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Life Cycle Assessment of an automated paper testing system

A key product in the paper industry's future

Master's thesis in Industrial Ecology

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Cover: The ABB process industries' product: L&W Autoline. The picture is used with permission from ABB

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Abstract

Climate change has led to an increased usage of renewable paper products, resulting in a greater demand for high-quality products. Therefore, the need for paper testing machines will increase as well. In this master thesis, a life cycle assessment was conducted on ABB Process Industries' product L&W Autoline in size small with the three most commonly used modules. L&W Autoline is used in pulp and paper mills to measure the quality of the paper produced. The LCA was an attributional one, from cradle to grave. It measured the impact categories; climate change, depletion of abiotic resources, eutrophication, acidification, terrestrial ecotoxicity, fossil and nuclear (non-renewable energy resources) and water (renewable energy resources). The results from this study can be used internally to improve the product and gain knowledge in the supply chain. The report also fills a knowledge gap regarding capital goods.

The results showed that the environmental impacts of the production phase are dominant when L&W Autoline is used in Sweden. The main contributors in the production phase are aluminium and the circuit boards, despite the circuit boards' small weight relative to the total weight of L&W Autoline. The report contains two sensitivity analyses; one that compared the use phase between China and Sweden and another that compared the gold coating on the circuit boards. The results from the two countries showed that the use phase was dominant when used in China. The sensitivity analysis showed that it depends on the electricity mix in the different countries where China's consists of more hard coal than Sweden's, which mainly consists of nuclear and hydroelectricity. Therefore, it is crucial to make the L&W Autoline energy efficient, primarily when used in countries with a fossil-based electricity mix. The results from the sensitivity analysis regarding the gold coating in the circuit boards showed a significant decrease in environmental impact for both impact categories investigated. Therefore, the final recommendations are that ABB further investigates the origin, acquisition and production of the materials, especially for gold in the circuit boards and aluminium.

Keywords: Life cycle assessment, ABB, Pulp and paper industry, Machinery, OpenLCA, Capital equipment

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Sammanfattning

Klimatförändringarna har lett till en ökad efterfrågan av förnybara pappersprodukter, vilket resulterat i en ökad efterfrågan av högkvalitativa pappersprodukter. Detta medför även en ökad användning av papperstestningsmaskiner. I detta examensarbete utfördes en livscykelanalys av ABB Process Industries produkt L&W Autoline i storleken small med de tre mest använda modulerna. L&W Autoline används i massa- och pappersindustrin för att mäta papperskvalitén. Den utförda livscykelanalysen var en "attributional" LCA från vagga till grav. Som mätte karakteriseringsmetoderna "climate change", "depletion of abiotic resources", "terrestrial ecotoxicity", "acidification", "eutrophication", "fossil" och "nuclear (non-renewable energy resources)" och "water (renewable energy resources)". Resultaten från denna studie kan användas internt för att förbättra produkten och erhålla kunskap för hela livscykeln. Rapporten fyller också en kunskapslucka inom LCA gällande kapitalvaror.

Resultaten visade att produktionsfasen är dominerande när L&W Autoline används i Sverige. Den huvudsakliga bidragsgivaren i produktionsfasen är aluminium och kretskorten. Detta trots att kretskortens vikt är liten i förhållande till L&W Autolines totala vikt. Rapporten innehåller också två känslighetsanalyser; en som jämförde användningsfasen mellan Kina och Sverige och en när guldbeläggningen från kretskorten togs bort. Resultaten visade att användningsfasen var dominerande när den användes i Kina. Känslighetsanalysen visade att det beror på elektricitetsmixen där Kinas består av mer stenkol än Sveriges, som främst består av kärnkraft och vattenkraft. Det är därför av vikt att göra L&W Autoline mer energieffektiv, särskilt när den används i länder med en fossilbaserad elektricitetsmix. Resultaten från känslighetsanalysen avseende guldbeläggningen i kretskorten visade en signifikant minskning av miljöpåverkan för de undersökta kategorierna. De slutgiltiga rekommendationerna är därför att ABB bör undersöka materialens ursprung, förvärv och produktion, speciellt för guldet i kretskorten och aluminiumet.

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Matilda Lidfeldt & Sara Mårtenson, Gothenburg, June 2021

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Acronyms

BoM Bill of Materials.

CED Cumulative energy demand.
CO_2 Carbon dioxide.

EOL End of Life.
EPD Environmental Product declaration.

GHG Greenhouse gas.
GWP Global warming potential.

LCA Life Cycle Assessment.

PMMA Poly(methyl methacrylate).
PVC Polyvinylchloride.

RoW Rest of world.

1
Introduction

This chapter contains background to the importance of the studied product related to the pulp- and paper industry, ABB's sustainability work and the thesis' aim.

1.1 Background

The pulp and paper industry is characterised as an industry with high capital intensiveness and some core products that are well established. There has been quite a low level of innovation within the industry [2]. This is changing due to one of the present times most considerable challenges, climate change. Thus resulting in a demand for renewable products [3] that can contribute to a low carbon bio-economy. This transition derives from the realisation that there is a need for a global shift to mitigate climate change.

The forest industry in Sweden accounted for 2.1 percent of Sweden's GDP year 2016 [4], and 9-12 percent [5] of total employment, export, revenue and value-added, making it a large industry in Sweden. As a large actor, the pressure increases to prove its sustainability regarding both products and management. One of the pulp and paper industries' advantages is that it is renewable. Other beneficial aspects originate from the growing forests that provide carbon sequestering, habitats for animals and other ecosystem services [3]. On the other hand, many forests are monocultural plantations that does not support biodiversity as much as natural forests [6]. The pulp and paper industry also contributes to environmental problems such as global warming, acidification and pollution in the air, water and ground.

The development of bio-based products replacing fossil-based products will be an immense opportunity for the industry in the following years. With the European Union's political directives striving to become a bio-based economy, the pulp and paper industry can replace products from other sectors, earn more revenues and expand [2]. Therefore, the forest and pulp and paper industries' challenge is to provide materials and products that previously have consisted of other materials while also developing new products. The trade-off between the demand for resources and the environmental values is a massive challenge for the industry to lead the transition into a bio-economy and a more environmentally sustainable world [3].

For the industry to handle future demand and become competitive, innovations within technology such as digitalisation will become necessary. It is estimated that digitalisation will save money, increase productivity and safety, as well as reduce waste [7]. The

Swedish Swiss company ABB manufacture products that contribute to the digitalisation within the pulp and paper industry. One of these products is called L&W Autoline, which is an automated and digitalised paper and board testing system. Its function is to monitor the quality of the product, resulting in less waste, better quality and more efficient use of raw materials. Therefore, the product contributes to a more environmentally sustainable industry that can manage upcoming challenges and mitigate climate change.

1.2 Company background - ABB sustainability work

ABB has set a sustainability agenda for 2030. They work both according to the Paris agreement and the Science-Based Targets initiative as they strive for the 1.5 degrees target [8]. In their report, they state:

"With our 2030 sustainability strategy, we are actively enabling a low-carbon society as well as working with our customers and suppliers to implement sustainable practices across our value chain and the lifecycle of our products and solutions. We are equally committed to driving social progress, along with our suppliers and in our communities." [8]

ABB strives to have transparency throughout the whole value chain. They have decided on three focus areas where their most significant impacts exist; reduce carbon emissions, preserve resources, and promote social progress. By 2030 ABB commits to support customers in reducing their CO_2 emissions, achieve carbon neutrality across their operation and engage with suppliers and customers to reduce emissions along the whole supply chain. As a company, ABB can have the biggest impact on reducing greenhouse gas emissions by providing technology that reduces energy consumptions. ABB delivers products and technology to sectors that consume much energy, such as the industry, building and transport sector. With these sectors accounting for three-quarters of global energy consumption, ABB has set the target to reduce the CO_2 emissions by at least 100 megatons [9].

As well as supporting suppliers and customers, ABB aims to achieve carbon neutrality across its operations by transitioning to renewable energy sources. In 2019, 30 percent of the energy came from renewable sources. It will also be done by improving energy efficiency and converting the vehicle fleet to non-emitting alternatives. Since the year 2013, ABB has reduced its emissions by 40 percent [9].

ABB's other target to preserve resources centres around the concept of circularity. They state that *"by 2030, 80 percent of ABB products and solutions will be covered by our circularity approach"*. Circularity will be achieved by reducing waste, making products more durable, and increasing their rate of recycling and reusability. By the year 2030, none of their waste should go to landfill in areas where this is possible. Through their supply chain framework, they will actively work to ameliorate circularity across their supply chain [10].

Work to promote social progress is also a part of the ABB sustainability agenda. It includes goals that aim to reduce incidents, increase women in senior management roles, and achieve a top-tier employee engagement score [11]. This part will not be further described due to the thesis' focus on environmental sustainability.

ABB's material analysis showed that *"products, solutions and services"* have the most significant impact on ABB and the highest relevance for their stakeholders. The analysis is based on surveys with different stakeholder groups, such as customers, government, and civil society representatives. To reduce this impact, there is a need for innovation and to minimise the effect of the product's use. Thus, life cycle assessment will play a significant role in ABB's sustainability work in the future [12].

1.3 Aim

The aim is to execute a cradle-to-grave Life Cycle Assessment (LCA) of ABB's product L&W Autoline in the size small, with the three most commonly used modules. Modules are the measurement instruments inserted into the machine. The reason for executing a LCA within the equipment manufacturing industry is due to that the demand for disclosing their environmental footprint is increasing [13].

The information obtained from the LCA will contribute to knowledge about the environmental aspects of this product that has not previously been investigated. The thesis results can be used as a part of ABB's global sustainability work to achieve their global sustainability agenda for 2030. Additionally, the LCA results can be used internally to improve the product's environmental footprint throughout its whole life cycle. The environmental impact can be reduced by identifying hotspots in the life cycle. The report also fills a gap that has not previously been investigated by examining capital goods in the paper industry. The thesis is a collaboration with ABB Process Industries.

2
Theory

This chapter contains a definition of sustainability to understand the thesis' aim, a theory about the LCA methodology, previous LCA studies and the research questions.

2.1 Sustainability definition

There are several definitions of sustainability. The Brundtland [14] definition is one of the most common ones and was created in the year 1987 during the World Commission on Environment and Development. It is defined as follows:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [14].

Thus, the Brundtland definition treats the issue of fairness between and within generations. The goal is to meet human needs. Three sustainability dimensions must be considered to meet the human needs; the social, ecological and economic [14]. The social dimension can be described as the criteria needed to meet human needs. Human rights and health are a means of sustainable development rather than the core aspects of the dimension. The economic dimension consists of two parts, finite natural resources and human-made capital. Finite natural resources consists of the substances available for humans to extract from the crust of the Earth. The latter includes the assets made by humans to create goods and services [15]. The report states that social and economic development will be impossible if the ecological dimension is disregarded. Therefore, the social and economic development must consider the environmental terms [14].

In this thesis, the ecological dimension is the only dimension that will be assessed. The ecological dimension can be divided into two parts. The first one is the ability to produce natural goods for humans, called the environmental production capacity. The other one treats various pollutants and environmental impacts, known as the environmental assimilative capacity. One argument for being cautious with our ecological resources is that we do not know what future generations will need. The only sure thing is that we rely on natural resources today and that future generation will continue to do so [15].

2.2 Life cycle assessment framework

Life cycle assessment, LCA, is a method used to determine the environmental impacts of products, goods, processes or services during the entire life cycle. It is a standardised method according to ISO 14040, which states that the application of an LCA can be used to identify improvement possibilities throughout the life cycle, for decision-making and planning, to select and measure environmental indicators and for marketing claims [1]. It has gained increased interest from manufacturers and consumers due to the growing environmental awareness and the impacts of products and processes.

When the whole life cycle is included, it consists of the raw material acquisition (cradle), production (gate), use and finally disposal (grave), which is called a cradle-to-grave assessment. An LCA can be either an attributional or consequential LCA. An attributional LCA is descriptive; it describes the product system at its current state. While a consequential LCA is change-oriented, it describes the expected consequences of a change in the system [16].

According to the ISO 14040, an LCA consists of four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation [1]. All phases are interdependent and should be seen as an iterative technique where they are all finalised together.

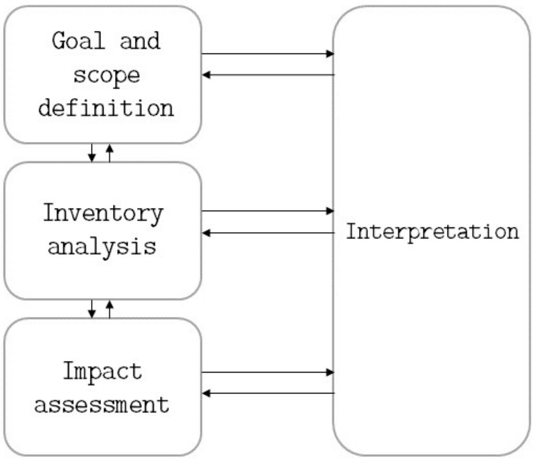

Figure 2.1: Framework for LCA, modified version based on ISO 14040. [1]

2.2.1 Goal and scope definition

In the goal and scope definition, the goal is first defined, followed by the scope. The goal should include the intended application, the reason to why it is performed, the application, and the intended usage of the results [1]. Initially, the goal of the project can be vaguely described. However, it is crucial to formulate a more specific purpose later. Typical research questions of an LCA include hotspot identification and possible improvements.

In the scope, an initial flowchart is introduced, and the system boundaries are defined. Then the functional unit is presented. It is a quantitative measure of the studied system. The system's input and outputs can be related to the reference flow, corresponding to the functional unit. Next, the impact categories are decided on, they vary depending on the project, but typical examples are climate change, eutrophication and acidification. After that, the system boundaries are defined [17]. The data quality requirements should be stated to interpret the reliability of the work. Significant assumptions and limitations should also be noted in the goal and scope definition [1]. It should be noted that different LCA's are often incomparable since the author's assumptions, modelling choices and limitations affect the results.

2.2.2 Inventory analysis

The inventory analysis is an iterative process that is one of the most time-consuming steps in an LCA. A flowchart is constructed to show the study's activities and flows related to its system boundaries [17]. The data is collected and calculated, which can be very resource-intensive. First, the data needs to be validated, then the data is related to the unit process and lastly to the reference flow [1]. Sometimes there is a need for allocation when, for example, several product systems share the same activities [17].

2.2.3 Impact assessment

According to the ISO 14040 standard [1], there are both mandatory and optional elements. The inventory analysis data is translated into specific environmental impact categories and category indicators in the impact assessment. The translation of the elementary flows is beneficial for making them more environmentally relevant, more comprehensible, and presentable. The environmental impact of, for example, global warming is calculated by characterising the different relevant elementary flows.

The first mandatory element includes selecting impact categories or category indicators [17]. The impact categories can be divided into midpoints and endpoints. Midpoints, such as climate change and resource depletion, are more common to use than endpoints, including human health and natural resources [18]. The next step is called classification, assigning the inventory analysis results to the chosen categories or indicators. The last mandatory step is called characterisation, where the elementary flows are multiplied with their characterisation factor, which depends on the results from the classification [17].

2.2.4 Interpretation

Interpretation is the last step when the inventory analysis and impact assessment results are interpreted according to the goal and scope [1]. There are various options for presenting the result; it could be in a bar chart showing the most critical parameters or weighted results. The result could also be analysed in different ways, including dominance analysis and break-even analysis. Sensitivity analysis is a method where small systematically changes are made to see if it leads to reversal results [17].

2.3 Previous LCA's

Previous LCA reports have not been done on a similar machine as investigated in this LCA report. Machines used in the paper industry are often excluded since they are capital goods. Capital goods are defined as machineries that are used in the production of the producer good [19]. Many LCA studies exclude the production of capital goods even though the ISO standards state that capital goods are a part of the product system. The reason for this often varies, but it is a way of simplifying the LCA. However, it has been stated that it is still unclear how much capital goods contribute in an LCA. One analysis by Frischknecht et al. [19] showed that the exclusion of capital goods could have a significant impact depending on which impact categories were studied. It is, therefore, of importance to further investigate the impacts of capital goods in LCA's, but also to reflect on these aspects when modelling. The focus in the literature has mainly been on the environmental aspects of the paper as a final product.

