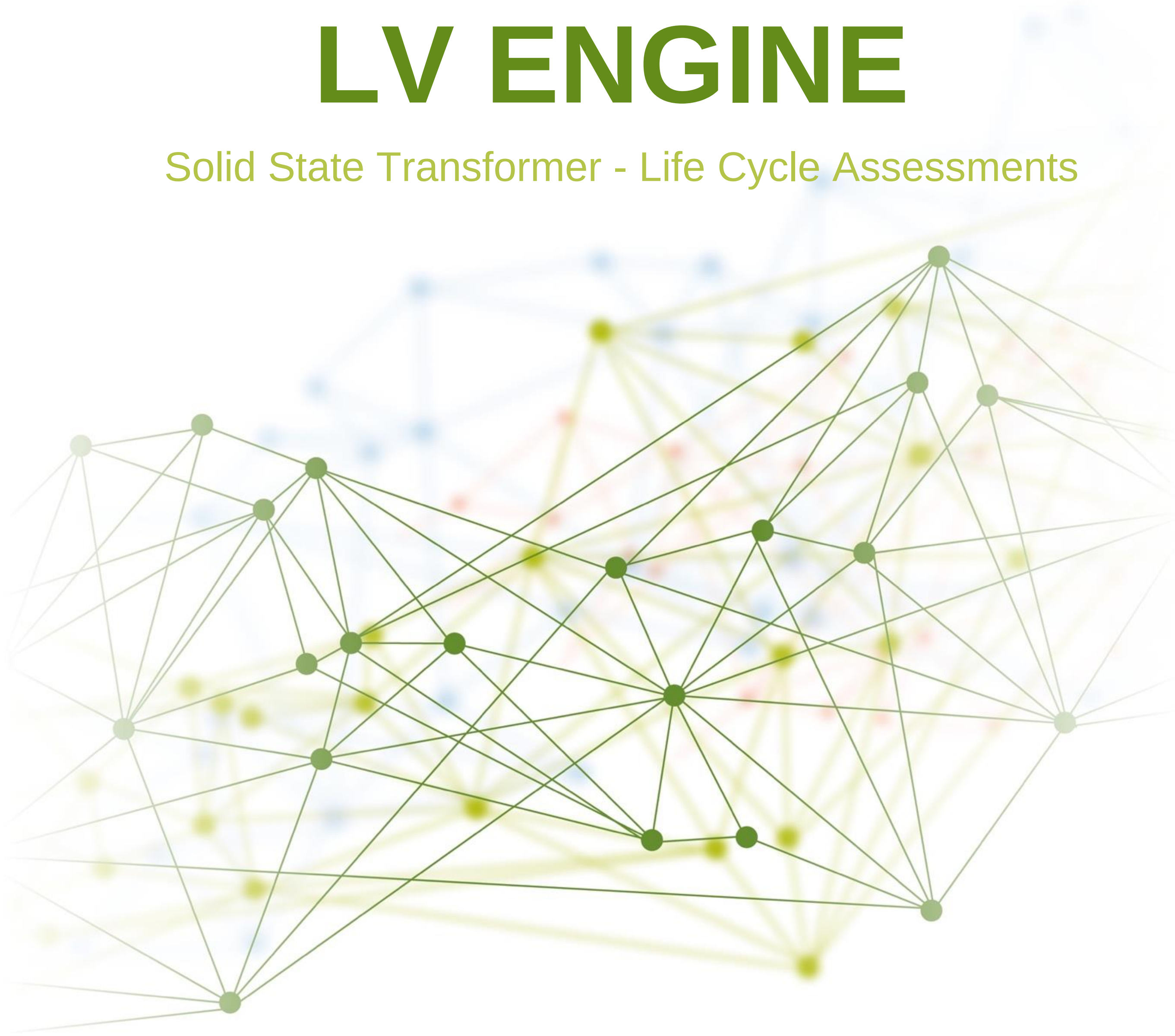
LV ENGINE

Solid State Transformer - Life Cycle Assessments



About Report

Report Title	:	LV Engine #2 - Smart Transformer Technical Design (Life cycle assessment)
Report Status	:	Final
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Contents

Glossary of Terms

Abbreviation/Terms	Definition
SST	Solid State Transformer
LCA	Life Cycle Assessment
SPEN	SP Energy Networks
GHG	Greenhouse gas
LCT	Low Carbon Technologies
NIC	Network Innovation Competition

Disclaimer

This report has been prepared as part of the LV Engine project, a globally innovative project to demonstrate the functionalities of a Smart Transformer, funded by Ofgem through the Network Innovation Competition mechanism. All learnings, outcomes, models, findings information, methodologies or processes described in this report have been presented on the information available to the project team at the time of publishing. In particular, it should be noted the material reported at this stage are subject to modifications as a result of new findings from the product design process, prototyping and benchtop testing exercises. It is at the discernment and risk of the reader to rely upon any learnings outcomes, findings, information, methodologies or processes described in this report.

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Executive Summary

Aim of this report

As part of the NIC project LV Engine Deliverable 2, a Life Cycle Assessment (LCA) is required to be conducted on the basis of the detailed technical design of the Solid State Transformer (SST). This report outlines the findings of the LCA for the SST Topology 1 and compares it to a conventional ground mounted, oil-filled 400kVA transformer following the ISO14040[1] standard framework and methodology. This report is one of the two reports which have been prepared to satisfy Deliverable 2 specified in LV Engine Project Direction.

Reference	Project Deliverable	Evidence
Deliverable 2	Detailed technical design of SST by the manufacturer and life cycle assessment.	Production of two documents: 1. Detailed design: The information will be provided as much as it complies with IRP agreement with the manufacturing partner, that can include the topology (stages) of SST, the cooling system, the choice of conductor, the control algorithm, SST protection logic, and all the lessons learnt within WP 3. 2. Life cycle assessment: The results of life cycle assessment based on manufacturing and material process which will be conducted by an academic or consultant partner.

Summary of findings

The results indicated that the primary contributor to the emissions is from the use phase of the assessment (91.3% of total emissions from product assessment) which is due to the unit losses over the assumed life time. In addition, SST Manufacture and Assembly have a greater impact on human health and ecosystem quality with a contribution of approximately 20% in each. This is mainly due the use of power electronics which require the extraction of rare earth materials.

When compared with the conventional distribution transformers, the SST produces 57% more emissions per kVA. The differences are mainly due to the presence of power electronics in the SST. Power electronic switching results in higher losses within the SST (417.8MWh) when compared to the conventional transformer (316MWh) over their life cycles. Power electronics also have a significant impact on the emissions from manufacturing & assembly, resulting in a larger impact during this stage for the SST.

However, the assessments in this report has been based on a number of assumptions that will be confirmed during the project lifetime and therefore should not be taken as the final emissions of the SST. Furthermore, by applying the forecasted values for the electricity network carbon emissions up to 2050, the overall carbon impact of the SST is reduced significantly. This would result in the total life cycle carbon emissions falling by approximately 51%. Applying this forecast is more representative of the contribution to climate change that the SST will have over its life cycle. Moreover, as per previous literature, **the SST is expected to produce greater benefits through the enabling of LCT uptake and deferred reinforcement. In other word, although this report focuses only on the comparison between SST and conventional transformer, for the real environmental impact assessment the**

reduction in network expansion and extra cabling should be taken account as the positive impact of SST deployment. This report only focuses on SST environmental impact as a unit rather than looking into SST as a solution which then reduces overall environmental impact.

As a result, it is recommended that a further LCA is completed to account for the losses produced from the live trials (within LV Engine Work Package 6) and also account for comparative technologies such as an Online Tap Changer (OLTC) to present a more holistic comparison. In addition, Topology 2 will be accounted for in this additional assessment.

1 Introduction

The LV Engine project is an Ofgem funded Network Innovation Competition (NIC) project which aims to carry out a globally innovative network trial of smart transformers to facilitate the connection of Low Carbon Technologies (LCTs). Conventionally, electricity networks provide an AC supply. However, many LCTs operate on a DC voltage which requires conversion, such as electric vehicles and photovoltaics. LV Engine intends to design a Smart Transformer which can provide a Low Voltage DC supply to customers for the first time whilst maximising the use of our existing AC network. The main part of a Smart Transformer is a solid state transformer (SST) works as a digitally controlled power electronic converter, facilitating a DC supply as well as voltage regulation and power flow control.

As part of Deliverable 2, the project has committed to carrying out an LCA of the SST (herein referred to as SST) by using the detailed design produced within Work Package 3. The LV Engine demonstrates a move away from traditional specifications and a move towards performance and outcome specifications which include carbon emissions. The information from the study can be used to report more accurately on the proposed environmental benefits of the LV Engine use cases. This project also forms part of a wider ambition to understand and actively manage whole life carbon associated with SP Energy Networks operations in line with PAS2080 Carbon Management in Infrastructure.

The aim of this LCA is to quantify the environmental impacts, in particular greenhouse gas (GHG) emissions, associated with the equipment manufacturing, installation, use and disposal that forms part of the LV Engine project. This report documents the approach taken for the LV Engine LCA, following the ISO14040[1] standard frameworks, as well as outlining data sources and assumptions, results and future recommendations.

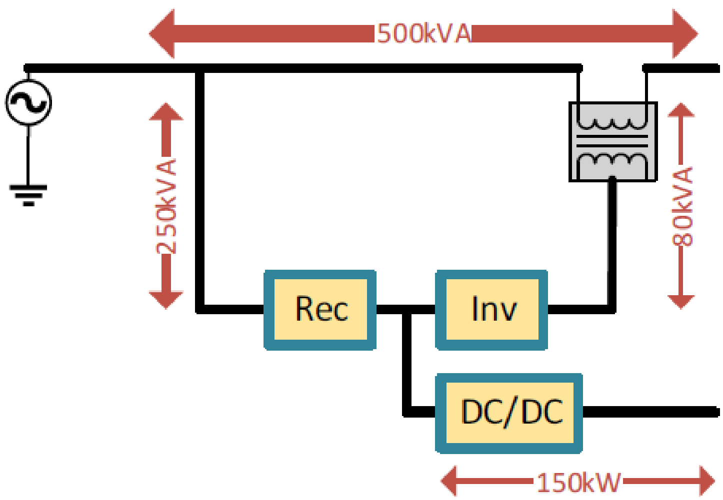


Figure 1 Block diagram of the LV Engine SST.

Figure 1 outlines a block diagram of the components within the SST which must be considered as part of the LCA analysis. This includes the SST manufacturing, installation, use and disposal of each component. The SST supplier has provided accurate component and assembly data, where possible, to support this.

In line with the ISO 14040 standard, a recognised LCA software has been used to input the data, build a system model and boundary and calculate the environmental impact.

As a result, this report will inform a comparison between the LV Engine use case and a conventional ground mounted 400kVA transformer including the external carbon benefits of each.

The layout of this document is:

- A review of Conventional Transformer LCA;
- An outline of the LCA methodology and process applied;
- The different phases of the LCA applied to the use case and base case; and
- The outcomes of the LCA analysis and recommended further work

2 Conventional Transformer LCA Review

A review of previous LCAs was completed to understand the environmental impacts of conventional transformers. Some of the relevant case studies used to create a base case for conventional transformers has been captured below:

- In 2011, an LCA study[5] was completed for various transformer types to assess life cycle costs and environmental impacts. For a 400kVA distribution transformer it was shown that the overall equivalent carbon emissions from a 30-year lifetime is 149,057 kgCO_2eq with the use phase accounting for 144,176 kgCO_2eq or over 96%. The manufacturing phase was shown to contribute 4436 kgCO_2eq to the overall carbon emissions.
- A 2016 LCA completed on a 210MVA power transformer[2] assessed the manufacture, use and disposal of the equipment. The study showed that the area with the largest impact on carbon emissions was the use phase, mainly in the losses of the transformer. This study is not relevant for comparison purposes due to the size of the transformer but emphasises the life cycle phase of a transformer that has the largest impact on carbon emissions.
- Another environmental impact study completed for distribution transformers[3] showed that the use phase, mainly losses, can account for up to 96% of carbon emissions which equated to approximately 161,000 kgCO_2eq throughout a 30-year lifetime.
- A study published in February 2020 compared novel transformer technologies, including an SST, with a 630kVA conventional distribution transformer[4]. This study, which followed the ISO14040 standard, showed that an SST when compared to conventional technologies, has a much higher impact on equivalent CO_2 emissions. The fabrication and disposal areas of the life cycle are similar for the different technologies however the SST has almost double the carbon emissions when operational losses are considered. The study acknowledges that the SST technology could overcome this contribution through significant environmental benefits in facilitating LCT uptake and reducing conventional reinforcement when compared with conventional transformers.

