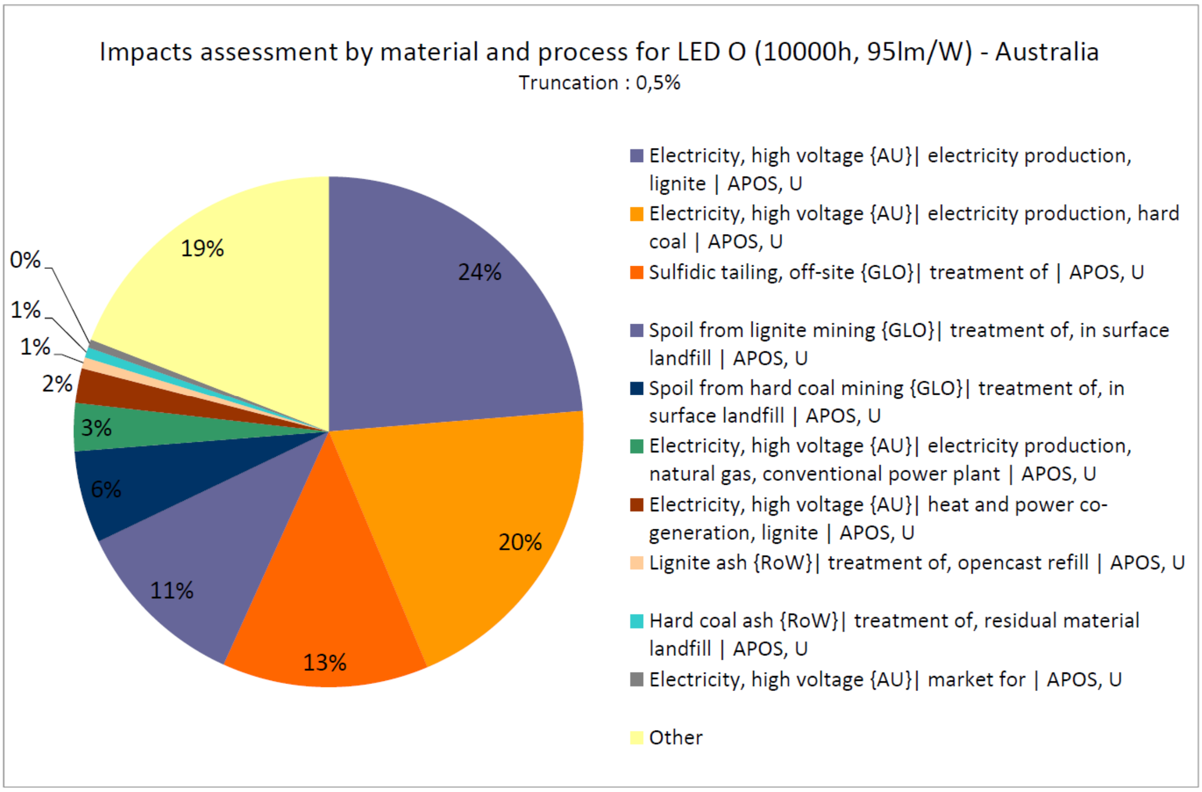


Chart 4: Impact Assessment by material for LED O - Australia

Chart 4 confirms that the energy consumption in the use phase is the most impacting for lamps used in Australia. “Electricity high voltage production, lignite” and “Electricity high voltage production, hard coal” represent 44% of potential total impacts for LED O. All other lamps present a similar allocation of the potential impacts (see Annex B).

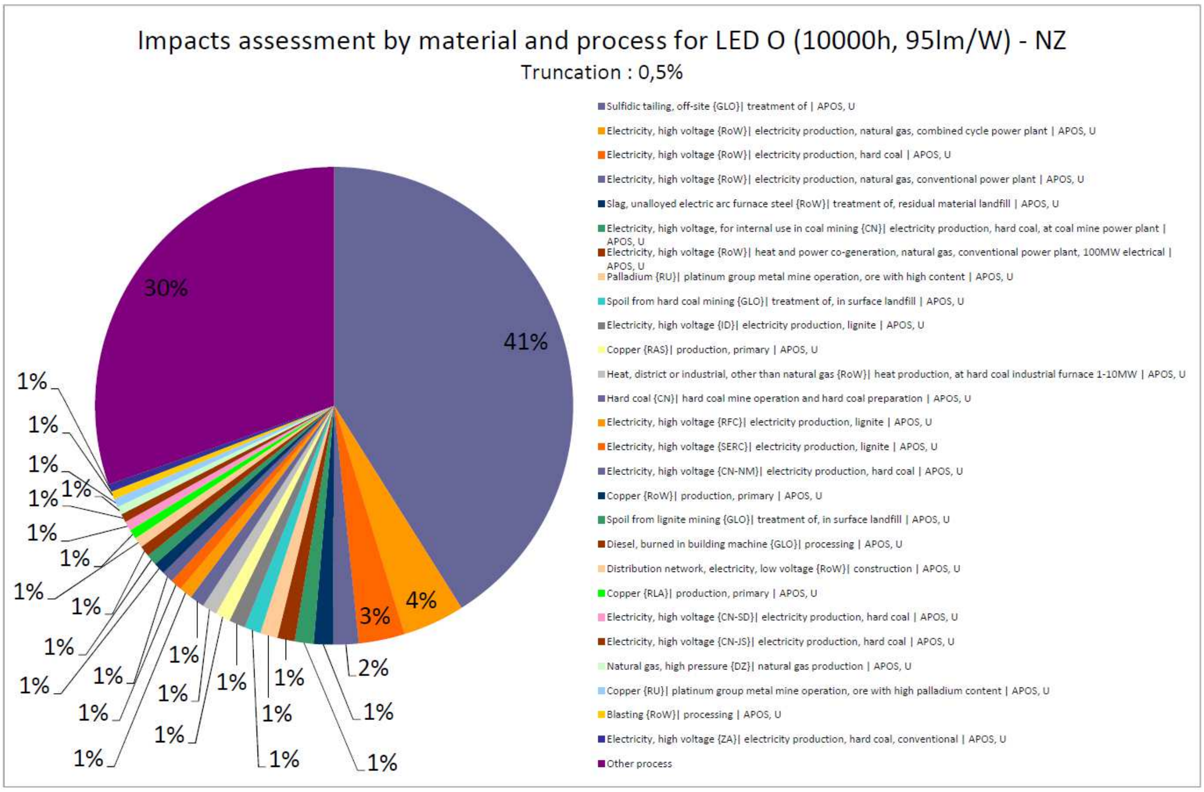


Chart 5: Impact Assessment by materials and process for 1 unit of LED O in New Zealand

For lamps used in New Zealand, the larger contributor to the potential impacts is “sulfidic tailing” which represents 41% of the potential impacts of LED O. It results from the extraction of raw materials (especially gold) needed for the manufacturing of the printed wiring board of LEDs lamps. Depending of the quality of the LED lamp and the size of the printed wiring board, the associated impacts could be mitigated like for LED N1 (33% of potential impacts) and N2 (29% of potential impacts). The “sulfidic tailing” is also the major contributor to the potential impacts for CFL (24%). These figures confirm that the manufacturing phase tends to be the most impacting phase for LEDs and CFL lamps used in New Zealand. For incandescent lamp, Rhodium and sulfidic tailing are the two processes which generate the most potential impacts. However, the sum of all the potential impacts generated by electricity production for the use phase (68.9%) contribute more to the overall potential impacts.

V. IMPACT ASSESSMENT PER FUNCTIONAL UNIT (26.8 MLM.H)

The following charts and tables compare the potential impacts of each lamp using the functional unit (26.8 Mlm.h) defined in part III.G and the reference flow presented in Table 6. The potential impacts in Chart 6, 8 and 9 are normalized for each impact category over the most impacting lamp in this category. The closer the curve is to the outer circle, the higher the potential impacts generated by the lamp are. The tables 6 and 7 show the values the radar graphs are based on.

A. AUSTRALIA

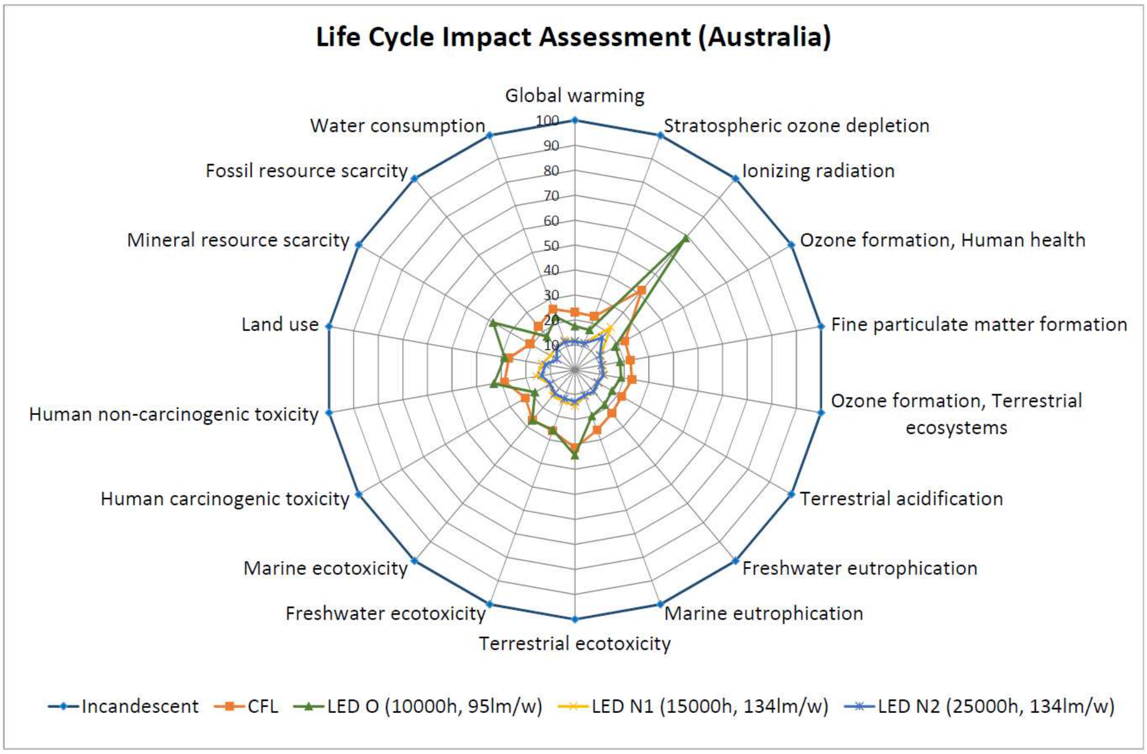


Chart 6: Life Cycle Impacts Assessment (LCIA) for Australia

Category of impact	Unit	Incandescent	CFL	LED O	LED N1	LED N2
Global warming	kg CO2 eq	1771.50	408.27	309.56	206.16	201.93
Stratospheric ozone depletion	kg CFC11 eq	1.39E-03	3.17E-04	2.37E-04	1.59E-04	1.57E-04
Ionizing radiation	kBq Co-60 eq	5.25	2.18	3.62	1.17	0.89
Ozone formation, Human health	kg NOx eq	3.39	0.78	0.63	0.40	0.39
Fine particulate matter formation	kg PM2.5 eq	2.08	0.47	0.38	0.23	0.22
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.41	0.79	0.64	0.41	0.39
Terrestrial acidification	kg SO2 eq	6.17	1.33	1.06	0.67	0.65
Freshwater eutrophication	kg P eq	2.86	0.66	0.53	0.34	0.33
Marine eutrophication	kg N eq	0.19	0.05	0.04	0.02	0.02
Terrestrial ecotoxicity	kg 1,4-DCB	1698.65	533.98	584.37	247.46	219.48
Freshwater ecotoxicity	kg 1,4-DCB	122.55	32.09	31.61	16.78	15.35
Marine ecotoxicity	kg 1,4-DCB	162.24	42.90	43.21	22.54	20.50
Human carcinogenic toxicity	kg 1,4-DCB	156.78	35.99	28.95	18.44	18.00
Human non-carcinogenic toxicity	kg 1,4-DCB	2448.74	702.00	808.93	381.10	332.34
Land use	m2a crop eq	7.89	2.12	2.26	1.06	0.95
Mineral resource scarcity	kg Cu eq	2.63	0.55	1.00	0.30	0.22
Fossil resource scarcity	kg oil eq	438.39	99.84	76.56	51.01	49.99
Water consumption	m3	3.63	0.94	0.82	0.46	0.43
Energy consumption (use phase)	kWh	1791	394.5	281.6	200	200

Table 6: Life Cycle Impacts Assessment (LCIA) for Australia

The most impacting lamp used in Australia is the incandescent lamp. The energy consumption of the incandescent lamps is 4.5 to 9 times higher than any other lamps, generating 4.3 to 5.8 times more GHG emissions (Chart 7).

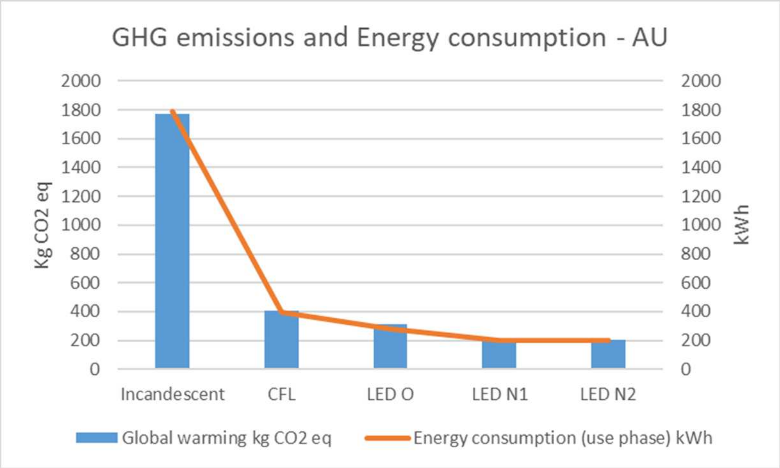


Chart 7. GHG emissions and energy consumption -AU

The less impacting lamps are the LED N1 (15000h,134lm/W) and LED N2 (25000h, 134lm/w), thanks to their higher efficacy. Part IV.A shows that most of the potential impacts of lighting are generated by the use phase, confirming that high efficacy lamps should be favoured in order to reduce energy consumption.

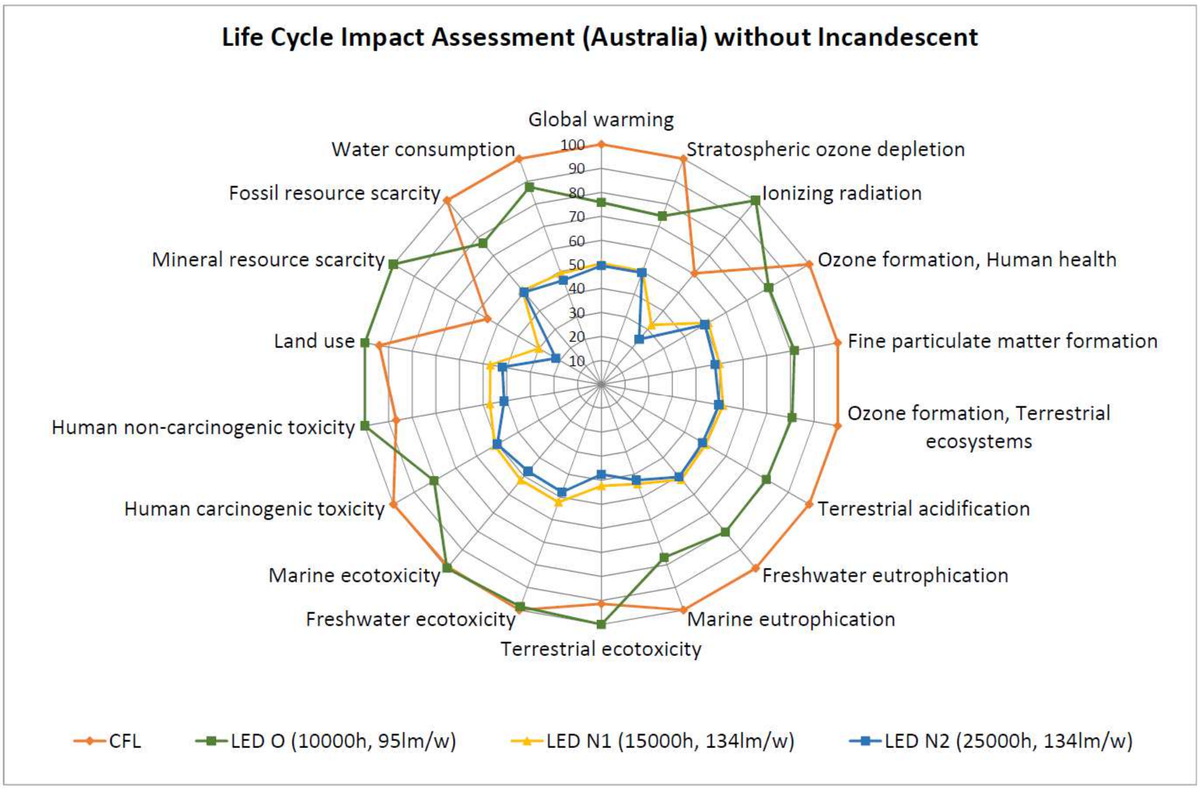


Chart 8: Life Cycle Impacts Assessment (LCIA) for Australia without incandescent

Chart 8 shows the Life Cycle Impact Assessment without incandescent lamp, for better visibility. Old LEDs generate slightly less potential impacts and have a lower energy consumption than CFL lamps. Therefore, LEDs should be preferred to CFL, even if they have a shorter lifetime and a lower efficacy than more recent LEDs lamps.

It is interesting to note that LED N1 (15000h, 134lm/W) and LED N2 (25000h, 134lm/W) have a quite similar potential impacts despite a longer lifetime for LED N2. This shows that, in Australia further increasing new LED's lifetime alone neither reduces significantly the potential environmental impacts, nor the energy consumption. An uncertainty analysis of each lamp is available in Annex C.

B. New Zealand

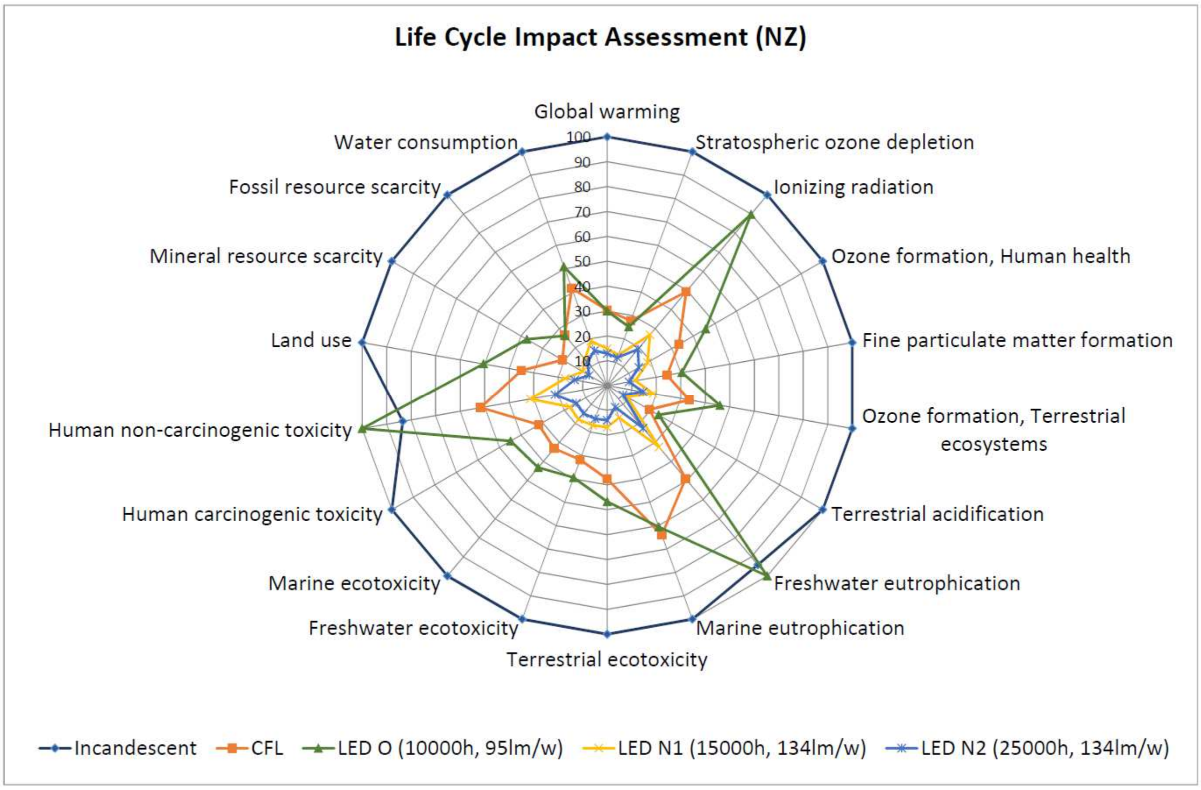


Chart 9: Life Cycle Impacts Assessment (LCIA) for New Zealand

Category of impact	Unit	Incandescent	CFL	LED O	LED N1	LED N2
Global warming	kg CO2 eq	210.57	63.94	63.10	31.43	27.20
Stratospheric ozone depletion	kg CFC11 eq	1.81E-04	5.01E-05	4.56E-05	2.37E-05	2.17E-05
Ionizing radiation	kBq Co-60 eq	3.76	1.86	3.38	1.00	0.72
Ozone formation, Human health	kg NOx eq	0.32	0.11	0.15	0.06	0.05
Fine particulate matter formation	kg PM2.5 eq	0.36	0.09	0.11	0.04	0.03
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.33	0.11	0.15	0.06	0.05
Terrestrial acidification	kg SO2 eq	1.06	0.21	0.25	0.10	0.08
Freshwater eutrophication	kg P eq	0.08	0.04	0.09	0.03	0.02
Marine eutrophication	kg N eq	1.70E-02	1.09E-02	1.03E-02	2.36E-03	1.59E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1021.18	384.54	477.41	171.62	143.64
Freshwater ecotoxicity	kg 1,4-DCB	51.71	16.46	20.43	8.85	7.42
Marine ecotoxicity	kg 1,4-DCB	64.30	21.29	27.74	11.57	9.54
Human carcinogenic toxicity	kg 1,4-DCB	14.46	4.60	6.48	2.50	2.07
Human non-carcinogenic toxicity	kg 1,4-DCB	405.84	251.36	486.37	152.41	103.65
Land use	m2a crop eq	2.92	1.02	1.47	0.50	0.39
Mineral resource scarcity	kg Cu eq	2.71	0.56	1.01	0.31	0.23
Fossil resource scarcity	kg oil eq	70.18	18.62	18.42	9.79	8.77
Water consumption	m3	0.71	0.29	0.36	0.13	0.11
Energy consumption (use phase)	kWh	1791	394.5	281.6	200	200

Table 7: Life Cycle Impacts Assessment (LCIA) for New Zealand

The less impacting lamp used in New Zealand is LED N2, followed by LED N1 and CFL lamp.

