

DESIGN FOR REMANUFACTURING: A STUDY OF ELECTRIC VEHICLE TRANSMISSION



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DESIGN FOR REMANUFACTURING: A STUDY OF ELECTRIC VEHICLE TRANSMISSION

This report is submitted in accordance with requirement of the Universiti Teknikal
Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)



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DECLARATION

I hereby, declared this report entitled “Design For Remanufacturing: A Study Of Electric Vehicle Transmission” is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:



ABSTRAK

Industri pengangkutan mengeluarkan 25% daripada *Greenhouse Gases* (GHG) yang dihasilkan oleh industri berkaitan tenaga. Dengan peranan yang besar dalam sektor automotif, *Electric Vehicle* (EV) dijangka dapat mengurangkan kesan-kesan rumah hijau. Selaras dengan bilangan tambahan pengeluaran EV, penghujung hayat komponennya perlu dikaji dengan teliti untuk mengelakkan kesan negatif baharu terhadap alam sekitar. Pengilangan semula adalah salah satu kaedah yang boleh digunakan untuk mengurangkan kesan terhadap alam sekitar oleh komponen EV. Pengilangan semula ialah proses perindustrian untuk memulihkan produk lama kepada produk baharu dan diberi nilai tambah. Kajian ini memberi tumpuan kepada pengilangan semula transmisi EV atau *transmission*. Kajian ini juga akan melakukan penilaian kitaran hayat (LCA) yang dibina dengan menggunakan perisian openLCA untuk membandingkan antara kitaran hayat transmisi EV yang baharu dengan transmisi EV yang dikilangkan semula. Jenis LCA yang digunakan ialah *cradle to gate* yang lebih memfokuskan kepada bahan yang digunakan semasa proses pengilangan produk. Keputusan menunjukkan transmisi yang dikilangkan semula menghasilkan impak yang lebih rendah terhadap alam sekitar berbanding transmisi yang baharu. Dari segi *abiotic depletion*, ia menunjukkan bahawa pengilangan semula mampu meminimumkan 84% penggunaan bahan mentah berbanding transmisi yang baru dikeluarkan secara keseluruhan dan menyumbang 63% lebih rendah *Global Warming Potential* (GWP) berbanding transmisi yang baru dikeluarkan. Penyumbang utama terhadap keputusan tersebut adalah daripada jumlah penggunaan bahan dan penggunaan tenaga yang lebih sedikit oleh proses pengilangan semula transmisi berbanding transmisi yang baharu.

ABSTRACT

The transportation industry releases 25% of the Greenhouse gases (GHGs) produced by energy-related industries. With a substantial presence in the automotive sector, Electric Vehicles (EVs) are expected to lower the impact of the greenhouse effect. EVs have grown in popularity in recent years. Their participation is important in lowering GHG emissions into the atmosphere. Corresponding to the additional number of EVs production, the end of life of their components needs to be carefully studied to avoid new negative environmental impacts. Remanufacturing is one of the methods that can be used to reduce and eliminate the environmental impact of EV components. Remanufacturing is an industrial process to restore an old product to a new with value-added product. In addition, there is a minimal amount of study regarding the remanufacturing of EV transmissions. The study included the life cycle assessment constructed by using the openLCA software to compare between the life cycle of a new EV transmission with the remanufactured EV transmission. The type of LCA used is cradle to gate which is focused more on the injected material used to manufacture the product. The result shows that the remanufactured transmission performs significantly better than the newly manufactured component in terms of all environmental impact categories considered. In terms of abiotic depletion, it shows that remanufacturing able to minimise 84% the used of raw material compared to newly manufactured transmission in total and contributed 63% lesser of Global Warming Potential (GWP) compared to the newly manufactured transmission. The savings are chiefly due to lower power consumption and material requirements as a result of the reuse of components.

DEDICATION

The name of Allah, the Most Gracious and the Most Merciful

my beloved father, Azman Bin Musa

my appreciated mother, Norlaila Binti Ali

my cats

my siblings

my supervisor

my fellow friends

for giving me moral support, love, money, cooperation,
encouragement, and also understandings

Thank You So Much & Love You All Forever

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LIST OF ABBREVIATION

EV	-	Electric vehicle
GHG	-	Greenhouse gas
CO ₂	-	Carbon dioxide
SO ₂	-	Sulphur dioxide
EF	-	Environmental Footprint
EU	-	European Union
ICE	-	Internal combustion engine
ELV	-	End-of-life vehicle
LCA	-	Life cycle assessment
OEM	-	Original equipment manufacturer
EEE	-	Electrical and electronic equipment
EoL	-	End of Life
PHEV	-	Plug-in hybrid
NAP	-	National Automotive Policy
TNBES	-	Tenaga Nasional Berhad Energy Services
MGTC	-	Malaysian Green Technology Corp
RM	-	Ringgit Malaysia
HEV	-	Hybrid electric vehicle
BEV	-	Battery electric vehicle
FCEV	-	Fuel cell electric vehicle
EREV	-	Extended range electric vehicle
SEV	-	Solar electric vehicle
DC	-	Direct current
EVB	-	Electric vehicle battery
kW	-	Kilowatt
AC	-	Alternating current
RPM	-	Revolution per minute

SD	-	System dynamic
DES	-	Discrete event simulation
LCC	-	Life cycle cost
LCIA	-	Life Cycle Impact Assessment
LCR	-	Life cycle replacement
UNEP	-	United Nation Environment Programme
CLD	-	Causal loop diagram
SFD	-	Stock flow diagram
BOM	-	Bill of Material
GWP	-	Global Warming Potential
ADP	-	Abiotic Depletion Potential



CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electric vehicles (EVs) have grown in popularity in recent years, and there are a variety of reasons for this. Their participation is critical in lowering greenhouse gas (GHG) emissions into the atmosphere. Transportation was responsible for 25% of the GHGs created by energy-related industries. Climate change is caused by the greenhouse effect, which is a natural occurrence. Industrial revolutions, humans have consumed massive amounts of fossil fuels such as oil and gas. Huge volumes of carbon dioxide are released into the atmosphere by fossil fuels. The gases released into the atmosphere operate as an invisible "blanket," warming the earth and trapping heat from the sun. This effect is known as the "Greenhouse Effect."

With a substantial presence in the automotive sector, EVs are expected to lower the impact of the greenhouse effect. The automobile industry is undergoing rapid and widespread change. Automobiles cause numerous environmental and fuel-related issues. As a result, electric vehicles are becoming more mainstream and becoming increasingly important in the automobile industry. Various firms such as Tesla, Nissan, Hyundai, Honda, Ford, and Tata are optimistic about the EV market because of its environmental, fuel economy, and other benefits. The battery, motor, and transmission system are the several components of an EV, but the main focus of this study is only for the transmission system.

More than 1 million new EVs were registered for the first time, and 60% of them from China (MacDonald, 2016). According to Deloitte Insight, worldwide EV estimate global unit sales will expand at a rate of 29 percent per year over the next 10 years. Electric

car sales will increase from 2.5 million in 2020 to 11.2 million in 2025, and 31.1 million in 2030. Electric cars would account for around 32% of new automobile sales, according to the report (Bryan Walton, 2022).

Corresponding to the additional number of EVs production, the end of life of its components needs to be carefully studied to avoid from new bad environmental impact. Remanufacturing is one of the methods that can be used to reduce and eliminate the environmental impact of electric vehicle (EV) components. Remanufacturing is the process of restoring a used product to its original state by regaining the component's added value when it was initially made (Dietz, 2015). In another research, remanufacturing also can be defined as the supplier taking their product back and restore them to like a new state of product or better in an industrial process (Lindkvist Haziri & Sundin, 2020). The author also said significant energy consumption and emissions to air and water, such as carbon dioxide (CO₂) and sulphur dioxide (SO₂), can be reduced by extending the lifespan of components. Comparing remanufacturing against new manufacturing and/or material recycling reveals that remanufacturing provides environmental benefits. This is due to reduced resource depletion, reduced global warming potential, and higher prospects of closing the loop for safer toxic material management (Lindkvist Haziri & Sundin, 2020).

In the production phase, the automobile industry is reliant on a variety of raw materials and rare metals, which limits the sector's future growth. The automobile sector consumes 12% of total world steel consumption, as per World Steel Association (Gabhane & Kaddoura, 2017). In addition, according to the US Geological Survey, it is also responsible for 60% of global lead use, with reserves expected to run out by 2030 (Otter, 2018). Remanufacturing is a strategy to minimize at the same time to reduce the dependency of automotive industry to the new raw material supply.

1.2 Problem Statement

Government all across the world are enacting policies and programmes to minimise the carbon emissions (Angius et al., 2016). The same article also stated that the United Kingdom aims to reduce carbon emissions by 45% by 2020. The European Union (EU) has

established goals for 2021 and 2022 that will reduce air pollution emissions by 18 and 40 percent, respectively, compared to 2007 levels (Rauh, 2019). Not to left behind, Malaysian's 9th Prime Minister has announced the target for Malaysia to become a carbon neutral country by 2050 at the earliest (Fang, 2022). The annual carbon dioxide emissions from a typical passenger vehicle are approximately 4.6 metric tonnes (Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2021). Thus, EVs is a good option to replace the internal combustion engine (ICE) vehicle to compliment the global goals towards minimizing the carbon emissions due to the zero-exhaust emission.

Figure 1.1 below depicts the rapid selling of electric vehicles in China, Europe, the United States, and other nations from 2010 to 2020. By 2020, around 3 million new electric vehicles will have been registered. For the first time, Europe has the largest number with 1.4 million new registrations. The second one, China with 1.2 million new electric vehicle registrations, and United States with 295 000 new EV registrations. This increasing trend in electric vehicle sales is extremely beneficial since it has the potential to minimize the world's indirect reliance on natural resources such as petroleum.

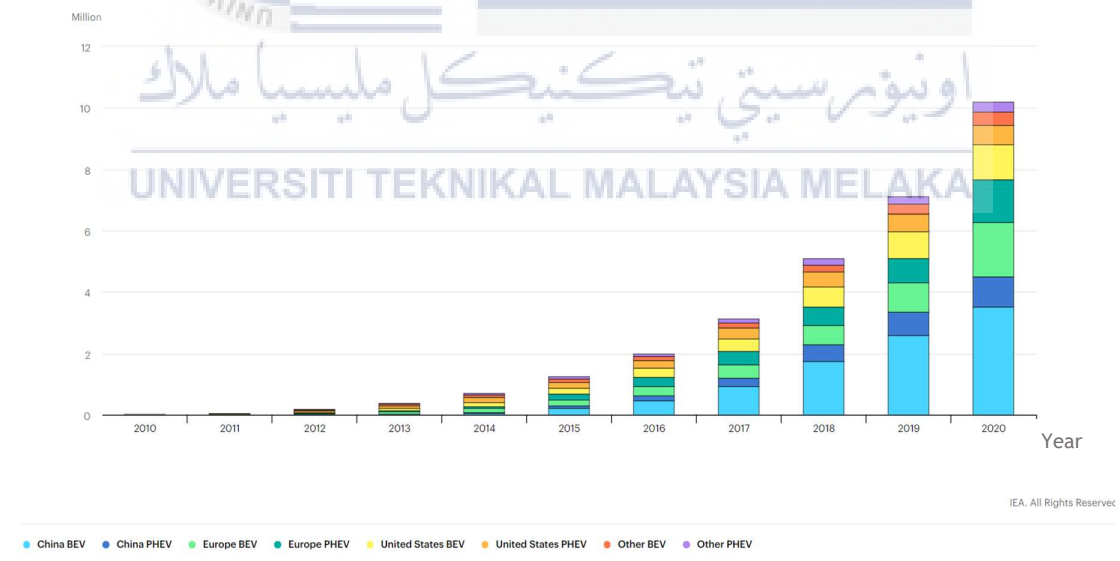


Figure 1.1: Global electric passenger car stock, 2010-2020 (Global electric passenger car stock for 2010-2020, 2020).

