On behalf of Dell

LCA of Dell Servers

R6515, R7515, R6525, R7525

Client:	Dell
Title:	Life Cycle Assessment Dell Servers R6515, R7515, R6525, R7525
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On behalf of Sphera Solutions, Inc., and its subsidiaries

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List of Acronyms

ADP	Abiotic Depletion Potential
ANSI	American National Standards Institute
AP	Acidification Potential
BGA	Ball Grid Array
BOM	Bill of Materials
CML	Centre of Environmental Science at Leiden
CPU	Central Processing Unit
DIMM	Dual Inline Memory Module
EoL	End of Life
EIPT	Enterprise Infrastructure Planning Tool
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
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MB	Mainboard / Motherboard
ODP	Ozone Depletion Potential
PCF	Product Carbon Footprint
PCI	Peripheral Component Interconnect
PERC	PowerEdge RAID Controller

POCP	Photochemical Ozone Creation Potential
PSU	Power Supply Unit
PWB	Printed Wiring Board
RAID	Redundant Array of Independent Disks
RAM	Random Access Memory
SERT	Server Efficiency Rating Tool
SPEC	Standard Performance Evaluation Corporation
SSD	Solid-State Drive
TEC	Typical Energy Consumption
VOC	Volatile Organic Compound

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 Sphera to carry out an LCA on the Dell R6515, R7515, R6525, R7525 Servers. Goals for this ISO 14040/14044 compliant study include:

- Life Cycle Assessment (LCA) of the Dell R6515, R7515, R6525, R7525 Servers across their full life cycle;
- Determine environmental hotspots over the product's life cycle with specific focus on material/part/product manufacturing use and EoL;
- 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 computing services capable of handling very demanding workloads and applications, such as data warehouses, ecommerce, AI/Machine Learning, and high-performance computing (HPC) for four years with the following load profile for light-medium and heavy workload respectively:

- 100% load mode: 10% and 15% of the time
- 50% load mode: 35% and 55% of the time
- 10% load mode: 30% and 20% of the time
- Idle mode: 25% and 10% of the time

The reference flow for each system is one (1) Dell Server, including its internal power supply and packaging.

The servers were evaluated considering their typical market configurations and weight, summarized in the table below:

Component	R6515	R7515	R6525	R7525
Chassis	1U Rack Chassis with up to 4 x 3,5" Hard Drives for 1CPU configuration incl. rails and bezel	2U Rack Chassis with up to 8x3,5" Drives for 1 CPU Configuration incl. rails and bezel	1U Rack Chassis with up to 4x3,5" Drives for 2 CPU Configuration incl. rails and bezel	2U Rack Chassis with up to 8x3,5" Drives for 2CPU Configuration incl. rails and bezel
Mainboard	12 layers, OSP finishing	12 layers, OSP finishing	14 Layers	14 Layers
Processor(s)	1x AMD EPYC 7452	1x AMD EPYC 7452	2x AMD EPYC 7452	2x AMD EPYC 7452
Processor Thermal configuration	1x Standard Heatsink for CPU	1x Standard Heatsink for CPU	2x Standard Heatsink for CPU	2x Standard Heatsink for CPU
DIMMs	8x Micron 16GB	8x Micron 16GB	16x Micron 16GB	16x Micron 16GB

Raid/ Internal Storage Controller	Yes	Yes	Yes	Yes
Hard Drives	2x 4TB SATA	2x 4TB SATA	2x 4TB SATA	2x 4TB SATA
PCIe Riser Card	1x16 LP PCIe	No	1x16 LP, 2x16 LP	Half Length, 4x8
Network Daughter Card	Dual Port	Dual Port	Quad Port	Quad Port
Fans	6x Standard Fans	6x Standard Fans	6x Standard Fans	6x Standard Fans
Power Supply	2 PSUs	2 PSUs	2 PSUs	2 PSUs
Additional Network Cards:	Dual Port	Dual Port	No	No
Packaging	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam

The data collection relied in the combination of new information on the content of the products, dimensioned photographs of new components and data from the previous Dell Server study (R740) where applicable – see in Annex C: , the Summary of the study and in **Error! Reference source not found.**the Critical Review document; for further information, please refer to (thinkstep, 2019).

The intended time reference for the study is the 2021 calendar year and the geographical coverage considers both an EU and US in two scenarios.

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

Overall results for the Dell R6515

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	39100	53600
Acidification Potential [kg SO2 eq.]	9,91	9,81
Eutrophication Potential [kg Phosphate eq.]	0,913	0,877
Ozone Layer Depletion Potential [kg R11 eq.]	3,45E-08	3,44E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,687	0,684
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	3450	4280

Overall results for the Dell R7515

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	44200	61900
Acidification Potential [kg SO2 eq.]	10,9	10,7
Eutrophication Potential [kg Phosphate eq.]	1,02	0,975
Ozone Layer Depletion Potential [kg R11 eq.]	3,31E-08	3,30E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,754	0,75
Global Warming Potential 100 years excl.biogenic carbon [kg CO2 eq.]	3920	4930

Overall results for the Dell R6525

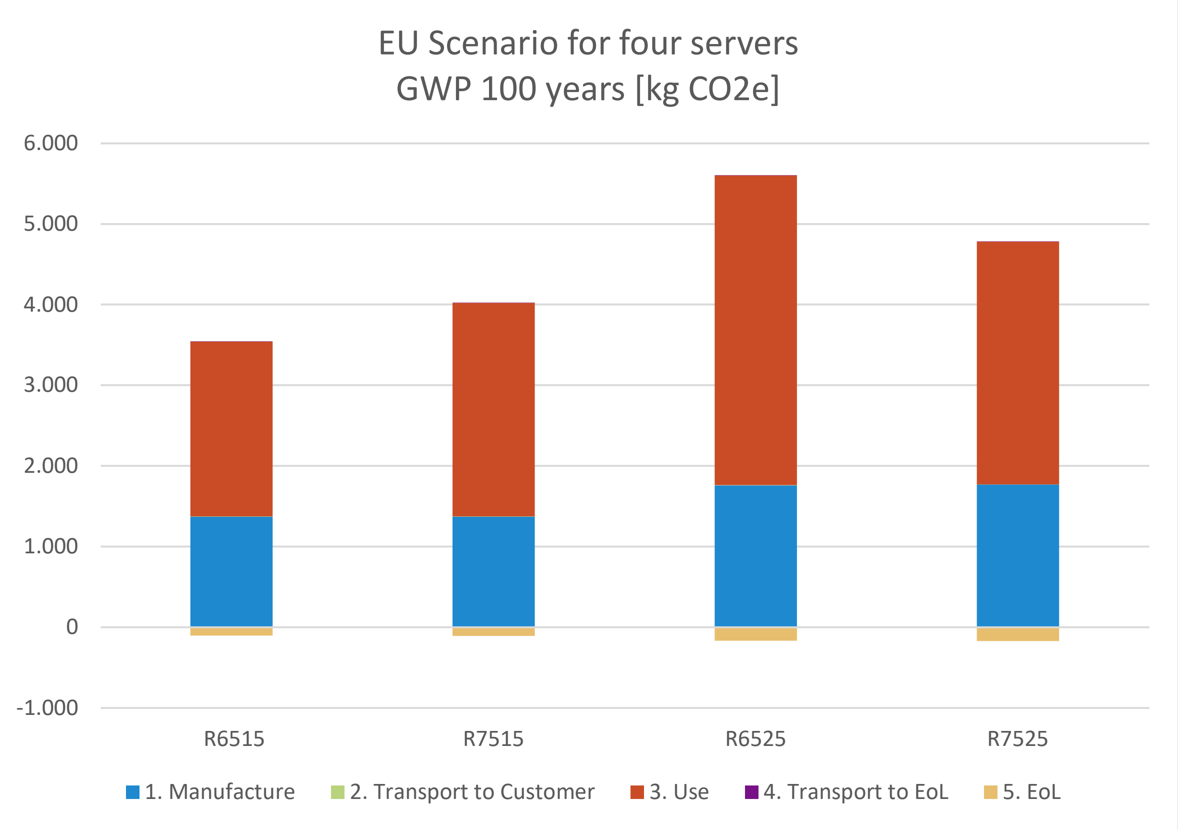
Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	61400	86900

Acidification Potential [kg SO2 eq.]	14,9	14,7
Eutrophication Potential [kg Phosphate eq.]	1,4	1,34
Ozone Layer Depletion Potential [kg R11 eq.]	2,06E-08	2,06E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	1,04	1,03
Global Warming Potential 100 years excl.biogenic carbon [kg CO2 eq.]	5440	6910

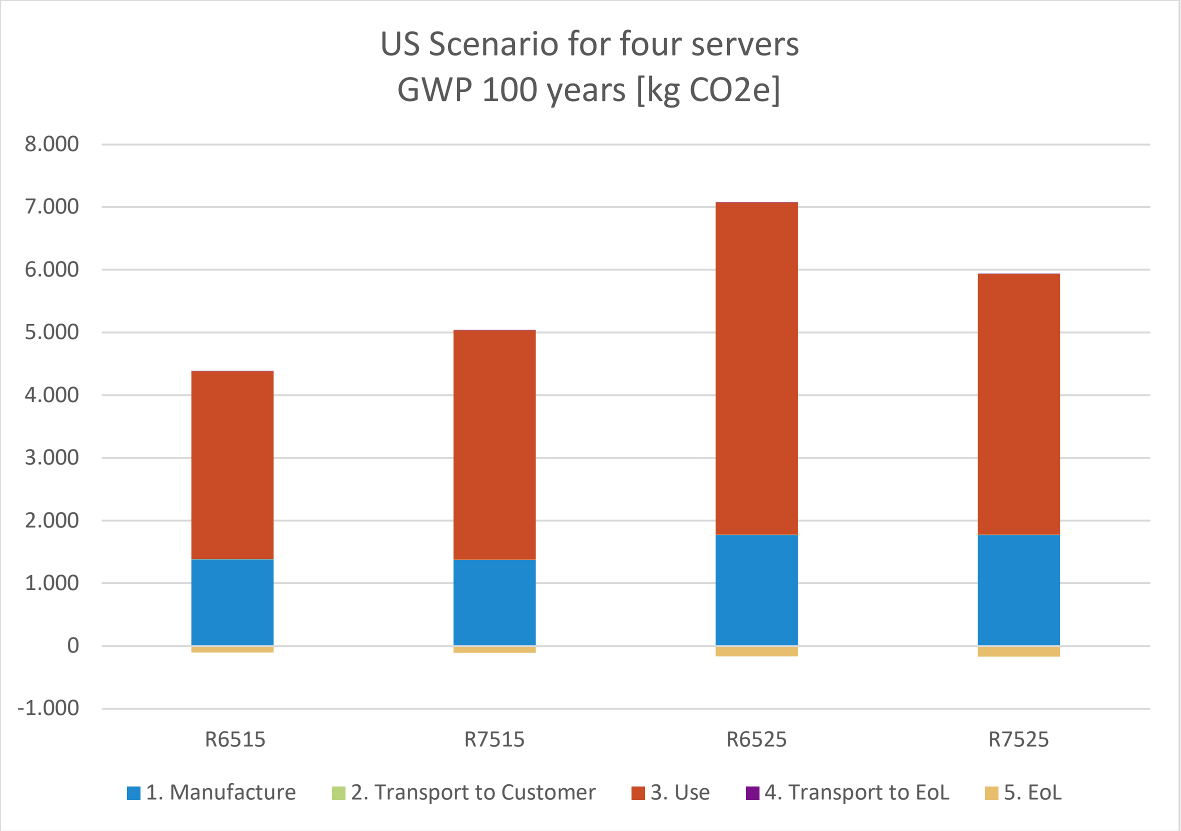
Overall results for the Dell R7525

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	52300	72300
Acidification Potential [kg SO2 eq.]	13,2	13
Eutrophication Potential [kg Phosphate eq.]	1,21	1,16
Ozone Layer Depletion Potential [kg R11 eq.]	2,00E-08	1,99E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,913	0,908
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	4620	5770

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.



Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell servers in the EU



Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell servers in the US

Analysis results indicate that the major fraction of the impact – in all servers, for both EU and US scenarios – derives from the manufacturing and the use phase of the Dell Servers. The transport to end of life has a minimal contribution in both cases and the end of life credits contribute to a reduction of circa 3% of the life cycle impacts for all the servers. Overall, the US scenario has approximately 20% to 21% higher impact than the European one, due to the differences in the electricity grid mix and fuel used, as well as distances travelled.

Most of the part production impacts during manufacturing are from the components containing electronics, which account for only 26% to 31% of the total mass of the products, and especially the SSDs. The biggest contribution of the SSDs comes from the NAND flash, for which several assumptions were made regarding package dimensions, die/package ratio and die stack per package to model these chips. The same assumptions as for R740 (thinkstep, 2019) have been used.

Overall, the results of the present study exemplify that the configuration of the servers can have a high impact on the environmental results within its lifetime. This leads to the recommendation to a) increase the data quality of considered components, by e.g. having access to BOMs and b) focus more on the manufacturing part of products and hence more on the supply chain of those components. Looking at this issue from a (post-)consumer perspective, the reuse (or refurbishment) of used SSDs from servers 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 R6515, R7515, R6525 and R7525 Servers across their full life cycle;
- Determine environmental hotspots over the products' 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 Systems

The Dell Servers R6515, R7515, R6525, R7525 were evaluated considering their typical market configurations and weight, summarized in Table 2-1.

Table 2-1: Typical market configuration of the Dell Servers R6515, R7515, R6525 and R7525#

Component	R6515	R7515	R6525	R7525
Chassis	1U Rack Chassis with up to 4 x 3,5" Hard Drives for 1CPU configuration incl. rails and bezel	2U Rack Chassis with up to 8x3,5" Drives for 1 CPU Configuration incl. rails and bezel	1U Rack Chassis with up to 4x3,5" Drives for 2 CPU Configuration incl. rails and bezel	2U Rack Chassis with up to 8x3,5" Drives for 2CPU Configuration incl. rails and bezel
Mainboard	12 layers, OSP finishing	12 layers, OSP finishing	14 Layers	14 Layers
Processor(s)	1x AMD EPYC 7452	1x AMD EPYC 7452	2x AMD EPYC 7452	2x AMD EPYC 7452
Processor Thermal configuration	1x Standard Heatsink for CPU	1x Standard Heatsink for CPU	2x Standard Heatsink for CPU	2x Standard Heatsink for CPU
DIMMs	8x Micron 16GB	8x Micron 16GB	16x Micron 16GB	16x Micron 16GB
Raid/ Internal Storage Controller	Yes	Yes	Yes	Yes
Hard Drives	2x 4TB SATA	2x 4TB SATA	2x 4TB SATA	2x 4TB SATA
PCIe Riser Card	1x16 LP PCIe	No	1x16 LP, 2x16 LP	Half Length, 4x8
Network Daughter Card	Dual Port	Dual Port	Quad Port	Quad Port
Fans	6x Standard Fans	6x Standard Fans	6x Standard Fans	6x Standard Fans
Power Supply	2 PSUs	2 PSUs	2 PSUs	2 PSUs
Additional Network Cards:	Dual Port	Dual Port	No	No
Packaging	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam	Cardboard boxes and plastic film and foam

2.2. Product Function(s) and Functional Unit

The functional unit for each system (R6515, R7515, R6525 and R7525) is 1 piece of general purpose rack server equipment and its provision of computing services capable of handling very demanding workloads and applications, such as data warehouses, ecommerce, AI/Machine Learning, and high-performance computing (HPC) for four years with the load profile specified in section 3.2.5.

2.3. System Boundaries

The system boundaries are defined in Table 2-2.

Table 2-2: 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	× Network infrastructure outside of the product itself
✓ Transport to customers	× Refurbishment/Reuse of parts
✓ Use stage	
✓ Transport to recycling	
✓ End of life (disposal/recycling)	

2.3.1. Time Coverage

The intended time reference for the study is the 2021 calendar year. Data collected from Dell relate to this year.

2.3.2. Technology Coverage

This study assesses the cradle-to-grave impacts of the products based on a global production and technology mix. The data was collected by using a combination of dimensioned photographs, data from the Life Cycle Assessment of Dell R740 study (thinkstep, 2019), additional data on usage, recycling and transport, as well as data on additional configuration.

2.3.3. Geographical Coverage

The geographical coverage of this study considers the following conditions:

The products are assembled in Lodz, Poland (representative for Dell server production in Europe). 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 assembly in Mexico and use and recycling in the USA has also been considered as part of this report.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3.

Allocation of background data (energy and materials) taken from the GaBi 2021 databases is documented online (Sphera Solutions Inc., 2020).

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

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 (avoided burden 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 this study. As summarized in section 0, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, 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.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

Various impact assessment methodologies are applicable for use in the European context including e.g. Environmental Footprint v3.0 (EF 3.0), CML, ReCiPe, etc. The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-3.

For the present study, the methodologies for calculating the different impact categories were selected considering the EPEAT requirements, which mention that the LCA shall use “either U.S. EPA TRACY 2.1, or CML 2001 (Nov09), or ILCD 2011, or LIME2”. Using the same calculation methods as in the previous studies also provides comparability between results with other Dell products.

This assessment is therefore 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 exclude 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 2-3: 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)
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)
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	kg PO_4^{3-} equivalent	(Guinée, et al., 2002)

	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.		
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)
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)

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 the 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. The goal is to model all relevant foreground processes using measured or calculated primary 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. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

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

2.9. Type and Format of the Report

In accordance with the ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions, and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using the GaBi 10 Software system for life cycle engineering, developed by Sphera Solutions Inc. The GaBi 2021 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Internal Sphera Review

In the previous study (thinkstep, 2019), 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 **Error! Reference source not found.**.

The present study follows the same kind of approach considered in the previous study (thinkstep, 2019), therefore, an internal review by an internal 'independent' expert[1] at Sphera was deemed sufficient by

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[1] *GEC CAB agrees that the use of the term 'independent' in servers criterion 12.5.1 means that the person or team reviewing the LCA must be independent from the preparation of the original LCA report, but does not have to be employed by an independent or external organization to the one that prepared the LCA.*
To make conformance to the verification requirement 12.5.1 (b) clear, the verification statement should clearly indicate how the party is independent and that the verification confirmed the scope of the LCA and that ISO 14044 methodology was followed in preparation of the LCA (the criterion references Section 6.1 of ISO 14044 (Critical review).")
(from the email sent on 6.11.2020 by Beverly Kennedy, Director, Conformity Assurance Services, Green Electronics Council)

Green Electronics Council to validate the quality of the present report, data assumptions and quality of the results.

The Internal Review Statement can be found in Annex A. The Internal Review Report containing the comments and recommendations by the internal expert from Sphera, as well as the practitioner's responses was made available to Dell.

The internal review was performed in accordance to ISO 14044, section 6.2 by Dr Rajesh Kumar Singh, Sr Director, Sustainability Consulting, Sphera.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data for the material content of the products, distribution, product use and EoL were discussed and collected using customised data collection templates, which were sent out by email to Dell. Upon receipt, each questionnaire was cross-checked for completeness and plausibility. The data were discussed though online communication and in regular project meetings.

The data collection relied in the combination of new information on the content of the products, dimensioned photographs of new components and data from the previous Dell Server study (R740) where applicable.

During photograph mapping, new parts and materials were identified using the high-resolution photos provided with a dimension reference, together with component datasheets and supporting information (see as an example Figure 3-1).

If gaps, outliers, or other inconsistencies occurred, Sphera engaged with Dell to resolve any open issues.

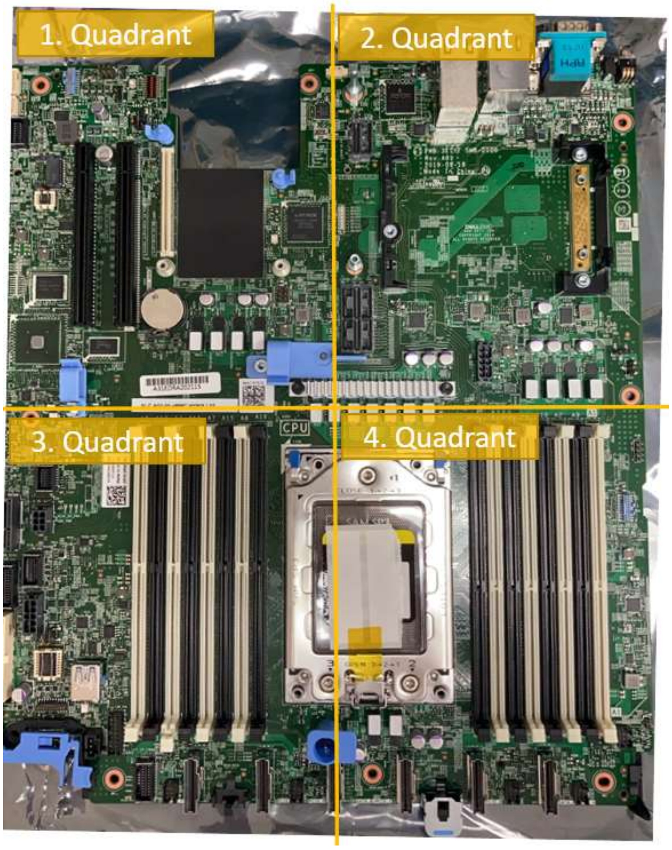


Figure 3-1: Example of component mapping from dimensioned photographs (Motherboard from the servers R6515 and R7515)

3.2. Product Systems

3.2.1. Overview of Product Systems

For each of the considered products, a GaBi model representing its life cycle was prepared following the structure described in Figure 3-2.

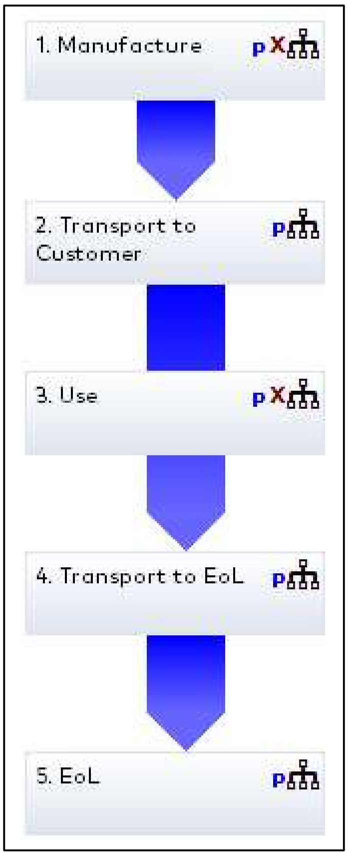


Figure 3-2: GaBi screenshot of the of the life cycle of the Dell Servers

This, as well as the following charts, are valid for all four servers assessed. The composition of the respective systems is explained in the following chapters.

3.2.2. Product Composition

Table 3-1 summarizes the main components of the products considered in this study for the assessed Dell Servers R6515, R7515, R6525, R7525.

Table 3-1: Composition overview of the Dell Servers R6515, R7515, R6525, R7525

Components	R6515 Weight (kg)	R7515 Weight (kg)	R6525 Weight (kg)	R7525 Weight (kg)
Chassis	10,883	11,755	11,142	12,014
Fans, incl. case	1.59	1,59	1,59	1,59
Packaging	7,105	7,105	7,105	7,105
Mainboard, incl. CPU	1,611	1,611	3,060	3,060
PSU	2,992	2,992	2,992	2,992
SSD	0,267	0,267	0,267	0,267
Ethernet card	0,075	0,075	0,075	0,075

Memory bars	0,184	0,184	0,367	0,367
PCI Riser Cards	0,084	Not applicable	0,167	0,072
Raid Card	0,146	0,146	0,15	0,15
TOTAL WEIGHT	24,936	25,725	26,916	27,692

Table 3-2, Table 3-3, Table 3-4 and Table 3-5 describe the main composition of the assessed Dell Servers R6515, R7515, R6525, R7525, including number of units existing in each server, the corresponding mass, the contribution for the total mass and the quality of the data collected. The weight of electronic board and additional data on them is estimated via pictures and data provided by Dell.

