LIFE CYCLE ASSESSMENT

Ribbon Apollo 9603 and 9408

9603

9408

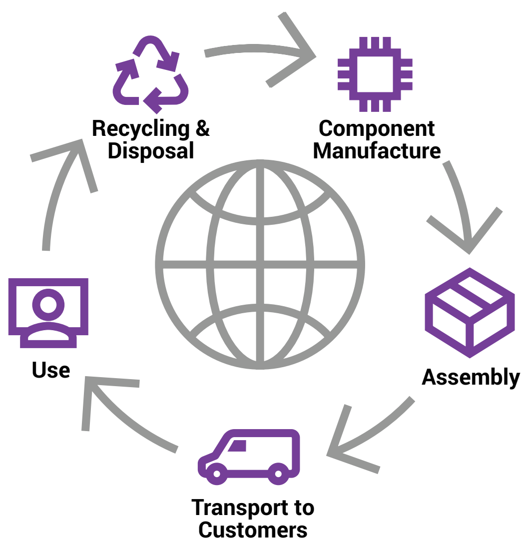
ribbon

9603

9408

1. Review Process

Ribbon is committed to reducing the environmental impacts of our products, covering all stages of the lifecycle. We use lifecycle assessment to find the most significant contributors to the environmental impact of our products and inform our sustainability strategies at the product and corporate level.



What is an LCA?
A life cycle assessment is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle. (ISO 14040:2006, sec 3.2.)

2. Executive Summary

Ribbon commissioned a lifecycle assessment of its Apollo 9603 and 9408 in their most frequently purchased configurations.

The Apollo 9603 and 9408 are optical transport platforms, with the 9603 focused at metro level with the 9408 able to manage metro to ultralong haul duty. Both units have the flexibility to provide a wide range of capacity through the addition of service cards. The 9603 capacity is between 800 Gbs to 4.8 Tbs while the 9408 ranges from 1.6 Tbs to 12.8 Tbs.

The purpose of the study was to identify environmental hotspots which would allow future improvements, provide information on value chain carbon emissions and to meet client needs.

The study is focused solely on Global Warming Potential resulting from emissions over a 100-year timeframe (GWP 100). The system boundaries cover from cradle-to-grave which includes the impacts from raw material resource extraction through to end of life disposal and recycling. The functional unit is the same for both models, although this does not mean the two models should be compared directly. The 9408 has a greater capacity than the 9603 and while there is overlap, they typically occupy different positions within the network. Therefore, there is a separate Functional Unit which has the same parameters. These are 1 unit with a 15 year operational life in the network located in Germany. The load profile for both units is static, as Ribbon Product Engineers advise that, as it is an optical product, load variation does not impact energy consumption. The temperature of the installed environment is advised as being the influential variable regarding energy consumption. However, in a typical datacentre there is likely to be an almost net nil situation. This is on the basis that an increased environmental temperature will reduce the energy consumption of the chillers and associated cooling equipment but will increase the energy consumption of the Apollo through increased fan energy consumption.

The configuration of the Apollo units can be found in Table 1:

Study parameters	9603	9408
Lifetime of the product	15 years	15 years
Use location	Germany	Germany
Cards	1 x TM400_2 card with Dual 400G Transponder/ Muxponder with 100G/200/300/400G D-CFP2 uplink and 2xQSF28/56PDD clients supporting 100GE/400GE/OTU4.	1 x MPQ_8 Octal 400G/800G transponder muxponder
Capacity	800 Gbs	1.6 Tbps
Power Supplies	1 + 1 redundancy	1 + 1 redundancy
Mass (packaged)	22.831 kg	36.882 kg

Table 1 Apollo 9603 and 9408 configurations

Data was collected for each Apollo unit from a Bill of Materials and compared with measured component weights. The energy in use data was sourced from a power meter.

The timeframe for the study is 2024 and the geographical coverage concentrates on deployment in Germany, as it represents the most popular installation location for each variant. To examine sensitivity, a variant in which deployment in New York, USA was also reviewed.

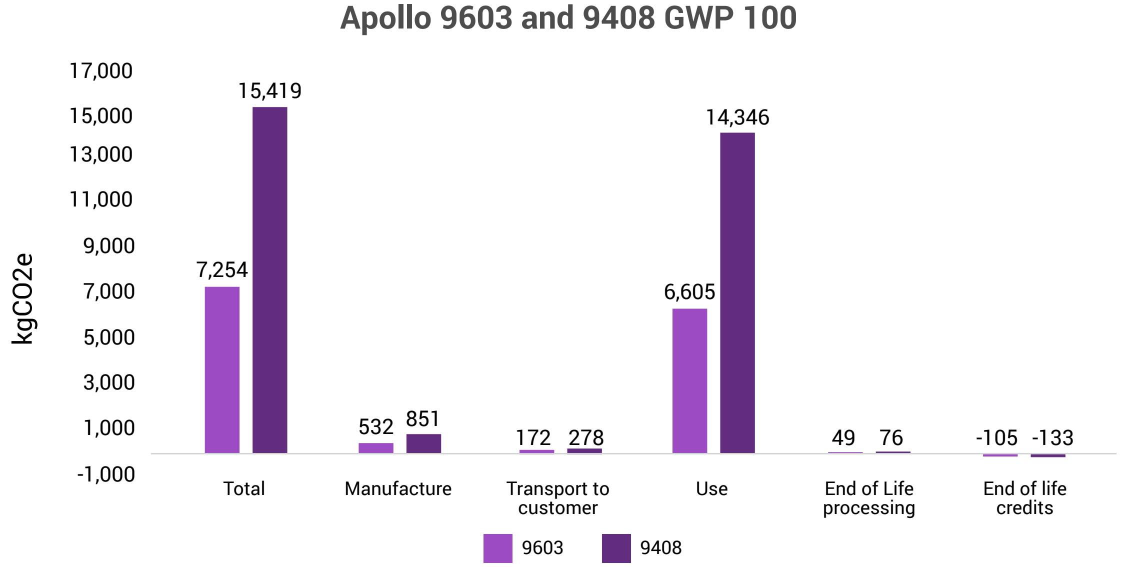


Figure 3 GWP 100 emmissions by lifecycle stage

Figure 1 shows that the use phase dominates the overall lifecycle emissions at 91% for the 9603 and 93% for the 9408. Manufacturing emissions are the next most significant source at 7% for the 9603 and 6% for the 9408. Transport emissions are relatively small, but are dominated by air travel as it is both the longest leg of the journey to the customer and the most impactful per km travelled. The recovery of metals at the end of life, particularly gold results in end of life credits, which offset some of the impacts earlier in the lifecycle.

