Life Cycle Assessment of Dell Latitude 7300 25th Anniversary Edition

On behalf of Dell

thinkstep

On behalf of thinkstep AG and its subsidiaries

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List of Acronyms

ANSI	American National Standards Institute
APJ	Asia Pacific including Japan
BGA	Ball Grid Array
BTO	Build to Order
BOM	Bill of Materials
CMC	Chassis Management Controller
CML	Centre of Environmental Science at Leiden
CPU	Central Processing Unit
DIMM	Dual Inline Memory Module
DVD	Digital Versatile Disk
ELCD	European Life Cycle Database
EoL	End of Life
EMEA	Europe, Middle East and Africa
EP	Eutrophication Potential
EPEAT	Electronic Product Environmental Assessment Tool
ESSA	Energy Smart Solution Advisor
EU	European Union
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GB	Gigabyte, unit of digital information
GHG	Greenhouse Gas
GWP	Global Warming Potential
IC	Integrated Circuit
ILCD	International Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
IOM	Input/Output Module
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment

MB	Mainboard / Motherboard
ODD	Optical Disk Drive
PCF	Product Carbon Footprint
PCI	Peripheral Component Interconnect
PERC	PowerEdge RAID Controller
PSU	Power Supply Unit
PWB	Printed Wiring Board
RAID	Redundant Array of Independent Disks
RAM	Random Access Memory
SSD	Solid-State Drive
TDP	Thermal Design Power
TEC	Typical Energy Consumption
USH	Unified Security Hub
VOC	Volatile Organic Compound
WEEE	Waste Electrical and Electronic Equipment

Glossary

Life cycle

A view of a product system as “consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

“Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

“Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14040:2006, section 3.4)

Life cycle interpretation

“Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations” (ISO 14040:2006, section 3.5)

Functional unit

“Quantified performance of a product system for use as a reference unit” (ISO 14040:2006, section 3.20)

Allocation

“Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

“An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.”

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.”

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study." (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

Executive Summary

In order to meet EPEAT standard regulations and to understand how life cycle assessment (LCA) can be used to support the development and reporting of environmentally sustainable products, Dell commissioned thinkstep to carry out an LCA on the Dell Latitude 7300 25th AE laptop. Goals for this ISO 14040/14044 compliant study include:

- Life Cycle Assessment (LCA) of the Dell Latitude 7300 25th AE laptop across its full life cycle;
- Determine environmental hotspots over the product's life cycle with specific focus on material/part/product manufacturing and use;
- Generate results to answer customer enquiries;
- Gain public relations/marketing advantage by communicating results (online/offline) in white papers, sustainability reports, customer communications, and conferences;
- Meet the EPEAT standard regulations.

System boundaries of the study are from cradle-to-grave, accounting for all life cycle activities from extraction of raw materials and energy sources from the environment through to disposal and recycling of products at end of life. The functional unit used in the assessment, which can serve as the basis for comparisons to similar products, is the provision of portable computing services for five years with the following load profile:

- P_{off}: 25% of the time
- P_{sleep}: 45%of the time
- P_{long_idle}: 5% of the time
- P_{short_idle}: 25%of the time

The reference flow is one (1) Dell Latitude 7300 25th AE laptop, including its power supply and packaging.

The Dell Latitude 7300 25th AE is a 13 inch laptop equipped with 16GB RAM, a 256GB M.2 SSD and an Intel Core i5-8250U processor with a TDP limit of 15W. The Dell Latitude 7300 25th AE with the given configuration weighs around 2.8 kg including packaging and the data was collected by using a combination of analysing Bill of Materials, physical product teardown and dimensioned photographs.

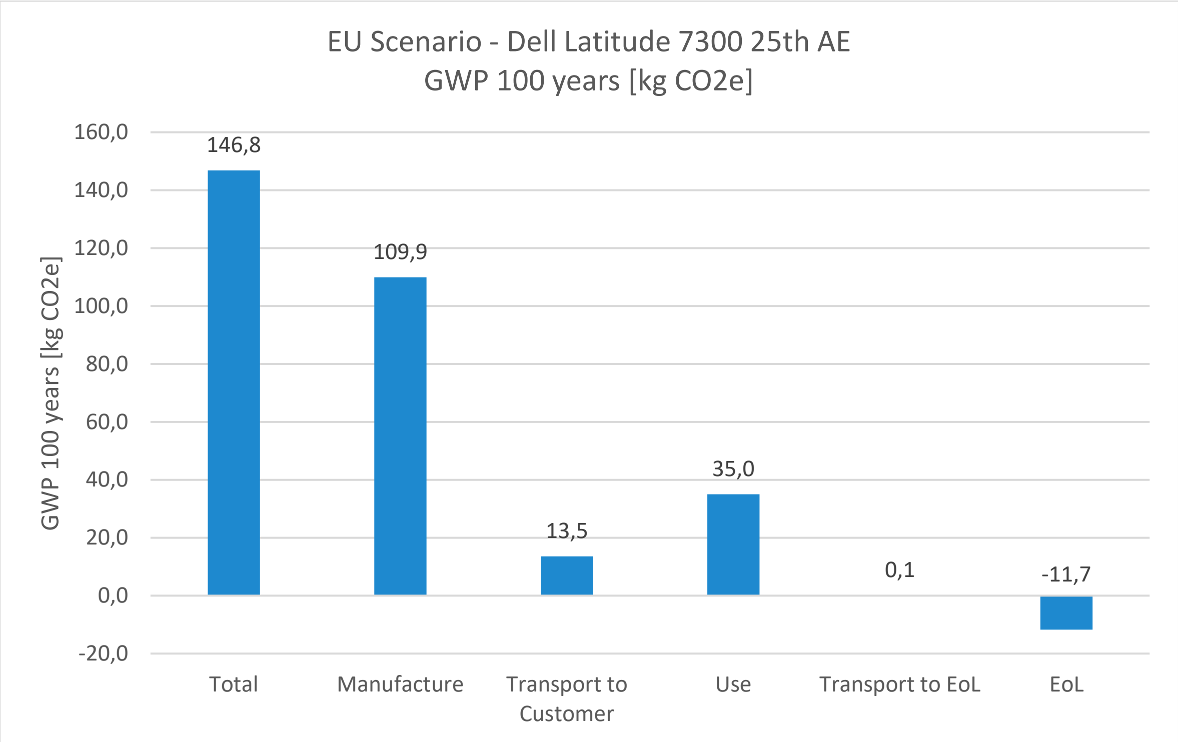
The intended time reference for the study is the 2018 calendar year and the geographical coverage considers both an EU and US in two scenarios.

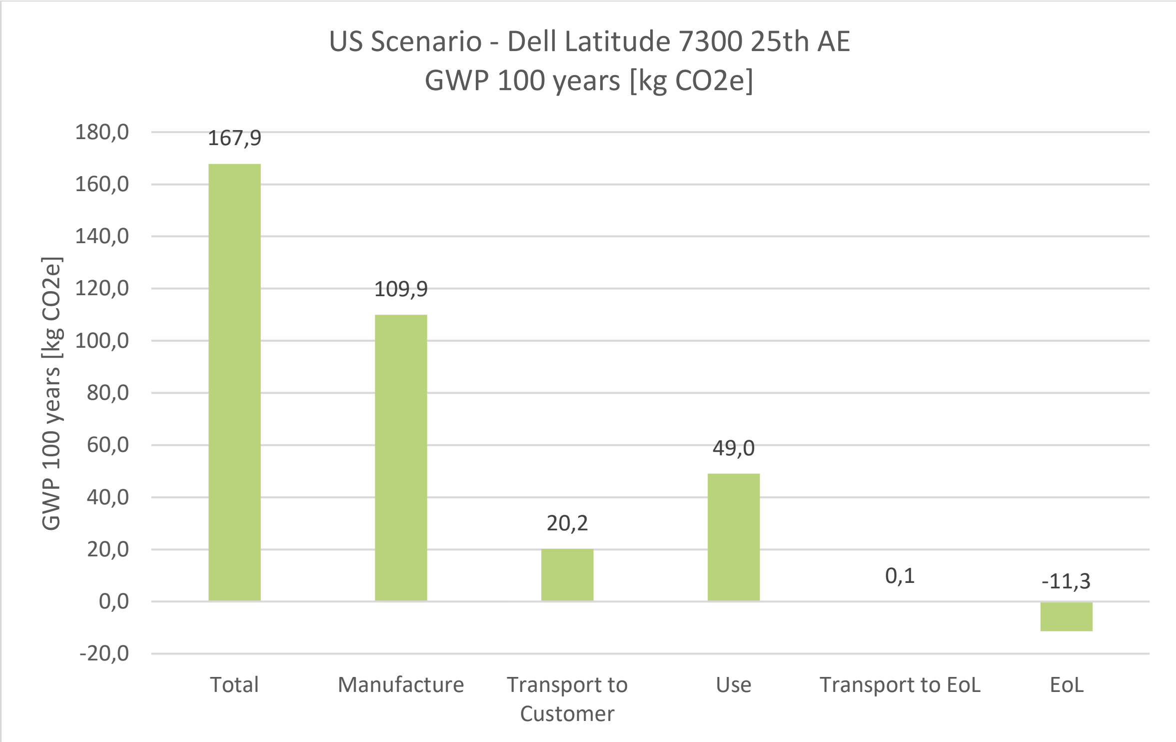
The following table summarizes the results of the study for all considered impact categories.

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	1,70E+03	2,04E+03
Acidification Potential [kg SO2 eq.]	5,99E-01	6,70E-01
Eutrophication Potential [kg Phosphate eq.]	5,21E-02	5,73E-02

Ozone Layer Depletion Potential [kg R11 eq.]	1,90E-07	1,90E-07
Photochem. Ozone Creation Potential [kg Ethene eq.]	4,44E-02	4,84E-02
Global Warming Potential 100 years incl. biogenic carbon [kg CO2 eq.]	1,47E+02	1,68E+02

As the overall conclusions remain valid also for the other impact categories and GWP is considered the most robust and widely used impact category, the following diagrams shows the results for GWP over all life cycle phases for the EU and US scenario.





Analysis results indicate that the major fraction of the impact – approximately 85% and 83% in the EU and the US respectively – derives from the manufacturing (65% and 60%) and the use phase of the Dell Latitude 7300 25th AE. The transport to end of life has a minimal contribution in both cases and the end of life credits contribute to a reduction of about 7% and 6% of the life cycle impacts respectively. Overall, the US scenario has approximately 14% higher impact than the European one, due to the differences in the electricity grid mix and fuel used, as well as distances travelled.

The majority of the part production impacts during manufacturing are from the components containing electronics, which account for only around 30% of the total mass of the Dell Latitude 7300 25th AE. A large contribution compared to the very small weight of the component comes from the SSD and there the NAND flash, due to its complexity regarding package dimensions, die/package ratio and die stack per package.

Overall, the results of the present study exemplify that the manufacturing of a laptop has a high impact on the environmental results within its lifetime, especially considering that modern CPUs and other use phase relevant components are optimized regarding their energy consumption and will most likely further improve in this regard. This leads to the recommendation to a) focus more on the manufacturing part of products and hence more on the supply chain of those components and b) further increase the data quality of considered components, by e.g. having access to BOMs for all components. Looking at this issue from a (post-)consumer perspective, the reuse (or refurbishment) of the laptop device or used components such as SSDs could potentially extend their designated lifetime. This would require an appropriate take-back system (if reused externally after use by the first customer) or an appropriate data erasure system (if reused internally).

1. Goal of the Study

This study was commissioned by Dell Technologies Inc. with the following main goals:

- Life Cycle Assessment (LCA) of the Dell Latitude 7300 25th Anniversary Edition (AE) laptop across its full life cycle;
- Determine environmental hotspots over the product's life cycle with specific focus on material/part/product manufacturing and use;
- Generate results to answer customer enquiries;
- Gain public relations/marketing advantage by communicating results (online/offline) in white papers, sustainability reports, customer communications, and conferences; and
- Meet the EPEAT standard regulations.

This study meets the requirements of the international standards for Life Cycle Assessment (LCA) according to ISO 14040 (ISO, 2006) / ISO 14044 (ISO, 2006).

2. Scope of the Study

2.1. Product System(s)

The Dell Latitude 7300 25th AE is a 13 inch laptop equipped with 16GB RAM, a 256GB M.2 SSD and an Intel Core i7-8665U processor with a TDP limit of 15W. This configuration is a typical configuration according to Dell sales and marketing figures and thus representative for this product category.

2.2. Product Functional Unit

The functional unit is 1 piece of laptop and its provision of portable computing functionalities for five years with the load profile specified in section 3.2.4. The target system under investigation is the Dell Latitude 7300 25th AE.

2.3. System Boundaries

The system boundary is defined in Table 2-1.

Table 2-1: System boundaries

Included	Excluded
✓ Extraction of raw materials	× Production of capital equipment (factories, tooling, etc.)
✓ Manufacture of parts	× Employee travel / commuting
✓ Transport to assembly	× Additional air conditioning requirements
✓ Assembly, incl. waste during production	× Refurbishment/Reuse of parts
✓ Transport to customers	
✓ Use stage	
✓ Transport to recycling	
✓ End of life (disposal/recycling)	

2.3.1. Time Coverage

The intended time reference for the study is the 2018 calendar year, which corresponds to the data provided for the assembly and recycling. Data collected from Dell relate to this year.

2.3.2. Technology Coverage

This study assesses the cradle-to-grave impacts of the product based on a global production and technology mix. Primary production data was gathered from Dell and its partners and included the physical product for disassembly, additional data on usage, recycling and transport, as well as data on additional configuration that was not part of the physical product received, e.g. RAM bars and power supply unit.

2.3.3. Geographical Coverage

The geographical coverage of this study considers the following conditions:

The product is assembled in China. The components are mainly sourced from China. The use phase considers a European electricity grid mix (EU-28) and the recycling of the product takes place in Europe. A scenario that considers use and recycling in the USA has also been considered as part of this report.

2.4. Allocation

2.4.1. Multi-output Allocation

There are no significant multi-output processes within the foreground system. As a result, all impacts from the foreground system are fully allocated to the product under study.

Allocation of background data (energy and materials) taken from the GaBi 2019 databases is documented online at http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/.

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3.

Material recycling (substitution approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end of life to give the net scrap output from the product life cycle. This remaining net scrap is sent to material recycling. The original burden of the primary material input is allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modelled using industry average inventories.

Energy recovery (substitution approach): In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power and heat outputs using the regional grid mix and thermal energy from natural gas. The latter represents the cleanest fossil fuel and therefore results in a conservative estimate of the avoided burden.

Landfilling (substitution approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

2.5. Cut-off Criteria

No cut-off criteria are defined for the product sample and data provided for this study. All available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

Some data for upstream production chains, e.g. the packaging of electronic components that are populated onto the PWBs (tape-and-reel packaging), were not considered in this study due to a lack of available data and a high probability of very low environmental relevance.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-2. Various impact assessment methodologies are applicable for use in the European context including e.g. CML, ReCiPe, and selected methods recommended by the ILCD. This assessment is predominantly based on the CML impact assessment methodology framework (CML 2001 update January 2016). CML characterisation factors are applicable to the European context, are widely used and respected within the LCA community, and required for Environmental Product Declarations under EN 15804.

Global warming potential and non-renewable primary energy demand (represented by ADP fossil) were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterisation factors taken from the 5th Assessment Report (IPCC, 2013) for a 100-year timeframe (GWP100) as this is currently the most commonly used metric.

The global warming potential results include the photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4.

Eutrophication, acidification, and photochemical ozone creation potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others.

Ozone depletion potential was chosen because of its high political relevance, which eventually led to the worldwide ban of more active ozone-depleting substances; the phase-out of less active substances is due to be completed by 2030. Current exceptions to this ban include the application of ozone depleting chemicals in nuclear fuel production. The indicator is therefore included for reasons of completeness; however, the few identifiable values in the background data do not necessarily reflect important considerations for the product under study.

Table 2-2: Impact category descriptions

Impact Category	Description	Unit	Reference
Global Warming Potential (GWP100)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	(IPCC, 2013)

Abiotic Resource Depletion (ADP fossil)	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of non-renewable energy resources are reported separately.	MJ (net calorific value)	(van Oers, de Koning, Guinée, & Huppes, 2002)
Eutrophication Potential	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg PO_4^{3-} equivalent	(Guinée, et al., 2002)
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	kg SO_2 equivalent	(Guinée, et al., 2002)
Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg C_2H_4 equivalent	(Guinée, et al., 2002)
Ozone Depletion Potential (ODP)	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants.	kg CFC-11 equivalent	(Guinée, et al., 2002)

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

The selected impact categories fit the requirement of NSF/ANSI 426 – 2017 (NSF, 2017).

2.7. Interpretation to Be Used

The results of the LCI and LCIA were interpreted according to this Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results.
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations.

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. Software and Database

The LCA model was created using the GaBi 9 Software system for life cycle engineering, developed by thinkstep AG. The GaBi 2019 LCI database provides the life cycle inventory data for the raw and process materials obtained from the background system.

2.10. Critical Review

A critical review according to ISO 14044, section 6.2 was performed by Colin Fitzpatrick, Department of Electronics and Computer Engineering, University of Limerick. The Critical Review Statement can be found in Annex D: .

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data for the material content of the product were collected using a combination of dimensioned photographs, physical product teardown and analysing Bill of Materials (BOM) that were provided by Dell. During the product teardown, parts and materials were identified, weighed and measured (see Figure 3-1). During photograph mapping, the same procedure was applied to high-resolution photos with a dimension reference, together with component datasheets and supporting information. The teardown was conducted on a near mass-production-ready version of the product provided by Dell.

Data on distribution, product use and end of life were collected and discussed though online communication and in regular project meetings.

If gaps, outliers, or other inconsistencies were found, thinkstep engaged with Dell to resolve any open issues.