Table 3-2: Material composition of the Dell Server 6515

Components	Units	Mass (kg)	Mass (%)	DQI*
Chassis	1	10,883	43,64	Data provided by Dell
Fans, incl. case	6	1,59	6,38	Measured**
Packaging	1	7,105	28,49	Measured**
Mainboard, incl. CPU	1	1,611	6,46	Measured
PSU	1	2,992	12,00	Measured**
SSD	2	0,267	1,07	Data provided by Dell**
Ethernet card	2	0,075	0,30	Data provided by Dell
Memory bars	8	0,184	0,74	Measured**
PCI Riser Cards	1	0,084	0,34	Data provided by Dell
Raid Card	1	0,146	0,59	Data provided by Dell
TOTAL WEIGHT		24,936		Calculated

* measured / calculated / estimated / literature
** Assumed to be identical as in R740

Table 3-3: Material composition of the Dell Server 7515

Components	Units	Mass (kg)	Mass (%)	DQI*
Chassis	1	11,755	45,7	Data provided by Dell
Fans, incl. case	6	1,59	6,18	Measured**
Packaging	1	7,105	27,62	Measured**
Mainboard, incl. CPU	1	1,611	6,26	Measured
PSU	1	2,992	11,63	Measured**
SSD	2	0,267	1,04	Data provided by Dell**
Ethernet card	2	0,075	0,29	Data provided by Dell
Memory bars	8	0,184	0,71	Measured**
PCI Riser Cards	0	0	0	Data provided by Dell
Raid Card	1	0,146	0,57	Data provided by Dell
TOTAL WEIGHT		25,725		Calculated

* measured / calculated / estimated / literature
** Assumed to be identical as in R740

Table 3-4: Material composition of the Dell Server 6525

Components	Units	Mass (kg)	Mass (%)	DQI*
Chassis	1	11,142	41,4	Data provided by Dell
Fans, incl. case	6	1,59	5,91	Measured**

Packaging	1	7,105	26,4	Measured**
Mainboard, incl. CPU	1	3,06	11,37	Measured
PSU	2	2,992	11,12	Measured**
SSD	2	0,267	0,99	Data provided by Dell**
Ethernet card	1	0,075	0,28	Data provided by Dell
Memory bars	16	0,367	1,37	Measured**
PCI Riser Cards	2	0,167	0,62	Data provided by Dell
Raid Card	1	0,15	0,56	Data provided by Dell
TOTAL WEIGHT		26,916		Calculated

* measured / calculated / estimated / literature

** Assumed to be identical as in R740

Table 3-5: Material composition of the Dell Server 7525

Components	Units	Mass (kg)	Mass (%)	DQI*
Chassis	1	12,014	43,38	Data provided by Dell
Fans, incl. case	6	1,59	5,74	Measured**
Packaging	1	7,105	25,66	Measured**
Mainboard, incl. CPU	1	3,06	11,05	Measured
PSU	2	2,992	10,8	Measured**
SSD	2	0,267	0,96	Data provided by Dell**
Ethernet card	1	0,075	0,27	Data provided by Dell
Memory bars	16	0,367	1,33	Measured**
PCI Riser Cards	1	0,072	0,26	Data provided by Dell
Raid Card	1	0,15	0,54	Data provided by Dell
TOTAL WEIGHT		27,692		Calculated

* measured / calculated / estimated / literature

** Assumed to be identical as in R740

3.2.3. Manufacturing phase

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

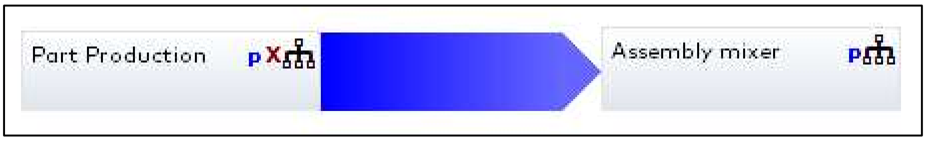


Figure 3-3: GaBi screenshot of the manufacturing phase

Part production includes the different components of the server grouped into 11 different plans, as depicted in Figure 3-4. Overall, the electronic components of the product consist of over 3500 capacitors, over 3000 resistors and over 220 single ICs.

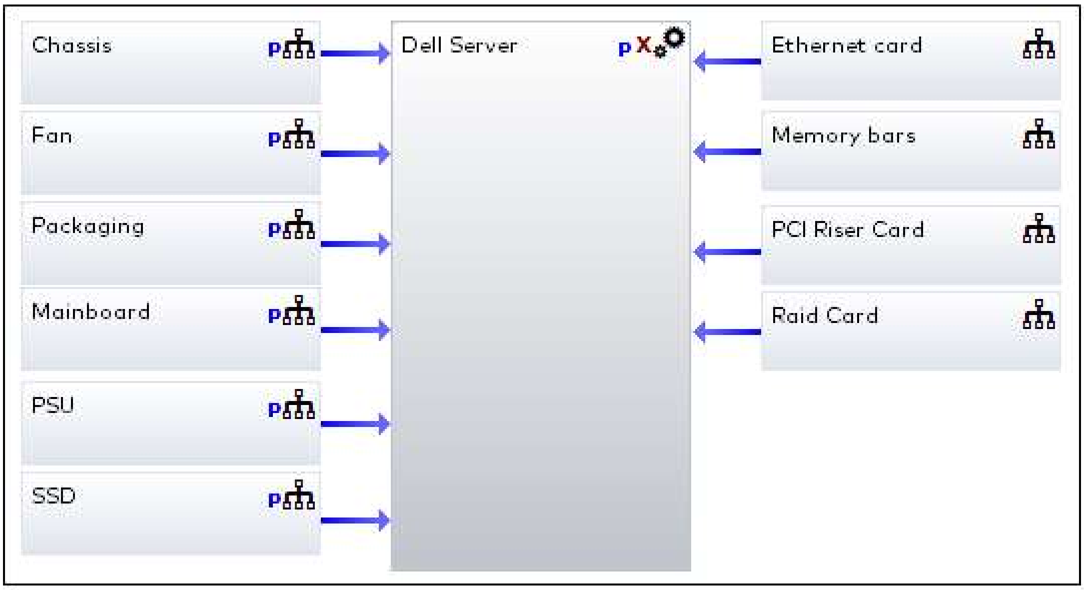


Figure 3-4: GaBi screenshot of the part production

Inside each one of the 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).

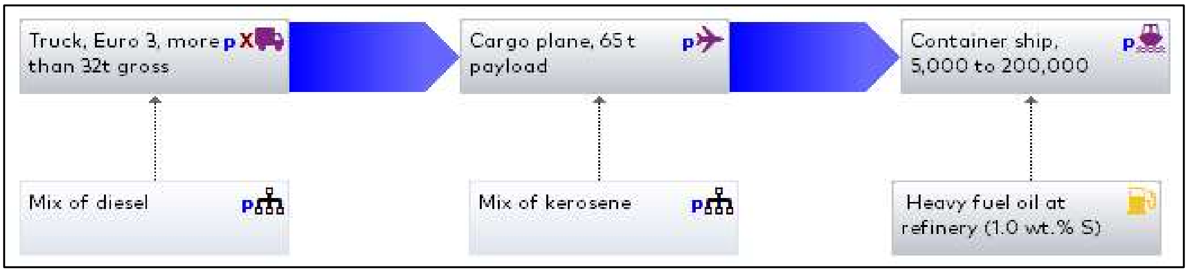


Figure 3-5: GaBi screenshot of the transport module

Table 3-6 summarizes the distances of transport to assembly in the different scenarios considered (EU and US).

Table 3-6: Transport to assembly scenarios

Components	Poland			Mexico		
	Truck [km]	Plane [km]	Ship [km]	Truck [km]	Plane [km]	Ship [km]
Chassis	1200		18000	1000		14000
Fan, incl. case						
Packaging						
Mainboard, incl. CPU	140	8300		100	14000	
PSU						
SSD						
Ethernet card						
Memory bars						
PCI Riser Card						
Raid Card						

The different modules considered in the manufacturing phase of the servers are described in further detail bellow.

Chassis

Figure 3-6 shows the chassis module. The amounts of each material were adjusted depending on the server.

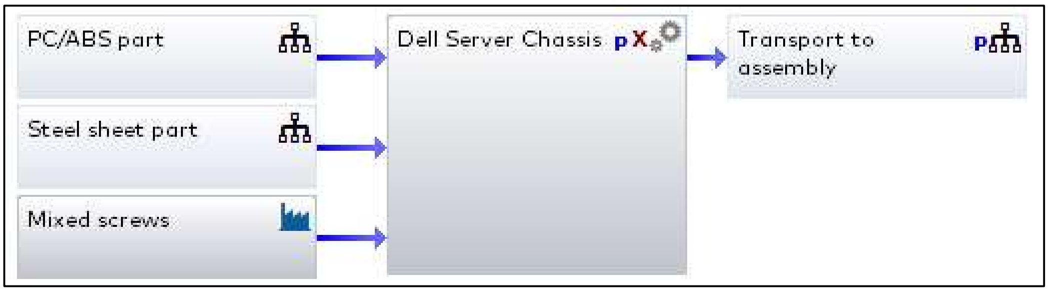


Figure 3-6: GaBi screenshot of the chassis module

Fans

Figure 3-7 shows the fans module. All the evaluated products include 6 fans in their configuration.

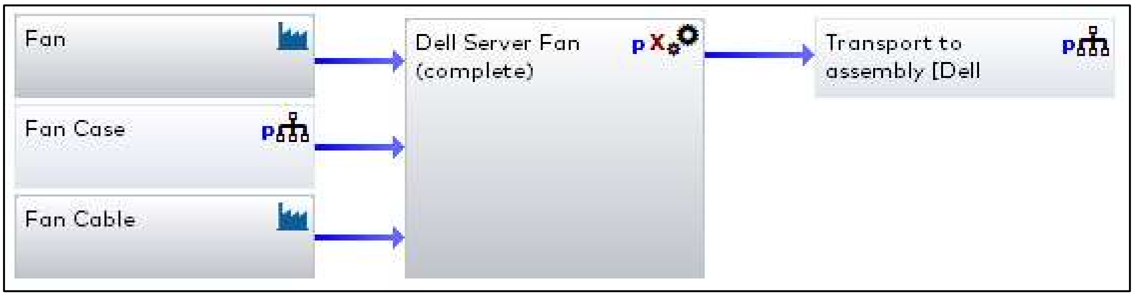


Figure 3-7: GaBi screenshot of the fans module

Packaging

The assumption used for the packaging is the same as defined for the server Dell R740 (thinkstep, 2019) and depicted in Figure 3-8.

Figure 3-8: GaBi screenshot of the packaging module

The weights of each material are displayed in Table 3-7.

Table 3-7: Dell Servers packaging

Packaging	Weight (kg)
Corrugated board	5,67
Expanded polyethylene	1,44

Mainboard

Figure 3-9 shows the mainboard module. For each server, the different mainboards were specifically modelled.

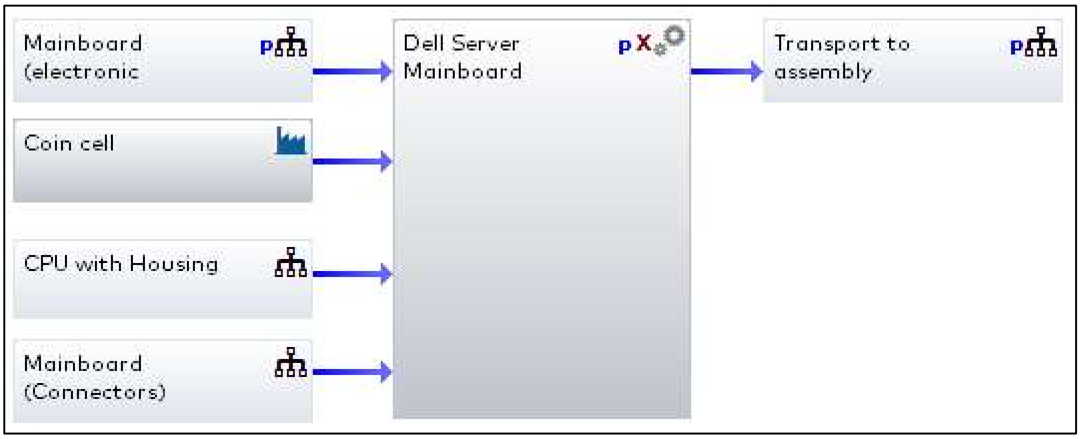


Figure 3-9: GaBi screenshot of the mainboard module

Within the Mainboard, one of the main components is the CPU. For the Dell Servers considered, the CPU AMD Opteron Rome 58,5 mm x 75,4 mm AMD EPYC 7452 (DPN: Y96PT) is included:

- 1 piece for R6515 and R7515;
- 2 pieces for R6525 and R7525.

Table 3-8 summarizes the weight of the different components in the CPU and Table 3-9 summarizes the technical details of the CPU.

Table 3-8: Dell AMD Opteron Rome AMD EPYC components (as set up in GaBi)

Electro-mechanic components	Weight (g)
CPU	107,2
Heatsink	330
Plastic mount	7,78
Thermal paste	0,7
CPU socket on mainboard	
Stainless Steel	194,8
Plastic	1,3
Total weight (1 CPU)	641,8

Table 3-9: Dell AMD Opteron Rome AMD EPYC details

CPU	Substrate (mm x mm)	Die (mm x mm)	Die area (mm2) (90 % of Chip size)	Tech node	Technology	CPU
Family: AMD Opteron Rome AMD EPYC 7452	58,5x75,4	8 ICs each 11,6 x 8,09	675,68	14 nm	CMOS	Family: AMD Opteron Rome AMD EPYC 7452

PSU

Figure 3-10 shows the PSU module.

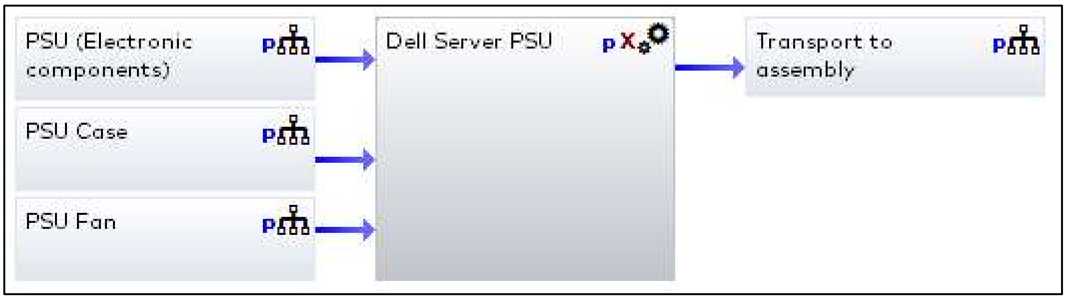


Figure 3-10: GaBi screenshot of the PSU module

SSD

Figure 3-11 presents the SSD module.

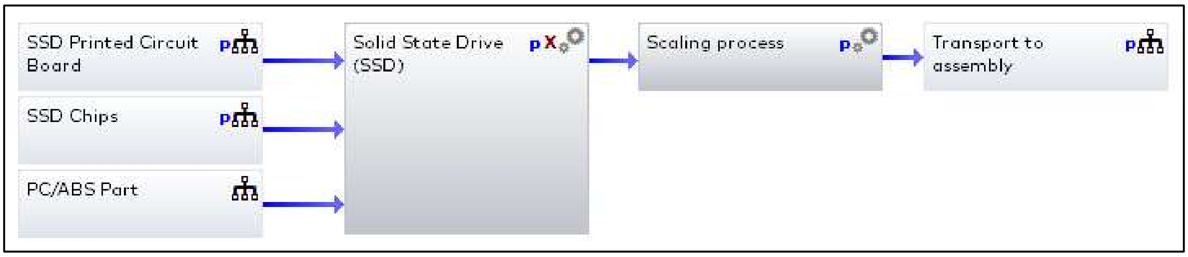


Figure 3-11: GaBi screenshot of the SSD module

The SSD configuration is the same for all the evaluated products and displayed in further detail in Table 3-10. It is assumed in the present study that the NAND -flash technology is applied in the SSD as in the previous study, for the Dell Server R740 (thinkstep, 2019) and scaled according to capacity.

Table 3-10: Dell Servers SSD configuration and significant components

Electro-mechanic components	Weight (kg)	Pieces (Nr.)
SSD 4TB		2
Memory Chip (DRAM)	85,42	5 (per SSD)
Memory Chip (Flash)	257,18	8 (per SSD)

Table 3-11 shows the parameter and assumptions taken for the SSD in the previous study (thinkstep, 2019).

Table 3-11: 3.84TB SSD NAND Flash Parameter and Assumptions

	3.8 TB SSD – NAND Flash
Package dimension (mm)	14 x 18.3
Die / package ratio	60%
Die stack per package	16
Chips per SSD	8
Total die area per chip (mm^2)	2460
Total die area per SSD (mm^2)	19676

Ethernet Card

Figure 3-12 shows the Ethernet Card module. For each Server the configuration was adjusted accordingly.

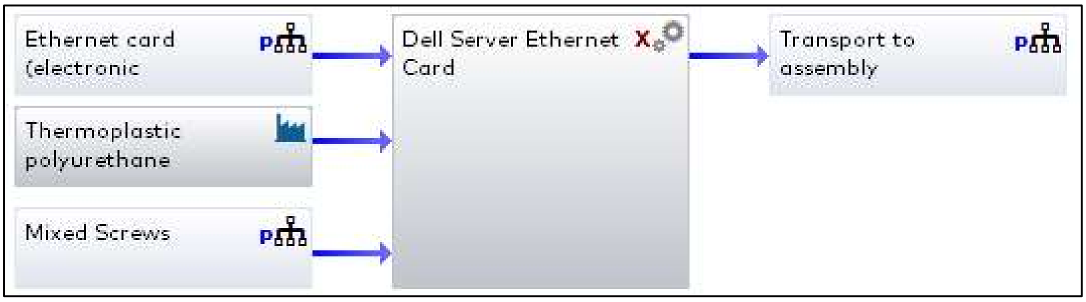


Figure 3-12: GaBi screenshot of the Ethernet card module

Memory bars

Figure 3-13 shows the Memory bars module. For each Server the number of memory bars was adjusted accordingly. In the case of R6515 and R7515, 8 bars were considered. In the case of R6525 and R7525 16 bars were considered.

Figure 3-13: GaBi screenshot of the Memory bars module

PCI Riser Card

Figure 3-14 shows the Memory bars module. For each Server the configuration and number of cards was adjusted accordingly.

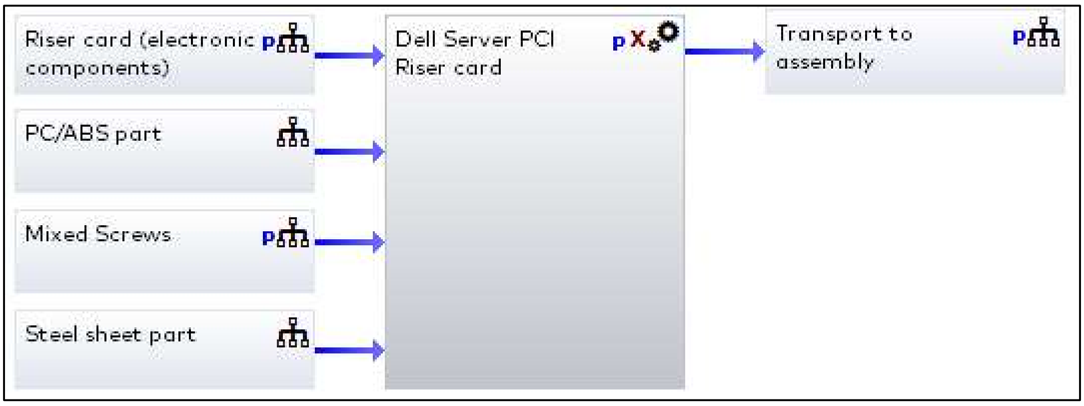


Figure 3-14: GaBi screenshot of the PCI Riser card module

Raid Card

Figure 3-15 shows the Raid Card. For each Server, the configuration was adjusted accordingly.

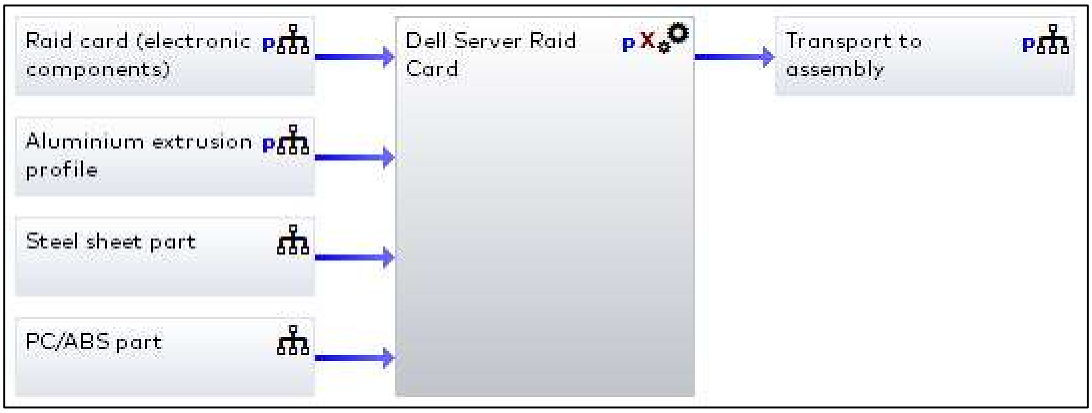


Figure 3-15: GaBi screenshot of the Raid card module

3.2.4. Distribution

Transport to customer in the United States and in Europe was included. The assumptions made in this study are the same as for the Dell R740 (thinkstep, 2019), where the servers produced in Europe supply customers in Europe and servers produced in Mexico supply customers in the US. Therefore:

- Transport to customer in Europe:
    - 100% truck transport from Poland to customer in Europe (1,200 km)
- Transport from Mexico assembly site to the hub location for finished goods in El Paso, US:
    - 10% air transport (1,500 km)
    - 90% truck transport (1,200 km)

The transport module used in the distribution phase is the same as depicted in Figure 3-5. The parameters were adjusted accordingly.

3.2.5. Use

The LCA calculations for the present study used Server Efficiency Rating Tool (SERT) data extraction method.

As some server products are not populated in the Enterprise Infrastructure Planning Tool (EIPT), this makes the calculation for the LCA input data impossible, as it is not possible to determine the average power values at 10%, 50% and 100% utilization from the EIPT tool.

For these systems, the specific configuration being evaluated for LCA have been tested using the Standard Performance Evaluation Corporation (SPEC) organizations SERT version 2.0.2. SERT is used as the assessment workload for ENERGY STAR 3.0 for servers, ErP Lot 9 regulations and in the ISO/IEC server efficiency standard ISO/IEC 21836. The SERT tool runs a set of different worklets at different system utilization levels and combines mean power, performance, and efficiency values to obtain an overall server efficiency score.

For this study, the following four working modes were defined for the use stage:

- Idle mode: state in which the server is not asleep but there is no application running
- 10% load mode

- 50% load mode
- 100% load mode: full work mode when server is executing tasks with CPU loading of 100%

Figure 3-16 shows the representation of the Use phase in GaBi software.