The manufacturing impacts are dominated by the production of Printed Circuit Boards (PCBs). However, the mass of the PCB and sheet metal, which are the two heaviest components on the BOM, could not be directly determined and so were derived through the estimated area of the PCB for the sheet metal through chassis mass minus component mass. The component masses were predominantly gathered using the Bill of Materials specification and searches via Artificial Intelligence with manual sample checks for accuracy.

Nevertheless, this limitation is not considered significant when assessing the overall conclusions of the study, as in-use energy is significantly higher than the manufacturing stage, and all other lifecycle stages are a fraction of the manufacturing stage. These conclusions are reaffirmed when examining installation in New York. Despite the increase in transport emissions due to the increased distance between the sub-contract manufacturer and the installation location, the carbon intensity of the New York grid means that the lifetime impact of the 9603 decreased from 7,253 kgCO2e to 4,800 kgCO2e. The decrease was similar for the 9408 which decreased by 35% to 10,039 kgCO2e.

The recommendations for improvement for the physical unit centre around addressing energy in use and subsequently major components such as the PCBs and sheet metal weight. As cooling dominates the energy consumption, design choices to improve cooling performance while reducing fan energy consumption is the most impactful way to reduce the overall lifetime impact.

3. Goal of the study

Ribbon Communications commissioned the study with the following goals:

- A full Lifecycle Assessment of a Ribbon Apollo 9603 and 9408 modular optical transport solutions
- Identify product environmental hotspots to focus improvements in future iterations of the product.
- Support the generation of value chain emissions for the Ribbon organisation
- Generate results to respond to customer environmental data requests

The study meets the requirements of ISO 14040:2006 and 14044:2006 lifecycle assessment international standards.

The purpose of the study is not to compare the 9603 and 9408 products and to direct the purchasing of one model over another. The purpose of the single report is to meet similar requests from customers for each model and reflect that the materials, assembly location, transport and methodologies chosen have a significant degree of overlap and, as a result, there is efficiency in providing a single report rather than two separate reports with repetition.

4. Scope of the study

4.1. Apollo 9603 and 9408 Product Systems

The Apollo 9603 and 9408 are optical transport platforms, with the 9603 focused at metro level with the 9408 able to manage metro to ultralong haul duty. Both units have the flexibility to provide a wide range of capacity through the addition of service cards. The 9603 capacity is between 800 Gbs to 4.8 Tbs while the 9408 ranges from 1.6 Tbs to 12.8 Tbs.

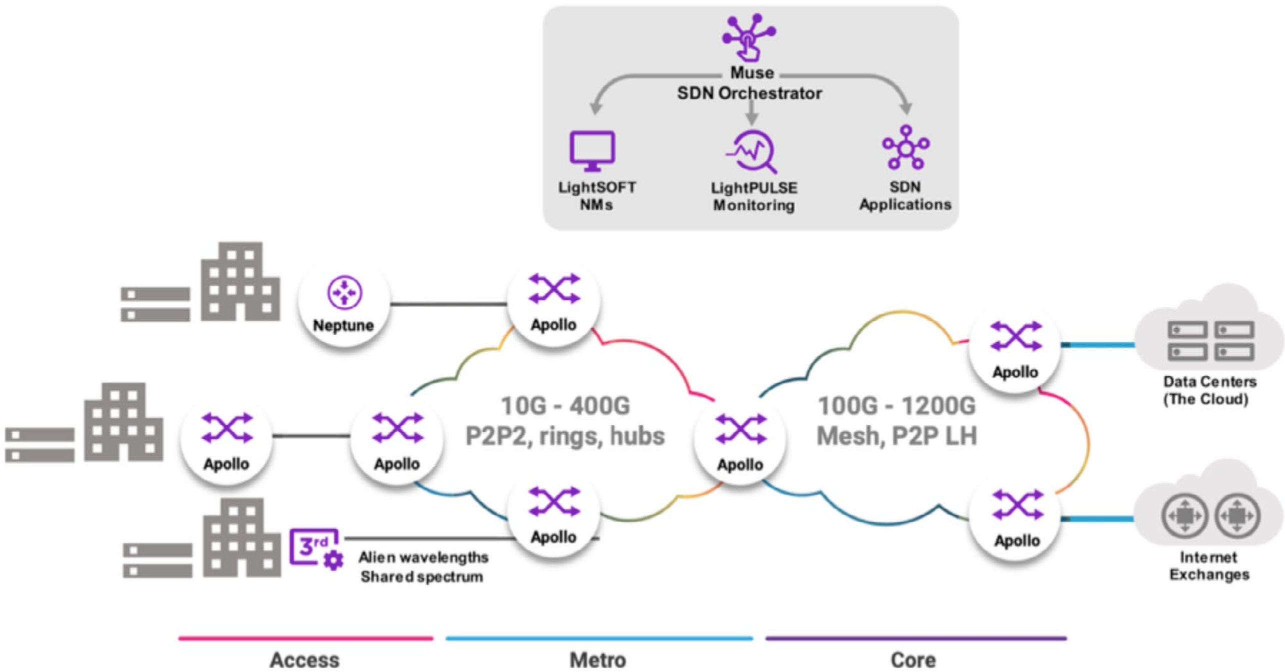


Figure 2 demonstrates the position within the network

Figure 2 demonstrates the position within the network architecture supporting metro and core optical transport.