As a result of this review, it was expected to see that:

- Transformer losses during the use phase (that is when operating) have the largest impact on carbon emissions;
- SST technology is likely to have a larger impact on carbon emissions associated than conventional transformers due to power electronic switching.
- Greater emissions are significantly outweighed by the environmental benefits in deferring reinforcement and facilitating LCT uptake.

From the review, the base case selected was a 400kVA conventional distribution transformer due to a comprehensive study having been completed[5]. This will be used in comparison with the SST LCA outlined in the report.

3 Methodology

The ISO14040 standard clearly describes the framework and principles for completing an LCA study. It outlines four main steps which an LCA should include:

1. Define the goal and scope of the LCA
2. Life cycle inventory (LCI) – Create an inventory of the system being studied
3. Life cycle impact assessment (LCIA) – Determine the environmental impacts of the system
4. Interpretation and dissemination of results.

The scope includes the definition of system boundaries, functional unit, intended use/audience of the study and data collection methods.

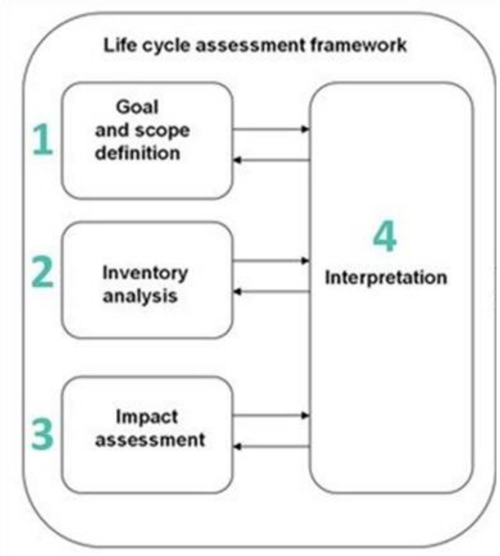


Figure 2 ISO14040 Life cycle assessment process stages and interactions[1]

3.1 Goal

The goal of this LCA is to understand the environmental impact of the SST's manufacture, installation, use and disposal with a focus on carbon emissions.

The LCA study will be used to report more accurately on the environmental impacts of the SST life cycle which will be the be accounted for in the proposed environmental benefits of the SST use cases within Work Package 6.

3.2 Functional Unit

The functional unit within an LCA study is what all outputs will be defined against. The functional unit is of importance when two products or systems will be compared against one another by establishing a relative and comparable measure. This is the unit that will be used to compare the environmental impact of the SST with conventional transformer technology.

As the main purpose of the LV Engine SST is to provide additional flexibility and functionality to the LV network, as well as introduce a DC supply to customers on the low voltage network, **the functional unit chosen for this LCA is 1 kVA of power** output from the SST.

3.3 System Boundaries

The system boundaries define what will be included in the life cycle analysis. The system being studied in this case incorporates the following:

- SST Manufacturing and Assembly
- SST Installation Site Works
- SST Use and Disposal

The life cycle inventory (stage 2 in Figure 2) follows the modular approach defined within the PAS2080 framework which is shown in Figure 3.

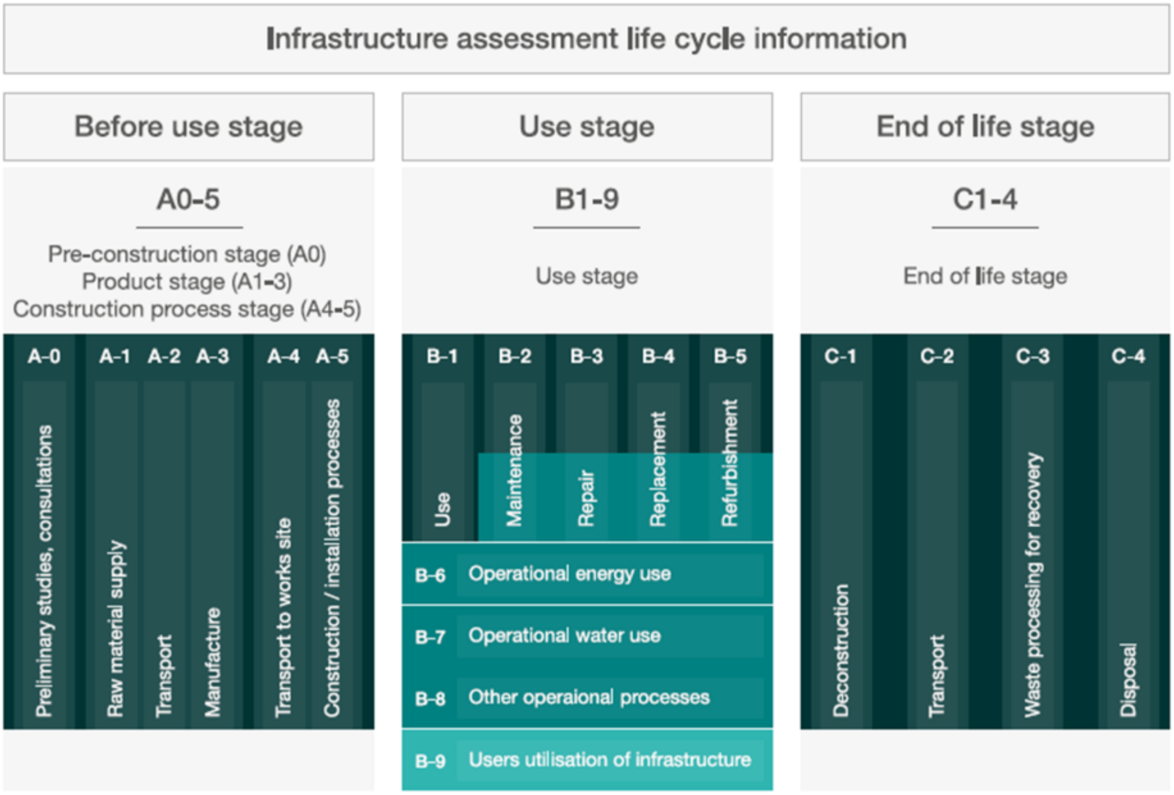


Figure 3 Framework for the life cycle inventory of an infrastructure asset as outlined in PAS2080:2016 Carbon Management in Infrastructure[6].

At this stage in the LV Engine LCA study, stage B-9 will not be included. This will form an additional LCA report when the environmental benefits of the SST use cases are clearer and rely less on assumptions. An accurate comparison can then be made with conventional transformer technology use. As B-9 has been excluded from both cases, it can still enable a relative comparison of technologies.

These stages are attributed to the SST life cycle stages as defined in Figure 4 to outline clear system boundaries.

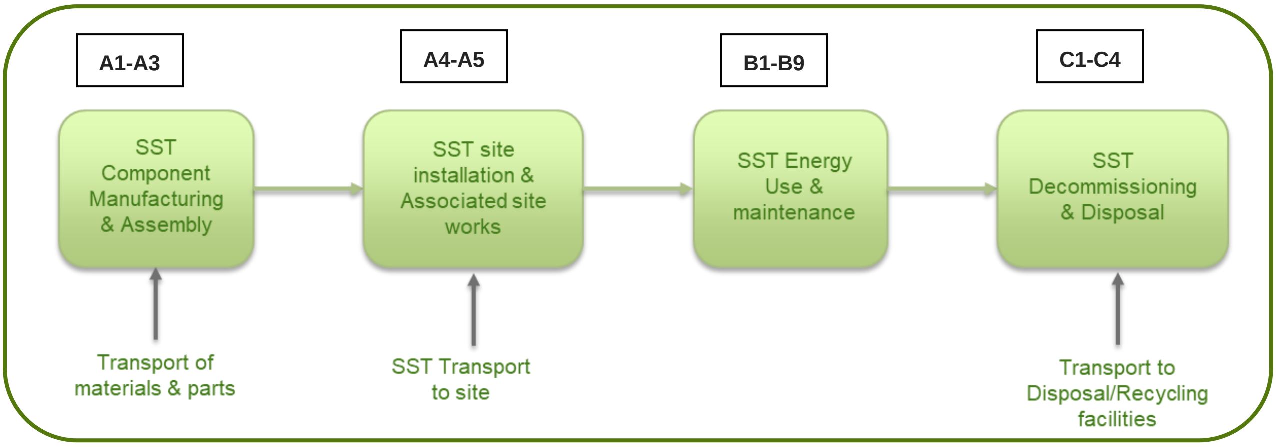


Figure 4 System boundaries of the LV Engine Life cycle Analysis

Installation of any additional low carbon technologies installed due to the presence of the SST as well as the LV network outside of the SST sites will not be considered within the assessment at this time. The production of the manufacturing facilities and transport vehicles used for the SST is also outside the scope of this assessment.

Each stage of the analysis in Figure 4 has been detailed in Section 4.

3.4 Stakeholders and Intended Audience

The intended audience for this report is Ofgem as this forms part of the project's formal delivery, as well as the UK DNOs. Secondary stakeholders include the LV Engine project team, SP Energy Networks management, and the Scottish Power sustainability team. Table 1 outlines how the findings intend to be disseminated with the defined groups

Table 1 Life cycle analysis stakeholder engagement

Stakeholder	Importance	Main Areas of Interest	Method and Frequency of Communication
LV Engine Project Team	High	Methodology, Results and Impact	Meetings weekly. Final report/presentation.
Ofgem	High	Results and Impact	Reported within Deliverable 2
UK DNOs	High	Impact and Comparison	Presented within planned dissemination events
SPEN Management	High	Results and Impact	Final Report/Presentation
SPEN Sustainability Team	High	Methodology and Results	Monthly meeting for review. Final report/presentation.

3.5 LCA Software

Although the ISO 14040 standard does not specify the need for use of a software it is considered standard best practice to use an analysis software to record and control the inputs and outputs of an LCA.

The software used for this LCA is SimaPro V9.0. SimaPro is an established software within the field of life cycle analyses and has been used in numerous studies across different industries. SimaPro software contains several databases of materials and processes commonly utilised within manufacturing. The materials and processes contained within these databases have inputs and outputs detailed so that the environmental and societal impacts of products and projects can be comprehensively, accurately and efficiently quantified. The data used within this study will mainly come from the Eco-Invent database which is integrated within SimaPro V9.0. This is a well-established material database that has been used within several life cycle analyses and is compliant with ISO 14040.

The software allows the user to model assemblies, sub-assemblies, product life cycle use cases and waste handling scenarios. SimaPro contains several impact assessment methodologies and calculations that provide LCA outputs in terms of environmental and societal impacts. The software allows easy interrogation of LCA results and identification of the areas of the SST that have the largest environmental impact.

3.6 Data Sources and Quality

There were several data sources used to collect all the information needed for this LCA study. Table 2 lists the data collected along with the source of data and details where assumptions or estimates have had to be used.

Where possible, bespoke carbon factors were used to model the carbon emissions of the various stages within the study. Where it was not possible to obtain a bespoke emission factor, generic carbon factors contained within SimaPro were used to build a conceptual understanding of the carbon associated with the SST life cycle stages.

Table 2 LCA Data Sources and Assumptions

LCA Stage	Data Sources	Data Assumptions	Data Confidence
A1-A3: SST Manufacture & Assembly	• Manufacture Bill of Quantities • Component & Assembly drawings • Manufacturer Data Sheets • Eco-Invent material data	• Estimates were used for Power Electronic Switches material quantities based on component dimensions.	High
A4-A5: SST Transport & Site installation	• Equipment Supplier Drawings • Assembly & Installation Site Locations	• Distances were taken from Google Maps. • Assumed method of transport, shipping from US.	Medium
B1-B9: SST Energy Use and Maintenance.	• Manufacturer Data Sheets • Supplier Energy Losses calculations.	• Based on lifetime of components and 30-year life of SST, replacement rate of components calculated. • Energy Losses estimate only.	Medium
C1-C4: SST Decommissioning & Disposal	• Manufacturer data sheets • Eco-invent waste disposal scenarios • Eco-invent recycling scenarios	• SST enclosure is recycled. • Power electronics devices and components are disposed through bespoke electronics waste markets.	Medium

The data used within this study is shown in Appendix D.