Unfortunately, those fact led to the second problem statement where EVs manufacturing industries still relying on the natural resources such as aluminium, steel, cast iron, stainless steel, and lithium to build the components for the EVs. This

increasing demand on metals and the emissions associated with their production has resulted in increasing pricing and challenges ensuring the process's supply chain. To avoid this, remanufacturing of the components at the End-of-Life vehicles (ELVs) is one of the ways. Finally, there is minimal amount of study regarding the remanufacturing of EVs transmission. Most scholars are interested in EVs battery because it is the main components for EV such as a study by Fotouhi et al., 2016, Wang et al., 2020, and Xiong et al., 2020. That research only focusing on EV battery. There is several study regarding EV transmission, such as written by Sirohi et al., 2017, Joshi & Ugale, 2020, and Carlos Daniel Pires, 2018, only focusing on the design structure of EV transmission. Therefore, it is important to study about EVs transmission because it still relying to the raw material resources to manufacture the part.

1.3 Objectives

The objectives of this study are as follow:

- i. To study the concept of electric vehicle transmission.
- ii. To identify the main component for the remanufactured electric vehicle transmission.
- iii. To propose the environmental impact performance analysis of newly manufactured and remanufactured electric vehicle transmission.

1.4 Scope

The scope of the thesis is to study the concept of EV remanufacturing in Malaysia particularly for transmission part. An interview will be conduct with automotive engine workshop to identify the main component of the EV transmission and the component that mostly need to be change for remanufactured transmission. Furthermore, the life cycle assessment will be proposed by using openLCA software to compare the environmental impact between the newly transmission versus the remanufactured transmission. The type of LCA use is cradle to gate which is focused more to the manufacturing flow.

1.3 Importance of Study

The primary goal of this research is to determine and quantify Malaysian acceptance toward EV and the remanufactured product. This study is important to create an awareness to Malaysian and Malaysian automotive industries regarding the EVs problem occur at the ELVs of the EVs especially for the transmission component. In general, present researchers have undertaken substantial research on the life cycle assessment of electric vehicle batteries and have established a preliminary research system. However, there is lack of study on electric vehicle transmission component. It is important to establish a basic study regarding the life cycle assessment (LCA) of EV transmission to cope with the massive wave of end-of-life of EV in the future.

1.6 Organization of the Thesis

The first part of this thesis is chapter 1, introduction. It starts with background of study which briefly explain the main idea of this study. The problem statement is presented in the second section of this chapter, followed by the objectives, scope, importance of the study, and summary. Next, chapter 2 is about literature review which will describe in more detail regarding the idea of this study. Next, on the Chapter 3: Methodology, will be identify the method approach that suitable with the aim of the thesis. Chapter 4 is for Result and Discussion and the final chapter will be conclusion.

1.7 Summary

The main focus of this thesis is to study the concept of transmission for EVs. Remanufacturing is an industrial process of restoring a used product to like a new condition by recovering the value added to the component like when it was first produced. This study is important in respond to the Malaysia's government target to be a carbon neutral country by 2050. The results will indicate if remanufacturing able to solve the problem of raw material exploitation to manufacture an EV. Findings will provide multidisciplinary

viewpoints and important information for the preparation for the ‘greener’ option for automotive industries.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Literature Review

This chapter will summarize previous research on related articles, journals, websites, and books conducted by the researchers. The topic has been covered in this chapter is remanufacturing, remanufacturing in general, remanufacturing in the automotive industry, and remanufacturing in Electrical Vehicle (EV), electric vehicle, the history of EVs, the type of EV and their working principle, the main component of the EV, EV transmission, and the process flow of the remanufacturing of an EV transmission.

2.2 Remanufacturing

Consumers, businesses, governments, and the general public are becoming more aware of the importance of sustainability issues, prompting many industries to implement environmentally conscious policies in their product development, manufacturing, distribution, service, and end-of-life management. In recent years, the market for remanufactured items for secondary use has grown dramatically as a result of more excellent consumer and industry knowledge of the benefits from remanufacturing (Mitsutaka Matsumoto, Shanshan Yang, 2016).

Several formal definitions of remanufacturing have been proposed over the years, most of them describe remanufacturing as "an industrial technique for restoring value to old

and degraded products by replacing components or reprocessing used component parts to a 'like-new' condition” (L. Zhang et al., 2016). From the latest research by Sitharangsie, S., Ijomah, W., & Wong (2019), stated remanufacturing as one of the well-known recovery procedures that can restore a used product to its original manufacturer's specifications in terms of quality, performance, and warranty by restoring it to its original manufacturer's specifications (Sitharangsie, S., Ijomah, W., & Wong, 2019).

Remanufacturing is different from other end-of-life recovery operations such as recycling, repair, reuse, and reconditioning, even though it employs similar methods and results in the same end product. Remanufacturing differs from recycling in that remanufacturing will use the value initially added to the raw material during the manufacturing process.

Recycling is described as returning a product to its original state as raw material, which may then be used in another manufacturing process to create a new product. Newspapers, glass bottles, and aluminium cans are examples of consumable items that are commonly referred to as "recycling." However, the term can also refer to long-lasting items such as engines. As a result of altering the raw material during the manufacturing process, recycling devalues the raw material in this respect (Geyer et al., 2016).

Reuse is a technique or a practice that involves reusing something. This can be done in order to use the product for its intended purpose or in order to perform a new function with it. Reuse only can be done if the object is still in good condition and can be used without undergoing a significant changes (Cooper & Gutowski, 2017).

Reconditioning, on the other hand, is the process of restoring a product that has achieved the end of its useful life or has been used to a reasonable performance level that is lower than the original Manufacturer's standard, with the warranty limited to the primary worn parts. It shows that the only method that can restore an end-of-life product's performance to at least Manufacturer standards while simultaneously providing a warranty comparable to that of a new manufactured item is remanufacturing.

2.2.1 Remanufacturing in General

Remanufacturing involves disassembling a product into its sub-components, remanufacturing the components, and then reassembling the product. Working parts that are still in good condition and can be reused will be used in new products. This procedure includes quality assurance as well as potential component upgrades or changes. Remanufacturing provides significant economic and environmental benefits. Remanufacturing aims to relieve client burdens because these products are typically less expensive, costing roughly 60% - 80% of the cost of a new one. They are less expensive because less raw materials are required, and because the product has already been made, it merely has to be restored to its previous (or higher) quality. When there is a significant demand for a specific product, a remanufactured version may be available with a shorter lead time (David Parker et al., 2015). Figure 2.1 below shows the process step to remanufacture a product.



Figure 2.1: The remanufacturing life cycle (MCT Reman Ltd, 2018).

Furthermore, remanufacturing certain things uses less energy than manufacturing them from scratch. As a result, CO2 emissions are reduced, and the amount of waste that ends up in landfills is reduced (David Parker et al., 2015). It also benefits the local remanufacturing business and the general population as a result of the employment opportunities it creates. In Sweden, for example, a circular economy (which includes remanufacturing) has the potential to generate 100,000 new jobs (Kalmykova et al., 2018).

As a result, remanufacturing has opportunity to explore in a variety of industries. Smart phone, ink cartridges, photocopiers, and disposable cameras, to name a few, have all been remanufactured with extended lifespans by automobile manufacturers and the electrical and electronic equipment (EEE) industries. Comparable industrial case studies can be found in the mechanical machines and tools business in addition to textiles, rubber products, and nautical goods.

2.2.2 Remanufacturing in Automotive Industry

Automobile parts, office machines, and single-use cameras, as well as construction equipment, industrial equipment, aerospace components, mining equipment, military trucks, medical equipment, computers, and vending machines, have all benefited from remanufacturing industries around the world (Matsumoto & Ikeda, 2015). Due to the enormous demand for automotive replacement parts, rules on end-of-life vehicle recovery efforts, and rising worries about the environmental impact of conventional manufacturing, the automotive industry has emerged as a leading potential to benefit from remanufacturing (Rego & Mesquita, 2015).

In addition, the global market for Automotive Part Remanufacturing is projected to reach \$198 billion by 2024, up from \$53 billion in 2018 (Global Market Study on Automotive Parts Remanufacturing, 2022). In terms of value, electrical & electronics parts are anticipated to lead the automotive parts remanufacturing market by component. This segment's rise is primarily attributable to the rising replacement rate of alternators and starters. Over 30 percent of the market for remanufactured automobile parts comprises engines and related components. The passenger vehicles sector is expected to increase at the fastest rate, accounting for 37.1% of the automotive parts remanufacturing market. Individual purchasing power is increasing, as is the demand for personal transportation, which is two of the drivers driving the segment's rise in the worldwide car parts remanufacturing market.

On a geographical basis, North America is expected to maintain its position as the market leader in revenue share for the worldwide automotive parts remanufacturing market. The European Union, which is expected to follow North America, will produce significant demand for remanufactured automobile components in the future years, according to reports. In addition, the automotive parts remanufacturing market is expected to develop at the fastest rate in China, followed by Latin America and Southeast Asia Pacific, owing to the increasing number of automobile sales in these areas, which has resulted in a significant need for automotive parts.

2.2.3 Remanufacturing in Electric Vehicle (EV)

One of the automobile industry's potential directions for attaining sustainable development is electric cars (EVs). According to the International Energy Agency (2017), global sales of pure battery electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) grew from 1,670 to 12,480 between 2005 and 2010. The number of alternative-fuel vehicles has increased even more rapidly since then. By 2015, there were 1,256,900 electric vehicles on the road, up over 752 times from ten years previously. The rapid growth of usage of EVs nowadays creates future opportunities for remanufacturing industries.

The battery is one of the most critical parts of an electric vehicle. The rapid adoption of electric vehicles has resulted in a significant demand for EV batteries. The EV's mileage is directly influenced by the battery's working life. The battery life of a Tesla Model S P90D, for example, is 430 kilometres with a 95-kilowatt-hour battery (Tesla, 2017). Customers' desire to purchase an EV may be influenced by the range of a battery's operational range. Electric vehicles (EVs) cannot use their batteries once their service life has elapsed, unlike gasoline-powered vehicles. When a battery's capacity goes below 70–80 percent, it must be removed for performance and safety reasons.

2.3 Electric Vehicle

EVs have gained popularity in recent years for a variety of reasons. The main effect they provide is a reduction in the number of emissions of greenhouse gases (GHG). Various initiatives are being undertaken to reduce emissions from the automotive industries. Transportation electrification is a practical option with numerous benefits. Electric vehicles have the potential to provide energy security by diversifying energy sources, enhance economic growth by spawning new innovative sectors, and, most crucially, protect the environment by reducing tailpipe emissions. Due to the employment of more efficient drivetrains and electric motors, electric vehicles outperform internal combustion engine (ICE) vehicles (European Environment Agency, 2018).

EV registrations accounted for roughly 1.5 percent of overall new vehicle registrations in the EU-28 in 2017 (European Environment Agency, 2018). The EU has a wide range of cultural and economic contrasts. As an illustration, 5% of all new car registrations in Sweden are for electric vehicles (European Environment Agency, 2018). With 39.2 percent of all new car registrations outside of the European Union, Norway is the clear frontrunner (EAFO, 2018). Continuous development of EV technology is critical to improving EV performance and ensuring competitiveness. For example, development emphasis has been made on power train, battery, and charging infrastructure technologies.

Many factors, including the environmental impact of ICEs and the concern of a declining source of petroleum, have led to a decline in the use of coal-fired power plants. The advancement of new technology has substantially altered the future possibilities for EVs. Several automakers are working hard to develop new electric vehicles:

- i. By 2023, General Motors wants to have an all-electric car (GM Media Online, 2018).
- ii. In the future, Ford plans to provide seven plug-in hybrids that are both electric and unique (Ford, 2018).
- iii. Mazda, Denso, and Toyota are collaborating on electric car technology (Press Room, 2018).