Nevertheless, one LCA was found that examined the environmental impacts of a newsprint paper machine and not the system of consumer good paper [13]. That LCA shows that the machine's use phase is dominating for almost all the impact categories. The recommendation from that LCA is therefore to prioritise the energy efficiency of the machine and the electricity mix. However, the study showed that regarding metal depletion, the manufacturing phase was the largest. The report concludes that the use phase is crucial since the newsprint paper machine has a long lifetime and high energy consumption. It also concludes that fossil resource depletion and global warming are the most relevant impact categories for this type of machine. The conclusion is that capital goods are an important investment that creates path dependencies, and therefore, a decision should be taken with good consideration, not only focusing on the final paper goods [13].

Another LCA focusing on electric-motors also concluded that the most significant contributors to environmental impacts are energy usage, the large number of materials and their production [20]. They further on describe the main reasons for conducting an LCA on a machine, similar to the one studied in this report. The reasons are as follows; to collect information about the environmental impacts, to have the possibilities to reduce these and also to be able to inform on the most environmentally friendly usage option and recycling of a machine [20].

2.4 Research questions

The main objective in this LCA is to analyse L&W Autoline regarding its environmental footprint. This will be done by answering the following research questions:

- Which are the hotspots in the life cycle (cradle-to-grave) of L&W Autoline?
- How can ABB improve their product, L&W Autoline, to make it more environmentally friendly?
- How does the location of the use phase affect the environmental impact of the product?

3

Goal and scope definition

In the following chapter, the LCA's goal and scope will be determined. The following section presents the LCA's aim, functional unit, modelling and chosen impact categories.

3.1 Goal and context

The goal of the LCA study is to assess the environmental impacts of ABB's product L&W Autoline in the size small, with the three most common module inserts. The information obtained from the LCA will contribute to knowledge about the environmental aspects of this product that has not previously been investigated. The LCA results can be used internally to improve the product's environmental footprint through its whole life cycle. The research questions can be found in section 2.4.

The LCA will measure the environmental impacts of L&W Autoline with five midpoint categories from the impact assessment method CML 2001 (baseline) method, which are climate change, depletion of abiotic resources, acidification, eutrophication and terrestrial ecotoxicity. The midpoint categories were chosen because they were deemed reasonable by previous literature studies [13]. The following midpoints were investigated from the impact assessment method cumulative energy demand; non-renewable energy resources (fossil and nuclear), and renewable energy resource (water).

3.2 Scope definition

The master thesis is available for everyone through Chalmers University of Technology's platform. It is conducted in collaboration with ABB.

3.2.1 L&W Autoline

The product analysed in this thesis is the L&W Autoline, which is an automated and digitalised paper or board testing system. The L&W Autoline has two sizes: small (S) and large (L). The L&W Autoline L has thirteen module slots available, while the L&W Autoline S has six module slots. These can result in various combinations depending on the measurement needs, such as measuring optical and surface properties, structural properties, and strength properties with eighteen different modules. It is a complete laboratory system that aims to help paper and board mills to monitor and optimise product quality and efficiency by automating the testing system.

The L&W Autoline handles every step from sample preparation to the final report. L&W Autoline reduces time-consuming manual testing and human errors, resulting in fewer production losses and consistent and better paper quality. The measurement methods used are adapted to industry standards, and the data is saved for up to one year, which helps to identify quality trends over time. It can run at all times and analyse multiple samples simultaneously. L&W Autoline meets customer demands in high testing accuracy and provides sufficient and complete statistics compared to manual testing. It helps the mills become more digital since the information can be shared throughout the organisations quickly [21].

This report focuses on L&W Autoline S, a relatively new offering from ABB, making it interesting to examine its environmental impact. This size is targeted at customers that do not have much space in their laboratories, do not require many paper properties to be measured or do not have the economy to purchase the largest size. The most common size is L&W Autoline L; since it is common to add modules as time goes by. However, the small one can be rebuilt into a large one if there is a need for it. L&W Autoline S is also believed to fill a gap in countries with low usage of automated paper testing. When these countries get higher demands in quantity and quality, they will need to change to automated paper testing, making L&W Autoline S an economic possibility. In this study, when referring to the L&W Autoline base unit in size small filled with modules, it is called L&W Autoline. When referring to the modules, they are called L&W Autoline modules, and when referring to the base unit only, it is called L&W Autoline base unit.

3.2.2 Modelling aspects and data sources

ABB provided blueprints and CAD drawings of the components they have designed. The drawings showed the material of the components, and the CAD programme; `Autodesk Inventor Professional` depicted the volumes. The components in the L&W Autoline was presented as a Bill of Materials, BoM. The data needed for the inventory analysis was received from the research and development department at ABB Process Industries by e-mailing and Teams-meetings. There were also informal interviews held with people from different divisions at ABB to collect data. The densities for the raw materials were obtained from literature to calculate the components' weight. For some components, Environmental Product Declarations, EPDs, were available from ABB's website.

At the beginning of April, a field study at the production site in Kista, Sweden, was conducted. During the visit, the machine was studied, and the components that still lacked data were weighted and analysed. After the field study, the data was compiled, and the modelling in `openLCA` was finished. The results from `openLCA` were compiled in Excel in the form of different diagrams.

The programme chosen for the LCA modelling was `openLCA`. In `openLCA`, the flows of the processes were modelled. The purpose of the software programme `openLCA` is to calculate environmental, social and economic indicators. It has an open-source software and architecture that enable the import and export of data and can handle large databases [22]. There are numerous different databases to choose from that provide the background data for the life cycle inventory. In this case, *Ecoinvent 3.7* was used with the system model "Allocation, cut-off by classification". It is the largest transparent life cycle inventory database used worldwide, which is continuously updated. *Ecoinvent* contains well documented background data for all regions [23]. A process often used in *Ecoinvent* is "market". The process includes all activities with the same reference product, an average transport, and the product's input to cover losses that might occur in trade and transport. The regions can either be local or global [24]. For this report, it has been useful since it helps cover the knowledge gaps.

The cut-off method works well with an attributional LCA since it does not include processes outside the product's life cycle [25]. The system model "Allocation, cut-off by classification" is based on the recycled content or cut-off approach. This means that the product under investigation has to account for the burden of waste disposal but does not receive any credit for eventual positive impacts from recycling. In this case, it would imply that the product under investigation only bears the effects of the waste collection. In contrast, a future product made from the recycled material will bear the burden of the recycling process [26]. This method encourages recycling since other disposal methods can create an environmental burden on the product. However, if waste disposal results in positive environmental impacts, it can decrease the recycling. This can happen for incineration with energy recovery [25], where the avoided energy production makes it more favourable to incinerate than recycle.

3.2.3 Functional unit

The functional unit is "amount of paper analysed over 128 520 hours in an L&W Autoline". The functional unit is related to the adequate usage time over the lifetime of the machine. Over a year, the machine runs 51 out of 52 weeks and analyses four paper sheets per hour. Every paper sheet takes approximately 15 minutes to analyse; it runs every hour of the day for 51 weeks over 15 years. Thus, the reference flow becomes "one L&W Autoline".

3.2.4 Modelled system and system boundaries

The modelled system for L&W Autoline will be modelled from cradle to grave as an attributional LCA, based on the system's current state. The system's flowchart is shown in Figure 3.1. The boxes correspond to processes and the arrows correspond to material and energy flows, as well as transports. The system consists of a background and a foreground system. The foreground system consists of the system's processes under investigation, which a decision-maker, such as ABB, can influence. The background system includes all other processes that are not affected by the raw material acquisition and energy-mix decisions [17].

The foreground system consists of the production, use and End of Life, EOL, phase. The life cycle starts with the production phase. The first step is to extract raw materials for the product. The materials are then produced, including either the step injection moulding or metal working, depending on if it is a plastic or metal. The components used in L&W Autoline are either produced by ABB themselves or a third party, which are then transported to the production site in Kista. In Kista, they assemble the final product, L&W Autoline, which is then shipped to customers as a finished product. The use phase starts at the pulp and paper mills, which are the consumers, and lasts for at least 15 years. The use phase includes the service ABB offers to their customers every year during L&W Autoline's lifetime. The EOL phase is when the product is discarded either at the mills or in Kista by ABB. It is then transported from the mill or ABB to the waste management provider.

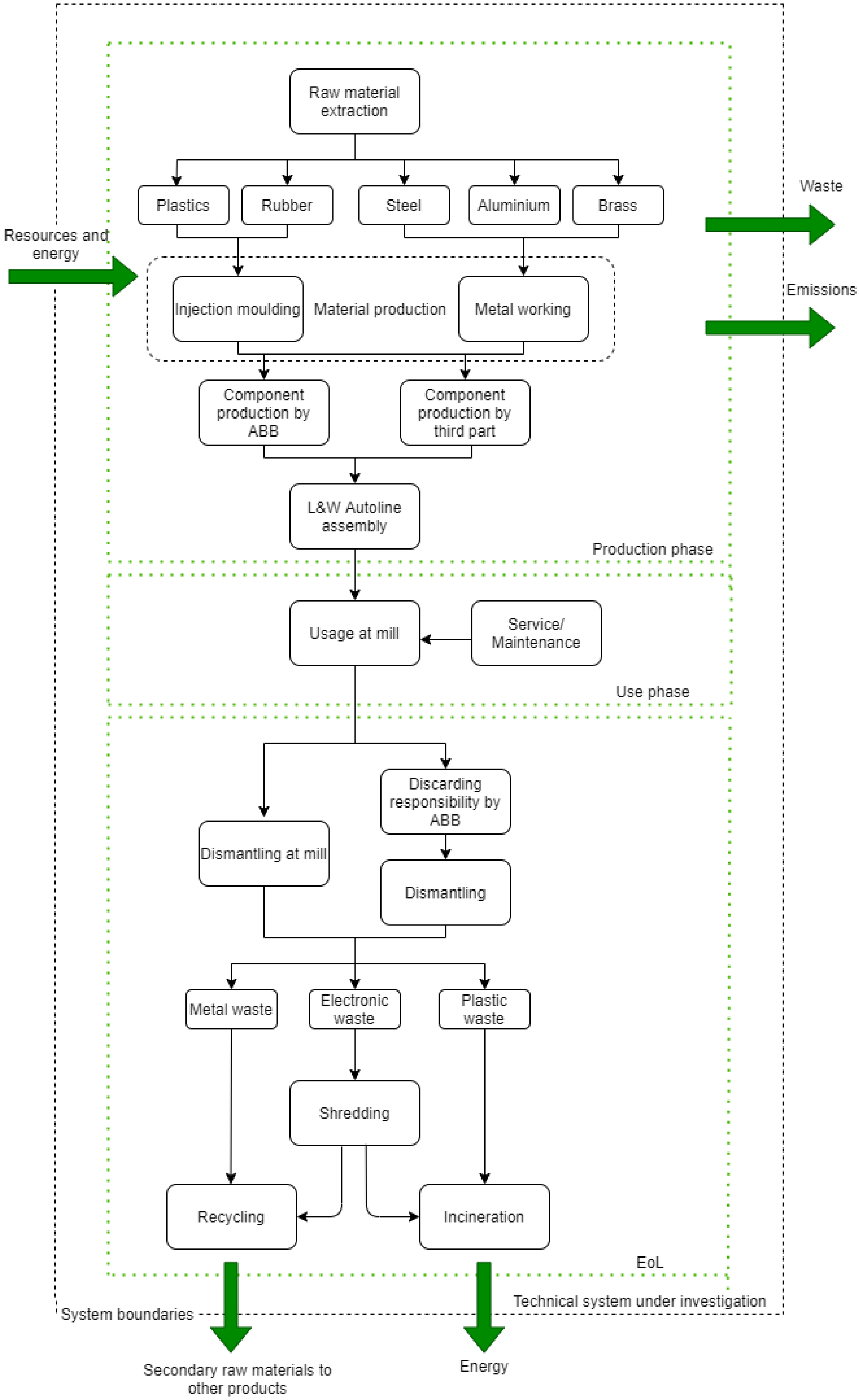

Figure 3.1: Flowchart of modelled system

Other system boundaries that are to be taken into consideration are time and geography. For time, the boundary is set for the lifetime of the product under study, in this case, 15 years. There are many different geographical boundaries in the study. The extraction of raw materials and manufacturing of components are set worldwide. However, the assembly of L&W Autoline is set in Stockholm, Sweden. The L&W Autoline is shipped worldwide. In this study, the use phase is modelled for Sweden and China. Two sensitivity analyses were conducted to compare the use phase in Sweden and China and the life cycle with and without gold coating in circuit boards.

The cut-off criterion is a boundary used within the technical system. Although an LCA strives to be as complete as possible, some elements are cut-off due to lack of resources, time or data [17]. Therefore, personnel-related environmental impacts will not be studied in this LCA. Neither will the production and maintenance of capital goods such as vehicles and buildings or packaging material be. Buildings in the foreground system will not be included. End-point categories will not be used since it is difficult to determine what is included in each category [17].

3.2.5 Impact assessment methods

The impact assessment method chosen were CML 2001 (baseline) and Cumulative energy demand, supplied by *Ecoinvent 3.7*. CML was created in the Netherlands, Leiden University, in 2001 and contained the most common impact categories [27]. The other impact assessment method used in this study is Cumulative energy demand that has been practised for a while. It was developed in the seventies as a result from the first oil price crisis [28].

From CML 2001 the following midpoint characterisation factors were chosen [29]:

– Acidification potential - average Europe
– Climate change - GWP_{100}
– Depletion of abiotic resources
– Terrestrial ecotoxicity - TETP inf.
– Eutrophication - generic

From the Cumulative energy demand the following midpoint characterisation factors were examined:

– Fossil (non-renewable energy resource)
– Nuclear (non-renewable energy resource)
– Water - Hydroelectricity (renewable energy resource)

Acidification can occur in many ways; one is through acidic rain. To form acidic rain, water in the atmosphere reacts with acidic gases. The acidic rain often falls far from its origin and damages the ecosystems that receive the precipitation because it is decreasing the pH in waters and soils [29]. However, the actual effect on the environment depends on the characteristics of the areas, such as buffering capacity [17]. Acidification can cause fish mortality and damage to forests. The following gases can cause acidification; ammonia, nitrogen oxides and sulphur oxides, SO_2. The acidification potential is measured in kg SO_2 equivalents and refer to the pollutant's maximum ability to produce the acidifying hydrogen ions [17].

Eutrophication is mainly affected by emissions from nitrogen and phosphorus. Other nutrients that also cause eutrophication are ammonia, nitrates and nitrogen oxides, by their emissions to air or water [29]. These emissions accumulate and result in an abnormal increase in plant growth, such as algaes, which causes an increase in oxygen consumption. Nitrogen originates from agricultural fertilisers, and phosphorous comes from sewage effluents. The limiting nutrient differs depending on the ecosystem and its geographical location. Thus, geographical variation is neglected [17]. Eutrophication affects the water and terrestrial ecosystems; the CML 2001 (baseline) measures generic eutrophication. The impact category is measured in kg phosphate, PO_4^{3-}, equivalents [29].

Climate change is caused by greenhouse gas (GHG) emissions that raise the global temperature. This results in rising sea levels, climatic phenomenon abnormality, and environmental damage. The characterisation of the greenhouse gases depends on their radiative forcing in the atmosphere, signifying their ability to absorb infrared radiation and heat the atmosphere [17]. The factors are expressed as Global Warming Potentials (GWP), which the Intergovernmental Panel on Climate Change, IPCC, develops. There are many GHGs, some common includes carbon dioxide (CO_2), methane, nitrous oxide and chlorofluorocarbons (CFCs), which are compared to CO_2 as the reference. The reference unit is kg CO_2 equivalent, and the time horizon can vary, the most common one is 100 years (GWP_{100}) [29]. The GHGs have different life spans, and therefore one alters the time horizon depending on what one wants to investigate.

The depletion of abiotic resources is divided into two impact categories; "elements, ultimate reserves" and "fossil fuels". Abiotic resources consist of, for example, iron ore, oil and wind energy, so-called non-living resources [17]. It measures the scarcity of a non-living resource. Thus it is affected by the extraction rate, and the sum of the substance [29]. The reference unit for the abiotic depletion "elements, ultimate reserves" is kg Antimony equivalents.

The ecotoxicity category can be divided into three impact categories; freshwater aquatic ecotoxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity. It refers to the maximum tolerable concentrations of heavy metals in an ecosystem. Substances, such as heavy metals, can result in toxic effects on the ecosystem, leading to biodiversity or species loss [29]. The reference unit for all ecotoxicity categories is kg 1.4-dichlorobenzene equivalents.