Confidence in the quality of data collected for this study was assessed against the following criteria:

- Source type – Primary or Secondary sources
- Method in which data was collected (Measured, Estimated, Calculated etc)
- Time-related period of which the data is representative
- Geographical coverage of the data

3.7 Life Cycle Impact Assessment Method

There are various life cycle impact assessment methods available to use within SimaPro. The focus of this LCA is to model the whole life carbon emissions over the anticipated life cycle of the SST however other environmental impact categories will be presented. The Impact 2002+ impact assessment method has been selected, which focuses on four impact categories including human health, ecosystem quality, climate change and resources. This impact method gives information on the following:

- Climate change focusing on emissions to air
- Respiratory Inorganics
- Carcinogens
- Radiation
- Ecotoxicity and Land Use
- Non-renewable energy and mineral use

The impact assessment method totals all the inputs and calculates the outputs for each impact category. Taking climate change as an example, SimaPro totals all outputs in terms of kgCO_2eq. The outputs from the materials defined within the SST assembly are totalled and converted into kgCO_2eq using a factor defined for each. For example, any sulphur hexafluoride (SF_6) that is an output of any of the SST materials, manufacturing, use or disposal is multiplied by a factor of 23500 per kg to obtain a result in kgCO_2eq.

SimaPro uses this in-built impact assessment method to calculate and present the environmental impacts of the data defined within all stages of the life cycle inventory.

The output unit for each impact category is given in Table 3.

Table 3 Life cycle impact assessment categories and output units.

LCA Impact Category	Damage Categories	Output Unit
Human Health	• Carcinogens • Radiation • Respiratory organics and inorganics.	DALY (Disability Adjusted Life Years)
Ecosystem Quality	• Ecotoxicity • Land Occupation	PDF*m^2*yr (Potentially Disappeared Factor)
Climate Change	• Global Warming	Kg CO_2eq
Resources	• Mineral Extraction • Non-Renewable Energy	MJ primary

4 Life cycle Inventory Assessment

The life cycle inventory assessment is focused on the collection, organisation and processing of the data involved with the project from manufacturing, through installation and use, to decommissioning. A lifetime of 30 years is assumed for the use phase of the SST.

This section will detail the data that has been collected for each stage of the life cycle following the modular approach outlined in the PAS2080 framework, along with the source of the data.

For each aspect of the SST, information was collected and input into the SimaPro software, defined by materials and components contained within the Eco-Invent database along with bespoke calculations where applicable.

4.1 **A1-A3:** SST Manufacture & Assembly

The initial design of the SST has been completed with details of components and assembly being provided by the supplier.

The SST is separated in three distinct modules; the AC/DC Rectifier, the DC service and the DC/AC Inverter as per Figure 1. These modules are all connected and contained within a steel enclosure. The breakdown of the components within each sub-assembly is outlined in Table 4.

Table 4 SST Sub-assemblies and components detailing manufacturers and quantities

SST Sub-Assembly	Component	Quantity	Manufacturer & P/N
AC/DC Rectifier	SiC Mosfet	4	Mitsubishi FMF800DX2-24B
	Capacitor	3	TDK B32373A4207J020
	Shunt Converter Inductor	4	Falco Electronics, PMA216
DC/AC Inverter	SiC Mosfet	3	Mitsubishi FMF400DX2-24B
	Capacitor	3	TDK B32373A7606J020
	Series Converter Inductor	6	Falco Electronics, T29020
	Coupling Transformer	3	Signal Transformer, 360-000415-00
DC/DC Link	SiC Mosfet	2	Mitsubishi FMF800DX2-24B
		2	Mitsubishi FMF400DX2-24B
	Capacitors	6	TDK, B25631B0157K700
		3	TDK, B25631B2206K000
		8	TDK, B32656S1474+562
		8	TDK, B32656S7105+562
		6	TDK, B25690C1248K203
		7	TDK, B25631B1606K200
		14	TDK, B32656S1824+562
	150kW DC-DC Transformer	1	muRata Electronics, CD179C
SST Enclosure	Enclosure	1	Gridbridge

An explanation of the breakdown of the SST assemblies is as follows:

- Each module consists of power electronic switches, capacitors, inductors and control systems. The modules do have some differences in topology which will be outlined here. The full detail of the SST assembly and functionality can be found in the final design document.

- The SiC Mosfet switches were represented in the LCA as silicon carbide and copper materials which are used in the manufacture of the switches. The quantities for each were derived from the component dimensions given in the manufacturer's data sheets.
- The capacitors were selected to be film type capacitors with component weights obtained from manufacturer's data sheets. The series and shunt inductors were represented in the analysis as ring-core type inductors with the component weights obtained from manufacturer's data sheets.
- The coupling and DC-DC transformers were represented by LV transformers with weights and dimensions obtained from the manufacturer's datasheets. The enclosure was selected as steel and estimated weights provided by the SST supplier.

The SST assembly modelled in SimaPro is shown in Figure 5. Only the top two levels of the assembly are shown. Figure 6 shows the detailed assembly for the AC/DC Rectifier Module with components and inputs from the Eco-invent database. Items shown in blue are assembly and part definitions, with items in green being material/component inputs from the Eco-invent database.

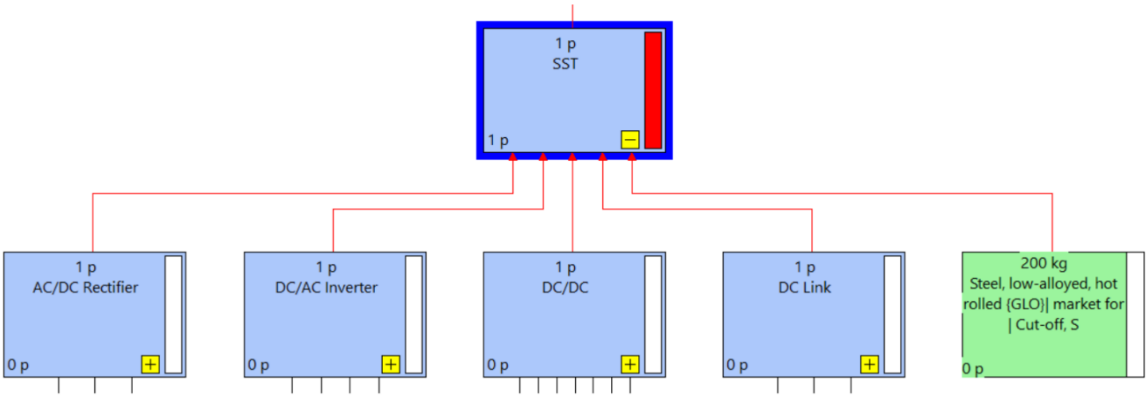


Figure 5 SST Assembly modelled within SimaPro (Assembly and Sub-assemblies in Blue)

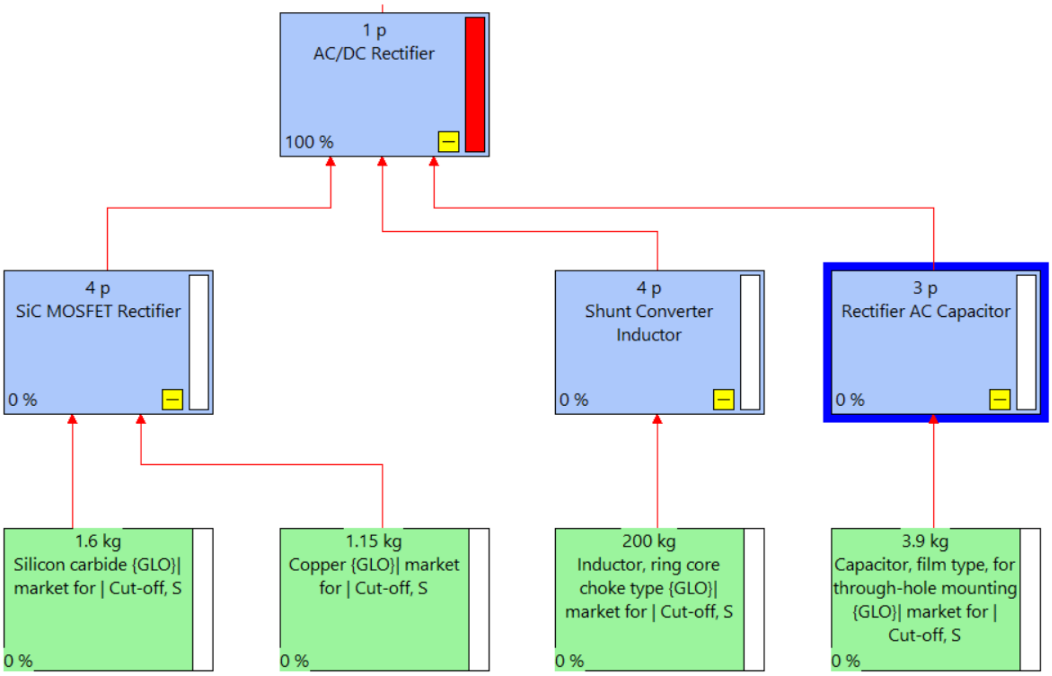


Figure 6 AC/DC rectifier module sub-assembly modelled in SimaPro (Eco-invent database inputs in Green

4.2 **A4-A5:** SST Transport & Site Installation

Following manufacture and assembly of the SST, transportation to site is required. The assembly site is in Raleigh, North Carolina, USA and one of the installation sites is in Wrexham, Wales. These two sites were used in the calculation of the transport inputs to the LCA. The distance and transportation method of the various stages of transporting the SST to the installation site is shown in Table 5. For input into the SimaPro software the transportation is defined in tonnes per kilometre. The estimated weight of the SST provided by the supplier is 2000kg or 2 tonnes.

Transportation Stage	Distance (km)	Method	LCA Input (tkm)
Assembly site to Port (Raleigh, NC to Wilmington, NC)	188	HGV	376
US to UK	6000	Shipping	12000
UK Port to Installation Site	30	HGV	60

Table 5 Transportation Distances and Methods of the SST from Assembly site to Installation site.

This information is based on estimates at this stage with detailed transportation to be determined later within the project.

The installation methods and associated site works are in the process of being defined. At this stage they will not be included in this life cycle assessment but will be included in the next issue of the report once more detail is known.

4.3 **B1-B9:** SST Use & Maintenance

The main aspect of SST use considered were the associated losses during its lifetime. Loading profiles and estimated losses were obtained from the manufacturer. The loading profiles and percentage of time estimated for each were provided. Estimated annual losses of the SST were calculated and then total losses were determined using an expected lifetime of 30 years.

Loading Profile	Losses (kW)	Percentage of Time at loading profile (%)
No load	0.750	76%
50% load	3	20%
Full Load	10.5	4%

Table 6 SST Losses at different loading profiles including percentage time at loading profiles

Based on these figures it was determined that the annual losses of the SST would be 13,928 kWh. Over the equipment's lifetime these losses will total 417,852 kWh.

At present, maintenance of the SST has not been clearly defined. Discussions are currently ongoing with the supplier to assess what maintenance will be required over the SST's lifetime. For the purposes of this life cycle assessment it is assumed that over the 30 year life of the SST at least 20% of the power electronic switches and capacitors will need to be replaced.

This replacement stage has been represented as additional components within the use phase of the SST, an additional 2 SiC Mosfet switches and 1 of each type of capacitor.

The other general maintenance requirements will have a relatively small environmental impact when compared to the energy losses associated with the SST and have been considered negligible for this study.

4.4 **C1-C4:** SST Decommissioning & Disposal

The final stage of the SST life cycle is decommissioning and disposal methods. The modules of the SST have been treated separately for disposal.

Most of the components used within the SST are disposed of through the electronics waste market which is defined in the Eco-invent database. The steel SST enclosure can be recycled.