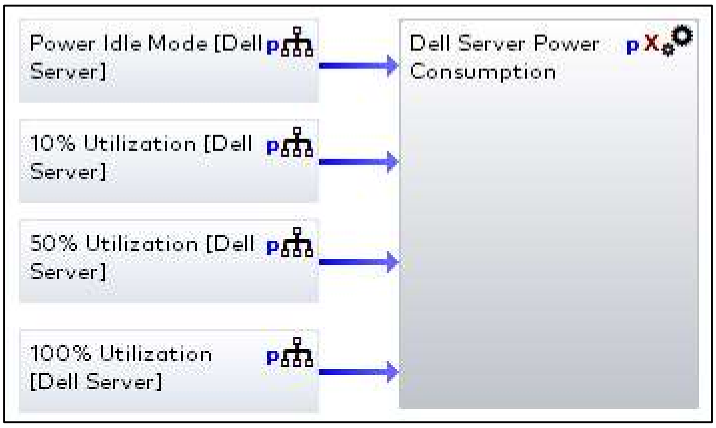


Figure 3-16: GaBi screenshot of the Use phase module

Idle Mode

The Idle values were directly measured.

10% Utilization Power Level

The lowest utilization power value recorded in the SERT test is the 12.5% utilization level for the Hybrid SSJ worklet. The 12.5% Hybrid SSJ power value is used as assumption for the 10% utilization power value in the LCA calculations.

50% Utilization Power Level

For the 50% Utilization Power Level, the following formula was used:

$$Power_{50\%} = EXP(0.65 * LN(Geomean(Power_{CPUn(50)})) + 0.3 * (Power_{MEMORYn(50)})) + 0.05 * LN(Geomean(Power_{STORAGEn(50)})))$$

Where:

Geomean = Geometric Mean

$Power_{CPUn(50)}$ = All 50% utilization level power values for the SERT CPU worklets

$Power_{MEMORYn(50)}$ = All 50% utilization level power values for the SERT memory worklets

$Power_{STOn(50)}$ = All 50% utilization level power values for the SERT storage worklets

100% Utilization Power Level

For the 100% Utilization Power Level, the following formula was used:

$$Power_{100\%} = EXP(0.65 * LN(Geomean(Power_{CPUn(100)})) + 0.3 * (Power_{MEMORYn(100)})) + 0.05 * LN(Geomean(Power_{STORAGEn(100)})))$$

Where:

Geomean = Geometric Mean

PowerCPUn(50) = All 100% utilization level power values for the SERT CPU worklets

PowerMEMORYn(50) = All 100% utilization level power values for the SERT memory worklets

PowerSTOn(50) = All 100% utilization level power values for the SERT storage worklets

This calculation yields a mean power value for all the worklets running at 50% or 100% respectively. These calculated power values are then used in the LCA calculations in the same manner the EIPT power values are used.

Table 3-12 presents a summary of the power values used for the LCA calculation of the Use phase.

Table 3-12: Power values used in the Use Phase of the Dell Servers R6515, R7515, R6525, R7525

	R6515	R7515	R6525	R7525
100% Power (Watt)	244,2	281,5	449,8	389
50% Power (Watt)	194,1	228,4	360,3	271,9
10% Power (Watt)	132,1	164,7	238	186,4
Idle power (Watt)	94,7	128,4	128,6	102,5

The power consumption at the 100%, 50%, 10% and idle load modes was provided by Dell for the typical configuration that is evaluated in this study and separately for light-medium and heavy workload. The light-medium workload is considered in this study as the baseline for evaluation, whereas the heavy workload is included as a scenario.

Table 3-13, Table 3-14, Table 3-15 and Table 3-16 present the power consumption values for each one of the servers, based on the values provided by Dell.

Table 3-13: Use phase scenarios for the Dell Server R6515

	Light-medium workload				Heavy workload			
	100% Load mode	50% Load mode	10% Load mode	Idle mode	100% Load mode	50% Load mode	10% Load mode	Idle mode
T(h)	2,4	8,4	7,2	6	3,6	13,2	4,8	2,4
P (W)	244,2	194,1	132,1	94,7	244,2	194,1	132,1	94,7
Lifespan (yr)	4	4	4	4	4	4	4	4
Power (kWh/yr)	213,92	595,11	347,16	207,39	320,88	935,17	231,44	82,96

Table 3-14: Use phase scenarios for the Dell Server R7515

	Light-medium workload				Heavy workload			
	100% Load mode	50% Load mode	10% Load mode	Idle mode	100% Load mode	50% Load mode	10% Load mode	Idle mode
T(h)	2,4	8,4	7,2	6	3,6	13,2	4,8	2,4
P (W)	281,5	228,4	164,7	128,4	281,5	228,4	164,7	128,4
Lifespan (yr)	4	4	4	4	4	4	4	4
Power (kWh/yr)	246,59	700,27	432,83	281,2	369,89	1100,43	288,55	112,48

Table 3-15: Use phase scenarios for the Dell Server R6525

	Light-medium workload				Heavy workload			
	100% Load mode	50% Load mode	10% Load mode	Idle mode	100% Load mode	50% Load mode	10% Load mode	Idle mode
T(h)	2,4	8,4	7,2	6	3,6	13,2	4,8	2,4
P (W)	449,8	360,3	238	128,6	449,8	360,3	238	128,6
Lifespan (yr)	4	4	4	4	4	4	4	4
Power (kWh/yr)	394,02	1104,68	625,46	281,63	591,04	1735,93	416,98	112,65

Table 3-16: Use phase scenarios for the Dell Server R7525

	Light-medium workload				Heavy workload			
	100% Load mode	50% Load mode	10% Load mode	Idle mode	100% Load mode	50% Load mode	10% Load mode	Idle mode
T(h)	2,4	8,4	7,2	6	3,6	13,2	4,8	2,4
P (W)	389	271,9	186,4	102,5	389	271,9	186,4	102,5
Lifespan (yr)	4	4	4	4	4	4	4	4
Power (kWh/yr)	340,76	833,65	489,86	224,48	511,15	1310,01	326,57	89,79

3.2.6. End-of-Life

Figure 3-17 shows the End-of-Life module in GaBi software.

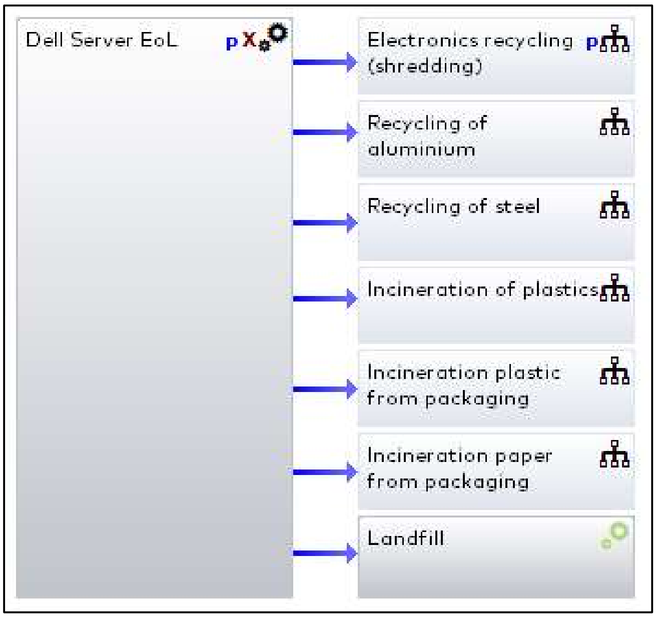


Figure 3-17: GaBi screenshot of the End-of-Life module

Assumptions for the End of Life (EoL) are the same as the assumptions used for the Dell R740 Server (thinkstep, 2019) and follow the primary data that was collected by Dell and the recycling contractor Wi-setek.

Based on this primary data, weighted averages were calculated for the materials described in Table 3-17.

Table 3-17: EoL recycling, energy recovery and landfill rates per material

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

The distance to EoL is 680km, by truck. This value is the average distance from seven primary locations to one of the biggest recyclers for servers in Europe. The transport module used for the End-of-Life is the same as depicted in Figure 3-5. The parameters were adjusted accordingly.

3.3. Background Data

Documentation for all GaBi datasets can be found online (Sphera Solutions Inc., 2020).

3.3.1. Fuels and Energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2020 databases in the version CUP 2020.2. Table 3-18 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.

Table 3-18: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	EU-28	Electricity grid mix	Sphera	2020	No
Electricity	US	Electricity grid mix	Sphera	2020	No

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2021 database. Documentation for all GaBi datasets can be found at http://www.gabi-software.com/support/gabi/gabi-database-2020-lci-documentation/.

A list with datasets used can be found in Annex B: .

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 2021 database was used to model transportation. Transportation was modelled using the GaBi global transportation datasets. Fuels were modelled using the geographically appropriate datasets.

Table 3-19: Transportation and road fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
Euro 6 truck, 34-40 t gwt	GLO	Truck-trailer - diesel driven, Euro 6, cargo - 34 - 40 t gross weight / 27t payload capacity	Sphera	2020	no
Euro 5 truck, 34-40 t gwt	GLO	Truck-trailer - diesel driven, Euro 5, cargo - 34 - 40 t gross weight / 27t payload capacity	Sphera	2020	no
Rail	GLO	Rail transport cargo – average - average train, gross tonne weight 1000t / 726t payload capacity	Sphera	2020	no
Diesel	EU-27	Diesel mix at filling station	Sphera	2020	no

3.4. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment". As the complete inventory comprises hundreds of flows, the below table only displays a selection of flows based on their relevance to the subsequent impact assessment in order to provide a transparent link between the inventory and impact assessment results. For reasons of readability and presentation, only the LCI tables for the EU Light Medium workload scenarios are presented. The transport as well as the use phase LCI results differ for the other scenarios.

Table 3-20: LCI results of Dell Server 6515 (in kg)

Type	Flow	Total	Manufacturing	Transport to Customer	Use	Transport to EoL	EoL
Resources	Water use	1,17E+07	1,59E+06	8,54E+01	1,02E+07	4,84E+01	-4,75E+04
	Wood	2,98E-03	2,98E-03	7,63E-11	1,09E-08	4,33E-11	-9,32E-11
	Crude oil	8,81E+01	5,27E+01	4,62E-01	3,76E+01	2,62E-01	-2,91E+00
	Hard coal	5,41E+02	3,00E+02	1,85E-03	2,75E+02	1,05E-03	-3,33E+01
	Natural gas	3,17E+02	1,18E+02	3,39E-02	2,01E+02	1,92E-02	-1,95E+00
	Uranium	3,18E-02	4,92E-03	1,21E-07	2,70E-02	6,84E-08	-9,54E-05
Emissions to air	CO_2	3,18E+03	1,23E+03	1,48E+00	2,05E+03	8,38E-01	-9,79E+01
	CH_4	6,60E+00	2,84E+00	2,07E-03	4,02E+00	1,17E-03	-2,65E-01
	N_2O	5,42E-02	2,24E-02	1,06E-02	1,53E-02	6,00E-03	-4,77E-05
	NO_x	4,92E+00	2,90E+00	4,05E-04	2,48E+00	2,29E-04	-4,63E-01
	SO_2	5,23E+00	3,71E+00	4,53E-04	2,17E+00	2,57E-04	-6,51E-01
	NMVOC	6,48E-01	3,81E-01	9,12E-04	2,79E-01	5,17E-04	-1,38E-02
	CO	3,07E+00	1,61E+00	2,25E-03	1,64E+00	1,27E-03	-1,75E-01
	PM10	2,57E-03	4,70E-03	1,12E-07	8,86E-04	6,36E-08	-3,03E-03
	PM2.5	2,70E-01	2,11E-01	2,32E-04	7,63E-02	1,32E-04	-1,76E-02
	Heavy metals	6,05E-03	5,28E-03	3,57E-07	1,91E-03	2,03E-07	-1,15E-03
Emissions to water	NH_3	1,50E-02	2,11E-03	3,24E-07	1,30E-02	1,84E-07	-3,64E-05
	NO^{3-}	4,89E-01	9,90E-02	8,86E-05	3,93E-01	5,02E-05	-2,40E-03
	PO_4^{3-}	2,42E-02	3,17E-03	1,40E-05	2,11E-02	7,94E-06	-5,52E-05
	Heavy metals	2,07E+00	9,97E-01	1,30E-05	1,08E+00	7,38E-06	-5,27E-03
Emissions to soil	PAH	4,27E-11	4,27E-11	1,09E-18	1,56E-16	6,20E-19	-1,34E-18
	Heavy metals	2,14E-01	2,33E-04	8,93E-02	1,32E-04	-1,76E-02	0,00E+00

Table 3-21: LCI results of Dell Server 7515 (in kg)

Type	Flow	Total	Manufacturing	Transport to Customer	Use	Transport to EoL	EoL
Resources	Water use	1,39E+07	1,58E+06	8,82E+01	1,24E+07	5,00E+01	-4,75E+04
	Wood	2,98E-03	2,98E-03	7,88E-11	1,32E-08	4,46E-11	-9,33E-11
	Crude oil	9,60E+01	5,25E+01	4,77E-01	4,57E+01	2,70E-01	-2,99E+00
	Hard coal	5,99E+02	2,99E+02	1,90E-03	3,35E+02	1,08E-03	-3,42E+01
	Natural gas	3,61E+02	1,17E+02	3,49E-02	2,45E+02	1,98E-02	-1,91E+00
	Uranium	3,77E-02	4,91E-03	1,25E-07	3,29E-02	7,06E-08	-9,51E-05
Emissions to air	CO_2	3,62E+03	1,22E+03	1,53E+00	2,49E+03	8,65E-01	-1,00E+02
	CH_4	7,46E+00	2,83E+00	2,13E-03	4,90E+00	1,21E-03	-2,68E-01
	N_2O	5,84E-02	2,28E-02	1,09E-02	1,86E-02	6,19E-03	-4,63E-05
	NO_x	5,44E+00	2,89E+00	4,17E-04	3,02E+00	2,36E-04	-4,69E-01
	SO_2	5,69E+00	3,70E+00	4,67E-04	2,65E+00	2,65E-04	-6,59E-01
	NMVOC	7,07E-01	3,79E-01	9,41E-04	3,40E-01	5,33E-04	-1,40E-02
	CO	3,43E+00	1,62E+00	2,32E-03	1,99E+00	1,31E-03	-1,88E-01
	PM10	2,62E-03	4,85E-03	1,16E-07	1,08E-03	6,56E-08	-3,32E-03
	PM2.5	2,87E-01	2,11E-01	2,40E-04	9,29E-02	1,36E-04	-1,79E-02
	Heavy metals	6,38E-03	5,24E-03	3,69E-07	2,33E-03	2,09E-07	-1,20E-03
Emissions to water	NH_3	1,07E-02	1,85E-03	6,36E-08	8,92E-03	3,60E-08	-2,41E-05
	NO^{3-}	5,81E-01	9,82E-02	9,17E-05	4,85E-01	5,20E-05	-2,40E-03
	PO_4^{3-}	2,17E-02	2,88E-03	1,42E-05	1,88E-02	8,04E-06	-4,17E-05
	Heavy metals	2,29E+00	9,96E-01	1,32E-05	1,30E+00	7,46E-06	-5,24E-03
Emissions to soil	PAH	4,27E-11	4,27E-11	1,13E-18	1,90E-16	6,40E-19	-1,34E-18
	Heavy metals	1,46E-03	1,15E-03	2,26E-06	3,36E-04	1,28E-06	-3,37E-05

Table 3-22: LCI results of Dell Server 6525 (in kg)

Type	Flow	Total	Manufacturing	Transport to Customer	Use	Transport to EoL	EoL
Resources	Water use	1,99E+07	2,01E+06	9,22E+01	1,80E+07	5,23E+01	-8,27E+04
	Wood	2,20E-08	2,91E-09	8,24E-11	1,92E-08	4,67E-11	-1,61E-10
	Crude oil	1,30E+02	6,76E+01	4,99E-01	6,63E+01	2,83E-01	-4,68E+00
	Hard coal	8,16E+02	3,84E+02	1,99E-03	4,85E+02	1,13E-03	-5,29E+01
	Natural gas	4,99E+02	1,47E+02	3,65E-02	3,55E+02	2,07E-02	-2,95E+00
	Uranium	5,36E-02	6,10E-03	1,30E-07	4,76E-02	7,38E-08	-1,57E-04
Emissions to air	CO_2	5,02E+03	1,56E+03	1,60E+00	3,61E+03	9,05E-01	-1,56E+02
	CH_4	1,03E+01	3,66E+00	2,23E-03	7,10E+00	1,26E-03	-4,48E-01
	N_2O	4,74E+00	2,06E+00	2,43E-03	2,89E+00	1,37E-03	-2,06E-01
	NO_x	7,04E-02	2,57E-02	1,14E-02	2,69E-02	6,47E-03	-9,78E-05
	SO_2	7,43E+00	3,84E+00	4,37E-04	4,37E+00	2,47E-04	-7,80E-01
	NMVOC	9,47E-01	4,76E-01	9,84E-04	4,93E-01	5,58E-04	-2,31E-02
	CO	4,74E+00	2,06E+00	2,43E-03	2,89E+00	1,37E-03	-2,06E-01
	PM10	3,56E-03	5,03E-03	1,21E-07	1,56E-03	6,87E-08	-3,04E-03
	PM2.5	3,73E-01	2,67E-01	2,51E-04	1,35E-01	1,42E-04	-2,93E-02
	Heavy metals	8,37E-03	6,65E-03	3,86E-07	3,38E-03	2,19E-07	-1,65E-03
Emissions to water	NH_3	1,50E-02	2,09E-03	6,66E-08	1,29E-02	3,77E-08	-3,97E-05
	NO^{3-}	8,20E-01	1,22E-01	9,59E-05	7,03E-01	5,44E-05	-4,18E-03
	PO_4^{3-}	3,06E-02	3,41E-03	1,48E-05	2,73E-02	8,41E-06	-7,74E-05
	Heavy metals	3,10E+00	1,22E+00	1,38E-05	1,89E+00	7,81E-06	-8,94E-03
Emissions to soil	PAH	3,16E-16	4,17E-17	1,18E-18	2,75E-16	6,69E-19	-2,31E-18
	Heavy metals	1,93E-03	1,48E-03	2,37E-06	4,87E-04	1,34E-06	-4,09E-05

Table 3-23: LCI results of Dell Server 7525 (in kg)

Type	Flow	Total	Manufacturing	Transport to Customer	Use	Transport to EoL	EoL
Resources	Water use	1,60E+07	2,01E+06	9,49E+01	1,41E+07	5,38E+01	-8,23E+04
	Wood	1,79E-08	2,90E-09	8,48E-11	1,50E-08	4,80E-11	-1,61E-10
	Crude oil	1,16E+02	6,75E+01	5,13E-01	5,20E+01	2,91E-01	-4,74E+00
	Hard coal	7,11E+02	3,84E+02	2,05E-03	3,80E+02	1,16E-03	-5,36E+01
	Natural gas	4,23E+02	1,47E+02	3,76E-02	2,79E+02	2,13E-02	-2,90E+00
	Uranium	4,33E-02	6,10E-03	1,34E-07	3,74E-02	7,60E-08	-1,56E-04
Emissions to air	CO_2	4,24E+03	1,56E+03	1,64E+00	2,83E+03	9,31E-01	-1,58E+02
	CH_4	8,78E+00	3,65E+00	2,30E-03	5,57E+00	1,30E-03	-4,50E-01
	N_2O	6,55E-02	2,60E-02	1,18E-02	2,12E-02	6,66E-03	-9,64E-05
	NO_x	6,48E+00	3,84E+00	4,49E-04	3,43E+00	2,55E-04	-7,84E-01
	SO_2	6,91E+00	4,98E+00	5,03E-04	3,01E+00	2,85E-04	-1,09E+00
	NMVOC	8,40E-01	4,75E-01	1,01E-03	3,87E-01	5,74E-04	-2,32E-02
	CO	4,11E+00	2,06E+00	2,50E-03	2,27E+00	1,41E-03	-2,18E-01
	PM10	2,99E-03	5,06E-03	1,25E-07	1,23E-03	7,07E-08	-3,30E-03
	PM2.5	3,44E-01	2,67E-01	2,58E-04	1,06E-01	1,46E-04	-2,95E-02
	Heavy metals	7,59E-03	6,63E-03	3,97E-07	2,65E-03	2,25E-07	-1,69E-03
Emissions to water	NH_3	1,22E-02	2,10E-03	6,85E-08	1,01E-02	3,88E-08	-3,95E-05
	NO^{3-}	6,69E-01	1,21E-01	9,87E-05	5,52E-01	5,59E-05	-4,16E-03
	PO_4^{3-}	2,47E-02	3,40E-03	1,53E-05	2,14E-02	8,65E-06	-7,59E-05
	Heavy metals	2,69E+00	1,22E+00	1,42E-05	1,48E+00	8,03E-06	-8,90E-03
Emissions to soil	PAH	2,57E-16	4,16E-17	1,22E-18	2,16E-16	6,89E-19	-2,30E-18
	Heavy metals	1,80E-03	1,45E-03	2,43E-06	3,83E-04	1,38E-06	-4,20E-05

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. 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 chapters, 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.

4.1. Overall results

Two scenarios are defined given the two regions in which the Dell Servers are produced, 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:

- Most components are sourced from China.
- Assembly of components take place in Poland and Mexico,
- Transportation to European and US customer, and
- Use stage takes place in the EU and in the US.

Table 4-1, Table 4-2, Table 4-3 and Table 4-4 show the impact assessment results for all impact categories under consideration within this study.

Table 4-1: Overall results for the Dell R6515

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	39100	53600
Acidification Potential [kg SO2 eq.]	9,91	9,81
Eutrophication Potential [kg Phosphate eq.]	0,913	0,877
Ozone Layer Depletion Potential [kg R11 eq.]	3,45E-08	3,44E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,687	0,684
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	3450	4280

Table 4-2: Overall results for the Dell R7515

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	44200	61900
Acidification Potential [kg SO2 eq.]	10,9	10,7
Eutrophication Potential [kg Phosphate eq.]	1,02	0,975
Ozone Layer Depletion Potential [kg R11 eq.]	3,31E-08	3,31E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,754	0,75
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	3920	4930

Table 4-3: Overall results for the Dell R6525

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	61400	86900
Acidification Potential [kg SO2 eq.]	14,9	14,7
Eutrophication Potential [kg Phosphate eq.]	1,4	1,34
Ozone Layer Depletion Potential [kg R11 eq.]	2,06E-08	2,06E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	1,04	1,03
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	5440	6910

Table 4-4: Overall results for the Dell R7525

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	52300	72300
Acidification Potential [kg SO2 eq.]	13,2	13
Eutrophication Potential [kg Phosphate eq.]	1,21	1,16
Ozone Layer Depletion Potential [kg R11 eq.]	2,00E-08	1,99E-08
Photochemical Ozone Creation Potential [kg Ethene eq.]	0,913	0,908
Global Warming Potential 100 years excl. biogenic carbon [kg CO2 eq.]	4620	5770

For the life cycle of the Dell servers in the United States, the GWP is ca. 20% - 21% higher than the GWP in Europe, depending on the server considered. 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 – in both the EU and the US, for all the servers – has origin in the manufacturing and the use phase. The share of Greenhouse gas emissions of the manufacturing stage ranges from 28 % to 39 % depending on the scenario and whether a light-medium or a heavy use scenario in the use stage is considered. Transportation of each component to the assembly location is included in the manufacturing stage and accounts for less than 1% of the overall results in all the products.