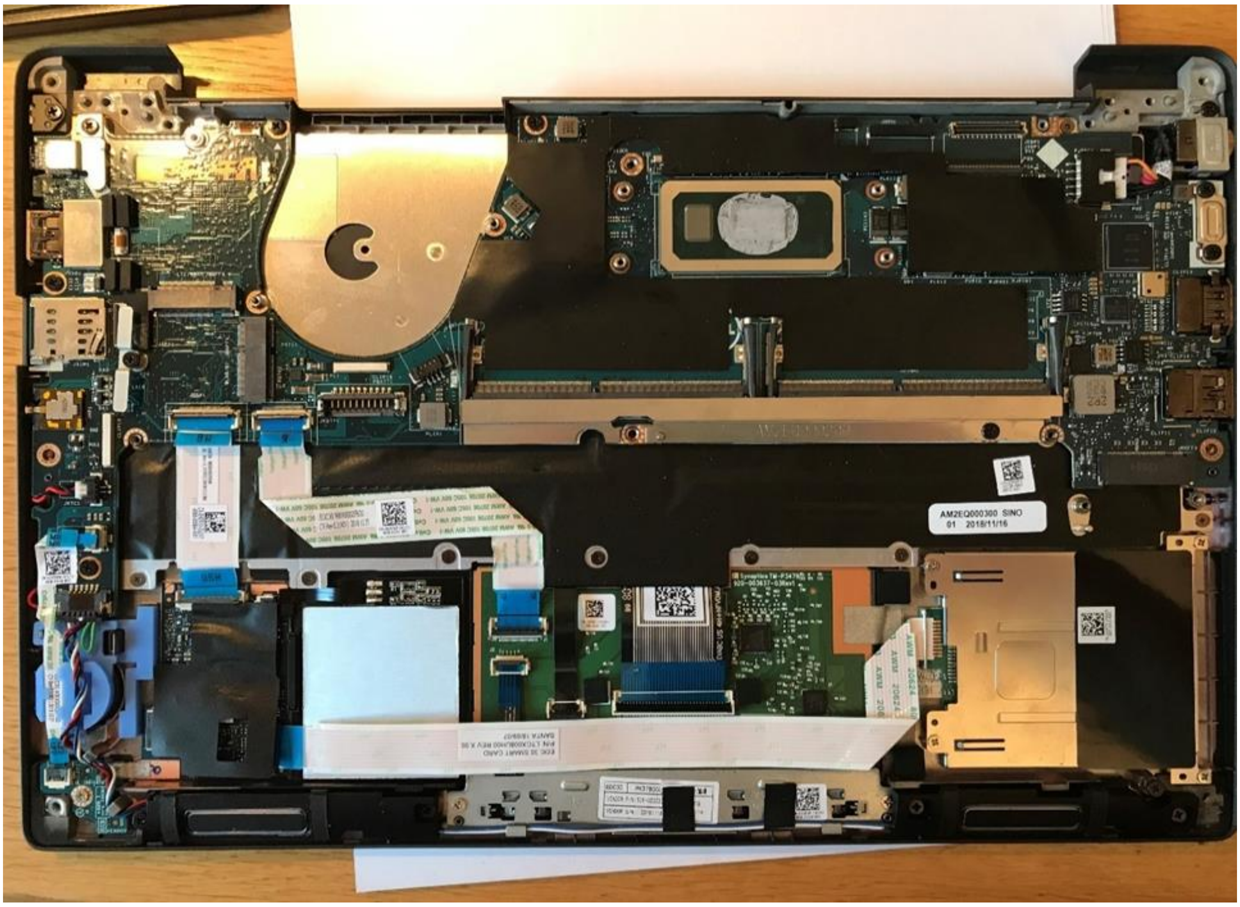


Figure 3-1: Product teardown Dell Latitude 7300 25th AE

3.2. Product System

3.2.1. Product Composition

Table 3-1 presents the main components of the product system considered in this study: the Dell Latitude 7300 25th AE.

Table 3-1: Part composition of the product system

Component	Weight (g)	Comments / Assumptions
PWBs	155,9	BOM analysis, teardown and estimated with pictures
Power supply unit	291,0	teardown; counted and weighted
Display	199,9	teardown; counted and weighted
Battery unit	243,6	teardown and data sheets
Other electronic	43,4	teardown; counted and weighted
Mechanical	640,0	teardown; counted and weighted
SSD	6,9	teardown and data sheets
Packaging	1290,1	data provided by Dell
Total weight	**2870,7**	

3.2.2. Manufacturing

Final assembly occurs in China. Components are largely sourced from East Asia. These components are described in more detail within this section.

Solid State Drives

Due to its complexity, the SSD is separately evaluated from other ICs and is listed in **Fehler! Verweisquelle konnte nicht gefunden werden.**Table 3-2.

The following table shows the parameter and assumptions taken for the NAND Flash of the 256GB SSD. The assumption of a die/package ratio of 60% is based on a sensitivity analysis in a previous study and lab results from other NAND flash chips and is a value typically found within the industry.

Table 3-2: 256GB SSD NAND Flash Parameter and Assumptions

	256GB SSD
Package dimension (mm x mm)	14 x 18.3
Die / package ratio	60%
Die stack per package	4
Chips per SSD	2
Total die area per chip (mm2)	2460
Total die area per SSD (mm2)	19676
Part number	KXG60ZNV256G

Other PWB

For the other printed wiring boards, e.g. mainboard, RAM, Unified Security Hub (USH) or Wi-Fi adapter, either a BOM was analyzed, the physical component was evaluated via product teardown or high-resolution photographs were provided by Dell.

Table 3-3: Dell Latitude 7300 25th AE printed wiring boards (mixed)

PWB Mixed	Area (cm2)	Pieces	Comments / Assumptions
RAM (16GB)	20,88	1	estimated via teardown and data provided by Dell
Unified Security Hub (USH)	8,35	1	BOM analysis
UL Indicator PWB	3,57	1	Estimated via teardown
Card Reader PWB	2,64	1	Estimated via teardown
Touchpad PWB	51,51	1	Estimated via teardown
Intel 9560NGW (WiFi)	**6,6**	**1**	**estimated with pictures and datasheets**

CPU

An Intel Core i7-8665U CPU is included in the Dell Latitude 7300 25th AE, which has an Intel® UHD Graphics 620 graphic processer integrated. The CPU is soldered onto the mainboard and was evaluated by analyzing the BOM received from Dell and is included in the large ICs category. The fan and heatsink are included in the mechanical parts of the laptop.

Table 3-4: Dell Latitude 7300 25th AE CPU, heatsink and fan

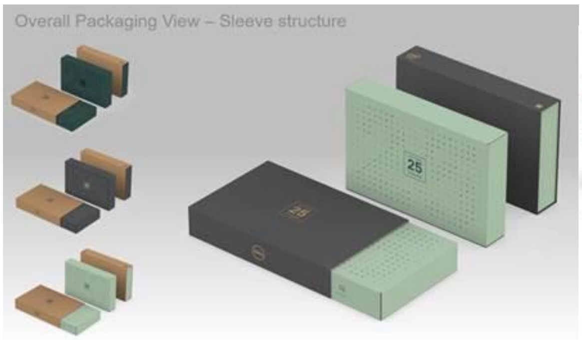
Electro-mechanic components	Weight (g)	Pieces
CPU	-	1
Heatsink	23,36	1
Fan	**14,40**	**1**

Table 3-5: Dell Latitude 7300 25th AE CPU Details

CPU	Substrate (mm x mm)	Die area (mm2)	Tech node	Technology
Intel® Core™ i7-8665U 1.9GHz, 4C/8T, 8MB Cache, Turbo, HT (15W)	**46 x 24**	**126**	**14nm**	**CMOS**

Packaging

The packaging of the Dell Latitude 7300 25th AE is detailed in Table 3-6 and shown below.



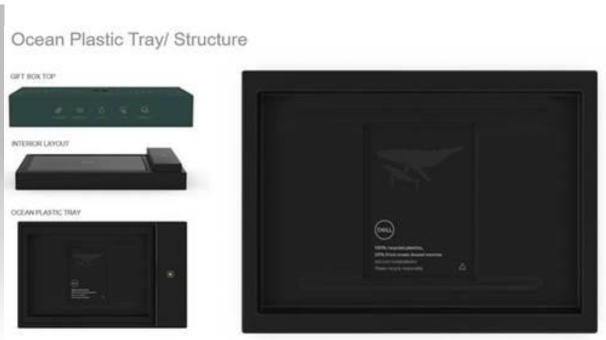


Table 3-6: Dell Latitude 7300 25th AE packaging

Item	Material	Weight (g)
Ship Box	Corrugated Fibreboard	357,9
Cushion L/R	Corrugated Fibreboard	256,6
Sleeve	Corrugated Fibreboard	121,7
Telescope Box Lid	Corrugated Fibreboard with grey board	236
Telescope Box Lid Insert	Corrugated Fibreboard	48,2
Accy Box	Corrugated Fibreboard	43,5
Telescop Box Base	Corrugated Fibreboard	86
System Tray Corr Insert	Corrugated Fibreboard	10
System Tray	Ocean Bound Plastic	108,5
System Wrap	OPP plastic	5
Envelop	Wood-free paper	14,8
Stickers	Wood-free paper	2
Total weight		**1290,1**

Battery

The battery is the heaviest single component of the Dell Latitude 7300 25th AE and the details are shown in Table 3-7.

Table 3-7: Dell Latitude 7300 25th AE battery

Battery	Type	Capacity (mAh)	Capacity (Wh)	Voltage (V)	Weight (g)
Dell MXV9V	Li-Polymer	7500	60	7,6	243,60

3.2.3. Distribution

Transport to customer in the United States and in Europe was included. All Dell laptops are produced in China. For EU customers, the laptops are shipped by air transport to the Netherlands and distributed from there by road transport. The same conditions apply for transport to US customers. Therefore:

- Transport to customer in Europe:
    - 100% air transport from China (ChengDu) to Netherlands (Amsterdam/Tilburg) (8,000 km)

- 100% road transport from Netherlands to customer (942 km) (average value based on different end destinations)

- Transport to customer in USA:
  - 100% air transport from China (ChengDu) to USA (Los Angeles) (11,580 km)
  - 100% road transport from Los Angeles to customer (2623 km) (average value based on different end destinations)

Data for EU transport distances was provided by Dell, whereas the assumptions for US transport are based on typical distances for products sold in the US

3.2.4. Use

For this study, the power consumption of the Dell Latitude 7300 25th AE was measured and provided by Dell. The measurement considered four different load modes and resulted in the following power consumption:

- P_{off} = 0,32 Watt
- P_{sleep} = 1,34 Watt
- Pl_{ong_idle} = 1,34 Watt
- P_{short_idle} = 4,62 Watt

The lifetime of the product is assumed to be 5 years, which corresponds to the warranty given by Dell.

Dell provided the percentage of time at each load mode as follows:

- P_{off}: 25%
- P_{sleep}: 45%
- P_{long_idle}: 5%
- P_{short_idle}: 25%

Table 3-8 illustrates the different use phase parameters for the scenarios considered in the study.

The Typical Energy Consumption (E_{TEC}) formula represents annual energy consumption in kWh:

$$E_{TEC} = \frac{8760}{1000} \times \left(P_{off} \times T_{off} + P_{sleep} \times T_{sleep} + P_{long\_idle} \times T_{long\_idle} + P_{short\_idle} \times T_{short\_idle}\right)$$

In the above equation:

- P_x: power consumption in the various modes (W);
- T_x: ratio of time spent in the various modes (h).

Table 3-8: Use phase scenario for the Dell Latitude 7300 25th AE

	P_{off}	P_{sleep}	P_{long_idle}	P_{short_idle}
T (h)	6	10,8	1,2	6
P (W)	0,32	1,34	1,34	4,62
Lifespan (yr)	5	5	5	5
Power (Wh/yr)	700,8	5282,28	586,92	10117,8

3.2.5. End of Life

Assumptions for the End of Life (EoL) follow the primary data that was collected by Dell and the recycling contractor Wisetek.

Statistics from the EPA Municipal Solid Waste report suggest that of electronic consumer products sold in the United States 39,8% are recycled (EPA, 2015). Similar statistics for the European Union show a recycling rate of 41,2% (eurostat, 2019). To reflect this information, this data was implemented for the EoL scenarios and the rest is considered to be landfilled.

In addition, based on the primary data from the recycling contractor Wisetek, weighted averages were calculated for the following materials:

Table 3-9: EoL scenario for electronic materials

Material	Recycling rate [%]	Energy recovery [%]	Landfill [%]
Electronics	82,32	0	17,68
Aluminium	100	0	0
Steel	100	0	0
Plastic	0	0	100
Copper	98,3		1,7
Paper Packaging	0	100	0
Plastic Packaging	0	100	0

The distance to EoL is 680 km. This value is the average distance from seven primary locations to one of the major recyclers for electronics in Europe.

3.3. Background Data

3.3.1. Fuels and Energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2019 databases. Table 3-10 shows the most relevant LCI datasets used in modelling the product systems. Electricity consumption was modelled using national and regional grid mixes that account for imports from neighbouring countries and regions.

Documentation for all GaBi datasets can be found at http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/.

Table 3-10: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	EU-28	EU-28: Electricity grid mix	thinkstep	2016	No
Electricity	US	US: Electricity grid mix	thinkstep	2016	No

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2018 database. Documentation for all GaBi datasets can be found at http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/.

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities.

The GaBi 2019 database was used to model transportation. Truck transportation was modelled using GaBi global truck transportation datasets.

A list of all datasets can be found in Annex C:

3.4. Life Cycle Inventory

As shown in Figure 3-2, the GaBi LCI model consists of three main phases, each separated by a transport step: manufacture, use, and end-of-life. Each phase is described in more detail in the following sections.

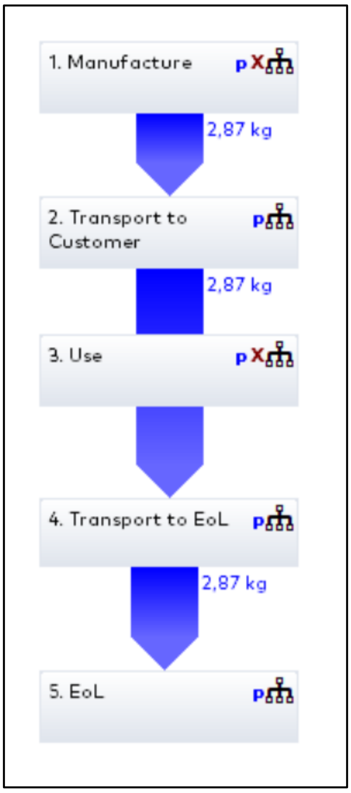


Figure 3-2: GaBi screenshot of the life cycle of the Dell Latitude 7300 25th AE

3.4.1. Manufacture phase and transport to customer

The manufacture of the product consists of two main modules – part production and assembly – as depicted in Figure 3-3.

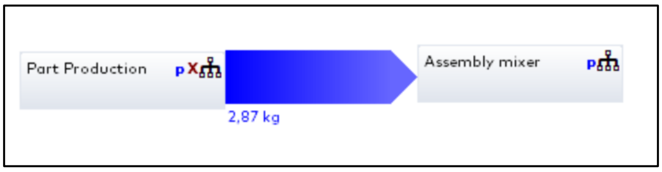


Figure 3-3: GaBi screenshot of the manufacture of the Dell Latitude 7300 25th AE

Part production includes the different components of the laptop grouped into 8 different plans, as depicted in Figure 3-4.

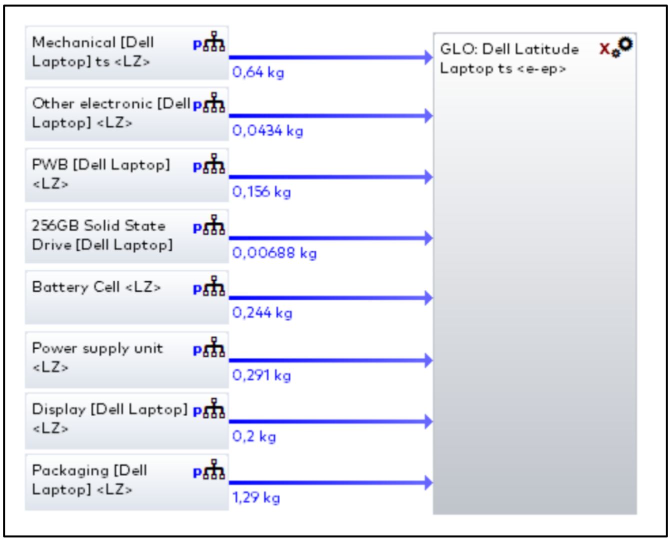


Figure 3-4: GaBi screenshot of the part production of the Dell Latitude 7300 25th AE

Inside each one of the 8 plans, there is a transport module built in, as shown in Figure 3-5, to represent the shipping of parts to the assembly site (transport to assembly). This module is parametric and adjusted according to the scenarios (transport distance and mode of transportation). Based on data provided by Dell, the distance to assembly is considered with 200km by truck over mainland China.

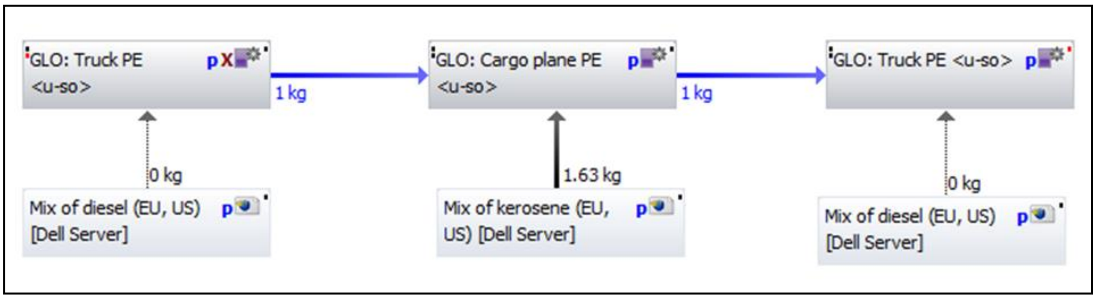


Figure 3-5: GaBi screenshot of the transport to assembly of the electronic components of Dell Latitude 7300 25th AE

The assembly of the laptop includes the waste occurring at the facility and is shown in Figure 3-6.

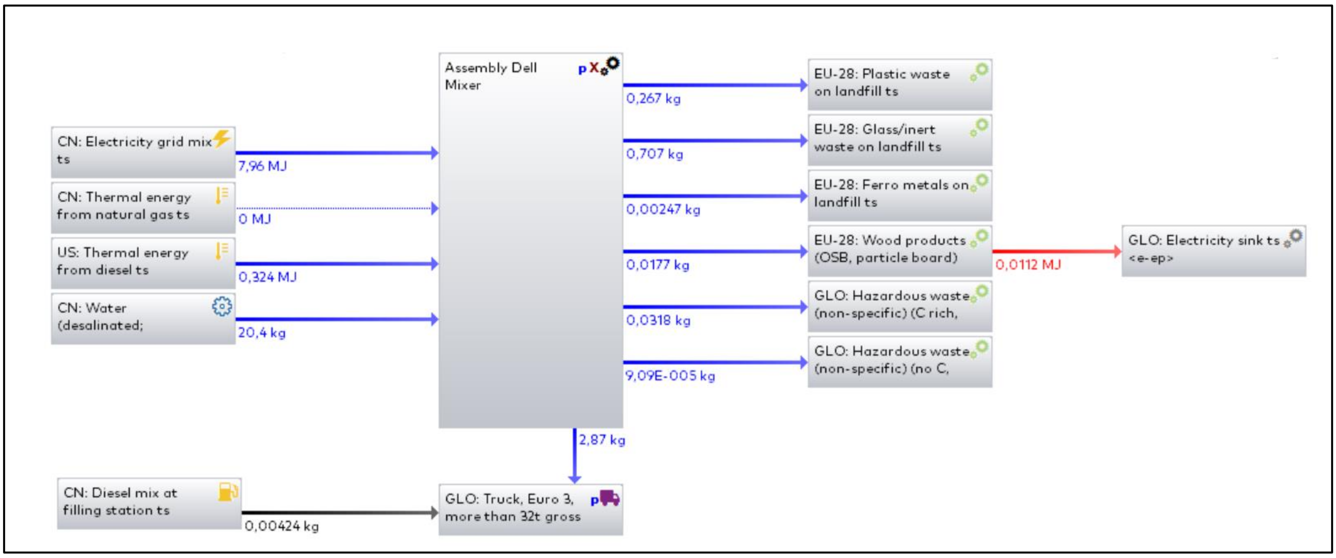


Figure 3-6: GaBi screenshot of the assembly of Dell Latitude 7300 25th AE

3.4.2. Use phase

As described in section 3.2.4, the total consumption in the use phase is split between idle and different load modes. Figure 3-7 depicts the modelling approach on the top-level plan.