The most impacting one is the incandescent lamp, confirming that these lamps should be avoided. The Greenhouse Gas emitted by the incandescent lamp over the complete life cycle is 210.57 kg CO2eq. It is 3.3 times higher than a CFL lamp (63.94 kg Co2eq) and an old LED with short lifetime (63.10 kgCo2eq). It is also around 7 times higher than the most recent LED lamps (31.43 kgCO2eq for LED N1 and 27.20 kgCO2eq for LED N2). The energy consumption during use stage (1791 kWh) is from 4.5 to 9 times higher than any other lamps (Chart 10)

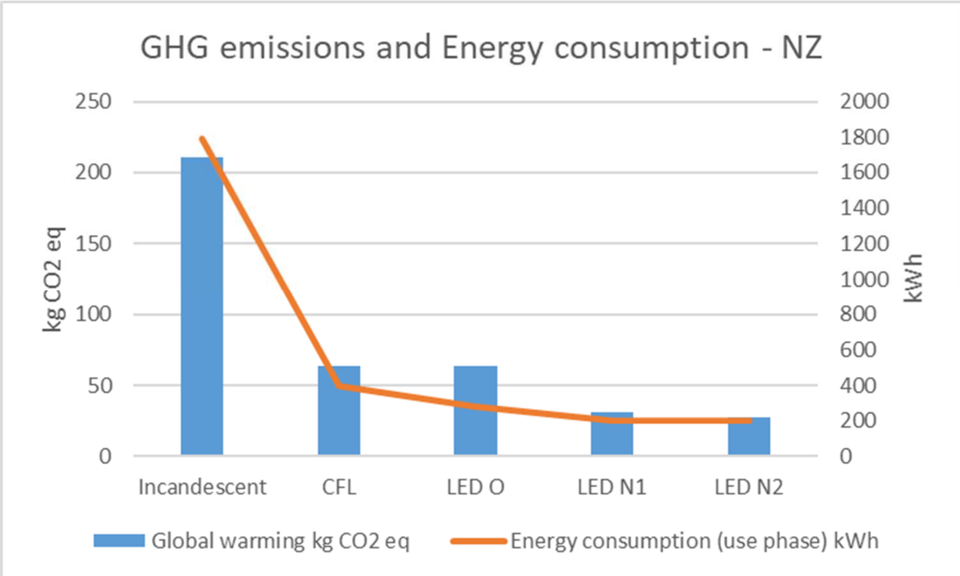


Chart 10. GHG emissions and energy consumption - NZ

When comparing the short lifetime's LED to the CFL lamp, Chart 9 shows that the CFL lamp generates less potential impacts in almost all categories, when LED O has a lower energy consumption over the use phase (394.5KWh for CFL and 281.6 kWh for LED O).

It's is interesting to note that LED O generates slightly more potential impacts than an incandescent lamp for two categories of impacts (Human non-carcinogenic toxicity and Freshwater eutrophication). This can be explained by the sulfidic tailing, results of the extraction of the materials (especially gold) needed to produce the printed wiring board of LED lamp. LED O is an old model of LED with a high weight printed wiring board (15g) and a short lifetime. This short lifetime doesn't allow to mitigate the potential impacts of sulfidic tailing over the use time. LED B's potential impacts are largely reduced due to improvements in the manufacturing process (printed wiring board only weights 8.2g), a higher efficacy and a longer lifetime.

This result shows that it is mandatory to avoid the use of incandescent lamps. In order to reduce significantly the potential impacts of indoor lighting, they should be replaced either by a CFL lamp or a high quality LED lamp for the best results. LEDs present the lowest energy consumption during the use phase but the potential environmental impacts can vary with the quality of the lamp, especially its lifetime. As shown in part IV.A, the manufacturing potential impacts of some lamp types used in New Zealand tends to be higher than the potential impacts of the use phase. It is then necessary to be careful when choosing a LED lamps. First price and old LED lamps could present potential impacts from 2 to 3 times higher than the latest models available. It is therefore recommended to use good quality LEDs with at least 15,000h lifetime and an efficacy higher than 100lm/W.

An uncertainty analysis of each lamp is available in Annex C.

C. COMPARATIVE ANALYSIS BETWEEN NEW ZEALAND AND AUSTRALIA

The following charts show the Life Cycle Impact Assessment for Australia and New Zealand using a unique scoring at endpoint level. All categories of impacts are weighted and aggregated under one unique score (Unit: Pt). A point (Pt) represents the annual environmental load (i.e. entire production/consumption activities in the economy) in the US divided up into the share of one American. It is important to understand that one point is not an individual's very own environmental impact. It represents the individual's annual share regardless of whether that individual participated in the economy's environmental impacts directly or indirectly. It helps to have a better view at the endpoint level (damage oriented) by showing which category of impacts actually causes the more potential damages but it also introduced a certain numbers of uncertainties.

Note: *The following charts 11, 12 and 13 use ponderation and weighting which is subject to interpretation. ISO standard states that weighting shall not be used for comparative life cycle assessment meant to be disclosed to the public. As such the inclusion of these charts in this report is not fully compliant with the ISO standard, however it is considered a useful alternative method of presenting the data provided the uncertainties are taken into consideration. All standard weighting and normalization factors from Recipe Endpoint have been used. All the details of these factors can be found in the Recipe 2016 documentation (*https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf).

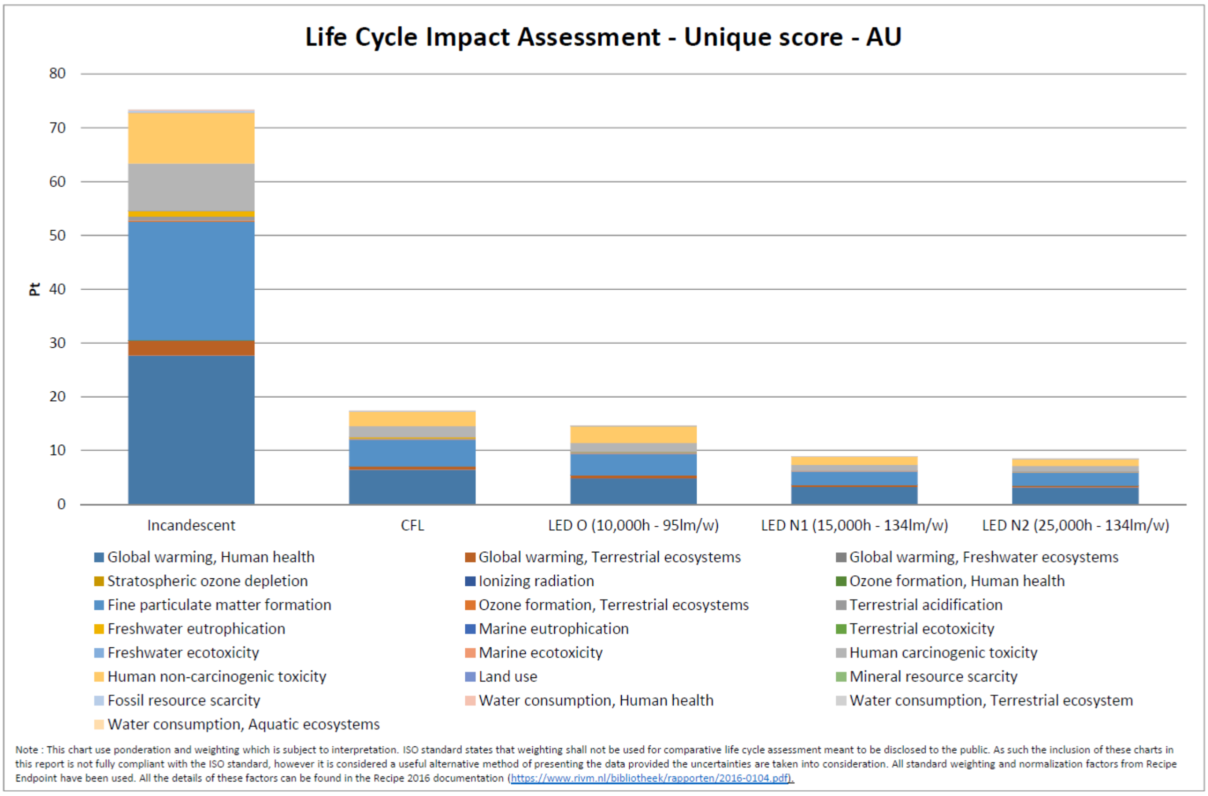


Chart 11: Life cycle Impacts Assessment – Australia – Unique score

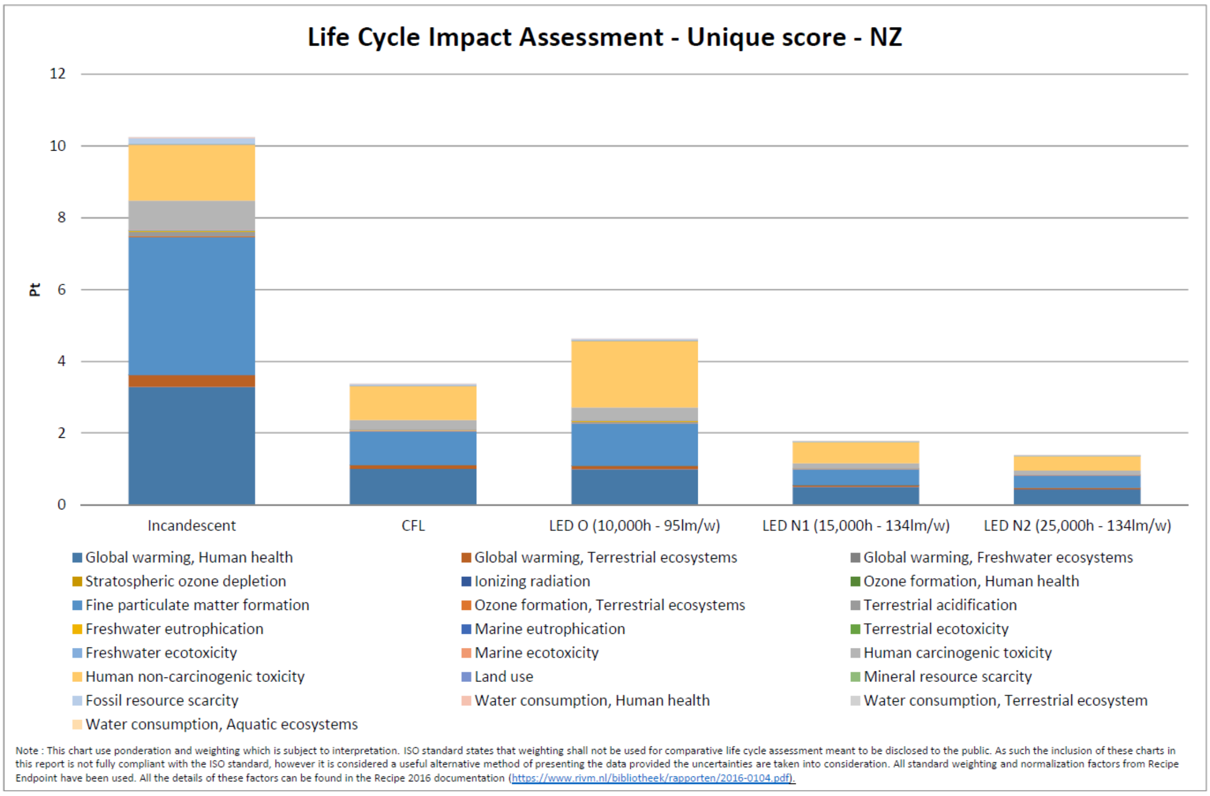


Chart 12: Life cycle Impacts Assessment – New Zealand – Unique score

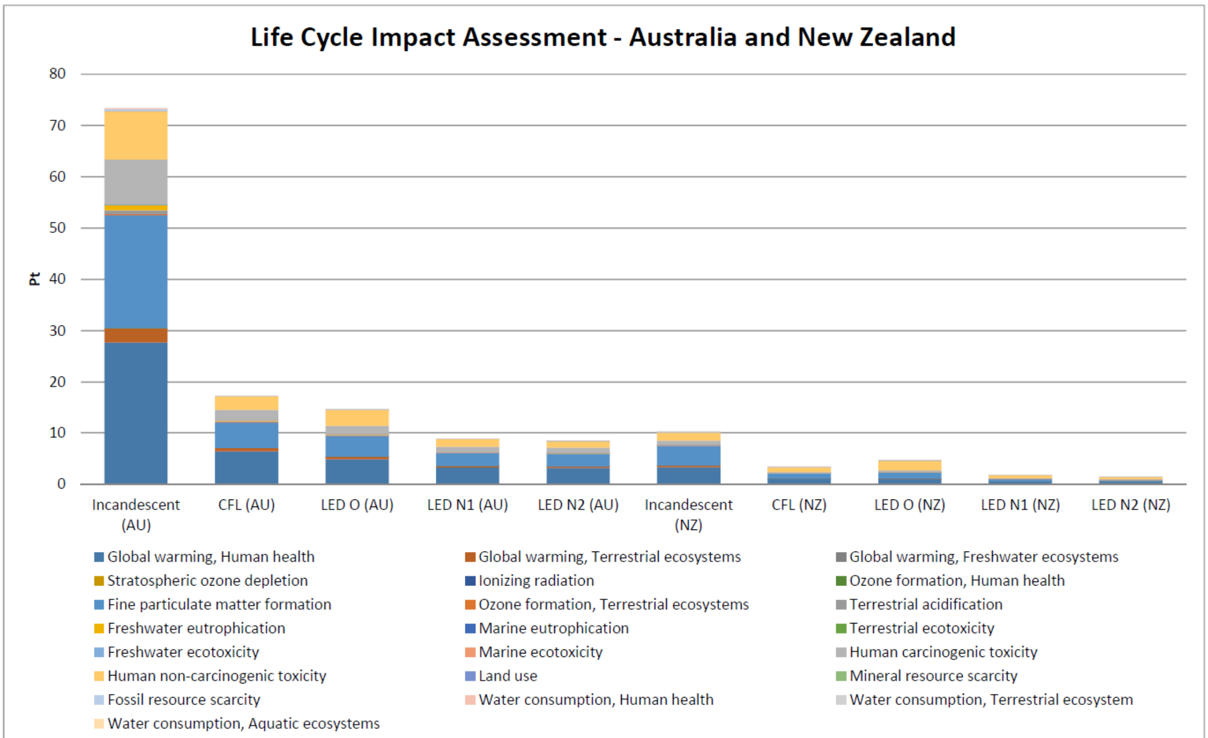
A detailed table with all the calculated endpoint potential impacts is available in Annex E. Looking at the charts 11 and 12, unique scoring confirms all the previous analysis.

Australia:

- Incandescent is the most impacting lamps.
- Old LEDs are slightly better than CFL lamps from potential impacts point of view and it also helps to reduce the energy consumption.
- New LEDs are the less impacting lamps.
- Increasing the lifetime of new LEDs (134lm/W) over 15,000h doesn't prove to reduce significantly the environmental potential impacts.

New Zealand:

- Incandescent is the most impacting lamp.
- Old LEDs are more impacting than CFL lamps.
- New LEDs are the less impacting lamps.
- Good quality LEDs should be preferred in New Zealand to reduce significantly the potential environmental impacts.



Note : This chart use ponderation and weighting which is subject to interpretation. ISO standard states that weighting shall not be used for comparative life cycle assessment meant to be disclosed to the public. As such the inclusion of these charts in this report is not fully compliant with the ISO standard, however it is considered a useful alternative method of presenting the data provided the uncertainties are taken into consideration. All standard weighting and normalization factors from Recipe Endpoint have been used. All the details of these factors can be found in the Recipe 2016 documentation (https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf).

Chart 13: Life cycle Impacts Assessment – Australia and New Zealand – Unique score

Finally, it is interesting to note that in chart 13 the potential impacts of an incandescent lamp used in New Zealand (10.243 Pts) is almost comparable to a new LED used in Australia (8.8 Pts). This confirms the huge impacts of electricity consumption in Australia. It shows that by switching the same lamps in both country, the reduction of potential impacts will be way more significant in Australia than in New Zealand.

D. Discussion

This study confirms that LEDs with good efficacy and lifetime are the best choice when aiming to reduce environmental impacts.

Nevertheless, lifetimes considered in this study are the one given by producers, and this can be shortened during the use phase (number of commutation, heat dissipation, driver failure, etc…). The behaviour of the user could also reduce the rate lifetime (perception of lumen depreciation, esthetical consideration, etc..). The real lifetime of each system should be evaluated, regarding the scenario involved, to improve LCA result pertinence.

Moreover, for this study the lumen output is considered as constant in the whole lifetime, which is not actually the case. For example, a LED reach generally 70% of its initial lumen output at end of life. A more precise investigation on the real Lumen output for each lamps may lead to different results, but lumen depreciation concerned also incandescent (5%) and CFL (35%) and will probably not change LED superiority regarding environmental global impacts.

Economic and social aspects should not be underestimated. A Life Cycle Cost analysis could help to validate the result of classic LCA by exploring the economical aspect. Taking into account light quality with criteria like CCT, CRI or by evaluating circadian impact of blue light, could help to ensure that the preferential lighting system will not induce health, comfort, security or well-being externalities. Human behaviour could also have an impact on LCA results. The lifetime could be shortened by a wrong perception of lumen depreciation by the user. Some rebound effect could also occur (e.g. people tend to use more than usual each lamp after switching for a more efficient lamps, thinking they can afford it because the lamp has a lower energy consumption, or they could use the money saving for activities more environmentally impacting than lighting). In any case, an awareness is necessary to help people in any technology transition. All these human and systemic effects are outside the boundaries of this study, and therefore not considered.

Finally, some of the beneficial effects of switching to LED are not assessed in this report, such as the beneficial effects generated by the reduction of the energy demand. As the population is growing, the need to increase the energy network and the generation infrastructure could have significant economic and environmental impacts especially in isolated areas like New Zealand. Reducing the global energy demand of lighting by using LED have the potential to mitigate some of these impacts but are not considered in this work.

VI. SUMMARY AND RECOMMENDATION

This study confirms that incandescent lamps are the most impacting lamp studied especially due to their higher energy consumption. The differences between the potential impacts of incandescent lamps and the other lamps studied is more noticeable in Australia than New Zealand, due to a higher impacts generated by electricity consumption. Nevertheless, incandescent lamps still generate 3.3 times more Co2eq emissions than the CFLs and the old LEDs in New Zealand. Incandescent lamps should be avoided not only from an environmental impacts point of view but also to reduce the global energy demand for lighting purpose and the electricity bill of the users.

LEDs with high efficacy are the best choice for both Australia and New Zealand. They are the less impacting lamps from an environmental impacts point of view, and they also have the lowest energy consumption over a complete life cycle. They have the higher potential to reduce significantly the electricity bill of user when they replacing Incandescent, CFL or even the old LED lamps.

All in one, this study confirms also that each country has its own specifications, and choices related to lighting strategy differs especially regarding local electricity mix generation and product available on the market. The major differences between New Zealand and Australia, are what to focus on between higher efficacy, longer lifetime or both:

- Life Cycle Impact Assessment shows that in Australia, after reaching an efficacy of 134lm/W, LEDs with 15,000h and 25,000h lifetime present very similar potential impacts. The old LED with lower efficacy, do not proves to reduce significantly the potential impacts compared to a CFL lamp. Australia should then focus on high efficacy product rather than an even longer lifetime to reduce significantly the environmental potential impacts of lighting.
- In New Zealand the manufacturing phase of some lamp types tends to be the most impacting phase; meaning that lifetime, but also the manufacturing quality of the lamps are the important parameters. Life Cycle Impacts Assessment shows that a low quality LED contributes to reduce the energy consumption but it also generates higher potential impacts than a CFL lamps and higher than an incandescent lamp for two impacts categories (human non-carcinogenic and freshwater eutrophication). It is then recommended to be careful when switching for LED lamps. It should be done more likely with high quality LEDs (efficacy > 100lm/W and lifetime > 15,000h)

Finally, even if end of life stage contributes less than 1% of the potential impacts, there is still room to improve conception of lamps in order to facilitate reparation, recycling and reuse. As LED production phase is more impacting than for others lamps, developing re-lamping to follow improvement of LED products as confirmed by *SSL R&D Multi-Year Program Plan*, but also facilitating repair, reuse and recycling will lead to big improvement in overall environmental performance.