- iv. By 2022, Daimler wants to electrify its whole fleet (AG, 2018).
- v. Renault, Nissan, and Mitsubishi are all working on 100% electric vehicles, with a goal of releasing 12 EVs by 2022 (Electrek, 2018a).
- vi. By 2020, Jaguar Land Rover plans to have all of its vehicles powered by electric motors (Reuters, 2018).
- vii. Volvo Cars plans to electrify its whole cars by the year 2019, and the company hopes to have five electric vehicles on the road by the year 2020. Additionally, Volvo Cars wants to develop its own electric motors and management technology for its future electric vehicles (Volvo, 2018).
- viii. The Volkswagen Group, which owns brands such as Audi and Porsche, has announced that by the year 2030, it plans to provide an electric and hybrid version of each one of its 300 vehicle models (Electrek, 2018b).

2.3.1 Adaptation of Electric Vehicle in Malaysia

The Malaysian government's National Automotive Policy (NAP) encourages the use of electric vehicles and the construction of infrastructure that is compatible with the usage of electric vehicles (Yusop et al., 2016). By the year 2030, Malaysia plans to have introduced 100,000 electric vehicle units and 2,000 electric buses, and the country's national auto industry would be responsible for this (MEC, 2016). In addition, TNB Energy Services Sdn Bhd (TNBES), a Tenaga Nasional Bhd subsidiary, and Malaysia Green Technology Corp (MGTC) have each set aside RM1.5 million to establish 100 electric vehicle charging stations in an appropriate location. These charging stations will be available to drivers of electric vehicles and will be located in the Klang Valley area. On the other hand, Perodua has made an announcement that they will be collaborated with Daihatsu to come out with their own affordable EV models. This revelation is in line with Malaysia's stated goal of being carbon neutral by the year 2050, as outlined in the 12th Malaysian Plan, which was unveiled in September of that year. The implementation of such a strategy will be seen during the October 2021 Budget announcement. All relevant duties and taxes will be waived for electric cars sold in 2022 (Malay Mail, 2022).

Toyota was the first business to launch a hybrid electric vehicle (HEV) in Malaysia in 2009, followed by Honda in 2010, Mitsubishi and Nissan in 2013, and finally Mitsubishi and Nissan in 2014. Honda, Hyundai, Toyota, Nissan, Volvo, Mercedes-Benz, and BMW have begun to incorporate a variety of electric vehicle (EV) models in their product line-ups in Malaysia. This is in contrast to the practises of the country's domestic automakers (Proton and Perodua), which continue to equip all of their existing models with internal combustion engines (ICEs). As a direct consequence of this, the number of electric vehicles (EVs) that were registered in Malaysia in 2017 and 2018 reached a record high of close to 9,000 each year. More than 95% of electric vehicles registered are plug-in hybrid electric vehicles (PHEV), although the ratio of battery electric vehicles (BEV) has recently risen from 5% to 8% in the year 2021 (Lim, 2021). As of right now, there are over 31,000 registered electric vehicles driving throughout Malaysia, with battery electric vehicles making almost 5% of that total (Veza et al., 2022). The current adoption rate in Malaysia is dismally low, despite the fact that there has been such a significant growth.

2.3.2 History of Electric Vehicle

Electric cars have undergone a great deal of change for the last century. It comes as a pleasant surprise to hear that electric vehicle were previously the most popular option for usage in transportation. The development of the electric motor set the stage for the introduction of the first electric-powered cars. Robert Anderson had a thought with the idea for the first electric-driven carriage somewhere between the years 1832 and 1839. Figure 3 shows Robert Anderson with his electric vehicle prototype. This early prototype was powered by primary cells that could not be recharged (G.M, 2011).

DC electric motor and rechargeable battery improvements helped EV development. For example, the first commercially accessible EV was a New York City electric taxi in 1897. In only three short years, EVs have become the preferred mode of transportation, accounting for 28% of all cars on the road (Energy Agency, 2020).



Figure 2.2: Robert Anderson (sit at the front) with his first electric carriage (The First Electric Car: A Brief History of Electric Vehicles | Enel X Way, 2022).

In 1908, Henry Ford introduced the Model T, the first gasoline-powered automobile, into the market. In gasoline-powered cars, a device called as electric starter that was invented by Charles Kettering in 1912 eliminated the need for a hand crank to ignite the fuel. In addition, the easy access to low-cost fuel contributed to the reduced operating costs of gasoline-powered cars in comparison to electric vehicles (EVs). On the other side, electric vehicles were restricted to traveling comparatively shorter distances, and there were a restricted number of charging stations accessible (Kumar & Alok, 2020). These factors led to the broad acceptance of gasoline-powered automobiles and the gradual downfall of electric vehicles over time. In the year 1935, EV are no longer been used on the road.

Recently, the number of internal combustion engine (ICE) automobiles has decreased. Climate warming, concerns about peak oil output, and advancements in EV technology all contribute to the rising percentage of electric vehicles. The move to the new technology happens quite quickly. In 2019, a total of 143 new electric vehicles were introduced, with an additional 450 models expected to be released by 2022. The United States' Tesla Motors, China's BYD Motors and BJEV Motors, Germany's BMW, and Japan's Nissan are among the most important manufacturers. By 2027, China will produce 44% of the world's electric vehicles, followed by Europe (29%), North America (12%), and Japan/Korea (12%) (Carlier, 2022). Figure 4 shows the anticipated rise in the proportion of the worldwide market that will be taken up by sales of electric vehicles.

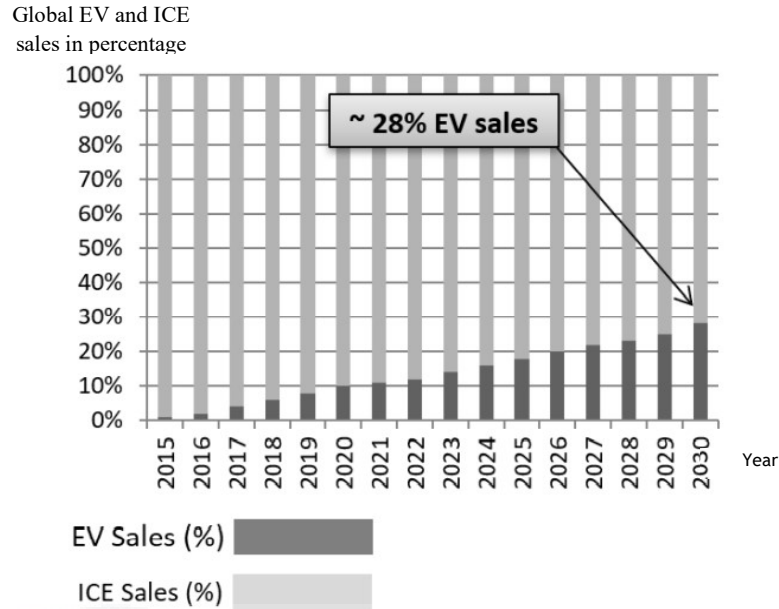


Figure 2.3: EV and ICE sales forecast (J. Hamilton et. al, 2020).

2.3.3 Type of Electric Vehicle and Their Working Principle

There are two powertrain options for EVs: all-electric or integrate with internal combustion (ICE). An electric car powered solely by batteries is a simple example. However, there are others that use different energy sources. Automobile manufacturers are experimenting with a variety of techniques in this ongoing transformative process. The BEV, HEV, and PHEV are the three primary methods, as shown below. Other types of EVs, such as fuel cell electric vehicles (FCEVs), extended-range electric vehicles (EREVs), and solar electric vehicles (SEVs), have a modest market share and are unlikely to develop rapidly in the foreseeable future (Casper & Sundin, 2021).

a) Hybrid Electric Vehicle (HEV)

In HEVs, both an internal combustion engine and an electric motor are used to provide their power. Electric propulsion is used by HEVs when power consumption is low. Because the engine is shut off during periods of inactivity, such as traffic jams, it offers a major advantage in low-speed areas like cities. GHG emissions are also reduced by this method (Hu et al., 2019). Greenhouse gas emissions are reduced as a result of this feature.

The HEV uses the ICE when extra speed is needed. Additionally, the two powertrains can work together to improve performance.

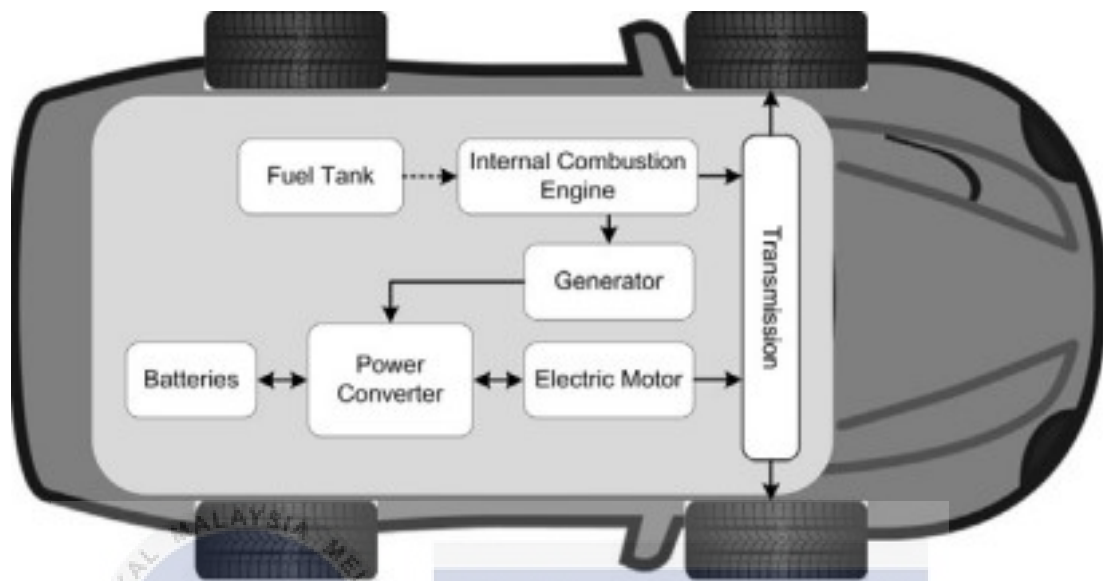


Figure 2.4: Power train configuration of an HEV (Tran et. al, 2020).

b) Plug-In Hybrid Electric Vehicle (PHEV)

HEVs that can run only on electric power were the driving force for the PHEV concept (Bai et al., 2020). When it comes to powering the vehicle, it has the ability to run on both gas and electricity. Figure 2.5 depicts the powertrain of HEV. HEVs don't require as large a battery as PHEVs because they employ electric engine as their primary driving power. PHEVs are electric-only vehicles from the get-go. To recharge the battery pack, the ICE is summoned when the car's battery pack is running low on juice. With the help of the grid, PHEVs may recharge their batteries and perform regenerative braking, which is not possible with HEVs. PHEVs have a smaller carbon footprint than HEVs because they can run on electricity most of the time. They also use less gas, which brings down the cost. These are now easy to find, and the popularity of the Chevrolet Volt and Toyota Prius shows how popular they are.