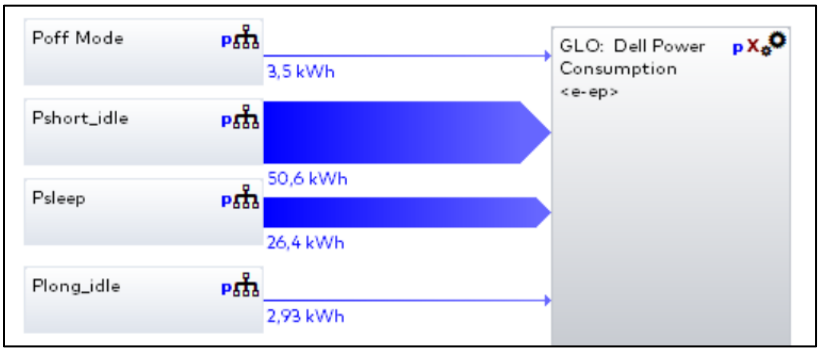


Figure 3-7: GaBi screenshot of the use phase of the Dell Latitude 7300 25th AE

The GaBi model can be adjusted to reflect the mix of customers from the US or EU, i.e. the proportion of electricity from each region's electricity grid mix. A screenshot of a power mode plan is depicted in Figure 3-8.

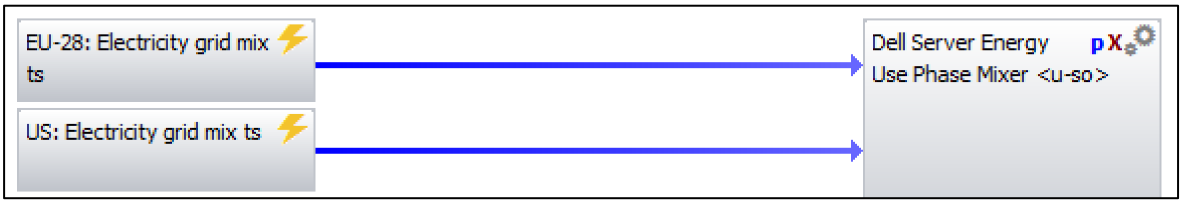


Figure 3-8: GaBi screenshot of a power mode plan of Dell Latitude 7300 25th AE

3.4.3. End of Life

End-of-life is modelled as described in chapter 3.2.5. For recycling, large mechanical parts are first separated manually. The remaining parts (electronics such as printed wiring boards and the electronic parts of the SSDs) are shredded and then further processed to recover copper and precious metals (see Figure 3-9).

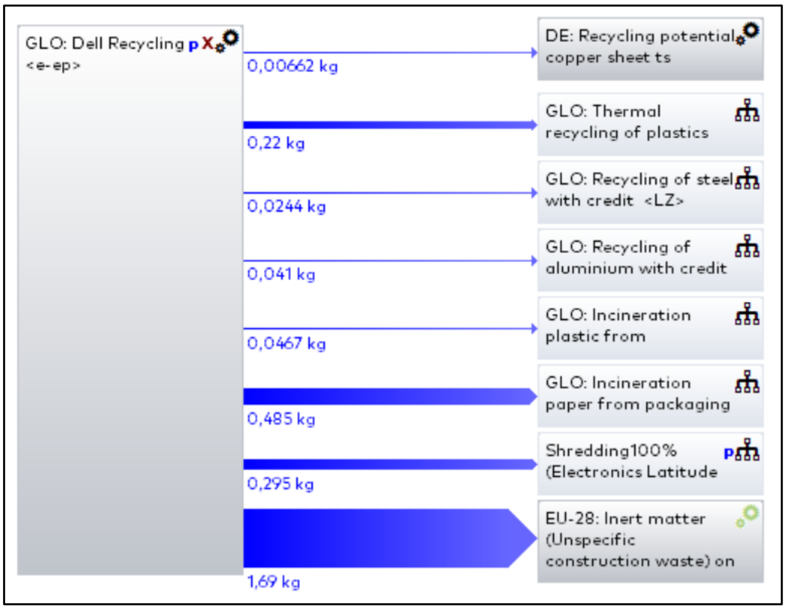


Figure 3-9: GaBi screenshot of the End of Life of the Dell Latitude 7300 25th AE

4. Results

This chapter contains the results of the LCA study. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

The results will be discussed for the impact category Global Warming Potential (GWP) in the following chapter, as the overall conclusions remain valid also for the other impact categories and GWP is considered the most robust and widely used impact category. A table summarizing all impact category results can be found below and diagrams in Annex B:

4.1. Overall Results

Two scenarios are defined given the two regions in which the Dell is sold, used, and sent to end of life:

- Europe; and
- United States of America.

The study made the following assumptions, which are based on information provided by Dell:

- Manufacturing and assembly take place in China (see **Fehler! Verweisquelle konnte nicht gefunden werden.**),
- transportation to European and US customer, and
- Use stage and EoL take place in the EU and in the US.

Table 4-1 shows the impact assessment results for all impact categories under consideration within this study.

Table 4-1: Overall results for the Dell Latitude 7300 25th AE

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	1,70E+03	2,04E+03
Acidification Potential [kg SO2 eq.]	5,99E-01	6,70E-01
Eutrophication Potential [kg Phosphate eq.]	5,21E-02	5,73E-02
Ozone Layer Depletion Potential [kg R11 eq.]	1,90E-07	1,90E-07
Photochem. Ozone Creation Potential [kg Ethene eq.]	4,44E-02	4,84E-02
Global Warming Potential 100 years incl. biogenic carbon [kg CO2 eq.]	1,47E+02	1,68E+02

For the life cycle of the Dell Latitude 7300 25th AE in the United States, the GWP is ca. 14% higher than the GWP in Europe. The main reason for this is the use phase and hence the emissions associated with the production of electricity within the respective electricity grid mix.

In a detailed view of the carbon footprint of these two scenarios in Figure 4-1 and Figure 4-2, it is clear that the major fraction of the impact – approximately 85% in both the EU and the US – derives from the manufacturing and the use phase of the Dell Latitude 7300 25th AE. The production of the parts in the EU accounts for around 65% of the total GWP, whereas in the US the production accounts for around 60% of the total impact. Transportation of each component to the assembly location is included in the manufacturing stage and accounts for less than 1% of the overall results because the components are sourced from China and the assembly site is located in China. Concerning the assembly of the Dell Latitude 7300 25th AE, the associated carbon footprint contributes to around 1% to the overall impact and includes treatment of wastes that occur at the facility during assembly.

The lower impact of the transport to the customer in the EU can be mainly explained by the underlying assumptions of longer distances and different modes of transport. The transport to end of life has a less relevant contribution in both cases and the end of life credits contribute to a reduction of about 7% and 6% of the life cycle impacts respectively.

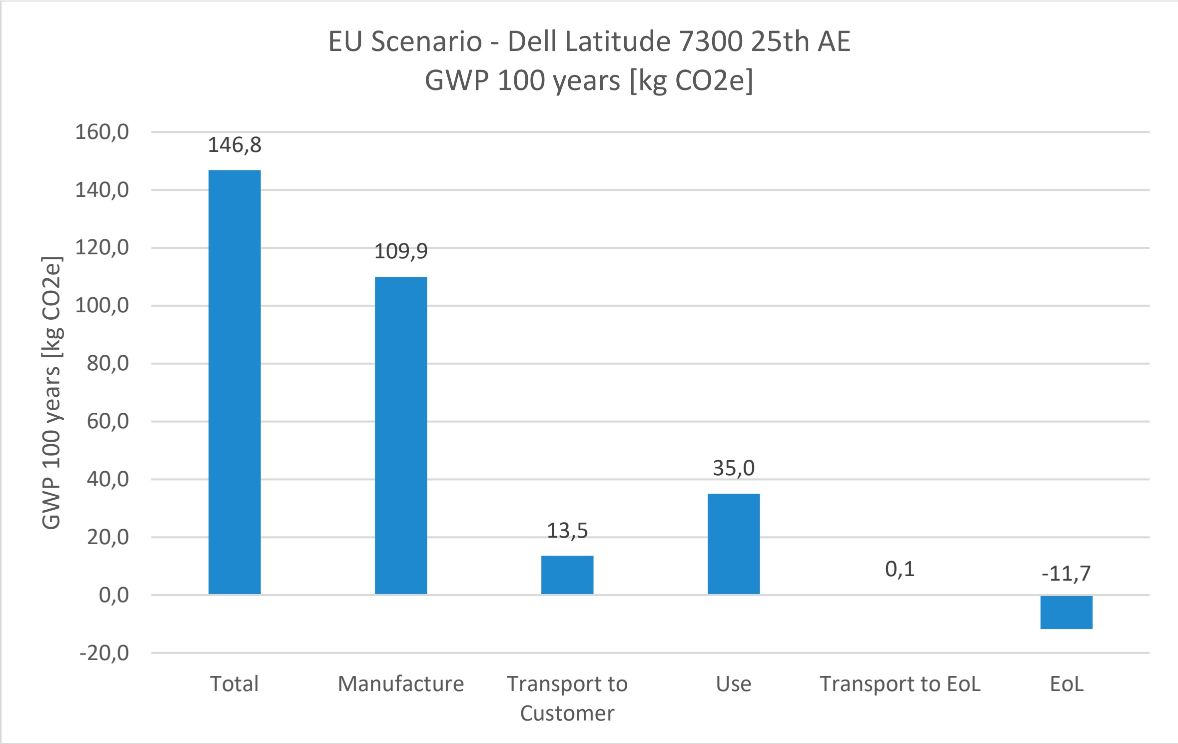


Figure 4-1: Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell Latitude 7300 25th AE in the EU

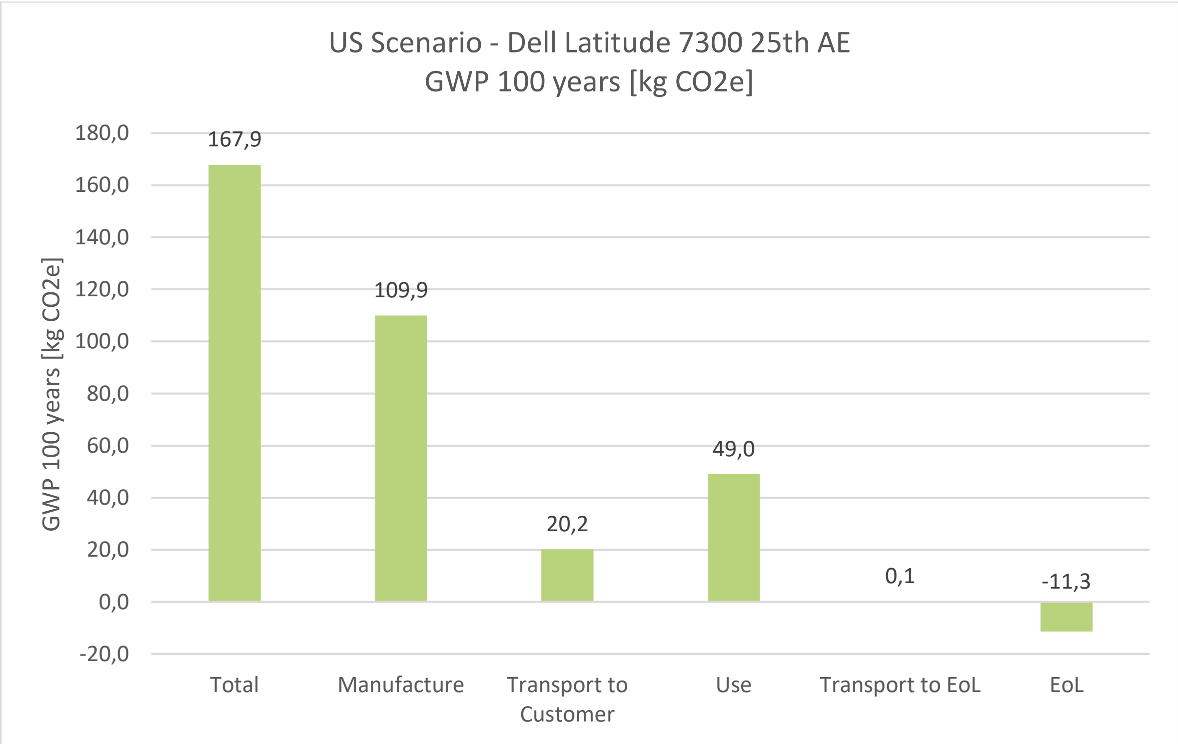


Figure 4-2: Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell Latitude 7300 25th AE in the US

4.2. Manufacturing of the Dell Latitude 7300 25th AE

4.2.1. General

In the previous section, it was shown that the manufacturing of the Dell Latitude 7300 25th AE in the EU has a contribution of 110 kg CO_2e, contributing to approximately 65% to the total of the life cycle impact.

Figure 4-3 presents the contribution of the different parts to the total impact resulting from the part production, not including assembly.

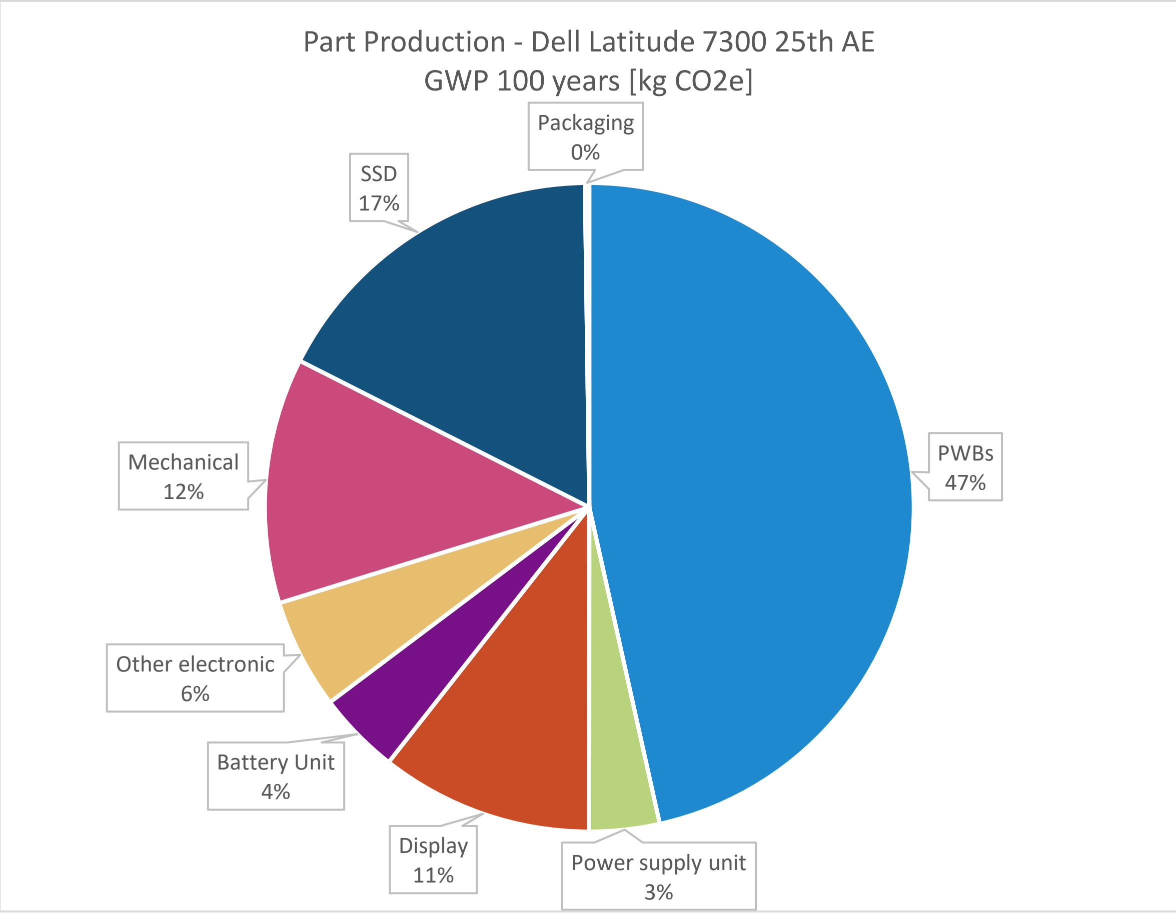


Figure 4-3: Contribution of the production of different modules to the global warming potential (GWP) of the Dell Latitude 7300 25th AE

It becomes very clear that the large majority of the part production impacts are from the components containing electronics and especially the PWBs and the SSD. The results of the detailed assessment and sensitivity analyses for these will be shown in the next sections. In Table 4-2, the impact contribution of each component is shown in terms of kg CO_2e.

Table 4-2: Carbon footprint of main components of the Dell Latitude 7300 25th AE

Main Components	Global Warming Potential (GWP 100 years) [kg CO2e]
PWBs	50,1
Power supply unit	3,8
Display	11,4
Battery Unit	4,4
Other electronic	5,9
Mechanical	13,2
SSD	18,7
Packaging	0,2
Total	**107,8**

It is interesting to understand the relation between the mass and the impact of each of the parts. Figure 4-4 illustrates the mass of the main components in comparison to their corresponding weight. As shown, over 88% of the part production impact comes from the components containing electronics which account for only 33% of the total weight of the Dell Latitude 7300 25th AE.

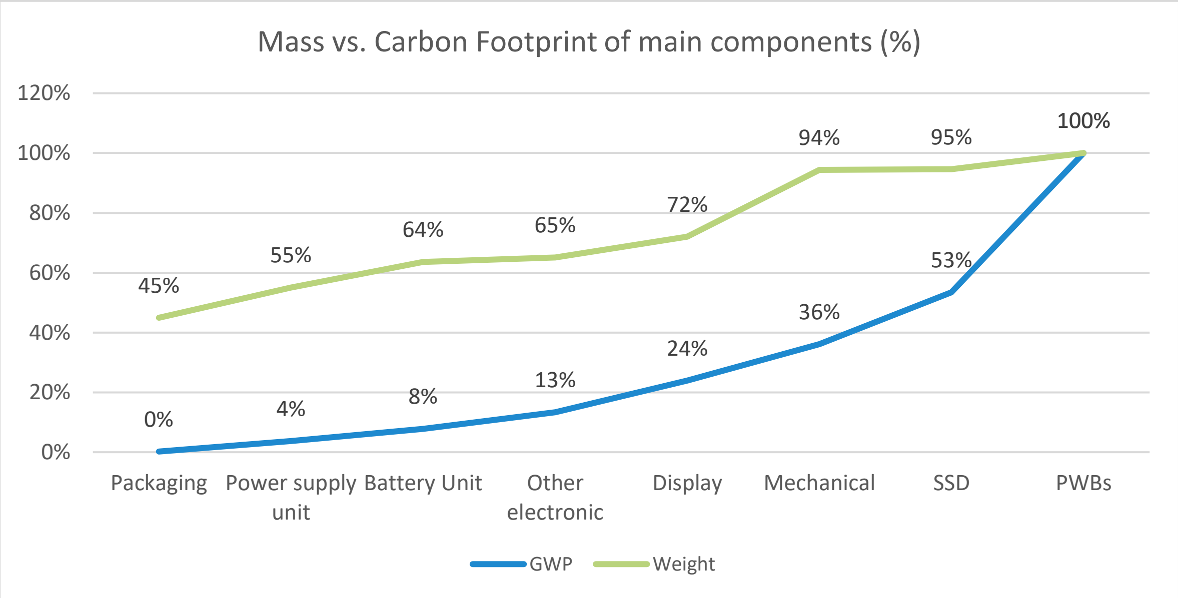


Figure 4-4: Comparison of masses and associated global warming potential (production) on the components in the Dell Latitude 7300 25th AE

It is thus possible to show that the global warming potential is not directly linked to mass. While the mechanical components and packaging dominate the mass of the product (22% and 45% respectively), the impact of those components (GWP) per unit of mass are relatively low. By contrast, the PWBs, the SSD and display – together contribute only 13% of the total mass, but their impact per unit mass is a large share (74%) of the total GWP of the parts. This is a typical phenomenon in electronic products where the energy consumption, waste, and emissions of electronics manufacturing processes far outweigh the regular metallurgical or plastic production processes of the chassis and packaging.