Figure 3 Ribbon Apollo 9603

The Apollo 9603 is a 2U rackmount unit with 3 slots for interchangeable blades used across the Apollo family. Power supply is possible via 110 V or 230 V AC from 2 x PSUs with 1 + 1 redundancy and a typical power consumption of 128W in the chosen configuration.

Figure 4 Ribbon Apollo 9408

The Apollo 9408 is a high density platform for 100GbE, 400GbE, and future 800GbE transport. It is designed to provide network operators with a low cost per bit for long haul and high traffic density metro applications. Apollo 9408 achieves this by exploiting next generation Jannu 5nm 140G baud transceiver technology. It distinctively features a combination of continuous baud rate and continuous modulation controls that maximize the line rate, from 400G to 1200G.

The 9408 is a 2RU form with 8 single slot or 4 double slot blades. The blades can utilise a variety of cards which vary the capacity and power consumption. The MPQ_4 card chosen as part of this study is designed to high density and lower power consumption. There is full redundancy in terms of the power supply unit as with the 9603.

The configuration chosen for the study is outlined in Table 2. The Ribbon product team defined the configuration chosen based on sales data from the previous 12 months.

Study parameters	9603	9408
Lifetime of the product	15 years	15 years
Use location	Germany	Germany
Cards	1 x TM400_2 card with Dual 400G Transponder/ Muxponder with 100G/200/300/400G D-CFP2 uplink and 2xQSF28/56PDD clients supporting 100GE/400GE/OTU4	1 x MPQ_8 Octal 400G/800G transponder muxponder
Capacity	800 Gbs	1.6 Tbps
Power Supplies	1 + 1 redundancy	1 + 1 redundancy
Mass (packaged)	22.831 kg	36.882 kg

Table 2 Apollo configurations

4.2. Product Functional Unit

This study comprises of 2 parallel studies, so there are 2 functional units.

The first Functional Unit is for 1 x Apollo 9603 performing network communication services over a lifetime with 15 years within the network in Germany. The load profile is advised to be static and independent of network traffic. Variation in electricity consumption is due to differences in the temperature of the operating environment and the number and type of service cards installed.

The functional unit for the 9408 is the same as the 9603.

4.3. System Boundaries

4.3.1. Activity boundaries

The system boundary is defined in Figure 5.

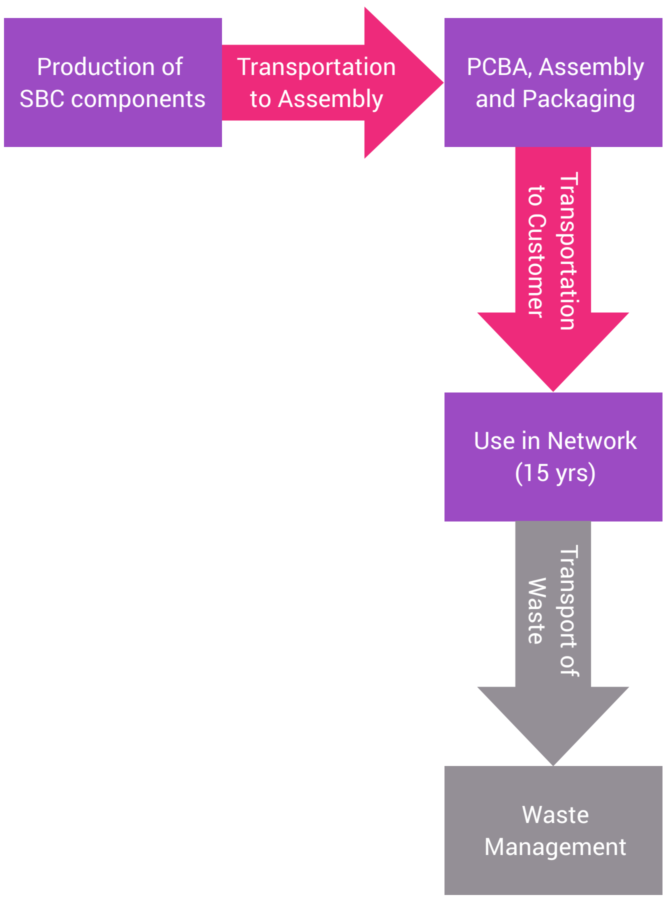


Figure 5 Study systems boundary

The system boundary includes, as is typical with Ecoinvent, the production of capital equipment associated with the manufacture of factories and tooling,

The system boundary excludes factors such as Ribbon employee travel, commuting, administration and impact of R&D related to activities such as physical equipment design and software creation.

Excluded during the use phase is the energy and upstream impacts of the environment in which the Apollo unit will be installed. Primarily this relates to the provision of air conditioning and network infrastructure. Also excluded during this phase is the refurbishment or re-use of parts. Take-back and second-life provision is not a service actively provided by Ribbon. It is possible that an Apollo unit may be moved by the telecommunications provider from one area of the network to another physical location over the 15-year lifecycle, but data on the frequency and distances travelled are not known. As a consequence, this has been excluded from the use phase.

4.3.2. Time Coverage

The reference period for the study is the calendar year 2024, which corresponds to the data provided for manufacture and distribution.

4.3.3. Technology coverage

The study utilises cradle-to-grave impacts based on global market production mixes unless more specific data was considered more appropriate. For example, waste management specific to Europe was chosen due to the installation location.

Primary data was collected from Ribbon based on energy consumption through simulated loads, component data sourced from compliance documentation and transport routes. Primary data relating to the scope 1 and 2 emissions from the subcontract manufacturer was also gained.

4.3.4. Geographical coverage

The geographical coverage considers the following:

- Components are sourced from the Ecoinvent provider which best represents Shenzhen, China
- The components are transported via a combination of truck and container ship from Shenzhen to Thailand for assembly.
- Printed Circuit Board Assembly, unit assembly and packaging take place in Bangkok, Thailand.
- The finished article is transport via a combination of truck and airplane to Frankfurt, Germany.
- The use phase assumes the item is used in Germany.
- Recycling takes place within the EU in accordance with EU regulations in Germany.