The case in which the servers are used in the US under Heavy-Usage conditions is not shown in this report. This scenario would follow the trends shown in chapter 4.3 resulting in higher total, e.g. GPW, impacts as the US grid mix is linked to a higher GWP per kWh compared to the EU grid mix which is used for the comparison of the different workloads in chapter 4.3.2. In this case the share of the manufacturing GPW impacts compared to the total life cycle GPW impacts would range from 19% (R7525 representing the lowest overall share of manufacturing impacts) to 25% (R7515).

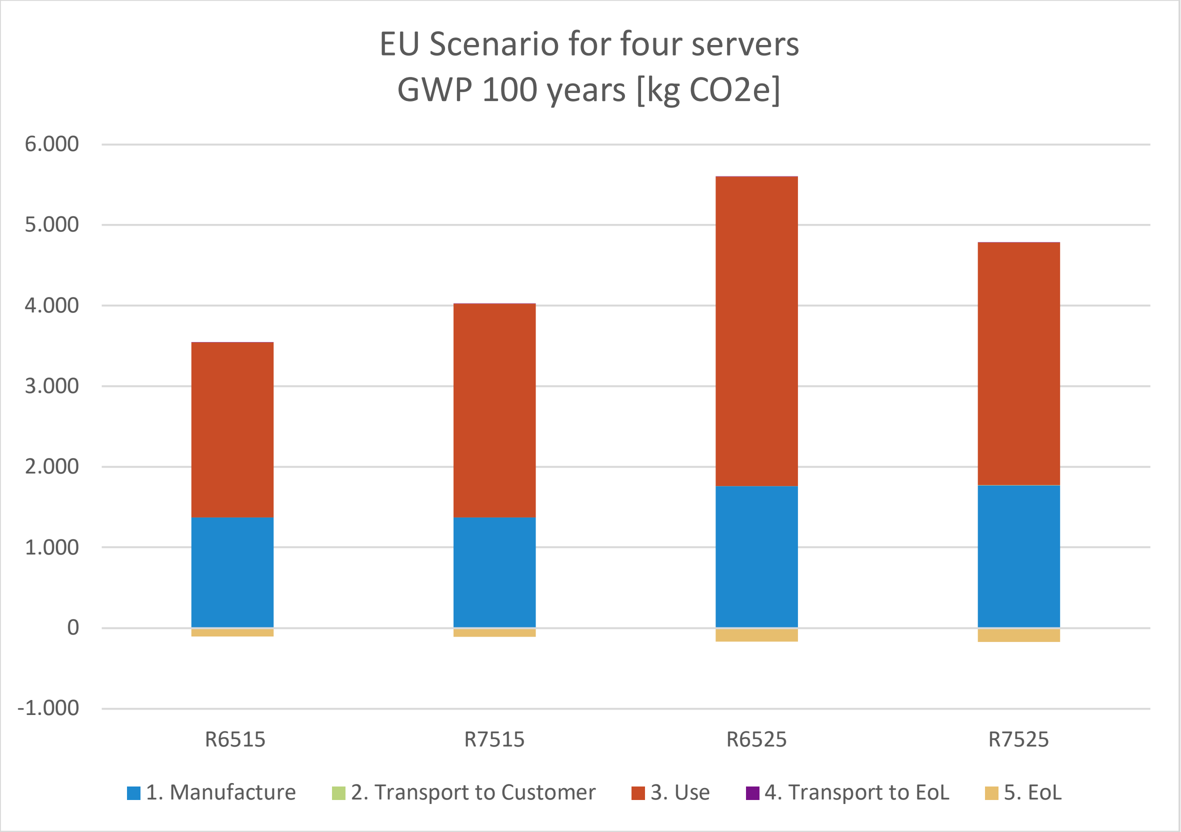


Figure 4-1: Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell servers in the EU

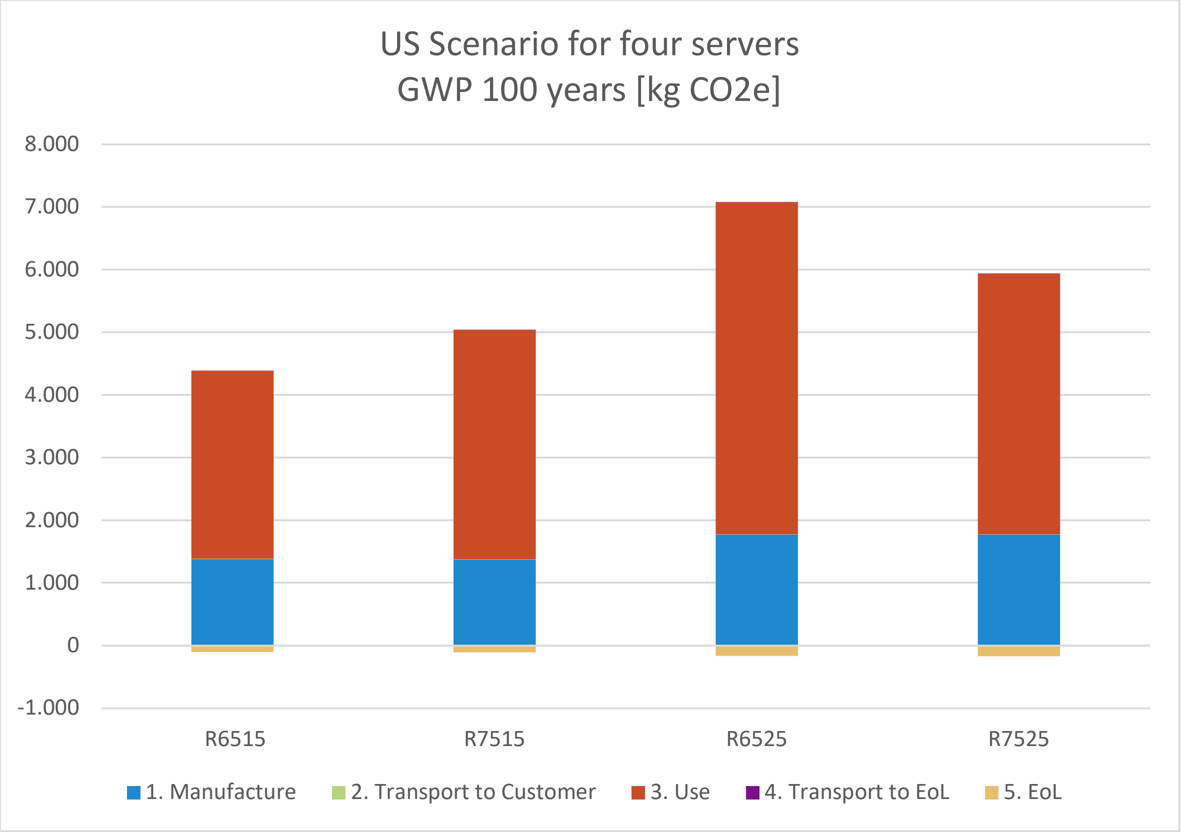


Figure 4-2: Contribution of the different stages of the life cycle to the global warming potential (GWP) of the Dell servers in the US

4.2. Manufacturing of the Dell Servers

Dell Server R6515

In the case of Dell R6515, the manufacturing has a contribution of 1,343 kg CO_2e, approximately 39% to the total of the life cycle impact in the light-medium use scenario and 36% to the total of the life cycle impact in the heavy use scenario.

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

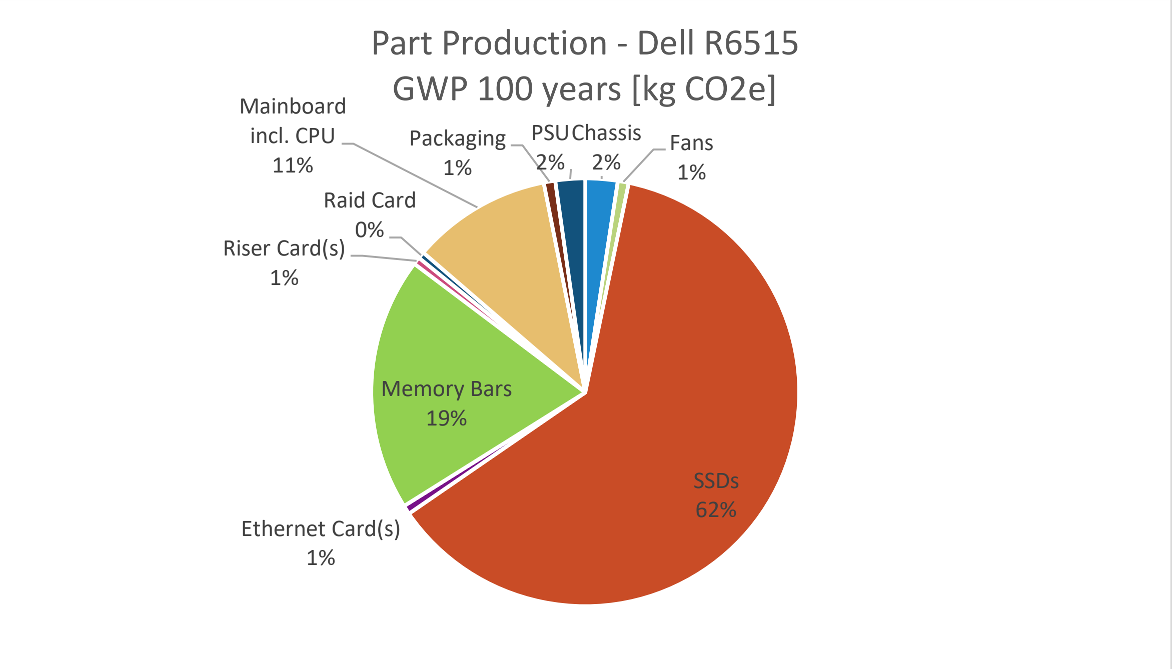


Figure 4-3: Contribution of the production of different modules to the global warming potential (GWP) of the Dell R6515 – EU Scenario

Dell Server R7515

In the case of Dell R7515, the manufacturing has a contribution of 1,338 kg CO_2e, approximately 34% to the total of the life cycle impact in the light-medium use scenario and 32% to the total of the life cycle impact in the heavy use scenario.

Figure 4-4 to Figure 4-6 presents the contribution of the different parts to the total impact resulting from the part production, not including assembly.

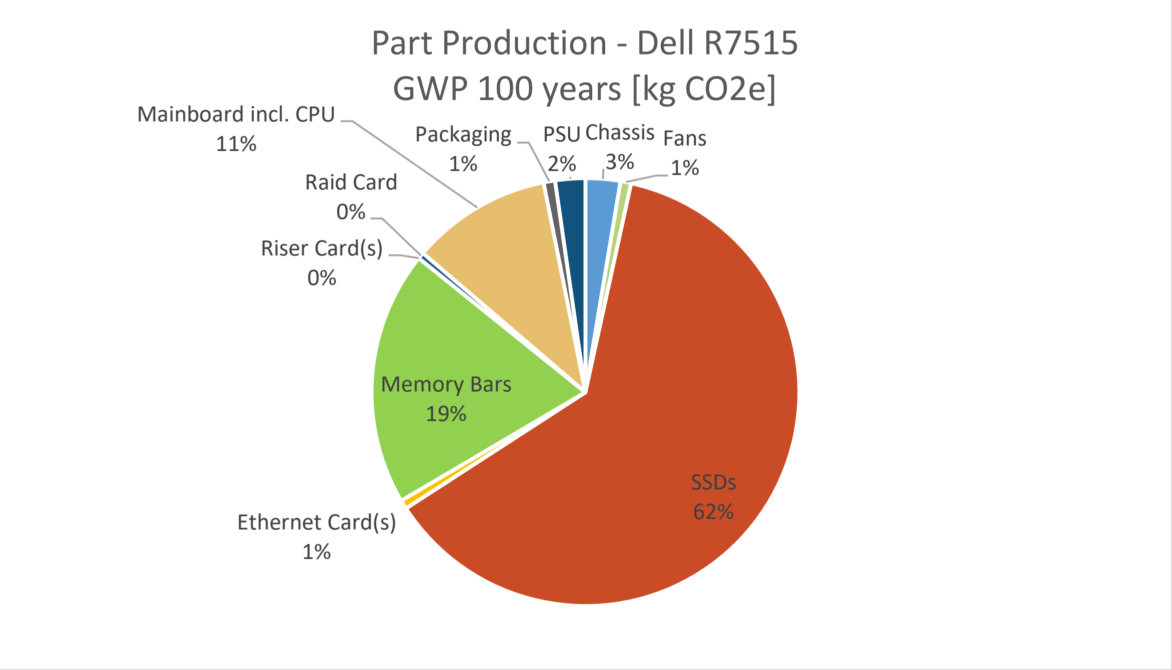


Figure 4-4: Contribution of the production of different modules to the global warming potential (GWP) of the Dell R7515 – EU Scenario

Dell Server 6525

Dell R6525 has a contribution of 1,709 kg CO_2e, contributing to approximately 32% to the total of the life cycle impact in the light-medium use scenario and 28% to the total of the life cycle impact in the heavy use scenario.

Figure 4-5 presents the contribution of the different parts to the total impact resulting from the part production, not including assembly.

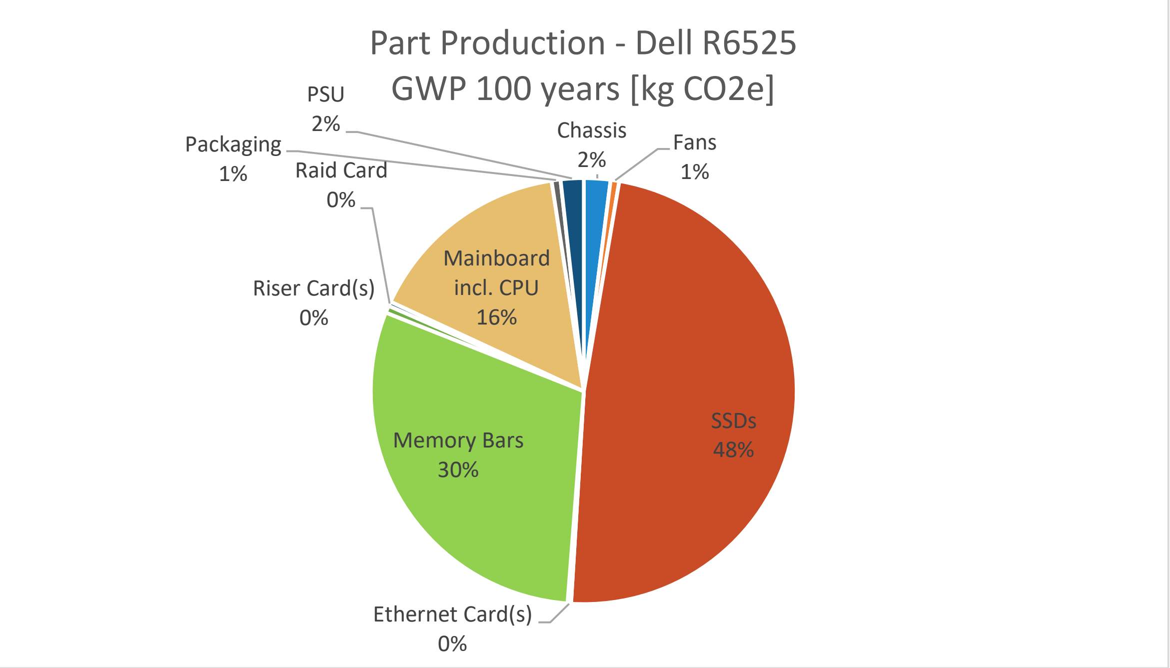


Figure 4-5: Contribution of the production of different modules to the global warming potential (GWP) of the Dell R6525 – EU Scenario

Dell Server R7525

Dell R7525 has a contribution of 1,707 kg CO_2e, contributing to approximately 37% to the total of the life cycle impact in the light-medium use scenario and 33% to the total of the life cycle impact in the heavy use scenario.

Figure 4-6 presents the contribution of the different parts to the total impact resulting from the part production, not including assembly.

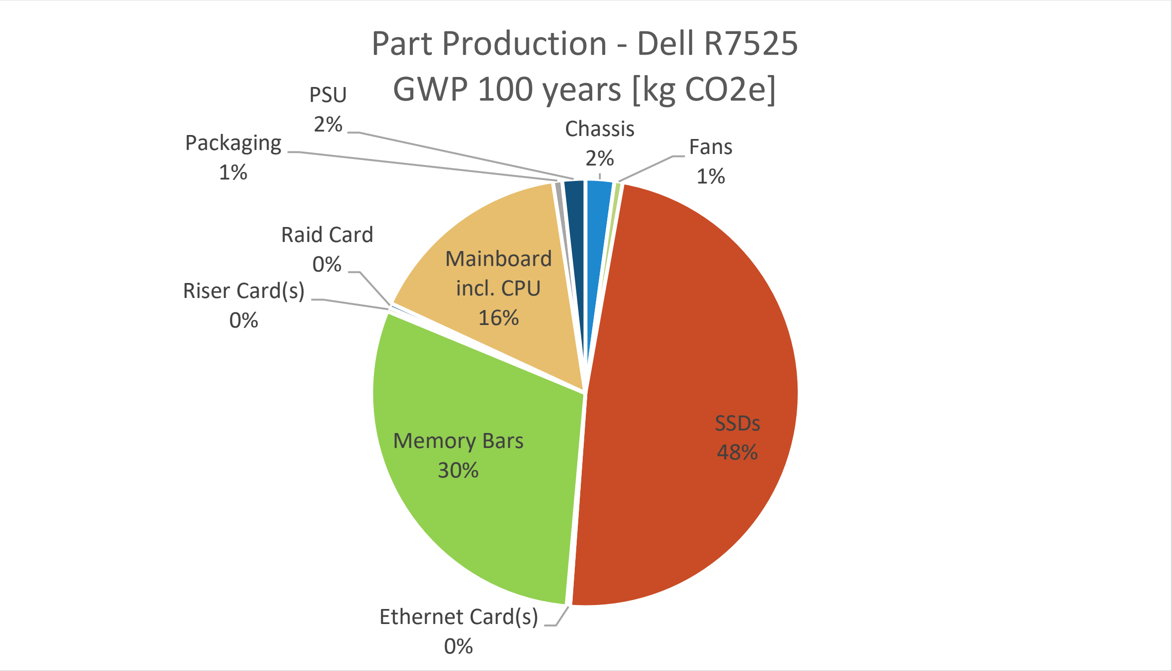


Figure 4-6: Contribution of the production of different modules to the global warming potential (GWP) of the Dell R7525 – EU Scenario

It becomes very clear that in all the servers the large majority of the part production impacts are from the components containing electronics and especially the two 4TB SSDs. The results of the detailed assessment and sensitivity analyses for these will be shown in the next sections. In Table 4-5 the impact contribution of each component is shown in terms of kg CO2e.

Table 4-5: Carbon footprint of main components of the Dell Servers

Main Components	Global Warming Potential (GWP 100 years) [kg CO2e]			
	R6515	R7515	R6525	R7525
Chassis	33,6	36,0	36,0	38,3
Fans	11,2	11,2	11,2	11,2
SSDs	854,7	854,7	854,7	854,7
Ethernet Card(s)	9,3	9,3	4,8	4,8
Memory Bars	263,7	263,7	527,4	527,4
Riser Card(s)	7,9	0,0	9,8	5,6
Raid Card	6,7	6,7	6,1	6,1
Mainboard incl. CPU	145,2	145,2	277,4	277,4
Packaging	11,9	11,9	11,9	11,9
PSU	30,9	30,9	30,9	30,9
Total	**1375,2**	**1369,7**	**1770,3**	**1768,4**

It is interesting to understand the relation between the mass and the impact of each of the parts. Figure 4-7, Figure 4-8, Figure 4-9 and Figure 4-10 illustrate the mass of the main components in comparison to their corresponding weight.

Considering for example the Dell Server R6515, over 95% of the part production impact comes from the components containing electronics which account for only 16% of the total weight. The two 4TB SSDs again are a significant outlier, accounting for approximately 64% of the total GWP while only accounting for 1% of the weight.