Packaging has the lowest impact per unit mass, since here the largest part of mass comes from paper, in which production – when compared with the processes in the other modules – is relatively less energy-consuming. In addition, for the Dell Latitude 7300 25th AE packaging with a high share of secondary content was used.

4.2.2. PWBs

Figure 4-5**Fehler! Verweisquelle konnte nicht gefunden werden.** depicts the contribution of the main elements in the PWBs and their respective contributions to the carbon footprint.

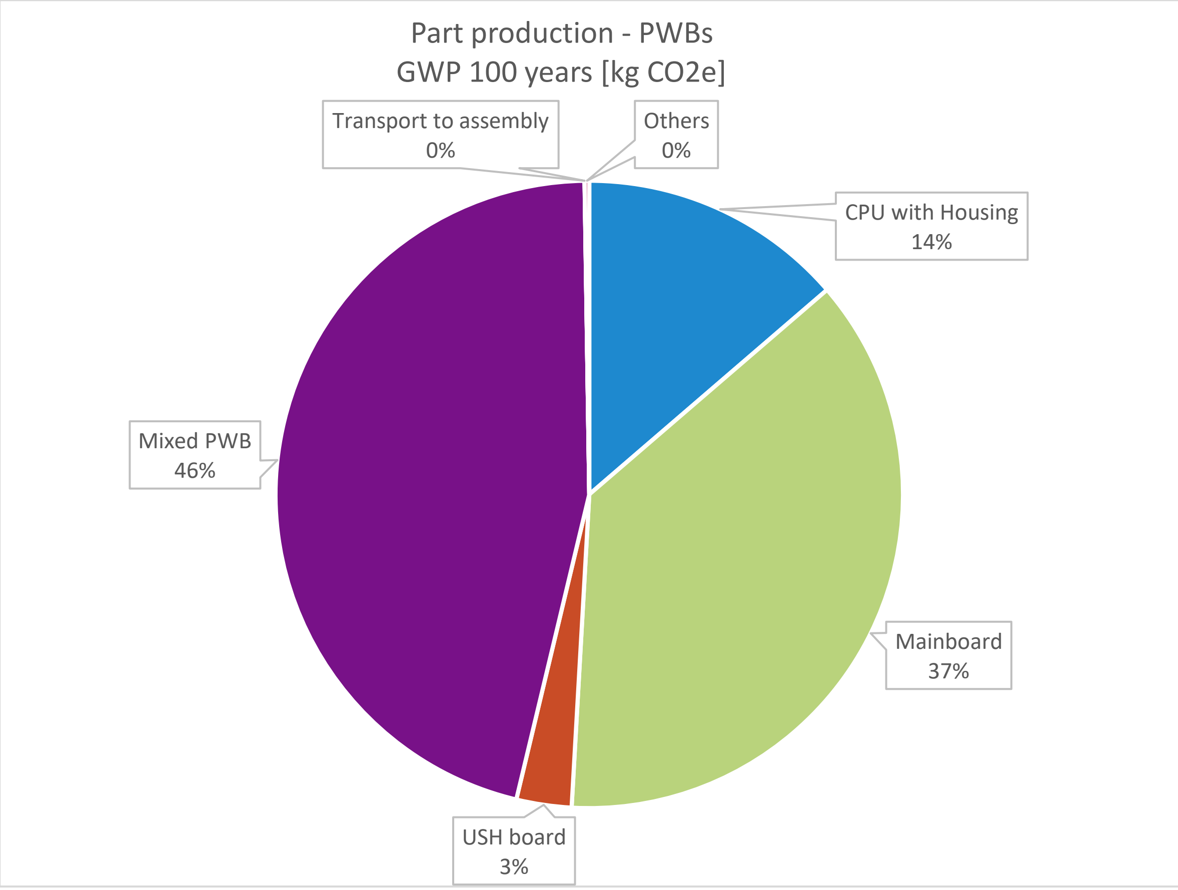


Figure 4-5: Contribution of the elements of the mainboard for the carbon footprint of this component of the Dell Latitude 7300 25th AE

Three main submodules generate almost all the impact from the PWBs:

- The mixed PWB, which includes the 16GB RAM bar, the WiFi adapter, touchpad, cardreader and other smaller PWBs.
- The mainboard itself, which was in detail evaluated via a BOM provided by Dell and was highly populated board with a significant amount of electronics consisting of around 1400 parts such as resistors, capacitors and ICs. The mainboard was estimated to be 12-layer HASL.
- The CPU and the corresponding heatsink contribute with 14% to the total impact of the PWBs.

The following characteristics help to explain this impact distribution and are true for all electronics discussed within this study:

- PWB manufacturing is a multi-step, highly energy intensive process with a significant amount of waste production and direct emissions. For Dell's circuit boards, some also require the use of gold which is a precious metal with very energy and emission intensive upstream production steps of extraction and processing.
- Active components (ICs, diodes and transistors) contain a semiconductor die which has a highly energy intensive manufacturing process, increasing in direct proportion with the area of the chips. In addition, active components often require gold or other precious metals. Therefore, large ICs such as memory chips, CPUs, and graphic cards etc., will have a high carbon footprint due to the energy demand of the production steps.
- Passive components do not contain a die, but can contain a small amount of precious metals. Large and massive passive components can therefore have a high contribution to environmental impacts, but small components are generally less relevant to the overall impact;
- Connectors can also contain gold and/or other precious metals in small amounts.

4.2.3. Solid State Drive

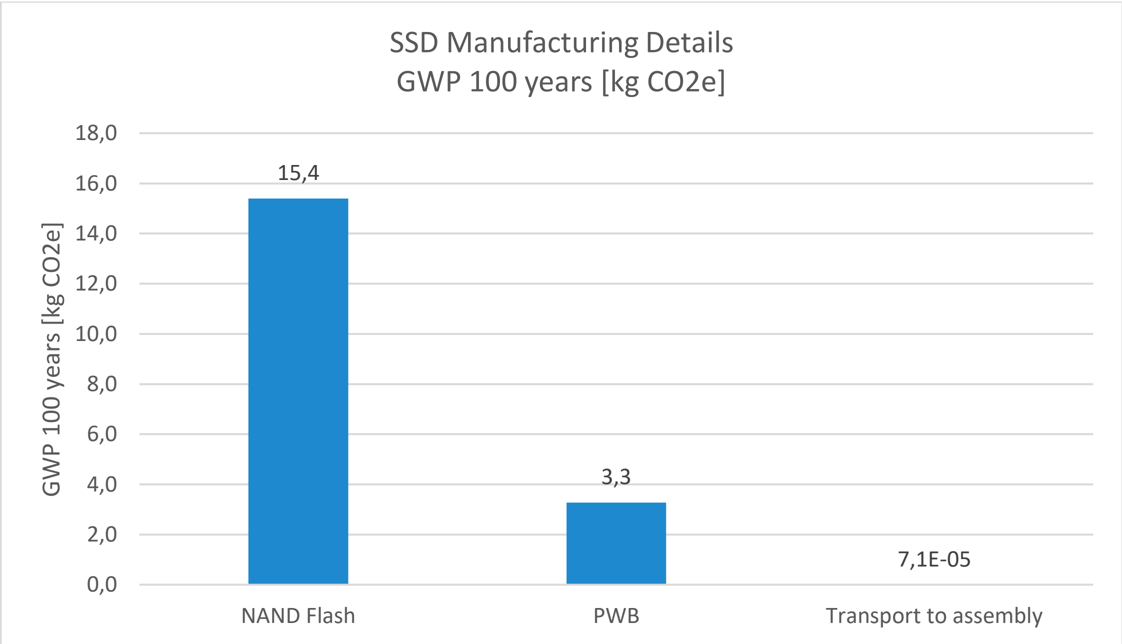


Figure 4-6: SSD manufacturing impacts

Figure 4-6 shows that the majority of the impact of the 256GB M.2 SSD comes from the NAND flash. As described in chapter 3.2.2, several assumptions were made regarding package dimensions, die/package ratio and die stack per package to model these chips. The data for these parameters are based on the part number of the chips and publicly available data from Toshiba and others (Toshiba, 2018) (Tallis, 2018). Based on a sensitivity analysis in a previous study and lab results from other NAND flash chips show that the assumption of a die/package ratio of 60% is a suitable value that is typically found within the industry.

4.2.4. Mechanical

The mechanical part includes all components and materials belonging to the chassis, e.g. the A-Cover covering the display. For the Latitude 7300 25th AE Dell includes an A-Cover that is made of a polycarbonate (PC) and carbon fibre (CF) laminate (PCCF). This laminate has a core of post-industrial PC fibre and recycled non-woven CF. Within the mechanical elements, this PCCF has the highest contribution to the impact. The high impact of the material can mainly be explained by the high energy intensity of the production process.

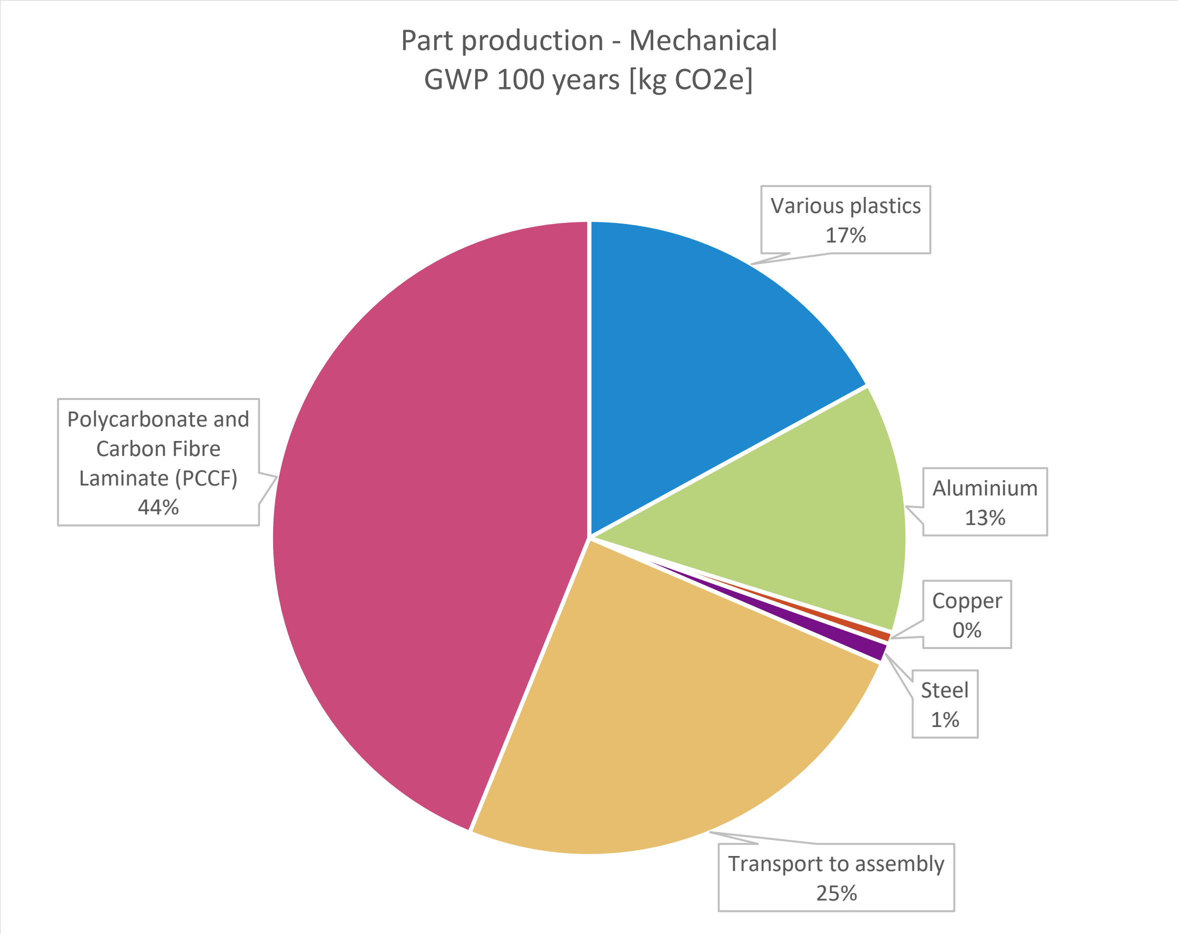


Figure 4-7: Contribution of the mechanical elements for the carbon footprint of this component of the Dell Latitude 7300 25th AE

4.3. Use phase of the Dell Latitude 7300 25th AE

In this section, the scenario based on the two regions where the current study considers that the Dell Latitude 7300 25th AE is used is presented.

4.3.1. Regional Scenario

The following two locations are considered within this scenario and represent the two most typical cases for Dell products:

- The Dell Latitude 7300 25th AE is used 100% in the EU
- The Dell Latitude 7300 25th AE is used 100% in the US

Figure 4-8 includes the carbon footprint results for the two scenarios based on the mode of the use phase and the region where it is used over the entire lifespan of the product.

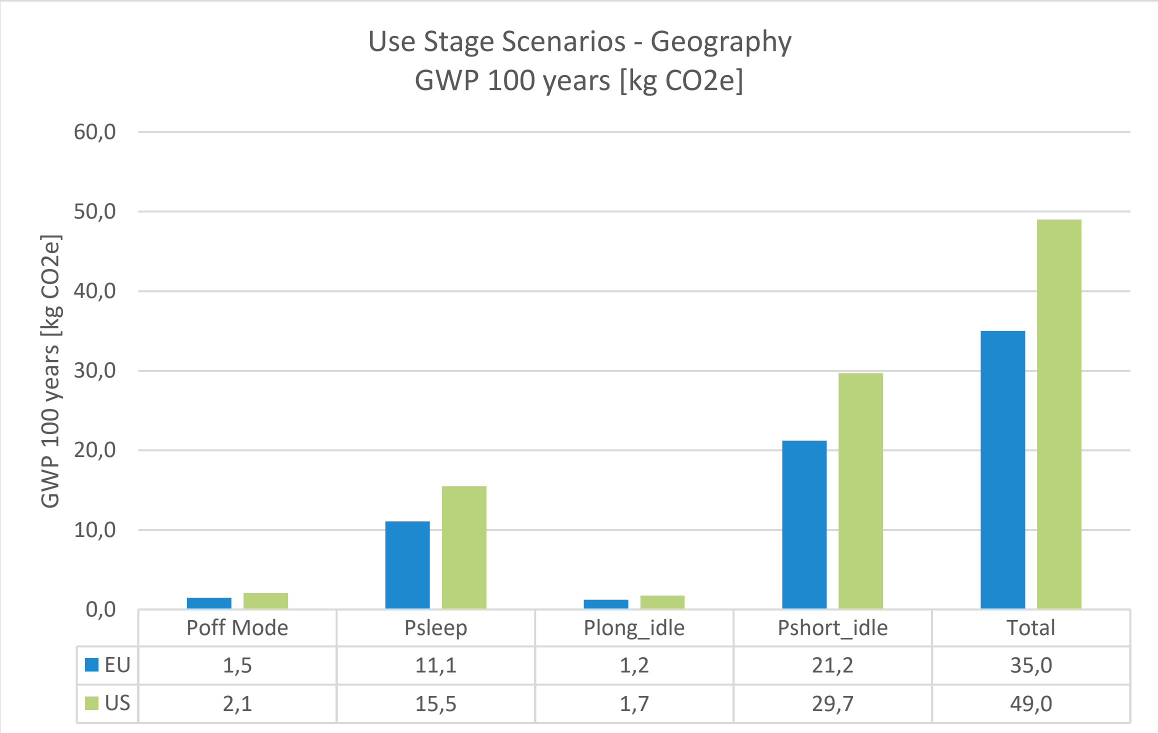


Figure 4-8: Global Warming Potential of the Dell Latitude 7300 25th AE use stage in Europe and the USA

As expected, the Dell Latitude 7300 25th AE working at P_{short_idle} load mode leads to the highest electricity consumption and therefore the highest carbon footprint, given the rather high share of this load mode and especially due to its highest consumption. The only difference between P_{sleep} and P_{long_idle} is the amount of time the laptop performs in each mode, leading to a higher contribution of the P_{sleep} mode to the overall impact.

Overall, the use of the Dell Latitude 7300 25th AE in the USA shows higher GWP impacts compared to a usage in the EU. This can be associated with the different share of renewable and non-renewable energy carriers in the respective electricity grid mixes.

4.4. End of Life (EoL) of the Dell Latitude 7300 25th AE

Recycling of the Dell Latitude 7300 25th AE results in a credit of approximately 11 kg CO_2e to future product systems, corresponding to a reduction of ca. 7% and 6% of the total product's life cycle impact in the EU and US respectively.

Table 4-3 shows the impacts and credits associated with the end of life treatment of the laptop assuming the recycling rate of electronic consumer products and the values provided by Wisetek (chapter 3.2.5). Due to the data collection procedure undertaken within the study, it was possible to determine quite precisely the amounts of electronics and other materials used within the product.

Credits shall be understood as avoidance of impacts associated with primary production of the material which is sent to recycling. In cases where the recycled (secondary) material can be used directly to replace the primary material, the primary production of the same amount of material can be avoided and thus all environmental impacts associated with primary production are also avoided. Therefore, credits are displayed as having a *negative* impact.

In the case of aluminum and steel, the metal can be recycled (almost) completely and the secondary material can have the same value as the primary one, making metal recycling an economically, as well as environmentally, worthwhile enterprise.

Mechanical recycling, however, may not always be viable for non-metals, such as plastics and paper. In this model, packaging paper and plastic are incinerated yielding energy (thermal and electric), and this amount is credited much the same way as materials: the amount of energy that is yielded will not need to be produced elsewhere, and therefore the burdens associated with a given amount of energy production are avoided. Incineration, however, has the disadvantage of also producing emissions of greenhouse gases; therefore, the impacts in this case are higher than the generated credits.