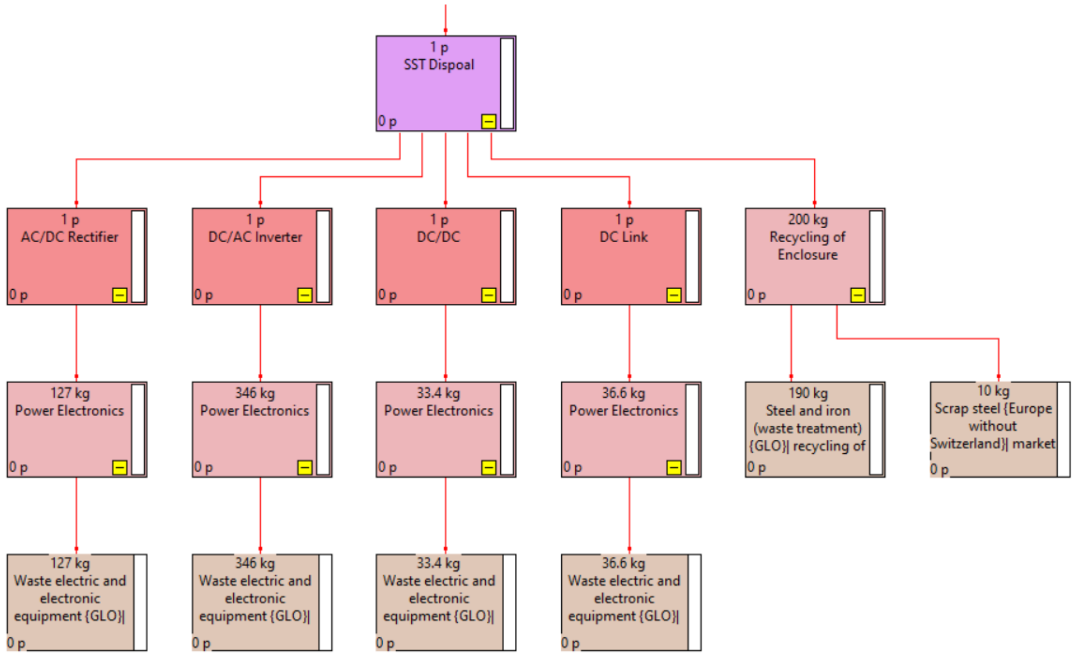


Figure 7 Modelling of SST Disposal in SimaPro showing waste flows and disposal methods

4.5 SST SimaPro Model

The final SimaPro model used for this LCA study is presented in Figure 8. Only the top level is shown with reference given to the applicable PAS2080 framework stages.

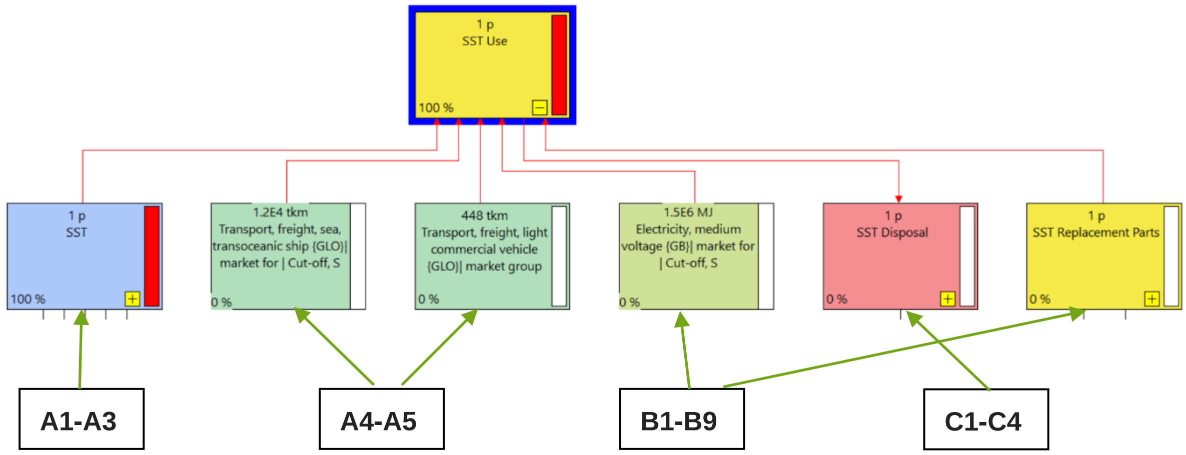


Figure 8 SimaPro model for SST life cycle

The full detailed SimaPro model is shown in Appendix A.

5 Life cycle Impact Assessment & Interpretation

Following the definition and input of all the life cycle stages, the impact assessment was completed. This was done in SimaPro using the Impact 2002+ method as described in section 3.7. The totals for each of the impact categories from the SST impact analysis are shown in Table 7.

Table 7 Life cycle impact assessment results showing values for each life cycle stage and total of the SST for every impact category.

Life cycle Inventory Stage for SST					
Impact Category	**A1-A3**	**A4-A5**	**B1-B9**	**C1-C6**	**Total**
Human Health (DALY)	0.033	0.001133	0.13545	0.0000408	0.17
Ecosystem Quality (PDF*m^2*yr)	13,300	256.8	49,440	19.1	63015
Climate Change (kgCO_2eq)	19400	966	214,240	28.4	234,634
Resource (MJ primary)	309000	15,570	4,531,000	421	4,855,991

Table 7 shows that the life cycle stage which has the most significant impact in all environmental categories calculated is **B1-B9, SST use and maintenance**. This is mainly due to losses over the 30-year lifetime of the SST. The contribution of the SST losses during the life cycle is over 70% in all categories and over 90% in the case of carbon emissions.

Figure 9 gives the percentage contribution of each stage of the life cycle for each impact category including climate change. **Stages A1-A3, SST Manufacture and Assembly,** have a greater impact on human health and ecosystem quality with a contribution of approximately 20% in each. This is mainly due the use of power electronics which require the extraction of rare earth materials.

In Figure 9, the colours denote different LCA phases. Yellow represents Use, Blue represents Maintenance and Green represents SST Manufacturing & Assembly. Other phases only represent approx. 1% of contributions to environmental impact.

The results of the LCA impact assessment for all of the individual damage categories considered in the Impact 2002+ method is shown in Appendix B.

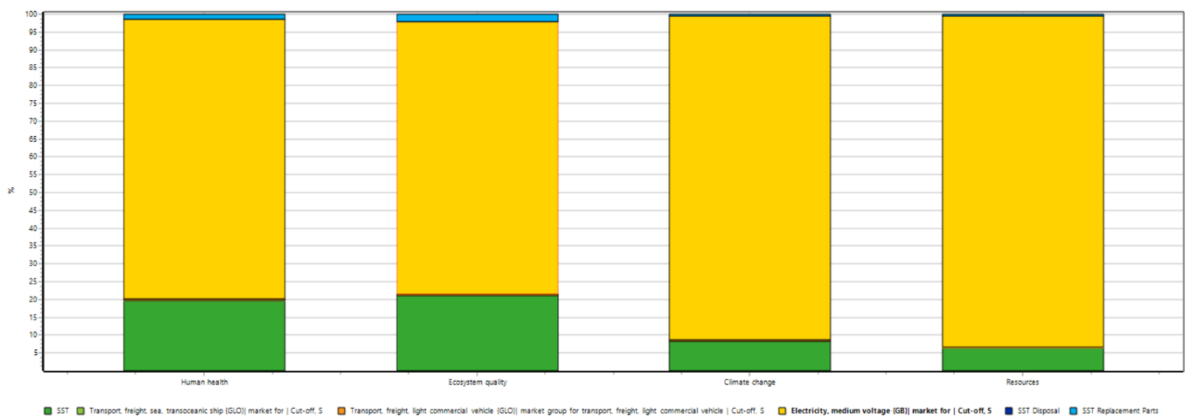


Figure 9 Percentage contributions of SST life cycle phases to impact categories.

5.1 Life Cycle Carbon Emissions

Considering carbon emissions, within the climate change impact category, the total for the 30-year lifetime of the SST is 234,634 $kgCO_2eq$, with the use phase (B1-B9) accounting for 214,240 $kgCO_2eq$ which equates to 91.3%. The manufacturing phases (A1-A3) accounted for 8.2%, with phases A4-A5 and C1-C6 only accounting for 0.5% of equivalent carbon emissions. In the case of a conventional transformer it has been shown that the use phase accounts for approximately 96% of carbon emissions, with manufacturing accounting for 3% and the remaining phases 1%. Figure 10 shows the breakdown of each aspect of the lifecycle carbon emissions for the SST.

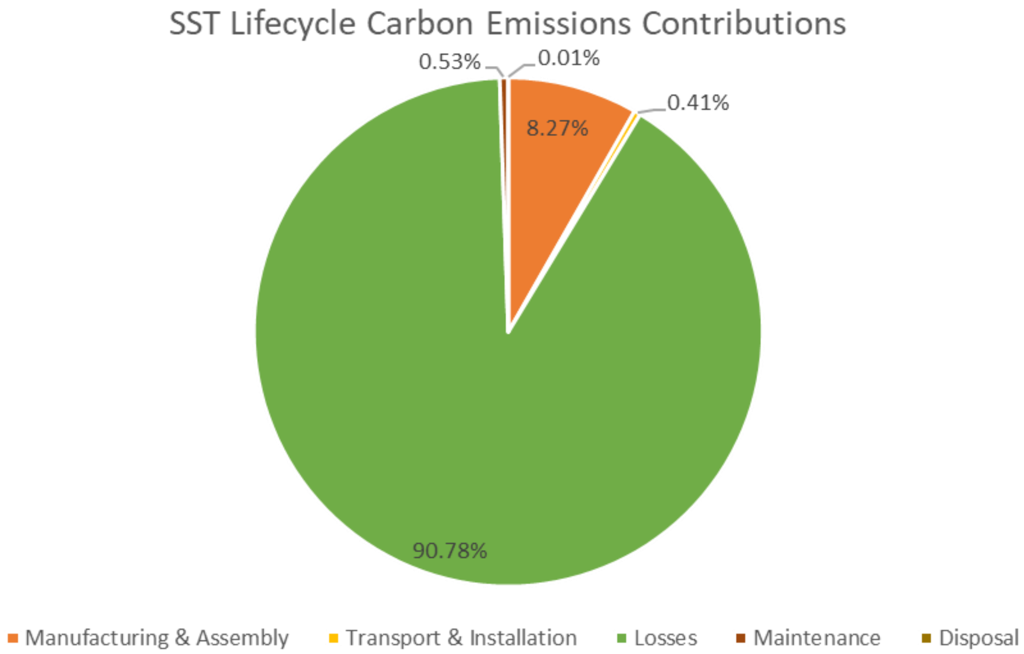


Figure 10 Breakdown of the SST lifecycle carbon emissions

Focusing on the use phase (B1-B9) of the SST, losses were the factor which contributed most, with 213,000 $kgCO_2eq$ attributed to this. This output was calculated using the share of technologies in the electricity market as of 2014 within the Eco-invent database. As a result, the carbon emissions due to SST losses from this LCA study is a value of 0.509 $kgCO_2eq$ per kWh. This share is expected to change with more renewable energy sources being installed, reducing the carbon emissions of the electricity network.

According to Ofgem's forecast of carbon emissions from the electricity system the $kgCO_2eq$ per kWh will decrease over the coming decades due to future decarbonisation. In 2014 the value from Ofgem was approximately 0.517 $kgCO_2eq$ per kWh.

By accounting for this forecast and aligning the SST to this trend, the carbon emissions from the SST losses over its lifetime using the Eco-invent figure, Ofgem's 2014 figure and Ofgem's forecast to 2050 is presented in Table 8. It has been deemed reasonable to assume this as power electronics applied to the electricity network is still an emerging technology with room to develop and evolve. The annual losses of the SST are estimated to be 13,928 kWh.

Table 8 SST Carbon emissions due to losses using various estimated values of $kgCO_2eq/kWh$ outputs for the electricity industry.

Scenario	Electricity Industry Carbon Emission Output (kg CO_2eq per kWh)	SST Carbon Emission output due to losses ($kgCO_2eq$)
Eco-invent 2014	0.509	213,000
Ofgem 2014	0.517	216,166.39
Ofgem 2020 - 2050 forecast	0.430 – 0.01 (reduces by 0.0145 per year)	92,001.99

Table 8 shows that using the forecasted values for the electricity network carbon emissions up to 2050, the overall carbon impact of the SST is reduced significantly. This would result in the total life cycle carbon emissions falling by approximately 51%, from 234,634 $kgCO_2eq$ to 113,635.99 $kgCO_2eq$, as shown in Table 9.

Table 9 SST Total Lifecycle carbon emissions using various losses contribution forecasts.

Lifecycle Stages	A1-A3	A4-A5	B1-B9	C1-C6	Total
Climate Change ($kgCO_2eq$) (using Ecoinvent carbon emission value)	19400	966	214,240	28.4	**234,634**
Climate Change ($kgCO_2eq$) (using Ofgem carbon emission forecast)	19400	966	93,241.99	28.4	**113,635.99**

This may be more representative of the contribution to climate change that the SST will have over its life cycle and should be accounted for in any wider counterfactual being reviewed as part of the project. Furthermore, the use of technologies such as the SST will facilitate more low carbon technologies resulting in a higher likelihood of the forecasted electricity network carbon emissions being met.