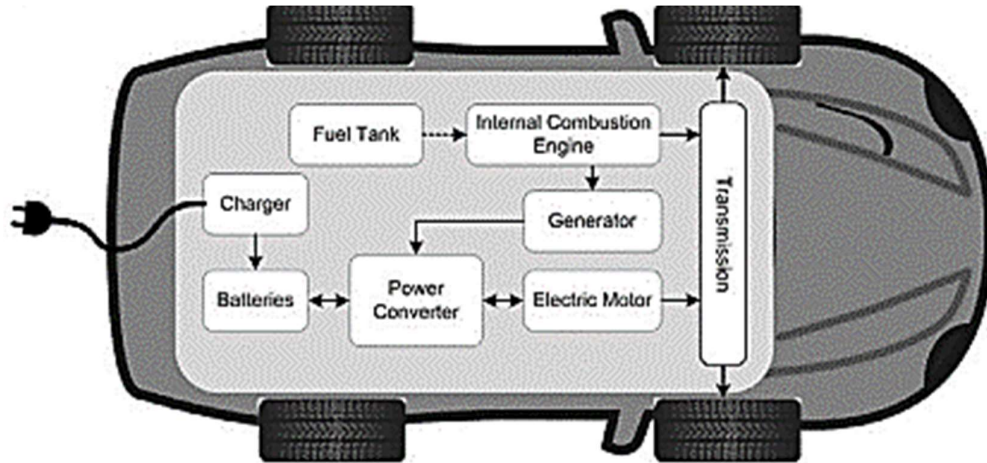


Figure 2.5: Power train configuration of a PHEV (Tran et. al, 2020).

c) Battery Electric Vehicle (BEV)

BEVs are electric cars whose drivetrains are only powered by batteries. BEVs can only run on the energy stored in their batteries, so their range is directly related to the size of their batteries. They can usually go between 100 and 250 km on a single charge, but the best models can go between 300 and 500 km (Mukherjee & Ryan, 2020). A BEV can only move forward with the help of its electric motor. Since a BEV will only use electricity to move, it will always be in charge-depleting mode since it will have an electric propulsion system. When the car is stopped, the massive battery packs can be charged both inside and outside the vehicle. Regenerative braking can be used to charge them up from the inside. Figure 2.6 depicts the power train of BEV.

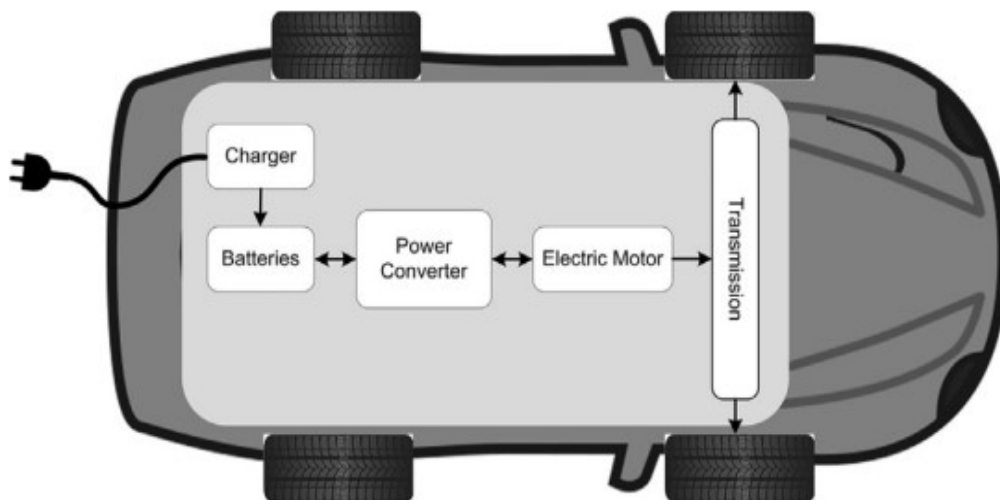


Figure 2.6: Power train configuration of a BEV (Tran et. al, 2020).

Next, Figure 2.7 as below demonstrates the basic structure of BEVs: The electric motor(s) that turn the wheels are coupled to a power converter circuit and are powered by batteries. The range of a vehicle is determined by the driving style and condition of the driver, vehicle configurations, road conditions, climate, and age of the battery. Depending on the battery capacity, charging a typical internal combustion engine (ICE) vehicle might take up to eight hours when the battery pack is low. BEVs are advantageous in that they are easy to configure, operate, and maintain. These do not emit greenhouse gases (GHG) and are therefore environmentally beneficial (Casper & Sundin, 2021). Even at modest speeds, electric power generates huge and speedy torques. Due to these advantages and their restricted range, these vehicles are suitable for city driving.

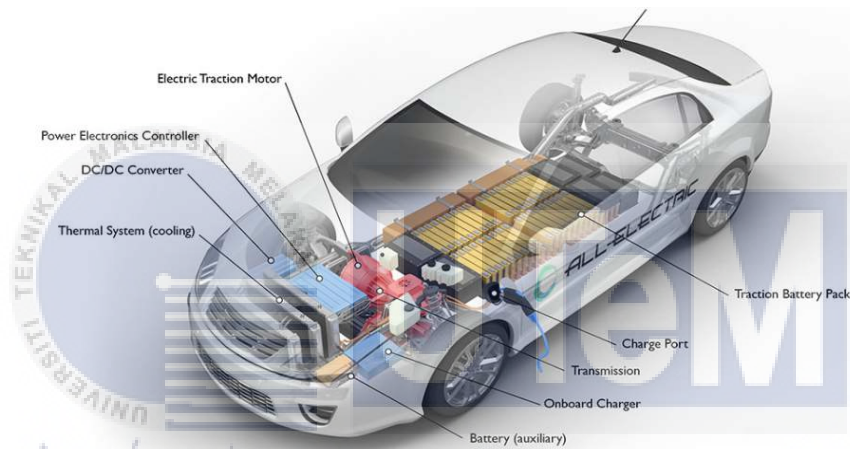


Figure 2.7: Illustration of EV's core components (Alternative Fuels Data Center: How Do All-Electric Cars Work?, 2017).

2.3.4 Main Components of Electric Vehicle

There are three basic components that make up an electric vehicle. These components make up the electric engine: the motor controller, the battery, and the engine itself. Other than that, EV consist of sub-primary component such as transmission, DC/DC convertor, auxiliary battery, thermal system, and charging port (Hailu & Redda, 2020). The illustration of the component is as shown in Figure 2.7. The description of each component is as per Table 2.1 below:

Table 2.1: Basic components of EV

Component	Description
<p>Traction battery pack</p> 	<p>The term "EVB" stands for "electric vehicle battery," which is another name for the traction battery pack. It is what gives an electric car its propulsion, the electric motors. The function of the battery is similar to that of an electrical storage system. DC current is the form in which it keeps the energy. When the kW capacity of the battery is increased, the range will also be increased. The design of the battery affects not just its lifespan but also how it operates. It is predicted that a traction battery pack will last for 200,000 miles over its lifespan.</p>
<p>Controller</p> 	<p>The operation of a power electronics controller is what dictates how an electric vehicle functions. It controls the flow of electrical energy from the batteries to the electric motors so that everything works properly. The position of the driver's foot on the pedal controls not just the speed of the vehicle but also the frequency of the voltage changes that are fed into the motor. Additionally, it governs the amount of torque that is generated.</p>
<p>Inverter</p> 	<p>The electricity supplied by the batteries is converted into AC power by the inverter. Additionally, it converts the alternating current (AC) that is produced by the regenerative braking system into direct current (DC). This is then put to use in the process of recharging the batteries. The inverter has the ability to alter the speed at which the</p>
<p>Electric traction motor</p> 	<p>In an electric car, the electric traction motor is the most important component. The mechanical energy is created as a result of the transformation of the electrical energy by the motor. These energies cause the wheels to turn. The electric motor is the primary component that sets an electric car apart from other types of cars, such as conventional cars. The regenerative braking system of an electric motor is an essential component of the motor itself. The vehicle's kinetic energy is converted into another form and stored for later use via this process, which results in the vehicle travelling at a slower speed. Direct current (DC) & alternating current (AC) engines are the most prevalent types of motors.</p>
<p>Transmission</p>	<p>Through the use of a gearbox and transmission, one may transfer the mechanical power generated by an electric motor to the wheels of the vehicle. Electric vehicles have two types of transmission systems: single speed and multi speed. However, most EV used single speed transmission as its</p>

	<p>simplicity, light weight, and cheaper. To prevent electricity from being wasted, the transmission efficiency needs to be good.</p>
<p>DC/DC converter</p> 	<p>The traction battery pack maintains a consistent voltage throughout its delivery. However, the many components of the vehicle each have their own unique set of needs. The DC-DC converter brings the output power that is flowing from the battery to the desired level so that it may be distributed. In addition to this, it supplies the voltage necessary for charging the auxiliary battery.</p>
<p>Auxiliary battery</p> 	<p>In electric cars, the accessories get their supply of electrical power from a separate set of batteries known as the auxiliaries. In the event that the primary battery dies, the car's auxiliary batteries will continue to supply power to the vehicle. It protects the electrical system from being affected by the decrease in voltage that occurs when the engine is started.</p>
<p>Thermal system</p>	<p>The thermal management system of an electric vehicle is accountable for ensuring that the primary components, such as the electric motor, controller, and so on, remain at an appropriate temperature for normal operation. In order to achieve its greatest potential, it continues to operate while the battery is charged. It makes use of thermoelectric cooling, cooling using forced air, and liquid cooling all at the same time.</p>
<p>Charging port</p> 	<p>An external power source can be connected to the electric car via the charging connector. The battery pack is being charged by it. There are instances in which the charging port is situated at the front or the back of the car.</p>

2.4 Electric Vehicle Transmission

The transmissions of automobiles are constantly evolving as new technology is introduced. Transmissions consist of two types: manual and automatic (Gupta, 2020). Even if the speed difference between an electric vehicle and a conventional vehicle is negligible, an automatic transmission is used since it is more convenient to drive. Gearboxes in electric

vehicles are divided into single-speed and multi-speed kinds, which are the most typical type. The transmission is the component of a vehicle that is responsible for transmitting the power generated by the vehicle's engine to the wheels of the vehicle. As was discussed before, electric vehicles can have either a single-speed or multi-speed gearbox.

a) Single-speed transmission

There is only one gear combination utilised for transmission in these kinds of gearbox, hence the speed of the vehicle is always the same. A single reduction gear, a reversed gear, or a compound gear train are the most common components found in it (Hailu & Redda, 2020). The reduction gear is designed to work on the premise of decreasing the RPM of a high-speed motor or engine while simultaneously increasing its torque. The compound gears in a reversed gear train single speed transmission are positioned in the opposite order of a standard transmission. The illustration labelled Figure 2.8 below illustrates the single-speed transmission that is applied in electric vehicles. Numerous well-known automobile models, like the Chevrolet Bolt, the Tesla Model S, and others, all include transmissions with a single gear and a single speed.

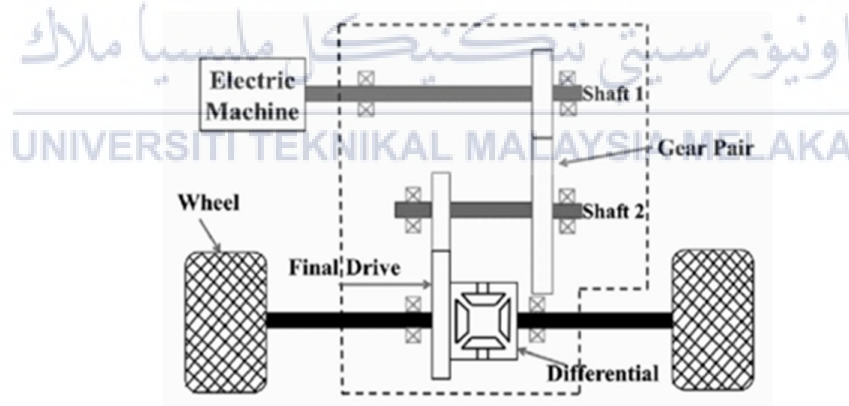


Figure 2.8: Single speed transmission in EV (Ruan et. al, 2017).

b) Multi-speed transmission

Transmission systems with multiple gear ratios are not commonly found in electric vehicle. Two distinct gear ratios are attainable within the compound planetary gear system as a direct result of the fact that it possesses two degrees of freedom. A compound planetary gear system, which includes a double pinion planetary gear set as well as a single pinion

planetary gear set, makes up the transmission (Yang et al., 2019). The two-speed gearbox that is utilised in electric vehicles is depicted in the following Figure 2.9. Transmissions of this kind can be found in a variety of vehicles, including the Porsche Tycan.