After separating the mechanical parts, the electronic assemblies (e.g. the printed wiring boards and electronic parts of the SSDs) are shredded. This process requires energy (leading to an impact) but enables the subsequent separation and recycling of precious metals (e.g. gold, silver, etc.). In Table 4-3 it is shown that the post-shredding mechanical recycling of these metals yields rather high credits, especially gold.

The landfilled portion of the product, i.e. the portion that is not recycled, produces some emissions, but these are minor, primarily due to the assumption that the waste is largely inert. Transport to recycling (680 km by truck) also has a very minor impact (see Figure 4-1 and Figure 4-2).

Table 4-3: Net results of recycling the laptop constituent materials

		Net results (GWP 100 years) [kg CO2-Equiv.] EU	Net results (GWP 100 years) [kg CO2-Equiv.] US
Mechanical Recycling	Aluminium	-3,26E-01	-3,15E-01
	Steel	-3,75E-02	-3,62E-02
	Copper	-1,45E-02	-1,40E-02
Waste paper	Paper packaging	4,38E-01	4,24E-01
Thermal treatment	Thermal recycling, Plastic	2,76E-01	2,67E-01
Incineration	Plastic packaging	5,51E-02	5,32E-02
Shredding	Power	4,47E-02	4,32E-02
Post-shredding mechanical recycling	Copper	-6,04E-01	-5,83E-01
	Gold	-1,14E+01	-1,10E+01
	Palladium	-1,67E-01	-1,62E-01
	PWB	2,24E-02	2,16E-02
	Silver	-1,19E-02	-1,15E-02
	Platinum	-5,26E-03	-5,08E-03
Landfill	Emission from inert wastes	2,65E-02	2,71E-02

5. Interpretation

5.1. Identification of Relevant Findings

- The use phase contributes approximately 25% to the total the life cycle GWP of the laptop. During this phase the source of electricity determines the environmental impact, as the use pattern is considered identical in both the US and EU scenarios.
- The two regions differ in their contribution to the global life cycle. The US scenario has approximately 14% higher impact than the European one, due to the differences in the electricity grid mix and fuel used, as well as distances travelled.
- The manufacturing stage accounts for 65% (60% in US) of the product carbon footprint.
- The transport to assembly has minimal effect, since all components are sourced from the same location as the assembly takes place (China).
- Considering only the manufacturing stage, the electronic components have by far the highest impact (~88%) of all modules. dominated by the PWBs and the M.2 SSD used within the configuration.
- 88% of the part production impact comes from the components containing electronics which account for only around 30% of the total mass of the Dell Latitude 7300 25th AE. The extensive packaging of anniversary product dominates the mass of the product (45%) but the impact per unit is relatively low (<1% of part production) due to high amount of recycled content. By contrast, the PWBs and the SSD contribute only ~6% to the total mass, but their impact per unit mass is very high. This is a typical phenomenon in electronic products where the energy consumption, wastes and emissions of electronics manufacturing far outweigh the regular metallurgical or plastic production processes. This is especially true for such high density and high capacity chips used for high capacity SSDs, as their PWB are highly populated.
- The chassis is the highest non-electronic component contributing to GWP in the manufacturing stage, with 13.2 kg CO_2-equivalents and accounting for around 12% of the total manufacturing impact. Being a portable device, the total weight of the chassis is minimized, and this is reflected in the results. This polycarbonate (PC) and carbon fibre (CF) laminate (PCCF) has the highest contribution to the impact. The high impact of the material can be explained by the high energy intensity of the production process. Using the PCCF reduces the amount of virgin carbon fibre in the product and thus the environmental impact of this virgin material.
- Recycling given the primary data resulted in a net reduction of 11 kg CO_2-equivalents. This represents a reduction of the total impact by around 6%.
- Considering the net gains from recycling, the largest gain comes from the recycling of gold (>90%), followed by copper and aluminium (~5% and ~3% of the total net gain

respectively). The recycling benefit from aluminum is very high, hence the higher net gain in contrast to the low aluminum content in the product.

With portable electronic devices such as the Dell Latitude 7300 25th AE becoming more energy efficient by adopting the newest low-power technology, the shift of the environmental burden from the use phase to the manufacturing stage that can already be observed in this study becomes more important. In addition, components that are commonly configurable as *Build to Order* (BTO), such as the SSD, can have a high impact on the environmental results of the product. One would expect the impact of the SSD to increase with increasing storage capacity, as the SSD impact is primarily a function of the area of dies and number of dies within a chipset. The form factor (M.2) of the SSD would stay the same, but the number of dies would vary depending on the SSD variant evaluated. The sources show that the 1 TB variant has two NAND packages each containing eight 512Gb BiCS4 3D TLC dies, or 16 dies total, which would increase the SSD impact by roughly a factor of two. However, it's unclear if the 512GB variant uses 256 or 512Gb dies, meaning that either 16 or 8 dies could be used, leading to either the same impact as the 256 model (8 dies) or, as in the case of the 1 TB variant, also increasing SSD impact by a factor of two.

Overall, this leads to the recommendation to a) focus more on the manufacturing part of products and hence more on the supply chain of those components and b) further increase the data quality of considered components, by e.g. having access to BOMs for all components. Looking at this issue from a (post-)consumer perspective, the reuse (or refurbishment) of the laptop device or used components such as SSDs from laptops could potentially extend their designated lifetime. This would require an appropriate take-back system (if reused externally after use by the first customer) or an appropriate data erasure system (if reused internally).

5.2. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2018 database were used. The LCI datasets from the GaBi 2018 database are widely distributed and used with the GaBi 8 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.2.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are based on primary measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be good considering the goal and scope of this study. All background data are sourced from GaBi databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. Only upstream component packaging was knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.2.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report.

5.2.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2017. All secondary data come from the GaBi 2018 databases and are representative of the years 2010-2017. As the study intended the reference year 2017, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Two scenarios (US and EU) were used to represent regional differences. Geographical representativeness is considered to be acceptable.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.3. Model Completeness and Consistency

5.3.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.3.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by predominantly using LCI data from the GaBi 2018 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

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Annex A: Manufacture of submodules as represented in GaBi 9

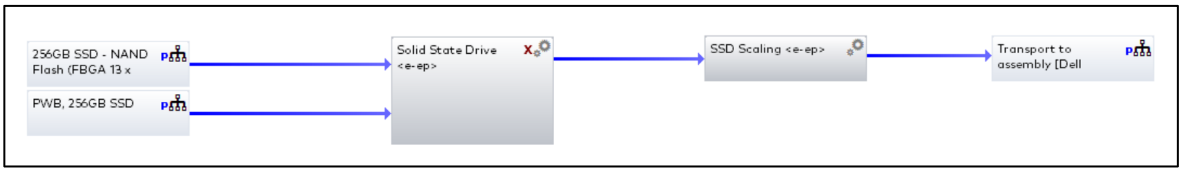

Figure A.5-1 Top-level SSD model for the Dell Latitude 7300 25th AE

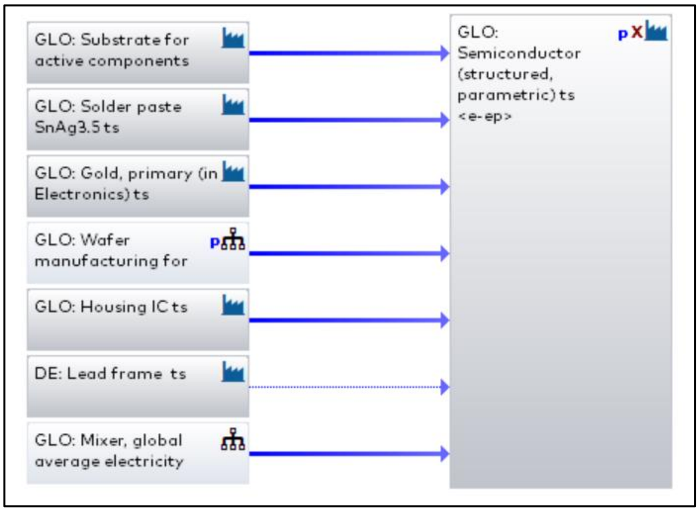

Figure A.5-2 Top-level SSD model for the Dell Latitude 7300 25th AE

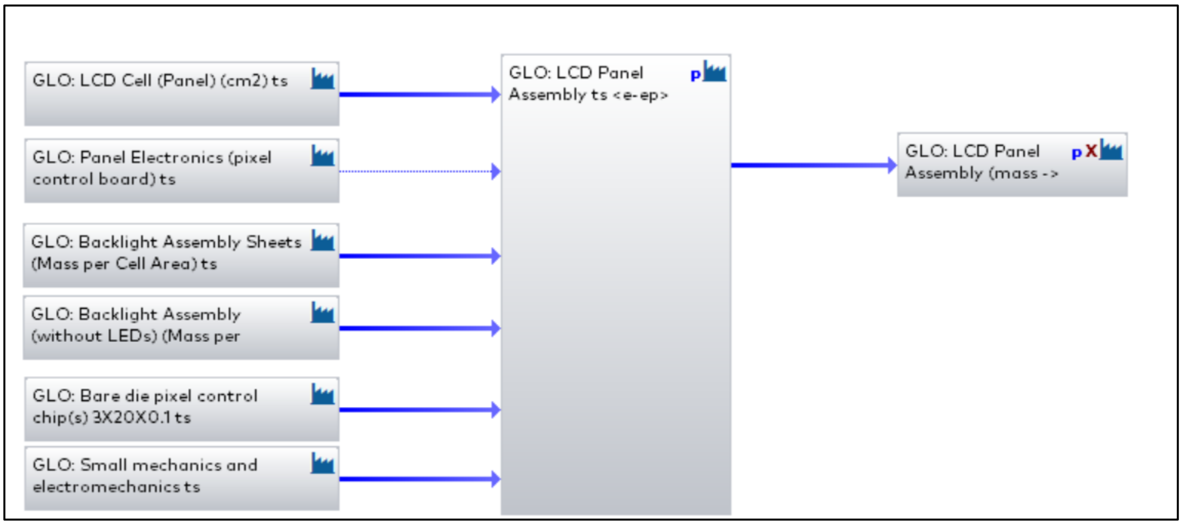

Figure A.5-3 **LED display model for the Dell Latitude 7300 25th AE**

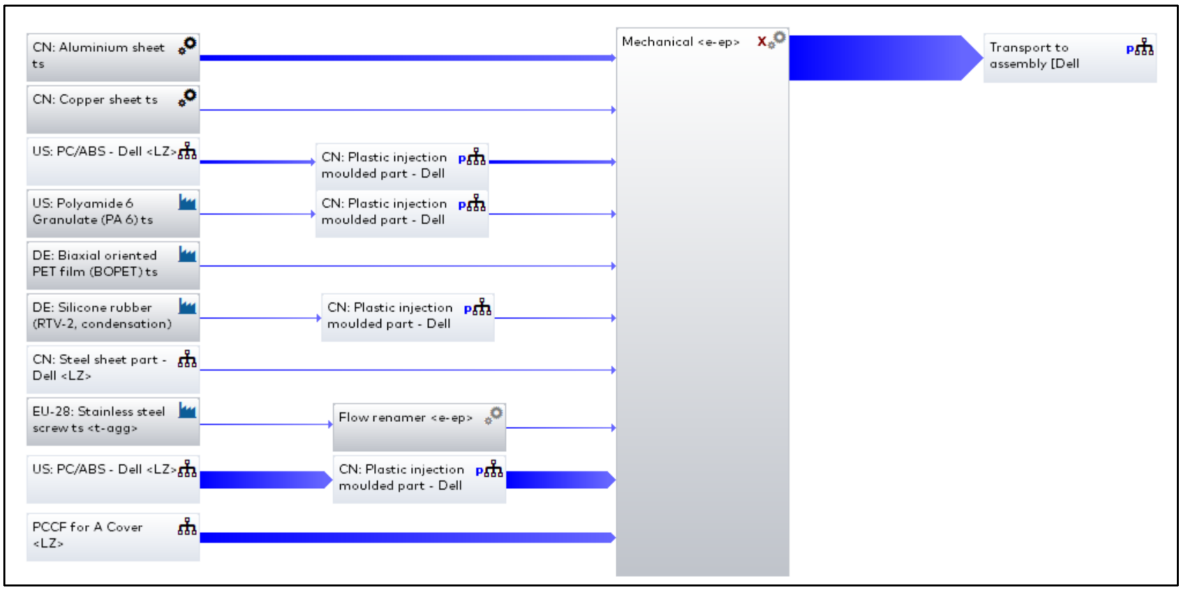

Figure A.5-4 **Mechanical model for the Dell Latitude 7300 25th AE**

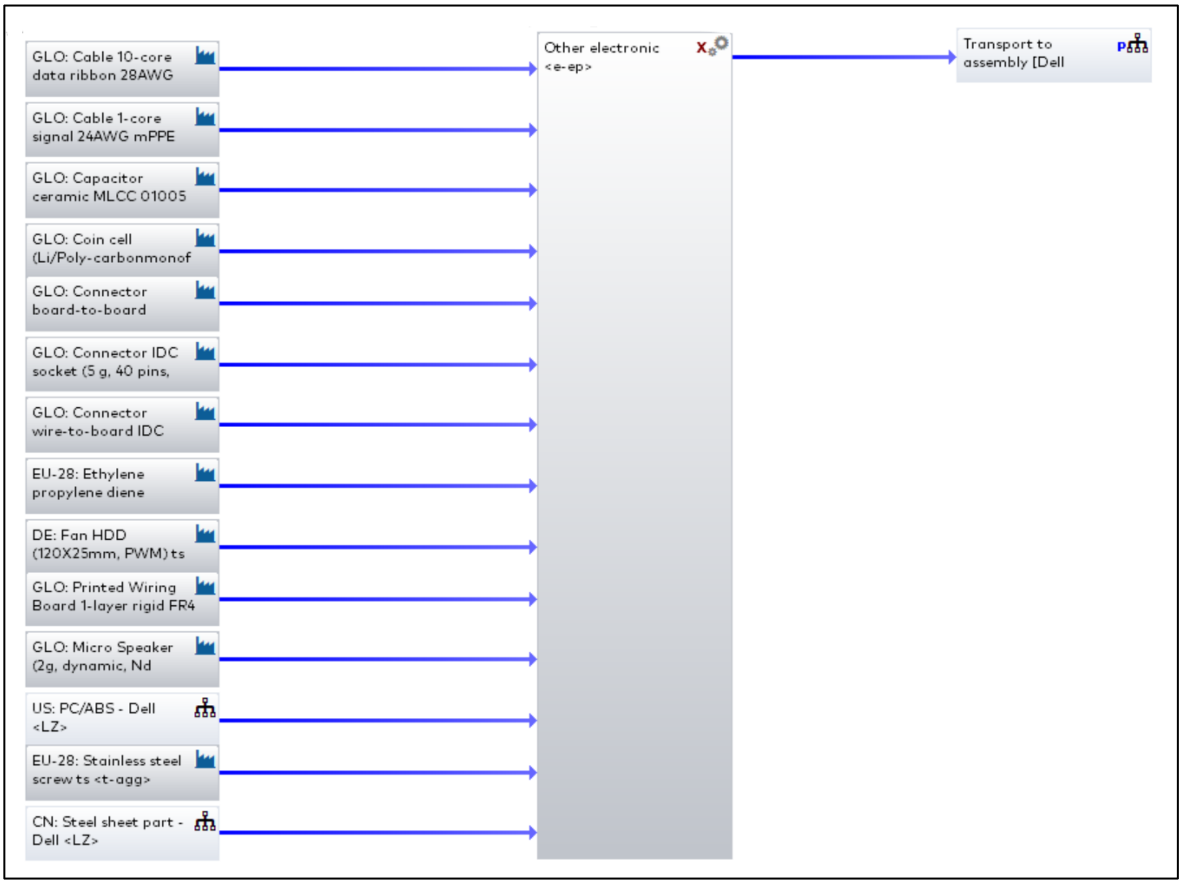

Figure A.5-5 Top level other electronics model for the Dell Latitude 7300 25th AE