A scenario which considers implementation in the US is also included as part of the sensitivity analysis.

4.3.5. Impact categories

The impact category chosen for the study is limited to Global Warming Potential (GWP) over a 100-year period. This is the impact category of most interest to Ribbon stakeholders.

The GWP is assessed using IPCC 2021 characterisation factors from the 6th Assessment Report (IPCC, 2021).

4.4. Allocation

4.4.1. Multi-output allocation

The only identified multi-output process in the system foreground relates to the activities of the subcontract manufacturer. The subcontract manufacturing site produces a variety of products for several organisations. There is no separate metering for utility consumption and benefits from site-level services such as heating, ventilation and cooling. The data provided by the site allowed for the economic allocation of the scope 1 and 2 related emissions based on Ribbon revenue to overall plant revenue.

The background allocation process was chosen to be “as determined by the process” within Ecoinvent 3.10.

4.4.2. End-of-life allocation

Modelling utilised Ecoinvent 3.10 Cut off database. Allocation at the Point of Substitution was trialled in previous LCAs but led to unexpected results primarily relating to the downstream impacts of paper and cardboard recycling and subsequent manufacturing of products unrelated to the foreground system.

End-of-life modelling followed the preferred order of ISO 14044 4.3.4.3 whereby the closed loop/allocation to material losses dominates for activities such as metal recycling. In this approach, credits are given to the lifecycle for the substitution of primary material, and the burdens of the approach are allocated to the lifecycle stage in which the material is lost from the technosphere. The recycling activities to recover the materials to a point whereby they are comparable to primary materials are included within the lifecycle impacts of the product.

4.5. Cut-off criteria

The project included all available energy and material flows identified in the foreground model. The bill of materials included unit masses, areas or other physical data, which was converted to mass wherever possible. For some components, this data was not available, and so expert judgement was utilised to close the gap, ensuring the mass balance was maintained relative to measured assembly weights.

4.6. Interpretation

The interpretation of the LCI and LCIA includes the following aspects:

- Identification of significant parameters and findings
- An assessment of the completeness, sensitivity and consistency of these results
- Conclusions, limitations and recommendations

4.7. Data Quality requirements

To ensure the study allows for reproducibility and is consistent with the goal and scope of the study, data was managed in the following ways:

- Primary data is considered to be the most accurate, followed by calculated data, literature and estimated data
- Ensuring that all relevant input and outputs have been captured and validated against an overall mass and energy balance
- Ensuring that the results are not due to inconsistencies within the modelling methodologies

4.8. Software and Database

The LCA model used OpenLCA v2.5 with Ecoinvent 3.10 which provides the lifecycle inventory information for the background system.

5. Lifecycle Inventory Analysis

5.1. Data Collection Procedure

Primary data was collated from Ribbon staff in the Hardware Engineering and Logistics teams. Further primary data relating to energy inputs in the PCBA and assembly stage was gathered from the sub-contract manufacturer.

The complete finished units were weighed, with a gross and net weight of each major component to represent the packaged and unpackaged weight. A Bill of Materials (BOM) was provided. Wherever possible, the PLM system was interrogated for item weight, but this was rarely successful as this is not data typically required by the Ribbon team. Artificial Intelligence based queries were run on major components such as integrated circuits, memory chips, resistors, transistors, inductors, switches and ports based on the BOM specification for the main chassis and the referenced service card, which were then combined with the BOM quantity. A mass balance exercise was undertaken in which a gap between the measured complete unit mass and the sum of the component masses along with the main components that had not resulted in a weight value in the previous steps. Heat sinks mass was calculated by using data from a reference heat sink and scaled by volume. The volume was calculated in the first instance by using the dimensions which occasionally were defined in the BOM description. For those which did not have the dimensions in the BOM description, an estimate of the area and depth was calculated from equipment drawings. The printed circuit board (PCB) weight was estimated using the area calculated from drawings with an estimated thickness of 0.125 inch which was the thickest PCB used in the SBC LCA. The PCB, in most instances, performed a structural role, which is why the thickest option from a previous product was chosen. Reviewing the BOM for items which had not been allocated a mass the most notable either by size, expected contribution to the overall impact or by volume was sheet metal for the case and mechanical parts such as screws, nuts and stand-offs. The weight for metal parts was calculated as the known total weight minus all the previous components listed above.

Packaging weight by module was provided for cardboard, protective foam and polyethene bag.

The energy in use was based on measured data in the Ribbon laboratory. An average power demand for the 9603 of 128 W and 278 W for the 9408 was used.

The transportation of the completed Apollo unit used known data on shipping routes to calculate the mileage travelled by differing transport modes

The sub-contract manufacturer data collection is discussed in 4.4.1.

5.2 Product Systems

5.2.1. Product Systems

Component	9603		9408	
	Weight (g)	Comments	Weight (g)	Comments
Base chassis	14,567	incl. fan, PSU, heat buffer and spooler	24,948.00	incl. fan, PSU, heat buffer and spooler
Common and Packet Cards	1,260	Dual 400G Transponder Muxponder	2,330	Octal 400G/800G transponder muxponder
Panel blank & accessories	3,496		1,624	
Packaging	3,508		7,980	
TOTAL	**22,831**		**36,882**	

Table 3 Product system breakdown

The main components of the 9603 and 9408 considered in the study are listed above. The following tables provide more details on the main components.