5.2 SST vs Conventional Transformer

When compared with the eco-design study[5] completed for conventional distribution transformers, the SST has a higher environmental impact. The findings show that the SST over its lifetime will contribute 234,634 $kgCO_2eq$ whereas the conventional transformer will contribute 149,057 $kgCO_2eq$. In both cases the use phase contributes over 90% of carbon emissions. The SST's power rating is 500kVA whereas, the power rating for the conventional transformer used in the eco-design study is 400kVA. The two can be compared for carbon emissions per 1kVA output as shown in Table 10 for each life cycle stage.

Table 10 Life cycle carbon emissions for SST and conventional transformer

Life cycle Stage		Carbon Emissions ($kgCO_2eq/kVA$)	
		SST	**Conventional Transformer**
A1-A3	SST Manufacture & Assembly	38.8	11.09
A4-A5	SST Transport & Site Installation	1.932	0.355
B1-B9	SST Use & Maintenance	428.48	360.44
C1-C4	SST Decommissioning & Disposal	0.0568	0.783
Total		**469.27**	**372.64**

The differences are mainly due to the presence of power electronics in the SST. Power electronic switching results in higher losses within the SST (417.8MWh) when compared to the conventional transformer (316MWh) over their life cycles. Power electronics also have a significant impact on the emissions from manufacturing & assembly, resulting in larger impact during this stage for the SST. This is due to need for extraction and processing of rare earth minerals associated with the production of power electronic devices. It is expected that advancements in semi-conductor technology will increase the efficiency of the SST to match that of a conventional transformer by 2050 therefore reducing losses and associated carbon emissions further.

6 Conclusion

The LCA carried out has quantified the environmental impacts of the LV Engine SST's life cycle, focusing on the carbon emissions. A comparison was made with conventional transformer technology, showing that the SST has a larger environmental impact.

This report presents the findings of the LCA for the SST and compares it to a conventional ground mounted, oil-filled 400kVA transformer following the ISO14040[1] standard framework and methodology.

The results indicated that the primary contributor to the emissions is from the Use Phase of the assessment (91.3% of total emissions from product assessment) which is due to the unit losses over the assumed life time. In addition, SST Manufacture and Assembly have a greater impact on human health and ecosystem quality with a contribution of approximately 20% in each. This is mainly due the use of power electronics which require the extraction of rare earth materials.

When compared with the conventional distribution transformers, the SST produces 57% more emissions per kVA. The differences are mainly due to the presence of power electronics in the SST. Power electronic switching results in higher losses within the SST (417.8MWh) when compared to the conventional transformer (316MWh) over their life cycles. Power electronics also have a significant impact on the emissions from manufacturing & assembly, resulting in larger impact during this stage for the SST. This is as expected from prior investigation and previous literature.

The above has been calculated with several assumptions that will be confirmed during the project lifetime and therefore should not be taken as the final emissions of the SST. The results outlined in this report will be used to refine the design and project use cases of the SST to reduce the emissions from all lifecycle stages. This will be undertaken where any alterations made will not adversely affect the performance of the SST. Furthermore, by applying the forecasted values for the electricity network carbon emissions up to 2050, the overall carbon impact of the SST is reduced significantly. This would result in the total life cycle carbon emissions falling by approximately 51%. Applying this forecast is a more representative of the contribution to climate change that the SST will have over its life cycle. Moreover, as per previous literature, the SST is expected to produce greater benefit through the enabling of LCT uptake and deferred reinforcement.

7 Learning

Through completion of this life cycle analysis study and report there have been several learning points:

- From the review of previous literature, the life cycle analysis of similar SST technology has been assessed which showed that the environmental impact is worse for an SST when compared to a conventional transformer. The information gained from previous literature will be used in further analysis and comparison of the derived environmental benefits of the live trials of the SST within Work Packages 5 and 6.
- The ISO 14040 standard was used directly within this study, with no alterations or deviations made. This standard can be used for studies of electrical equipment and the wider electricity network. An LCA study can be facilitated through the use of an established software providing a standardised approach and a broad range of material/component information.
- The majority of carbon emissions associated with the SST came from power losses. Equipment utilising more power electronic devices on the electricity network will increase losses and associated carbon emissions. Improving efficiency of power electronic devices should be a priority as more are introduced onto the network.

- The second largest contributing area to carbon emissions from the SST was manufacturing and assembly. This is again due to the use of power electronic devices. These devices require more rare earth minerals to be extracted and processed which have higher associated carbon emissions and other environmental impacts. Reducing the carbon emissions from these processes should be a continuing focus of research and development within power electronics. Alternatively, power electronic devices which utilise materials that have lower associated carbon emissions should be selected for use in equipment, if technical requirements can be satisfied.
- Other environmental impacts, such as human health and ecosystem quality, were shown to be impacted by the SST mainly through losses and manufacturing. These areas should be carefully considered within the lifecycle of new and existing equipment. While focusing on reducing carbon emissions these other environmental categories must not be overlooked when making decisions on materials, design or use cases.
- This study will form learning for managing whole life carbon associated with SP Energy Networks operations in line with PAS2080 Carbon Management in Infrastructure. The results from the study, the process used, and these learnings will be disseminated to the project partners and the wider industry.

8 Future Work

Due to the unavailability of data some assumptions have been made as detailed in this report. This initial LCA study has not considered in detail the use cases for the SST nor the HV SST Topology (also referred to as Topology 2) and the resultant environmental benefits. Therefore, it is recommended that at least one additional LCA study is made during the LV engine project to account for the potential environmental benefits of the use cases.

This will better account for the work conducted in work package 5 for the live trials and the derived benefits which will include facilitation of LCTs, voltage and reactive power control and avoidance of network reinforcement which will be accounted for in Work Package 6. With these benefits accounted for in the LCA a more accurate comparison between the SST and the conventional use cases can be made.

This revised study should account for:

- the exact assembly methods
- the installation methods required on site
- data from live operations
- any auxiliary equipment needed
- other similar technologies (such as an on-line tap changer) and similar innovation project, as data availability allows

It should be noted that given the results obtained during this initial study and that losses account for the majority of carbon emissions, it is envisaged that any changes or additions to assembly, site installation or use will not have a significant impact on the overall carbon emissions. However, they may contribute significantly to the other environmental impact categories presented in this report.

References

1. ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework, 2016
2. LIFE CYCLE ASSESSMENT OF POWER TRANSFORMER-CASE STUDY, Hegedic, M. et al, 2016
3. Ecodesign Requirements for Power, Distribution and Small Transformers, Univeristy of Ciombra, April 2013
4. Sustainability assessment of novel transformer technologies in distribution grid applications, Hunizker, C. et al, February 2020
5. Sustainable Industrial Policy – Building on the Ecodesign Directive – Energy-Using Product Group Analysis/1: LOT 2: Distribution and power transformers, Vito: Vision on Technology, January 2011.
6. PAS 2080:2016 Carbon Management in Infrastructure, The British Standards Institute, 2016

Appendix A Life Cycle Analysis SimaPro Model

The full SimaPro model is presented in Figure A 1 with all life cycle inventory inputs shown. The extent of the model means it is difficult to present in this report, however the full model is available upon request. Eco-invent database items are shown in green, which hold the material and component inputs and environmental outputs for the LCA. The blue items are user defined such as assembly, sub-assemblies and components. The reddish items defined the disposal and waste managements methods/inputs.

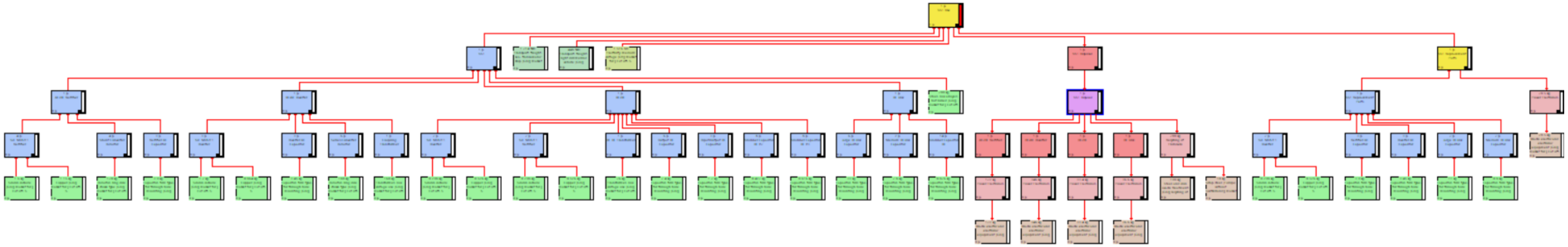


Figure A 1 Full SimaPro model for SST life cycle

Appendix B Life Cycle Intermediate Damage Categories

The intermediate damage category outputs for the SST life cycle are shown in Figure B 1. The SST use phase shown in yellow is dominant in most categories except for Carcinogens, Respiratory Organics, Aquatic Eutrophication and Mineral Extraction. The SST manufacture and assembly contribute a large amount in these categories. This is influenced by the presence of power electronics which require a large amount of materials with damaging extraction methods.

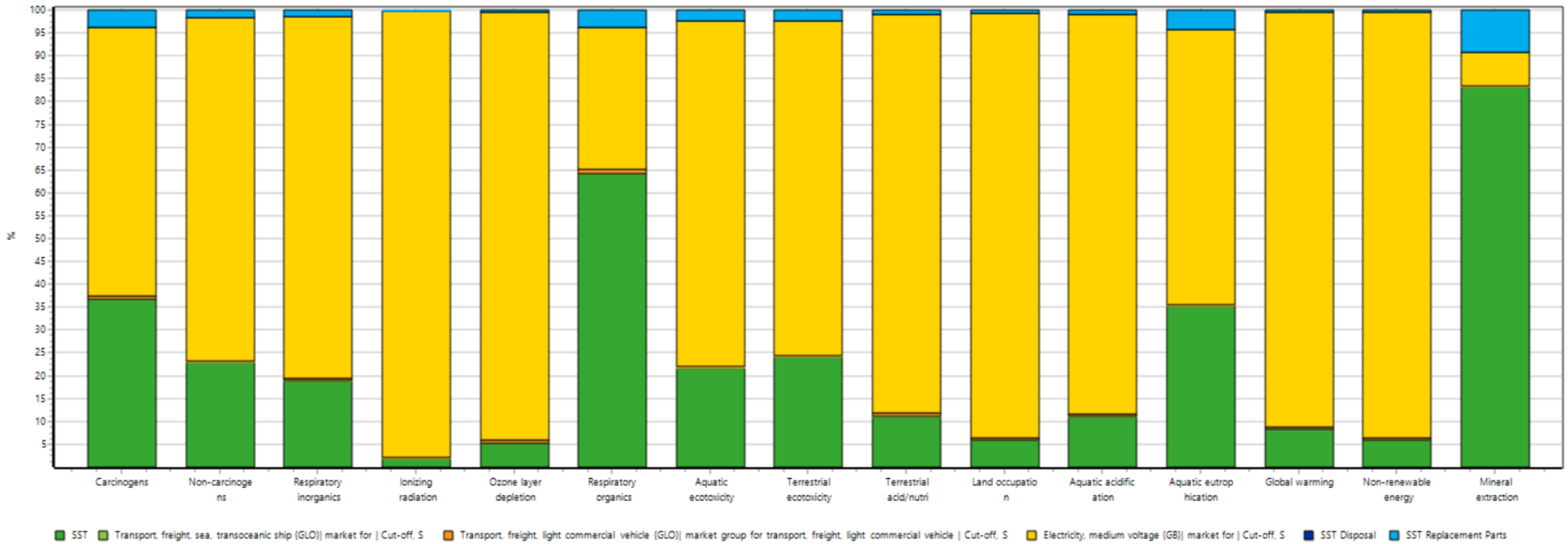


Figure B 1 SST Life cycle Damage Categories as defined in Life cycle impact assessment method Impact 2002+

Appendix C Terminology & Definitions

Lifecycle Analysis – Overall process for assessing and presenting on the environmental impacts of a product over its lifecycle.

Lifecycle Inventory – Collection of data and information for all phases of a product's lifecycle.

Lifecycle Impact Assessment – Calculation of the environmental impacts of a product based on the inputs from the lifecycle inventory.