VII. References

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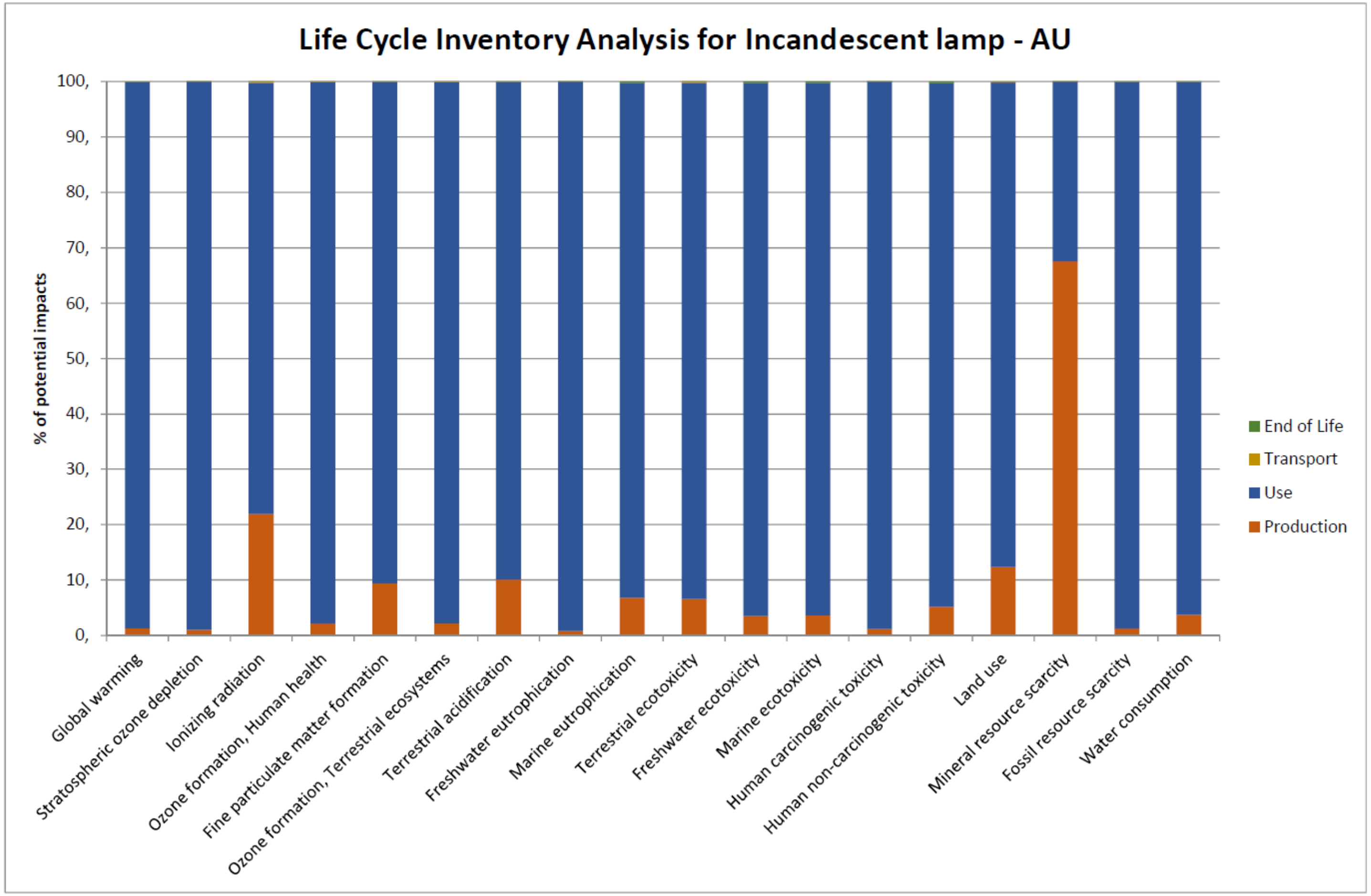
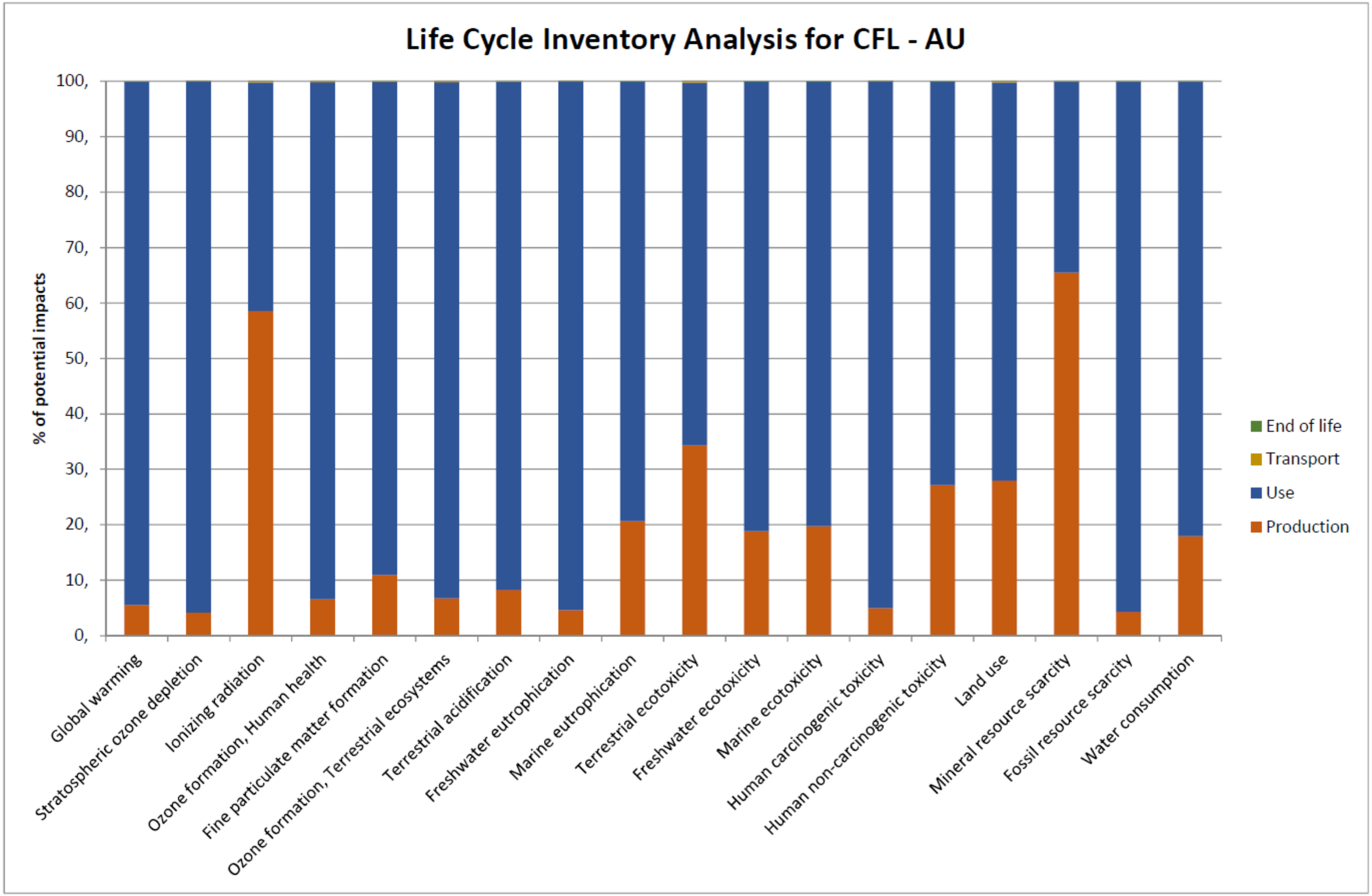
Simapro database Manual:
https://simapro.com/wp-content/uploads/2019/02/DatabaseManualMethods.pdf

VIII. ANNEX

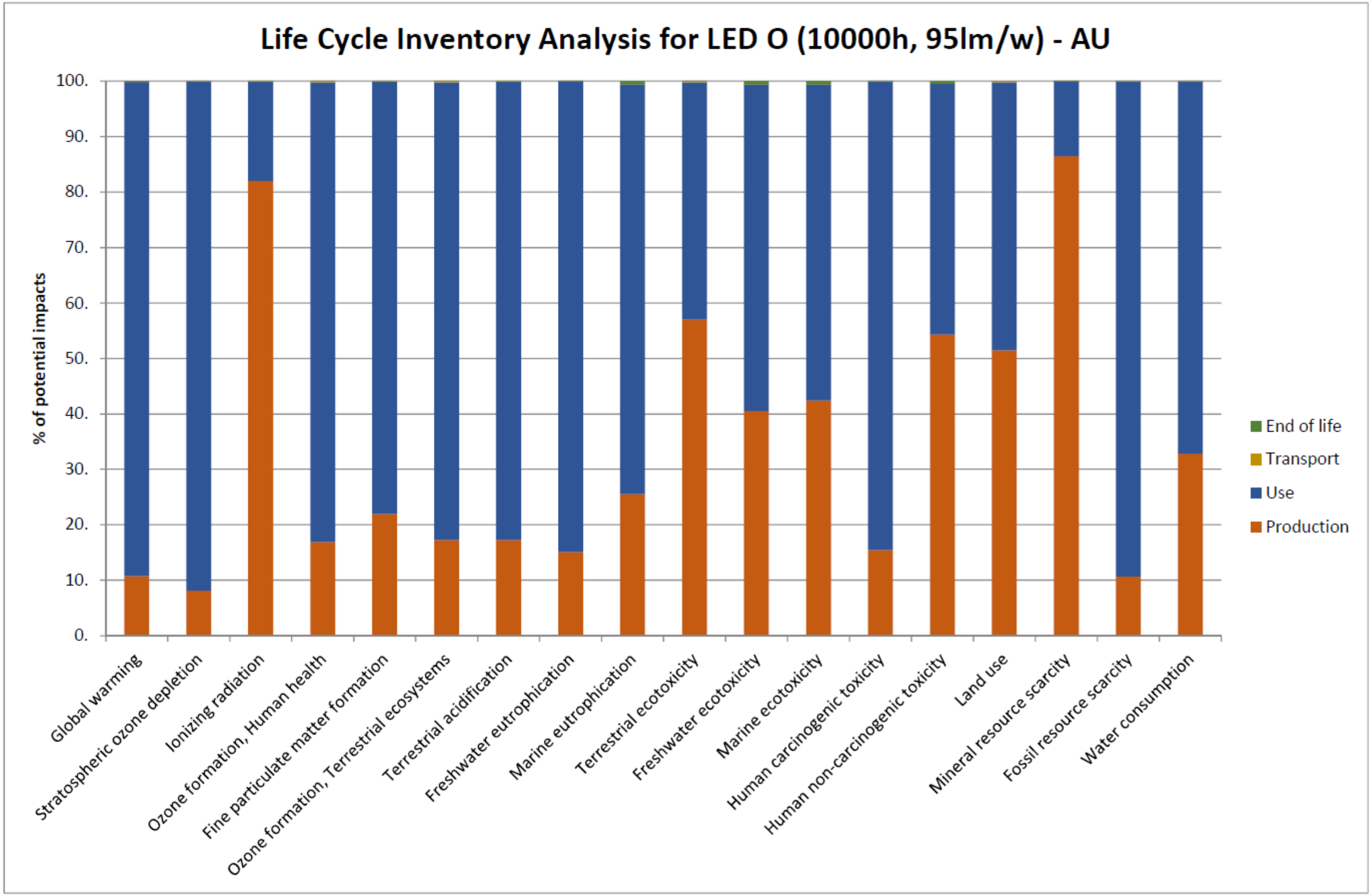
A. LIFE CYCLE INVENTORY ANALYSIS BY PHASE

1. Australia

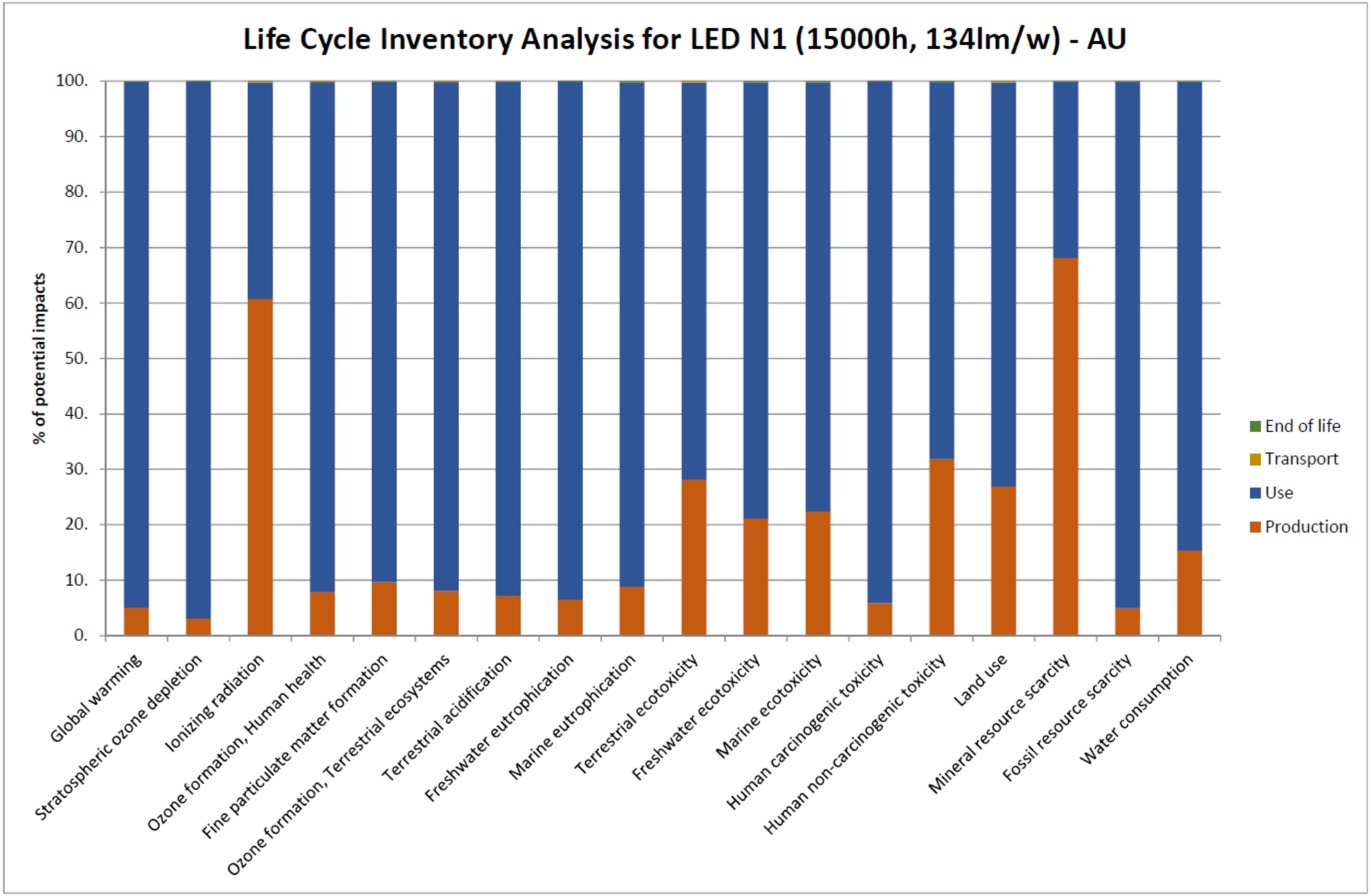




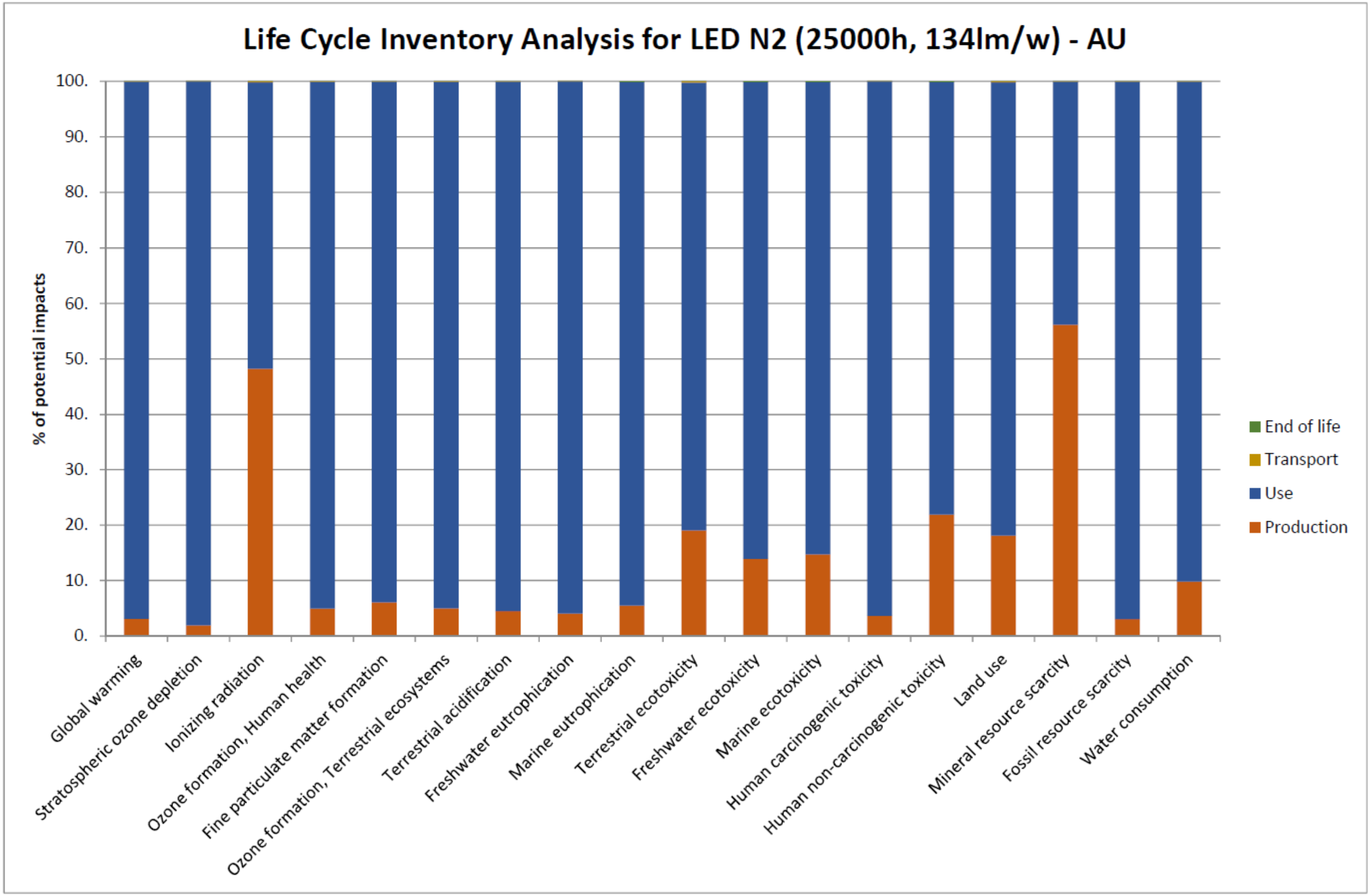
Life Cycle Inventory Analysis for CFL - AU
% of potential impacts
100,
90,
80,
70,
60,
50,
40,
30,
20,
10,
0,
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production



Life Cycle Inventory Analysis for LED O (10000h, 95lm/w) - AU
% of potential impacts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production

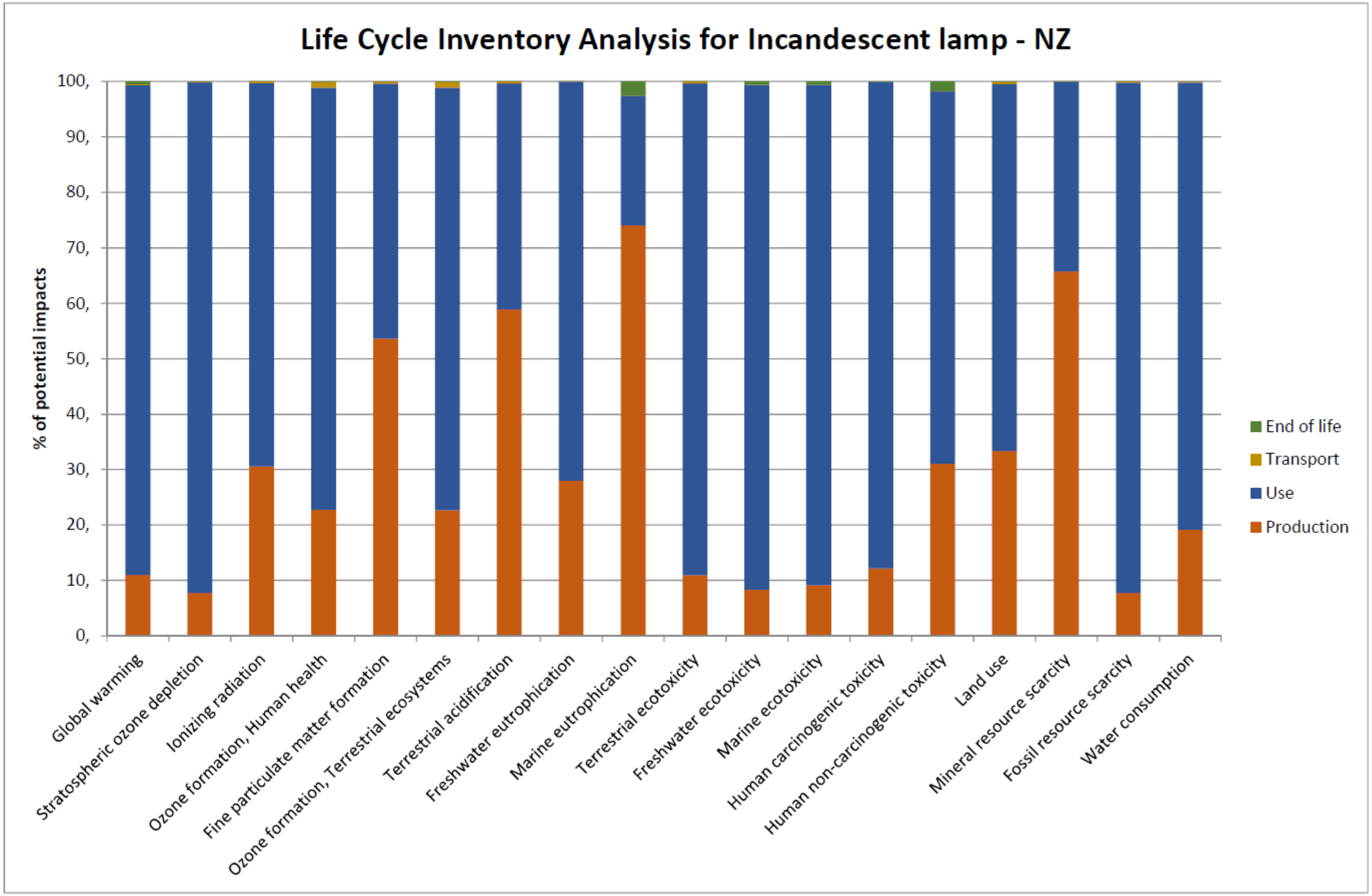


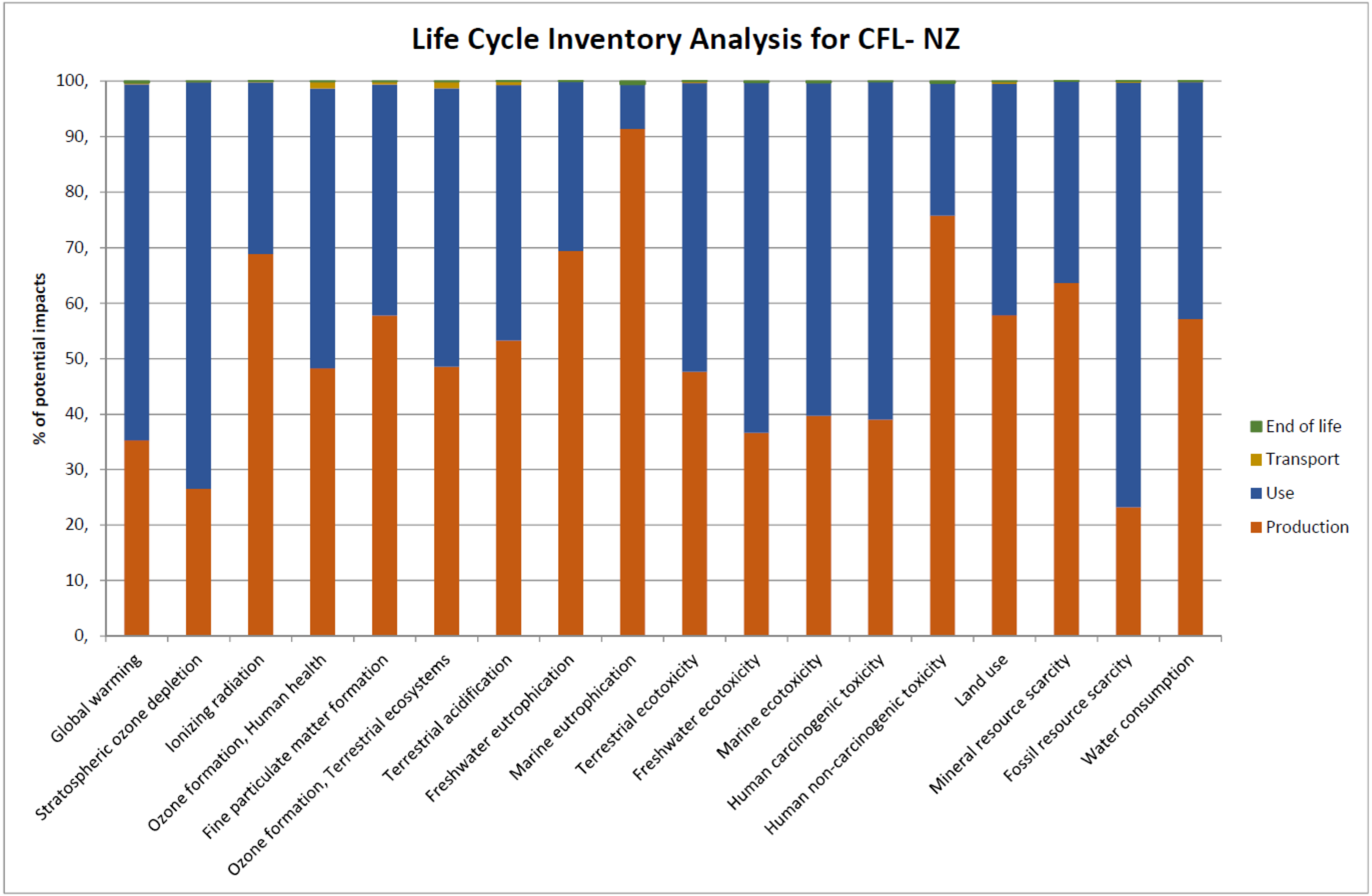
Life Cycle Inventory Analysis for LED N1 (15000h, 134lm/w) - AU
% of potential impacts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production