Component	9603		9408	
	Mass (g)	Comments	Mass (g)	Comments
Bead	0.81		0.94	
Capacitors	9.04		10.34	
Diode	1.22		0.95	
Fan	732.00		2,765.00	
Fuse	0.08		0.13	
Heatsink	43.33		179.48	
IC - Memory type	10.60		29.88	
Inductors	30.80		18.20	
Labels	2.00		2.00	
LEDs	1.75		14.00	
Microprocessor	6.42		6.52	
Blank Plate	80.00	Assumed ABS	690.00	Assumed ABS
Port/ Connector	200.49	Estimated	127.49	Estimated
Printed Circuit Board	302.36	Derived	328.42	Derived
PSU	500.00		2,030.00	
Resistors	2.16		3.07	
Screws, nuts, stand-off and sheet metal	12,613.66	Estimated	18,729.21	Estimated
Transformer	30.00		12.00	
Transistor	0.27		0.37	
TOTAL	**14,567.00**		**24,948.00**	
Mass Balance Check	-		-	

Table 4 Main chassis components

Table 4 details the component breakdown by mass and the mass balance check, although a difference in mass would not be expected given the calculation approach. The common cards and optical cards are included in the figures above and use the same calculation approach as the 1100 cards in the NPT LCA.

The breakdown of the main service card components was calculated below, which covers the TM400_2 for the 9603 and the MPQ_8 for the 9408. As each of these cards had its own separate BOM, the calculation approach is the same as described in 5.1.

Component	9603 - TM400_2		9408 - MPQ_8	
	Mass (g)	Comments	Mass (g)	Comments
Bead	0.70		0.63	
Capacitors	11.70		12.95	
Connectors	0.6		0.79	
Diode	0.2		0.29	
Fuse	0.0		0.01	
Heat Sink	440.6		17.12	
IC - Memory type	14.1		23.90	
Inductors	46.2		152.60	
LED	10.0		19.76	
Lightpipe	2.0		8.00	
Microprocessor	10.7		8.61	
Ports	125.0		300.00	
Printed Circuit Board	378.0	Derived	546.51	Derived
Resistors	2.5		2.79	
Sheet Metal	209.7	Estimated	1,235.86	Estimated
Switch	8.0		0.00	
Transistors	0.1		0.19	
TOTAL	1,260		2,330	
Mass Balance Check	-		-	

Table 5 Card components

The packaging breakdown can be found in Table 6. As mentioned previously, the packaged and unpackaged weight was provided which derives the total. The breakdown has then been estimated based on items founds in the bill of materials.

Component	9603		9408	
	Mass (g)	Comments	Mass (g)	Comments
Cardboard	2468.00		3,475.00	
Protective foam	870.00		4,405.00	
Protective bag	170.00		100.00	
TOTAL	3,508.00		7,980.00	
Mass Balance Check	-		-	

Table 6 Packaging data

A list of accessories was provided each Apollo unit, with the breakdown as shown in Table 7.

Component	9603		9408	
	Mass (g)	Comments	Mass (g)	Comments
AC Power cord	340.00		340.00	
ESD equipment	50.00		N/A	
Cable ties	230.00		N/A	
Cable assembly	1400.00		N/A	
Optical patch cord	340.00		680.00	
Circuit Breaker	224.00		N/A	
Support cards	162.00		304.00	
Screw sets	350.00		N/A	
Ground cable	400.00		300.00	
TOTAL	3,496.00		1,624.00	
Mass Balance Check	-		-	

Table 7 Accessories by mass

5.2.2. Component manufacturing

Component manufacturing for most components is managed by the sub-contract manufacturer and is understood to be sourced from China, specifically the Shenzhen area.

Energy data was collected from the sub-contract manufacturer and allocated on an economic basis as discussed in section 4.4.1. To ensure consistent boundaries the following was added to the PCBA and assembly process:

- Silver solder paste at the default rate per m2 of PCB in Ecoinvent. The area was derived from the drawings.
- Emissions relating to the capital equipment production and the sub contract factory. This data used the Ecoinvent desktop computer emissions as a proxy for input flows.

The sub-contract manufacturer is based in Thailand.

5.2.3. Transport

Transport to a customer location in Frankfurt, Germany was used for both models, with New York as the alternative location.

The transport involved a leg by truck from the sub-contract factory to the Bangkok Suvarnabhumi airport to Frankfurt airport. There was an equivalent leg by truck to the Ribbon site in Frankfurt.

For the variant in New York, the first leg of the journey is the same with a longer flight from Bangkok Suvarnabhumi to JFK airport.

5.2.4. Use

The use load profile used for the modelling matches those typically seen when deployed and the level recommended by Ribbon's sales team. Data was collected as described in section 5.1.

Unit	Power (W)	kWh
9603	128	16,819
9408	278	36,529

Table 8 Energy consumption in use

5.2.5. End of Life

The end of life modelling assumes that as the equipment is in a corporate environment the materials will be separated and individually recycled. Ribbon are not responsible for the end of life disposal and so the true fate of the Apollo materials is not known. However, to use municipal waste recycling rates was considered inappropriate given the purchasers of the Apollo are typically organisations with their own sustainability strategies and goals. In the European Union, electronic and electrical equipment must be sent for recycling.

The model assumes that the Apollo unit will travel 200 km to a point where it will be dismantled into the main components such as the steel chassis, fan, PCB and from that point will be transported onwards to specific recycling processes. The location of the recyclers who deal with the specific materials is not known but is assumed to take place in Europe. Ecoinvent markets for recycling activities are utilised as they include transport within the process.

The exact quantities of all the recoverable materials, in particular the metals used in electronic equipment manufacture, such as gold and silver, are not known but were estimated using data on direct consumption based on the components and use of silver solder paste from the Ecoinvent flows.

6. Results

The results of the study are an approximation of the impacts that would occur if all the processes described above were to occur. When using datasets such as Ecoinvent, despite the best efforts for completeness, some fraction of the environmental burden will be unaccounted for in the product system.

6.1. Overall Results

The overall impact across the major lifecycle stages can be seen in Figure 6.