Cumulative energy demand, CED, aims to assess the primary energy usage for the whole life cycle of a good or service. The direct and indirect uses of energy are included, while the wastes used are excluded. The results from CED can help point out where the energy savings should be prioritised in the life cycle phases. It is also important when comparing the results of an LCA study to one with only primary energy demand. CED is often best in combination with other impact assessment methods [28]. Since there is no clear basis for the characterisation factor of the primary energy carriers, the impact category is divided into two impact category groups; non-renewable resources and renewable resources. Where fossil, nuclear and primary forest are part of the first group, and biomass, geothermal, solar, wind and water are part of the second group. There is no normalisation or weighting made for this method. The reference unit is Mega Joule [29].

3.2.6 Data quality requirements

The data quality is assessed regarding accessibility, reliability and relevance [17]. Data from ABB and its suppliers are considered to be the most relevant and reliable. The best available data will be used; this depends on the time and geographical relevance. The newer and most relevant geographical data were prioritised. In `openLCA` the providers are often set to "market". "Market" accounts for a general transport distance and larger geography.

3.2.7 Assumptions and limitations

ABB had a limited amount of data, and some assumptions had to be made regarding the weights and materials of the product's components. Assumptions were made together with the production personnel at ABB for some components regarding material and weight. Due to the many components of the machine, assumptions have been made with data from *Ecoinvent 3.7*. Assumptions were made regarding some electrical components such as computers, computer screen, cables and circuit boards, and manufacturing and transportation of raw materials since there was no data available. The modelling in `openLCA` for the different components is presented in more detail in Chapter 4 and Appendix C.

This study is limited to focus only on the L&W Autoline base unit in the size small with three module inserts. Since there is room for six-module inserts, the remaining three slots are filled with three blind plates. The study is limited to focus on the components and parts that are in use in the L&W Autoline. Therefore extra blind plates that are not in use, case accessory kits and cleaning tools were not modelled. Smaller components where no data was available were excluded; this was deemed reasonable since they did not contribute significantly to the product's total weight. For further detail on the assumptions and limitations of this study, see Appendix A.

4

Inventory analysis

In this section, the modelling of the product is presented. The chapter is divided into the production phase, use phase, EOL phase and the two sensitivity analyses. The flows and processes presented are obtained from *Ecoinvent 3.7*. In Appendix C a more detailed presentation of the different flows and processes modelled in the study can be found.

4.1 Production phase

L&W Autoline S has room for six-module inserts, and an estimate from sales personnel suggested that it is most common to use three of these inserts at the mills. In this study, the modules Bendtsen roughness, Thickness and Grammage are evaluated. These are the three most frequently used L&W Autoline modules in the European market, based on sales records. The L&W Autoline modules were assessed in the same way as the base unit. In this study, three blind plates were evaluated. The blind plates are used to cover the slots that are not used by the modules; thus, the three remaining blind plates were excluded from the study.

The production phase starts with the extraction of raw materials. A BoM was provided with a list of all components in the machine. The L&W Autoline base unit contained over 600 components, and three L&W Autoline modules contained over 700 components together. The data collection step was thus a very time-consuming step and an iterative process. The weights and materials were obtained from drawings and a programme called `Autodesk Inventor Professional`. For the components that lacked drawings, the production personnel helped identify materials and weighted the products manually. Six common materials were modelled separately; aluminium, brass, polyvinyl chloride (PVC), poly(methyl methacrylate) (PMMA), rubber and steel.

4.1.1 Assumptions made for the production phase

ABB did not have any available data on the origin of the materials nor where they were produced; thus, these processes were based on *Ecoinvent* data. The provider for these processes was set to "Market". The market includes general transport, and for the production of material, it contains a mixture of different production ways. This sort of provider was selected for many processes due to a lack of data to cover the general transports and various production ways within each process. In the provider, Europe or Sweden was chosen whenever possible; otherwise, the provider was set for Rest of the World, RoW, or Global, GLO.

Some components are manufactured by a third party, and others by ABB themselves at the site in Kista. Many of the components that suppliers manufactured did not contain any further data on their sub-components and materials. For these more complex components, *Ecoinvent* processes were used and scaled to apply to the component used in the machine. In this case, estimations were made to choose the best available process correlated to the component by examining material inputs and their function. For some of these processes, the unit was Item; thus, the weight for the process was scaled according to the weight of the component for a more accurate result. An example of a product that will later be shown to have a significant impact was the circuit boards. These were taken from *Ecoinvent* data and thus therefore not consist of the exact materials used in ABB's circuit boards. It was confirmed that the ABB circuit boards did contain gold which later will be shown as a significant contributor to the environmental impacts. The circuit boards in L&W Autoline were weighed manually by ABB personnel.

For many components, a volume was given in `Autodesk Inventor Professional`, and the weight could then be based on the density. A LED assembly consisting of cables and LED strips were modelled as one "LED" from *Ecoinvent*. The motor in the L&W Autoline base unit and the module Thickness was modelled as an "electric motor for an electric scooter" from *Ecoinvent*. The weight was taken from the manufacturer's website [30]. The magnets in the product were modelled as a "permanent magnet for an electric motor", and the weight was based on a manufacturer's website [31]. The solenoid switches were assumed to be made of pure aluminium in order to calculate the weight. These were then modelled as a "switch, toggle type" from *Ecoinvent*. Two fans were modelled as a "fan, for the power supply unit, for a desktop computer". The weight of the fans was based on the assumption that the material consisted of plastics to obtain a density.

Six materials were found to be very common in the machine, and thus, they were modelled separately and then put into the "L&W Autoline Manufacturing" process. There were six materials modelled this way; aluminium, brass, PVC, PMMA, rubber and steel. However, they did not contain the step where they were manufactured into a component, i.e. a pneumatic valve, since there was no available data for this step. The metals included the step "metal working" to be converted from a semi-manufactured product into a final product. The plastics and rubber included the step "injection moulding" for the material to be converted into a usable product.

All screws, washers and nuts were given a weight based on expertise judgements by the production personnel in Kista. They were all modelled as steel. The locks and ball bearings were also assumed to be made of steel; the weight was taken from the manufacturer's website [32]. Aluzink was considered to be made only of steel since aluzink mainly consists of steel [33]. The compact unit was assumed to consist of 50 percent steel and 50 percent aluminium. An air filter was assumed to consist of 50 percent plastic and 50 percent aluminium. The cylinders in the modules consisted of a core of steel and an aluminium cover; the relationship between the materials is 50 percent. All pneumatic valves, pneumatic connectors and pneumatic fittings were assumed to be made of brass. Therefore some electronics might have been excluded. Some of the pneumatics were judged to be made of plastic, after expertise judgement of personnel in the production. The terminal springs were assumed to be made of PVC. A socket was modelled to only consist of PVC due to no data; therefore, some electronics might have been missed.

The cables that did not have a specified length were assumed to be one meter each for the L&W Autoline base unit and 0.8 meter for the modules, based on judgement by the production personnel. The cables that were not specified were assumed to be a "cable, unspecified" in *Ecoinvent*. The hoses were assumed to all be the same and therefore weigh 37 gram per meter, based on two weights that were given in the BoM. The weight for the component DIN Rail TS35X15 Hold 2m was found online [34]. The weight for pressure sensor term was also found online [35]. For the PLC safety, Pluto Pluto S20 V2 [36], and the spring pressure [37] the weight existed in some documents published by ABB online. The weight for the components wheel O100 with swivel plate, tension spring, some pneumatic valves, switch pan rockers, measuring head, control outlet, chassis, a transport box and Belt 6M ABB's were manually weighed by production personnel.

Three components in the L&W Autoline base unit; Optocoupler OBRIC0100-24VDC, Contactor 24-60V 50/60Hz 20-60VDC AF09 and Automatic fuse 10A 2p DIN rail mount, were assumed to be similar to EPD's found on ABB's website based on the judgement of the authors. Thus, these were modelled according to the material content presented in the EPD's. The material inputs from the EPD's were modelled in a separate process and then put in the "L&W Autoline S Manufacturing" process. These components were considered to be so small that they were not deemed interesting to model separately. See Appendix C for more detailed information about the modelling processes. All the assumptions made in this study can be found in Appendix A, as well as a list of the excluded components for the L&W Autoline base unit and L&W Autoline Modules.

4.1.2 Electricity usage during assembly

The electricity needed for the assembly was allocated regarding to their usage of the area on the production site. The usage area was estimated by ABB production personnel. Half of the electricity in the building in Kista was assumed to be used in the production. However, there are other products produced as well in Kista, and thus, an allocation based on the production area was made. The total production area in Kista is 1800 m^2. The L&W Autoline base unit requires 300 m^2, and the L&W Autoline modules require 100 m^2 of the production area.

The production personnel assemble both the base unit and the modules manually. Three L&W Autoline base units and six L&W Autoline modules are built at the same time. The L&W Autoline base unit takes approximately 7.5 days to produce for two people, while an L&W Autoline module takes 2.5 days for five people to manufacture. However, the number of people working on the product are not accounted for in this study. The storage of the products was not a part of the life cycle due to a lack of data.

The electricity usage for the whole building, including both production and offices at the site, is 585.8 MWh over a year. It was estimated by ABB personnel that approximately half of the electricity was used in the production, which results in 292.9 MWh per year for the production.

District heating and cooling were excluded since this is not directly related to the L&W Autoline production. It is related to the building, where there are offices that would still be used even if no production was performed. The electricity for storage of the components, the L&W Autoline base unit and the L&W Autoline modules were excluded due to lack of data.

The total electricity usage for production of the base unit and three modules is 390.974 kWh for an L&W Autoline with three modules. The calculations are shown in Appendix B. The electricity was modelled in `openLCA` as a Swedish electricity mix.

4.2 Transport from production to mill

L&W Autoline's are sold to customers all over the world. In this LCA an assumption of an average distance within the country of Sweden was made. It was modelled that the machine was transported from the production site in Kista to the city of Karlstad, a distance of approximately 300 km with a freight lorry of 16-32 metric ton, EURO6. ABB suggested the average distance to be Karlstad, which is a city with many paper mills. The EURO6 classification signifies that all transport vehicles must limit their emissions to a certain degree. In Sweden, all new transport vehicles must meet the directives of EURO6, and that is the reason why it is chosen for the modelling of this study [38].

4.3 Use phase

The use phase consists of electricity usage and compressed air and service of the machine over a lifetime. To model the most common scenario at the mills, it was modelled that the paper mills have one L&W Autoline that is constantly running, except for one week a year. The average usage of the L&W Autoline is based on estimations by ABB personnel. The results can differ since there was no clear statistics over the amount of paper producing machines a mill has and the amount of analysis done per hour. With two paper producing machines, the L&W Autoline is constantly running. The L&W Autoline is most commonly used for 15 years, 51 weeks a year, and every hour of the day. Once a year, the mills have a machine stop that lasts for a week.

The power consumption varies depending on the usage of the machine; the values obtained are based on an average usage of the machine. The electricity usage over a lifetime was calculated to approximately 12.2 MWh over a lifetime. The calculations can be found in Appendix B. For the use phase, a Swedish electricity mix was used in the modelling to represent a mill in Sweden.

The machine requires compressed air during usage. The amount of compressed air depends a lot on which L&W Autoline modules are used. The most common pressure in the pneumatic valves at the mills is 0.6 Mpa. This value was therefore used when modelled in `OpenLCA`. A new process was created for the compressed air to apply to Swedish conditions. This was done by modifying an *Ecoinvent* process for compressed air at 700 kPa gauge with Swedish electricity mix instead of the market electricity for a wider geography. Over a lifetime, the total air consumption for the L&W Autoline base unit and the three L&W Autoline modules results in approximately 1.25 $Nm^3/h \times 128520$ hours = 161 164.1 Nm^3. The calculations can be found in Appendix B.

A big part of ABB's work is to offer a Preventative Maintenance Agreement. The service consists of the calibration of the machines to certify the machines for the mills. The technicians bring weights, flow meters, et cetera to calibrate the instruments. Wearing parts such as membranes, knives, silicone gaskets and belts are changed if needed. It is mostly the L&W Autoline modules that need service since there is more wear on the modules than the base unit. In the base unit, there are almost no parts that are changed during service.

The service was modelled to include the impact of the spare parts used over the whole lifetime. The spare parts included were specific for the L&W Autoline base unit and the L&W Autoline modules included in this study. It was assumed for simplicity that every spare part was changed once during its lifetime. In L&W Autoline, the circuit boards are of the type PF4. But due to new upgrades, all of them will be changed to a PF5 during service within the coming years. There is a weight difference between them, where the PF5 weighs less but are modelled in the same way. Smaller components that were excluded from the manufacturing process were also excluded in the service. The impact from the travel of personnel was excluded due to this study's cut-off criteria; see more in 3.2.4 Modelled system. The calibration process was also excluded due to a lack of data.

4.4 End of Life phase

The End of Life phase varies a lot depending on the geography of where the machine has been used. In this report, the focus has been on EOL treatment for Scandinavia. However, the EOL treatments are quite similar in Europe due to European legislation. Dismantling of the product can either be done at the mill by the customers, or the L&W Autoline can be sent to ABB's production site in Kista. The waste treatment process of machines similar to L&W Autoline start with disassembling. Some materials are remelted while small electrical parts are shredded and then sorted. The materials from the shredding are attempted to recycle and remelt, but there is a risk that materials are not adequately separated [20].

The products and materials in the EOL is modelled differently based on if the materials are recyclable or not. For metals that are recycled, the machine does not receive any positive credit for the recycling due to the "Cut-off system model" used in the database *Ecoinvent 3.7*. The only environmental impact these metals have is the transport to the recycling company. The EOL was modelled to include transportation of 300 km with a freight lorry of 16-32 metric ton, EURO6. This to account for the transportation either from the mill to the recycling company or from the mill to ABB's site and then to the recycling company.

The environmental impacts from the recycling process are allocated to a future product according to the cut-off approach. This implied that all steel, aluminium, and brass in the L&W Autoline were modelled to be recycled. Thus, the environmental burden from EOL for these materials came from the transport of the materials to the waste treatment facility.

Since there was little information about how the materials and components were treated, waste flows from *Ecoinvent* were used. This was modelled in as much detail as possible, but due to the limitation of choices from *Ecoinvent* some materials and components were modelled together. Rubber could be modelled as a specific waste flow. However, the remaining plastics were modelled as "waste polyvinylchloride" even though different types of plastics were used in the production process. This was seen as reasonable since the waste treatment of different plastics is quite similar, and they arrive mixed to the waste treatment facility. The computer and computer screen were modelled as "used desktop computer" and "used liquid crystal display". The circuit boards were modelled as "used printed wiring boards". All the different cables, cable connectors and plugs for cables were modelled together as the waste flow "used cable".

The waste processes for "waste electric and electronic equipment" and "used printed wiring boards" include dismantling the products. In this process, the metals can be reused. The processes for "used liquid crystal display" and "used desktop computer" include dismantling the product where the metals can be recycled and the remaining components are incinerated. The waste treatment of rubber, plastics and the cables is eventually incinerated, which in L&W Autoline's case was assumed to be reasonable. This is due to the complexity of the components that contain different materials that might be hard to separate into the level needed for it to be recyclable.

The remaining components were more difficult to model since there was no available data and no suitable *Ecoinvent* flows. Therefore, the controller was modelled as "electronic scrap from control units". The remaining electronics such as fan, magnets, LED light, power supply unit, switches, motors, internet switch were modelled as "waste electric and electronic equipment" since there were no detailed data about their waste treatment process.

The providers for the flows were set as "treatment" since the transport already was accounted for. The geography was chosen for Europe and otherwise as close to Europe as possible. However, most processes only had global providers. One exception from this decision is the process "waste polyvinyl chloride" that had data for the geography of Sweden. In this case, it was set as "market" for Sweden since this was seen as more reliable than a global "treatment" provider.

4.5 Sensitivity analysis - Use phase in China

The intended market for L&W Autoline small is Asia. Thus, alternative modelling of the life cycle included a scenario where the use phase and EOL phase took place in China. The following section presents the changes made from the modelling scenario in Sweden. The reason for choosing Shanghai, in particular, is that there are many paper mills in that area, and it is a future potential market, where the first order is taking place within the next months.

The transportation from Kista to Arlanda airport is done by freight lorry, a distance of 30 km. From Arlanda airport to Shanghai Pudong International Airport, the distance with the flight was estimated to be 7780 km. The process chosen for it was "transport, freight, aircraft, unspecified". Autoline is then transported by freight lorry from the airport to the paper mill, and the chosen process for this was the same as for the scenario in Sweden. The distance for this was estimated to be 70 km based on the location of the paper mills in the area related to the largest airport. China has implemented even stricter new vehicle emissions standards in China 6 than EURO6. However, in `openLCA` there is no such alternative, thus the best option is still EURO6 [39] but with the provider set to RoW. In the use phase, the providers for the electricity and the electricity for the compressed air were changed to the State Grid Corporation of China, SGCC. The SGCC is the biggest utility company globally, which is why it was chosen for this study. For the EOL phase, all providers in the output were set to "market" instead of "treatment".