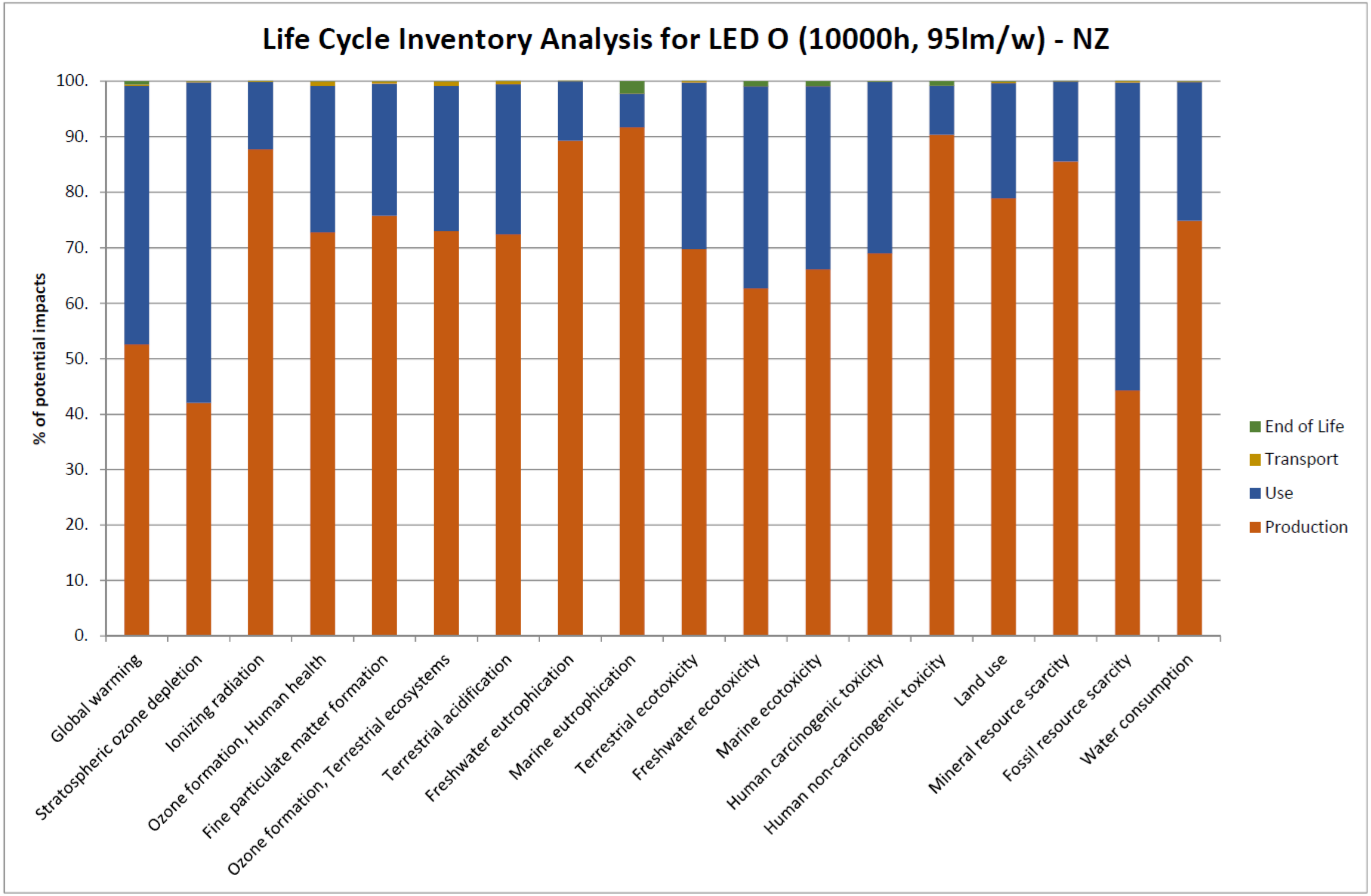


Life Cycle Inventory Analysis for LED N2 (25000h, 134lm/w) - AU
% of potential impacts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production

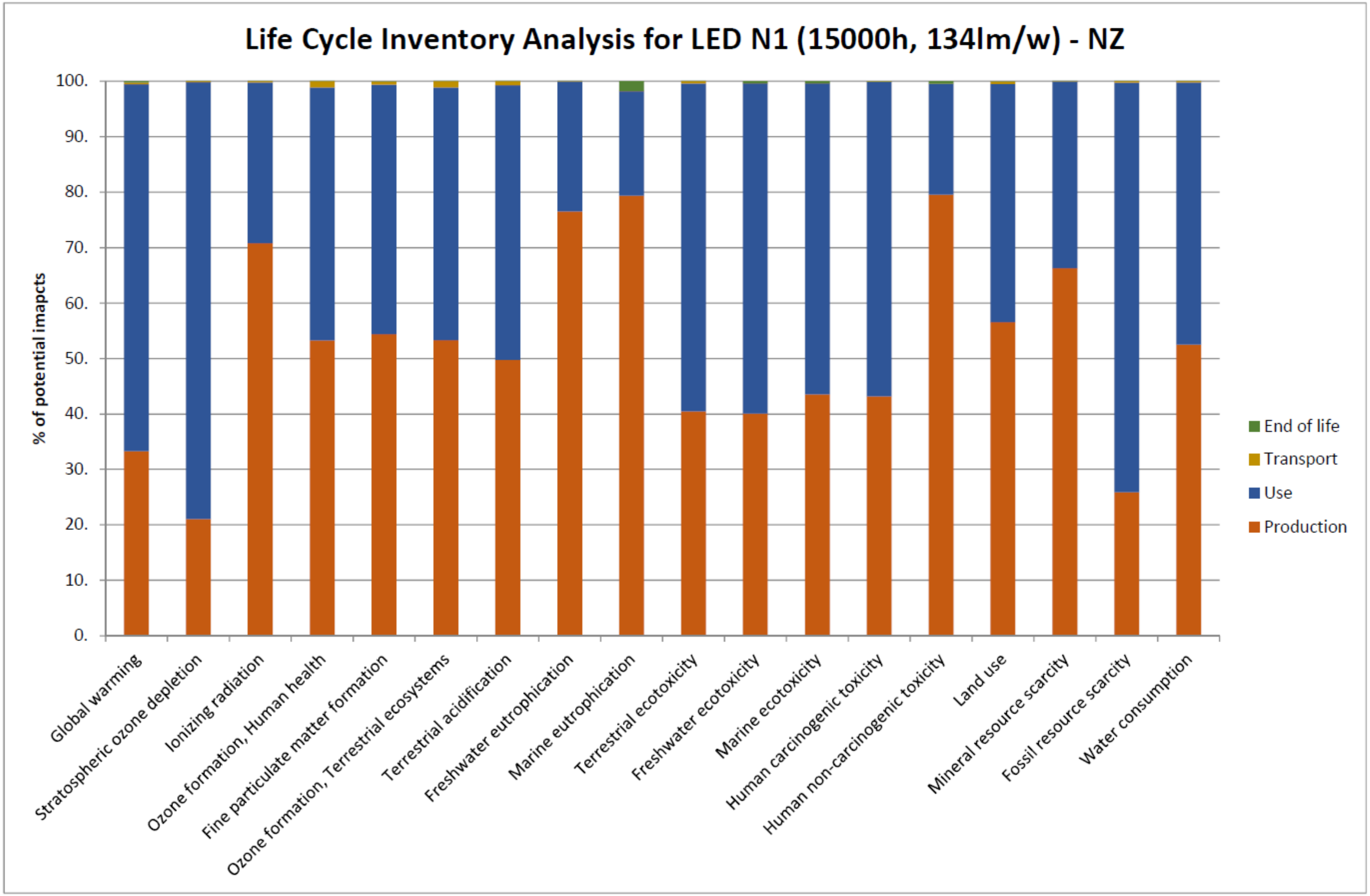
2. New Zealand

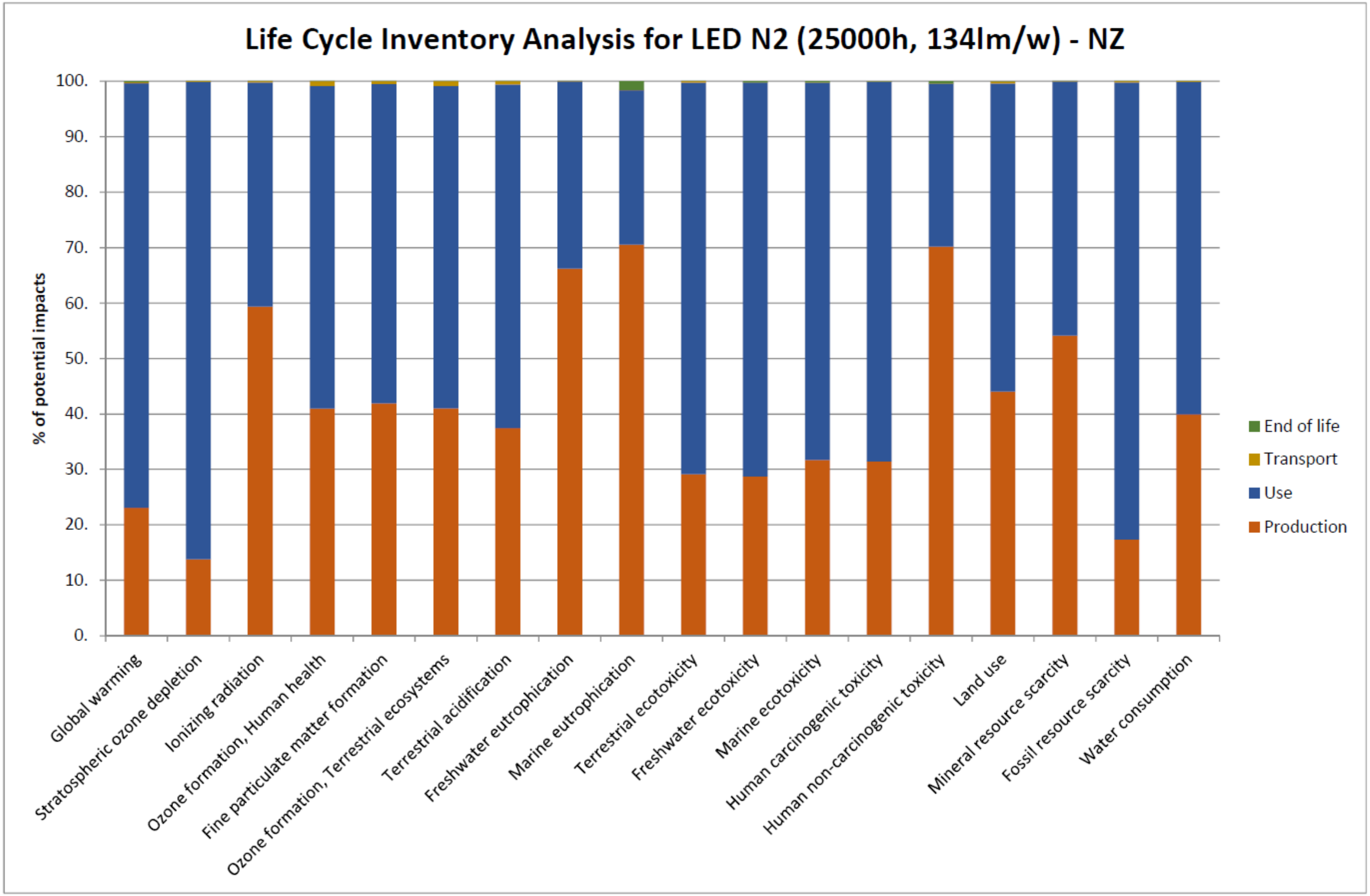



Life Cycle Inventory Analysis for CFL- NZ
% of potential impacts
100,
90,
80,
70,
60,
50,
40,
30,
20,
10,
0,
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production



Life Cycle Inventory Analysis for LED O (10000h, 95lm/w) - NZ
% of potential impacts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of Life
Transport
Use
Production

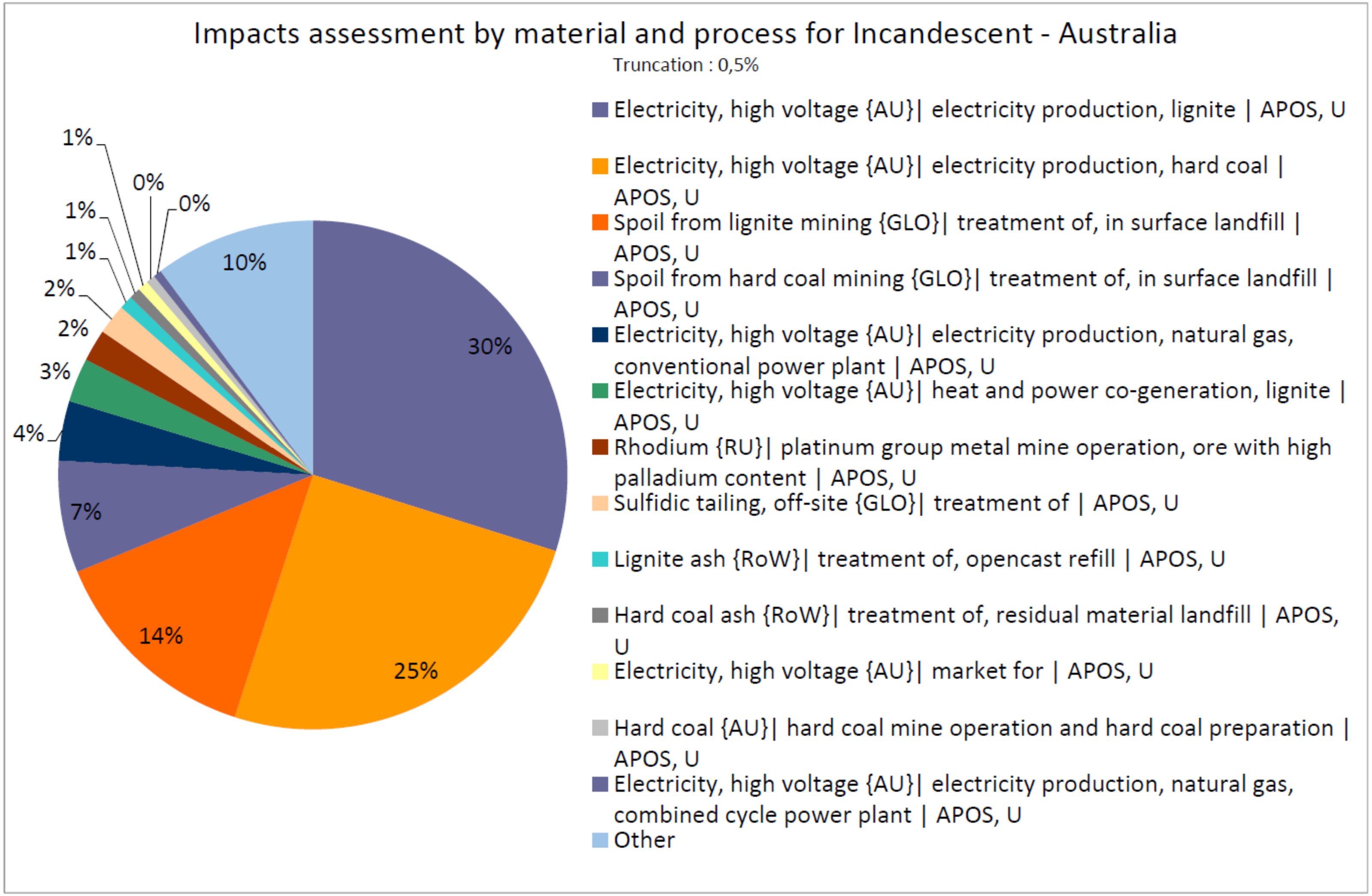

Life Cycle Inventory Analysis for LED N1 (15000h, 134lm/w) - NZ
% of potential imapcts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production