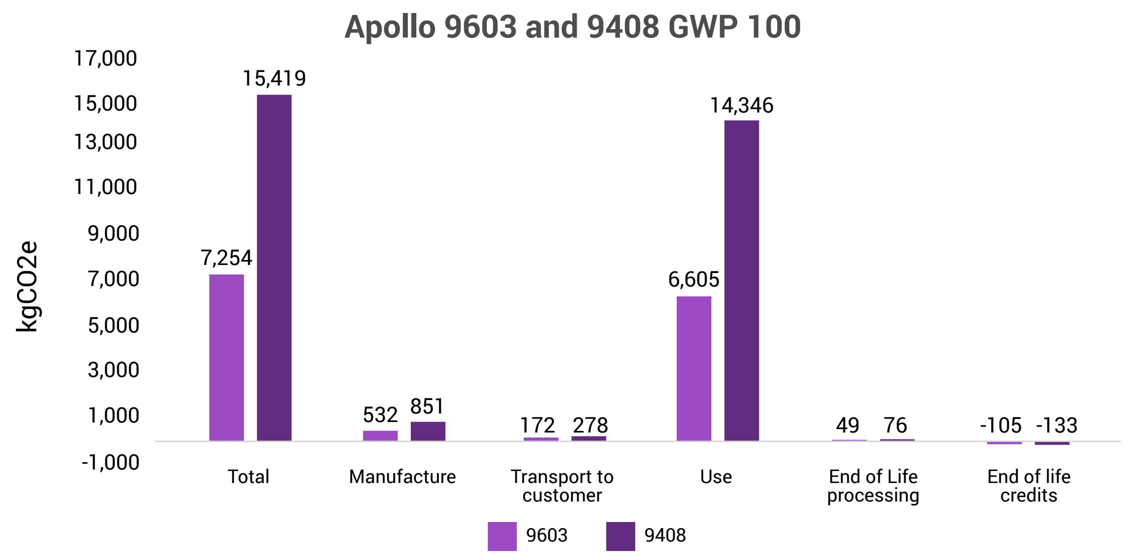
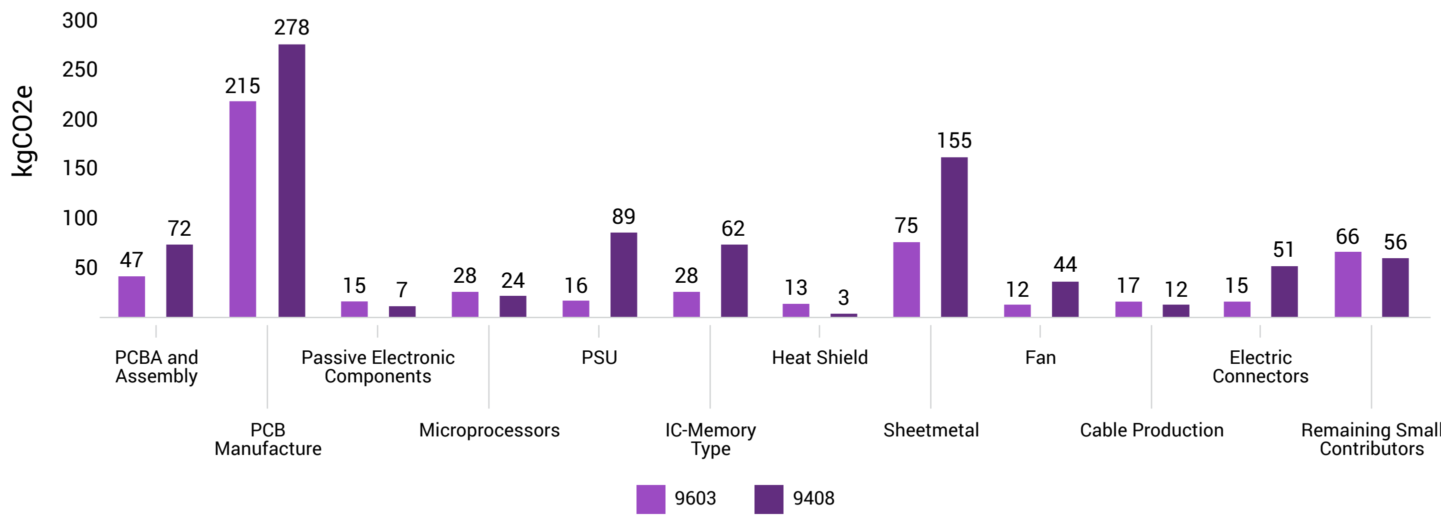


Figure 6 Apollo 9603 and 9408 GWP 100 by lifecycle stage when installed in Germany.

Figure 6 shows that the most significant lifecycle impacts occur during the use phase for both the 9603 and 9408. The use phase is responsible for 91% of the lifetime impacts for the 9603 and 93% for the 9408. The second highest lifecycle impact area is the manufacture, which comprises 7.3% and 5.5% of the 9603 and 9408 lifecycle impact, respectively. Transport to the customer is 2.4% and 1.8% respectively for the 9603 and 9408.

6.2. Component Manufacturing and Assembly Impacts



The manufacturing and assembly stage has a contribution of 532 and 851 kgCO2e. Figure 7 shows the breakdown of the contributors to the manufacturing and assembly impact.

Printed Circuit Board manufacture is the most significant individual contributor to the lifecycle impact, followed by sheetmetal production. These two categories contribute 55% of the 9603 and 51% of the 9408 manufacturing and assembly impacts. The assembly stage, which includes PCB assembly, assembly of the Apollo unit and placing in packaging, comprises 9% and 8% of the 9603 and 9408 impact, respectively.

By mass, the microprocessor and memory units are estimated to comprise 0.2% of the overall main chassis and card weight in both units, however their environmental impact is disproportionately high at just under 1% of the total unit impact. This proportion will rise if additional service cards are added to utilise the full unit capacity. This can be traced to the high energy consumption of microprocessor production, which also takes place in countries with high emissions per kWh of electricity.