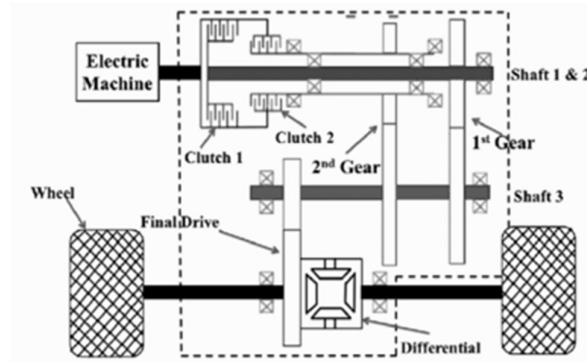


Figure 2.9: Multi-speed transmission in EV (Ruan et. al, 2017).

2.4.1 Basic Components of Single Speed Transmission



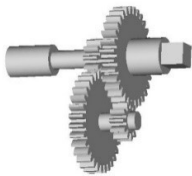



Figure 2.10: Exploded view of single speed transmission for EV (Carlos Daniel Pires, 2018)

As discussed above, there are two types of transmissions which is single-speed transmission, and multi-speed transmission. Single-speed transmission is the ‘state of art’ for the electric vehicle as they are less components, more simpler, less cost, less noise, and

small in size compared to multi-speed transmission (Ahssan & Gorji, 2018). The reason for this is, first and foremost, the electric motors' larger rpm range. Electric motors can rev to 20,000 rpm, but ICE cars typically rev to 6000-7000 rpm (Cooper & Gutowski, 2017). Second, ICE cars have a limited power band, which means that peak torque and power are generated within a narrow range of engine speeds, necessitating the need of numerous gears to reach greater speeds. EV, on the other hand, have a much wider power band than ICE cars, and their motors deliver efficient power throughout the range, even at zero rpm, allowing them to attain top speeds with just one transmission (Ruan et al., 2016). For this specific study, a model of EV transmission as shown in the Figure 2.10 above are chosen. Table 2.2 below shows the basic components of single-speed transmission of EV powertrain.

Table 2.2: Basic components of EV transmission and its function

Component and specification	Description
<p>a) Housing / Casing</p>  <p>Material: Aluminium Process: Die casting</p>	<p>The transmission housing protects the rotating components inside the transmission system. It provides a fluid-tight housing for lubricants and support for moving components.</p>
<p>b) Shaft</p>  <p>Material: Steel Process: Turning</p>	<p>Transmission shafts are revolving machine parts with a circular cross-section. This transfers power or motion from one component to another. In other words, it transfers power from the component that generates it to the part that absorbs it. The transmission shaft is a critical component of all spinning machinery. Input shaft and output shaft are the two types of shafts in the transmission.</p>
<p>c) Gear train</p> 	<p>A gear train is a mechanical device created by attaching gears to a frame such that their teeth mesh. The design of gear teeth ensures that the pitch circles of connecting gears roll over each other without sliding, allowing for the transferring of rotating from one gear to the next.</p>

Material: Steel Manufacturing process: Die-casting	
<p>d) Bearing</p>  <p>Material: Chrome Steel Manufacturing process: Forging</p>	<p>Rolling bearings are used in all mechanical transmissions. They provide support for the shaft and keep it in the proper place. They also withstand stresses operating on the shaft and transmit them to the housing, allowing the shaft to revolve freely and reducing friction. Rolling bearings in electric automotive transmissions must withstand high rotating speeds and high operating temperatures.</p>

2.5 Remanufacturing Process of Transmission

Since transmissions contain a large number of moving parts, wear is an extremely important factor to consider (Casper & Sundin, 2021). In addition, because a transmission is a component that has a high value, there is a significant amount of interest in remanufacturing it. Remanufacturing aims to relieve client burdens because these products are typically less expensive, costing roughly 60% - 80% of the cost of a new one (X. Zhang et al., 2019). They are less expensive because no new raw materials are required, and because the product has already been made, it merely has to be restored to its previous (or higher) quality. When there is a high demand for a product, a remanufactured version with a shorter lead time may be provided (David Parker et al., 2015). The process flow for remanufacturing as shown below in Figure 2.11.

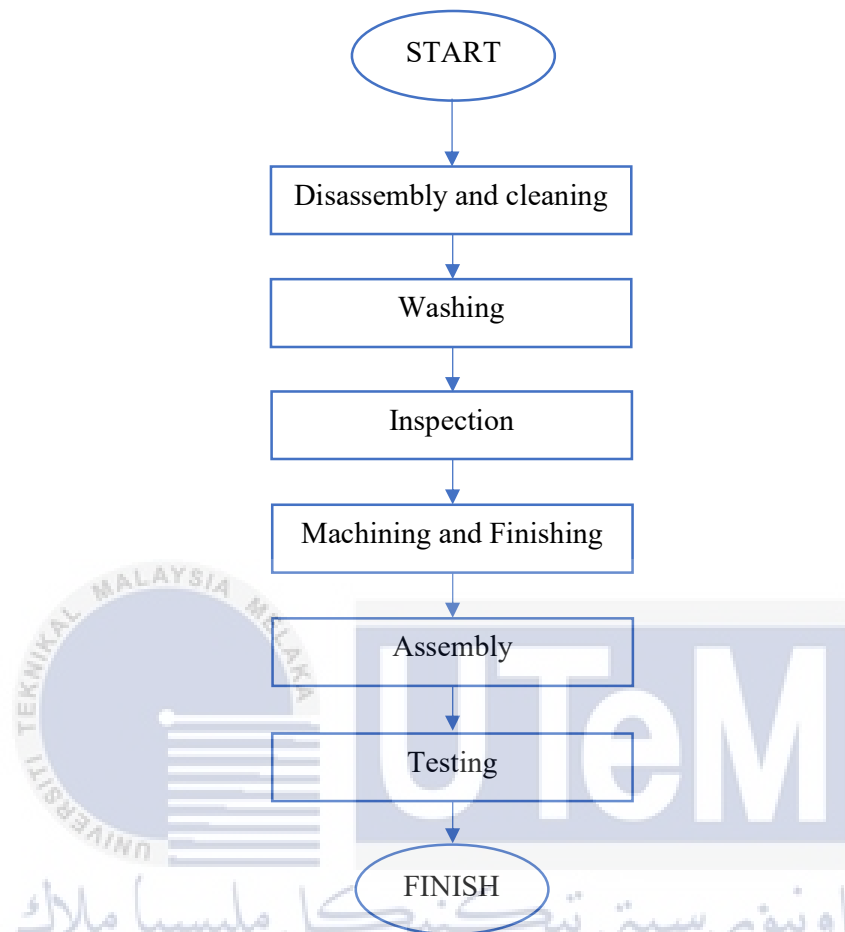


Figure 2.11: The process flow chart for remanufacturing of a transmission.

The explanation of each process for remanufacturing of transmission is describe below:

1. Disassembly and cleaning

First, the oil is evacuated by removing the plugs. Leaving a little debris within a transmission or neglecting to replace a damaged spline will result in early failure. Each transmission's components are maintained separate from those of other transmissions. All bearings, seals, band, and gaskets that are damaged are replaced. Daimler emphasises the replacement of all quality-relevant components with the most updated, theoretically improved replacement component. According to the article, this makes the remanufactured

components is same or better than the original, resulting in improved functionality and a better durability.

2. Washing

The parts are cleaned and thoroughly cleaned with consideration for their design, size, and composition. The objective is to maintain minimal drainage quantities to protect the environment and save costs on disposal.

3. Inspection

After the washing cycle, every component that still can be use was inspected and their dimensions are analysed to see if they can be reuse. All non-conforming components are removed and replaced with brand-new components. To ensure smooth gear shifting, the shifter forks, shifter shafts, and transmission synchronisation are all properly inspected.

4. Machining

Surfaces are machined if necessary. Parts of the body are painted.

5. Assembly

If necessary, the parts are updated to the latest technological modification level to ensure that they are technologically equivalent to new parts. All parts are built according to the manufacturer's instructions, and torque levels are meticulously adhered to.

6. Testing

Finally, the transmission is checked under dynamic loads on a case structure with various shift methods for each model to ensure that it works, is dependable, and will last longer. A report is written about what was observed through all the process flow.

2.6 Life Cycle Assessment of New and Remanufactured Transmission using openLCA software

The Life Cycle Assessment (LCA) is a technique for researching and quantifying the potential effects (Chau et al., 2015), which can conduct an analysis of the crucial elements that affect different products in order to determine their environmental, economic, and social impacts relevant societal impact caused by the objects during their whole life cycle (X. Zhang et al., 2018). It is implemented by manufacturers to enhance the quality of their production operations (Petrauskienė et al., 2021).

In general, present researchers have undertaken substantial research on the LCA of electric vehicle batteries and have established a preliminary research system. However, there is lack of study on electric vehicle transmission component. It is important to establish a basic study regarding the LCA of EV transmission to cope with the massive wave of end-of-life of EV in the future.

Most of the big country such as United Kingdom, United State, and China are already in the phase where their first batch of EV facing its end-of-life phase. Therefore, there is an urgency for that such countries to manage the waste created from the use of EV. However, the usage of EV in Malaysia still in the 'introduction' phase where there is minimal number of EV on the road recently (Rahman et al., 2018). It could be better if the end-of-life for the EV especially the transmission is studied earlier so that in the future Malaysia can cater any problem that might occur regarding the end-of-life for EV especially the transmission component. In this study, the openLCA software was used to propose the life cycle assessment for the remanufactured EV transmission.

CHAPTER 3

METHODOLOGY

3.1 Introduction of Methodology

In this chapter, methods had been discussed during the research throughout this semester. Selection of methods are crucial to completing this project smoothly and can minimize the problem occur. This chapter also helps reader or examiner to better understanding on what method and procedure was used for the research. For example, data collection, equipment, software and many more. To fulfil the requirements, this chapter is compulsory to produce and construct for evaluation purposes.

3.2 Gantt Chart

A Gantt chart is a graphical depiction of a task schedule that is used extensively nowadays. There is a specific kind of bar chart that depicts the beginning and ending times of project components like resources, schedule, and dependencies. These diagrams are helpful for planning a project and determining which activities need to be completed first and in what order. In most instances, the chart will be displayed in the form of a bar chart. The timeline for the project is shown by horizontal bars of varied lengths. The timetable may include the sequence of tasks, the duration of each activity, as well as the start and end dates for each task. The amount of work that is still outstanding on an assignment is represented by the horizontal bar as well. The Gantt chart that was used for the project study may be found in the appendices section.

3.3 Flow Chart of Study

A process or workflow is represented by a flowchart, which is a type of diagram that lists the steps, sequences, and alternatives involved in the process. The most fundamental representation of a process map is called a flowchart. There are numerous variations of flowcharts to choose from. It is an effective instrument for planning, visualising, documenting, and enhancing operations across a wide range of business sectors. As a result, a methodology flowchart (Figure 13) was constructed to help readers understand the process and methodologies employed during the research.

3.3.1 Process Planning

The process flow chart below shows the method used to complete this report study. The study is including literature review, data collection, life cycle assessment, system dynamic approach, result, and discussion.