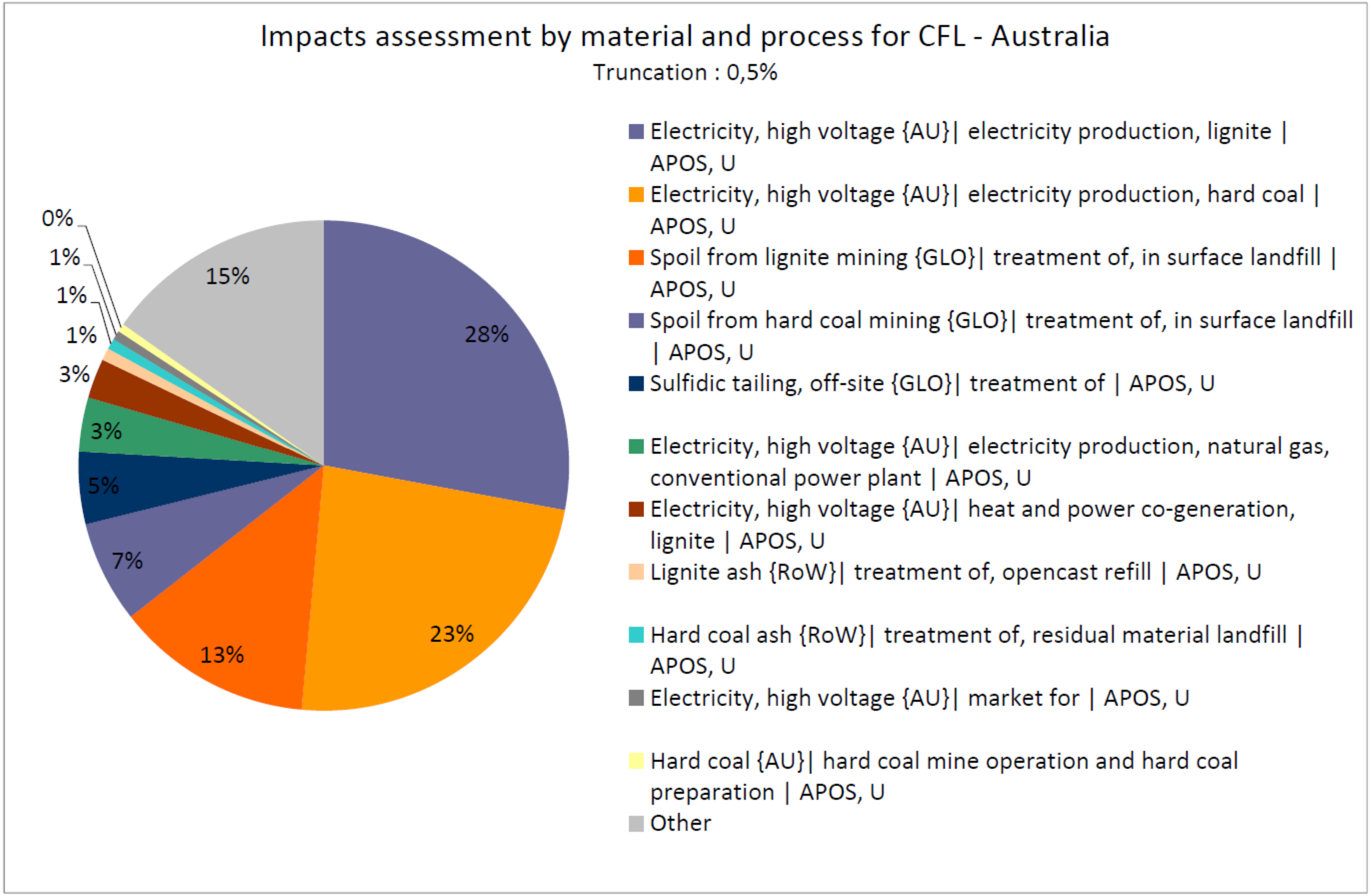


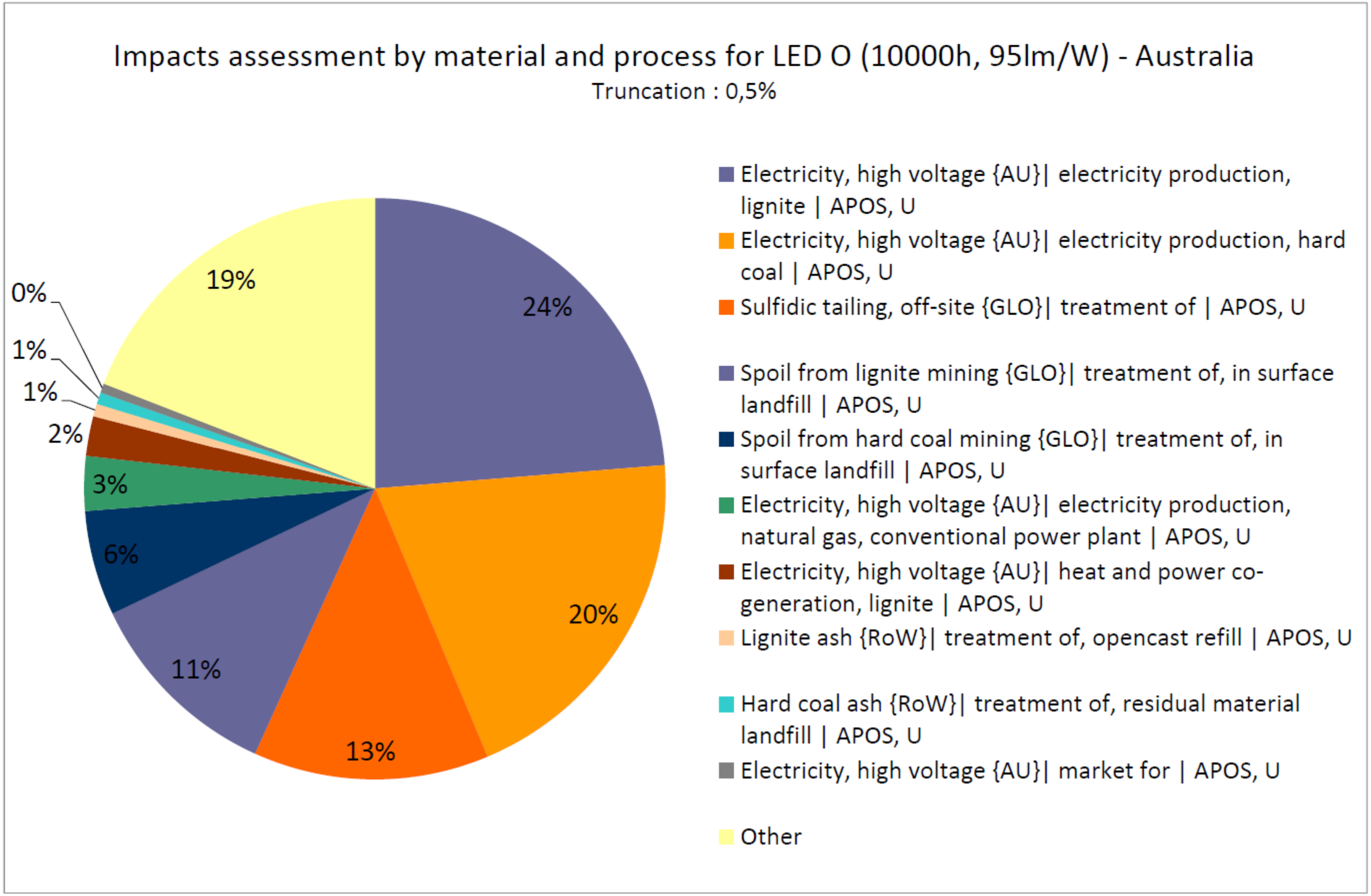
Life Cycle Inventory Analysis for LED N2 (25000h, 134lm/w) - NZ
% of potential impacts
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0.
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
End of life
Transport
Use
Production

B. Impact Assessment By Material Per lamp Unit

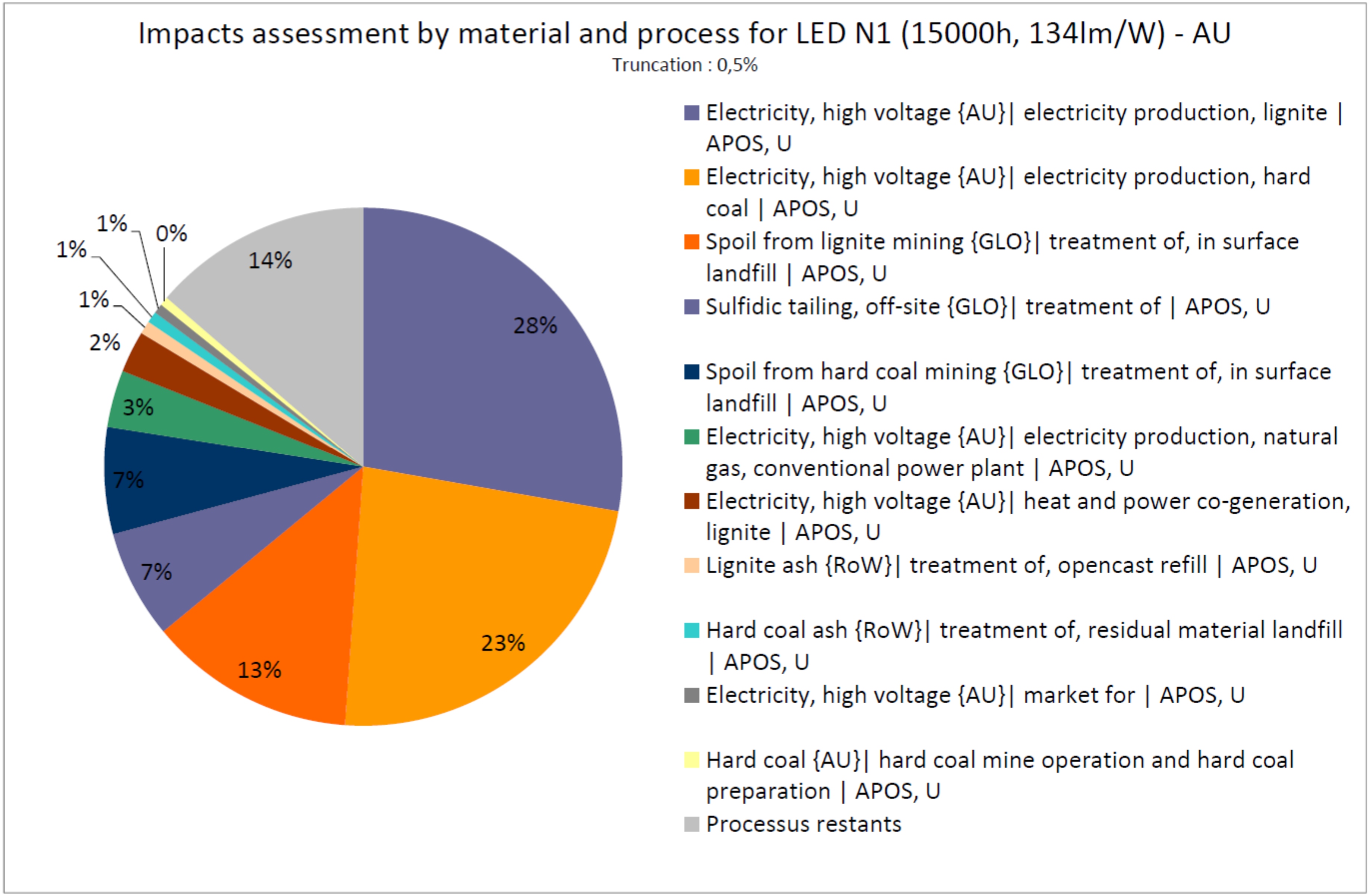
1. Australia

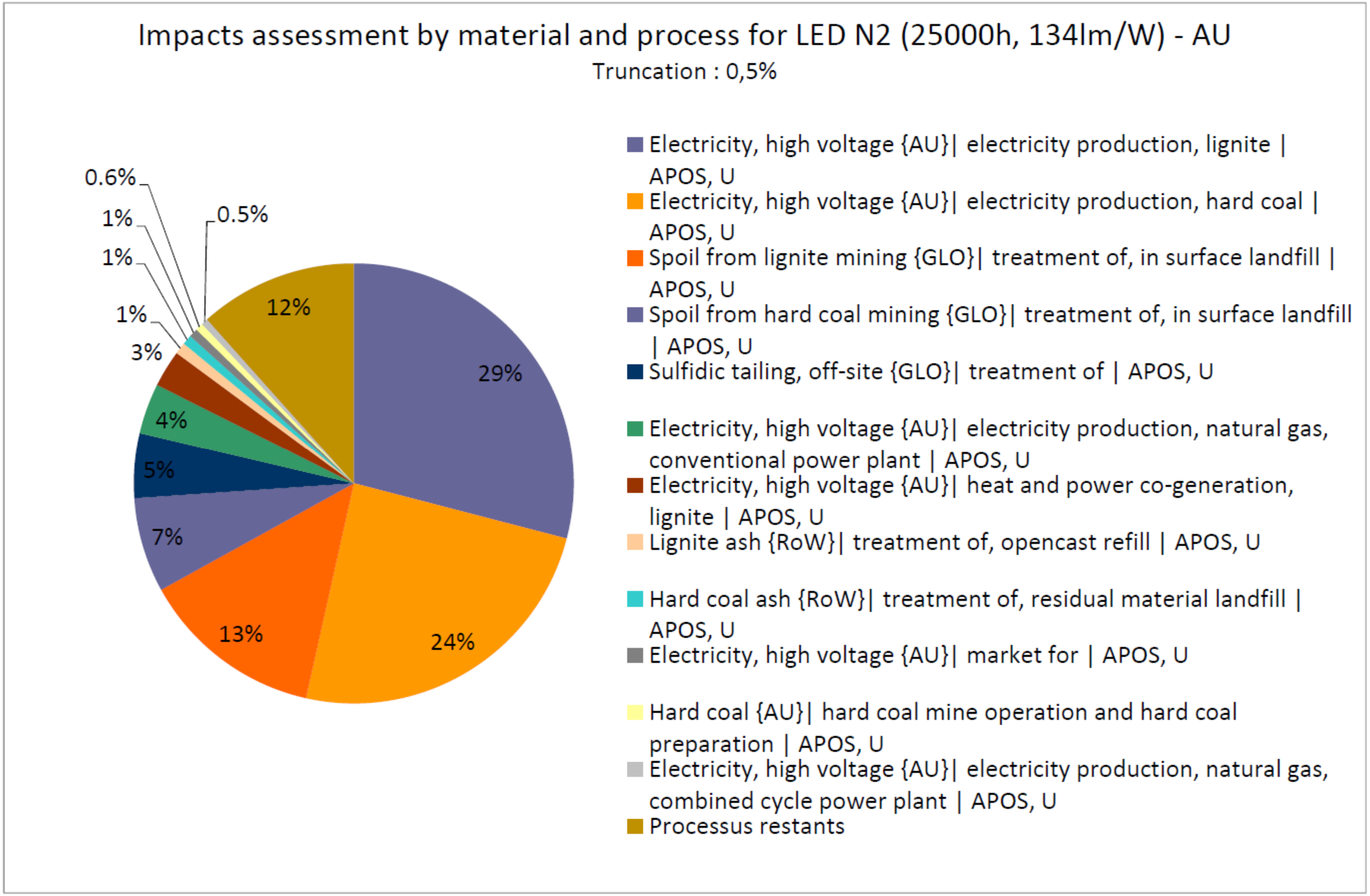



Impacts assessment by material and process for CFL - Australia
Truncation : 0,5%
28%
23%
13%
7%
5%
3%
3%
1%
1%
1%
0%
15%
Electricity, high voltage {AU}| electricity production, lignite | APOS, U
Electricity, high voltage {AU}| electricity production, hard coal | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Electricity, high voltage {AU}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {AU}| heat and power co-generation, lignite | APOS, U
Lignite ash {RoW}| treatment of, opencast refill | APOS, U
Hard coal ash {RoW}| treatment of, residual material landfill | APOS, U
Electricity, high voltage {AU}| market for | APOS, U
Hard coal {AU}| hard coal mine operation and hard coal preparation | APOS, U
Other

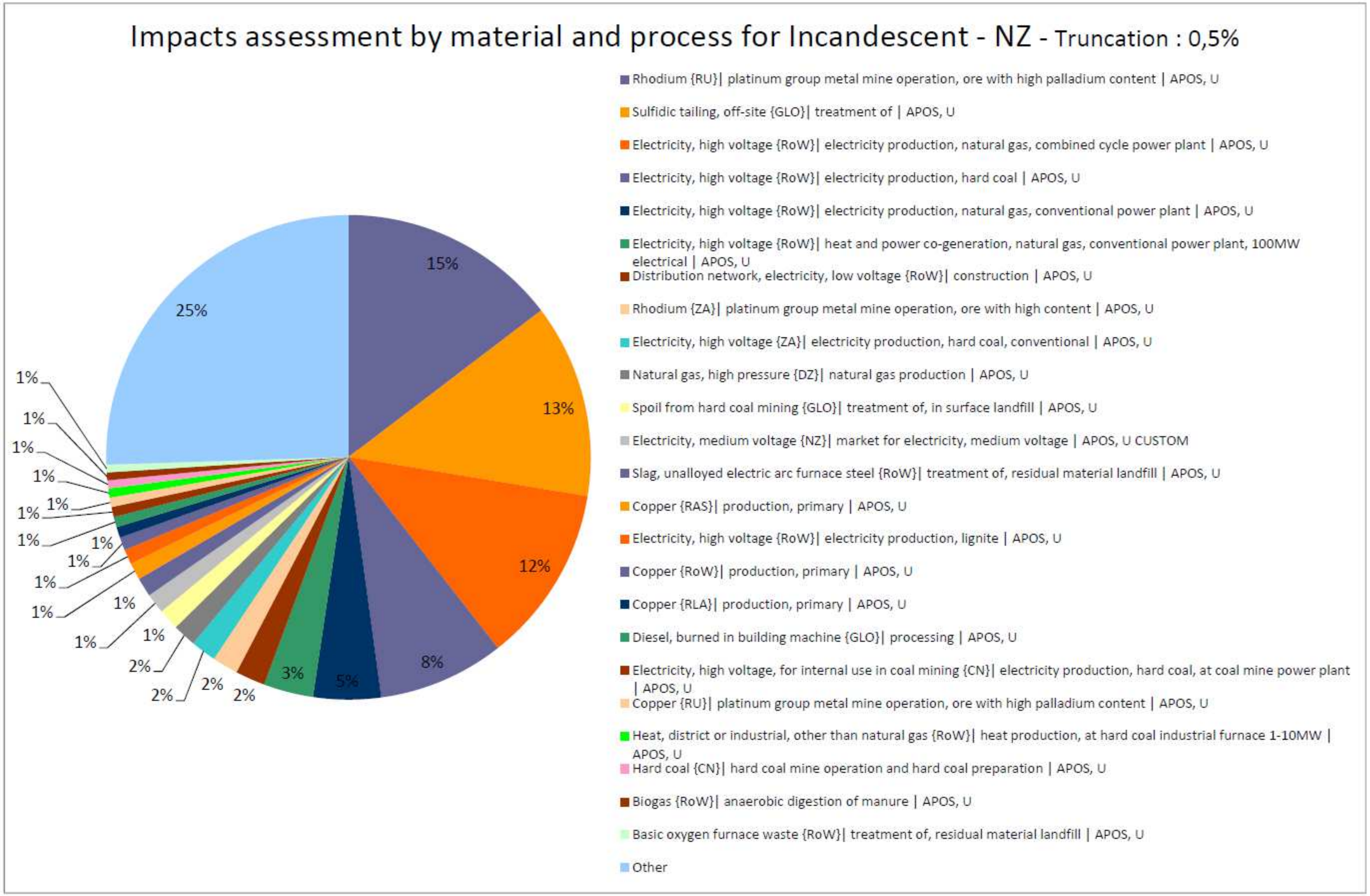


Impacts assessment by material and process for LED O (10000h, 95lm/W) - Australia
Truncation : 0,5%
24%
20%
13%
11%
6%
3%
2%
1%
1%
0%
19%
Electricity, high voltage {AU}| electricity production, lignite | APOS, U
Electricity, high voltage {AU}| electricity production, hard coal | APOS, U
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Electricity, high voltage {AU}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {AU}| heat and power co-generation, lignite | APOS, U
Lignite ash {RoW}| treatment of, opencast refill | APOS, U
Hard coal ash {RoW}| treatment of, residual material landfill | APOS, U
Electricity, high voltage {AU}| market for | APOS, U
Other

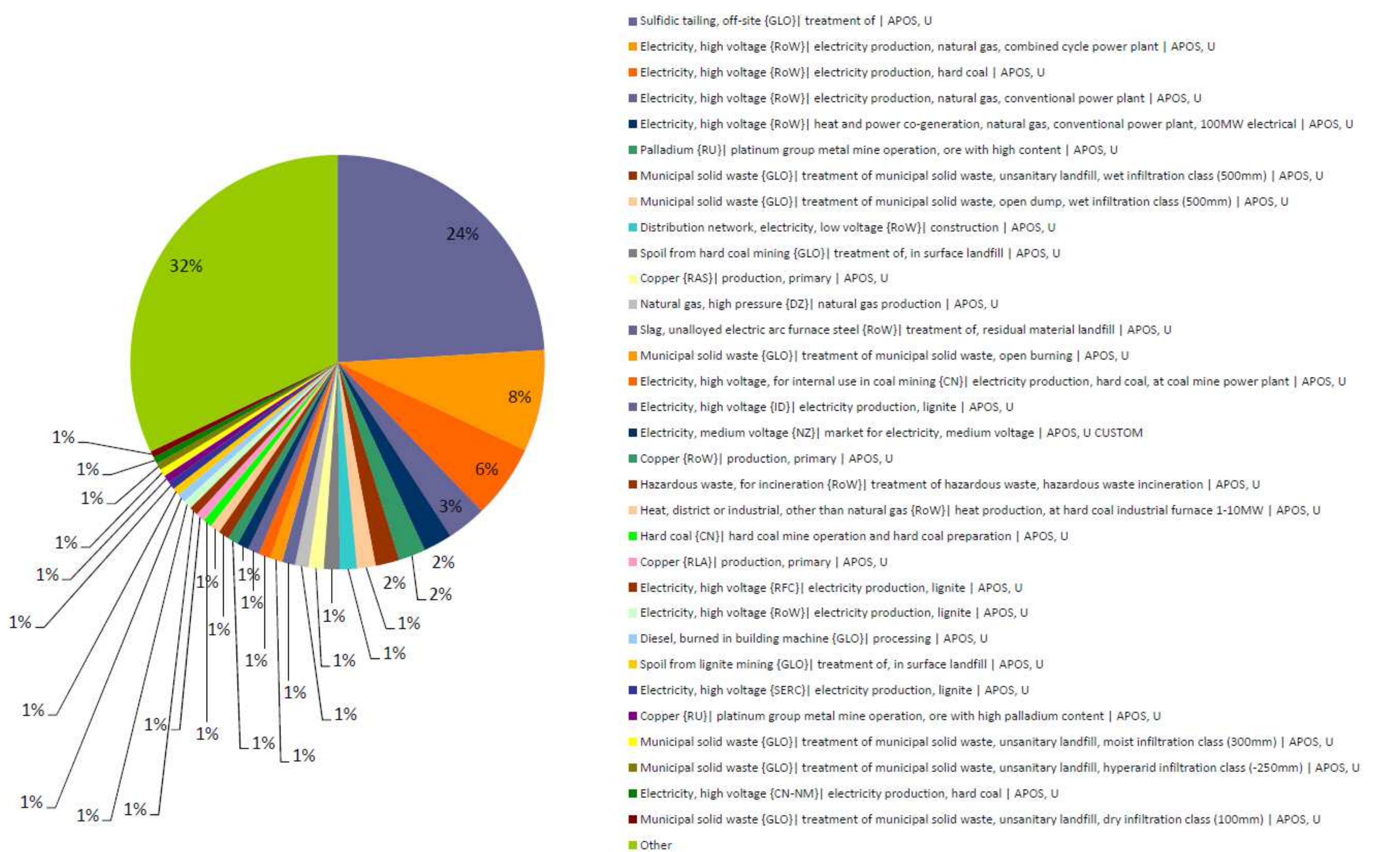

Impacts assessment by material and process for LED N1 (15000h, 134lm/W) - AU
Truncation : 0,5%
28%
23%
13%
7%
7%
3%
2%
1%
1%
1%
0%
14%
Electricity, high voltage {AU}| electricity production, lignite | APOS, U
Electricity, high voltage {AU}| electricity production, hard coal | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Electricity, high voltage {AU}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {AU}| heat and power co-generation, lignite | APOS, U
Lignite ash {RoW}| treatment of, opencast refill | APOS, U
Hard coal ash {RoW}| treatment of, residual material landfill | APOS, U
Electricity, high voltage {AU}| market for | APOS, U
Hard coal {AU}| hard coal mine operation and hard coal preparation | APOS, U
Processus restants