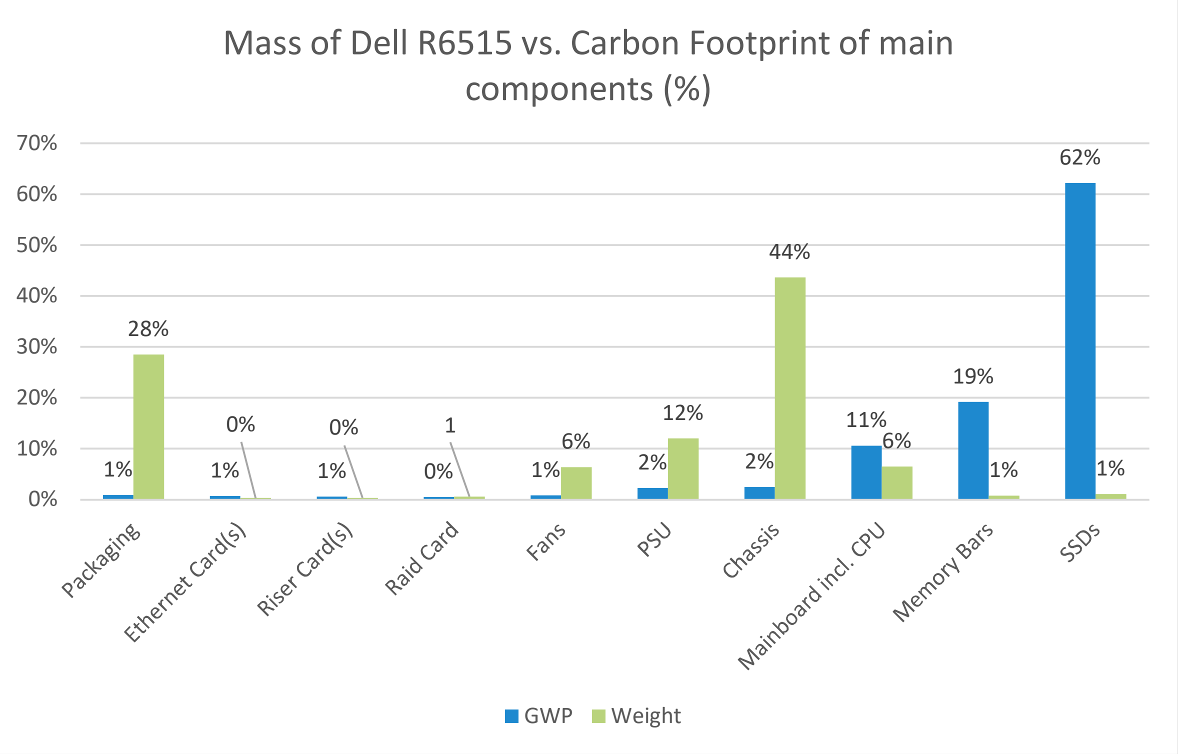


Figure 4-7: Comparison of masses and associated global warming potential (production) on the components in the Dell R6515

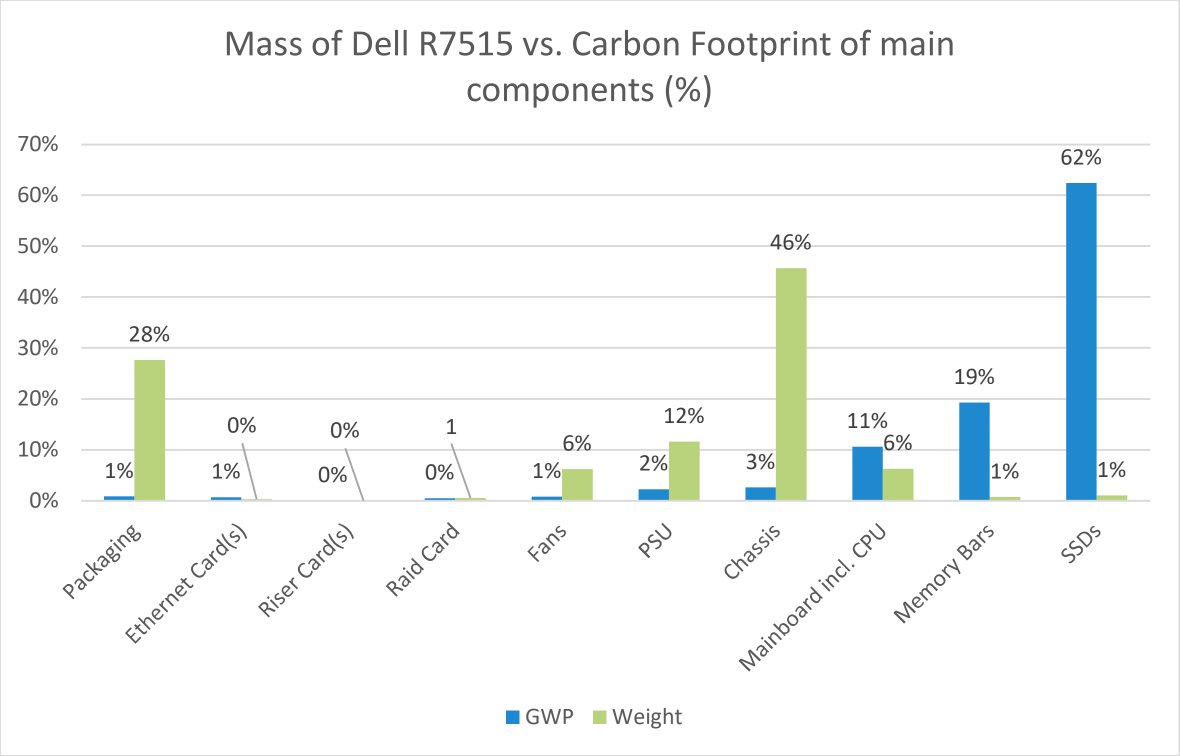


Figure 4-8: Comparison of masses and associated global warming potential (production) on the components in the Dell R7515

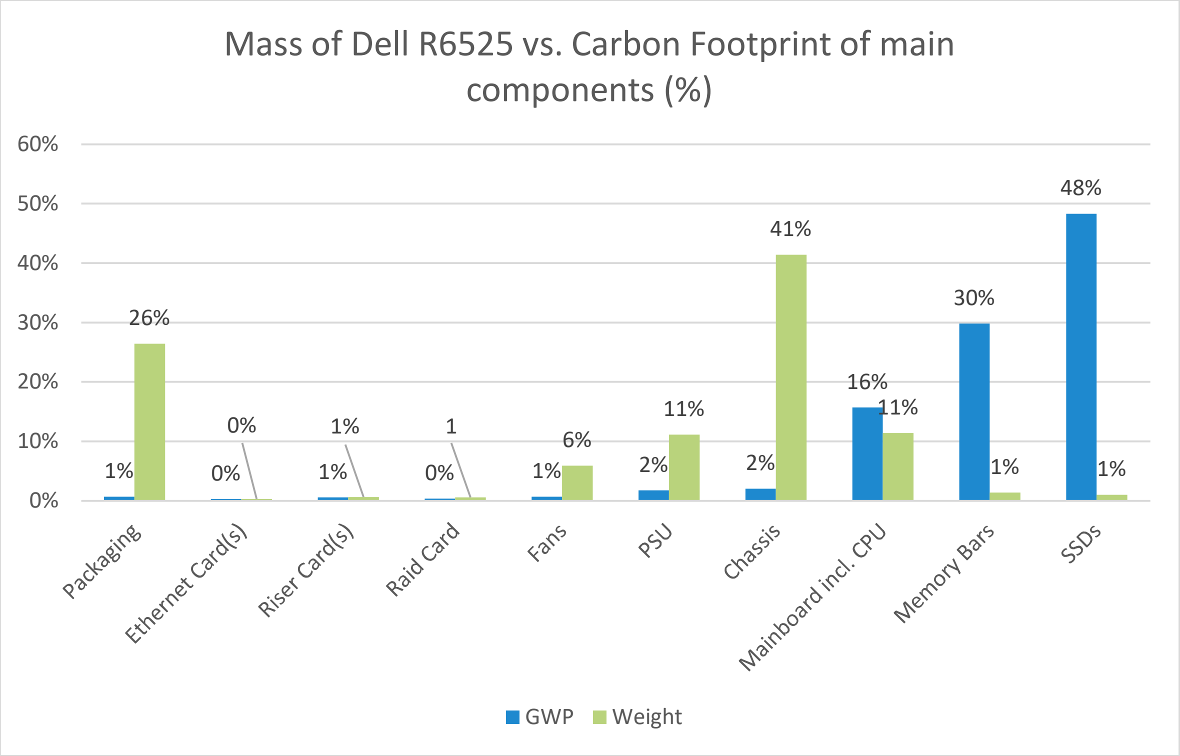


Figure 4-9: Comparison of masses and associated global warming potential (production) on the components in the Dell R6525

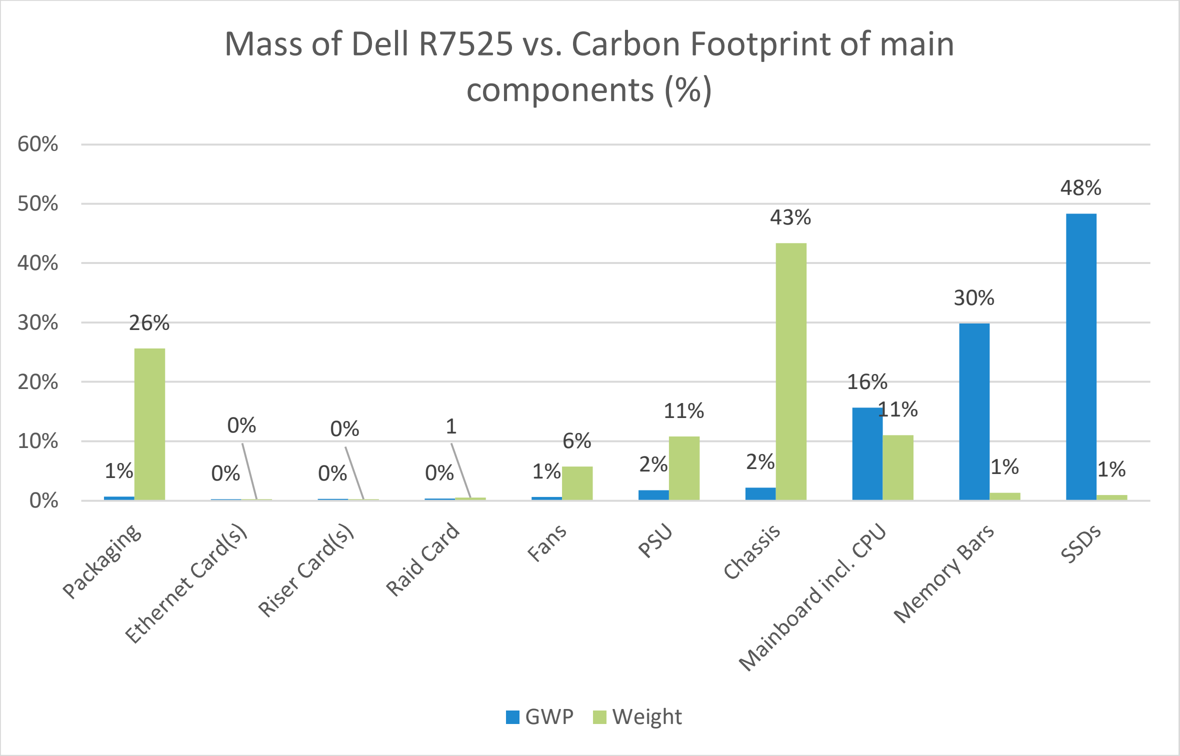


Figure 4-10: Comparison of masses and associated global warming potential (production) on the components in the Dell R7525

It is thus possible to show that the global warming potential is not directly linked to mass. While the chassis dominates the mass of the product (41% to 46%), the impact of this component (GWP) per unit of mass is relatively low. By contrast, the SSDs, the mainboard, RAMs and all other additional cards– together contribute only between 8% and 13% of the total mass, but their impact per unit mass is a large share (89% to 92%) of the total GWP of the servers. 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.

4.2.1.2 Solid State Drives

The typical configuration evaluated in this study considers two 4TB SSDs. They represent, in total, the largest contribution to the overall impact of manufacturing the system and around one quarter of the overall impact of the product.

Figure 4-11 shows that the majority of the SSD impact of the 4TB SSDs comes from the NAND flash. As described in section 3.2.3, 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 Samsung (Gibb, 2016) (PC Watch, 2016).

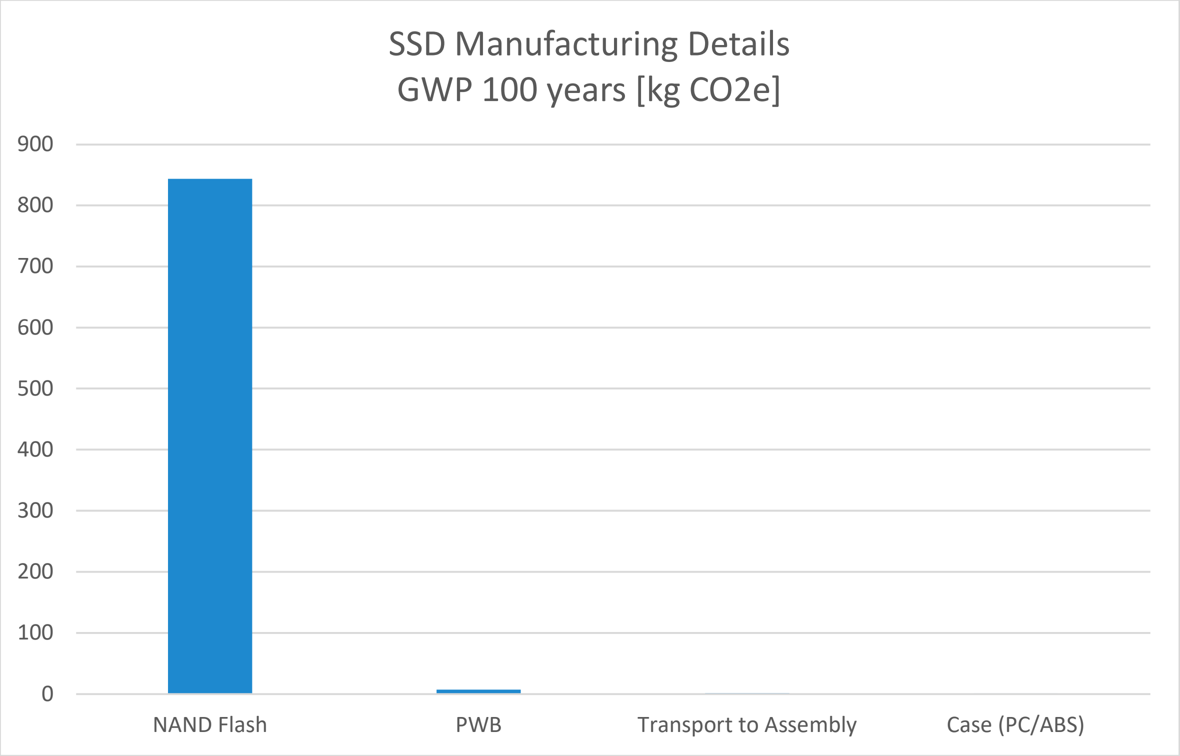


Figure 4-11: SSD manufacturing Impacts

4.2.1.3 Memory bars

One memory bar has a GWP of 33 kg C02e and its contribution to total GWP of the server is significant, as can be seen in the Table 4-5. Due to the higher number of memory bars installed in R6525/ R7525 (16) than in R6515/ R7515 (8), the numbers differ.

Figure 4-12 depicts the contribution of the main elements in the memory bar for the four Dell servers and their respective contributions to the carbon footprint.

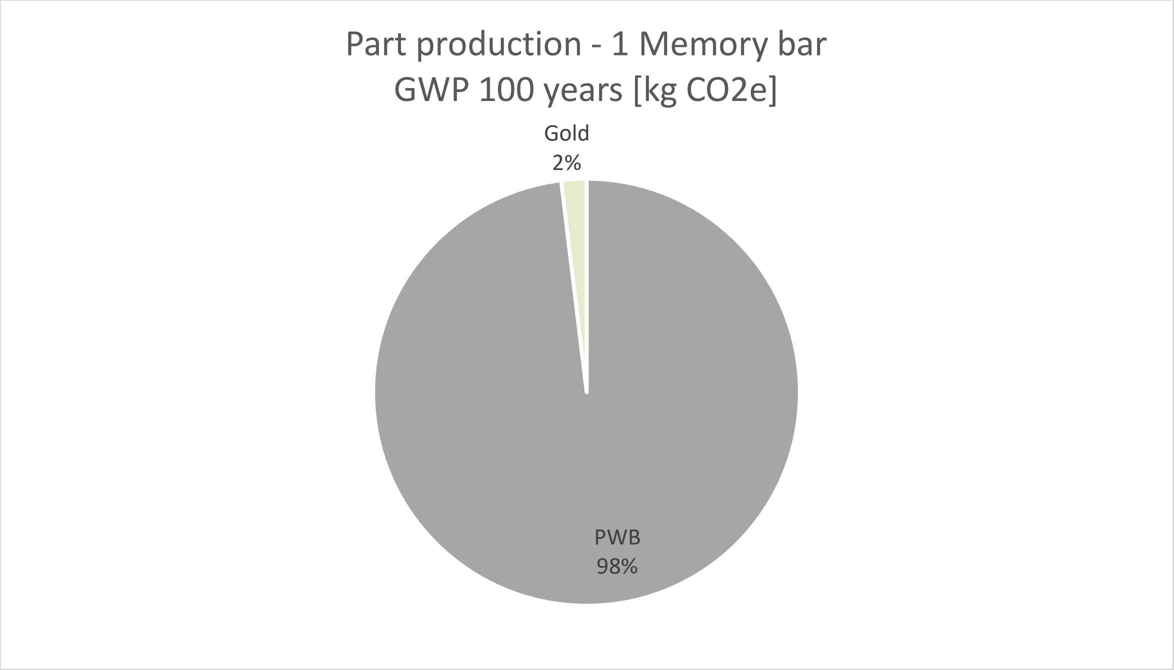


Figure 4-12: Contribution of the elements of the memory bar for the carbon footprint of this component of the Dell Servers

4.2.1.4 Mainboard

The four servers are sharing two motherboards. An identical motherboard is shared by R6515/R7515 and another motherboard is shared by R6525/R7525.

Figure 4-13 and Figure 4-14 depict the contribution of the main elements in the mainboard for R6515/R7515 and R6525/R7525 and their respective contributions to the carbon footprint.

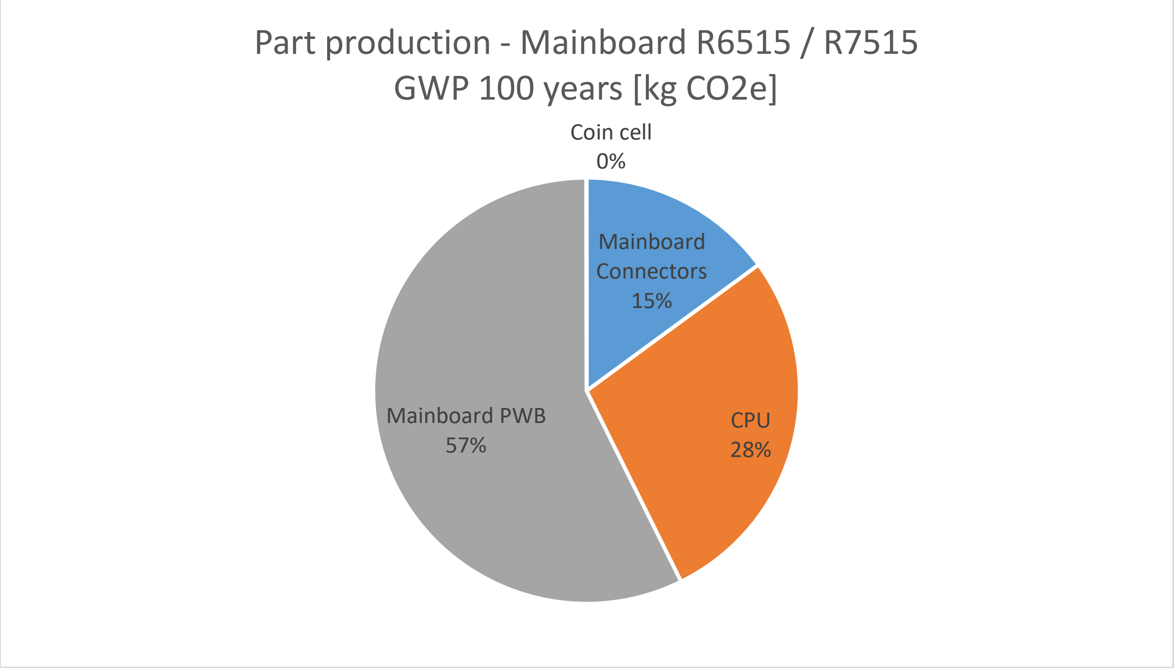


Figure 4-13: Contribution of the elements of the mainboard for the carbon footprint of this component of the Dell R6515 / R7515

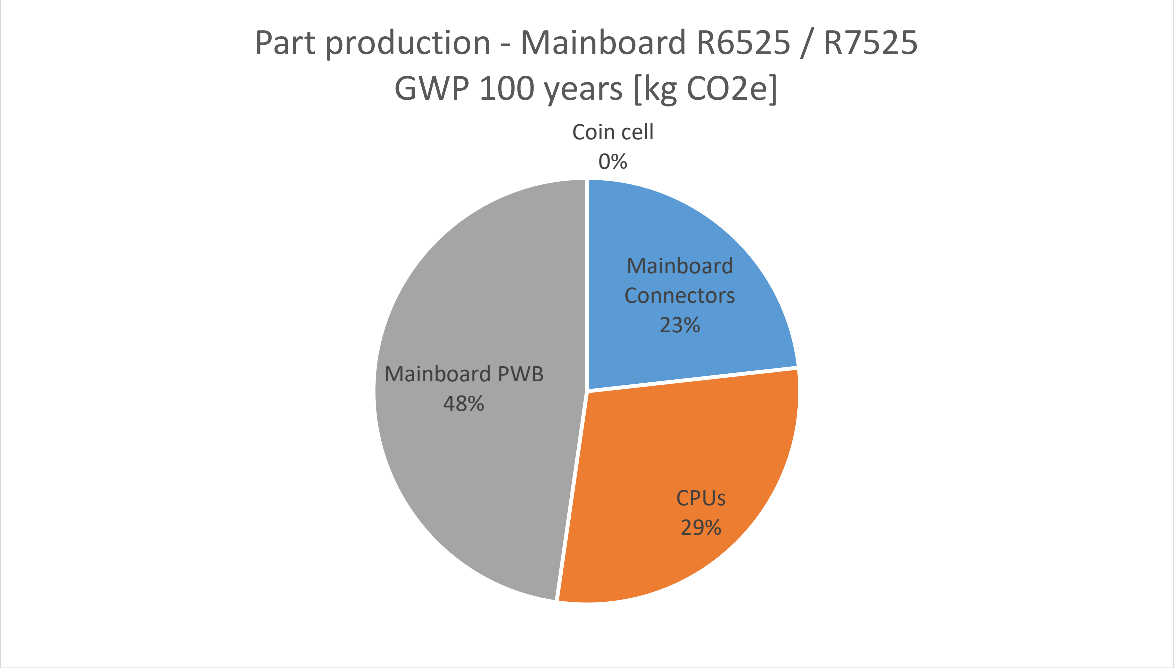


Figure 4-14: Contribution of the elements of the mainboard for the carbon footprint of this component of the Dell R6525 / R7525

The main impact on mainboard is coming from:

- Production and assembly of the substrate assembly (48-57%, from which around 50% is directly related with the production of the printed wiring board itself). Physical dimensions (length, width, thickness) of the mainboard were measured. Since panel optimization drawings were not provided, mainboard area was calculated by multiplying widest and longest dimensions of the board as a conservative estimate to account for cutting losses. Number of layers and surface finish for the PWBs were estimated based on visual inspection. The mainboard for R6515 and R7515 is a 12-layer substrate and has an area 1386 cm^2. For R6525 / R7525 it is 1400 cm^2 and has 14 layers. The numbers of layers are based on data provided. An AuNi finishing was assumed for both.
- CPU(s) and the corresponding heatsink(s) contribute with around 30% for the total impact of the mainboard.
- Due to the large number of bigger connectors used on the mainboard, they also account for around 15% of the total impact. for R6515 / R7515 and almost 30% for R6525 / R7525. The main reason for the higher contribution of the connectors for R6525 / R7525 mainboard is due to higher amount of PCI connectors and double amount (16 instead of 8) of memory bar slots, which consequently leads to higher amount of gold on the connectors surface.

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.

The mainboards analysed by Sphera were highly populated boards on both sides with a significant amount of electronics. The number of ICs was high, reflecting the high functionality.

4.3. Use phase of the Dell Servers

In this section, two distinct scenarios are presented based on a) the two regions where the current study considers that the Dell Servers are used and b) as well as a comparison of the standard light-medium workload with a heavy workload.

4.3.1. Regional Scenario

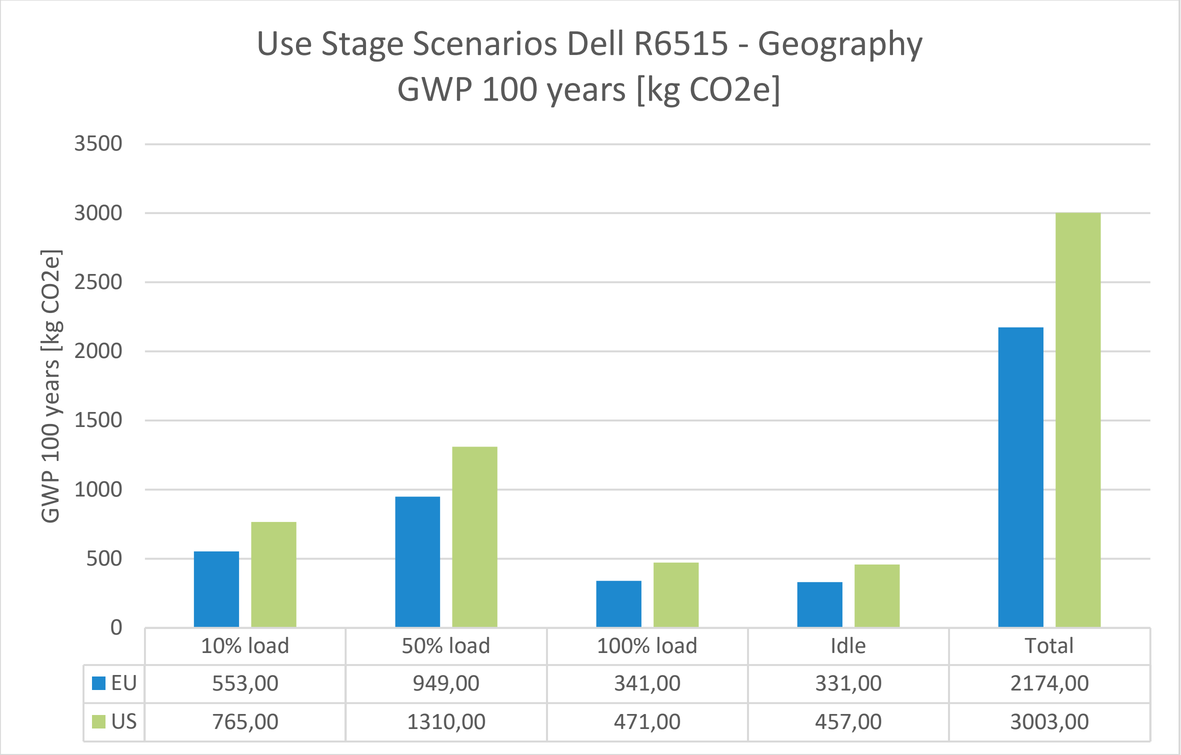
The following two locations are considered within this scenario and represent the two most typical cases for Dell products:

- The Dell Server is used 100% in the US
- The Dell Server is used 100% in the EU

The duty cycle of the server was the default light-medium workload described in section 3.2.5.