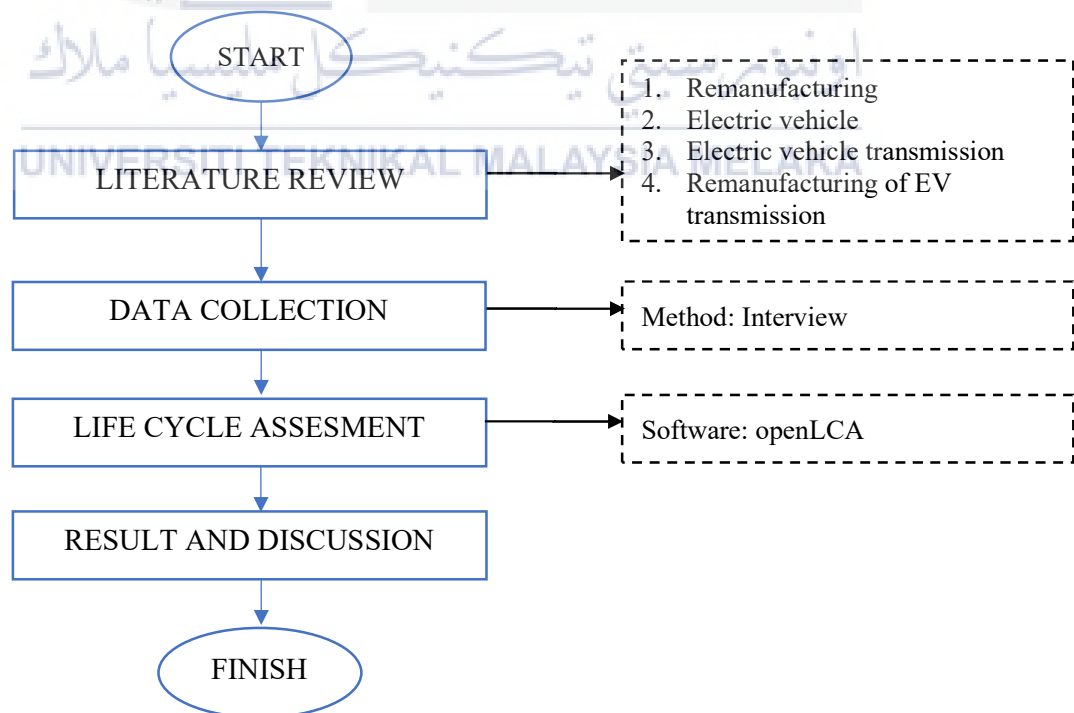


Figure 3.1: Process flow of study.

3.4 Data Collection

Data can be defined in as many types as possible of information formatted in a specific way. Therefore, the process of gathering, measuring, and analysing precise data from a range of relevant sources is known as data collection. This is done in order to find solutions to the problem statement, provide answers to questions, and evaluate outcomes and probability. There are two approaches to gathering data. Many terminologies, such as approaches, methods, and kinds, can be used interchangeably. The two ways of data gathering are called primary data collection and secondary data collection. Both types of data collection is used in this study.

Obtaining primary data is the first step. Primary data collection, as the name implies, is actual, first-hand data obtained by the data researchers themselves. This technique, which serves as the first phase in data collection, is carried out before anyone else does any extra or related research. There is several types of primary data collection available, such as, interviews, projective techniques, Delphi technique, focus group, and questionnaires. In this study, questionnaires were the method used to gain data from respondents.

Secondary data collection is the second type of data collection. The term "secondary data" refers to information that has been obtained by third parties and statistically analysed earlier. To put it another way, the data is derived from a secondary source. Secondary information is quicker to collect and less expensive than primary data, but it raises concerns about its integrity and accuracy. Quantitative information makes up the majority of secondary data. In contrast to the acquisition of primary data, there are no fixed techniques for collecting the secondary data. Instead, due to the fact that the material has already been gathered, the student can consult a variety of data sources, including article journals, books, official or non-official websites, newspaper articles, and magazines.

The data collection method is important to achieving the first objective of this study which is to study the concept of electrical vehicle transmission and evaluate the potential for implementation of remanufacturing activities among Malaysians.

3.4.1 Literature Review

A literature review is a survey of various scholarly sources that provides an overview of a certain subject. A literature review's goal is to provide a comprehensive overview of what has been said on a specific topic and by whom. Several scholars have been chosen, such as Robert Casper, Sitcharangsie, Ijomah, Yusop, and others. Their study has been read, analysed, and summarised to find the material regarding this study. Literature reviews are collections of the articles that are the most important and significant on remanufacturing, electric vehicles, EVs transmission, and the remanufacturing of the EV transmission.

Not to forget, other than article, journals, and books, the research also came from newspaper articles, government web pages, official web pages, and magazines that related to the topic studied. This section includes a description of the paper, a synopsis of the publication's main points, a discussion of gaps in the research, and an assessment of the publication's contribution to the subject.

3.4.2 Interview

There are three main types of research interviews, which is structured, semi structured, and unstructured. Structured interviews are verbal questionnaires that ask a set of predetermined questions without variation or follow-up questions. Thus, they are quick and easy to administer and may be useful if questions need clarification or respondents have literacy or numeracy issues. They are not useful for "depth" because they only allow limited participant responses. On the other hand, unstructured interviews have no preconceived notions. The lack of predetermined interview questions makes these interviews confusing and time-consuming. They are only used for "depth" or when little is known about the topic (or a different perspective of a known subject area is required).

Semi-structured interviews include several key questions that define the areas to be explored, but they also allow the interviewer or interviewee to diverge to explore an idea or

response. This method's flexibility, especially compared to structured interviews, allows participants to reveal or elaborate on information that the researcher may have overlooked. This is the type of interview used in this study to collect data and information from the automotive workshop. The main objective of the interview is to gather information regarding EV transmission main components and the frequency of the main components to be change or broken.




3.5 Life-Cycle Assessment


The second objective of this study is to identify variable for the assessment of environmental impact cost by extension of the life-cycle transmission through remanufacturing by using openLCA Software. Thus life-cycle assessment was conducted to fulfil this objective. The process of accumulating and analysing a product's or service's inputs, outputs, and potential environmental effects over its full life cycle is known as LCA (Lai et al., 2022). It's done by determining and quantifying the different sorts of materials, energy usage, and emissions into the atmosphere. The goal of this study's LCA is to identify the critical connections in the entire process, effectively reduce pollutant generation and emission, effectively realise source optimization, and control, as well as to adopt scientific, efficient, and systematic sustainability practises. Because LCA plays such an important part, it is utilised in a variety of fields, including materials, automobiles, buildings, waste management, foods, energy management, mining and smelting, and biofuels, among others.

There are several steps to construct the life cycle assessment of an EV transmission. Before creating the life cycle thinking for this product, it is important to clearly know what the components is, the material and manufacturing process involves producing a transmission. In regard of this study, the LCA is used to comparing between three components of EV transmission; shaft, gear, and bearing. Through the life cycle assessment, the understanding on what impact might occur to the environment due to the material used or the process involved in the remanufacturing of the EV can be analysed. Then, which components contributing to high risk to the environment can be identified.

LCA tools and software platforms are used to quickly compute and analyse large volumes of data. A variety of organisations have established them in recent years in response to rising demand for forecasting the life cycle and measuring the effects on environment of their goods or service. This is done in order to make the product or service more affordable and accessible to the market and the customer. The Life Cycle Assessment (LCA) programme calculates a variety of data that can be accessed via spreadsheets, excel data, and databases that can be accessed via various cloud storage services supplied by institutions, environmental specialists, and industrial sectors. As stated in Table 2.3, this section provides a summary of the typical LCA tools and software that are utilised by researchers as well as industry professionals.

Table 3.1: Typical software or tools to develop LCA.

Tools	Developer	Description
	GreenDelta Berlin	OpenLCA software is a piece of software with open source. It offers professional LCA and footprint analysis with a database that is generally available, gives parameters at numerous levels spanning from processes to projects, and is an uncertainty approximation.
	Pré-Consultant	SimaPro is used to gather, analyse, and track data on any product or service's sustainability performance. In order to guarantee the reliability of the findings, it offers complete openness and steers clear of the black box design process.
	iPoint-system	This software is flexible and good tool for modelling, calculating, visualising, and analysing material and energy fluxes. This software are able to compute carbon footprint, optimise production process, LCA, and evaluate both cost and environmental implications.

<p>Ga-Bi</p> 	<p>Pe-International</p>	<p>Ga-Bi is a comprehensive life cycle assessment engine that supports LCA, LCC, and LCR to help researchers make the best decisions possible about the life cycle of any product, from a matchstick to an aeroplane.</p>
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3.5.1 openLCA Software

GaBi, SimaPro, Umberto, and Open LCA were the types of software that offered the widest variety of features; as a result, they were the most well-known and widely utilised. GaBi and SimaPro are the two tools that have been available for purchase for more than 15 years and are the ones that are utilised the most frequently (Lopes Silva et al., 2019). However, the licence costs for both of them are quite expensive, and the source code is not publicly available. Because this software is more complicated than GaBi and SimaPro, and the licence price is almost the same, but it does not provide any additional features as the previous software's do, Umberto, which was developed by ifu Hamburg, is another tool that is preferred. Umberto was created by the iPoint-system.

Open LCA is free software that is available to anybody who wants to use it. It has a user-friendly interface and enables users to perform life cycle assessment calculations for all stages. Green Delta, Pe-International (the company that developed GaBi), PRé-Consultants (the company that developed SimaPro), and UNEP all contributed to the development of this software, which was created by Green Delta (United Nations Environment Programme). An additional benefit of using this software is that it enables the user to make modifications to the source code and collaborate with various databases that are utilised by GaBi and other software. OpenLCA was initially developed for the purpose of analysing the impact that objects and processes have on the environment; however, it is now also capable of analysing economic issues.

3.5.1.1 Procedure to Run an Analysis using openLCA Software

As mentioned before, openLCA is a user-friendly software with just a simple step to produce a life cycle analysis. Process flowchart below shows the procedure to run a life cycle analysis by using openLCA software.



Figure 3.2: Process flow to run an analysis by using openLCA software.

The following describes each procedure for running a life cycle analysis using openLCA software:

- i. Download the suitable database from openLCA nexus website and run the database in openLCA software. The database used during this study is Environmental Footprint database.



Figure 3.3: openLCA opening interface.

- ii. Create a new process and new flow for the studied topic. In this case, the studied topic is new EV transmission.

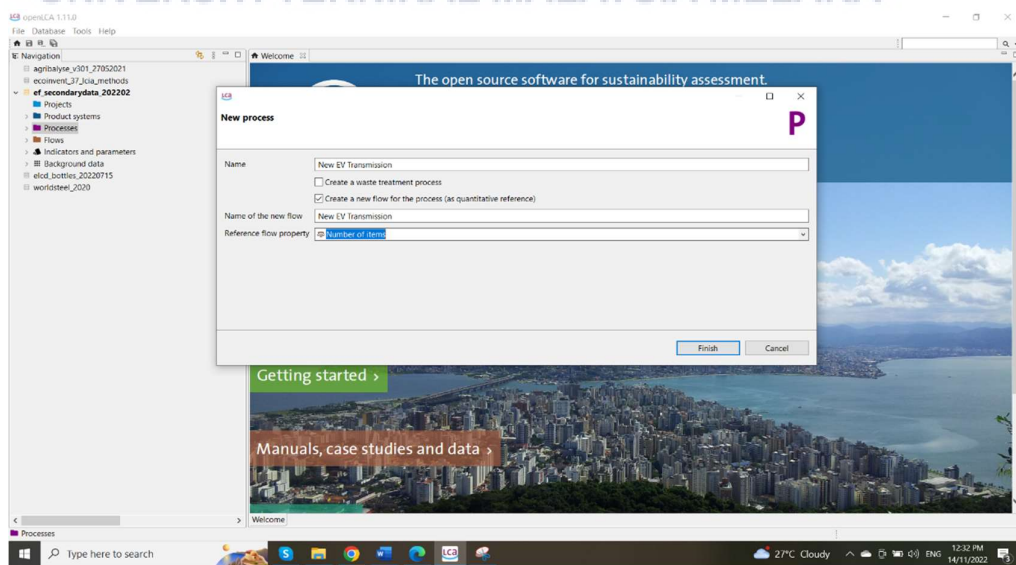


Figure 3.4: Creating new process.