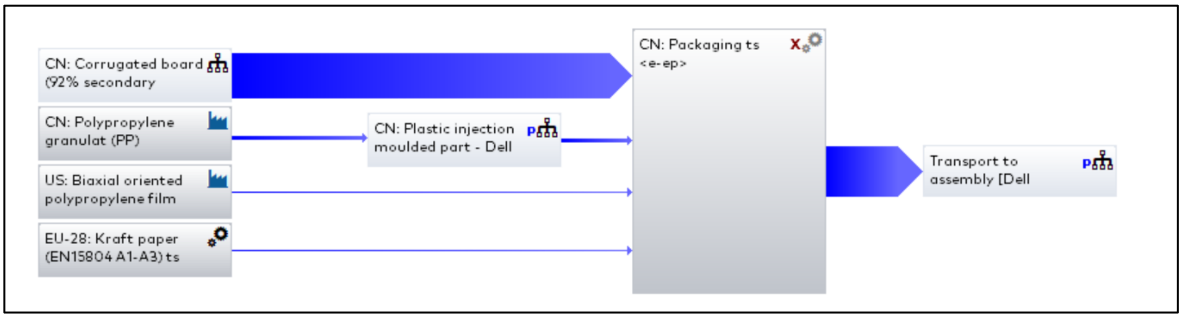

Figure A.5-6 Top level packaging model for the Dell Latitude 7300 25th AE

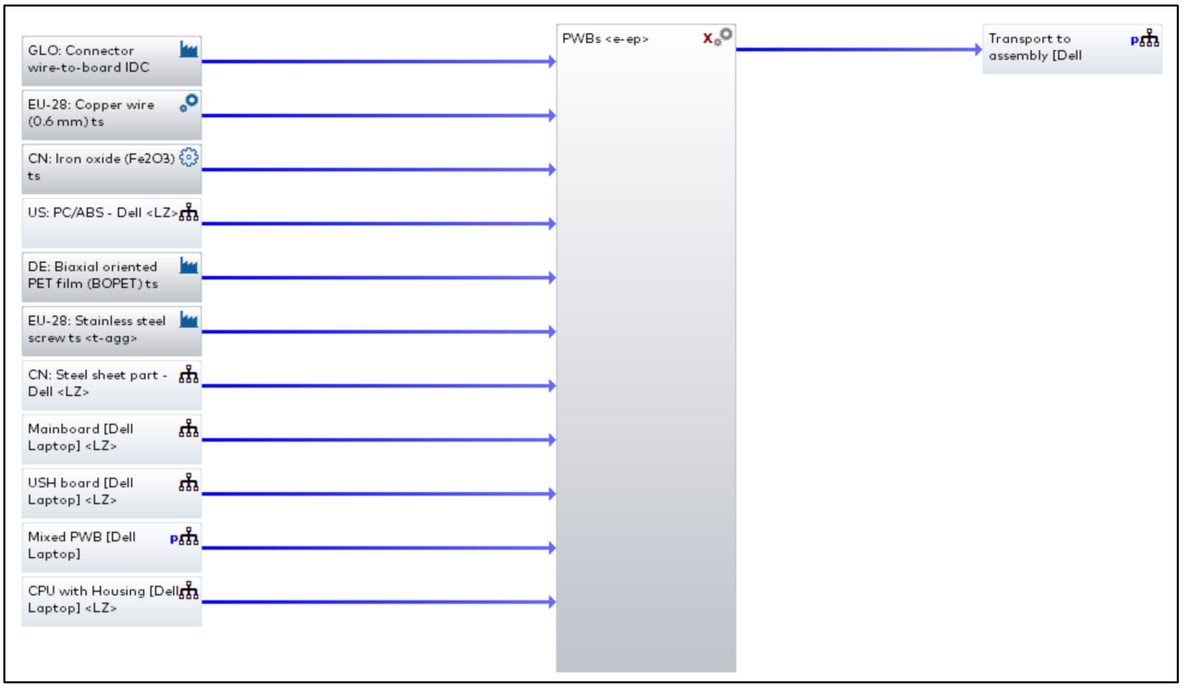

Figure A.5-7 Top level PWB model for the Dell Latitude 7300 25th AE

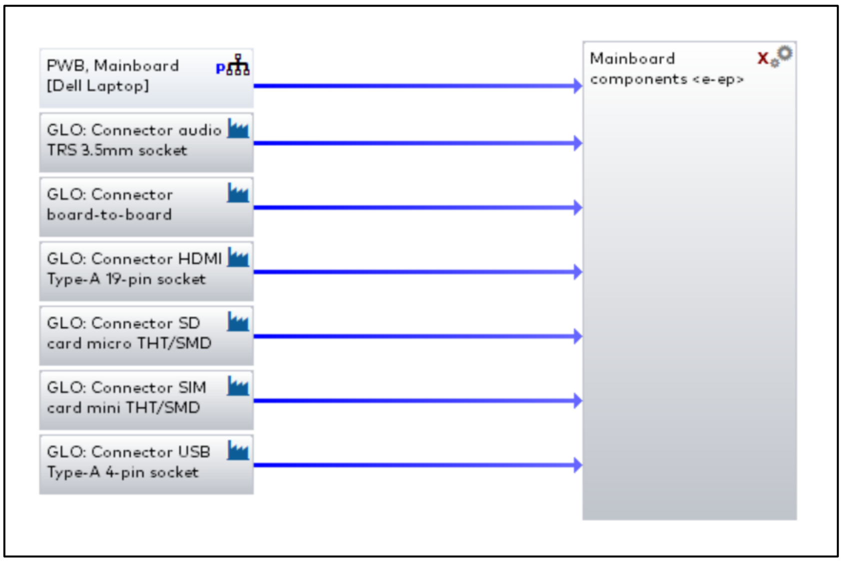

Figure A.5-8 Top level mainboard model for the Dell Latitude 7300 25th AE

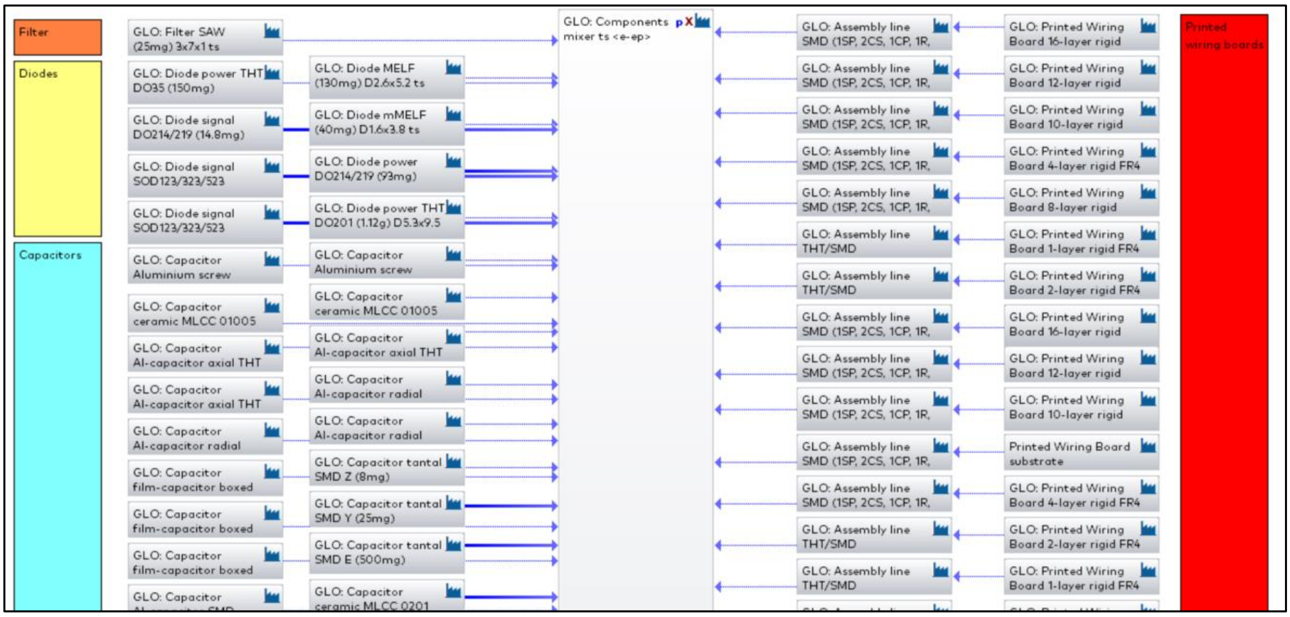

Figure A.5-9 Part of mainboard model for the Dell Latitude 7300 25th AE

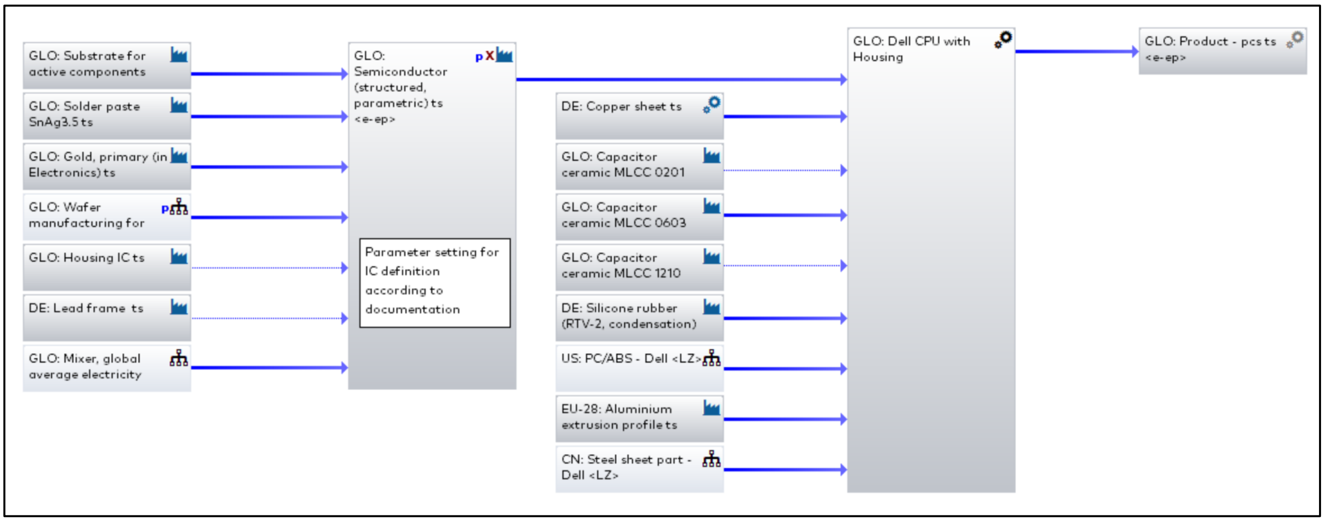

Figure A.5-10 CPU model for the Dell Latitude 7300 25th AE

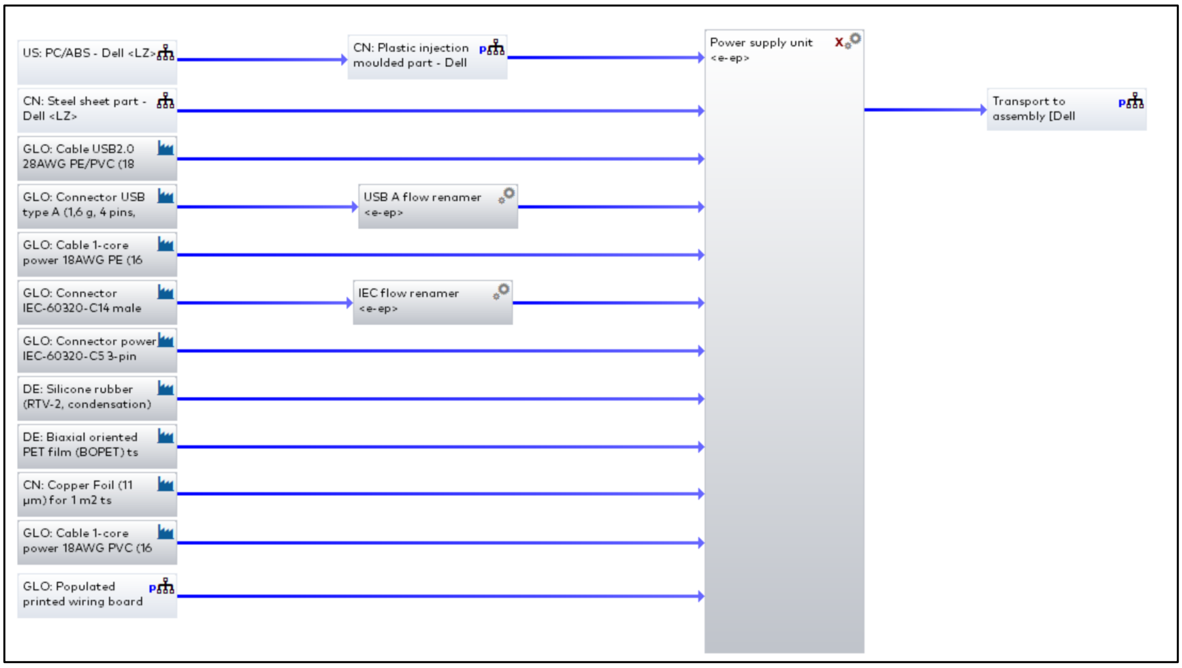

Figure A.5-11 Top-level PSU model for the Dell Latitude 7300 25th AE

Annex B: Result diagrams

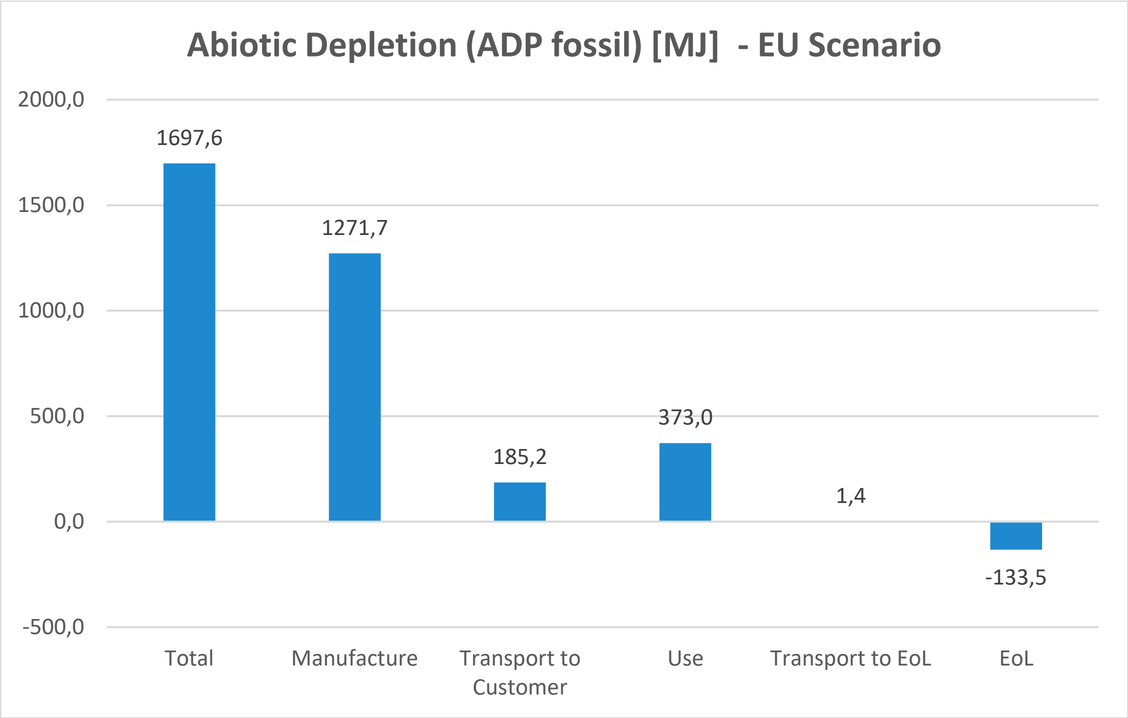

Figure B.5-12: Abiotic Depletion EU Scenario

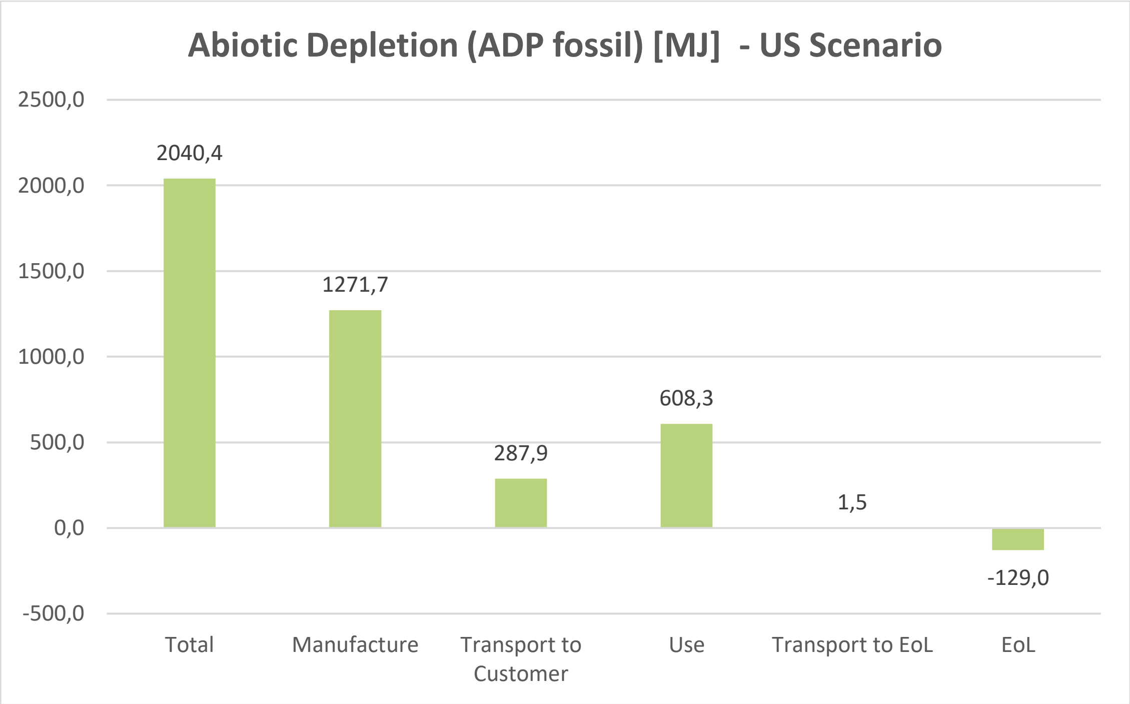

Figure B.5-13: Abiotic Depletion US Scenario

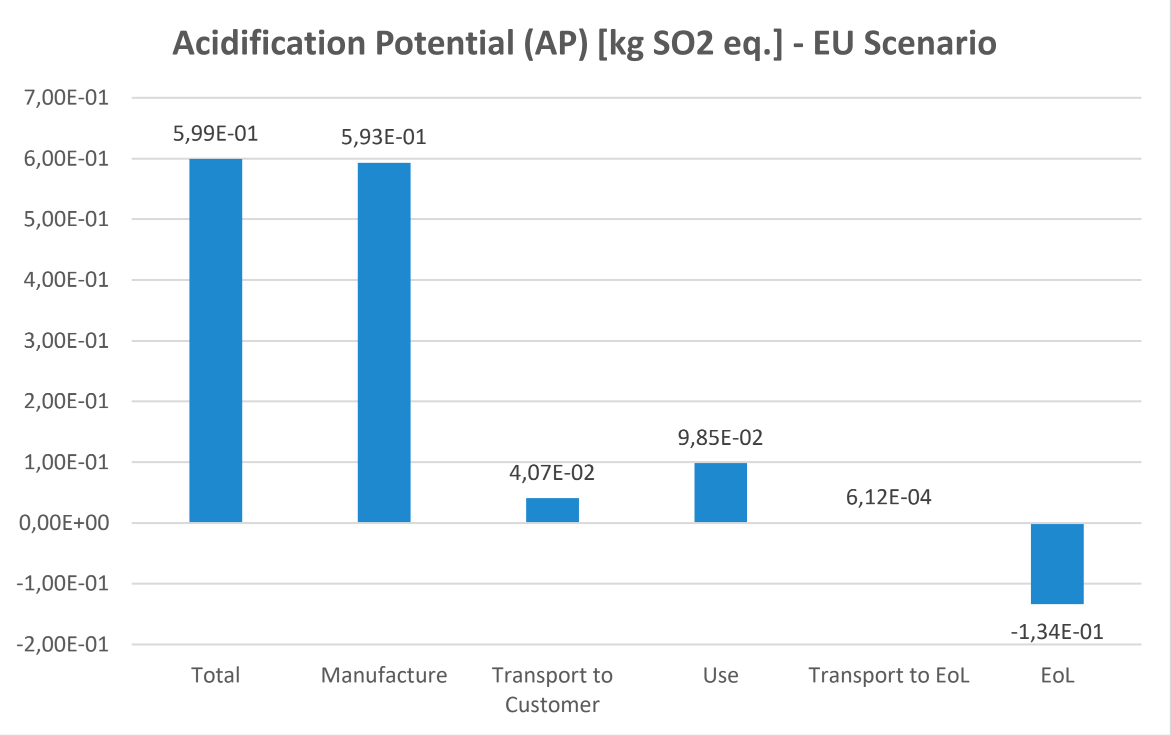

Figure B.5-14: Acidification Potential EU Scenario

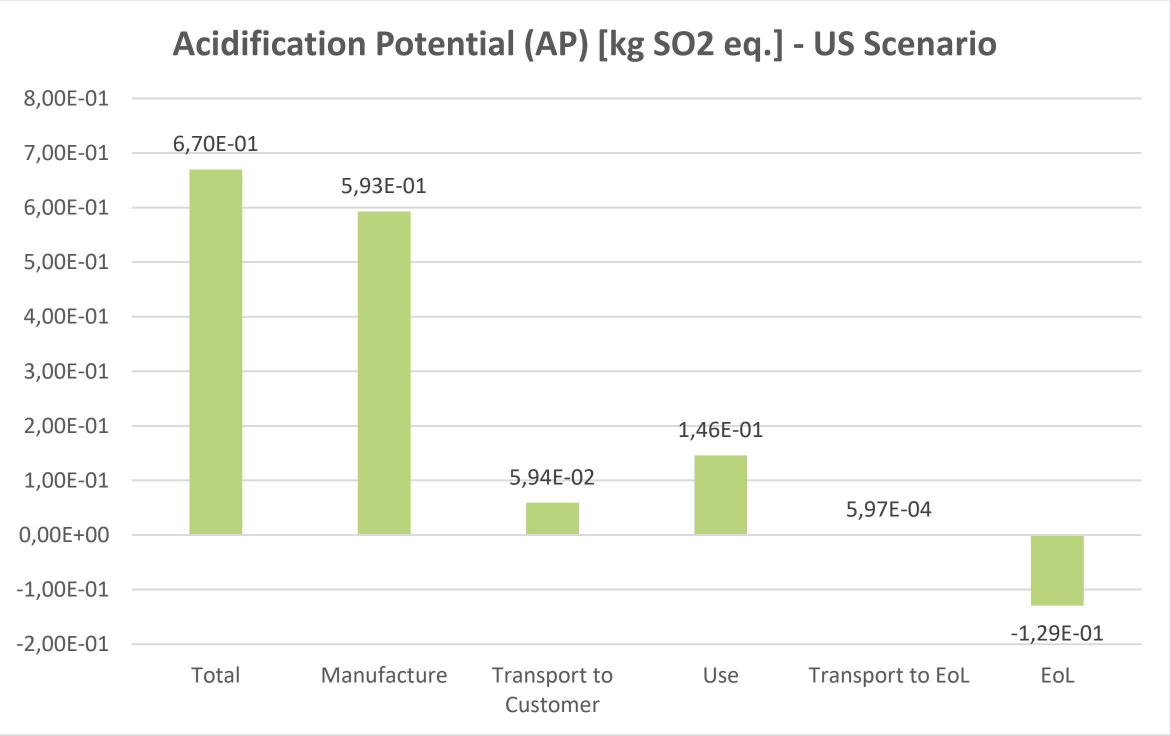

Figure B.5-15: Acidification Potential US Scenario

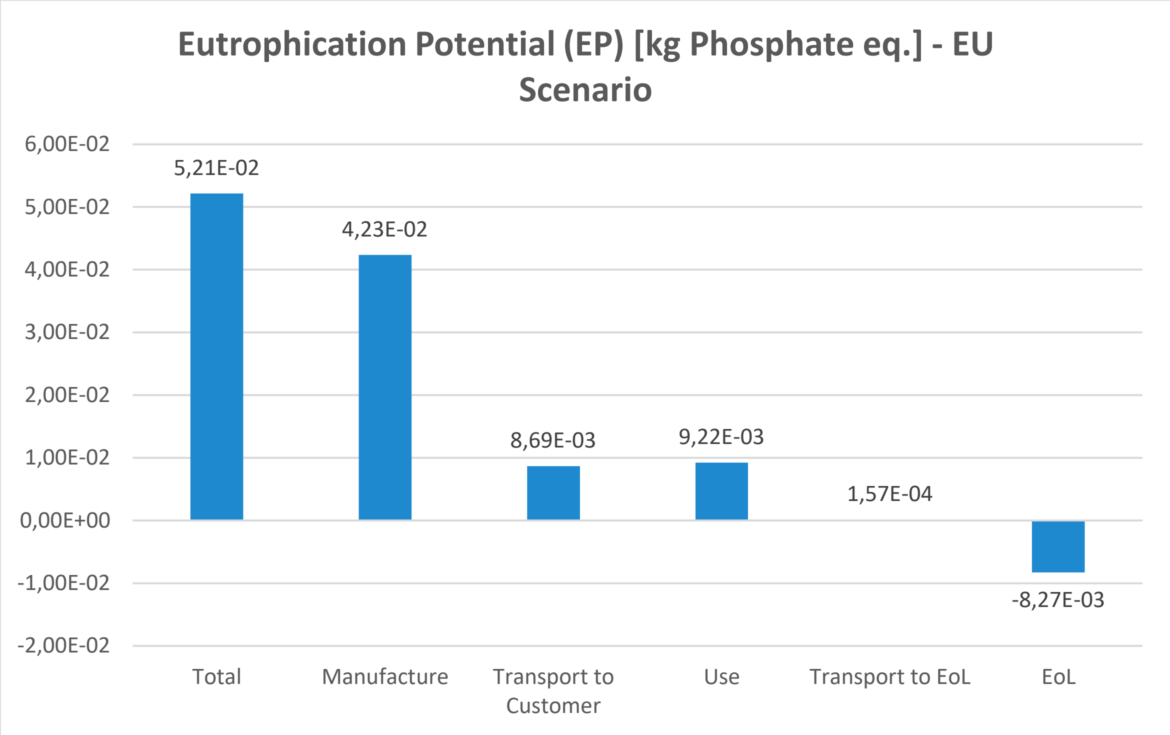

Figure B.5-16: Eutrophication Potential EU Scenario

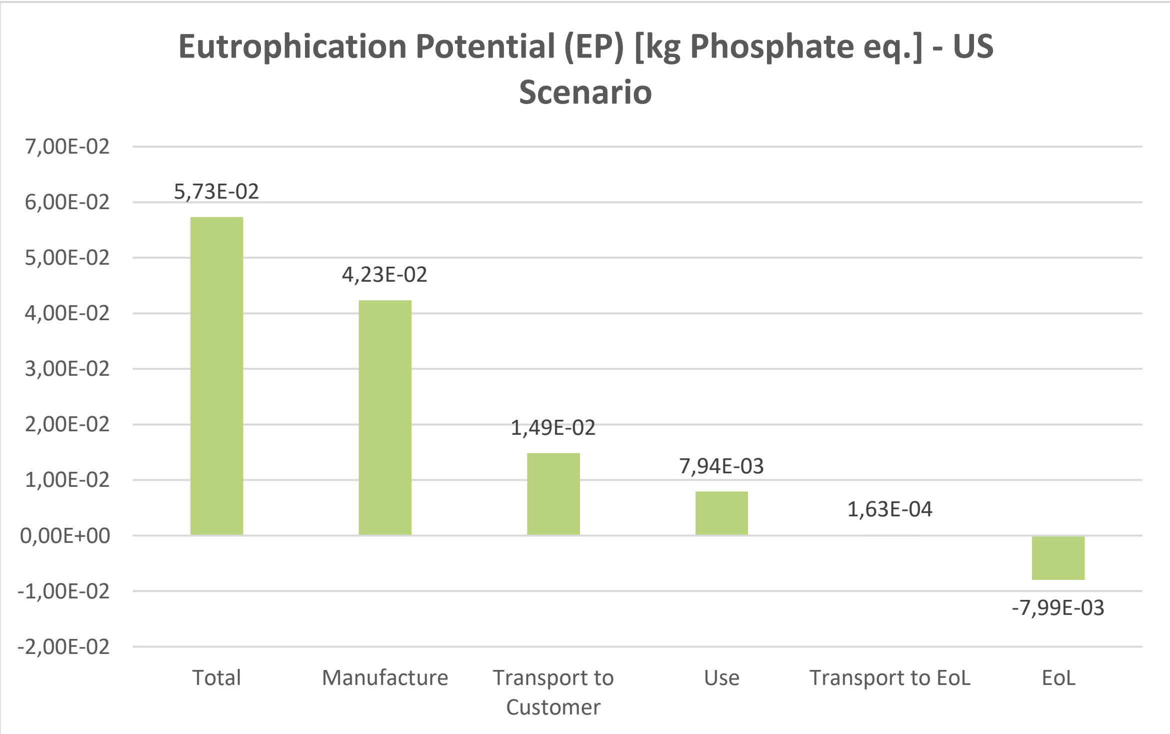

Figure B.5-17: Eutrophication Potential US Scenario

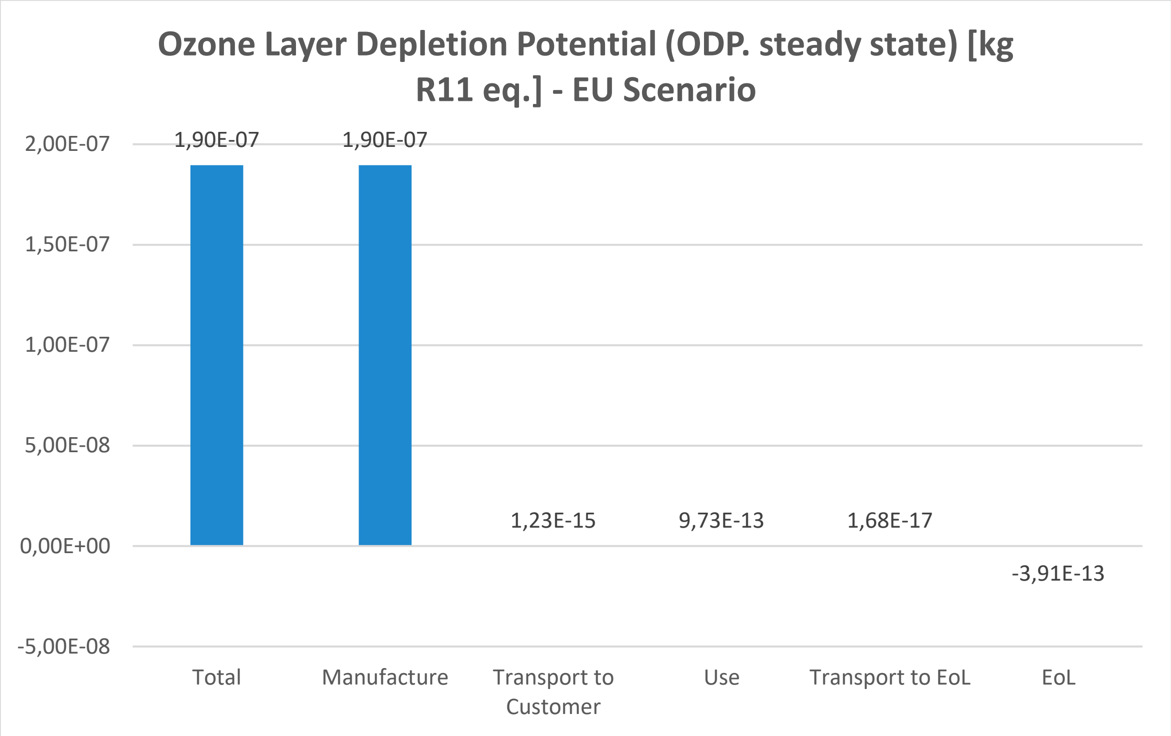

Figure B.5-18: Ozone Layer Depletion Potential EU Scenario

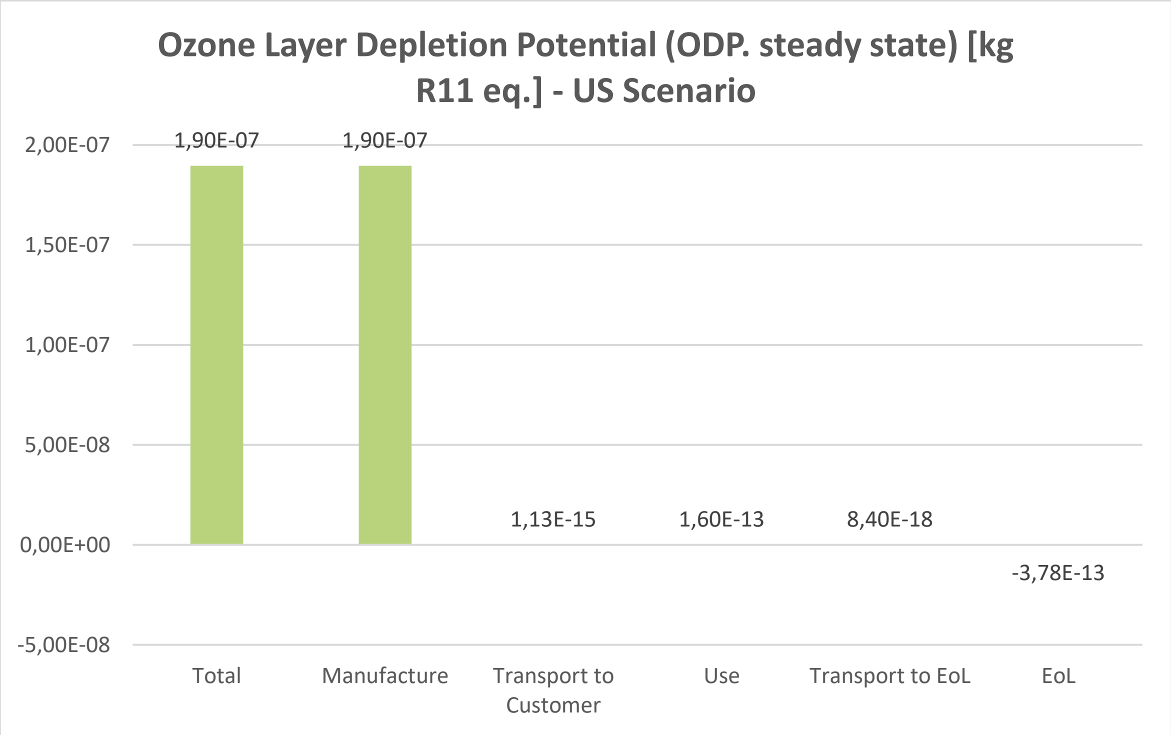

Figure B.5-19: Ozone Layer Depletion Potential US Scenario

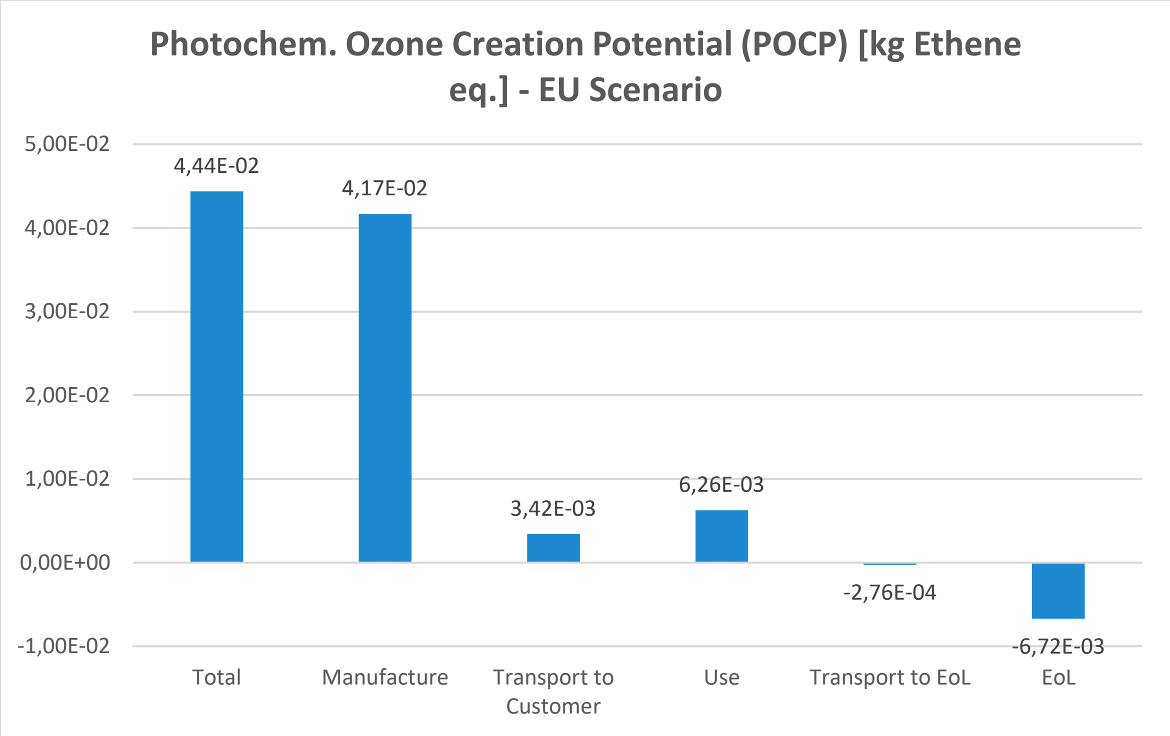

Figure B.5-20: Photochemical Ozone Creation Potential EU Scenario

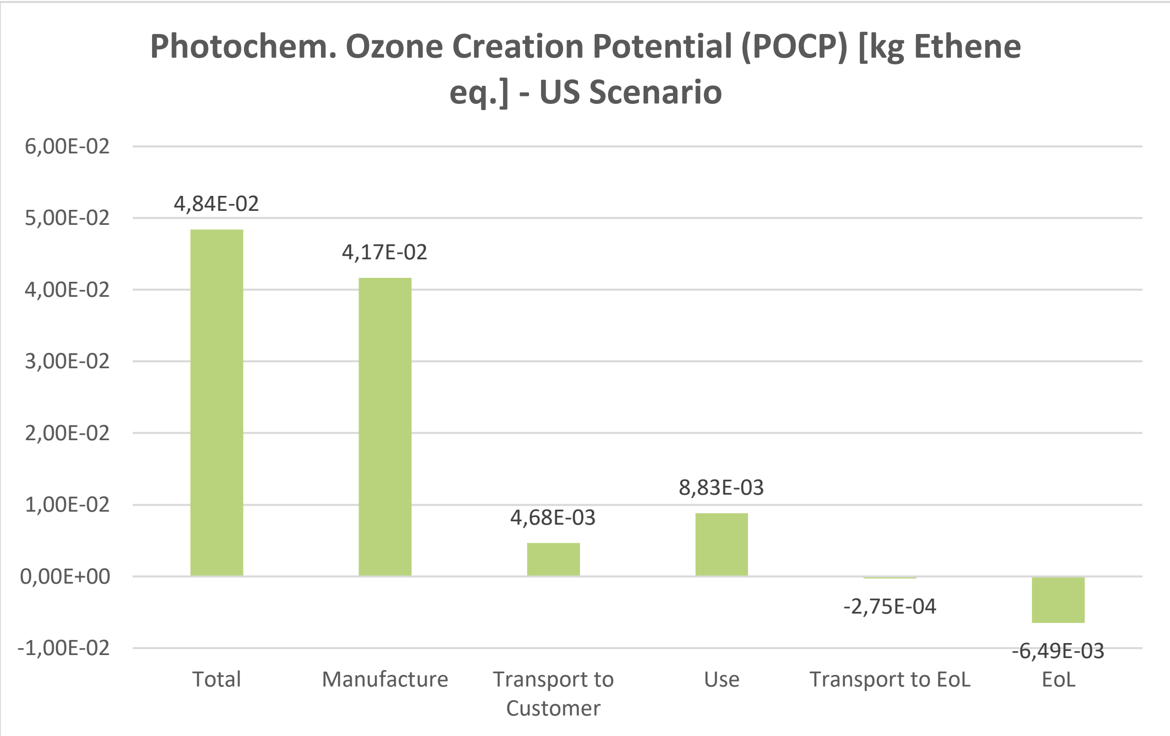

Figure B.5-21: Photochemical Ozone Creation Potential US Scenario

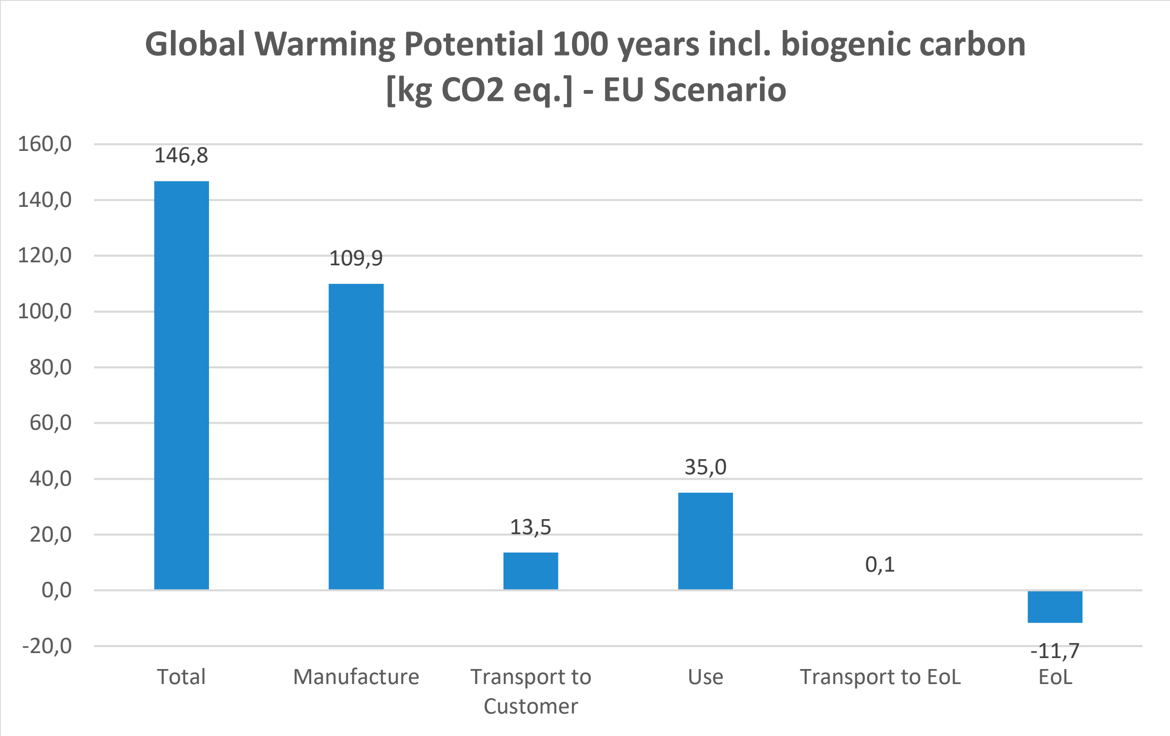

Figure B.5-22: Global Warming Potential EU Scenario

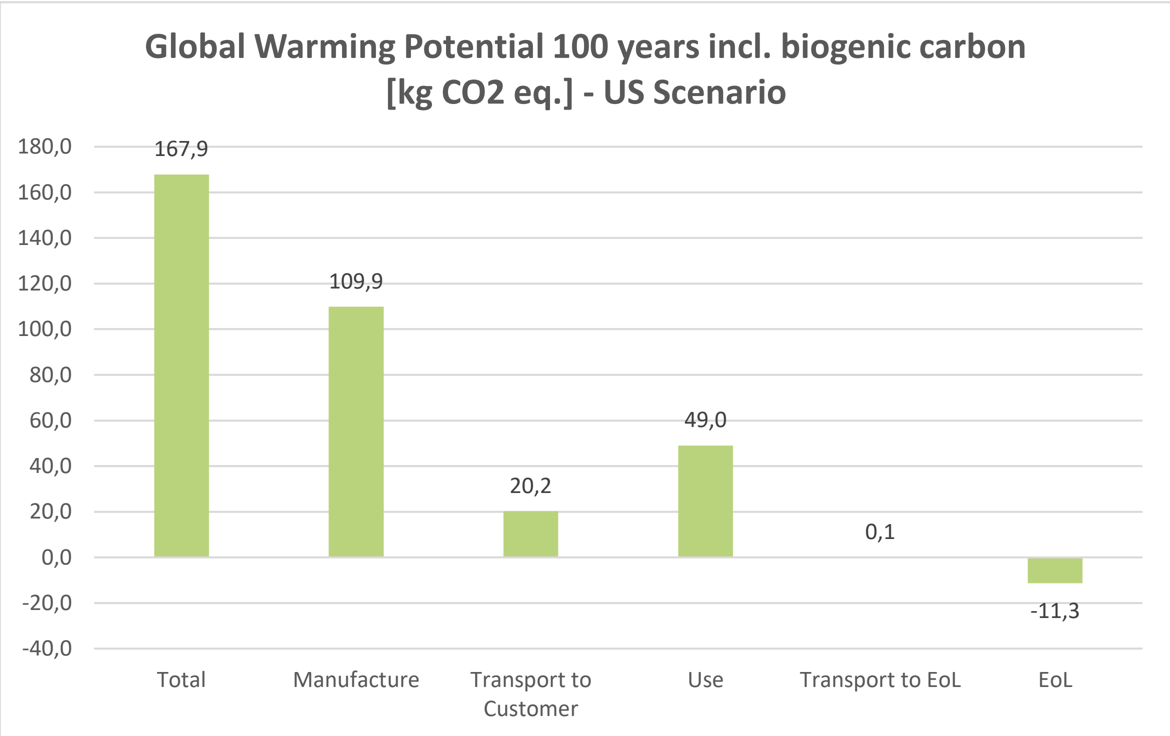

Figure B.5-23: Global Warming Potential US Scenario

Annex C: Background data

Table C.5-1: thinkstep GaBi background data used

Material	Geographic Reference	Dataset	Data provider	Reference Year
Transport				
	GLO	Truck, Euro 3, more than 32t gross weight / 24,7t payload capacity	ts	2017
	GLO	Cargo plane, 113 t payload	ts	2018
Energy				
	US	Diesel mix at filling station	ts	2014
	EU-28	Diesel mix at refinery	ts	2016
	US	Diesel mix at refinery	ts	2016
	CN	Electricity grid mix	ts	2016
	EU-28	Electricity grid mix	ts	2016
	US	Electricity grid mix	ts	2016
	MX	Electricity grid mix	ts	2016
	MY	Electricity grid mix	ts	2016
	SG	Electricity grid mix	ts	2016
	TW	Electricity grid mix	ts	2016
	EU-28	Kerosene / Jet A1 at refinery	ts	2016
	US	Kerosene / Jet A1 at refinery	ts	2016
	US	Thermal energy from diesel	ts	2016
	EU-28	Thermal energy from natural gas	ts	2016
	US	Thermal energy from natural gas	ts	2016
	CN	Thermal energy from natural gas	ts	2016
Mechanical				
	US	Acrylonitrile-Butadiene-Styrene Granulate (ABS)	ts	2018
	CN	Aluminium sheet	ts	2017
	DE	BF Steel billet / slab / bloom	ts	2018
	CN	BF Steel billet / slab/ bloom	ts	2018
	DE	Biaxial oriented PET film (BOPET)	ts	2017

	CN	Copper sheet	ts	2017
	CN	Corrugated board (paper and energy input open)	ts	2017
	DE	EAF Steel billet / Slab / Bloom	ts	2017
	EU-28	Ethylene propylene diene elastomer extrusion profile (EPDM)	ts	2017
	DE	Fan HDD (120X25mm, PWM)	ts	2017
	US	Polyamide 6 Granulate (PA 6)	ts	2018
	US	Polycarbonate Granulate (PC)	ts	2018
	DE	Silicone rubber (RTV-2, condensation)	ts	2018
	EU-28	Stainless steel screw	ts	2017
Electronic				
	GLO	Assembly line SMD (1SP, 2CS, 1CP, 1R, 1Rf) throughput 300/h	ts	2018
	GLO	Assembly line THT/SMD (1TP,1SP,1CS,1WO,1Rf) throughput 300/h	ts	2018
	GLO	Cable 10-core data ribbon 28AWG PE (25 g/m) 12.7x0.9	ts	2018
	GLO	Cable 1-core signal 24AWG mPPE (3.0 g/m) D1.1	ts	2018
	GLO	Capacitor Al-capacitor axial THT (21g) D21x40	ts	2018
	GLO	Capacitor Al-capacitor axial THT (300mg) D3.3x11	ts	2018
	GLO	Capacitor Al-capacitor radial THT (110mg) D3x5	ts	2018
	GLO	Capacitor Al-capacitor radial THT (15.41g) D18x41	ts	2018
	GLO	Capacitor Al-capacitor SMD (1.29g) D10x10.2	ts	2018
	GLO	Capacitor Al-capacitor SMD (2.54g) D12.5x13.5	ts	2018
	GLO	Capacitor Al-capacitor SMD (300mg) D6.3x5.4	ts	2018
	GLO	Capacitor Al-capacitor SMD (5.01g) D16x16.5	ts	2018
	GLO	Capacitor Al-capacitor SMD (7.89g) D18x21.5	ts	2018

	GLO	Capacitor Aluminium screw terminal (220g) D 51.6 x 75 mm	ts	2018
	GLO	Capacitor Aluminium screw terminal (400g) D 64.3 x 96 mm	ts	2018
	GLO	Capacitor ceramic MLCC 01005 (0.054mg) D 0.4x0.2x0.22	ts	2018
	GLO	Capacitor ceramic MLCC 0201 (0.17mg) D 0.6x0.3x0.3	ts	2018
	GLO	Capacitor ceramic MLCC 0603 (6mg) D 1.6x0.8x0.8 (Base Metals)	ts	2018
	GLO	Capacitor ceramic MLCC 0603 (6mg) D 1.6x0.8x0.8	ts	2018