Figure 4-15, Figure 4-16, Figure 4-17 and Figure 4-18 include 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.

Dell Server R6515



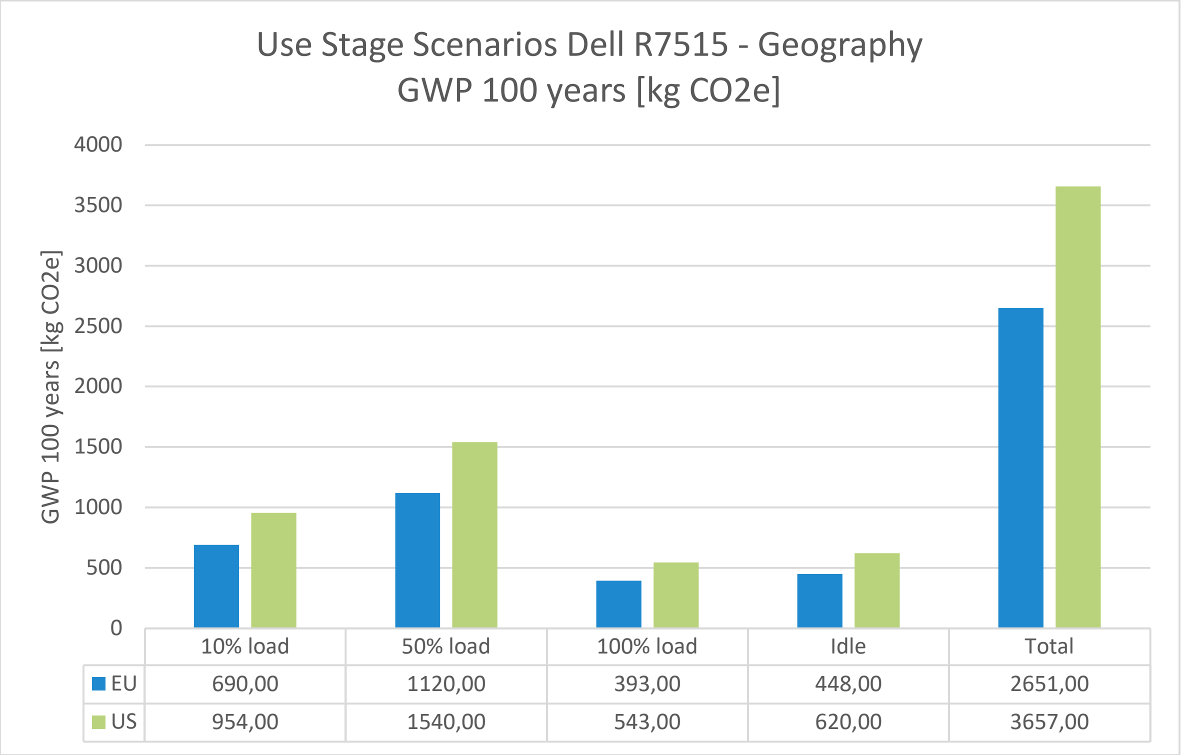
	10% load	50% load	100% load	Idle	Total
EU	553,00	949,00	341,00	331,00	2174,00
US	765,00	1310,00	471,00	457,00	3003,00

Figure 4-15: Global Warming Potential of the Dell R6515's use stage in Europe and the USA

As expected, the Dell R6515 working at 50% load mode leads to the highest electricity consumption and therefore the highest carbon footprint, given the high share of this load mode. In idle mode, the platform is not asleep, but there are no applications running, and thus this mode corresponds to lower power consumption. The 100% workload mode, although consuming almost 2,5 times as much as the idle mode (244,2W vs. 94,7W), accounts for similar emissions due to difference in time the server is running in each mode.

Overall, the use of the Dell R6515 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.

Dell Server R7515



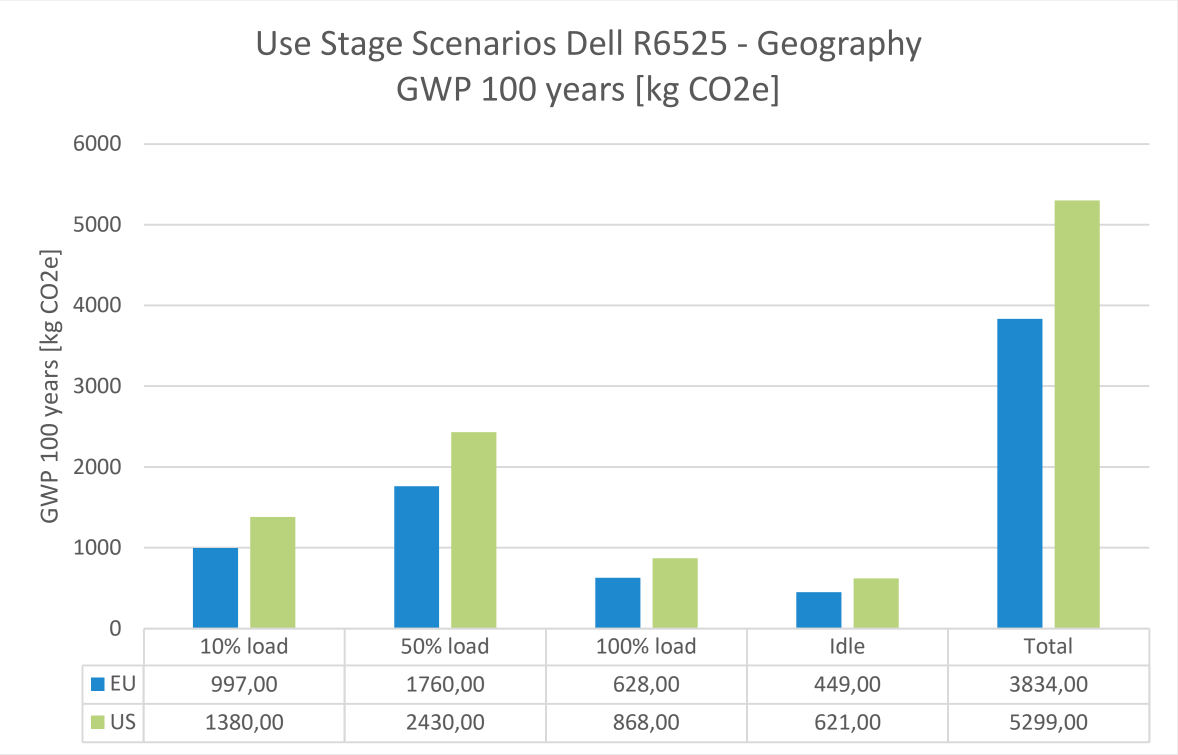
	10% load	50% load	100% load	Idle	Total
🟦 EU	690,00	1120,00	393,00	448,00	2651,00
🟩 US	954,00	1540,00	543,00	620,00	3657,00

Figure 4-16: Global Warming Potential of the Dell R7515's use stage in Europe and the USA

As expected, the Dell R7515 working at 50% load mode leads to the highest electricity consumption and therefore the highest carbon footprint, given the high share of this load mode. In idle mode, the platform is not asleep, but there are no applications running, and thus this mode corresponds to lower power consumption. The 100% workload mode, although consuming almost 2,2 times as much as the idle mode (281,5W vs. 128,4W), accounts for similar emissions due to difference in time the server is running in each mode.

Overall, the use of the Dell R7515 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.

Dell Server R6525



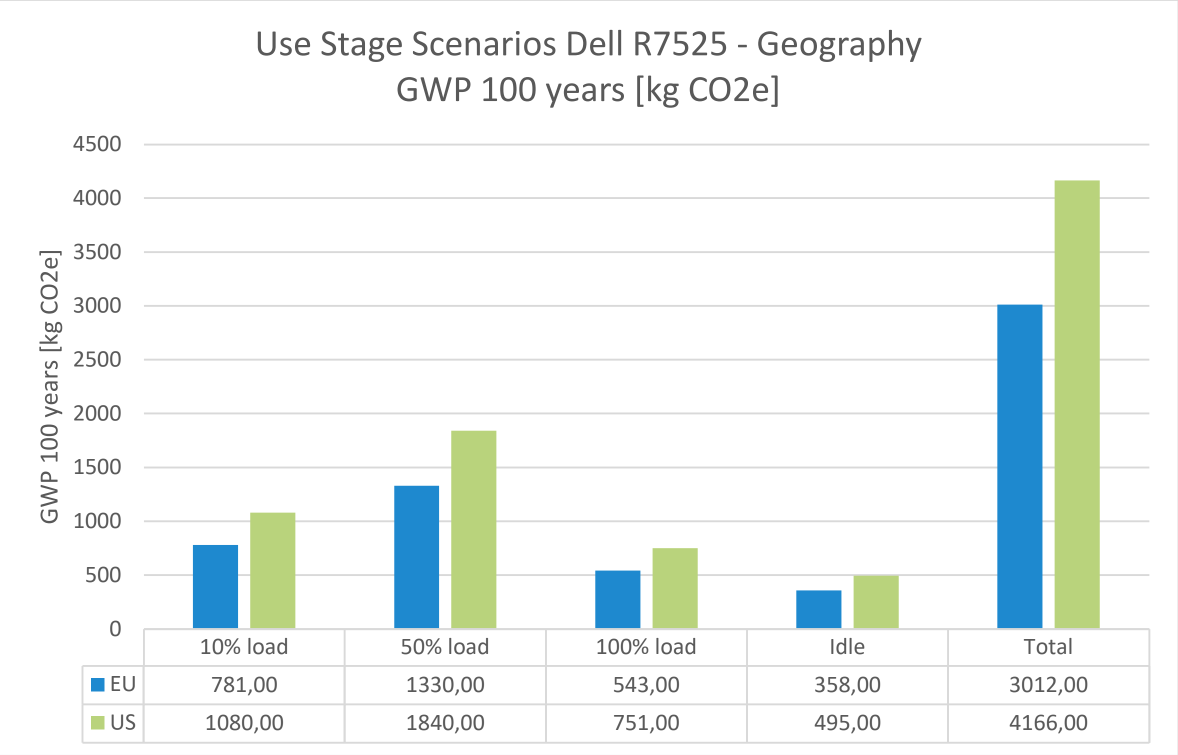
	10% load	50% load	100% load	Idle	Total
🟦 EU	997,00	1760,00	628,00	449,00	3834,00
🟩 US	1380,00	2430,00	868,00	621,00	5299,00

Figure 4-17: Global Warming Potential of the Dell R6525's use stage in Europe and the USA

As expected, the Dell R6525 working at 50% load mode leads to the highest electricity consumption and therefore the highest carbon footprint, given the high share of this load mode. In idle mode, the platform is not asleep, but there are no applications running, and thus this mode corresponds to lower power consumption. The 100% workload mode, although consuming almost 3,5 times as much as the idle mode (449,8W vs. 128,6W), accounts for similar emissions due to difference in time the server is running in each mode.

Overall, the use of the Dell R6525 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.

Dell Server R7525



	10% load	50% load	100% load	Idle	Total
🟦 EU	781,00	1330,00	543,00	358,00	3012,00
🟩 US	1080,00	1840,00	751,00	495,00	4166,00

Figure 4-18: Global Warming Potential of the Dell R7525's use stage in Europe and the USA

As expected, the Dell R7525 working at 50% load mode leads to the highest electricity consumption and therefore the highest carbon footprint, given the high share of this load mode. In idle mode, the platform is not asleep, but there are no applications running, and thus this mode corresponds to lower power consumption. The 100% workload mode, although consuming almost 3,8 times as much as the idle mode (389W vs. 102,5W), accounts for similar emissions due to difference in time the server is running in each mode.

Overall, the use of the Dell R7525 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.

4.3.2. Workload Scenario

In addition to the default light-medium workload, which is considered by Dell to be the typical workload of the server, a heavy workload was evaluated as sensitivity for the EU geography. The different load modes are described in detail in section 3.2.5.

As expected, the heavy workload scenario increases the overall GWP impacts of the lifecycle and shifts the burden more towards the use phase of the product.

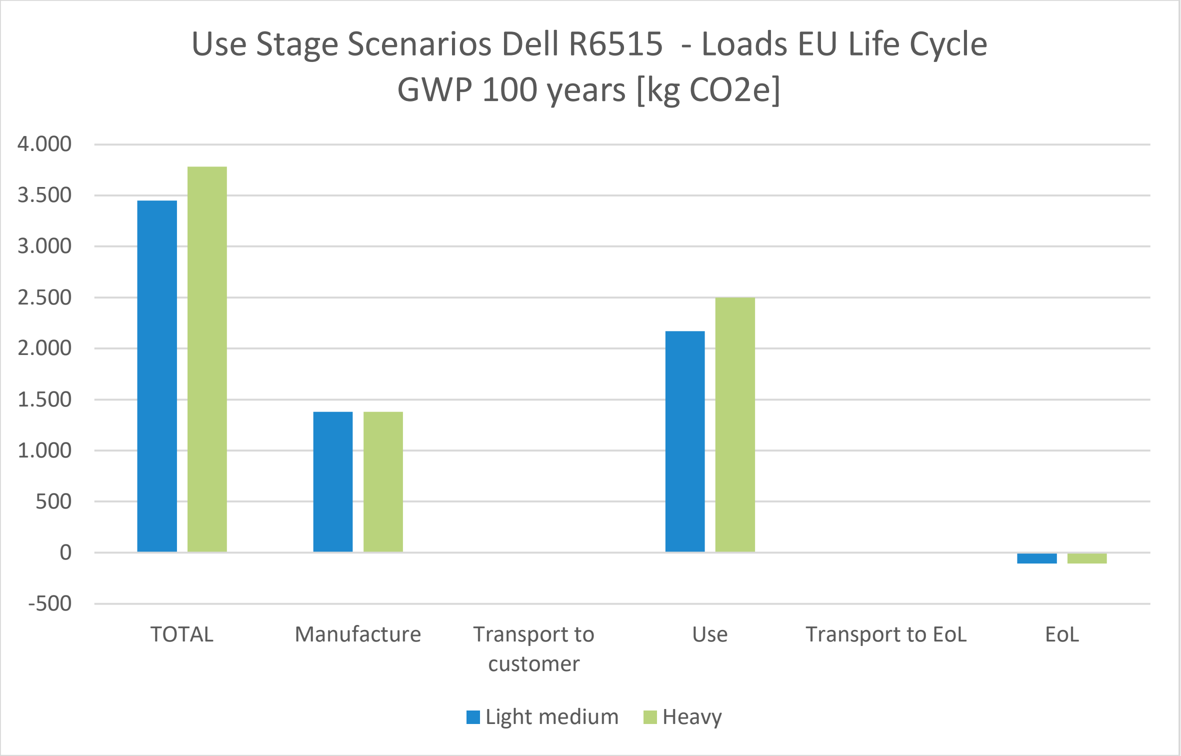


Figure 4-19: Global Warming Potential of the Dell R6515 for the two considered workloads

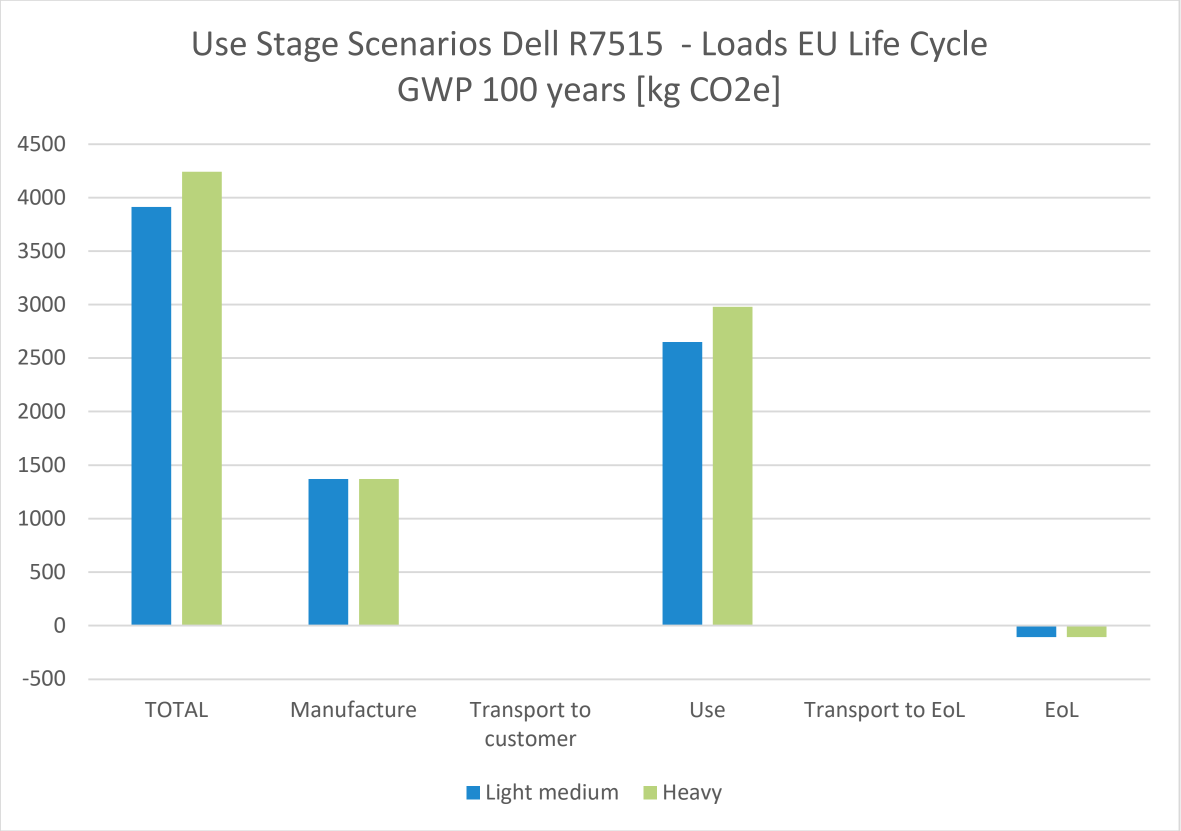


Figure 4-20: Global Warming Potential of the Dell R7515 for the two considered workloads

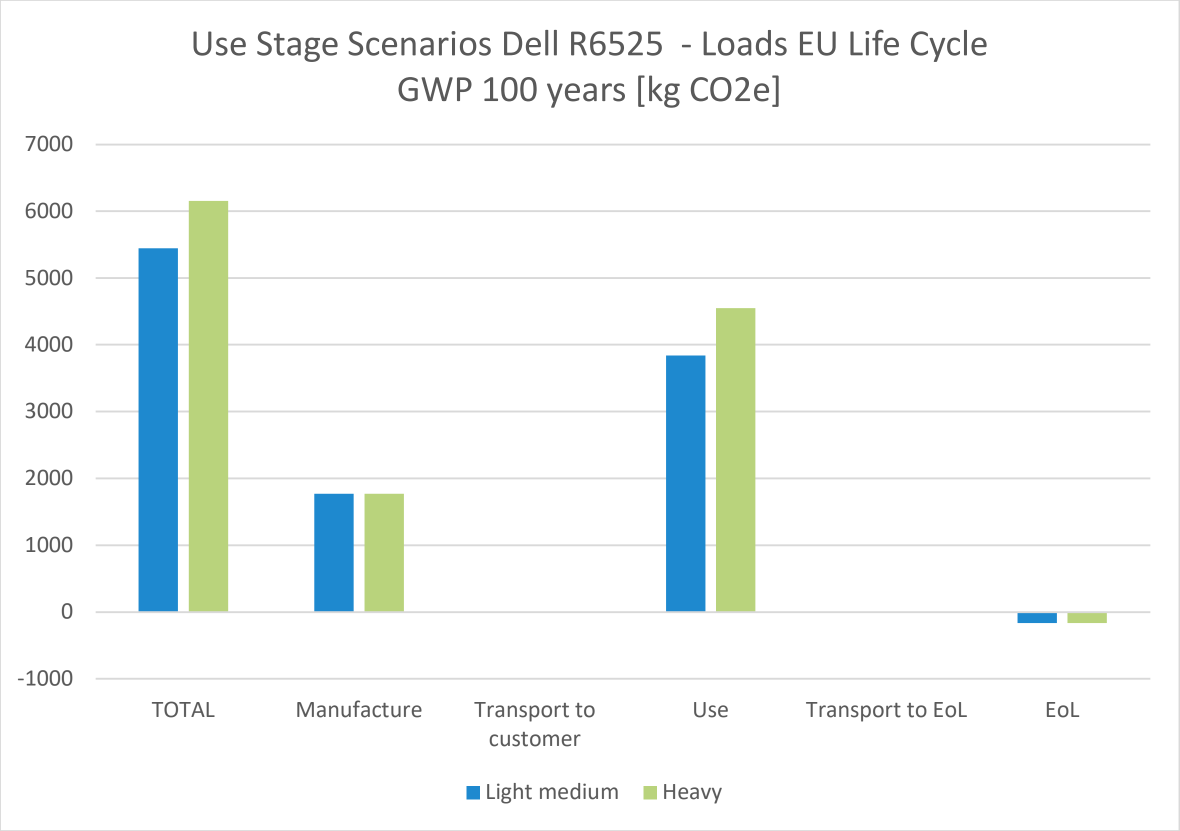


Figure 4-21: Global Warming Potential of the Dell R6525 for the two considered workloads

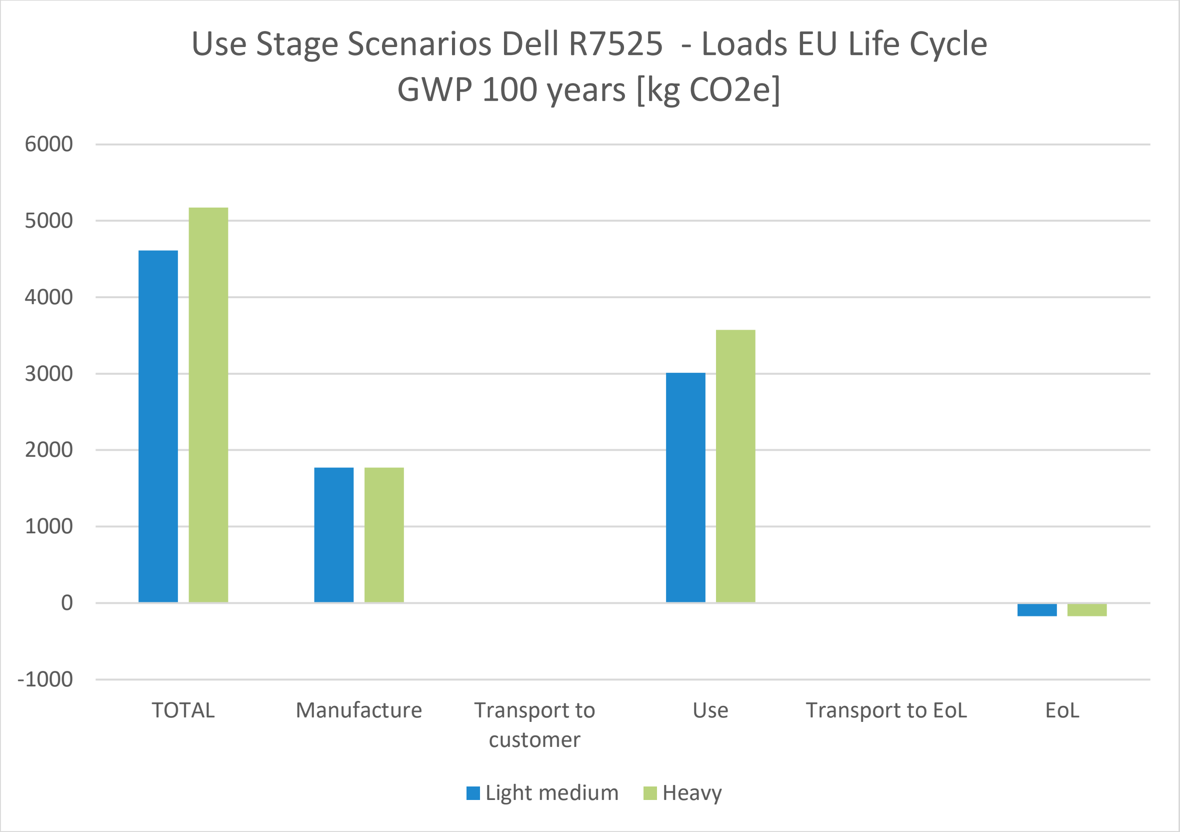


Figure 4-22: Global Warming Potential of the Dell R7525 for the two considered workloads

The detailed evaluation of the use phase and its different load modes shows that the shares, as expected, correspond directly with the amount of time the server runs in the different modes.