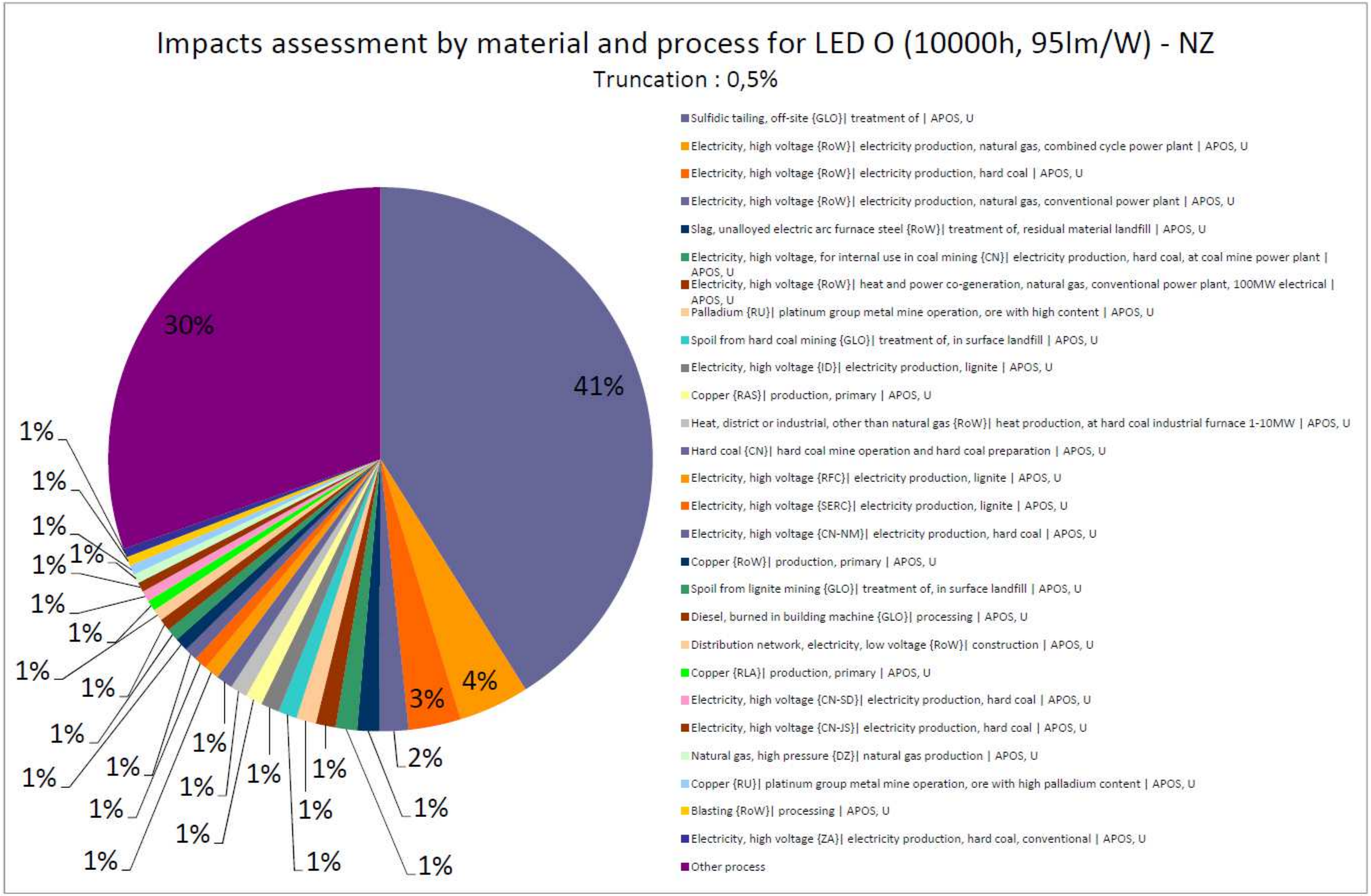

Impacts assessment by material and process for LED N2 (25000h, 134lm/W) - AU
Truncation : 0,5%
0.6%
1%
1%
0.5%
1%
3%
12%
29%
4%
5%
7%
13%
24%
Electricity, high voltage {AU}| electricity production, lignite | APOS, U
Electricity, high voltage {AU}| electricity production, hard coal | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Electricity, high voltage {AU}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {AU}| heat and power co-generation, lignite | APOS, U
Lignite ash {RoW}| treatment of, opencast refill | APOS, U
Hard coal ash {RoW}| treatment of, residual material landfill | APOS, U
Electricity, high voltage {AU}| market for | APOS, U
Hard coal {AU}| hard coal mine operation and hard coal preparation | APOS, U
Electricity, high voltage {AU}| electricity production, natural gas, combined cycle power plant | APOS, U
Processus restants

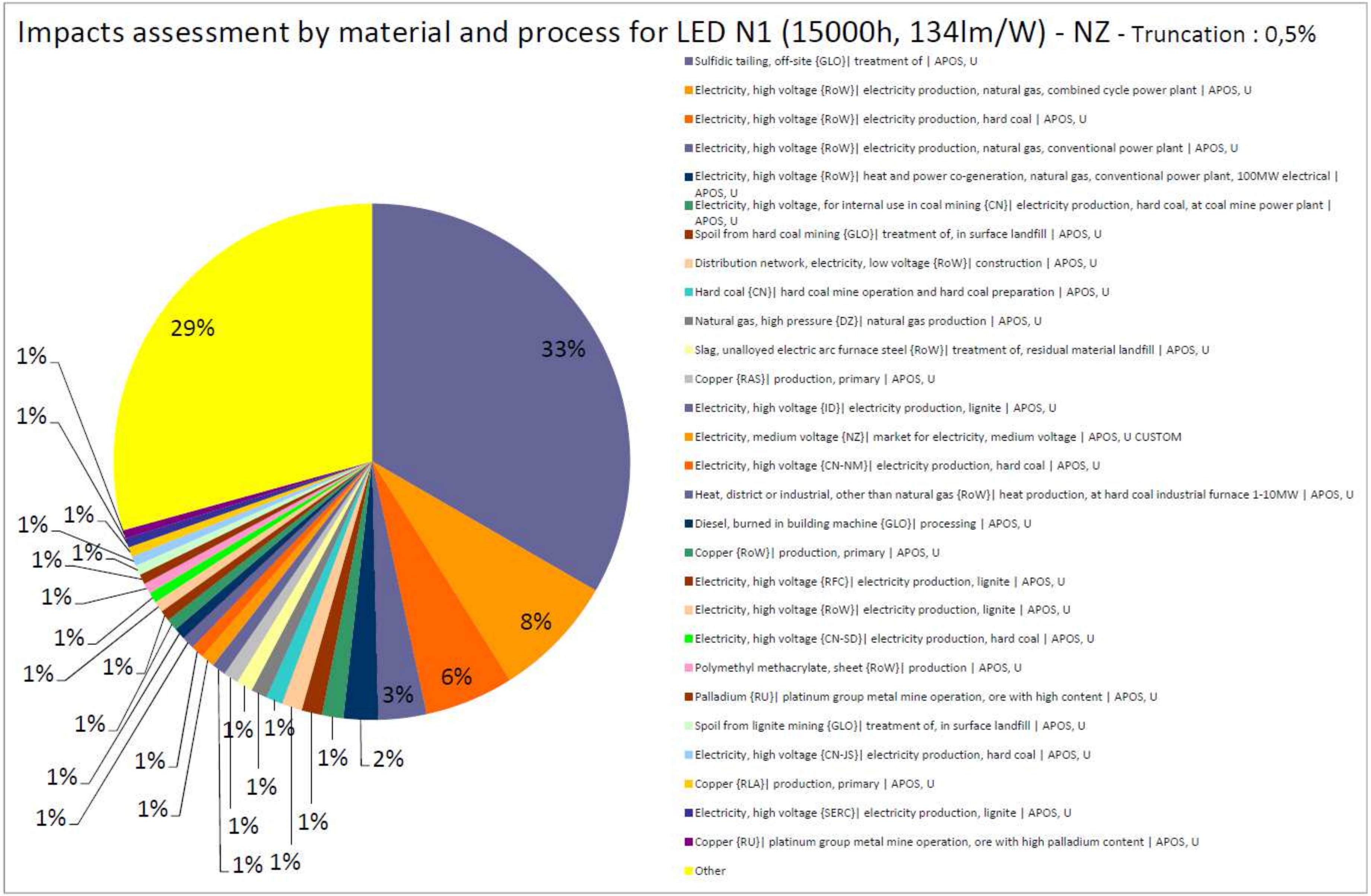
2. New Zealand



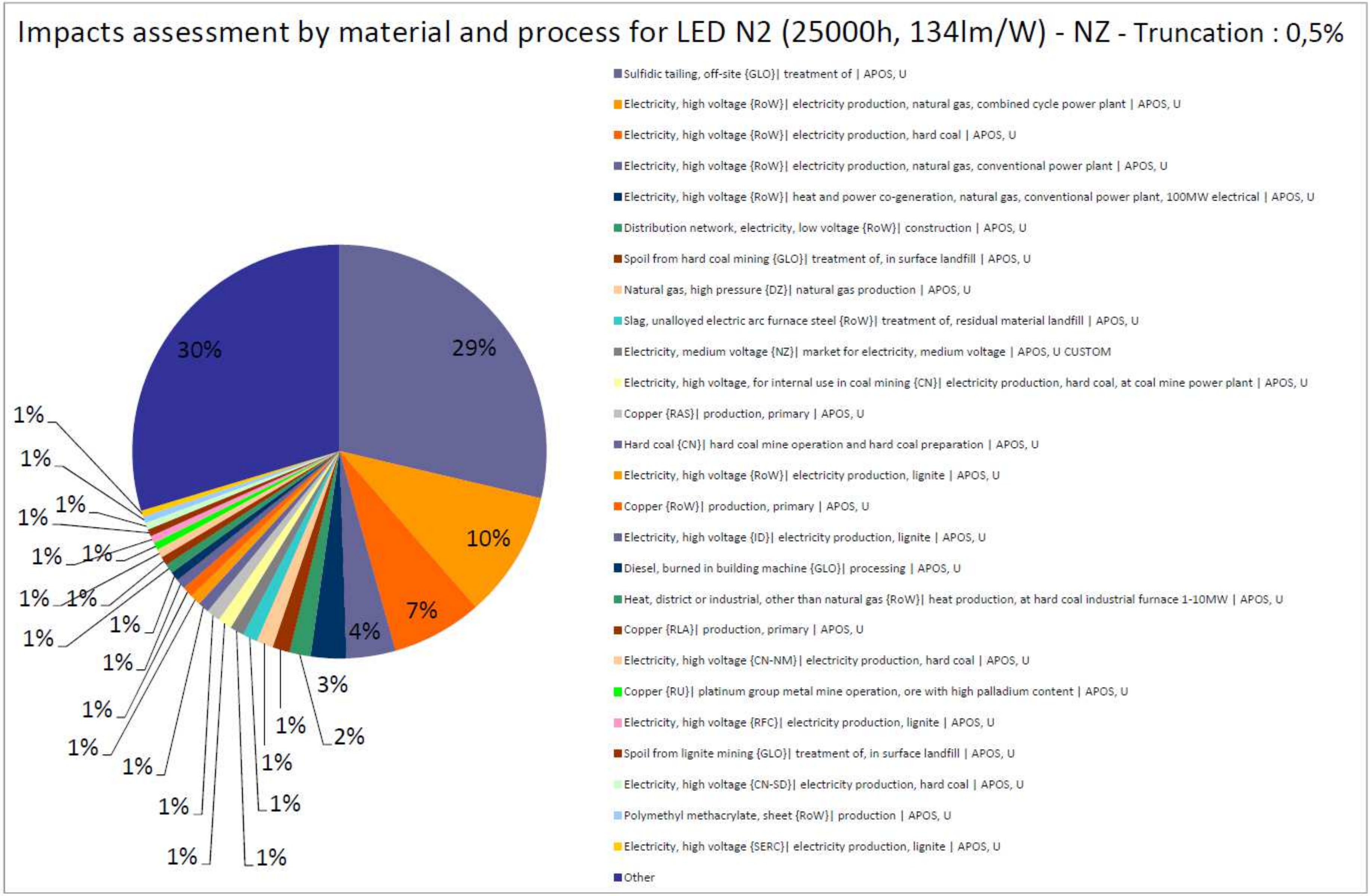
Impacts assessment by material and process for CFL - NZ - Truncation : 0,5%



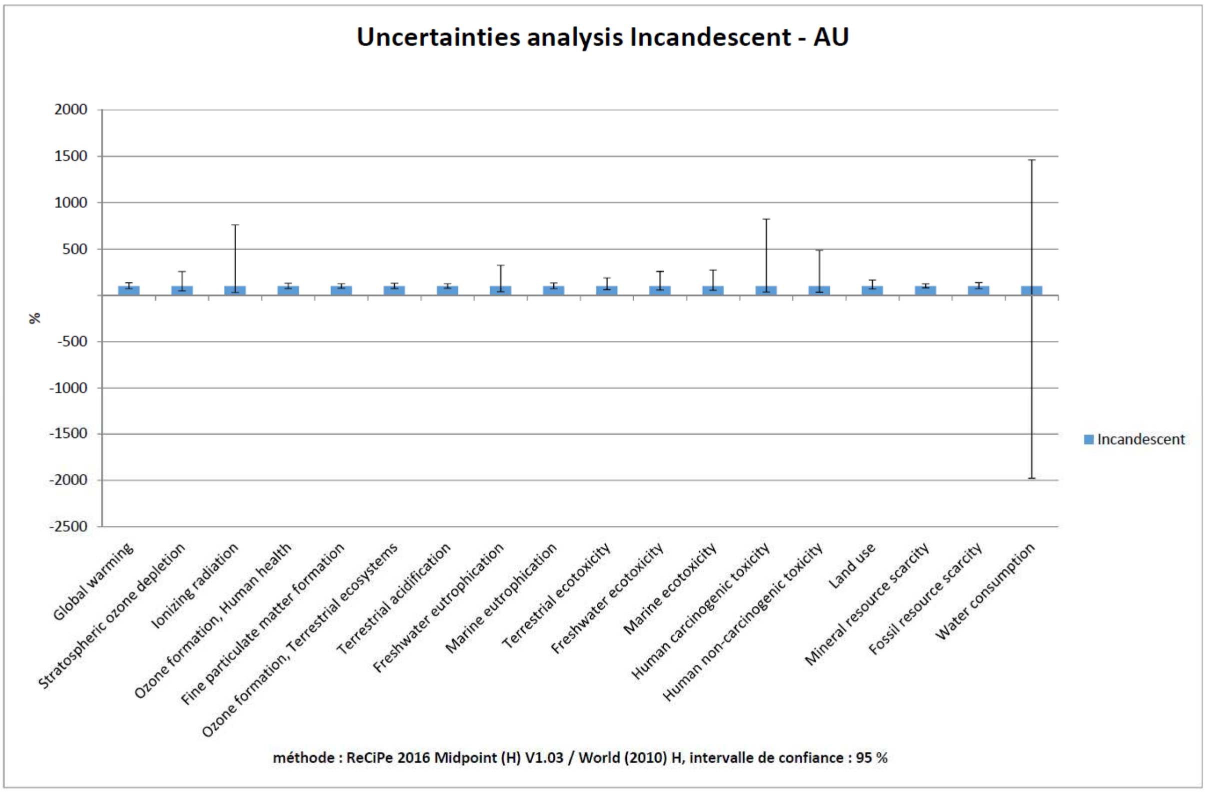

Impacts assessment by material and process for LED O (10000h, 95lm/W) - NZ
Truncation : 0,5%
41%
30%
4%
3%
2%
1%
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, combined cycle power plant | APOS, U
Electricity, high voltage {RoW}| electricity production, hard coal | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, conventional power plant | APOS, U
Slag, unalloyed electric arc furnace steel {RoW}| treatment of, residual material landfill | APOS, U
Electricity, high voltage, for internal use in coal mining {CN}| electricity production, hard coal, at coal mine power plant | APOS, U
Electricity, high voltage {RoW}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | APOS, U
Palladium {RU}| platinum group metal mine operation, ore with high content | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Electricity, high voltage {ID}| electricity production, lignite | APOS, U
Copper {RAS}| production, primary | APOS, U
Heat, district or industrial, other than natural gas {RoW}| heat production, at hard coal industrial furnace 1-10MW | APOS, U
Hard coal {CN}| hard coal mine operation and hard coal preparation | APOS, U
Electricity, high voltage {RFC}| electricity production, lignite | APOS, U
Electricity, high voltage {SERC}| electricity production, lignite | APOS, U
Electricity, high voltage {CN-NM}| electricity production, hard coal | APOS, U
Copper {RoW}| production, primary | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Diesel, burned in building machine {GLO}| processing | APOS, U
Distribution network, electricity, low voltage {RoW}| construction | APOS, U
Copper {RLA}| production, primary | APOS, U
Electricity, high voltage {CN-SD}| electricity production, hard coal | APOS, U
Electricity, high voltage {CN-JS}| electricity production, hard coal | APOS, U
Natural gas, high pressure {DZ}| natural gas production | APOS, U
Copper {RU}| platinum group metal mine operation, ore with high palladium content | APOS, U
Blasting {RoW}| processing | APOS, U
Electricity, high voltage {ZA}| electricity production, hard coal, conventional | APOS, U
Other process

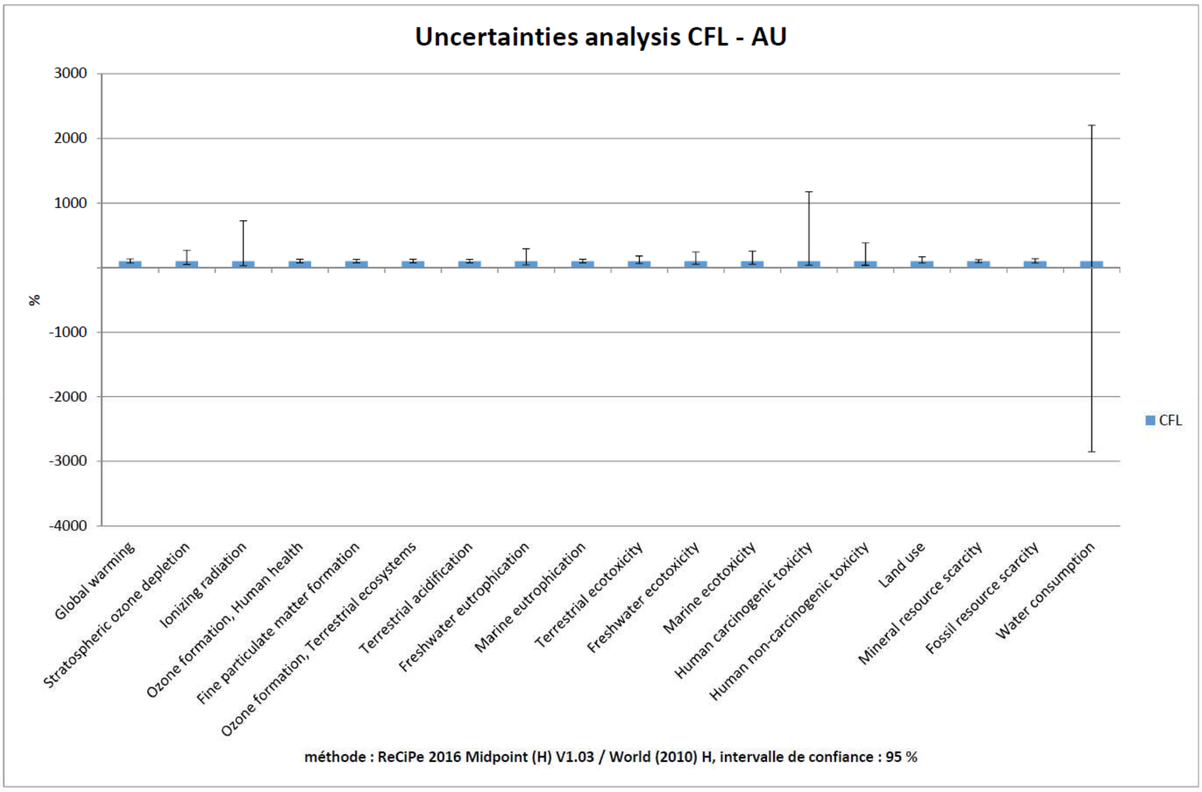


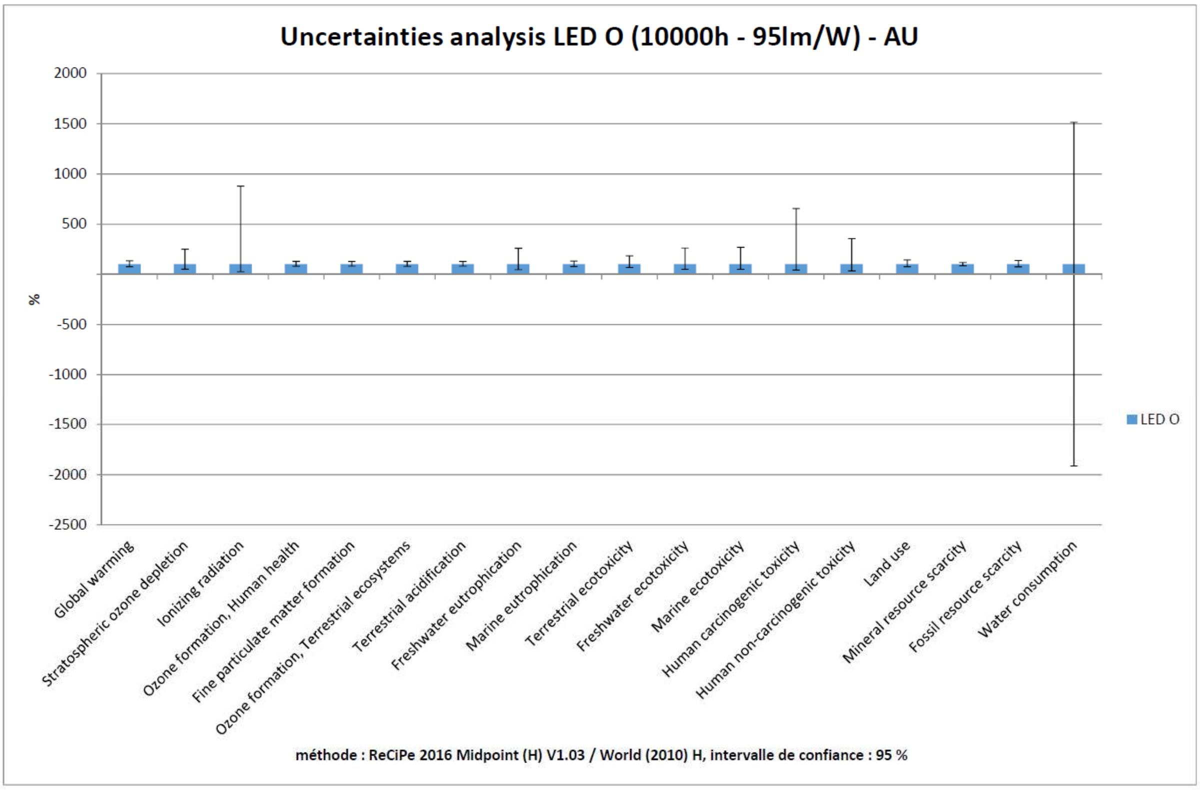
Impacts assessment by material and process for LED N1 (15000h, 134lm/W) - NZ - Truncation : 0,5%
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, combined cycle power plant | APOS, U
Electricity, high voltage {RoW}| electricity production, hard coal | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {RoW}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | APOS, U
Electricity, high voltage, for internal use in coal mining {CN}| electricity production, hard coal, at coal mine power plant | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Distribution network, electricity, low voltage {RoW}| construction | APOS, U
Hard coal {CN}| hard coal mine operation and hard coal preparation | APOS, U
Natural gas, high pressure {DZ}| natural gas production | APOS, U
Slag, unalloyed electric arc furnace steel {RoW}| treatment of, residual material landfill | APOS, U
Copper {RAS}| production, primary | APOS, U
Electricity, high voltage {ID}| electricity production, lignite | APOS, U
Electricity, medium voltage {NZ}| market for electricity, medium voltage | APOS, U CUSTOM
Electricity, high voltage {CN-NM}| electricity production, hard coal | APOS, U
Heat, district or industrial, other than natural gas {RoW}| heat production, at hard coal industrial furnace 1-10MW | APOS, U
Diesel, burned in building machine {GLO}| processing | APOS, U
Copper {RoW}| production, primary | APOS, U
Electricity, high voltage {RFC}| electricity production, lignite | APOS, U
Electricity, high voltage {RoW}| electricity production, lignite | APOS, U
Electricity, high voltage {CN-SD}| electricity production, hard coal | APOS, U
Polymethyl methacrylate, sheet {RoW}| production | APOS, U
Palladium {RU}| platinum group metal mine operation, ore with high content | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Electricity, high voltage {CN-JS}| electricity production, hard coal | APOS, U
Copper {RLA}| production, primary | APOS, U
Electricity, high voltage {SERC}| electricity production, lignite | APOS, U
Copper {RU}| platinum group metal mine operation, ore with high palladium content | APOS, U
Other
33%
8%
6%
3%
2%
29%
1%