4.6 Sensitivity analysis - Without gold coating on circuit boards

A sensitivity analysis was done based on what had a significant environmental impact in the results. It was, therefore, chosen to do modelling focusing on the production of the circuit boards with and without the gold coating. The circuit board production process was taken from *Ecoinvent* and edited for the gold amount. More details regarding this process can be found in Appendix C.

5

Results and discussion

This chapter integrates the two last steps of the LCA; the impact assessment and the interpretation of results. It also includes two sensitivity analyses, one regarding the use phase in different countries and one regarding the coating on the circuit boards. The chapter reflects the opinions of the authors and does not necessarily correlate to those of ABB.

5.1 Environmental impacts for each life cycle phase

The complete results are shown in Table D.1 and Table D.2 in Appendix D. The results are presented for each impact category in Figure 5.1 and Figure 5.2. These are presented for the impact categories; cumulative energy demand (fossil, nuclear and water), acidification, eutrophication, terrestrial ecotoxicity, depletion of abiotic resources and climate change. The results are presented in the three life cycle phases: production phase, use phase and EOL phase. Phases that had a big impact are further investigated to show where the environmental impact derives from. The transport from Stockholm to Shanghai was separated from the use phase for the Chinese sensitivity analysis to show the impact of the transport.

It should be taken into consideration that an LCA shows the potential environmental impacts of the product. However, the product can still contribute to a positive environmental impact depending on its purpose. Autoline is a product used to save paper, fibre, additives and energy at the paper mills, which has a positive environmental impact. To conduct this LCA, assumptions had to be made regarding material, origin and weights. Some components were excluded due to a lack of data. The decisions made for the *Ecoinvent* processes have a big impact on the results as well. In other words, simplifications had to be made to complete the LCA, and this could lead to uncertainties in the result.

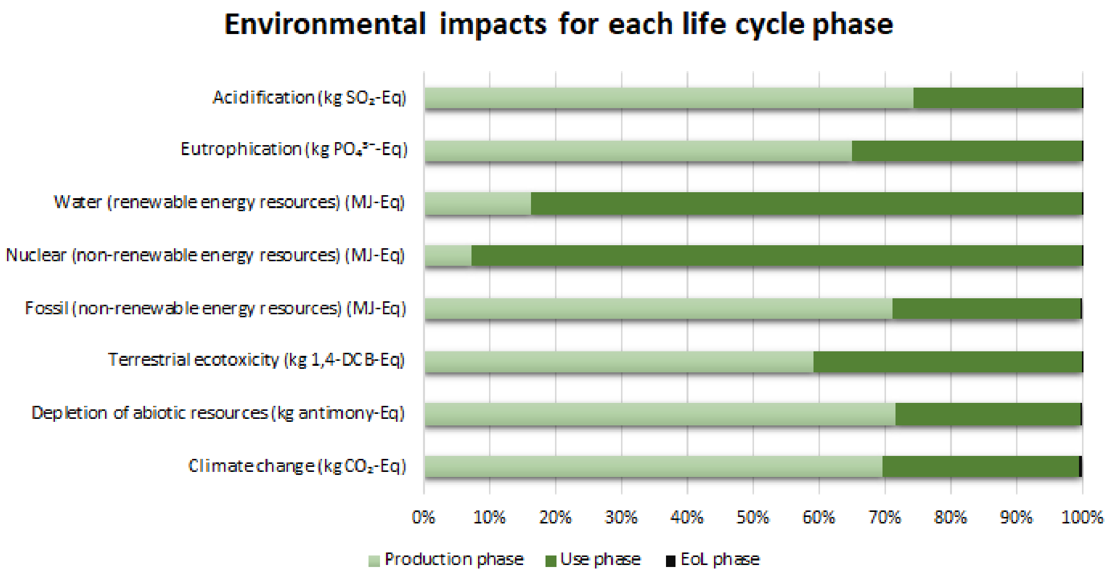

Figure 5.1: The life cycle of L&W Autoline presented for each impact category

Figure 5.1 shows the different impact categories for the life cycle phases of L&W Autoline when used in Sweden. When referring to the phases in the results, they are divided according to the Flowchart 3.1. It clearly shows that the production phase is dominant for the following impact categories; acidification (74 %), climate change (69 %), eutrophication (65 %), depletion of abiotic resources (71 %), terrestrial ecotoxicity (59 %) and fossil (non-renewable energy resources) (71 %). The production phase includes the raw material extraction, material production, component production and the assembly of L&W Autoline. The use phase is the dominating part of the life cycle for the impact categories; water (renewable energy resources) (81 %) and nuclear (non-renewable energy resources) (93 %). The use phase consists of the usage at mill and service of L&W Autoline. The EOL phase is negligible for all impact categories. The EOL phase includes the dismantling step, shredding, recycling and incineration.

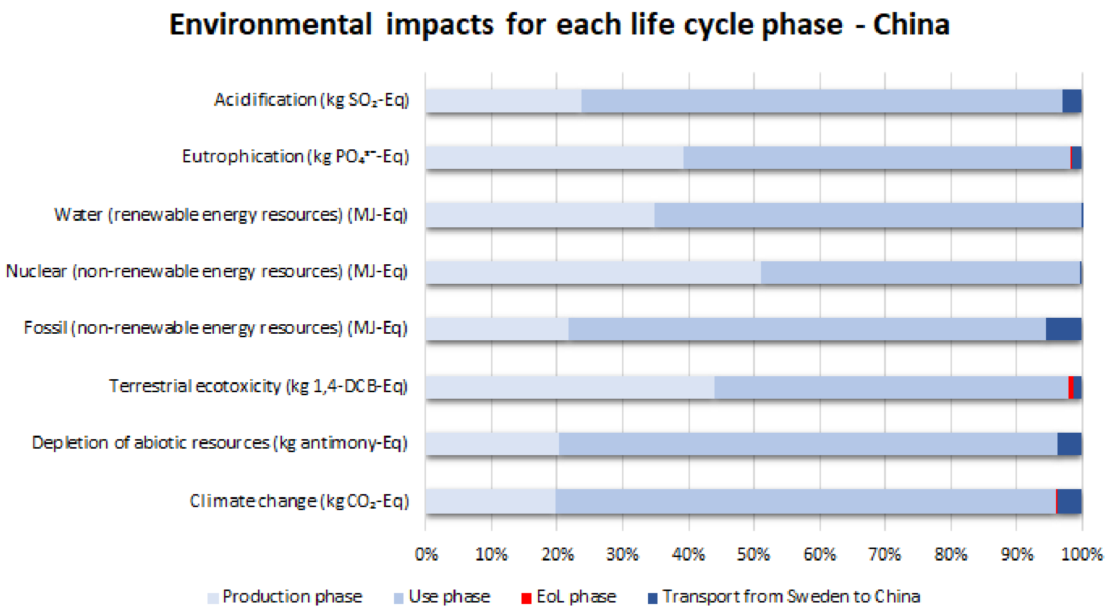

Figure 5.2: The life cycle of L&W Autoline in China presented for each impact category

Figure 5.2 shows the different impact categories for the life cycle phases of L&W Autoline when used in China. It shows that the use phase is the dominant phase for the following impact categories; acidification (68 %), climate change (76 %), depletion of abiotic resources (76 %), water (renewable energy resources) (65 %) and fossil (non-renewable energy resources) (73 %), eutrophication (59%) and terrestrial ecotoxicity (54%). However, the production phase is the dominating part of the life cycle for the impact category nuclear (non-renewable energy resources) (51 %). The transport from the production site in Sweden to the mill in China is negligible regarding water (renewable energy resources) and nuclear (non-renewable energy resources). For the remaining impact categories, transport is a minor contributor. The EOL phase is almost negligible for all impact categories, although it can be seen as a minor contributor in terrestrial ecotoxicity (1 %).

Fossil fuel burning such as hard coal creates emissions, including sulphur oxides, SO_2, and nitrogen oxides. Nitrogen oxides and sulphur oxides contribute to acidification, while eutrophication is affected by emissions from nitrogen and phosphorus when released into air and water. In Figure 5.1 it can be seen that both acidification and eutrophication have the largest environmental impact in the production phase. This is mainly affected by the gold mining operation for the circuit boards. Gold mining produces process water during the mining, which contains high concentrations of nitrogen and phosphorus [40] that contribute to eutrophication. The electricity used in the mining process consists of many fossil fuels that emit sulphur- and nitrogen oxides.

However, in the Chinese results, Figure 5.2 shows that the largest environmental impact for acidification and eutrophication comes from the use phase. The gold mining process and the Chinese electricity mix largely consist of fossil fuels, thereby emitting nitrogen- and sulphur oxides. The use phase of L&W Autoline consumes more electricity than the gold mining process, resulting in a higher acidification and eutrophication share for the use phase in China compared to the Swedish case.

For the Swedish scenario, two of the impact categories, water (renewable energy resources) and nuclear (non-renewable resources), have the biggest environmental impact in the use phase, which can be seen in Figure 5.1. Since these are both cumulative energy demand categories, it can be explained by the electricity consumption during the use phase.

Figure 5.2 shows that China has one impact category differing from the rest; nuclear (non-renewable resources), which has the most significant impact in the production phase (51%). For the nuclear (non-renewable energy resources), it is the production of the circuit boards that contribute the most because of the global electricity mix used in this production. Another impact category with a relatively high impact in the production phase (44%) is terrestrial ecotoxicity. Terrestrial ecotoxicity refers to the maximum tolerable concentration of heavy metals in ecosystems. The circuit boards and the steel production contribute the most to the production phase of this impact category. The circuit boards contain a certain amount of gold, which is a heavy metal, and that is what contributes to this impact category.

The EOL is, as previously mentioned, negligible for all impact categories examined for both countries. In Figure 5.2 the only impact category where EOL can be seen is for terrestrial ecotoxicity in China. This results from the waste treatment method; open burning of waste polyvinylchloride.

5.2 Selected LCIA results

This section presents selected results that were considered relevant to investigate in more detail. This includes analysing the foreground system to see what contributed to the most significant impact during the production phase regarding the impact categories; climate change and depletion of abiotic resources. It also consists of two sensitivity analyses; one of the use phase that focuses on the background system, more specifically the choice of the electricity mix and the other one on the foreground system, regarding the gold coating on the circuit boards. The country specific electricity mixes analysed are Sweden and China.

5.2.1 Environmental impacts from the production phase

The modelling results and previous literature [13] showed that climate change and depletion of abiotic resources were of relevance when studying a machine that uses electricity over many years and consists of a large number of metals. Since metals are non-renewable, it is of essence to spare these materials for future generations. Climate change is caused by GHG emissions, which is relevant to measure in a time where the focus is on decreasing these emissions.

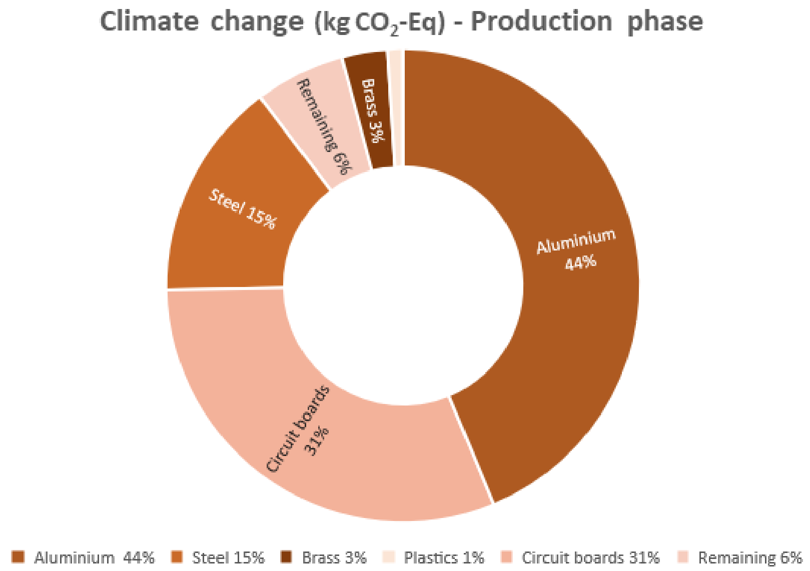

Figure 5.3: Results for Climate change - production phase

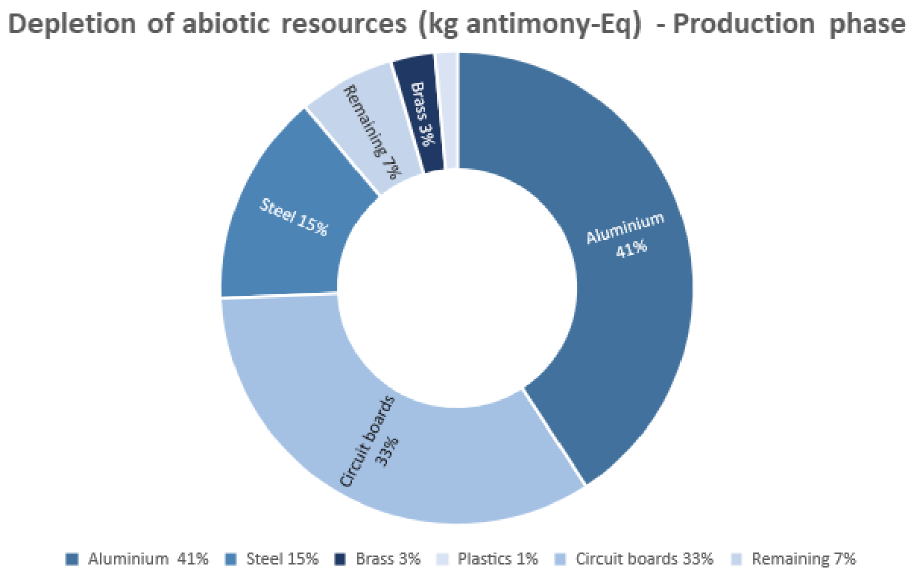

Figure 5.4: Results for Depletion of abiotic resources - production phase

To answer the research question *Which are the hotspots in the life cycle (cradle-to-grave) of Autoline?* Figure 5.3 and 5.4 show the production phase in more detail presented in a sunburst diagram. The processes presented in these diagrams are aluminium, steel, brass, plastics, circuit boards and remaining. The remaining process consists of components that did not have a big environmental impact in these two impact categories. The diagrams show that aluminium is the main contributor with 44% and 41%, followed by the circuit boards that account for 33% and 31% of the production phase for the two impact categories. Then follows steel for both cases. Plastics, brass and remaining correspond to a minor part of the impact categories. The results rely on *Ecoinvent* data and might not correspond to the acquisition, origin and production of the materials used in L&W Autoline. Since no specific material data was available for L&W Autoline, the results indicate what ABB should further investigate.

Aluminium and steel have a big impact on the production phase. However, that was not a surprise since they together account for 83 percent of the weight for the whole L&W Autoline. Aluminium requires a large amount of electricity for production. Electricity is one of the highest costs in aluminium production, and for reference, 5 percent of the produced electricity in the United States is used for aluminium production [41]. Therefore, it is not unexpected that aluminium contributes a lot to the impact categories due to the great electricity demand during its production. These results show that one of the answer to the research question *How can ABB improve their product, L&W Autoline to make it more environmentally friendly?* is to reduce the amount of aluminium used and investigate the options of using recycled aluminium.

It can be seen that the circuit boards account for a big part of this phase. In percentage, they account for approximately 0.4 percent of the whole weight of L&W Autoline. When investigating this further, the results showed that the gold, wafer and electricity mix contributed the most to the impact of the circuit boards. Despite their small total weight, the circuit boards still account for a significant part of the two impact categories. Thus it was decided to investigate this even further in a sensitivity analysis that studies the gold coating, which can be found in section 5.2.4.