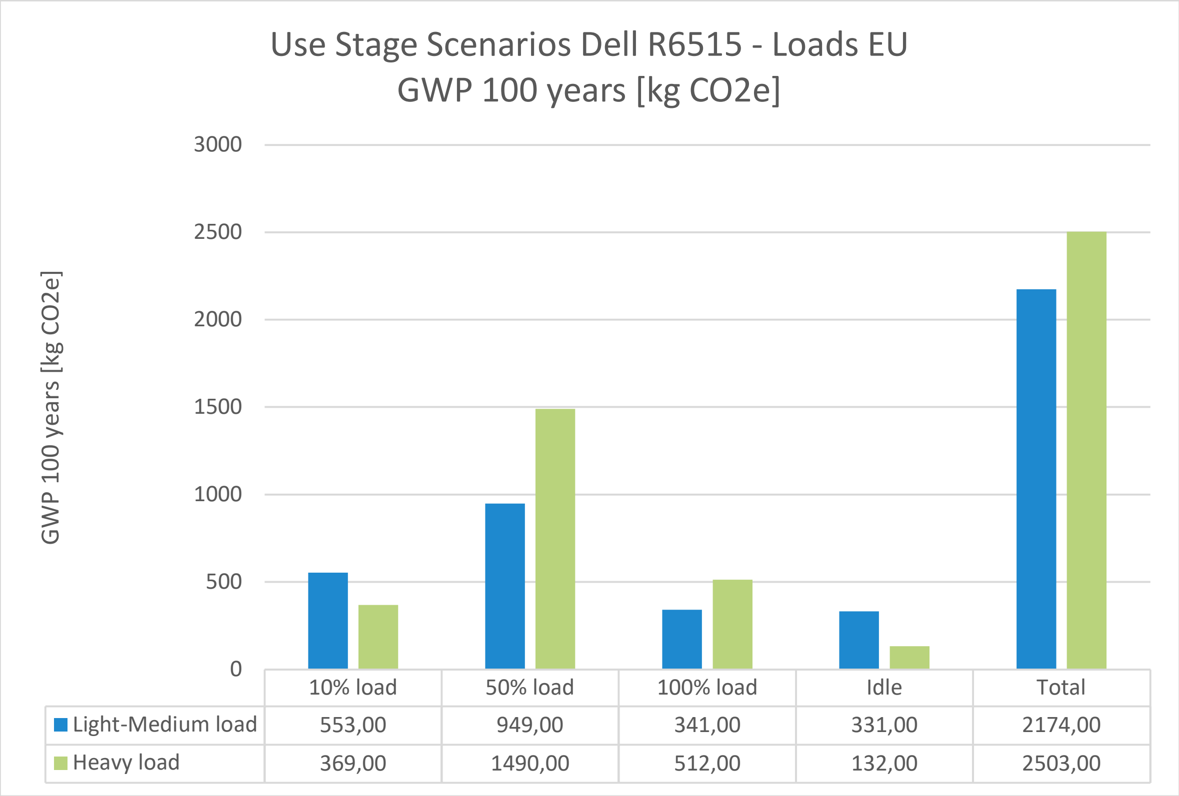
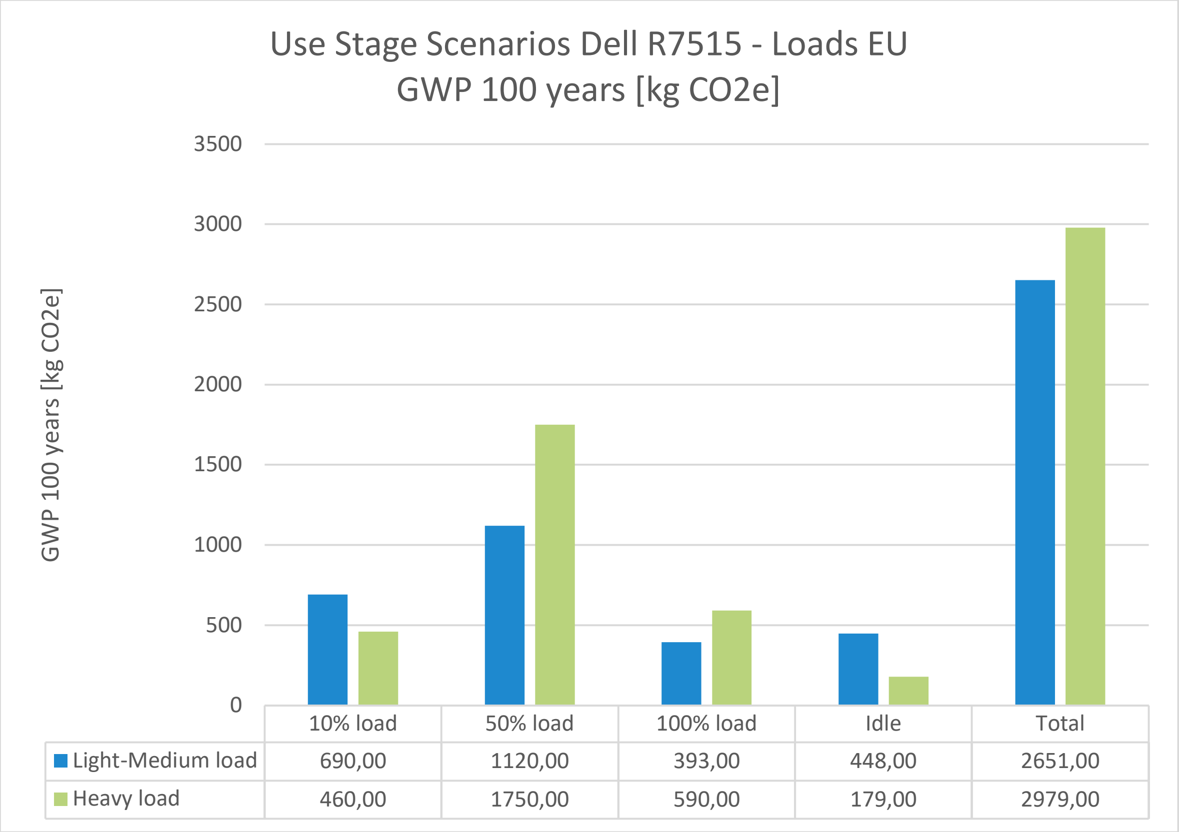
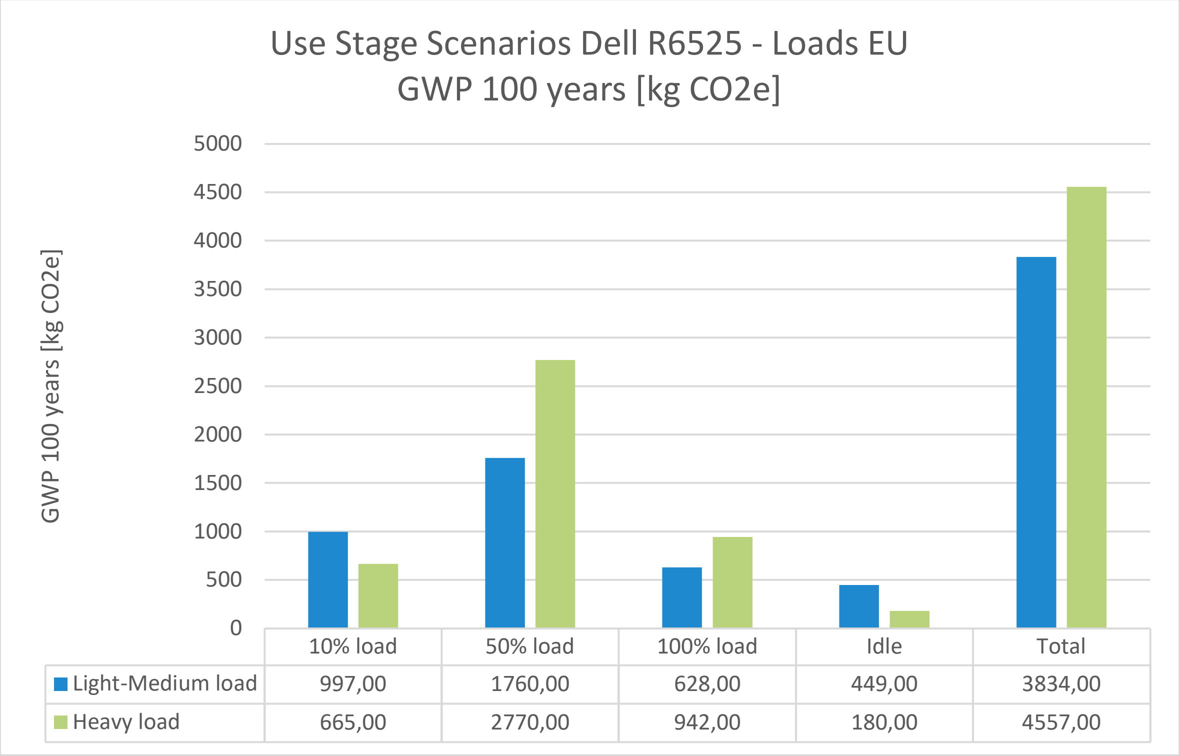


Figure 4-23: Global Warming Potential of use stage of the Dell R6515 in the two considered workloads



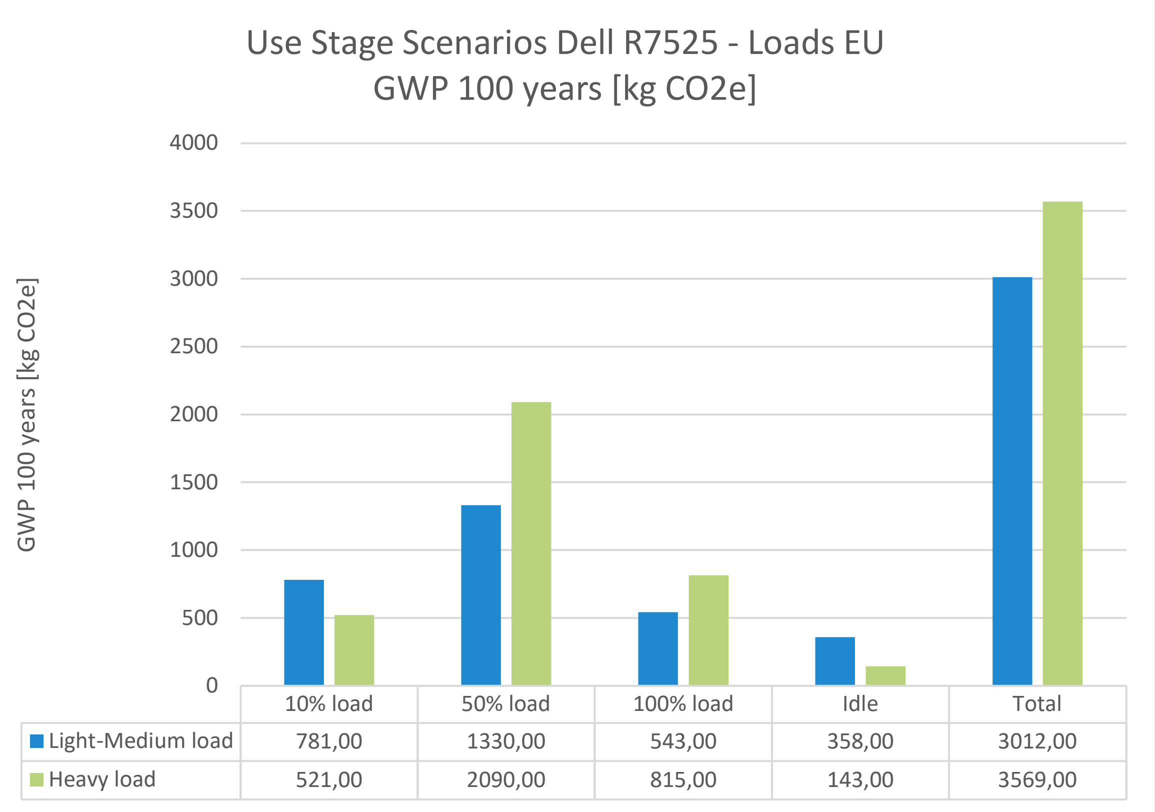
	10% load	50% load	100% load	Idle	Total
🟦 Light-Medium load	690,00	1120,00	393,00	448,00	2651,00
🟩 Heavy load	460,00	1750,00	590,00	179,00	2979,00

Figure 4-24: Global Warming Potential of use stage of the Dell R7515 in the two considered workloads



	10% load	50% load	100% load	Idle	Total
🟦 Light-Medium load	997,00	1760,00	628,00	449,00	3834,00
🟩 Heavy load	665,00	2770,00	942,00	180,00	4557,00

Figure 4-25: Global Warming Potential of use stage of the Dell R6525 in the two considered workloads



	10% load	50% load	100% load	Idle	Total
🟦 Light-Medium load	781,00	1330,00	543,00	358,00	3012,00
🟩 Heavy load	521,00	2090,00	815,00	143,00	3569,00

Figure 4-26: Global Warming Potential of use stage of the Dell R7525 in the two considered workloads

4.4. End of Life (EoL) of the Dell Servers

Recycling of the Dell Servers results in a credit of approximately 106 to 172 kg CO_2eq., depending on the product considered, which corresponds to a reduction of approximately 2% to 4% of the total product's life cycle impact, depending on the product.

Table 4-6 shows the impacts and credits associated with the end of life treatment of the server assuming the values provided by Wisetek (section 3.2.6). 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 aluminium 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 Figure 4-7 it is shown that some components (printed circuit boards) have a smaller contribution in terms of weight, but a higher contribution in terms of environmental impacts, due to the precious metals contained. Therefore, 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).

Table 4-6: Net results of recycling the server constituent materials

		Net results (GWP 100 years) [kg CO2e]			
		R6515	R7515	R6525	R7525
Mechanical Recycling	Aluminium	-2,1	-2,1	-4,2	-4,2
	Steel	-19,1	-21,0	-19,1	-20,8
Wastepaper	Paper packaging	-2,6	-2,7	-2,6	-2,6
Thermal treatment	Thermal recycling, Plastic	1,7	1,8	1,7	1,7
Shredding	Power	0,35	0,35	0,56	0,55
Post-shredding mechanical recycling	Copper	-3,5	-3,6	-6,2	-6,1
	Gold	-78,7	-79,4	-137,0	-137,4
	Palladium	-2,5	-2,5	-3,4	-3,4
	PWB (incineration of substrate)	0,60	0,50	0,80	0,80
	Silver	-0,06	-0,06	-0,09	-0,09
	Platinum	-0,09	-0,09	-0,12	-0,12
Landfill	Emission from inert wastes	0,04	0,04	0,04	0,04
Total		-105,96	-108,76	-169,60	-171,62

5 Interpretation

5.1 Identification of Relevant Findings

- Considering the overall results, the two regions have different contributions to the global life cycle. Regarding carbon footprint, the US scenario has approximately 25% higher impact than the European one in all the products, due to the differences in the electricity grid mix and fuel used, as well as distances travelled.
- Depending on the considered server, the use phase contributes between 64% and 71% to the total carbon footprint in the case of Europe and 71% to 77% in the case of US. During the use phase, the source of electricity determines the environmental impact, as the pattern is considered identical in both the US and EU scenarios.
- The share of Greenhouse gas emissions of the manufacturing stage ranges from 28% to 39% (19% to 39% if the Heavy Use US scenario, which is not shown in detail, is considered) depending on the scenario and whether a light-medium or a heavy use scenario in the use stage is considered.
- The transport to assembly, depending on the components, can be local transport with a truck accompanied be either air transport from China or ship transport. Avoiding the transport of components or products by air is highly recommended, as air transport has much higher impact than ground or sea transport.
- Regarding the manufacturing stage, for all products, 96% to 97% of the part production impacts come from the components containing electronics, which account for only 31% to 26% of the total mass of the products. The chassis dominate the mass of the products (41% to 46%) but the impact per unit is relatively low (~1% of part production). By contrast, the SSDs contribute only ~1% 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 SSDs used within the configuration of the servers dominate therefore the impacts in the manufacturing phase, contributing between 48% and 62% depending on the product.
- After the SSDs, the main contributor to the part production impacts is for all the products, the memory bars, which account with 19% to 30% of the total impacts. For the memory bars, the impact of the semiconductors is dominant.
- An identical motherboard is used the servers R6515 and R7515, which accounts for 11% of the total impacts, and another motherboard is used in the servers R6525 and R7525, accounting with 16% of the total impacts. The CPUs (1 for R6515 and R7515, 2 for R6525 and R7525) are included in this share.
- The chassis is the highest non-electronic component contributing to GWP in the manufacturing stage, with between around 34 and 38 kg CO2-equivalents, depending on the product. The contribution to the total mass and carbon footprint from this component demonstrate that steel production is not particularly high impact, especially when comparing with electronic components.
- Recycling given the primary data provided by Wisetek resulted in a net reduction of approximately 105 and 172 kg CO2-equivalents depending on the product. This represents a reduction of the total impact by around 3%.
- Considering the net gains from recycling, the largest gain comes from the recycling of gold (between 74% and 81%, depending on the server), followed by steel (~11% and 18% of the total net

gain, depending on the server). The recycling benefit from aluminium is very high, but the aluminium content is lower than that of steel in the chassis (leading to ~2% to 4% of total net gain overall).

5.2 Assumptions and Limitations

The way this study is conducted (including the data collection) is based on an analysis of the results of the server R740 (thinkstep, 2019). Therefore it is partly based on the collection of new data (e.g. the mainboards, memory bars, see Figure 3-1) and partly based on assumptions and GaBi plans based on the R740 study (see e.g. Table 3-2 to Table 3-5). The assumptions are mentioned within the respective sections of Chapter 3.2.

As the collection of new data for electronic boards was based on pictures provided by Dell, matching of components and datasets was not based on the tear down of a physical product. This procedure leads to limitations, e.g. regarding the size and weight of components and parts. This is of particular importance with regard to the hard drives, which have a high impact on the manufacturing results as there might be differences between SATA and NAND technology.

The data collection and modelling however was supported by regular meetings during the course of the project. Therefore, the study in itself is coherent and comparable to the results for R740.

5.3 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 2021 database were used. The LCI datasets from the GaBi 2021 database are widely distributed and used with the GaBi 10 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.

5.3.1 Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. 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. No data were 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.

5.3.2 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. Based on this information,

any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.3.3 Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2019. All secondary data come from the GaBi 2021 databases and are representative of the years 2015-2019. As the study intended to compare the product systems for the reference year 2021, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **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.

5.4 Model Completeness and Consistency

5.4.1 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.

5.4.2 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 2021 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.5 Conclusions and Recommendations

The high impacts of the SSD and memory bars within these typically and representatively configured Dell Server products exemplifies that the configuration of a server can have a high impact on the environmental results within its lifetime.

This is particularly relevant considering the SSDs and their price per GB, which is becoming more competitive when comparing to traditional HDDs, while offering superior performance. This will most probably increase the share of SSDs in sold products even more and thus increase the shift of the environmental burden from the use phase to the manufacturing stage. This effect was already observed in the previous study for the Dell R740 (thinkstep, 2019) and is also observed in this study.

This, together with the limitations mentioned in Chapter 5.2, leads to the following recommendations:

- Increase of data quality of considered components, by e.g. having access to BOMs
- Focus on the manufacturing part of products and hence more on the supply chain of those components.
- Focus on electronics, especially on parts with high impacts like SSDs and memory bars
- A server sold should be tailored to the needs regarding its specific application to allow for high efficiency probably influencing the electricity consumption during use as well as

avoidance of adding to much components for a rather basic tasks. Guidelines for customers might be helpful to lower environmental impacts. The high modularity offered by Dell already aims at this issue.

For some components like the mainboard a shift in e.g. substrate area or density of packaging might be considered. However, as the servers are supposed to fit in a rack and have a height of 1U or 2U, options might be limited if modularity and heat management is considered.

Looking at potential options from a (post-)consumer perspective, the reuse (or refurbishment) of used SSDs from servers 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).

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Annex A: Internal Review Statement

Life Cycle Assessment Dell Servers R6515, R7515, R6525, R7525 conducted in February 2021

Dell Technologies Inc. commissioned Sphera GmbH to conduct Life Cycle Assessment of Dell Servers R6515, R7515, R6525, R7525 for meeting the requirements of EPEAT standard regulations. Dr. Rajesh Kumar Singh, Senior Director, Sustainability Consulting, Sphera India has performed the independent review to this study. An independent critical review was carried out in line with requirements of ISO 14044, section 6.2.and also in conformance to the verification requirement 12.5.1.

The review of the study was performed to demonstrate conformance with the following standards:

- 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:

1. The methods used to carry out the LCA are consistent with the international standards ISO14040 and ISO 14044
2. The methods used to carry out the LCA are scientifically and technically valid
3. The data used are appropriate and reasonable in relation to the goal of the study
4. The interpretations reflect the limitations identified and the goal of the study
5. 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. This review is valid for the report issued in Feb 2021.