	GLO	Capacitor ceramic MLCC 1210 (50mg) D 3.2x1.6x1.6 (Base Metals)	ts	2018
	GLO	Capacitor ceramic MLCC 1210 (50mg) D 3.2x3.2x1.6	ts	2018
	GLO	Capacitor ceramic MLCC 2220 (450mg) D 5.7x5.0x2.5 (Base Metals)	ts	2018
	GLO	Capacitor ceramic MLCC 2220 (450mg) D 5.7x5.0x2.5	ts	2018
	GLO	Capacitor film-capacitor boxed RM15 (3.2g) 17.7x10x16.5	ts	2018
	GLO	Capacitor film-capacitor boxed RM27.5 (20.4g) 31x21x31	ts	2018
	GLO	Capacitor film-capacitor boxed RM5 (600mg) 7.2x6x11	ts	2018
	GLO	Capacitor film-capacitor unboxed RM15 (2.6g) 15x7x12	ts	2018
	GLO	Capacitor film-capacitor unboxed RM27.5 (11g) 27.5x11x17.5	ts	2018
	GLO	Capacitor film-capacitor unboxed RM7.5 (150mg) 7.5x1.5x6.0	ts	2018
	GLO	Capacitor tantal SMD E (500mg) 7.3x4.3x4.1	ts	2018
	GLO	Capacitor tantal SMD Y (25mg) 3.2x1.6x1.6	ts	2018
	GLO	Coil quad-chokes (2.5g) 14.5x13.3x8.0	ts	2018
	GLO	Copper mix (99,999% from electrolysis)	ts	2018
	GLO	Gold, primary (in Electronics)	ts	2018
	GLO	Housing IC	ts	2018

	GLO	IC BGA 48 (72mg) 8x6 mm MPU generic (14 nm node)	ts	2018
	GLO	IC PLCC 20 (751mg) 9x9 mm CMOS logic (250 nm node)	ts	2018
	GLO	IC PLCC 68 (5g) 24.2x24.2 mm CMOS logic (250 nm node)	ts	2018
	GLO	IC QFP 240 (6.20g) 32x32x3.5 [based on models 2004-2014]	ts	2018
	GLO	IC SO 20 (530mg) 12.8x7.5 mm CMOS logic (90nm node)	ts	2018
	GLO	IC SO 44 (910mg) 28.3x13.3x2.3 [based on models 2004-2014]	ts	2018
	GLO	IC SO 8 (76mg) 4.9x3.9 mm CMOS logic (90 nm node)	ts	2018
	GLO	IC SSOP 14 (120mg) 6.0x5.3x1.75 [based on models 2004-2014]	ts	2018
	GLO	IC SSOP 64 (340mg) 26x10.2x1.75 [based on models 2004-2014]	ts	2018
	GLO	ICOP 32 (373mg) 8x20 nm DRAM (57 nm node)	ts	2018
	GLO	LED SMD high-efficiency with lens max 0.5A (235mg) Au bondwire 9.0x7.0x4.4	ts	2018
	GLO	LED SMD high-efficiency with lens max 0.5A (59mg) Flip Chip 3.5x3.5x2.0	ts	2018
	GLO	LED SMD high-efficiency with lens max 1.5A (61mg) Flip Chip 3.5x3.5x2.0	ts	2018
	GLO	Liquid Crystal Display (LCD), Panel Assembly LED TFT, mixed TN-IPS technology <LC>	ts	2018
	DE	Populated printed wiring board (after RoHS) in waste incineration plant <p-agg>	ts	2018
	GLO	Printed Wiring Board 16-layer rigid FR4 with HASL finish (Subtractive method)	ts	2018
	GLO	Resistor MELF MMB 0207 (79mg) D2.2x5.8	ts	2018
	GLO	Resistor thick film flat chip 0201 (0.15mg)	ts	2018
	GLO	Ring Core Coil 8 g (Without housing)	ts	2018
	GLO	Semiconductor manufacturing WLP CSP CMOS logic with on-chip flash memory 130 nm tech node	ts	2018

	GLO	Semiconductor manufacturing WLP CSP DRAM 57 nm tech node	ts	2018
	GLO	Semiconductor manufacturing WLP CSP flash memory 45 nm tech node	ts	2018
	GLO	Solder paste SnAg3.5	ts	2018
	GLO	Solder paste SnAg3Cu0.5 (SAC-Lot)	ts	2018
	GLO	Substrate for active components (2-layer rigid FR4 chem-elec AuNi finish, mass)	ts	2018
	GLO	Transistor THT TO92 (250mg) D4.8x5.3	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 130 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 180 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 22 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 32 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 350 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 45 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 65 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic 90 nm tech node	ts	2018
	GLO	Semiconductor manufacturing CMOS logic with on-chip flash memory 130 nm tech node	ts	2018
	GLO	Semiconductor manufacturing DRAM 180 nm tech node	ts	2018
	GLO	Semiconductor manufacturing DRAM 57 nm tech node	ts	2018
	GLO	Semiconductor manufacturing flash memory 150 nm tech node	ts	2018
	GLO	Semiconductor manufacturing flash memory 45 nm tech node	ts	2018
	GLO	Semiconductor manufacturing flash memory 65 nm tech node	ts	2018
	GLO	Semiconductor manufacturing flash memory 90 nm tech node	ts	2018

	GLO	Semiconductor manufacturing for transistors, diodes & LEDs	ts	2018
Other				
	US	Tap water from groundwater	ts	2017
	CN	Water (desalinated; deionised)	ts	2017
Waste				
	DE	Recycling potential copper sheet ts	ts	2017
	GLO	Recycling of palladium from electronic scrap with credit	ts	2017
	GLO	Recycling of platinum from electronic scrap with credit	ts	2017
	EU-28	Recycling of gold from electronic scrap	ts	2017
	EU-28	Inert matter (Unspecific construction waste) on landfill	ts	2018
	EU-28	Plastic packaging in municipal waste incineration plant	ts	2018
	DE	Waste incineration (plastics)	ts	2018
	EU-28	Ferro metals on landfill	ts	2018
	EU-28	Glass/inert waste on landfill	ts	2018
	EU-28	Plastic waste on landfill	ts	2018
	GLO	Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)	ts	2018

Annex D: Critical Review Statement

Critical Review Statement