SST (Solid State Transformer) - The solid state transformer (SST) works as a digitally controlled power electronic converter, facilitating a DC supply as well as voltage regulation and power flow control.

Power Electronic Switch – A power electronic switch is mainly used in the conversion of AC power to DC power and vice versa. It is a combination of active switchable power semiconductor drivers that have been integrated into one. The active switching between the on and off states result in power losses and the magnitude of these losses are affected by the switching frequency capabilities of the switch.

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) – It is a type of transistor used to switch electronic signals. A gate signal is used to change the conductivity of the semi-conductor device to switch it on or off.

SimaPro – Lifecycle analysis software for inputs, calculations and results of lifecycle analysis.

Eco-Invent – Database that contains information on materials, processes and disposal methods. Database is integrated within SimaPro for use.

Impact 2002+ - This is one of the lifecycle impact assessment methodologies integrated within SimaPro. It is used to calculate and output environmental impact results.

Appendix D Life Cycle Analysis Data

The following section outlines the data used within the life cycle analysis, either presented as links to data sheets or the actual data sheets themselves where links were not available. The data shown below supports the information presented within the report. Only manufacturer datasheet pages relevant to this life cycle analysis have been shown.

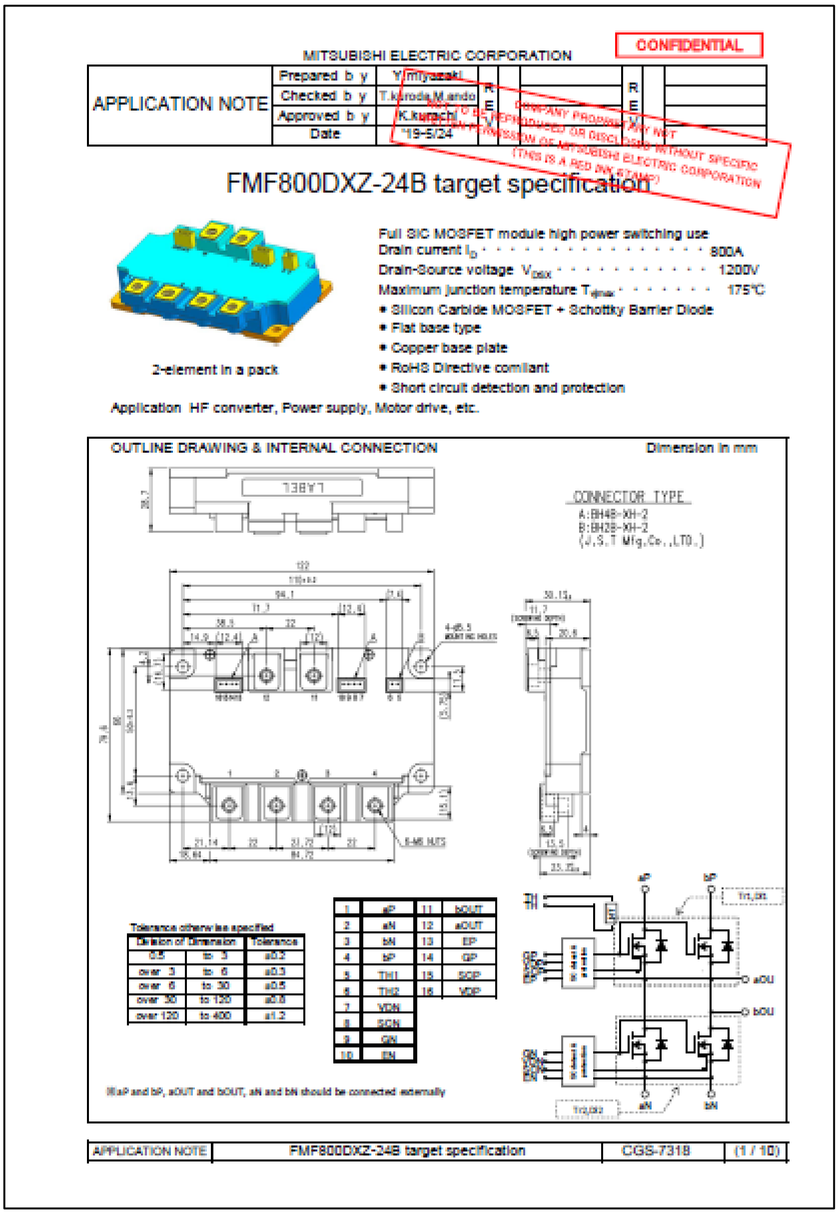
Capacitors

Table D 1 Capacitor Manufacture Part Numbers and Links to Data Sheets

Manufacturer & P/N	Data Source
TDK B32373A4207J020	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B32373A4207J020
TDK B32373A7606J020	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B32373A7606J020
TDK, B25631B0157K700	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B25631B0157K700
TDK, B25631B2206K000	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B25631B2206K000
TDK, B32656S1474+562	https://product.tdk.com/en/search/capacitor/film/mkp_mfp/info?part_no=B32656S1474J562
TDK, B32656S7105+562	https://product.tdk.com/en/search/capacitor/film/mkp_mfp/info?part_no=B32656S7105J562
TDK, B25690C1248K203	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B25690C1248K203
TDK, B25631B1606K200	https://product.tdk.com/en/search/capacitor/film/power/info?part_no=B25631B1606K200
TDK, B32656S1824+562	https://product.tdk.com/en/search/capacitor/film/mkp_mfp/info?part_no=B32656S1824J562

SiC Modules

Mitsubishi FMF800DX2-24B



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APPLICATION NOTE		
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	Approved b y	K.kurachi
	Date	'19-5/24

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COMPANY PROPRIETARY NOT

FMF800DXZ-24B target specification

2-element in a pack

Full SiC MOSFET module high power switching use

Drain current I_D · · · · · · · · · · · · · · · · 800A

Drain-Source voltage V_{DSX} · · · · · · · · · · · · 1200V

Maximum junction temperature T_{vjmax} · · · · · · · 175°C

- Silicon Carbide MOSFET + Schottky Barrier Diode
- Flat base type
- Copper base plate
- RoHS Directive comliant
- Short circuit detection and protection

Application HF converter, Power supply, Motor drive, etc.

OUTLINE DRAWING & INTERNAL CONNECTION

Dimension in mm

CONNECTOR TYPE
A:BH4B-XH-2
B:BH2B-XH-2
(J.S.T Mfg.Co.,LTD.)

Tolerance otherwise specified

Division of Dimension		Tolerance
0.5	to 3	±0.2
over 3	to 6	±0.3
over 6	to 30	±0.5
over 30	to 120	±0.8
over 120	to 400	±1.2

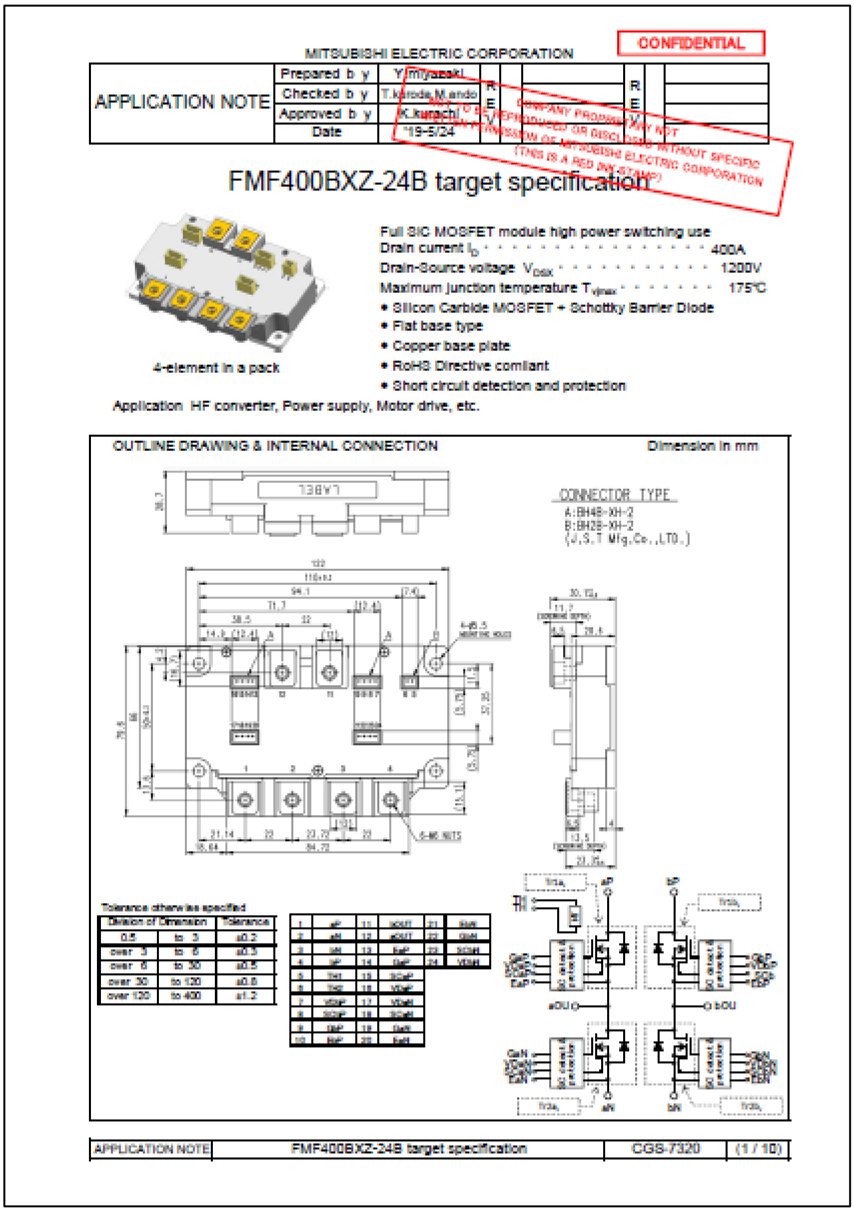
1	aP	11	bOUT
2	aN	12	aOUT
3	bN	13	EP
4	bP	14	GP
5	TH1	15	SCP
6	TH2	16	VDP
7	VDN		
8	SCN		
9	GN		
10	EN		

※aP and bP, aOUT and bOUT, aN and bN should be connected externally

APPLICATION NOTE	FMF800DXZ-24B target specification	CGS-7318	(1 / 10)

Figure D 1 Rectifier and DC Link SiC MOSFET Manufacturer Datasheet

Mitsubishi FMF400DX2-24B


CONFIDENTIAL

MITSUBISHI ELECTRIC CORPORATION

APPLICATION NOTE	Prepared by	Y.miyazaki
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	Approved by	K.kurachi
	Date	'19-5/24

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FMF400BXZ-24B target specification

4-element in a pack

Full SiC MOSFET module high power switching use
Drain current I_D · · · · · · · · 400A
Drain-Source voltage V_{DSX} · · · · · · · · 1200V
Maximum junction temperature T_{vjmax} · · · · · · · · 175°C
- Silicon Carbide MOSFET + Schottky Barrier Diode
- Flat base type
- Copper base plate
- RoHS Directive comliant
- Short circuit detection and protection

Application HF converter, Power supply, Motor drive, etc.

OUTLINE DRAWING & INTERNAL CONNECTION

Dimension in mm

CONNECTOR TYPE
A:BH4B-XH-2
B:BH2B-XH-2
(J.S.T Mfg.Co.,LTD.)