Review Process:

The review process was coordinated between Sphera GmbH team and the independent internal critical reviewer. The review process was commenced with the call on 10th February 2021 with the introduction of project with the reviewer. Goal, scope, system boundary and key outcomes were presented in the call and the overall timeframe and review process were discussed and agreed. This was followed by provisioning of the first draft of the final report on 11th February 2021 for comment and the reviewer further submitted a first round of comments of general, technical and editorial in nature on 19th February 2021. A systematic approach has been followed to ensure that every comment raised was satisfactorily addressed and concluded. A final updated report incorporating all the proposed changes was received on 23rd February 2021. The reviewer checked the implementation of the comments while closing down all comments. Review call was also held to address the actions taken as a result of the review comments and facilitated both stakeholders in reaching common understanding on remaining open or unclear aspects. All comments were adequately addressed and the related modifications in the report completed.

General Evaluation:

This evaluation is based on the final report received on February 23rd 2021. 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 such server products being placed on the market. A significant effort has been carried out to collect the data for the specified products with a good focus on mainboards which are highly populated on both sides with considerable amount of electronics. Study is conducted (including the data collection partly based on collection of new data ad partly based on assumptions and GaBi plans of R740 study) is based on analysis of the results of the server R740 (thinkstep, 2019).

The system under study was very carefully defined, modelled and report is well written and contains adequate results. The defined scope for this LCA study was found to be appropriate to achieve the stated goals. Various assumptions were addressed and backed by sensitivity analyses of critical data and methodological choices. The team went to great lengths to itemise every single component included in the system for inclusion in the models. Use stage assessment for various load profiles and working modes have been assessed appropriately. High quality of background datasets for the components and parts applied. Any major assumptions which had a significant bearing on the results, including the impacts of SSD and memory cards and portion of time spent in different modes during the use phase, are well justified and a range of figures are used for both.

It is also appropriate to include scenarios for both North America and Europe which considers the 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/ NAND flash and memory card. The report correctly identifies this as an area that warrants further investigation. The evaluation is comprehensive and includes considerate completeness, sensitivity and consistency checks. The report is prepared to a high standard.

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 plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed. The assumptions are transparently described and are found to be suitable and acceptable concerning the conclusions. The study is reported in a comprehensive manner and is transparent in its scope and methodologically choice. As the Independent Reviewer, I confirm that I have sufficient knowledge and experience of electronic products, the ISO standards and the geographical areas intended to carry out this review.

Dr. Rajesh Kumar Singh

February 25, 2021

Annex B: Background Data

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	KR	Electricity grid mix	Sphera	2020	No
	MX	Electricity grid mix	Sphera	2020	No
	MY	Electricity grid mix	Sphera	2020	No
	SG	Electricity grid mix	Sphera	2020	No
	TW	Electricity grid mix	Sphera	2020	No
Electronic	GLO	Assembly line SMD (1SP, 2CS, 1CP, 1R, 1Rf) throughput 300/h	Sphera	2020	No
	GLO	Assembly line SMD (1SP,1CS,1Rf) throughput 300/h	Sphera	2020	No
	GLO	Assembly line THT/SMD (1TP,1SP,1CS,1WO,1Rf) throughput 300/h	Sphera	2020	No
	GLO	Cable 1-core signal 24AWG PE (4.5 g/m) D1.4	Sphera	2020	No
	GLO	Cable 2-core audio headphone 32AWG PVC (2 g/m) D1.4	Sphera	2020	No
	GLO	Cable 4-core audio headphones with mic 32AWG PVC (4.7 g/m) D2.0	Sphera	2020	No
	GLO	Cable USB2.0 28AWG PE/PVC (18 g/m) D4.2	Sphera	2020	No
	GLO	Camera module (CMOS sensor)	Sphera	2020	No
	GLO	Capacitor Al-capacitor radial THT (110mg) D3x5	Sphera	2020	No
	GLO	Capacitor Al-capacitor radial THT (5.65g) D12.5x30	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 01005 (0.054mg) D 0.4x0.2x0.22 (Base Metals)	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 01005 (0.054mg) D 0.4x0.2x0.22	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 0201 (0.17mg) D 0.6x0.3x0.3 (Base Metals)	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 0201 (0.17mg) D 0.6x0.3x0.3	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 0603 (6mg) D 1.6x0.8x0.8 (Base Metals)	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 0603 (6mg) D 1.6x0.8x0.8	Sphera	2020	No
	GLO	Capacitor ceramic MLCC 1210 (50mg) D 3.2x1.6x1.6 (Base Metals)	Sphera	2020	No
	GLO	Capacitor film-capacitor unboxed RM15 (2.6g) 15x7x12	Sphera	2020	No
	GLO	Coil miniature wound SRR0804 (580mg) D10.5x3.8	Sphera	2020	No
	GLO	Coil multilayer chip 0402 (1mg) 1x0.5x0.5	Sphera	2020	No

	GLO	Connector board-to-board 0.4mm-pitch SMD 60-pin plug (25mg) 15x2.6x1.0mm	Sphera	2020	No
	GLO	Connector board-to-board 0.4mm-pitch SMD 60-pin socket (56mg) 15x2.6x1.0mm	Sphera	2020	No
	GLO	Connector coaxial micro-miniature W.FL SMD plug (18.6mg) 2.0x3.7x1.15mm	Sphera	2020	No
	GLO	Connector coaxial micro-miniature W.FL SMD socket (5.6mg) 1.7x1.7x0.85mm	Sphera	2020	No
	GLO	Connector D-sub DE-9 (RS-232/serial) 9-pin socket (7.2g) (gold-plated)	Sphera	2020	No
	GLO	Connector IC single-row (2 g, 10 pins)	Sphera	2020	No
	GLO	Connector PATA	Sphera	2020	No
	GLO	Connector PCI (2,6 g, 72 pins, gold plated)	Sphera	2020	No
	GLO	Connector RJ45/8P8C ethernet EMI/RFI shielded 8-pin socket (3.6g) (gold-plated)	Sphera	2020	No
	GLO	Connector SATA/SAS	Sphera	2020	No
	GLO	Connector Steck Klemme Leiste (3 g, 2 pins)	Sphera	2020	No
	GLO	Connector Steck Rck Einpress Male (4,2 g, 55 pins, gold plated)	Sphera	2020	No
	GLO	Connector SIM card mini THT/SMD socket (1.1g) 26x18x1.8mm	Sphera	2020	No
	GLO	Connector TRS 3,5 female (15 g, 1 pin, gold plated)	Sphera	2020	No
	GLO	Connector TRS 3,5 male (2,4 g, 1 pin)	Sphera	2020	No
	GLO	Connector USB micro (2,5 g, 4 pins, gold plated)	Sphera	2020	No
	GLO	Connector USB micro-AB THT/SMD 5-pin socket (260mg) 7.5x5.0x2.5mm	Sphera	2020	No
	GLO	Connector USB mini 5-pin socket (760mg) (gold-plated)	Sphera	2020	No
	GLO	Connector USB type A (1,6 g, 4 pins, gold plated)	Sphera	2020	No
	GLO	Connector USB Type-A 4-pin plug (9.2g) (gold-plated) 36x12x4.5mm	Sphera	2020	No
	GLO	Connector USB Type-B 4-pin socket (2.8g) (gold-plated)	Sphera	2020	No
	GLO	Connector wire-to-board IDC 2.54mm-pitch 2x10 (20-pin) cable-mounted socket (3.3g) (gold-plated)	Sphera	2020	No
	GLO	Diode power THT DO201 (1.12g) D5.3x9.5	Sphera	2020	No
	GLO	Diode power THT DO35 (150mg) D1.76x3.77	Sphera	2020	No
	GLO	Diode signal SOD123/323/523 (1.59mg) 0.8x0.75x1.6 with Au-Bondwire	Sphera	2020	No
	GLO	Diode signal SOD123/323/523 (9.26mg) 2.4x1.6x1 with Au-Bondwire	Sphera	2020	No
	GLO	Filter SAW (25mg) 3x7x1	Sphera	2020	No
	GLO	IC BGA 48 (72mg) 8x6 mm MPU generic (130 nm node)	Sphera	2020	No

	GLO	IC BGA 672 (6.6g) 27x27 mm CMOS (14 nm node)	Sphera	2020	No
	GLO	IC PLCC 20 (751mg) 9x9 mm CMOS logic (250 nm node)	Sphera	2020	No
	GLO	IC SO 8 (76mg) 4.9x3.9 mm CMOS logic (90 nm node)	Sphera	2020	No
	GLO	IC SSOP 24 (123mg) 8.2x5.3 mm CMOS logic (65 nm node)	Sphera	2020	No
	GLO	IC TSOP 28 (232mg) 8x13.4 mm flash (45 nm node)	Sphera	2020	No
	GLO	IC TSSOP 8 (23mg) 3x3 mm flash (45 nm node)	Sphera	2020	No
	GLO	IC TSSOP 16 (59mg) 4.4x5.0 mm flash (45 nm node)	Sphera	2020	No
	GLO	IC TSSOP 48 (187mg) 6.1x12.5 mm flash (45 nm node)	Sphera	2020	No
	GLO	IC TQFP 32 (146mg) 5x5 mm MPU generic (130 nm node)	Sphera	2020	No
	GLO	IC WLP CSP 49 (10.2mg) 3.17x3.17x0.55mm CMOS logic (14 nm node)	Sphera	2020	No
	GLO	IC WLP CSP 49 (10.2mg) 3.17x3.17x0.55mm CMOS logic (22 nm node)	Sphera	2020	No
	GLO	IC WLP CSP 49 (10.2mg) 3.17x3.17x0.55mm MPU generic (130 nm node)	Sphera	2020	No
	GLO	Key switch tact (242mg) 6.2x6.3x1.8	Sphera	2020	No
	GLO	LED SMD low-efficiency max 50mA (35mg) without Au 3.2x2.8x1.9	Sphera	2020	No
	GLO	Liquid Crystal Display (LCD), Panel Assembly LED TFT, mixed TN-IPS technology	Sphera	2020	No
	GLO	Lithium cobalt oxide cell (LiCoO2, LCO) - incl. housing, scaled up to 1 kg	Sphera	2020	No
	GLO	Micro Speaker (2g, dynamic, Nd magnet, SMD)	Sphera	2020	No
	GLO	Oscillator crystal (500mg) 11.05x4.65x2.5	Sphera	2020	No
	GLO	Phosphor bronze sheet part	Sphera	2020	No
	GLO	Printed Wiring Board 10-layer rigid FR4 with chem-elec AuNi finish (Subtractive method)	Sphera	2020	No
	GLO	Printed Wiring Board 1-layer rigid FR4 with chem-elec AuNi finish (Subtractive method)	Sphera	2020	No
	GLO	Printed Wiring Board 2-layer rigid FR4 with chem-elec AuNi finish (Subtractive method)	Sphera	2020	No
	GLO	Resistor flat chip 0603 (1.9mg)	Sphera	2020	No
	GLO	Resistor thick film flat chip 01005 (0.04mg)	Sphera	2020	No
	GLO	Resistor thick film flat chip 0201 (0.15mg)	Sphera	2020	No
	GLO	Resistor thick film flat chip 0402 (0.75mg)	Sphera	2020	No
	GLO	Resistor thick film flat chip 1206 (8.9mg)	Sphera	2020	No
	GLO	Ring Core Coil 8g (With housing)	Sphera	2020	No
	GLO	Thermistor SMD NTC 0402 (ca. 4mg)	Sphera	2020	No

	GLO	Thermistor SMD NTC 0603 (6mg)	Sphera	2020	No
	GLO	Thermistor THT NTC, Leaded Disk (120mg) D2.5x43	Sphera	2020	No
	GLO	Transistor power THT/SMD SOT93/TO218 3 leads (4.70g) 15.5x12.9x4.7	Sphera	2020	No
	GLO	Transistor signal SOT23 8 leads (18mg) 1.4x3x2	Sphera	2020	No
	GLO	Gold, primary (in Electronics)	Sphera	2020	No
	GLO	Housing IC	Sphera	2020	No
	DE	Lead frame	Sphera	2020	No
	GLO	Printed Wiring Board 2-layer rigid FR4 with chem-elec AuNi finish (Subtractive method)	Sphera	2020	No
	GLO	Semiconductor manufacturing CMOS logic 14 nm tech node	Sphera	2020	No
	GLO	Semiconductor manufacturing CMOS logic 45 nm tech node	Sphera	2020	No
	GLO	Semiconductor manufacturing DRAM 57 nm tech node	Sphera	2020	No
	GLO	Semiconductor manufacturing flash memory 45 nm tech node	Sphera	2020	No
	GLO	Solder paste SnAg3.5	Sphera	2020	No
Fabrication	GLO	Plastic extrusion profile	Sphera	2020	No
	GLO	Copper wire (0.6 mm)	Sphera	2020	No
	GLO	Plastic Film (PE, PP, PVC)	Sphera	2020	No
	GLO	Plastic injection moulding part (unspecific)	Sphera	2020	No
	GLO	Punching steel sheet small part	Sphera	2020	No
	RER	Copper sheet rolling	Sphera	2020	No
	CN	Aluminium die cast part, machined	Sphera	2020	No
Metal	CN	Aluminum ingot	IAI/ts	2020	No
	CN	Copper Foil (11 μm) for 1 m2	Sphera	2020	No
	CN	Iron oxide (Fe2O3)	Sphera	2020	No
	CN	Magnet Nd-Fe-Dy-B	Sphera	2020	No
	DE	Fixing material screws stainless steel (EN15804 A1-A3)	Sphera	2020	No
	GLO	Copper mix (99,999% from electrolysis)	Sphera	2020	No
	GLO	Steel finished cold rolled coil	Worldsteel	2020	No
Other	CN	Lubricants at refinery	Sphera	2020	No
	EU-28	Tap water	Sphera	2020	No
	EU-28	Water (desalinated; deionised)	Sphera	2020	No
	US	Laminated gorilla glass (0.7 x 0.76 x 0.7 mm)	Sphera	2020	No
Packaging	CN	Corrugated board (75% secondary content)	Sphera	2020	No
	CN	Corrugated board (paper and energy input open)	Sphera	2020	No
	CN	Kraftliner	Sphera	2020	No
	CN	Molded pulp loose from bagasse stand-alone plant case (estimation)	Sphera	2020	No
	CN	Semichemical Fluting	Sphera/ FEFCO	2020	No

	CN	Solid-Bleached sulfate (SBS) coated on one side (estimation)	Sphera	2020	No
	CN	Testliner	Sphera/ FEFCO	2020	No
	DE	Oriented Polypropylene film (OPP)	Sphera	2020	No
	EU-28	Greyboard 50% RC	Sphera	2020	No
	EU-28	Kraft paper (EN15804 A1-A3)	Sphera	2020	No
	US	Paper waste on landfill, post-consumer	Sphera	2020	No
Plastic	CN	Polypropylene granulate (PP) (estimation)	Sphera	2020	No
	DE	Acrylonitrile-Butadiene-Styrene Granulate (ABS) Mix	Sphera	2020	No
	DE	Polybutylene Terephthalate Granulate (PBT)	Sphera	2020	No
	DE	Polycarbonate Granulate (PC)	Sphera	2020	No
	DE	Polyphenylene sulfide granulate (PPS)	Sphera	2020	No
	DE	Silicone rubber (RTV-2, condensation)	Sphera	2020	No
	DE	Toluene diisocyanate (TDI; Phosgenation)	Sphera	2020	No
	EU-28	Ethylene Propylene Diene Elastomer (EPDM)	Sphera	2020	No
	EU-28	Polyether polyol	Sphera	2020	No
	EU-28	Polyurethane foam (PU, flexible)	Sphera	2020	No
	CN	Polyethylene terephthalate granulate (PET via DMT)	Sphera	2020	No
Waste	EU-28	Inert matter (Aluminium) on landfill	Sphera	2020	No
	EU-28	Inert matter (Steel) on landfill	Sphera	2020	No
	EU-28	Inert matter (Unspecific construction waste) on landfill	Sphera	2020	No
	EU-28	Municipal wastewater treatment (mix)	Sphera	2020	No
	EU-28	Plastic waste on landfill	Sphera	2020	No

Annex C: Executive Summary of Dell Server R740 study

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 PowerEdge R740 server. Goals for this ISO 14040/14044 compliant study include:

- Life Cycle Assessment (LCA) of a Dell R740 server 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 computing services capable of handling very demanding workloads and applications, such as data warehouses, ecommerce, AI/Machine Learning, and high-performance computing (HPC) for four years for four years with the following load profile:

- 100% load mode: 10% of the time
- 50% load mode: 35% of the time
- 10% load mode: 30% of the time
- Idle mode: 25% of the time

The reference flow is one (1) Dell PowerEdge R740 server, including its power supply and packaging.

The Dell PowerEdge R740 is 2U, 2-socket platform and was evaluated with the following typical market configuration: 2x Intel Xeon 140W CPUs, 12x 32GB DIMMs, 1x 400GB SSD, 8x 3.84TB SDDs, and 2x 1100W PSUs. The Dell R740 with the given configuration weighs around 29.5 kg including packaging and the data was collected by using a combination of dimensioned photographs and a physical product teardown.

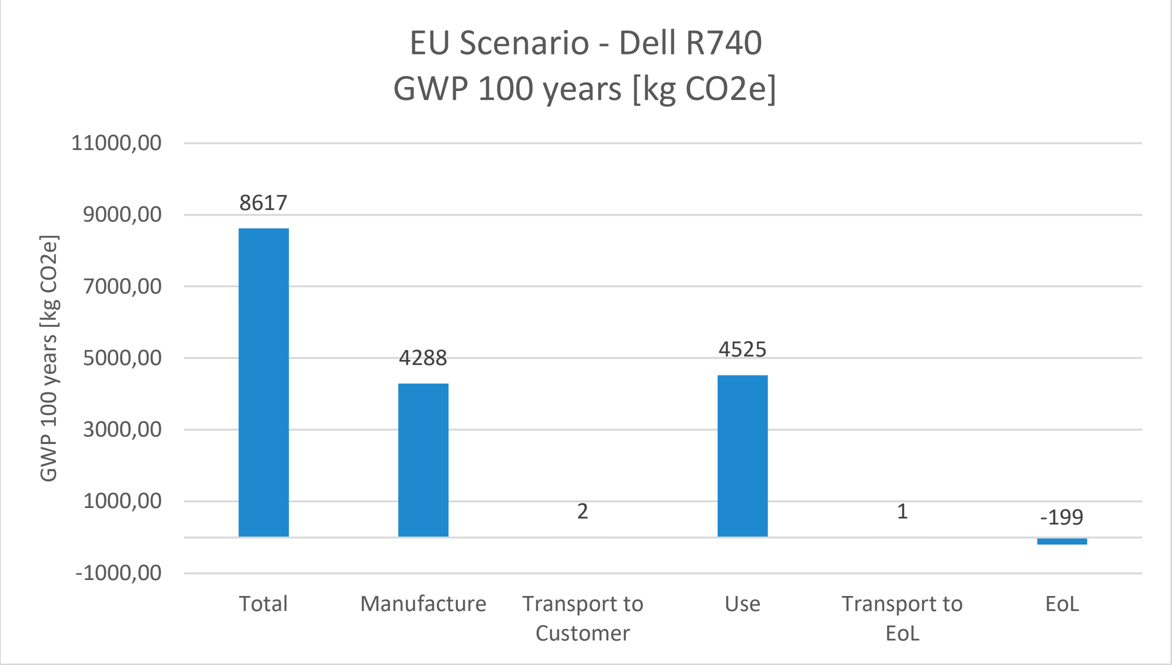
The intended time reference for the study is the 2017 calendar year and the geographical coverage considers both an EU and US in two scenarios.

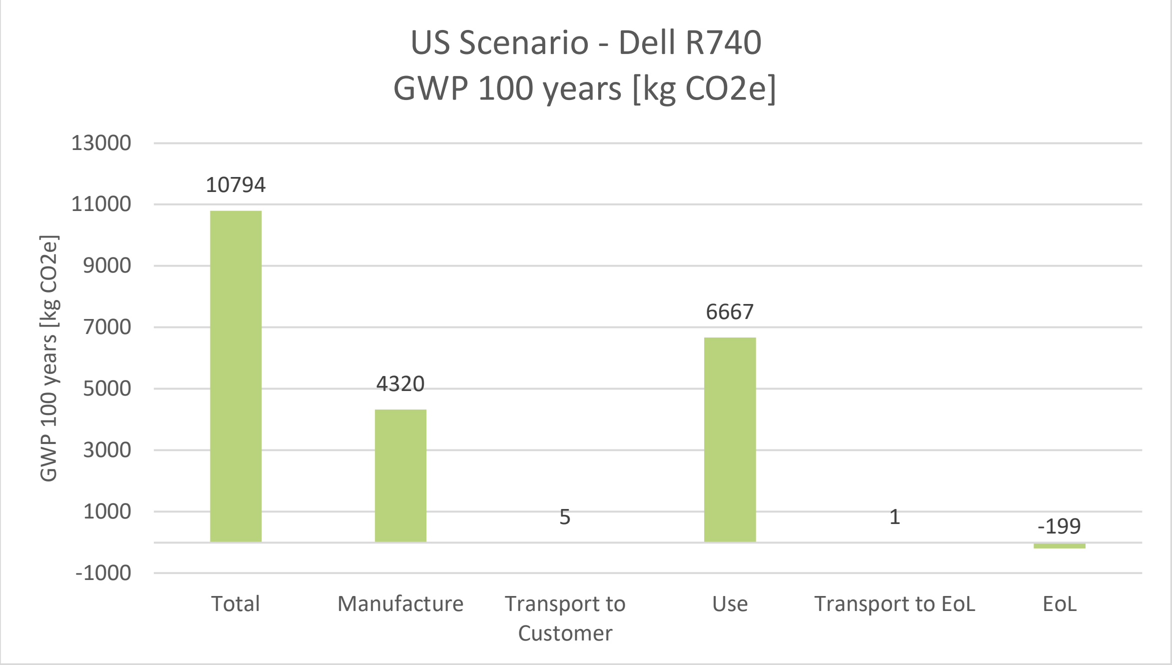
The following table summarizes the results of the study for all considered impact categories.

Impact Category	EU Scenario	US Scenario
Abiotic Depletion [MJ]	9,66E+04	1,30E+05
Acidification Potential [kg SO2 eq.]	3,01E+01	3,88E+01
Eutrophication Potential [kg Phosphate eq.]	2,43E+00	2,37E+00
Ozone Layer Depletion Potential [kg R11 eq.]	5,74E-08	4,67E-08

Photochem. Ozone Creation Potential [kg Ethene eq.]	1,96E+00	2,43E+00
Global Warming Potential 100 years incl. biogenic carbon [kg CO2 eq.]	8,62E+03	1,08E+04

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 98% in both the EU and the US – derives from the manufacturing and the use phase of the Dell R740. 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

2.3% and 1.8% of the life cycle impacts respectively. Overall, the US scenario has approximately 25% 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 30% of the total mass of the Dell R740, and especially the 400GB and 3.84TB SSDs. The biggest contribution of the SSDs comes from the NAND flash, for which several assumptions were made regarding package dimensions, die/package ratio and die stack per package to model these chips. Since the data for these parameters are based on the part number of the chips and publicly available data from Samsung (Gibb, 2016) (PC Watch, 2016), a scenario was calculated that considers different die/package ratios as this parameter is considered to be of the highest uncertainty and impact. The scenarios assume two different die/package ratios of 30% and 80% in addition to the default 60%. Results show that the overall manufacturing impacts of the Dell R740 are reduced by almost 40% if a die/package ratio of 30% is assumed for the nine SSDs built in.

Overall, the results of the present study exemplify that the configuration of a server can have a high impact on the environmental results within its lifetime. This leads to the recommendation to a) increase the data quality of considered components, by e.g. having access to BOMs and b) focus more on the manufacturing part of products and hence more on the supply chain of those components. Looking at this issue from a (post-)consumer perspective, the reuse (or refurbishment) of used SSDs from servers 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).