6.3 Transport Impacts

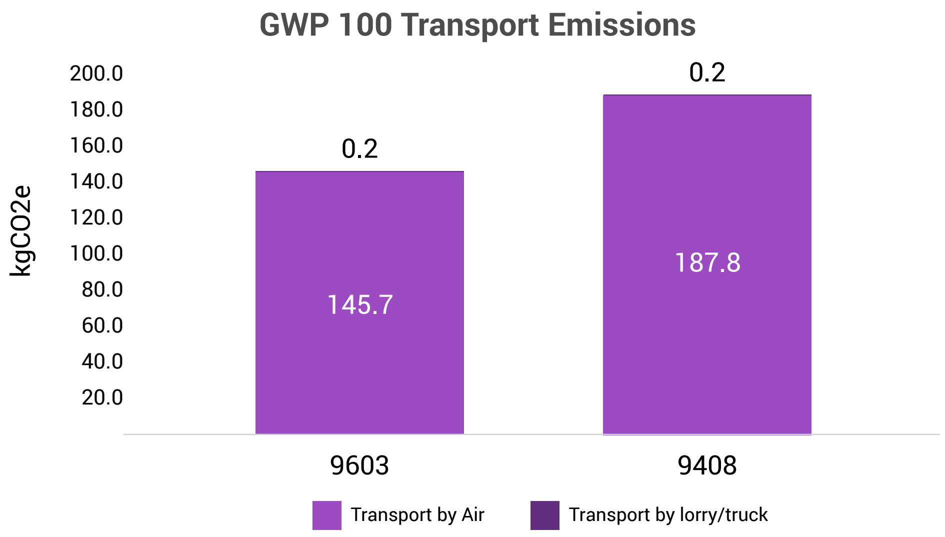


Figure 8 shows the total impact and breakdown of impact by travel mode. The graph demonstrates that transport by air from Thailand to the use destination is the dominant transport impact. Air travel is both longer in terms of miles travelled than the distance travelled by lorry/truck and significantly more impactful per mile travelled.

An alternative where the Apollo units are operated in New York showed that the transport impact would increase to 267 kgCO2e for the 9603 and to 431 kgCO2e for the 9408. This is driven primarily by the increased distance from the sub-contract manufacturer to the use location when compared with Germany.

6.4. Use Phase Impacts

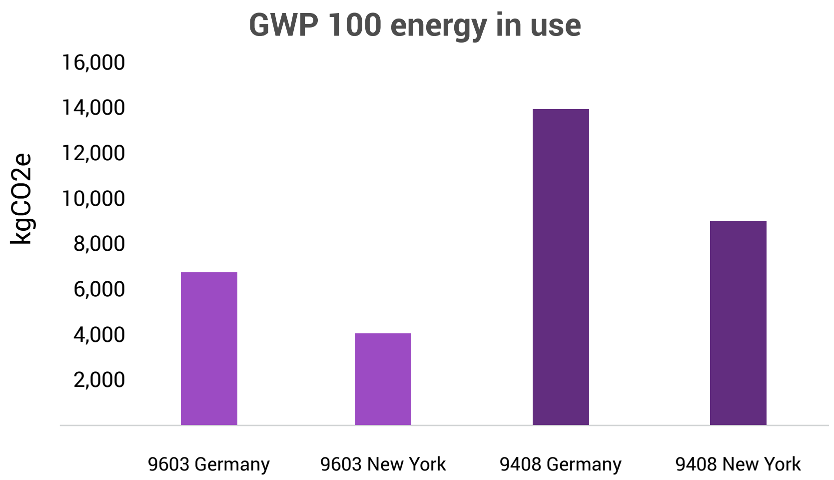


Figure 9 shows that the 9603 and 9408 lifetime impact can be significantly reduced when installed in a location with a lower carbon intensity. On a global basis, Germany falls in the mid-range of carbon impact per kWh of electricity, which means the use-phase impact can be proportionally lower or higher depending on its installed location. For example, deployment on the NPCC electrical grid, which supports New York and other major US north eastern cities, would see the use phase impact reduce by 39%.

6.5. End of Life Impacts

Recycling of the 9603 and 9408 results in a recycling impact credit of 56 kgCO2e and 57 kgCO2e respectively. This equates to a lifecycle impact reduction of less than 1% in each case.

Recycling credits are given where there is an avoidance of primary production as a result of recycling if the recycled material can be used instead of primary materials.

In the case of the metals, both used in the chassis and electronic components recovery can be undertaken. In this study there has been no assumption of material losses beyond those in the standard Ecoinvent processes. Ribbon does not have access to detailed end of life treatment statistics. However, the Spring Environmental team has visited within the UK facilities that undertake the first stage recovery of network equipment like that described on behalf of telecommunications providers. Maximising recovery of all the materials is a core to the business model.

Once the Apollo unit has been through the first process in which the main constituents are separated by hand, the populated PCBs are shredded and undergo further processes to recover valuable metals such as gold, silver and copper.

Most of the recycling credits for both units are due to the recovery of gold. Gold is a very high impact metal, and so the recovery of approximately 2.7 grams in the case of the 9603 results in a recycling credit of 37.9 kgCO2e. Further credits primarily come from the recovery of the sheet metal steel, aluminium in the heatsinks and copper. The values are higher for the 9408 due to the greater weight of PCB, sheet metal and electronic components than the 9603.

7. Interpretation

7.1. Conclusions of the study

The data in section 6 shows that the general data trends are generally the same between the 9603 and 9408 units. The major difference is in the scale of resource use, whether that be energy and or physical inputs. Nevertheless, direct comparisons are not recommended due to the different operating capacities of the machines. The functional unit is not conceived, deliberately, to compare the units directly and to reach conclusions regarding the relative performance.