- iii. Key in the input as in materials used to manufacture the product studied together with the weight, unit, and provider for each material.

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided was...	Provider	Data quality ...	Description
Aluminium DC cast ingot	Materials production/Metal...	7.29000	kg	none			Aluminiu...		Housing FL...
Aluminium sheet	Materials production/Metal...	76.00000	g	none			Aluminiu...		Gasket
lubricating oil	Organic chemicals/nan	4.70000	kg	none			lubricatin...		ATF
Stainless steel (hot rolled)	Materials production/Metal...	0.08600	kg	none			Stainless s...		Spring typ...
Stainless steel (hot rolled)	Materials production/Metal...	1.20500	kg	none			Stainless s...		Screws
Steel billet (50)	Materials production/Metal...	2.01900	kg	none			Secondar...		Shaft
Steel sheet, primary and secondary	Materials production/Metal...	13.83900	kg	none			CFF Steel ...		Gear train

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided pro...	Provider	Data quality ...	Description
New EV Transmission		1.00000	Item(s)	none					

Figure 3.5: Input and output interface.

- iv. Create the product system by clicking General information > create product system.

Figure 3.6: Creating new product system.

- v. The model graph for the product will be appear automatically. It shows the input and output of the product.

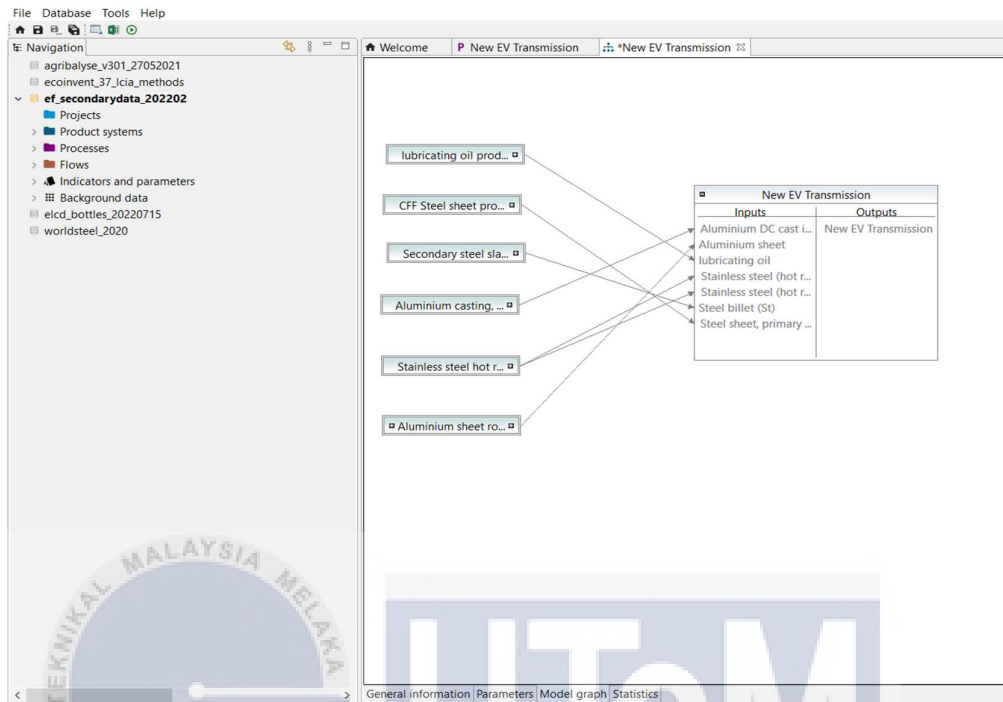


Figure 3.7: Model graph of new EV transmission.

- vi. Define the targeted amount to be analyse. In this study, the targeted amount is 10,000 units considering the number of productions for transmission per month.

Figure 3.8: Set the targeted amount before calculating.

- vii. Select the calculation properties and calculate the process.

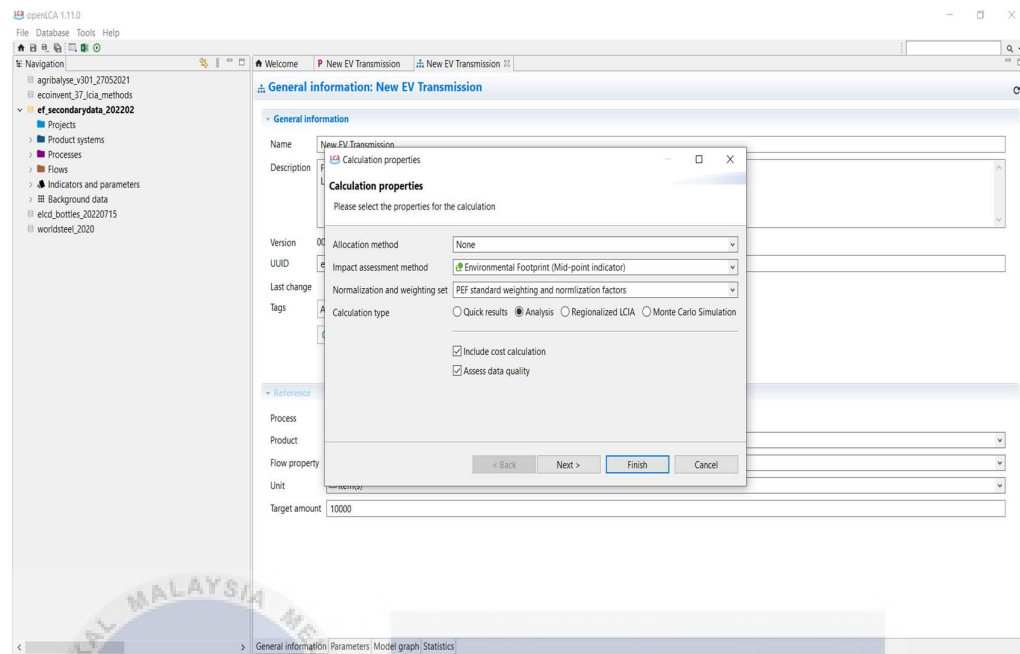


Figure 3.9: Setting calculation properties.

- viii. The analysis result will appear as shown in figure below.

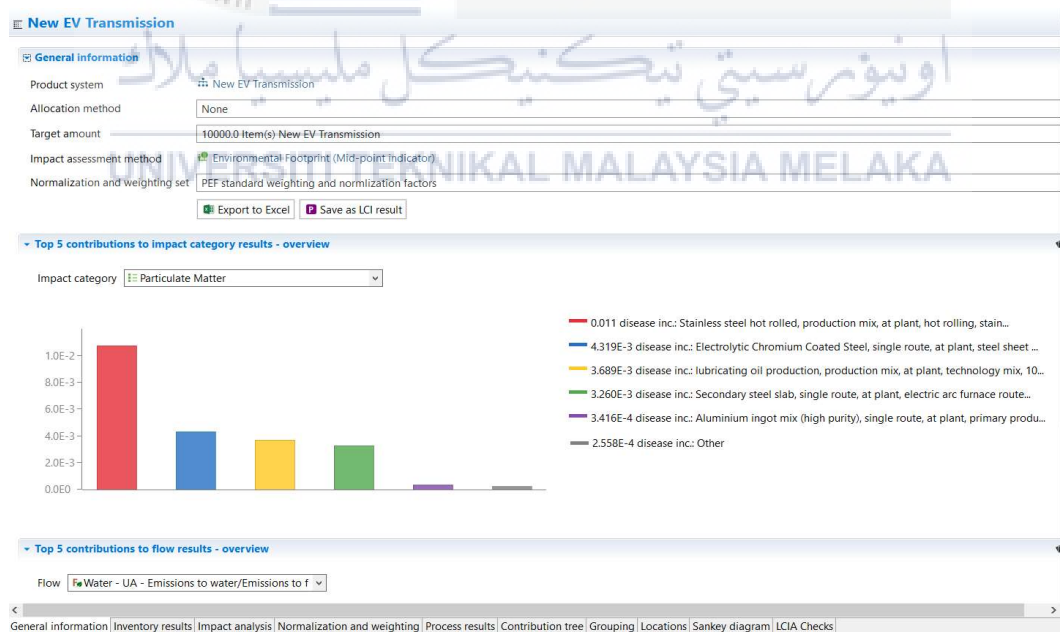


Figure 3.10: Analysis result.

3.5.1.2 Bill of Material

A bill of materials (BOM) is a complete list of the components, items, assemblies, subassemblies, intermediate assemblies, documents, drawings, and other materials required to manufacture a product. In a hierarchical format, the BOM can be viewed as the list used to produce the final product. The bill of material for the studied model is shown in the table below:

Table 3.2: Bill of material for the EV transmission.

No.	Component	Material	Mass (kg)	Quantity (unit)	Total mass (kg)
1.	Housing + Flange	Aluminium	7.290	1	7.290
2.	Shaft	Steel	2.019	3	6.057
3.	Gear Train	Steel	13.839	1 set	13.839
4.	Bearing	Chrome Steel	0.040	4	0.160
5.	Fixtures				
	a) Screws M4 x 35	Stainless Steel	0.113	16	1.810
	M4 x 16		0.0312	4	0.1248
	b) Spring-type pin	Stainless Steel	0.043	2	0.086
6.	Gasket	Aluminium	0.076	1	0.076
7.	Gear oil (lubricant) (ATF – automatic transmission fluid)	Castrol ATF Dex II Multivehicle	4.700	1	4.700
	TOTAL				34.143

3.6 Summary of Methodology

A methodology is a collection of approaches that are utilised in a particular field of study or activity. It is possible for the readers or examiners to grasp the flow of this study as well as the approach that was employed to run it thanks to the production of a flowchart about the methodology. The first method that has been utilised in this report is searching for a literature review on the topics of remanufacturing, electric vehicles, the component of electric vehicles, and the adaptation of EVs in Malaysia. This literature review can be found in article journals, books, newspaper articles, and on the websites of various government agencies, among other places. The literature review in the article journal comes from either a Malaysian scholar or an international scholar, and it analyses and summarises the findings of the researchers. In addition to this, it has been suggested that an interview session will be conducted with automotive workshop. The primary purpose of the interview is to collect information regarding EV transmission main components and the frequency of replacement or failure of these components. After that, the life cycle assessment of the EV transmission is constructed by utilising the openLCA software to compare the life cycle of the new EV transmission and the remanufactured EV transmission. This is done in order to create the life cycle assessment between them. By using this method, it is able to evaluate the impact that the remanufacturing of an EV transmission will have on the environment. The next chapter will discuss the finding from all methods proposed.

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter describes the result of the analysis and its discussion regarding the life cycle assessment. This research aims to compare the environmental impact of EV transmissions for both newly manufactured and remanufactured products. The reference model studied in this research is the prototype of an EV transmission by (Carlos Daniel Pires, 2018). The number of components, materials, and weight of the transmission model are also referred to in the same thesis by (Carlos Daniel Pires, 2018). The system boundaries of the life cycle assessment in this study only extend for cradle to gate, which is focused more on the manufacturing system of the product. A study stated that it's better not to include the usage phase when talking about remanufacturing. This is because it will affect the result the most because of the energy usage during the usage phase. (Zheng et al., 2019). Thus, the transmission's usage phase and EoL are not considered in this study. Lastly, the targeted amount of transmission per analysis is 10,000 units, considering the number of productions for transmission per month.