Tolerance otherwise specified

Division of Dimension		Tolerance
0.5	to 3	±0.2
over 3	to 6	±0.3
over 6	to 30	±0.5
over 30	to 120	±0.8
over 120	to 400	±1.2

APPLICATION NOTE	FMF400BXZ-24B target specification	CGS-7320	(1 / 10)

Figure D 2 Inverter and DC Link SiC MOSFET Manufacturer Datasheet

SiC Mosfet Gate Driver

https://www.tamuracorp.com/electronics/en/gatedriver/pdf/2DMB51008CC_EN.pdf

<u>Inductors</u>

Shunt Converter Inductor - Falco Electronics, PMA216

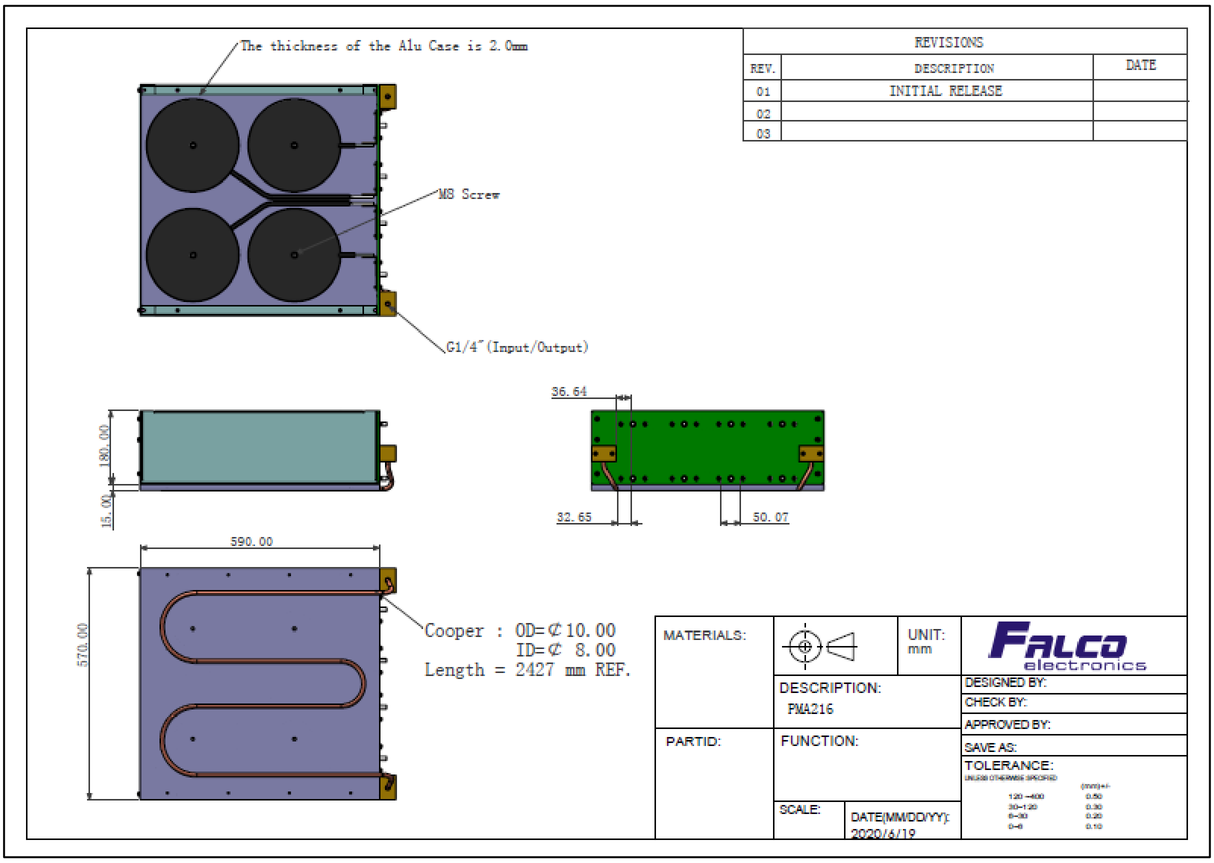


Figure D 3 Shunt Converter Inductor Manufacturer Datasheet

Series Converter Inductor - Falco Electronics, T29020

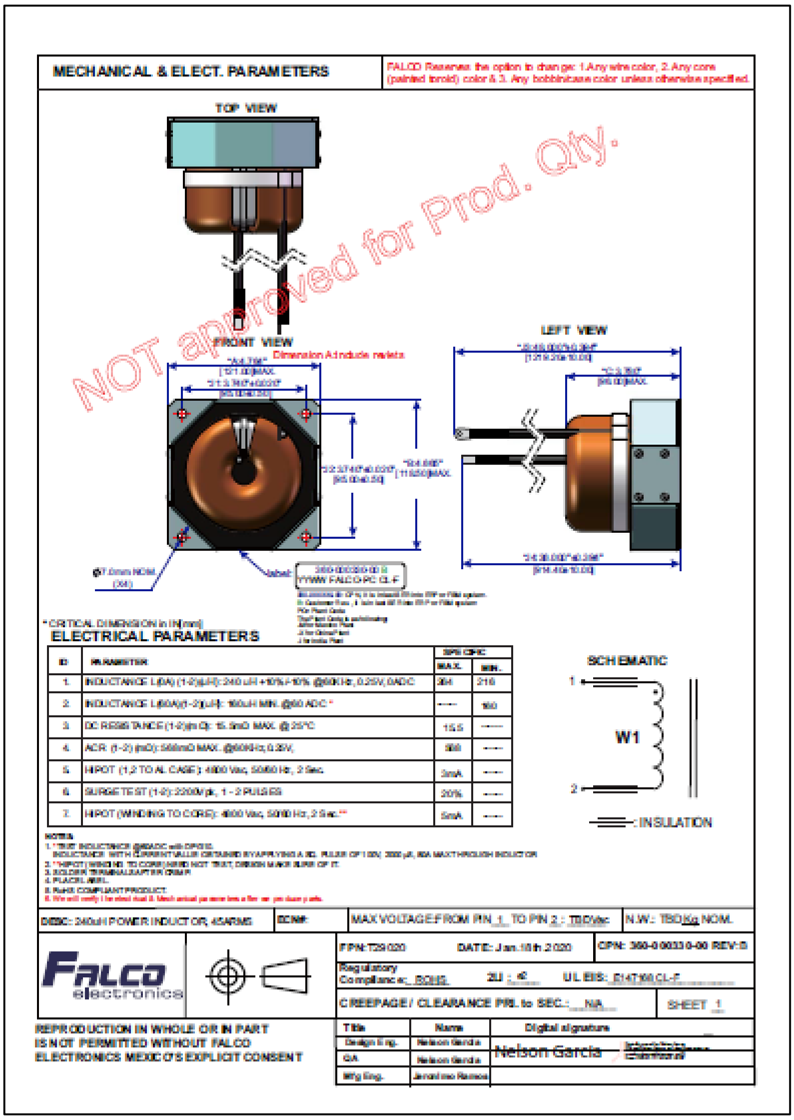


Figure D 4 Series Converter Inductor Manufacturer Datasheet

Transformers

Coupling Transformer - Signal Transformer, 360-000415-00

SCD – Power Transformer, 27.0 kVA, 12:1, 50Hz
360-000415-00

GridBridge Inc.
Raleigh, NC 27603

1 Electrical Specifications

High efficiency coupling transformer operating at 50Hz. Class H (180C) insulation, 4,000 V_{RMS} @ 50Hz dielectric withstand for 1 minute. There are two "worst case" operating points, maximum power and maximum current addressed in the table below.

1.1 *Electrical Specification Table*

Electrical Parameter	Specification	Notes
Operating frequency	50Hz	No changes for 60Hz operation reqd.
Nominal primary voltage	450V_{RMS} +/- 10%	
Nominal primary current	60A_{RMS}	
Nominal secondary voltage	37V_{RMS}	
Nominal secondary current	725A_{RMS}	
Turns Ratio	12:1 Pri:Sec	
Temperature rise, core & windings	75°C	At both max power and max current
Maximum power	27kVA	450V_{RMS}, 60A_{RMS} primary and 37V_{RMS}, 725A_{RMS} secondary
Maximum current	980A_{RMS}, secondary 82A_{RMS}, primary	0V_{RMS} primary and secondary, 35% overcurrent
Short circuit current	2000A_{RMS}, secondary 167A_{RMS}, primary	< 3sec, 0V_{RMS} primary
Maximum primary voltage	550V_{RMS}	Not to exceed 3 seconds, during a fault
Primary DCR	0.048 Ohm, maximum	
Secondary DCR	0.45 Ohm, maximum	
Efficiency at nominal	97%, minimum	
Dielectric withstand (primary to secondary, primary to base/core, secondary to base/core)	4,000V_{RMS} @ 50Hz	Hi-Pot test for 1 second
Ambient operating temperature	-40C to +85C	Not including self-heating
Insulation class	180C	Class H (OBJY2.E66312)
RoHS compliant	6 of 6	Directive 2002/95/EC

2 Mechanical Specifications

As specified by GridBridge Mechanical Reference Drawing 360-000415-00 included at the end of this document.

2.1 *Mechanical Specification Table (for reference only)*

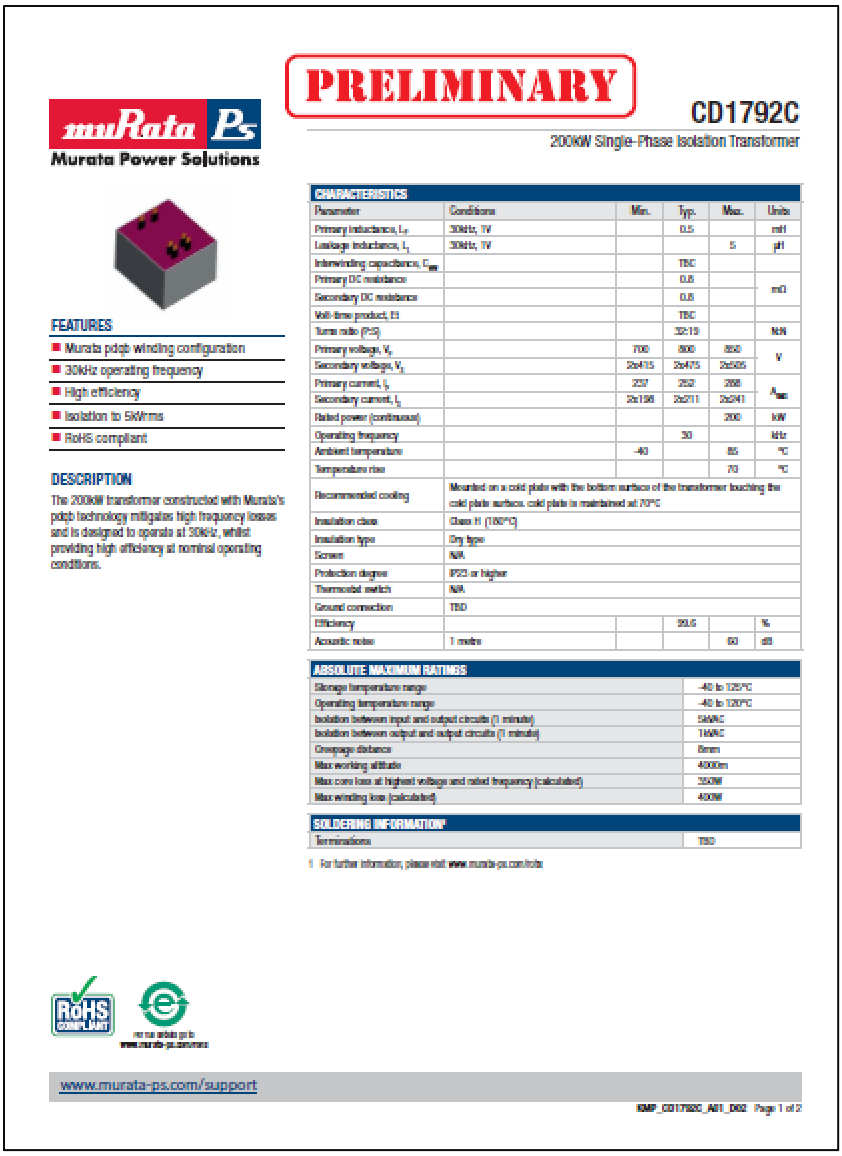
Mechanical Parameter	Specification	Notes
Envelope size	15" x 13" x 14" (WxDxH) estimated	Shown in mech drawing in section 7
Total weight	353 pounds, estimated	Shown in mech drawing in section 7
Thermal resistance to mounting surface	Bottom of core to be flush with mounting brackets	To accommodate heat transfer pad if needed
Terminations	Primary: Copper bus bar (1/2" x 1/16") Secondary: Copper bus bar (3" x 1/4")	82A_{RMS}, primary 980A_{RMS}, secondary

Proprietary/Confidential

Page 3 of 5

Figure D 5 Coupling Transformer Datasheet

150kW DC-DC Transformer - muRata Electronics, CD179C



PRELIMINARY

muRata Ps
Murata Power Solutions

CD1792C

200kW Single-Phase Isolation Transformer

FEATURES

- Murata pdqb winding configuration
- 30kHz operating frequency
- High efficiency
- Isolation to 5kVrms
- RoHS compliant

DESCRIPTION

The 200kW transformer constructed with Murata's pdqb technology mitigates high frequency losses and is designed to operate at 30kHz, whilst providing high efficiency at nominal operating conditions.