The main conclusions of the study are:

- Approximately 91% of the lifetime impacts occur in the use phase for the 9603 and 93% for the 9408. The location of installation will have the most significant bearing on the overall lifecycle impacts of each of the Apollo units. The installation in New York would reduce lifetime impacts to approximately 85% in the case of the 9603 and by 88% for the 9408, even when the increased transport emissions are taken into account.
- The manufacturing and assembly stage is responsible for approximately 7% to 5% of the lifetime emissions respectively for the 9603 and 9408.
- The highest impacts for manufacturing and assembly come from the manufacture of PCBs. The manufacture of PCBs is known to be an energy and resource intensive process due to the need for process baths which are held are high temperatures and the process of adding and removing of materials to leave the desired wiring pathways. PCBs represent 41% for the 9603 and 33% of the 9408's manufacturing stage impact.
- The microprocessors comprise a tiny fraction of the mass but contribute approximately 1% to the lifetime environmental impact for the reasons explained above.
- While the sheet metal used in the chassis is the largest single item by mass, the production of the sheet metal is a relatively small contributor to the overall footprint at 1% for both units.
- At the end of life, the recovery of gold is the most significant activity when considering the carbon emission metrics. Gold recovery provides a credit worth approximately 0.5% of the lifetime impact.

The result of this analysis shows that the environmental hotspots to inform future physical designs and development should focus on measures to reduce energy consumption in-life. The output of the electricity consumed by the Apollo units is primarily heat, which typically will be managed through being installed in an air-conditioned environment. Therefore, there is a consequential impact that reducing primary electricity consumption in the Apollo will have further downstream energy reductions. The fixed consumption is understood to only vary because of the environmental temperature. Therefore, a warmer environment which has a lower air conditioning consumption would result in increased fan consumption and vice versa. Based on data from Patterson, Michael. (2008)1 And Seaton I. (2019)2 a calculation that shows cooling demand from the unit fans and the datacentre cooling technology will result in an overall power demand increase of around 0-2W (2%) per degree. However, if the increased cooling energy requirement of the datacentre is ignored, then increasing the environmental temperature will increase the unit electricity consumption by approximately 3%.

The next focus areas is the sourcing of PCBs. A 5% reduction in emissions from each of these areas would reduce the lifetime emissions by less than 0.2%.

7.2. Data and Model quality assessment

7.2.1.Completeness

Each foreground process was checked for completeness via mass balance activity mentioned above and consistency of the boundaries. During the process of the study omissions were identified, such as the capital equipment employed at the sub-contract manufacturer which was updated in the final version. Information on the amount of solder paste used during PCB assembly was not available and so was estimated using industry benchmarks.

The PUE of any cooling associated in the datacentre is the only known and deliberate omission as there is significant variation between different datacentres and is not a statistic freely available to Ribbon in typical deployment locations.

Mass balance checks were undertaken wherever possible and where estimates were required to match the bottom-up component mass to the measured assembly mass, the allocation to the various materials was documented.

Reproducibility has been attempted through transparently communicating the input material types and weights and highlighting any shortfalls and documenting the modelling choices, particularly regarding end of life.

7.2.2.Consistency

The study aims to be compliant with ISO 14040/44 only and therefore does not need to deal with any inconsistencies between differing LCA standards.

The section above with regards to completeness comment on the efforts to ensure that all processes consistently operated using the same boundary conditions.

The study conclusions are considered consistent with the attributional approach to developing an LCA as the scope was not to directly make comparative assertions and therefore affect decision making between one product and another.

The temporal and spatial boundaries have been reviewed to ensure consistency with the production and use locations at the resolution allowed by the Ecoinvent database. The data provided by Ribbon was related to production in 2023 and 2024, matching the process dates within Ecoinvent.

There are no value choices required as only one impact category has been chosen, therefore, value choices comparing one impact category with another are negated.

7.2.3. Precision

The foreground data is calculated from either primary measured data in all of the lifecycle stages, with the exception of the end of life. The source of the data involved measured masses or mass from datasheets combined with the BOM. Where the mass was not available for individual components, it was interpreted from specifications and informed by using artificial intelligence to find data on the component mass. Sample data checks on the accuracy of the artificial intelligence derived information were undertaken with no discernible discrepancy that would affect the overall outcome of this study.

The background data is sourced from Ecoinvent v.3.10 where each process has documented uncertainty.

Areas for improvement primarily relate to the weight of 9603 and 9408 sheet metal and PCB weights which were derived using the process described in 5.2.1. Ideally these would use measured weights to improve precision. However, in total these two items contributed 3% of the 9603 and 2% of the lifecycle impact when the recycling credits were taken into account, which means that even with a 100% error margin in the estimates, it would not have changed the overall conclusion regarding energy in life being the dominant lifecycle impact.

Overall, the precision is considered to be good.

7.2.4. Sensitivity

The sensitivity of the results and conclusions were examined with regards to the main and expected variables that an Apollo unit will be subject. Primarily, this relates to the installation location, which determines transport and energy-in-use emissions. A variation in the end-of-life treatment for the packaging materials was also investigated regarding incineration of the cardboard and polyethylene bag.

The location significantly affects the overall lifetime impact of the Apollo unit, while the end-of-life treatment for the packaging materials was largely inconsequential.

The marginal decrease in electricity consumption from changes in the datacentre operating temperatures are not considered to materially affect the conclusions given the dominance of impact from the use phase.

The main area of sensitivity relates to the increasing population and capacity of cards. Adding a TM400_2 card to a 9603 would increase the overall impact by 2091 kgCO2e, 91% of which comes from energy in use. However, the impact per Gbps reduces significantly from 8.9 kgCO2e/Gbps to 5.84 kgCO2e/Gbps for the 9603 when increasing capacity from 800 Gbps to 1.6 Tbps. Similarly, the 9408 reduces its lifetime impact from 9.64 kgCO2e/Gbps at 1.6 Tbps to 4.29 kgCO2e/Gbps at 6.4 Tbps.

8. Glossary of terms

BOM – Bill of Materials. Schedule of components that makes up a large assembly.

GB – Gigabyte, which is one billion bytes of digital information.

PSU – Power Supply Unit. Unit which in the case of the study converts Alternating Current electricity supply to Direct Current as used by electronic devices

TB – Terrabyte, one thousand gigabytes of digital information.

9. References

[1]Patterson, Michael. (2008). The effect of data center temperature on energy efficiency. 1167 - 1174. 10.1109/ITHERM.2008.4544393

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