5.2.2 Environmental impacts from L&W Autoline module production

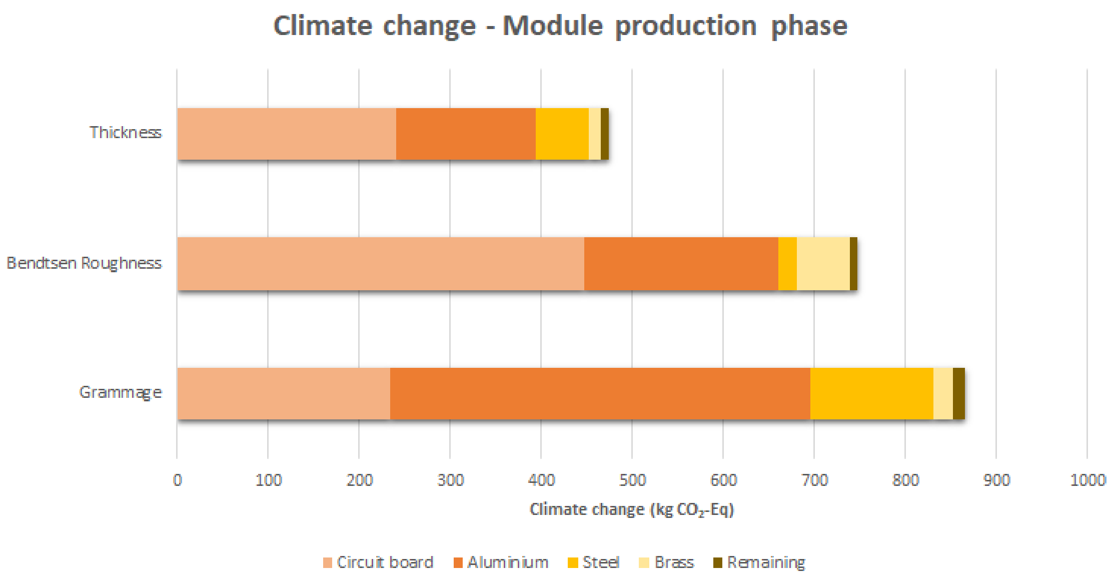

Figure 5.5: The contribution to impact for the impact category Climate change for the modules

Figure 5.5 shows the environmental impact from the three L&W Autoline modules investigated in this report. It shows that the module Grammage has the highest overall impact and Thickness the lowest. This results from the weight where Grammage weighs 51 kg, compared to Thickness, 18 kg, and Bendtsen Roughness, 19 kg. Similar to the results for the production of L&W Autoline (where these modules are included), shown in Figure 5.3, aluminium and the circuit boards account for the most considerable environmental impact.

5.2.3 Sensitivity analysis - electricity mix during use phase

Figure E.1 in Appendix E shows the Swedish electricity mix presented in a sunburst diagram. The results show that the Swedish electricity mix mainly consists of hydro- and nuclear power. Figure E.2 in Appendix E shows that the electricity mix for China mainly consists of hard coal.

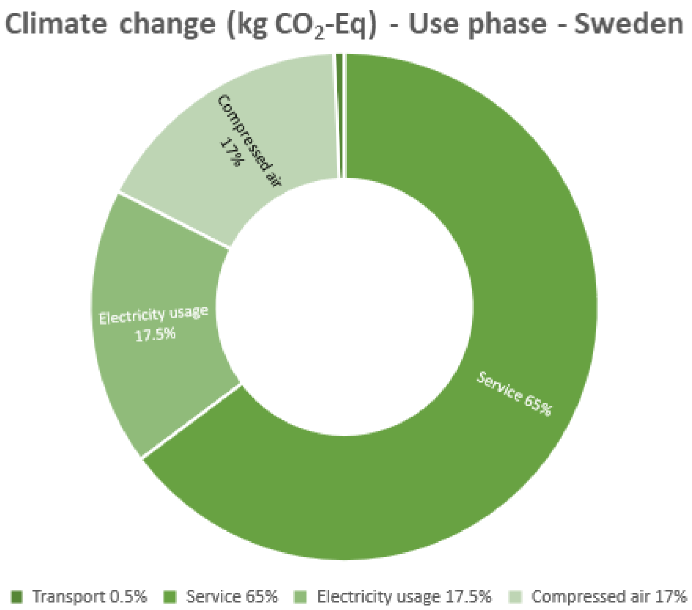

Figure 5.6: Results for the use phase in Sweden for the impact category climate change

Figure 5.6 presents the use phase in Sweden. The transport is from the production site in Kista to a general paper mill in Sweden. The modelling distance and the choice of transport vehicle for this process are described in section 4.2. The results show that the service is the most significant contributor to climate change when used in Sweden. This can be explained by the fact that the service consists of changing spare parts such as circuit boards.

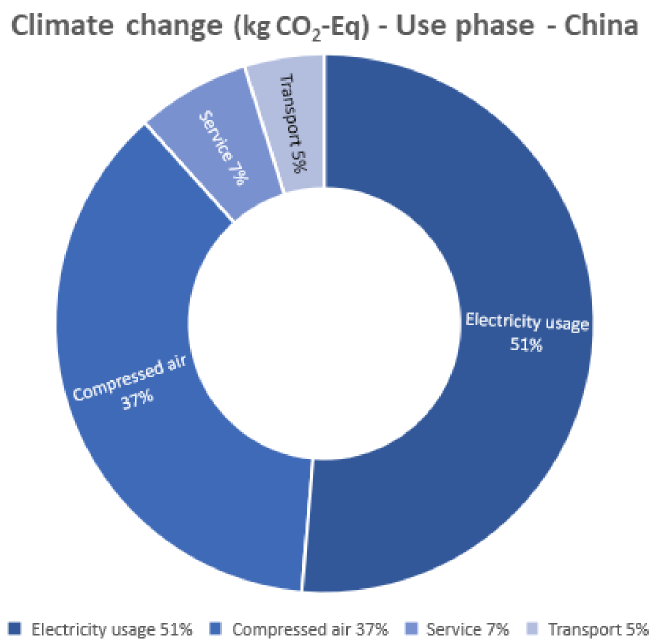

Figure 5.7: Results for the use phase in China for the impact category climate change

Figure 5.7 presents the use phase in China for the impact category climate change. The results show that electricity usage and compressed air contribute the most to climate change. Compressed air is a large contributor since it requires much electricity.

The results show that it is a clear difference between the use phases in the two countries. The most significant contributor to climate change in China is electricity usage, followed by compressed air. For Sweden, the most crucial contributor during the use phase is the service. The service includes changing spare parts, where four new circuit boards account for almost all of the impact of this process. In Sweden, electricity usage is not a significant contributor to climate change in total, as it is in China. This is due to the difference in electricity mix for the two countries that can be seen in Figure E.2 and E.1, where Sweden has more nuclear and hydropower compared to China's hard coal.

Figure E.2 and E.1 show the electricity mix for China and Sweden. Swedish electricity consists of mainly hydro- and nuclear power, while Chinese electricity has a large share of hard coal. This is a big reason to why the use phase between the two countries differs that much. The electricity consumption in the use phase at the paper mill is modelled the same way but has two different providers depending on the countries. To answer the research question *How does the location of the use phase affect the environmental impact of the product?* it is mainly affected by the electricity mix, which is part of the background system, in the country where it is used.

To relate to the research question *Which are the hotspots in the life cycle (cradle-to-grave) of L&W Autoline?* Figure 5.1 and 5.2 showed different hotspots for the life cycle phases. For China, the majority of the impact categories had the biggest environmental impact during the use phase. While for Sweden, most of the impact categories had the largest environmental impact during the production phase. Similar to previous studies [13] the results in this report also show that the use phase is dominating for countries with a background system consisting of a fossil energy mix, such as China. For Sweden, the hotspot is identified to be in the foreground system, the production. This can be explained by the high share of renewable electricity used in a Swedish mill during the use phase. While the electricity in China mainly consists of fossil electricity. ABB has the possibility to make decisions that influence the foreground system; this is done by reducing, reusing, recycling and changing materials. The background system is hard to influence but can be affected by making more energy-efficient machines, contributing to a lower impact in countries with a dirtier electricity mix. To refer again to the research question *How can ABB improve their product, L&W Autoline, to make it more environmentally friendly?* It is also of interest to look at a way of making L&W Autoline more energy efficient. This would be important when selling L&W Autoline to countries where electricity mainly consists of fossil energy since the biggest impact will be in the use phase.

5.2.4 Sensitivity analysis - gold coating on circuit boards

As previous results have shown, the gold coating on the circuit boards has contributed mainly to the impact of climate change and the depletion of abiotic resources. Therefore, a sensitivity analysis was done where the gold coating used on the circuit boards was removed to investigate the difference and potential climate benefits of replacing this material.

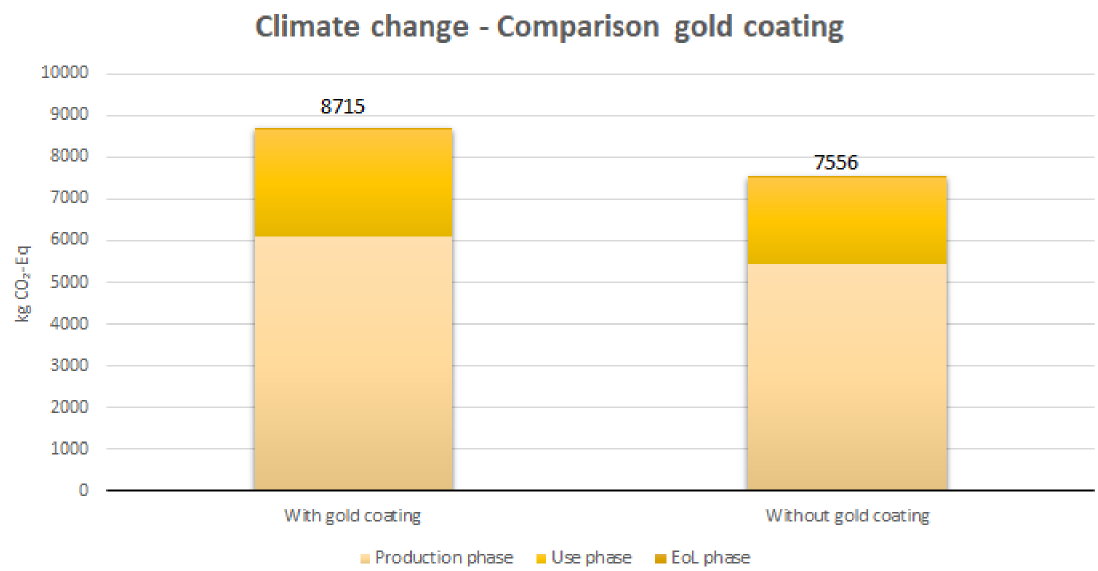

Figure 5.8: Results for climate change for comparison of gold coating

Figure 5.8 shows a decrease of approximately 1159 kg CO_2 equivalents over the whole life cycle when the gold is removed from the circuit boards, which corresponds to roughly a reduction of 13 percent in total over the entire life cycle.

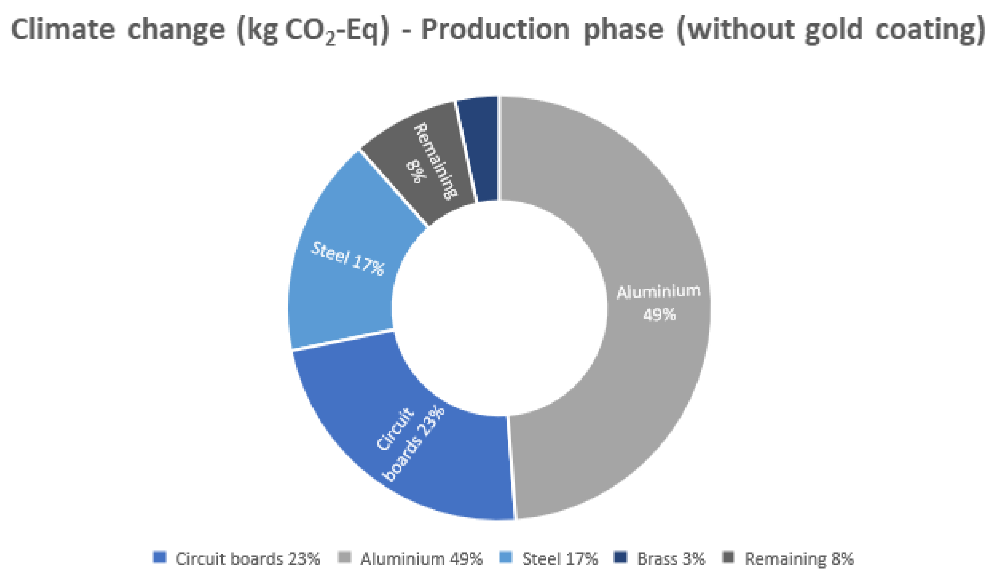

Figure 5.9: Results for the production phase of climate change for gold coating

Figure 5.9 shows that when gold is removed from the circuit boards, the results are still very similar to Figure 5.3 where the circuit boards accounted for 31 percent of the total impact during production. When gold is removed, aluminium (49%) is an even more significant contributor to climate change during the production phase. However, circuit boards (23%) still account for a big part of the production phase. When the gold coating is removed, the wafers and the electricity used during the production of circuit boards are the most significant contributors to the process. Thus, it is still vital for ABB to investigate the origin and production of the materials they use.

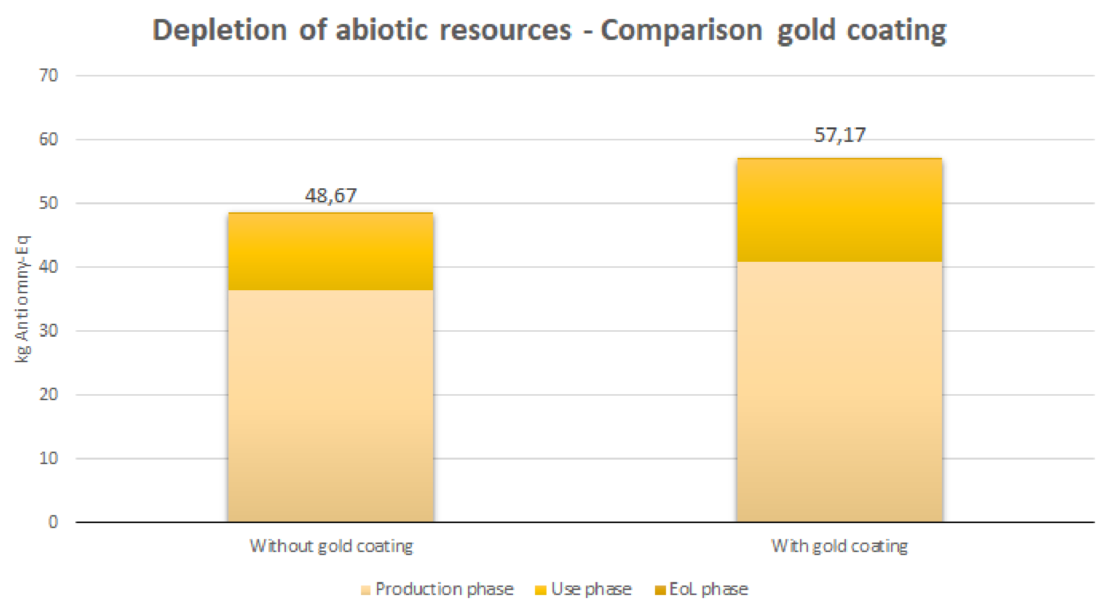

Figure 5.10: Results for depletion of abiotic resources for comparison of gold coating

The results are similar for the impact category depletion of abiotic resources for climate change when gold is removed. Figure 5.10 shows a decrease of approximately 8.5 kg-Antimony equivalents over the whole life cycle when gold is removed from the circuit boards, which corresponds to a reduction of roughly 15 percent in total.