CHARACTERISTICS					
Parameter	Conditions	Min.	Typ.	Max.	Units
Primary inductance, L_P	30kHz, 1V		0.5		mH
Leakage inductance, L_L	30kHz, 1V			5	µH
Interwinding capacitance, C_{WW}			TBC		
Primary DC resistance			0.8		mΩ
Secondary DC resistance			0.8		mΩ
Volt-time product, Et			TBC		
Turns ratio (P:S)			32:19		N:N
Primary voltage, V_P		700	800	850	V
Secondary voltage, V_S		2x415	2x475	2x505	V
Primary current, I_P		237	252	288	A_{RMS}
Secondary current, I_S		2x198	2x211	2x241	A_{RMS}
Rated power (continuous)				200	kW
Operating frequency			30		kHz
Ambient temperature		-40		85	°C
Temperature rise				70	°C
Recommended cooling	Mounted on a cold plate with the bottom surface of the transformer touching the cold plate surface. cold plate is maintained at 70°C				
Insulation class	Class H (180°C)				
Insulation type	Dry type				
Screen	N/A				
Protection degree	IP23 or higher				
Thermostat switch	N/A				
Ground connection	TBD				
Efficiency			99.6		%
Acoustic noise	1 metre			60	dB

ABSOLUTE MAXIMUM RATINGS	
Storage temperature range	-40 to 125°C
Operating temperature range	-40 to 120°C
Isolation between input and output circuits (1 minute)	5kVAC
Isolation between output and output circuits (1 minute)	1kVAC
Creepage distance	8mm
Max working altitude	4000m
Max core loss at highest voltage and rated frequency (calculated)	350W
Max winding loss (calculated)	400W

SOLDERING INFORMATION[1]	
Terminations	TBD

1 For further information, please visit www.murata-ps.com/rohs

www.murata-ps.com/support

KMP_CD1792C_A01_D02 Page 1 of 2

Figure D 6 DC-DC Transformer Datasheet

Enclosure – ERMCO-GRIDBRIGE

The enclosure weight is an estimate that has been provided by the SST supplier, ERMCO-GRIDBRIGE. This will be refined during the assembly of the SST.

Transportation Distance

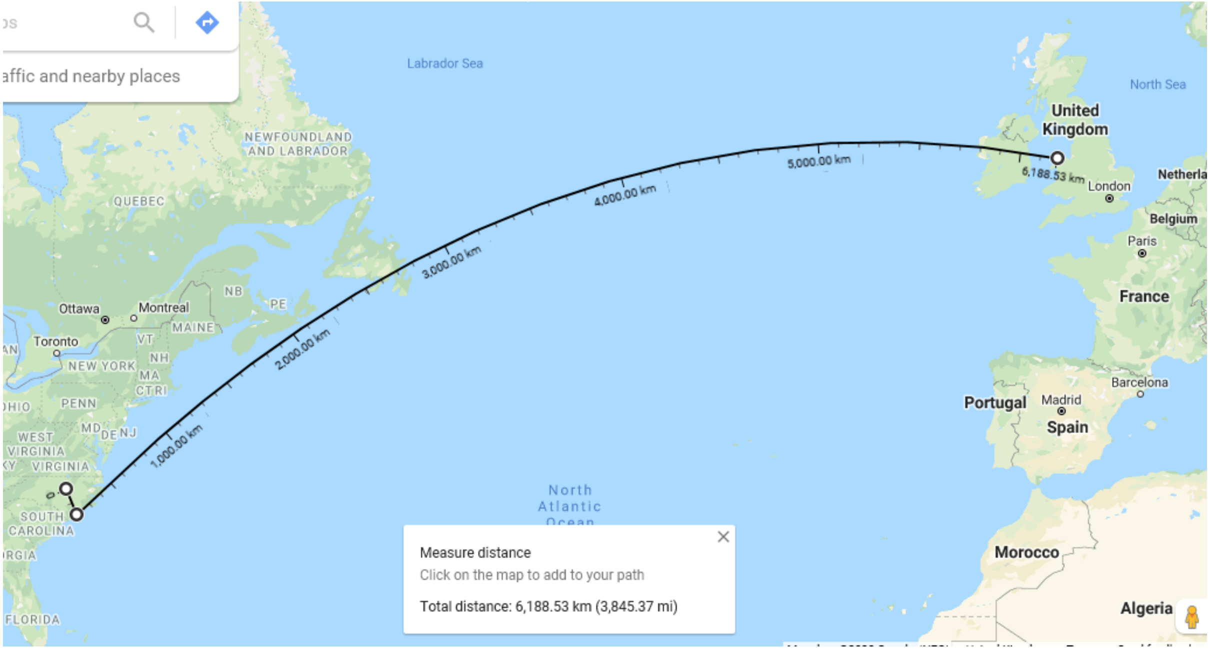


Figure D 7 Measured Distance Used for Transportation Calculations

SST Losses

The table below shows the device contribution to the overall losses of the SST at full load.

Table D 2 Component Contributions to SST Full Load Losses

Device/Component	Heat Load (W)	Qty.	Total Heat Load (W)	Notes
SiC Modules-Shunt	1400	3	4200	20kHz Fs, 65C Case 4th Leg=imbalance compensation
SiC Modules-Series	212	3	636	20kHz Fs, 65C Case
SiC Modules-DC HB	450	2	900	30kHz Fs, 65C Case
SiC Modules-DC-FB	290	4	1160	30kHz Fs, 65C Case
Shunt Conv. Inductors	350	4	1400	Supplier calculation, Max
Series Conv. Inductors	50	6	300	Estimate, Max
SSR Thyristor SS	85	3	255	980Arms Bypass, Steady State @1V
SSR Thyristor Peak (3Sec)	167	3	501	To clear series fuse. (est. 2kArms @1V)
Coupling Transformers	108	3	324	99.6% efficient
DC-DC Transformer	850	1	850	Calc. Max from muRata
System Power Supply	24	1	24	95% efficient, 480W
SiCSM	15	2	30	Estimate, 2nd for DC Service
System Conduction Loss	250	1	250	0.05% Est. @ 500,000
Other System Losses	250	1	250	DC Link, AC Caps, Etc
			10,579	**Total – Cont. Max (97.9%)***
			11,080	**Total – Peak Max (97.8%)***
			7,669	**AC Total – Cont. Max (98.5%)***

Disposal

Presented is an image of the disposal methods used for electronic waste as defined within the Eco-Invent database. The disassembly of the SST into its subassemblies is also shown.

Name	Status	Comment
SST Dispoal	None	Dissassembly case for the SST

Referring to assembly	Amount	Unit
SST	1	p

Processes	Amount	Unit	Distribution	SD2 or 2SD	Min	Max

Separation of sub-assemblies

Disposal scenarios	Sub-assembly	Percentage
AC/DC Rectifier	AC/DC Rectifier	100 %
DC/AC Inverter	DC/AC Inverter	100 %
DC/DC	DC/DC	100 %
DC Link	DC Link	100 %

Treatment of remaining waste

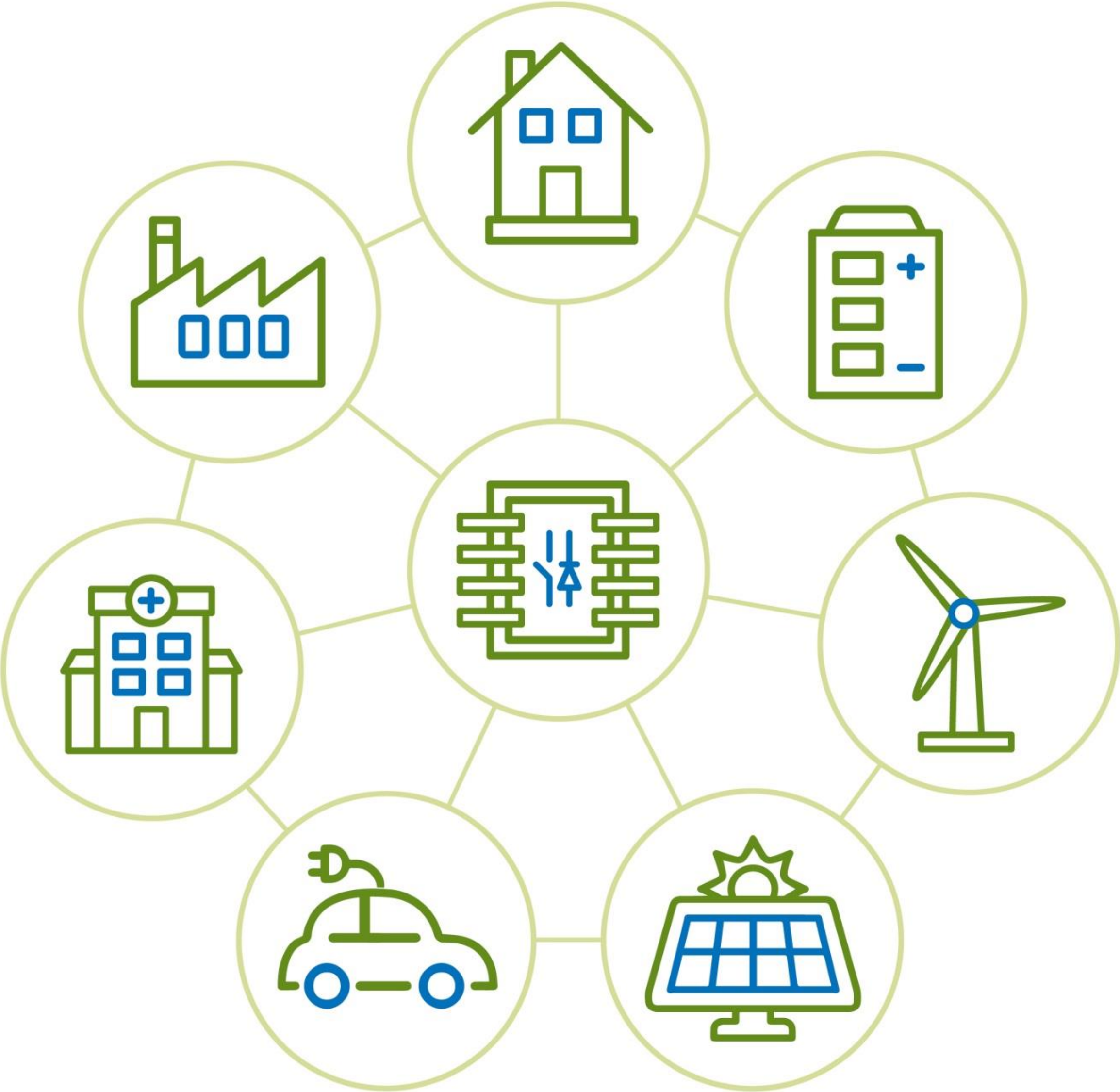
Waste scenarios	Percentage
Recycling of Enclosure	100 %

Figure D 8 Disassembly model of SST

Name	market for waste electric and electronic equipment
Process type	System
Process identifier	EI3ARSYS000011519610940
Infrastructure process	No
Status	None
Date	19/12/2018
Image	
Comment	In this market, expert judgement was used to develop product specific transport distance estimations. Production volume: 1 kg Included activities start: Included activities end: Energy values: Geography: The inventory is modelled for Global Technology level: 0 Technology: Start date: 01/01/2011 End date: 31/12/2018 Is data valid for entire period: True Time period: Macro-economic scenario name: Business-as-Usual Version: 3.0.3.0 Created: 8/2/2011 10:02:05 AM Last edited: 8/2/2011 10:02:05 AM Source: 25049_50d6665b-2b70-45de-b717-28e61494fa63_344760e2-b9c0-43b0-b9b0-11c2342c8d2b.spold UUID: 50d6665b-2b70-45de-b717-28e61494fa63
Collection method	
Data treatment	extrapolations: This dataset has been extrapolated from year 2011 to the year of the calculation (2018). The uncertainty has been adjusted accordingly.
Allocation rules	
Verification	
Record	data entry by: Guillaume Bourgault bourgault@ecoinvent.org Uberlandstrasse 129, CH-8600 Dubendorf, Switzerland is active author: False
Generator	generated by: [System] support@ecoinvent.org

External links	Comment
https://v35.ecoquery.ecoinvent.org/Details/PDF/60AB326F-B7AD-42E3-9A3E-BF2BD64E4B34/	

Figure D 9 Disposal Method and Parameters for Electric Waste within Eco-Invent Database



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