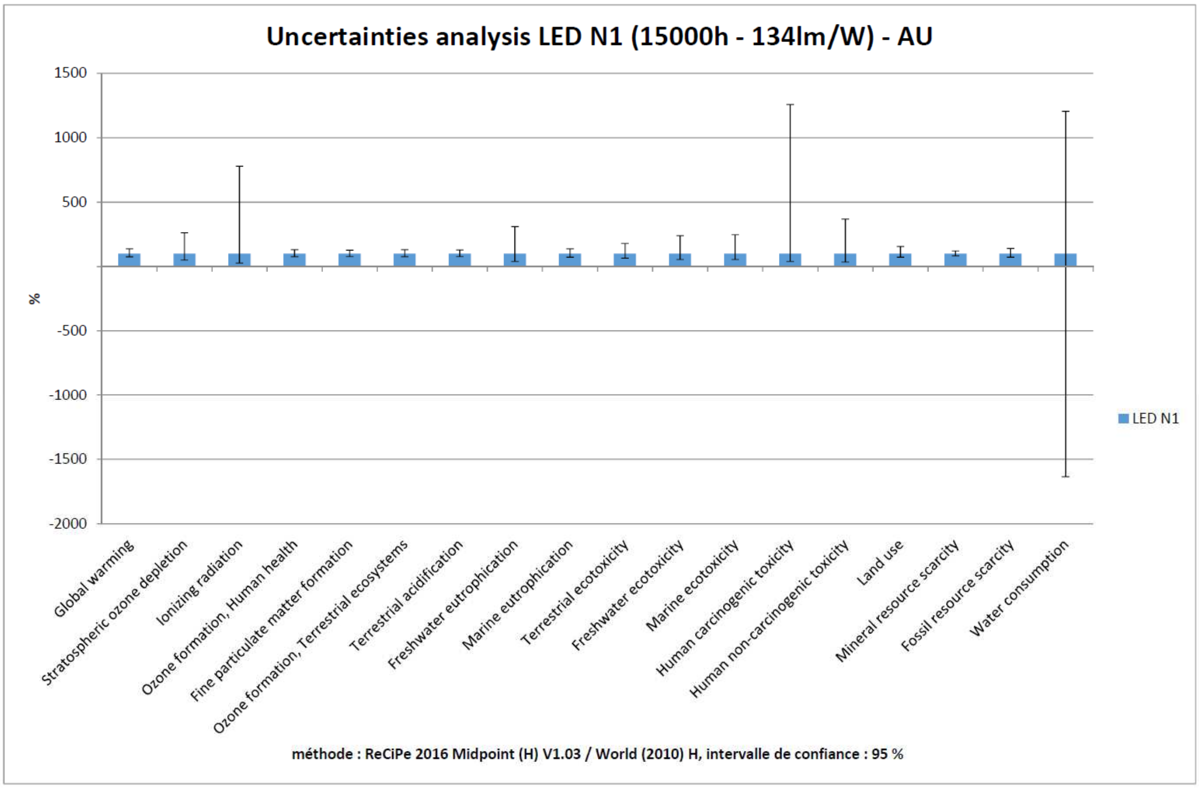

Impacts assessment by material and process for LED N2 (25000h, 134lm/W) - NZ - Truncation : 0,5%
30%
29%
10%
7%
4%
3%
2%
1%
Sulfidic tailing, off-site {GLO}| treatment of | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, combined cycle power plant | APOS, U
Electricity, high voltage {RoW}| electricity production, hard coal | APOS, U
Electricity, high voltage {RoW}| electricity production, natural gas, conventional power plant | APOS, U
Electricity, high voltage {RoW}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | APOS, U
Distribution network, electricity, low voltage {RoW}| construction | APOS, U
Spoil from hard coal mining {GLO}| treatment of, in surface landfill | APOS, U
Natural gas, high pressure {DZ}| natural gas production | APOS, U
Slag, unalloyed electric arc furnace steel {RoW}| treatment of, residual material landfill | APOS, U
Electricity, medium voltage {NZ}| market for electricity, medium voltage | APOS, U CUSTOM
Electricity, high voltage, for internal use in coal mining {CN}| electricity production, hard coal, at coal mine power plant | APOS, U
Copper {RAS}| production, primary | APOS, U
Hard coal {CN}| hard coal mine operation and hard coal preparation | APOS, U
Electricity, high voltage {RoW}| electricity production, lignite | APOS, U
Copper {RoW}| production, primary | APOS, U
Electricity, high voltage {ID}| electricity production, lignite | APOS, U
Diesel, burned in building machine {GLO}| processing | APOS, U
Heat, district or industrial, other than natural gas {RoW}| heat production, at hard coal industrial furnace 1-10MW | APOS, U
Copper {RLA}| production, primary | APOS, U
Electricity, high voltage {CN-NM}| electricity production, hard coal | APOS, U
Copper {RU}| platinum group metal mine operation, ore with high palladium content | APOS, U
Electricity, high voltage {RFC}| electricity production, lignite | APOS, U
Spoil from lignite mining {GLO}| treatment of, in surface landfill | APOS, U
Electricity, high voltage {CN-SD}| electricity production, hard coal | APOS, U
Polymethyl methacrylate, sheet {RoW}| production | APOS, U
Electricity, high voltage {SERC}| electricity production, lignite | APOS, U
Other

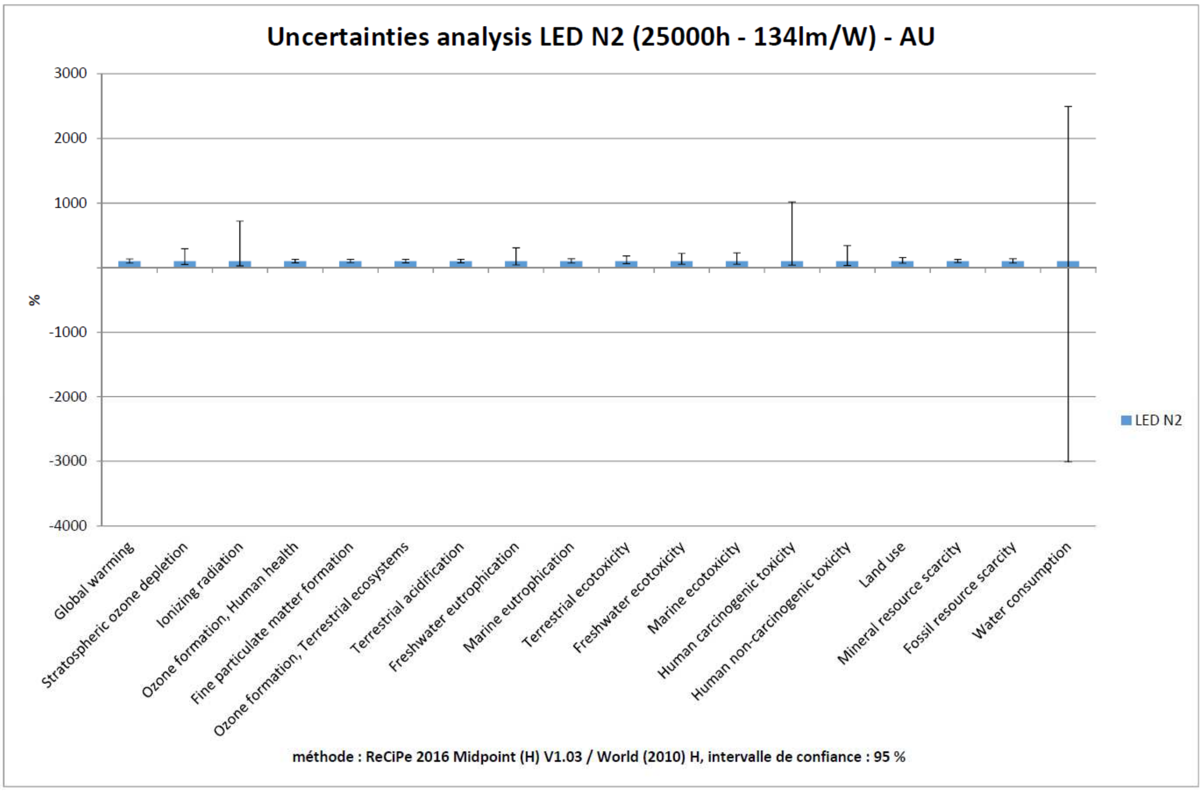
C. UNCERTAINTIES ANALYSIS



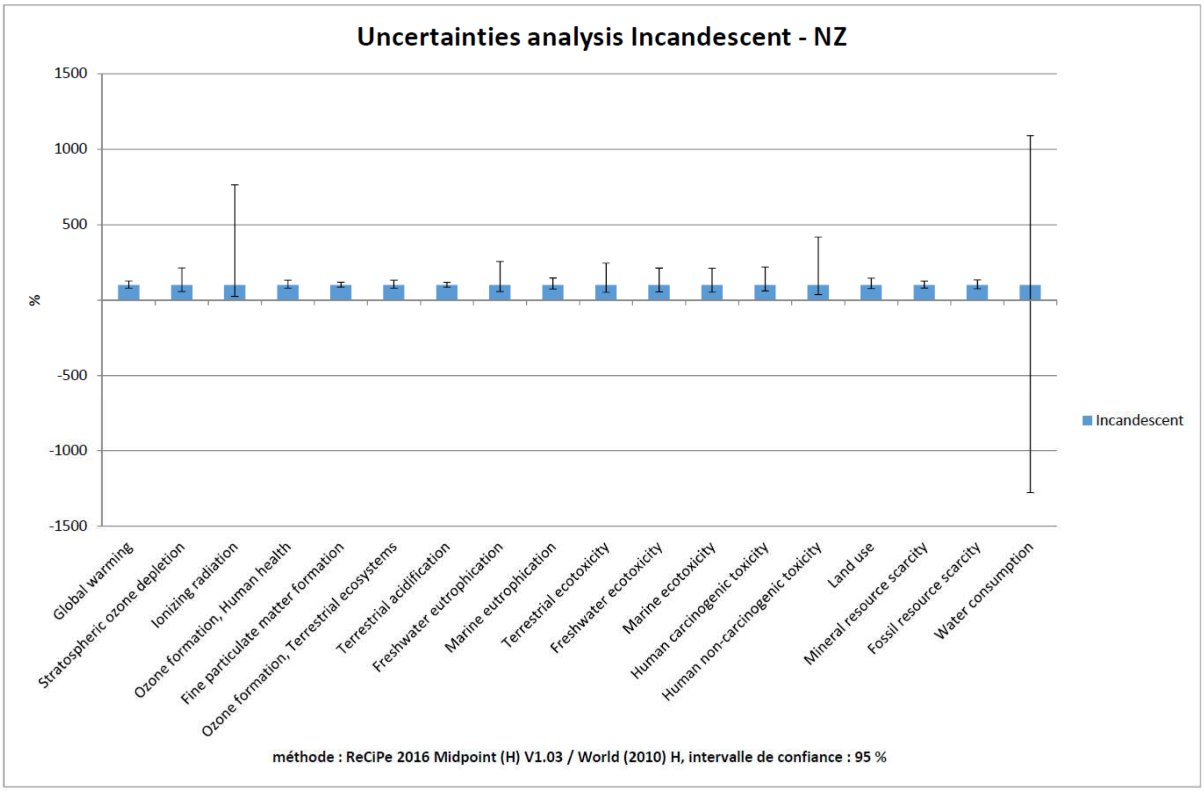



Uncertainties analysis LED O (10000h - 95lm/W) - AU
2000
1500
1000
500
%
-500
-1000
-1500
-2000
-2500
LED O
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %

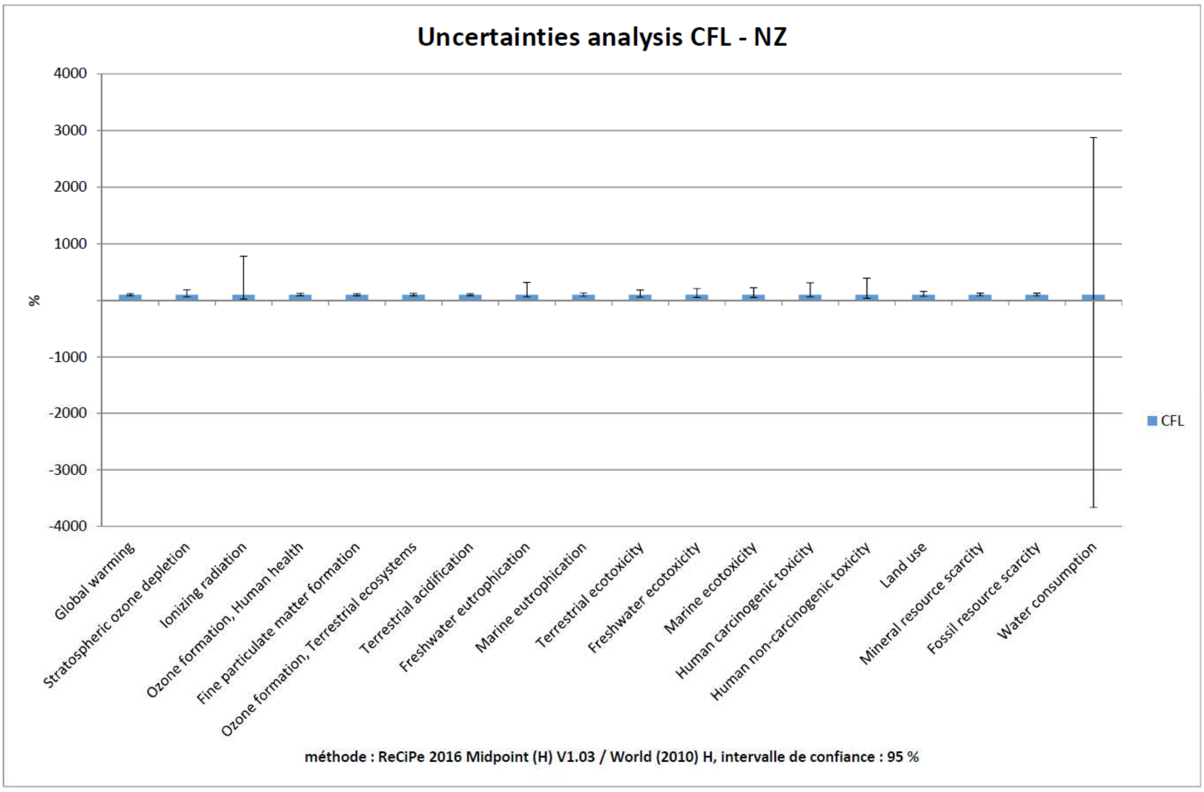

Uncertainties analysis LED N1 (15000h - 134lm/W) - AU
1500
1000
500
%
-500
-1000
-1500
-2000
LED N1
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %



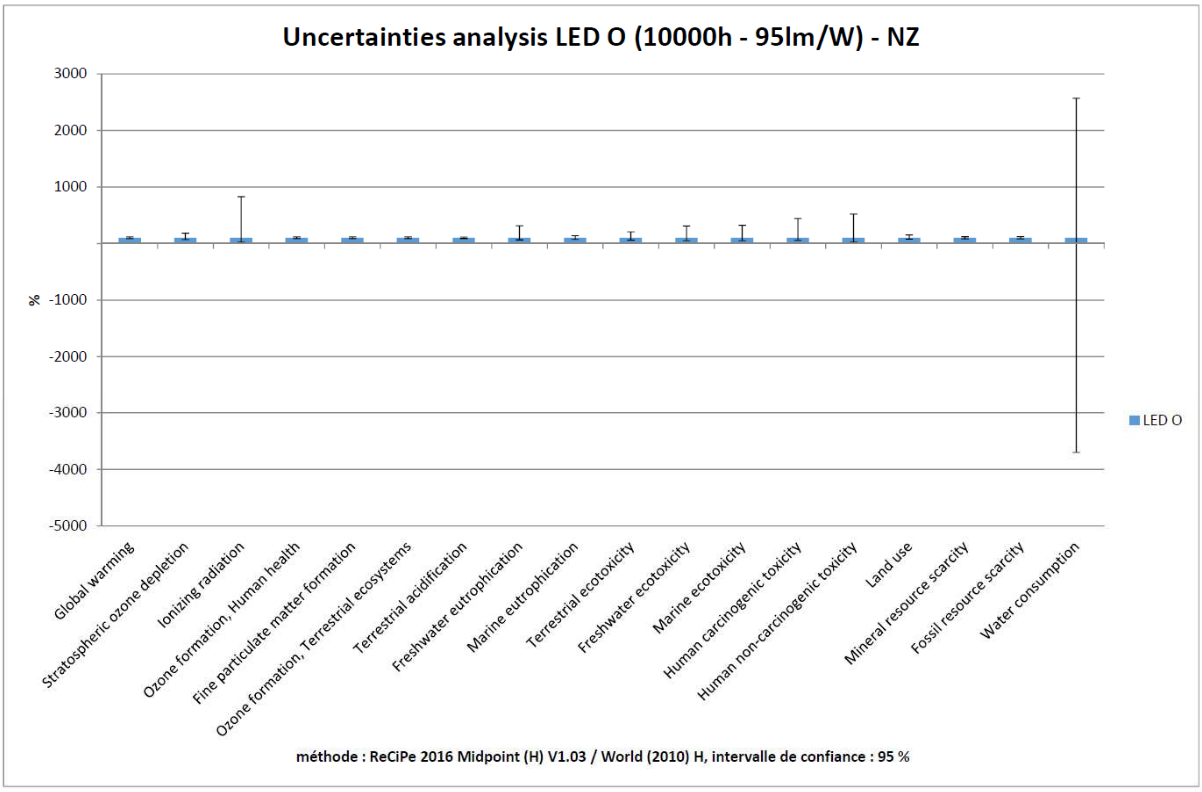
Uncertainties analysis LED N2 (25000h - 134lm/W) - AU
3000
2000
1000
%
-1000
-2000
-3000
-4000
LED N2
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %



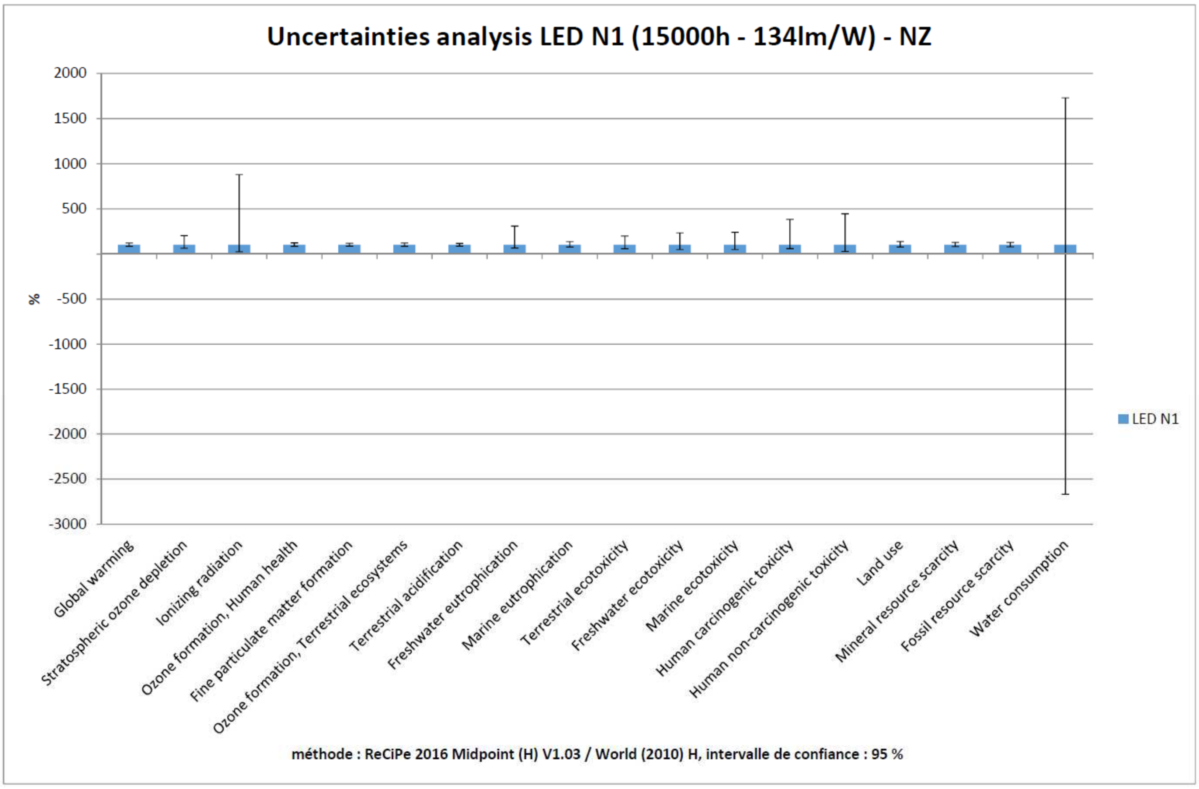
Uncertainties analysis Incandescent - NZ
1500
1000
500
%
-500
-1000
-1500
Incandescent
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %

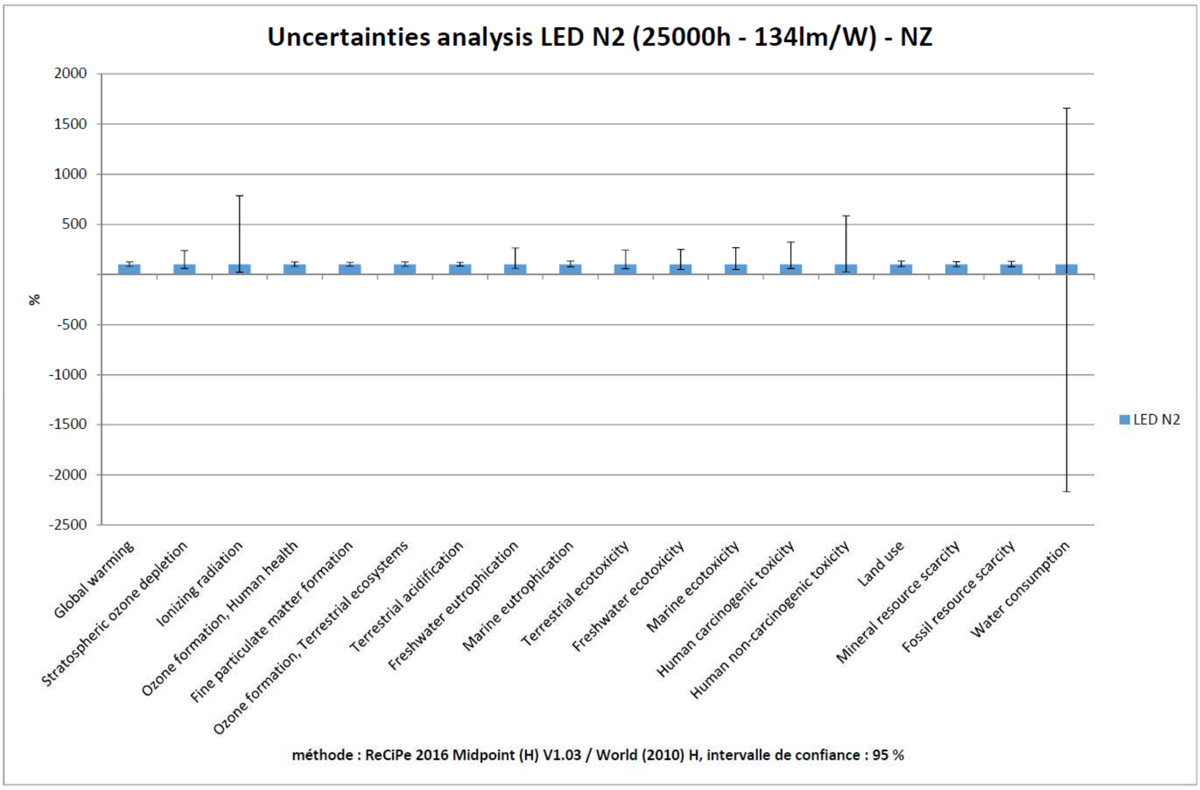


Uncertainties analysis CFL - NZ
4000
3000
2000
1000
%
-1000
-2000
-3000
-4000
CFL
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %



Uncertainties analysis LED O (10000h - 95lm/W) - NZ
3000
2000
1000
%
-1000
-2000
-3000
-4000
-5000
LED O
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %


Uncertainties analysis LED N1 (15000h - 134lm/W) - NZ
2000
1500
1000
500
%
-500
-1000
-1500
-2000
-2500
-3000
LED N1
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %


Uncertainties analysis LED N2 (25000h - 134lm/W) - NZ
2000
1500
1000
500
%
-500
-1000
-1500
-2000
-2500
LED N2
Global warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use
Mineral resource scarcity
Fossil resource scarcity
Water consumption
méthode : ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H, intervalle de confiance : 95 %

D. LIFE CYCLE INVENTORIES

The Life Cycle Inventories for CFL, LED and Incandescent Lamp have been collected by the US Department of Energy [5] and have been updated drawing upon more recent data [6] to reflect improvements in the manufacturing process among over the last years.