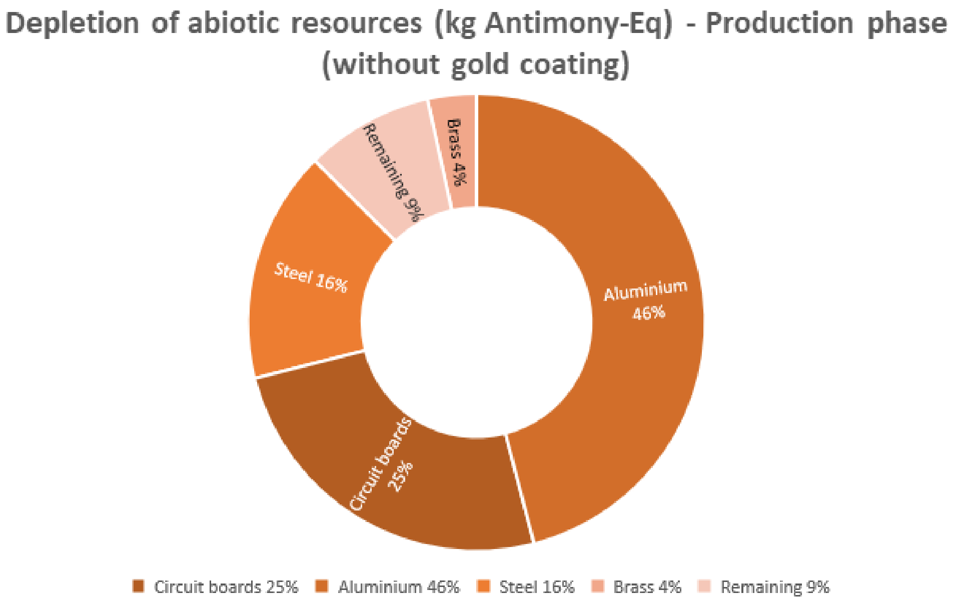

Figure 5.11: Results for the production phase of depletion of abiotic resources for gold coating

The results for the depletion of abiotic resources can be seen in Figure 5.11, which clearly shows that the circuit boards account for 25 percent of the total impact in depletion of abiotic resources for the production phase. This can be compared to Figure 5.4 where the circuit boards with gold coating contributed to 33 percent of the total impact.

These results confirm previous results related to the research question; *Which are the hotspots in the life cycle (cradle-to-grave) of Autoline?* That the circuit boards are a clear hotspot in the production phase. The sensitivity analysis shows that the gold coating is one of the main contributors. The wafers and electricity used during the production of circuit boards account for a big part of the environmental impact of the circuit boards as well. It also showed that aluminium, which accounts for a large amount of the weight in the L&W Autoline, has a large environmental impact on the investigated impact categories.

Thus, these results make it possible to answer the research question *How can ABB improve their product, L&W Autoline, to make it more environmentally friendly?* Since the results show that aluminium has a significant impact, this should be further investigated. Possible alternatives could be to reduce the amount of material used and opt for recycled material when purchasing. Another essential aspect that should be further investigated is the circuit boards, specifically their coating. Four options are presented, specifically to reduce the environmental impact of the circuit boards. The first one is to reduce the amount of gold used for the coating in the circuit boards. Another option is to recycle the circuit boards and, in that way, minimise the gold mining but also the wafers produced.

A third option is to find a substitute for the gold and compare the environmental impacts of the two alternatives. Finally, ABB should strive to collect more information regarding the material's acquisition, origin and production. To achieve this, a standardised system could be introduced, where all data is stored. The information will be required to become competitive in a future where companies will have more pressure on showing their environmental impacts.

6
Conclusion

Previous LCA's have often overlooked the impacts of capital equipment and only focused on the final consumer goods. This report has therefore contributed to an extended knowledge base regarding capital equipment used in the paper industry. It is vital since an investment of this type often creates a path dependency and is hard to reverse.

The production phase has shown to be of great importance for the life cycle of L&W Autoline. Six out of eight midpoint categories in Sweden showed that the most significant environmental impact occurred in the production phase. The majority of these results were explained by the production of aluminium and circuit boards. The results also showed that the impact category "depletion of abiotic resources" was relevant to investigate further due to its large share of metals. The results show that aluminium was the main contributor, followed by circuit boards in the production phase. Due to the circuit boards' significant environmental impact despite their small weight, it was decided to further investigate them in a sensitivity analysis. Since metals are non-renewable, they need to be used in as small amounts as possible and recycled to meet future demands. For the production phase, the impact category "climate change" was also investigated. These results were similar to previous results, where aluminium and circuit boards were the most significant contributors to GHG emissions.

A sensitivity analysis was conducted to study the impact of the country-specific electricity mix of Sweden and China and to see the importance of where L&W Autoline is used. It was noted that the Swedish electricity mix relies on renewable energy and thus is not a large contributor to the use phase. However, the use phase is of great importance when looking at the scenario in China, where the use phase is the dominating part of the life cycle. The reason for this is due to the electricity mix that mainly consists of fossil energy.

A second sensitivity analysis was executed to compare the entire life cycle of L&W Autoline and the production phase for the impact categories climate change and depletion of abiotic resources when the circuit boards included the gold coating and when it was excluded. The results showed a reduction of the environmental impact of the entire life cycle for 13 percent (climate change) and 15 percent (depletion of abiotic resources). For the production phase of the two impact categories, aluminium became an even bigger contributor. However, the circuit boards still accounted for a large part even when the gold coating was removed. This could be explained by the wafer production and electricity usage during production.

6.1 Recommendation for further research

For future studies, it would be interesting to collect data regarding savings in the paper mills when using an L&W Autoline. The products analysed in this report were three modules and one of the two sizes available for L&W Autoline. Therefore, more work can be done to investigate the environmental impacts of the larger size of L&W Autoline and the remaining modules. A future study can also focus on the use phase in other countries than the two investigated in this report. Since L&W Autoline is sold worldwide, it is also essential to look into the machine's energy efficiency. Depending on how much a country-specific electricity mix relies on fossil energy, it can have a tremendous environmental impact since L&W Autoline is used for at least fifteen years at the mills.

Another future research aspect is to study the production of aluminium and the circuit boards that have a significant environmental impact. This is to avoid switching to an even worse option from an environmental perspective and to be able to reduce the product's environmental impact. It would be interesting to compare the environmental impacts of gold to a substitute. A second option would be to study the effects of reducing the amount of gold and aluminium. Another alternative is to recycle the circuit boards and aluminium to analyse the potential effects on the product's environmental impact.

The final recommendation is to collect data from the suppliers regarding the material's acquisition, origin and production, which would make the results more reliable. The data acquisition should be transparent and standardised in order for ABB to investigate the environmental impacts of the materials and components used in L&W Autoline. This will become essential for companies to be competitive in a future where environmental awareness is ever increasing.

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A

Appendix

A.1 Modelling assumptions for L&W Autoline

- The cables without a specified length were assumed to be one meter each for L&W Autoline base unit and 0,8 meter for the L&W Autoline modules.
- The cables that were not specified were modelled as "cable, unspecified" in *Ecoinvent*.
- The hoses were all assumed to be similar with a weight of 37 gram per meter.
- Weight of screws, washers and nuts were based on expertise judgements of the personnel in the production.
- All pneumatic valves, pneumatic connectors and pneumatic fittings were assumed to be made of brass except for a couple of valves that were determined to be plastic from expertise judgement of the personnel. Therefore some electronics might have been excluded.
- The weight for pressure sensor term was based on a similar component found online.
- In this report, sales personnel at ABB determined the three most commonly used modules. Resulting in that three out of six blind plates are accounted for.
- Three components in Autoline base unit, Optocoupler OBRIC0100-24VDC, Contactor 24-60V 50/60Hz 20-60VDC AF09 and Automatic fuse 10A 2p DIN rail mount, were assumed to be similar to EPD's found on ABB's website. This was based on our judgement.
- The terminal springs were assumed to be made of PVC.
- The type of circuit board modelled in `openLCA` was chosen together with ABB personnel.
- The weight of the circuits boards was weighed by ABB personnel.
- A LED assembly consisting of cables and LED strips were modelled as one "LED" from *Ecoinvent*.
- A socket was modelled to only consist of plastic due to no data.
- Locks were assumed to be made of pure steel.
- The motor in L&W Autoline base unit and the module Thickness was modelled as an "electric motor for an electric scooter" from *Ecoinvent*. The weight was taken from the manufacturer's website.
- The weight of the magnets was based on a manufacturer's website.
- Ball bearings were assumed to be made of steel and the weight was taken from the manufacturer's website.

- The Solenoid switches weight was based on the assumption that the material consisted of aluminium.
- The two fans' weight was based on the assumption that the material consisted of plastics.
- For PLC safety Pluto Pluto S20 V2 and spring pressure the weight was found in ABB documents online.
- The weight for DIN Rail TS35X15 Hold 2m was found on a manufactures website.
- The weight for Wheel O100 with swivel plate, Belt, tension spring, some pneumatic valve, switch pan rockers, measuring head, control outlet, chassis, a transport box were manually weighed by ABB's production personnel.
- Aluzink was considered to be made of pure steel.
- The compact unit was assumed to consist of 50 percent steel and 50 percent aluminium.
- An air filter was assumed to consist of 50 percent plastic and 50 percent aluminium.
- A handle was assumed to consist of aluminium.
- The cylinders in the modules consist of a core of steel and an aluminium cover, the relationship between the materials are 50 percent.
- The storage of the components was excluded due to lack of data.
- The district heating and cooling of the building were excluded since it is not directly related to the production.
- The transportation from production to mill, and from mill to waste treatment facility was assumed to be 300 km each.
- The transport vehicle was assumed to be a Lorry 16-32 metric tons, EURO 6.
- The process "waste electric and electronic equipment" was assumed to include all the remaining electronic components that did not have a separate waste process. It was assumed that these components were not incinerated.

A.2 Excluded components for L&W Autoline base unit

- Photodetector
- Velcro fastening
- Holder for tools
- Fuses
- Strips
- Small "clips"
- Relay DC 24V Plug in
- Plastic wire
- Cable clip end sleeve, cable lug end caps, cable ducts, cable canal, hose shrinks and cable ties, holder for cable ties
- Female crimp terminals
- Ferrite Clamp Hinged
- Labels, warning signs and logotypes
- Thread inserts
- Rings
- Stifts

- Velcro
- Case accessories
- Tape and tape holder

A.3 Excluded components for the L&W Autoline Modules

- Cleaning paper 618
- Bag
- Signs, labels
- Nylon line
- Cable ties, cable lug end, cable lugs, cable clamps, cable canals
- Caps
- Tape
- Female Crimp Terminal
- Ferrite Clamp Hinged
- Braided sleeving
- Felt
- Plastic bag
- Stifts
- Linear sensor and optical sensor
- Drawings
- Case with accessories
- Silicone hoses
- Pneumatic restrictor
- Pneumatic sealing
- Photocell
- Protection foam for transportation
- Sensor flow
- Teflon cloth scale pan
- Velcro
- Signal transducer

B
Appendix

B.1 Calculations of the electricity usage during production

The electricity needed for the production was allocated with regards to their usage of area on the production site. The usage area was estimated by ABB production personnel.

- The total production area in Kista is 1800 m^2.
- The base unit requires 300 m^2 and the L&W Autoline modules require 100 m^2 of the production area.
- Three L&W Autoline base units and six L&W Autoline modules are built at the same time.
- The base unit takes approximately 7.5 days to produce for two people, while an L&W Autoline module takes 2.5 days for five people to manufacture.
- The average power consumption for the module Bendtsen Roughness is 15 W
- There is a 15 % DC loss

This results in the production area usage for the L&W Autoline base unit:

$$300/1800 = 16.7\,\%\, of\, total\, production\, area. \tag{B.1}$$

This results in the production area usage for the L&W Autoline modules:

$$100/1800 = 5.6\,\%\, of\, total\, production\, area. \tag{B.2}$$

The electricity usage for the whole building, including both production and offices at the site, is 585.8 Mwh over a year. It was estimated by ABB personnel that approximately half of the electricity was used in the production, which results in 292.9 Mwh per year for the production.

This leads to the production's electricity usage per day:

$$(292.9 Mwh/year)/365\, days \;=\; 802\, kwh\, per\, day. \tag{B.3}$$

District heating and cooling were excluded since this is not directly related to the L&W Autoline production. It is related to the building and would be used even if no production was conducted. Also, the number of people working on the product are not accounted for in this study. The storage of the products were not a part of the use phase due to lack of data.

With regards to the time it takes to build one L&W Autoline base unit, the electricity usage for the production becomes:

$$16.7\,\% \times 802\,kwh/day \times 7.5\,day \;=\; 1004.505\,kwh\,for\,three\,Autoline\,baseunits. \qquad \text{(B.4)}$$

$$\frac{1004.505\,kwh\,for\,3\,Autoline\,baseunits}{3\,Autoline\,baseunits} = 334.835\,kwh\,for\,one\,Autoline\,baseunit$$

With regards to the time it takes to manufacture one L&W Autoline module, the electricity usage for the production becomes:

$$5.6\,\% \times 802\,kwh/day \times 2.5\,day = 112.28\,kwh\,for\,six\,Autoline\,modules. \qquad \text{(B.5)}$$

$$\frac{112.28\,kwh\,for\,6\,modules}{6\,modules} \;=\; 18.713\,kwh\,for\,one\,module. \qquad \text{(B.6)}$$

The total electricity usage for production of the base unit and three modules is:

$$334.835\,kwh + 3 \times 18.713\,kwh \;=\; 390.974\,kwh\,for\,an\,Autoline\,with\,three\,modules. \qquad \text{(B.7)}$$

The electricity was modelled in `openLCA` as a Swedish electricity mix.

B.2 Calculations of the electricity usage during use phase

The power consumption varies depending on the usage of the machine, the values obtained are based on an average usage of the machine.

- The average power consumption 24 V DC for the Autoline base unit is 31.1 W
- There is a constant 230 V AC power consumption running for the L&W Autoline's display, router and fans that is 25.4 W
- The average power consumption for the module Grammage is 15 W
- The average power consumption for the module Thickness is 5 W
- The average power consumption for the module Bendtsen Roughness is 15 W
- There is a 15 % DC loss

The whole lifetime calculated in hours is:

$$15\,years \times 51\,weeks \times 7\,days \times 24\,hours \;=\; 128\,520\,hours\,over\,a\,lifetime \qquad \text{(B.8)}$$

The total average consumption for the L&W Autoline base unit is therefore calculated as:

$$31.1\,W \;\times 115\% + 25.4W \;= 60.765\,W \qquad \text{(B.9)}$$

This includes DC loss and the constant power consumption.
The result for the three L&W Autoline modules accounting for the DC losses is:

$$(15\,W + 5\,W + 10\,W) \times 115\% = 34.5\,W \tag{B.10}$$

This results in the total result for the L&W Autoline base unit and three L&W Autoline modules:

$$60.765\,W\ +\ 34.5\,W\ =\ 95.265\,W\,usage\,for\,an\,L\&W\,Autoline \tag{B.11}$$

Resulting in the electricity usage over a lifetime:

$$95.265W \times 128\,520\,hours\,over\,a\,lifetime\ =\ 12\,243.4578\,kwh\,over\,a\,lifetime \tag{B.12}$$

B.3 Calculations of the compressed air usage during use phase

The machine requires compressed air during usage. The amount of compressed air depends a lot on which L&W Autoline modules are used.
The whole lifetime in hours is therefore calculated as:

$$15\,years \times 51\,weeks \times 7\,days \times 24\,hours\ =\ 128\,520\,hours\,over\,a\,lifetime \tag{B.13}$$

The most common pressure in the pneumatic valves at the mills is 0.6 Mpa. This value was therefore used when modelling in `OpenLCA`.