Life Cycle Assessment of Dell Latitude 7300 25th Anniversary Edition

Commissioned by: Dell Computers

Conducted by: thinkstep AG

Reviewed by: Dr. Colin Fitzpatrick, University of Limerick, Ireland

Reference: ISO 14040 (2006): Environmental Management – Life Cycle Assessment- Principles and Framework

ISO 14044 (2006): Environmental Management – Life Cycle Assessment – Requirements and Guidelines

ISO/TS 14071 (2014): Environmental Management – Life Cycle Assessment- Critical Review Processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Scope of the critical review

The reviewer had the task to assess whether

- The methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044
- The methods used to carry out the LCA are scientifically and technically valid
- The data used are appropriate and reasonable in relation to the goal of the study
- The interpretations reflect the limitations identified and the goal of the study
- The study report is transparent and consistent

The critical review was performed concurrently to the study as it is intended to be disclosed to the public and may be used to support comparisons with equivalent products.

The analysis and verification of individual datasets is outside the scope of this review.

The review process

The review process was co-ordinated by Dell between Thinkstep and the critical reviewer. It began once the goal and scope definition had been finalised and commenced on June 11th 2019 with a clarification of how the models would be constructed. This study was conducted immediately following a similar LCA on a Dell Server product which meant that the reviewer and those conducting the study had been discussing many of the approaches for the laptop even before the formal commencement and many of the comments and recommendations from the server study were already adopted in the first draft. A draft final report was provided for comment on July 5th. A spreadsheet was used to log all comments including their exact location in the report, the comment and proposed change from the critical reviewer, and the action/answer to that comments when it was addressed. This ensured a systematic method of ensuring that comments were tracked. A video call was subsequently arranged for July 9th 2019 to allow the critical reviewer to make direct queries about the GaBi models utilised. The final report was provided on July 10th 2019.

General Evaluation

This evaluation is based on the final report received on July 10th 2019. The goal and scope of the assessment are defined unambiguously. The functional unit is clearly defined and measurable. The system boundary appropriately includes all major life cycle stages from manufacture through to end of life and the chosen system configuration is representative of laptops being placed on the market. The team went to great lengths to itemise every single component included in the system for inclusion in the models. Any major assumptions which had a significant bearing on the results, especially the die to package ratio is well justified. It is also appropriate to include scenarios for both North America and Europe which considers the distances for shipping and energy mix in the use phase. The allocation procedures employed for recycling were appropriate. The life cycle impact assessment is performed to a high standard and includes all mandatory elements. The life cycle interpretation is comprehensive. One interesting finding is the very high burden during the manufacturing stage due to the Solid Stage Drives and the sensitivity of the results to the die to package ratio. The report correctly identifies this as an area that warrants further investigation. This finding also highlights the potential significance of data-wiping and reuse at end of life for the SSDs in these products and further work should be done to advance this area. The evaluation is comprehensive and includes considerate completeness, sensitivity and consistency checks. The report is prepared to a high standard.

The team was at all times very open and receptive to my comments and all were addressed to my full satisfaction. They were also very open in demonstrating all aspects of the models employed as part of the calculations.

Conclusion

The study has been carried out in conformity with ISO 14040 and ISO 14044. The critical reviewer found the overall quality and rigour of the methodology and its execution to be very adequate for the purposes of this study. The study is reported in a comprehensive manner and is transparent in its scope and methodologically choice.

Colin Fitzpatrick

11th July 2019