Incandescent	Amount	Unit
Materials/assemblies		
Argon, liquid {RoW}| production | APOS, U	0,137	g
Nitrogen, liquid {RoW}| air separation, cryogenic | APOS, U	0,845	g
Oxygen, liquid {RoW}| air separation, cryogenic | APOS, U	7,29	g
Hydrogen, liquid {RoW}| market for | APOS, U	0,001	g
Ammonia, liquid {RoW}| market for | APOS, U	0,085	g
Aluminium, primary, ingot {CN}| production | APOS, U	1,15	g
Brass {RoW}| production | APOS, U	0,05	g
Epoxy resin, liquid {RoW}| production | APOS, U	1,55	g
Flux, for wave soldering {GLO}| production | APOS, U	0,15	g
Glass tube, borosilicate {RoW}| production | APOS, U	22,54	g
Phosphoric acid, industrial grade, without water, in 85% solution state {RoW}| purification of wet-process phosphoric acid to industrial grade, product in 85% solution state | APOS, U	0,002	g
Glass tube, borosilicate {RoW}| production | APOS, U	2,097	g
Glass tube, borosilicate {RoW}| production | APOS, U	2,165	g
Molybdenum {GLO}| market for | APOS, U	0,013	g
Rhodium {GLO}| market for | APOS, U	0,01	g
Liquid crystal display, minor components, auxilliaries and assembly effort {GLO}| production | APOS, U	38,2	g
Processes		
Wire drawing, copper {RoW}| processing | APOS, U	0,1	g
Electricity, medium voltage {CN}| market group for | APOS, U	0,372	kWh

[5] Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products Part 2: LED Manufacturing and Performance

[6] Luth Richter, Jessika & Tähkämö, Leena & Dalhammar, Carl. (2019). *Trade-offs with longer lifetimes? The case of LED lamps considering product development and energy contexts*. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.03.331

LED O	Amount	Unit
LED O Packaging assembly		
Materials/assemblies		
Aluminium oxide {GLO}| market for | Alloc Def, U	0.0135	g
Diode, auxilliaries and energy use {GLO}| market for | Alloc Def, U	0.055	g
Gold {GLO}| market for | Alloc Def, U	0.00006	g
Silicone product {GLO}| market for | Alloc Def, U	0.0196	g
Epoxy resin, liquid {GLO}| market for | Alloc Def, U	0.00006	g
Rare earth concentrate, 70% REO, from bastnasite {GLO}| market for | Alloc Def, U	0.00004	g
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	0.03	kWh
3 inch sapphire wafer	12/2438	p
Materials/assemblies		
Aluminium oxide {GLO}| market for | Alloc Def, U	16.6	g
Ethoxylated alcohol (AE7) {RoW}| ethoxylated alcohol (AE7) production, petrochemical | Alloc Def, U	3.5	kg
Zeolite, slurry, without water, in 50% solution state {RER}| production | Alloc Def, U	0.83	kg
Water, ultrapure {GLO}| market for | Alloc Def, U	105.3	kg
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	18.3	kWh
LED O Die Fabrication	12/2438	p
Materials/assemblies		
Acetone, liquid {RER}| production | Alloc Def, U	467	g
Gold {SE}| gold-silver-zinc-lead-copper mine operation and refining | Alloc Def, U	0.29	g
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U	115	g
Hydrogen fluoride {GLO}| market for | Alloc Def, U	282	g
Hydrogen, liquid {RER}| market for | Alloc Def, U	136	g
Nitrogen, liquid {RER}| market for | Alloc Def, U	5527	g
Ammonia, liquid {RER}| market for | Alloc Def, U	447	g
Oxygen, liquid {RER}| market for | Alloc Def, U	2.3	kg
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U	19	g
Sulfur hexafluoride, liquid {RER}| production | Alloc Def, U	13	g
Silicon carbide {GLO}| market for | Alloc Def, U	0.242	g
Zeolite, slurry, without water, in 50% solution state {RER}| production | Alloc Def, U	2.3	kg
Silver {GLO}| market for | Alloc Def, U	0.005	g
Aluminium, cast alloy {GLO}| market for | Alloc Def, U	0.003	g
Nickel, 99.5% {GLO}| market for | Alloc Def, U	0.004	g
Titanium dioxide {RER}| market for | Alloc Def, U	0.002	g
Palladium {GLO}| market for | Alloc Def, U	0.06	g
Gallium, semiconductor-grade {GLO}| production | Alloc Def, U	1.47	g
Indium {RER}| production | Alloc Def, U	0.01	g
Water, ultrapure {GLO}| market for | Alloc Def, U	240	kg
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	42.57	kWh

LED O Assembly	1	p
Materials/assemblies		
Rare earth concentrate, 70% REO, from bastnasite {GLO}| market for | Alloc Def, U	1	g
Polycarbonate {GLO}| market for | Alloc Def, U	11.1	g
Aluminium, cast alloy {GLO}| market for | Alloc Def, U	68.2	g
Copper {GLO}| market for | Alloc Def, U	5	g
Nickel, 99.5% {GLO}| market for | Alloc Def, U	0.003	g
Brass {RoW}| market for brass | Alloc Def, U	1.65	g
Cast iron {GLO}| market for | Alloc Def, U	4	g
Steel, chromium steel 18/8 {GLO}| market for | Alloc Def, U	0.0002	g
Copper concentrate {GLO}| market for | Alloc Def, U	4.8	g
Integrated circuit, logic type {GLO}| market for | Alloc Def, U	0.158	g
Capacitor, for surface-mounting {GLO}| market for | Alloc Def, U	0.993	g
Capacitor, electrolyte type, < 2cm height {GLO}| market for | Alloc Def, U	24.73	g
Diode, glass-, for surface-mounting {GLO}| market for | Alloc Def, U	1.091	g
Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U	15	g
Resistor, surface-mounted {GLO}| market for | Alloc Def, U	0.993	g
Resistor, wirewound, through-hole mounting {GLO}| market for | Alloc Def, U	1.568	g
Transistor, wired, big size, through-hole mounting {GLO}| market for | Alloc Def, U	1.387	g
Transformer, low voltage use {GLO}| market for | Alloc Def, U	30.15	g
Epoxy resin, liquid {GLO}| market for | Alloc Def, U	4.5	g
Flux, for wave soldering {GLO}| market for | Alloc Def, U	0.3	g
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	1.389	kWh
Assembly of liquid crystal display, auxilliaries and energy use {GLO}| market for | Alloc Def, U	176	g

LED N	Amount	Unit
LED N packaging assembly		
Materials/assemblies		
Aluminium oxide {GLO}| market for | Alloc Def, U	0.0135	g
Diode, auxilliaries and energy use {GLO}| market for | Alloc Def, U	0.055	g
Gold {GLO}| market for | Alloc Def, U	0.00006	g
Silicone product {GLO}| market for | Alloc Def, U	0.0196	g
Epoxy resin, liquid {GLO}| market for | Alloc Def, U	0.00006	g
Rare earth concentrate, 70% REO, from bastnasite {GLO}| market for | Alloc Def, U	0.00004	g
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	0.03	kWh
3 inch sapphire wafer	8/3250	p
Materials/assemblies		
Aluminium oxide {GLO}| market for | Alloc Def, U	16.6	g
Ethoxylated alcohol (AE7) {RoW}| ethoxylated alcohol (AE7) production, petrochemical | Alloc Def, U	3.5	kg
Zeolite, slurry, without water, in 50% solution state {RER}| production | Alloc Def, U	0.83	kg
Water, ultrapure {GLO}| market for | Alloc Def, U	105.3	kg
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	18.3	kWh
LED N Die Fabrication	8/3250	p
Materials/assemblies		
Acetone, liquid {RER}| production | Alloc Def, U	467	g
Gold {SE}| gold-silver-zinc-lead-copper mine operation and refining | Alloc Def, U	0.29	g
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U	115	g
Hydrogen fluoride {GLO}| market for | Alloc Def, U	282	g
Hydrogen, liquid {RER}| market for | Alloc Def, U	136	g
Nitrogen, liquid {RER}| market for | Alloc Def, U	5527	g
Ammonia, liquid {RER}| market for | Alloc Def, U	447	g
Oxygen, liquid {RER}| market for | Alloc Def, U	2.3	kg
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U	19	g
Sulfur hexafluoride, liquid {RER}| production | Alloc Def, U	13	g
Silicon carbide {GLO}| market for | Alloc Def, U	0.242	g
Zeolite, slurry, without water, in 50% solution state {RER}| production | Alloc Def, U	2.3	kg
Silver {GLO}| market for | Alloc Def, U	0.005	g
Aluminium, cast alloy {GLO}| market for | Alloc Def, U	0.003	g
Nickel, 99.5% {GLO}| market for | Alloc Def, U	0.004	g
Titanium dioxide {RER}| market for | Alloc Def, U	0.002	g
Palladium {GLO}| market for | Alloc Def, U	0.06	g
Gallium, semiconductor-grade {GLO}| production | Alloc Def, U	1.47	g
Indium {RER}| production | Alloc Def, U	0.01	g
Water, ultrapure {GLO}| market for | Alloc Def, U	240	kg
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	42.57	kWh

LED N Assembly	**1**	**p**
Materials/assemblies		
Polymethyl methacrylate, sheet {GLO}| market for | Alloc Def, U	25.27	g
Polycarbonate {GLO}| market for | Alloc Def, U	2.277	g
Steel, low-alloyed {GLO}| market for | Alloc Def, U	1.9	g
Zinc concentrate {GLO}| market for | Alloc Def, U	0.04	g
Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U	6.32	g
Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U	1.927	g
Inductor, ring core choke type {GLO}| market for | Alloc Def, U	0.913	g
Integrated circuit, logic type {GLO}| market for | Alloc Def, U	0	g
Capacitor, for surface-mounting {GLO}| market for | Alloc Def, U	0.115	g
Capacitor, electrolyte type, < 2cm height {GLO}| market for | Alloc Def, U	4.92	g
Diode, glass-, for surface-mounting {GLO}| market for | Alloc Def, U	0.222	g
Resistor, surface-mounted {GLO}| market for | Alloc Def, U	0.253	g
Resistor, metal film type, through-hole mounting {GLO}| market for | Alloc Def, U	0	g
Transistor, wired, big size, through-hole mounting {GLO}| market for | Alloc Def, U	0	g
Transformer, low voltage use {GLO}| market for | Alloc Def, U	2.667	g
Epoxy resin, liquid {GLO}| market for | Alloc Def, U	0	g
Flux, for wave soldering {GLO}| market for | Alloc Def, U	0.3	g
Processes		
Electricity, medium voltage {CN}| market group for | Alloc Def, U	5	MJ
Assembly of liquid crystal display, auxilliaries and energy use {GLO}| market for | Alloc Def, U	47.09	g

CFL	**Amount**	**Unit**
Materials/assemblies		
Argon, liquid {RoW}| production | APOS, U	0,004	g
Nitrogen, liquid {RoW}| air separation, cryogenic | APOS, U	0,119	g
Oxygen, liquid {RoW}| air separation, cryogenic | APOS, U	0,159	g
Hydrogen, liquid {RoW}| market for | APOS, U	0,002	g
Krypton, gaseous {RoW}| air separation, xenon krypton purification | APOS, U	0,0004	g
Rare earth concentrate, 70% REO, from bastnasite {CN}| production | APOS, U	0,001	g
Rare earth concentrate, 70% REO, from bastnasite {CN}| production | APOS, U	1,37	g
Ammonia, liquid {RoW}| market for | APOS, U	0,13	g
Nitric acid, without water, in 50% solution state {RoW}| nitric acid production, product in 50% solution state | APOS, U	7,9	g
Sulfuric acid {RoW}| production | APOS, U	1,67	g
Aluminium oxide {CN}| aluminium oxide production | APOS, U	0,008	g
Lead {GLO}| market for | APOS, U	0,19	g
Copper {RAS}| production, primary | APOS, U	0,402	g
Nickel, 99.5% {GLO}| nickel mine operation, sulfidic ore | APOS, U	0,003	g
Brass {CH}| production | APOS, U	1,65	g
Cast iron {RoW}| production | APOS, U	0,029	g
Steel, chromium steel 18/8, hot rolled {RoW}| production | APOS, U	0,0002	g
Mercury {GLO}| production | APOS, U	0,004	g
Capacitor, for surface-mounting {GLO}| production | APOS, U	0,086*40	g
Inductor, miniature radio frequency chip {GLO}| production | APOS, U	0,0168*3	g
Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | APOS, U	3.7	g
Resistor, surface-mounted {GLO}| production | APOS, U	0,0098*40	g
Resistor, surface-mounted {GLO}| production | APOS, U	0,19	g
Transistor, wired, big size, through-hole mounting {GLO}| production | APOS, U	3,7	g
Epoxy resin, liquid {RoW}| production | APOS, U	4,5	g
Flux, for wave soldering {GLO}| production | APOS, U	0,3	g
Glass tube, borosilicate {RoW}| production | APOS, U	1,2	g
Polyethylene terephthalate, granulate, amorphous {RoW}| production | APOS, U	2,39	g
Processes		
Assembly of liquid crystal display, auxilliaries and energy use {GLO}| market for | APOS, U	153	g
Diode, glass-, for surface-mounting {GLO}| production | APOS, U	0,032*40	g
Energy and auxilliary inputs, metal working factory {RoW}| with heating from natural gas | APOS, U	10,7	kg
Electricity, medium voltage {CN}| market group for | APOS, U	3,13*0,278	kWh

AUSTRALIA	Inc	LED O	LED N1	LED N2	CFL
Use phase (Kwh)					
Electricity, low voltage {AU}| market for | APOS, U	90	150	110	120	200
Packaging (g)					
Corrugated board box {RoW}| market for corrugated board box | APOS, U	40	37	26.7	26.7	81
Transport (tkm)					
Transport, freight, sea, transoceanic ship {GLO}| market for | APOS, U	0.755	1.7	0.455	0.455	2.26
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | APOS, U	0.0782	0.176	0.0471	0.0471	0.234

NEW ZEALAND	Inc	LED O	LED N1	LED N2	CFL
Use phase (Kwh)					
Electricity, low voltage {NZ}| market for electricity, low voltage | APOS, U	90	150	110	120	200
Packaging (g)					
Corrugated board box {RoW}| market for corrugated board box | APOS, U	40	37	26.7	26.7	81
Transport (tkm)					
Transport, freight, sea, transoceanic ship {GLO}| market for | APOS, U	0.782	1.76	0.471	0.471	2,34
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | APOS, U	0.0782	0.176	0.0471	0.0471	0,234

Packaging waste scenario		Inc.	LED O	LED N1	LED N2	CFL
		40g	37g	37g	37g	81g
Packaging landfill	Waste packaging paper {GLO}| treatment of waste packaging paper, sanitary landfill | APOS, U	40%	40%	40%	40%	40%
Packaging recycling	Core board (waste treatment) {GLO}| recycling of core board | APOS, U	60%	60%	60%	60%	60%

Lamp Waste scenario		Inc.	LED O	LED N1	LED N2	CFL
		78,2g	215g	180g	180g	234g
Lamp Landfill	Waste glass {GLO}| treatment of waste glass, sanitary landfill | APOS, U	95%	95%	95%	95%	95%
	Waste electric and electronic equipment {GLO}|, sanitary landfill | APOS, U					
Lamp recycling	Glass from used cathode ray tube {GLO}| treatment of | APOS, U	5%	5%	5%	5%	5%
	Waste electric and electronic equipment {GLO}| treatment of, shredding | APOS, U					

E. ENDPOINT POTENTIAL IMPACTS

Category (Pt)	Inc. (AU)	CFL (AU)	LED O (AU)	LED N1 (AU)	LED N2 (AU)	Inc. (NZ)	CFL (NZ)	LED O (NZ)	LED N1 (NZ)	LED N2 (NZ)
Global warming, Human health	27.6848	6.3804	4.8379	3.2219	3.1557	3.2907	0.9994	0.9862	0.4912	0.425
Global warming, Terrestrial ecosystems	2.7699	0.6384	0.484	0.3224	0.3157	0.3292	0.1	0.0987	0.0492	0.0425
Global warming, Freshwater ecosystems	7.57E-05	1.74E-05	1.32E-05	8.81E-06	8.63E-06	8.99E-06	2.73E-06	2.7E-06	1.34E-06	1.16E-06
Stratospheric ozone depletion	0.0124	0.0028	0.0021	0.0014	0.0014	0.0016	0.0004	0.0004	0.0002	0.0002
Ionizing radiation	0.0007	0.0003	0.0005	0.0002	0.0001	0.0005	0.0003	0.0005	0.0001	0.0001
Ozone formation, Human health	0.052	0.012	0.0097	0.0062	0.006	0.0049	0.0016	0.0022	0.0009	0.0007
Fine particulate matter formation	21.97	4.9364	4.0322	2.4692	2.3727	3.8323	0.9355	1.1684	0.4389	0.3424
Ozone formation, Terrestrial ecosystems	0.2458	0.0569	0.0459	0.0293	0.0283	0.0235	0.0079	0.0108	0.0044	0.0035
Terrestrial acidification	0.7307	0.158	0.1254	0.0793	0.077	0.125	0.0244	0.0298	0.0115	0.0092
Freshwater eutrophication	1.0695	0.2453	0.1972	0.127	0.1237	0.0314	0.0163	0.0333	0.0108	0.0075
Marine eutrophication	0.0002	4.57E-05	3.51E-05	2.02E-05	1.95E-05	1.61E-05	1.03E-05	9.76E-06	2.24E-06	1.51E-06
Terrestrial ecotoxicity	0.0108	0.0034	0.0037	0.0016	0.0014	0.0065	0.0025	0.003	0.001	0.0009
Freshwater ecotoxicity	0.0474	0.0124	0.0122	0.0065	0.0059	0.02	0.0064	0.0079	0.0034	0.0029
Marine ecotoxicity	0.0095	0.0025	0.0025	0.0013	0.0012	0.0038	0.0012	0.0016	0.0007	0.0006
Human carcinogenic toxicity	8.7656	2.0123	1.6188	1.0308	1.0065	0.8086	0.2571	0.3624	0.14	0.1158
Human non-carcinogenic toxicity	9.4079	2.697	3.1079	1.4642	1.2768	1.5591	0.9657	1.8686	0.5856	0.3982
Land use	0.039	0.0105	0.0112	0.0052	0.0047	0.0145	0.005	0.0073	0.0025	0.0019
Mineral resource scarcity	0.0043	0.0009	0.0016	0.0005	0.0004	0.0045	0.0009	0.0017	0.0005	0.0004
Fossil resource scarcity	0.3388	0.0803	0.0653	0.041	0.0395	0.1598	0.0408	0.037	0.021	0.0194
Water consumption, Human health	0.1657	0.0407	0.0325	0.02	0.0192	0.0225	0.009	0.0099	0.004	0.0032
Water consumption, Terrestrial ecosystem	0.0151	0.0042	0.0037	0.002	0.0018	0.0046	0.0019	0.002	0.0008	0.0007
Water consumption, Aquatic ecosystems	2.49E-07	1.03E-07	1.26E-07	4.73E-08	3.72E-08	2.61E-07	1.06E-07	1.28E-07	4.86E-08	3.85E-08
Total (Pt)	**73.3403**	**17.2949**	**14.5945**	**8.8299**	**8.4382**	**10.243**	**3.3764**	**4.6319**	**1.7669**	**1.3751**