- The rated air consumption for the L&W Autoline base unit is 0.2 Nl/min
- The rated air consumption for the module Grammage is 4.5 Nl/min
- The rated air consumption for the module Thickness is 1.2 Nl/min
- The rated air consumption for the module Bendtsen Roughness is 15 Nl/min

The total air consumption for an L&W Autoline is therefore:

$$0.2\,Nl/min + 4.5\,Nl/min + 1.2\,Nl/min + 15\,Nl/min\ =\ 20.9\,Nl/min \tag{B.14}$$

The conversion factor from Nl/min to Nm^3 is calculated as:

$$Nl/min \times 60/100\ =\ Nm^3/hour \tag{B.15}$$

Resulting in the total air consumption for L&W Autoline base unit and three L&W Autoline modules Nm^3 to be:

$$20.9\,Nl/min \times 60/1000\ =\ 1.254\,Nm^3/h \tag{B.16}$$

Over a lifetime the total air consumption for L&W Autoline base unit and the three L&W Autoline modules results in:

$$1.254\,Nm^3/h \times 127\,520 hours\ =\ 161\,164.06\,Nm^3 \tag{B.17}$$

C
Appendix

Alu EN-AW 6082 T6 production			
Process	Amount	Unit	Provider
Inputs			
Aluminium, wrought alloy	104.9056	kg	Market for aluminium, wrought alloy | aluminium, wrought alloy | Cutoff, U-GLO
Metal working, average for aluminium product manufacturing	104.9056	kg	Market for metal working, average for aluminium product manufacturing | metal working, average for aluminium product manufacturing | Cutoff U-GLO
Outputs			
Alu EN-AW 6082 T6	104.9056	kg	

Table C.1: Table for Alu EN-AW 6082 T6 production

Brass production			
Process	Amount	Unit	Provider
Inputs			
Brass	12.08366	kg	Market for brass | brass | Cutoff, U-RoW
Metal working, average for metal product manufacturing	12.08366	kg	Market for metal working, average for metal product manufacturing | metal working, average for metal product manufacturing | Cutoff U-GLO
Outputs			
Brass	12.08366	kg	

Table C.2: Table for Brass production

PMMA cast (plexi) production			
Process	Amount	Unit	Provider
Inputs			
Polymethyl methacrylate, sheet	3.920	kg	Market for polymethyl methacrylate, sheet | polymethyl methacrylate, sheet | Cutoff, U-GLO
Injection moulding	3.20	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Outputs			
PMMA cast (plexi)	3.92	kg	

Table C.3: Table for PMMA cast (plexi) production

PVC plastic production			
Process	Amount	Unit	Provider
Inputs			
Polyvinylchloride, suspension polymerised	5.530	kg	Market for polyvinylchloride, suspension polymerised | polyvinylchloride, suspension polymerised | Cutoff, U-GLO
Injection moulding	5.530	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Outputs			
PVC plastic	5.53	kg	

Table C.4: Table for PVC plastic production

Rubber production			
Process	Amount	Unit	Provider
Inputs			
Synthetic rubber	0.43	kg	Market for synthetic rubber | synthetic rubber | Cutoff, U-GLO
Injection moulding	0.43	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Outputs			
Rubber	0.43	kg	

Table C.5: Table for Rubber production

Steel EN 1.4301 Production			
Process	Amount	Unit	Provider
Inputs			
Steel, chromium steel 18/8	105.990	kg	Market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, U-GLO
Metal working, average for chromium steel product manufacturing	105.990	kg	Market for metal working, average for chromium steel product manufacturing | metal working, average for chromium steel product manufacturing | Cutoff, U-GLO
Outputs			
Steel EN 1.4301	105.990	kg	

Table C.6: Table for Steel EN 1.4301 Production

Automatic fuse 10A 2p DIN rail mount			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	0.00084	kg	Alu EN-AW 6082 T6 production
Cast iron	0.00368	kg	Market for cast iron | cast iron | Cutoff, U-GLO
Frit, for ceramic tile	0.00019	kg	Market for frit, for ceramile tile | frit, for ceramic tile | Cutoff, U-GLO
Glass fibre	0.01594	kg	Market for glass fibre | glass fibre | Cutoff, U-GLO
Glass fibre reinforced plastic, polyamide, injection moulded	0.07255	kg	Market for glass fibre reinforced plastic, polyamide, injection moulded | glass fibre reinforced plastic, polyamide, injection moulded | Cutoff, U-GLO
Graphite, battery grade	5.0E-6	kg	Market for graphite, battery grade | graphite, battery grade | Cutoff, U-GLO
Injection moulding	0.01462	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Metal working, average for aluminium product manufacturing	0.00084	kg	Market for metal working, average for aluminium product manufacturing | metal working, average for aluminium product manufacturing | Cutoff, U-GLO
Metal working, average for chromium steel product manufacturing	0.04741	kg	Market for metal working, average for chromium steel product manufacturing | metal working, average for chromium steel product manufacturing | Cutoff, U-GLO

Metal working, average for metal product manufacturing	0.01545	kg	Market for metal working, average for metal product manufacturing | metal working, average for metal product manufacturing | Cutoff, U-GLO
Nickel, class 1	0.00147	kg	Market for nickel, glass 1 | nickel, class 1 | Cutoff, U-GLO
Polycarbonate	0.00292	kg	Market for polycarbonate | polycarbonate | Cutoff, U-GLO
Polyethylene tereohtalate, granulate, bottle grade	0.01012	kg	Market for polyethylene tereohtalate, granulate, bottle grade | polyethylene tereohtalate, granulate, bottle grade | Cutoff, U-GLO
Polyethylene, low density, granulate	0.00059	kg	Market for polyethylene, low density, granulate | polyethylene, low density, granulate | Cutoff, U-GLO
Polyphenylene sulfide	0.00090	kg	Market for polyphenylene sulfide | polyphenylene sulfide | Cutoff, U-GLO
Silicone product	8.0E-5	kg	Market for silicone product | silicone product | Cutoff, U-RER
Silver	0.00034	kg	Market for silver | silver | Cutoff, U-GLO
Sodium silicate, solid	0.00051	kg	Market for sodium silicate, solid | sodium silicate, solid | Cutoff, U-RER
Steel EN 1.4301	0.04741	kg	Steel EN 1.4301 Production
Tetrafluoroethylene	0.00037	kg	Market for tetrafluoroethylene | tetrafluoroethylene | Cutoff, U-GLO
Tin	3.3E-5	kg	Market for tin | tin | Cutoff, U-GLO
Wire drawing, copper	0.02936	kg	Market for wire drawing, copper | wire drawing, copper | Cutoff, U-GLO
Zinc	0.00993	kg	Market for zinc | zinc | Cutoff, U-GLO
Outputs			
Automatic fuse 10A 2p DIN rail mount	0.19724	kg	

Table C.7: Table for Automatic fuse 10A 2p DIN rail mount production

Contactor 24-60V 50/60Hz 20-60VDC AF09			
Process	Amount	Unit	Provider
Inputs			
Injection moulding	0.1240	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Metal working, average for chromium steel product manufacturing	0.24480	kg	Market for metal working, average for chromium steel product manufacturing | metal working, average for chromium steel product manufacturing | Cutoff, U-GLO
Metal working, average for metal product manufacturing	0.00270	kg	Market for metal working, average for metal product manufacturing | metal working, average for metal product manufacturing | Cutoff, U-GLO
Polyethylene, low density, granulate	0.12340	kg	Market for polyethylene, low density, granulate | polyethylene, low density, granulate | Cutoff, U-GLO
Polyvinylchloride, suspension polymerised	0.00060	kg	Market for polyvinylchloride, suspension polymerised | polyvinylchloride, suspension polymerised | Cutoff, U-GLO
Silver	0.00270	kg	Market for silver | silver | Cutoff, U-GLO
Steel EN 1.4301	0.24480	kg	Steel EN 1.4301 Production
Wire drawing, copper	0.13610	kg	Market for wire drawing, copper | wire drawing, copper | Cutoff, U-GLO
Outputs			
Contactor 24-60V 50/60Hz 20-60VDC AF09	0.5076	kg	

Table C.8: Table for Contactor 24-60V 50/60Hz 20-60VDC AF09 production

Optocoupler OBRIC0100-24VDC			
Process	Amount	Unit	Provider
Inputs			
Injection moulding	0.0044	kg	Market for injection moulding | injection moulding | Cutoff, U-GLO
Metal working, average for chromium steel product manufacturing	0.0030	kg	Market for metal working, average for chromium steel product manufacturing | metal working, average for chromium steel product manufacturing | Cutoff, U-GLO
Metal working, average for metal product manufacturing	0.000166	kg	Market for metal working, average for metal product manufacturing | metal working, average for metal product manufacturing | Cutoff, U-GLO
Polyethylene, low density, granulate	0.00440	kg	Market for polyethylene, low density, granulate | polyethylene, low density, granulate | Cutoff, U-GLO
Steel EN 1.4301	0.24480	kg	Steel EN 1.4301 Production
Tin	7.7E-5	kg	Market for tin | tin | Cutoff, U-GLO
Wire drawing, copper	0.00120	kg	Market for wire drawing, copper | wire drawing, copper | Cutoff, U-GLO
Zinc	1.2E-5	kg	Market for zinc | zinc | Cutoff, U-GLO
Outputs			
Optocoupler OBRIC0100-24VDC	0.00869	kg	

Table C.9: Table for Optocoupler OBRIC0100-24VDC

L&W Autoline S Manufacturing			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	104.90560	kg	Alu EN-AW 6082 T6 production
Brass	12.08366	kg	Brass Production
Cable, connector for computer, without plugs	1	m	Market for cable, connector for computer, without plugs | cable, connector for computer, without plugs | Cutoff, U-GLO
Cable, network cable, category 5. without plugs	8	m	Market for cable, network cable, category 5. without plugs | cable, network cable, category 5. without plugs | Cutoff, U-GLO

Cable, unspecified	2.47	kg	Market for cable, unspecified | cable, unspecified | Cutoff, U-GLO
Computer, desktop, without screen	0.12	Item	Market for computer, desktop, without screen | computer, desktop, without screen | Cutoff, U-GLO
Controller, for electric scooter	0.39	Item	Market for controller, for electric scooter | controller, for electric scooter | Cutoff, U-GLO
Display, liquid crystal, 17 inches	0.30080	Item	Market for display, liquid crystal, 17 inches | display, liquid crystal, 17 inches | Cutoff, U-GLO
Electric motor, for electric scooter	0.64	Item	Market for electric motor, for electric scooter | electric motor, for electric scooters | Cutoff, U-GLO
Extrusion, plastic pipes	1.05	kg	Market for extrusion, plastic pipes | extrusion, plastic pipes | Cutoff, U-GLO
Fan, for power supply unit, desktop computer	1.9910	kg	Market for fan, for power supply unit, desktop computer | fan, for power supply unit, desktop computer | Cutoff, U-GLO
Integrated circuit, logic type	0.6288	kg	Market for integrated circuit, logic type | integrated circuit, logic type | Cutoff, U-GLO
Integrated circuit, memory type	0.011	kg	Market for integrated circuit, memory type | integrated circuit, memory type | Cutoff, U-GLO
Internet access equipment	7.072	Item	Market for internet access equipment | internet access equipment | Cutoff, U-GLO
Light emitting diode	0.11700	kg	Market for light emitting diode | light emitting diode | Cutoff, U-GLO
Permanent magnet, for electric motor	0.07954	kg	Market for permanent magnet, electric passenger car motor | permanent magnet, for electric motor | Cutoff, U-GLO
Plug, inlet and outlet, for network cable	1.88	Item	Market for plug, inlet and outlet, for network cable | plug, inlet and outlet, for network cable | Cutoff, U-GLO
PMMA cast (plexi)	3.920	kg	PMMA cast (plexi) Production
Power supply unit, for desktop computer	0.99	Item	Market for power supply unit, for desktop computer | power supply unit, for desktop computer | Cutoff, U-GLO
PVC plastic	5.530	kg	PVC plastic Production
Rubber	0.430	kg	Rubber Production
Steel EN 1.4301	105.990	kg	Steel EN 1.4301 Production
Switch, toggle type	0.19240	kg	Market for switch, toggle type | switch, toggle type | Cutoff, U-GLO
Outputs			
L&W Autoline S Manufactured	1	Item	

Table C.10: Table for L&W Autoline S Manufacturing

Bendtsen Roughness Manufacturing			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	12.29139	kg	Alu EN-AW 6082 T6 production
Brass	7.4904	kg	Brass Production
Cable, network cable, category 5. without plugs	4	m	Market for cable, network cable, category 5. without plugs l cable, network cable, category 5. without plugs l Cutoff, U-GLO
Cable, unspecified	0.5925	kg	Market for cable, unspecified l cable, unspecified l Cutoff, U-GLO
Extrusion, plastic pipes	0.87080	kg	Market for extrusion, plastic pipes l extrusion, plastic pipes l Cutoff, U-GLO
Integrated circuit, logic type	0.294	kg	Market for integrated circuit, logic type l integrated circuit, logic type l Cutoff, U-GLO
Plug, inlet and outlet, for network cable	1.88	Item	Market for plug, inlet and outlet, for network cable l plug, inlet and outlet, for network cable l Cutoff, U-GLO
PMMA cast (plexi)	0.13550	kg	PMMA cast (plexi) Production
PVC plastic	0.09370	kg	PVC plastic Production
Rubber	0.00516	kg	Rubber Production
Steel EN 1.4301	3.08349	Item	Steel EN 1.4301 Production
Switch, toggle type	0.020	kg	Market for switch, toggle type l switch, toggle type l Cutoff, U-GLO
Outputs			
Bendtsen Roughness Manufactured	1	Item	

Table C.11: Table for Bendtsen Roughness Manufacturing

Grammage Manufacturing			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	26.47879	kg	Alu EN-AW 6082 T6 production
Brass	2.83151	kg	Brass Production
Cable, network cable, category 5. without plugs	2	m	Market for cable, network cable, category 5. without plugs | cable, network cable, category 5. without plugs | Cutoff, U-GLO
Cable, unspecified	0.7850	kg	Market for cable, unspecified | cable, unspecified | Cutoff, U-GLO
Extrusion, plastic pipes	0.2950	kg	Market for extrusion, plastic pipes | extrusion, plastic pipes | Cutoff, U-GLO
Integrated circuit, logic type	0.154	kg	Market for integrated circuit, logic type | integrated circuit, logic type | Cutoff, U-GLO
Plug, inlet and outlet, for network cable	1.88	Item	Market for plug, inlet and outlet, for network cable | plug, inlet and outlet, for network cable | Cutoff, U-GLO
PVC plastic	1.7210	kg	PVC plastic Production
Rubber	0.00177	kg	Rubber Production
Steel EN 1.4301	20.41591	kg	Steel EN 1.4301 Production
Switch, toggle type	0.020	kg	Market for switch, toggle type | switch, toggle type | Cutoff, U-GLO
Outputs			
Grammage Manufactured	1	Item	

Table C.12: Table for Grammage Manufacturing

Thickness Manufacturing			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	8.79232	kg	Alu EN-AW 6082 T6 production
Brass	1.73775	kg	Brass Production
Cable, network cable, category 5. without plugs	4	m	Market for cable, network cable, category 5. without plugs | cable, network cable, category 5. without plugs | Cutoff, U-GLO
Cable, unspecified	0.630	kg	Market for cable, unspecified | cable, unspecified | Cutoff, U-GLO
Electric motor, for electric scooter	0.140	kg	Market for electric motor, for electric scooter | electric motor, for electric scooter | Cutoff, U-GLO
Extrusion, plastic pipes	0.2160	kg	Market for extrusion, plastic pipes | extrusion, plastic pipes | Cutoff, U-GLO
Integrated circuit, logic type	0.154	kg	Market for integrated circuit, logic type | integrated circuit, logic type | Cutoff, U-GLO
Integrated circuit, memory type	0.011	kg	Market for memory circuit, logic type | integrated circuit, memory type | Cutoff, U-GLO
Permanent magnet, for electric motor	0.0013	kg	Market for permanent magnet, electric passenger car motor | permanent magnet, for electric motor | Cutoff, U-GLO
Plug, inlet and outlet, for network cable	0.94	Item	Market for plug, inlet and outlet, for network cable | plug, inlet and outlet, for network cable | Cutoff, U-GLO
PVC plastic	0.03864	kg	PVC plastic Production
Rubber	0.00119	kg	Rubber Production
Steel EN 1.4301	8.85898	kg	Steel EN 1.4301 Production
Switch, toggle type	0.020	kg	Market for switch, toggle type | switch, toggle type | Cutoff, U-GLO
Outputs			
Thickness Manufactured	1	Item	

Table C.13: Table for Thickness Manufacturing

L&W Autoline Manufacturing			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline S Manufactured	1	Item	L&W Autoline S Manufacturing
Bendtsen Roughness Manufactured	1	Item	Bendtsen Roughness Manufacturing
Electricity, medium voltage	390.974	kWh	Market for electricity, medium voltage | electricity, medium voltage | Cutoff, U-SE
Grammage Manufactured	1	Item	Grammage Manufacturing
Thickness Manufactured	1	Item	Thickness Manufacturing
Outputs			
L&W Autoline Manufactured	1	Item	

Table C.14: Table for L&W Autoline Manufacturing

L&W Autoline Transportation to mill			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline Manufactured	1	Item	L&W Autoline Manufacturing
Transportation, freight, lorry 16-32 metricton, EURO6	1.04876E5	kg*km	Transport, freight, lorry 16-32 metric ton, EURO 6 | transport, freight, lorry 16-32 metric ton, EURO 6 | Cutoff, U-RER
Outputs			
L&W Autoline S Transported to mill	1	Item	

Table C.15: Table for L&W Autoline Transportation to mill

L&W Autoline Service			
Process	Amount	Unit	Provider
Inputs			
Alu EN-AW 6082 T6	0.23514	kg	Alu EN-AW 6082 T6 production
Brass	0.26885	kg	Brass Production
Cable, unspecified	0.0650	kg	Market for cable, unspecified | cable, unspecified | Cutoff, U-GLO
Computer, desktop, without screen	0.12	Item	Market for computer, desktop, without screen | computer, desktop, without screen | Cutoff, U-GLO
Electric motor, for electric scooter	0.780	kg	Market for electric motor, for electric scooter | electric motor, for electric scooter | Cutoff, U-GLO
Extrusion, plastic pipes	0.00296	kg	Market for extrusion, plastic pipes | extrusion, plastic pipes | Cutoff, U-GLO
Integrated circuit, logic type	1.03483	kg	Market for integrated circuit, logic type | integrated circuit, logic type | Cutoff, U-GLO
Steel EN 1.4301	8.63040	kg	Steel EN 1.4301 Production
Outputs			
L&W Autoline Serviced	1	Item	

Table C.16: Table for L&W Autoline Service

Compressed air L&W Autoline			
Process	Amount	Unit	Provider
Inputs			
Air compressor, screw-type compressor, 300	kW	9.0E-8	Market for air compressor, screw-type compressor, 300 kW | air compressor, screw-type compressor, 300 kW | Cutoff U-GLO
Electricity, medium voltage	0.10822	kWh	Market for electricity, medium voltage | electricity, medium voltage | Cutoff, U-SE
Lubricating oil	2.31111E-6	kg	Market for lubricating oil | lubricating oil | Cutoff, U-RER
Section bar rolling, steel	9.79E-5	kg	section bar rolling, steel | section bar rolling, steel | Cutoff, U-RER
Steel, low-alloyed, hot rolled	9.79E-5	kg	Market for steel, low-alloyed, hot rolled | steel, low-alloyed, hot rolled | Cutoff, U-GLO
Outputs			
Compressed air, 700 kPa gauge	1	m^3	
Compressed air, 700 kPa gauge	1	m^3	
Waste mineral oil	5.58317E-8	kg	Market for waste mineral oil | waste mineral oil | Cutoff, U-CH
Waste mineral oil	2.2552E-6	kg	Market for waste mineral oil | waste mineral oil | Cutoff, U-Europe without Switzerland

Table C.17: Table for Compressed air L&W Autoline

L&W Autoline S + 3 modules Use Phase			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline S Transported to mill	1	Item	L&W Autoline Transportation to mill
L&W Autoline Serviced	1	Item	L&W Autoline Service
Compressed air, 700 kPa gauge	1.61164E5	Nm^2	Compressed air L&W Autoline
Electricity, medium voltage	1.22435E4	kWh	Market for electricity, medium voltage I electricity, medium voltage I Cutoff, U-SE
Outputs			
L&W Autoline S Used	1	Item	

Table C.18: Table for L&W Autoline S + 3 modules Use Phase

L&W Autoline Waste Treatment			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline S Used	1	Item	L&W Autoline S + 3 modules Use Phase
Transport, freight, lorry 16-32 metric ton, EURO6	1.04876E5	kg*km	Market for transport, freight, lorry 16-32 metric ton, EURO6 I transport, freight, lorry 16-32 metric ton, EURO6 I Cutoff, U-RER
Outputs			
Electronics scrap from control units	0.390	kg	Treatment of electronics scrap from control units I electronics scrap from control units I Cutoff, U-RER
Used cable	5.31221	kg	Treatment of used cable I used cable I Cutoff, U-GLO
Used desktop computer	2.760	kg	Treatment of used desktop computer, manual dismantling I used desktop computer I Cutoff, U-RoW
Used liquid crystal display module	3.40	kg	Treatment of used liquid crystal display module, municipal waste incineration I used liquid crystal display module I Cutoff, U-RoW
Used printed wiring boards	2.14766	kg	Treatment of scrap printed wiring boards, shredding and separation I used printed wiring boards I Cutoff, U-RoW
Waste electric and electronic component	8.17124	kg	Treatment of waste electric and electronic component, shredding I waste electric and electronic component I Cutoff, U-GLO

Waste polyvinylchloride	13.87359	kg	Market for waste polyvinylchloride | waste polyvinylchloride | Cutoff, U-SE
Waste rubber, unspecified	0.43812	kg	Treatment of waste rubber, unspecified, municipal incineration | waste rubber, unspecified | Cutoff, U-Europe without Switzerland
Wasted Machine	1	Item	

Table C.19: Table for L&W Autoline Waste Treatment

The following four tables are edited for the market in China.

CHINA L&W Autoline Transportation to mill			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline Manufactured	1	Item	L&W Autoline Manufacturing
Transportation, freight, lorry 16-32 metric ton, EURO6	3.49587E4	kg*km	Transport, freight, lorry 16-32 metric ton, EURO 6 | transport, freight, lorry 16-32 metric ton, EURO 6 | Cutoff, U-RER
Transportation, freight, aircraft, unspecified	2.71979E6	kg*km	Transport, freight, aircraft, all distances to generic market for transport, freight, aircraft, unspecified | transport, freight, aircraft, unspecified | Cutoff, U-GLO
Outputs			
L&W Autoline S Transported to mill	1	Item	

Table C.20: Table for China L&W Autoline Transportation to mill

CHINA Compressed air L&W Autoline			
Process	Amount	Unit	Provider
Inputs			
Air compressor, screw-type compressor, 300	kW	9.0E-8	Market for air compressor, screw-type compressor, 300 kW | air compressor, screw-type compressor, 300 kW | Cutoff U-GLO
Electricity, medium voltage	0.10822	kWh	Market for electricity, medium voltage | electricity, medium voltage | Cutoff, U-CN-SGCC
Lubricating oil	2.31111E-6	kg	Market for lubricating oil | lubricating oil | Cutoff, U-RER
Section bar rolling, steel	9.79E-5	kg	section bar rolling, steel | section bar rolling, steel | Cutoff, U-RER
Steel, low-alloyed, hot rolled	9.79E-5	kg	Market for steel, low-alloyed, hot rolled | steel, low-alloyed, hot rolled | Cutoff, U-GLO
Outputs			
Compressed air, 700 kPa gauge	1	m^3	
Compressed air, 700 kPa gauge	1	m^3	
Waste mineral oil	5.58317E-8	kg	Market for waste mineral oil | waste mineral oil | Cutoff, U-CH
Waste mineral oil	2.2552E-6	kg	Market for waste mineral oil | waste mineral oil | Cutoff, U-Europe without Switzerland

Table C.21: Table for China Compressed air L&W Autoline

CHINA L&W Autoline S + 3 modules Use Phase			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline S Transported to mill	1	Item	CHINA L&W Autoline Transportation to mill
L&W Autoline Serviced	1	Item	L&W Autoline Service
Compressed air, 700 kPa gauge	1.61164E5	Nm^2	CHINA Compressed air L&W Autoline
Electricity, medium voltage	1.22435E4	kWh	Market for electricity, medium voltage | electricity, medium voltage | Cutoff, U-CN-SGCC
Outputs			
L&W Autoline S Used	1	Item	

Table C.22: Table for China L&W Autoline S + 3 modules Use Phase

L&W Autoline Waste Treatment			
Process	Amount	Unit	Provider
Inputs			
L&W Autoline S Used	1	Item	CHINA L&W Autoline S + 3 modules Use Phase
Outputs			
Electronics scrap from control units	0.390	kg	Market for electronics scrap from control units | electronics scrap from control units | Cutoff, U-GLO
Used cable	5.31221	kg	Market for used cable | used cable | Cutoff, U-GLO
Used desktop computer	2.760	kg	Market for used desktop computer | used desktop computer | Cutoff, U-GLO
Used liquid crystal display module	3.40	kg	Market for used liquid crystal display module | used liquid crystal display module | Cutoff, U-RoW
Used printed wiring boards	2.14766	kg	Market for used printed wiring boards, shredding and separation | used printed wiring boards | Cutoff, U-GLO
Waste electric and electronic component	8.17124	kg	Market for waste electric and electronic component | waste electric and electronic component | Cutoff, U-GLO
Waste polyvinylchloride	13.87359	kg	Market for waste polyvinylchloride | waste polyvinylchloride | Cutoff, U-RoW

Waste rubber, unspecified	0.43812	kg	Market for waste rubber, unspecified | waste rubber, unspecified | Cutoff, U-RoW
Wasted Machine	1	Item	

Table C.23: Table for China L&W Autoline Waste Treatment

The following process shows the circuit board process without the gold.

Circuit boards without gold			
Process	Amount	Unit	Provider
Inputs			
Transport, freight, lorry, unspecified	0.02	t*km	Market group for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, U-GLO
Chemical, organic	0.0086	kg	Market for chemical, organic | chemical, organic | Cutoff, U-GLO
Copper, cathode	0.082	kg	Market for copper, cathode | copper, cathode | Cutoff, U-GLO
Electricity, medium voltage	668.61	kWh	Market group for electricity, medium voltage | electricity, medium voltage | Cutoff, U-GLO
Electronic component factory	2.0E-8	t*km	Market for electronic component factory | electronic component factory | Cutoff, U-GLO
Epoxy resin insulator, SiO_2	0.4365	kg	Market for epoxy resin insulator, SiO_2 | epoxy resin insulator, SiO_2 | Cutoff, U-GLO
Epoxy resin, liquid	0.00044	kg	Market for epoxy resin, liquid | epoxy resin, liquid | Cutoff, U-RER
Epoxy resin, liquid	0.00206	kg	Market for epoxy resin, liquid | epoxy resin, liquid | Cutoff, U-RoW
Glass fibre reinforced plastic, polyamide, injection moulded	0.3169	t*km	Market for glass fibre reinforced plastic, polyamide, injection moulded | glass fibre reinforced plastic, polyamide, injection moulded | Cutoff, U-GLO
Gold	0.00¤	kg	Market for gold | gold | Cutoff, U-GLO
Heat, distric or industrial, other than natural gas	439.0	MJ	Market for heat, distric or industrial, other than natural gas | heat, distric or industrial, other than natural gas | Cutoff, U-GLO
Lead	0.037	kg	Market for lead | lead | Cutoff, U-GLO
Nickel, class 1	0.00328	kg	Market for nickel, class 1 | nickel, class 1 | Cutoff, U-GLO
Silver	0.0075	kg	Market for silver | silver | Cutoff, U-GLO
Tin	0.063	kg	Market for tin | tin | Cutoff, U-GLO
Wafer, fabricated, for integrated circuit	0.0180	m^2	Market for wafer, fabricated, for integrated circuit | wafer, fabricated, for integrated circuit | Cutoff, U-GLO
Zinc	0.00756	kg	Market for zinc | zinc | Cutoff, U-GLO
Outputs			
Integrated circuit, logic type	1.0	kg	

Table C.24: Table for production of integrated circuit, logic type without gold¤

¤The gold coating was set to 0.01082 kg before it was removed for the sensitivity analysis.

D

Appendix

Results of all impact categories				
Impact category	Production	Use phase	EoL phase	Total
Acidification (kg CO_2-Eq)	34.39	11.87	0.06	46.32
Climate change (kg CO_2-Eq)	6082.79	2577.3	54.78	8714.90
Depletion of abiotic resources (kg antimony-Eq)	41.01	16.00	0.16	57.17
Eutrophication (kg CO_2-Eq)	20.43	10.93	0.02	31.37
Terrestrial ecotoxicity (kg 1.4-DCB-Eq)	58.39	40.02	0.17	98.58
Fossil (non-renewable energy resources) (MJ-Eq)	68034.80	27150.80	335.44	95521.0
Nuclear (non-renewable energy resources) (MJ-Eq)	9148.79	114323.64	11.92	123484.0
Water (renewable energy resources) (MJ-Eq)	7597.92	38659.84	5.55	47978.30

Table D.1: Table for the results of the impact categories

Results of all impact categories - China					
Impact category	Production	Use phase	EoL phase	Transport	Total
Acidification (kg SO_2)	34.39	105.66	0.01	4.56	144.62
Climate change (kg CO_2-Eq)	6082.79	23326.27	15.79	1189.35	30614.20
Depletion of abiotic resources (kg antimony-Eq)	41.01	153.73	0.02	7.84	202.60
Eutrophication (kg PO_4^{3-})	20.43	30.76	0.01	0.88	52.08
Terrestrial ecotoxicity (kg 1.4-DCB-Eq)	58.39	71.48	1.23	1.64	132.75
Fossil (non-renewable energy resources) (MJ-Eq)	68034.80	227271.00	31.50	17630.46	312967.76
Nuclear (non-renewable energy resources) (MJ-Eq)	9148.79	8692.17	3.60	74.34	17918.90
Water (renewable energy resources) (MJ-Eq)	7597.92	14145.14	1.73	35.35	21780.15

Table D.2: Table for the results of the impact categories - China

E
Appendix

E.1 Electricity mix for studied countries

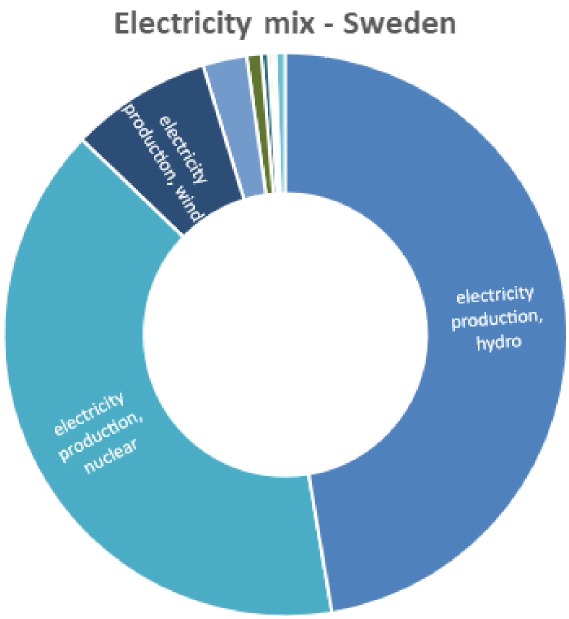

Figure E.1: Electricity mix for Sweden based on Ecoinvent data (Version 3,5, allocation cut-off)

The Swedish electricity mix consists of many different technologies. Therefore, only the most prominent contributing technologies are shown in the diagram since they are relevant to the results. For example, other ways of producing, for example, wind power, off- or onshore, were summed as one for simplicity. Figure E.1 shows the Swedish electricity mix presented in a sunburst diagram. The results show that the electricity mix mainly consists of hydro- and nuclear power.

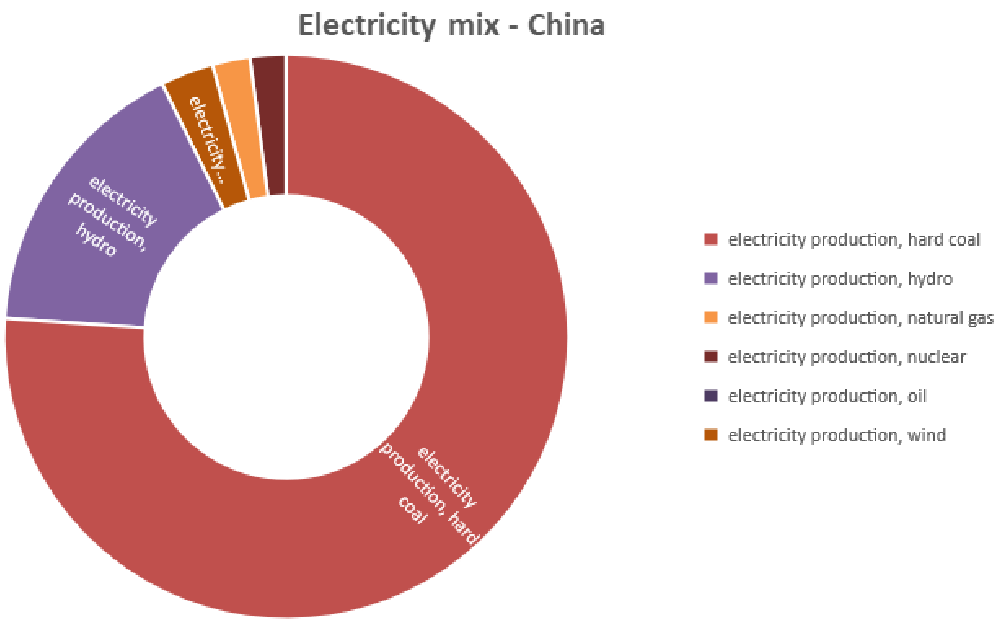

Figure E.2: Electricity mix for China based on Ecoinvent data (Version 3,5, allocation cut-off)

The Chinese electricity mix consists of many different technologies. Therefore, the graph is simplified in the same way as Figure E.1 is. Figure E.2 shows that the electricity mix for China mainly consists of hard coal.

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