4.2 Interview Result

An interview session has been made with four automotive workshops to gather information regarding the second objective of this study, which is to identify the main components for the remanufactured electric vehicle transmission. From the interview session, the expected result gained is the components that usually broken in EV transmission and the components is considered as the input parameter for the remanufactured transmission in the life cycle assessment. The method used to solicit feedback from respondents is by telephone call. This strategy was chosen because of its advantages with technical applications and its reach, which may cover a larger geographical area while saving time, energy, and money. In addition, respondents' tight job schedule was taken into account. Therefore, a time-consuming face-to-face interview is avoided. For professionalism and confidential matter, the actual name of the workshop will not be mentioned in this study. The automotive workshop will be labelled as Workshop A, Workshop B, Workshop C, and Workshop D.

Since the main objective of the interview session is to know which components that are likely to be broken in the EV transmission, that is the only topic will be discussed. Other interview questions can be reviewed in the Appendix B.

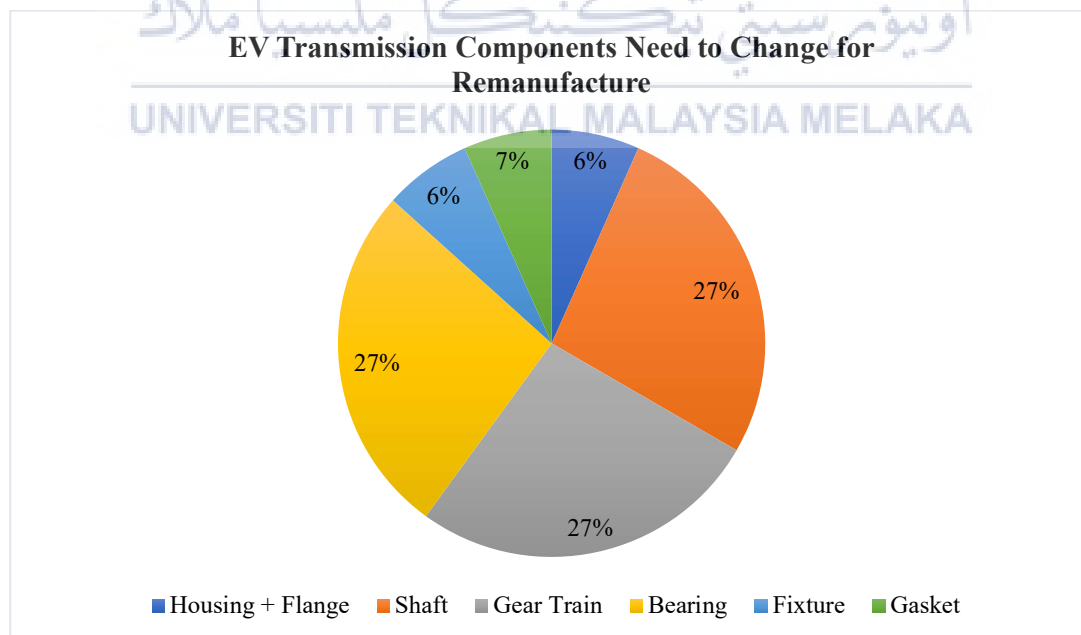


Figure 4.1: EV transmission components need to be change for remanufacture.

Figure 4.1 depicts the outcome from the interview sessions. According to the selected automotive workshops, there three main components that are likely broken when customer need to salvage their transmission, which is bearing, gear train, and shaft. This issue happened because these three components will involve rotating and vibrating motion during usage phase where it will experienced wear and tear, or dislocation, effect from constant friction. The other components only get 6-7% vote which is housing, flange, gasket, and fixtures. Therefore, bearing, gear train, and shaft will be considered as the components need to be change for the transmission to be remanufacture.

4.3 Life Cycle Assessment of New and Remanufactured Transmission

The findings of the life cycle assessment of new and remanufactured transmissions have been discussed in this subtopic. Among the topics discussed are gas emissions released into the environment and the life cycle impact assessment. After that, the data will be compared between the new and remanufactured transmissions. The most critical inventory data for the automotive industry are those governed by EURO standards. The regulated emissions considered in this study are carbon dioxide, carbon monoxide, sulphur dioxide, methane, and nitrogen dioxide. Using data from the Life Cycle Inventory, the Life Cycle Impact Assessment is looked at several types of environmental effects, such as abiotic depletion, fossil abiotic depletion, global warming, acidification, eutrophication (fresh water), eutrophication (marine), human toxicity, fresh water ecotoxicity, ozone layer depletion (ODP), and photochemical ozone formation.

4.3.1 Gas Emission Released by the Production of New Transmission

Aluminium and steel are the predominant materials used to produce the transmission's components. The manufacture of these raw materials will result in the use of

natural resources and primary energy sources like iron ore, coal, crude oil, and natural gas, as well as the generation of emissions like carbon dioxide, carbon oxide, and sulphur dioxide. Table 3.1 in Chapter 3 has a lists the components' material and weights and pertains to the primary newly manufactured transmission parts. Figure 4.2 below summarises the gas emission percentage from various types produced by the manufacturer or factory after producing a new gearbox or transmission. Details of the result from openLCA are attached in Appendix D. These findings are also presented using the aid of a pie chart for better understanding to the reader or examiner. The pie chart is extracted from openLCA software.

According to the Figure 4.2, the largest percentage of gas emissions for new transmission is carbon dioxide with 48%, followed by sulphur dioxide with 15%, carbon monoxide 14%, methane 12% and lastly, nitrogen dioxide with 10%. This result differs based on the material used to manufacture the transmissions.

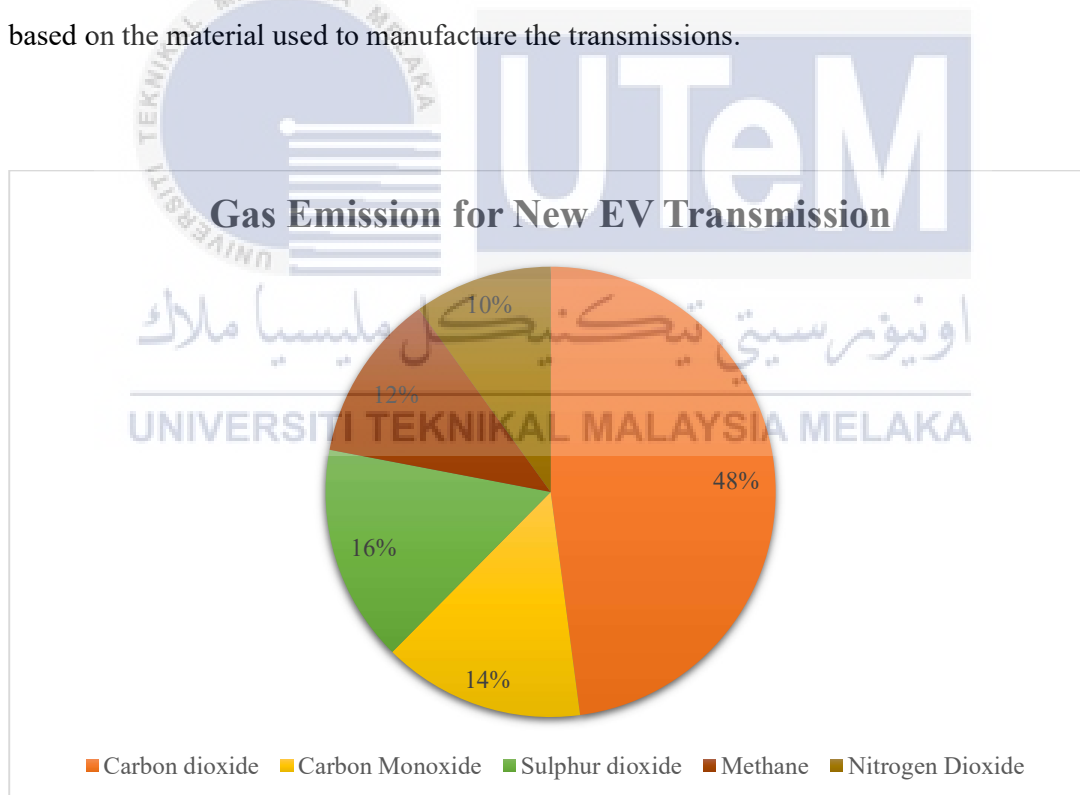


Figure 4.2: Percentage of gas emission released by manufacturing of new EV transmissions.

As previously stated, carbon dioxide is the most significant gas emission, with the production of stainless steel and steel materials accounting for 8.32 E+04 kg and 5.30 E+04

kg of emissions, respectively. Sulphur dioxide is the second largest emission released, and the main contributor of this emission is from the production of stainless steel and steel slab, respectively, at 431.11 kg and 124.72 kg. Methane, with 12% of the gas emissions, is in the third position on the chart. The primary source of methane released is lubricating oil production, with 239.18 kg. Finally, nitrogen dioxide has a 10% score, with the primary source of this emission being the manufacturing of stainless steel and lubricating oil, which respectively account for 191.94 kg and 97.30 kg. Based on the findings presented, it has been identified that the production of stainless steel has the most significant influence on the emission of greenhouse gases upon the production of EV new transmission.

4.3.2 Life Cycle Impact Assessment for New Transmission

Data from the life cycle inventory are used to compile the Life Cycle Impact Assessment (LCIA) for each environmental impact category. The Environment Footprint (EF) approach is used to analyse the interactions between all of the emissions that were recorded, and the results are used to determine the probable environmental implications.

Table 4.1: Environmental Impact for the EV transmission.

Impact category	Unit	Impact result
Abiotic depletion	kg sb eq	6.72
Abiotic depletion (Fossil)	MJ	5.46E+06
Global warming	kgCO ₂ eq	2.81E+05
Ozone layer depletion (ODP)	kgCFC11 eq	2.80E-04
Photochemical ozone formation	kg NMVOC eq	1726.47
Eutrophication (fresh water)	kgP eq	6.27
Eutrophication (marine)	kgN eq	236.77
Acidification	molH ⁺ eq	1525.47

Table 4.1 shows the absolute environmental impact of manufacturing the new EV transmission. According to the table, the value of abiotic depletion is 6.72 kg sb equivalent,

which refers to the resource used in minerals and metals. The most material used is chromium, copper, and nickel ore, with a total weight of 3260.73 kg, 2286.03 kg, and 1485.18kg. Copper, chromium, and nickel ore are beneficial for the production of stainless steel. In contrast, only copper and chromium are beneficial for the production of chromium-coated steel and lubricating oil production.

In addition to studying material resources, it is essential to look into energy resources. This is crucial not only from an environmental standpoint but also from a supply security standpoint. The total fossil fuel required for a newly manufactured EV transmission is $5.46\text{E}+06$ MJ. Crude oil is the main factor in the result, with total usage of $2.46\text{E}+06$ MJ, followed by hard coal ($1.24\text{E}+06$ MJ) and natural gas ($1.17\text{E}+06$ MJ). All those three resources are used to make stainless steel, chromium steel, and aluminium.

After that, the global warming potential is $2.81\text{E}+05$ kg CO₂ equivalent. The main gas impacting this result is the emission of carbon dioxide, with a value of $2.45\text{E}+05$ kg. Next, the total ozone layer depletion and photochemical ozone formation results are $2.80\text{E}-04$ kg CFC-11 equivalent and 1726.47 kg NMVOC equivalent. After that, the eutrophication result is 6.27 kgP equivalent (freshwater) and 236.77 kgN equivalent (marine). Finally, the acidification potential is 1525.47 mol H⁺ equivalent, with sulfur dioxide gas emissions released into the atmosphere being the primary contributor.

4.3.3 Gas Emission Released by the Production of Remanufactured Transmission

Figure 4.3 below summarises the gas emission percentage from various types produced by the manufacturer or factory after producing a new gearbox or transmission. Details of the result from openLCA are attached in Appendix D. These findings are also presented with the aid of a pie chart for better understanding by the reader or examiner. The pie chart is extracted from openLCA software.

Figure 4.3 shows that 46% of the gas emissions from remanufactured transmissions come from carbon dioxide, while 14% comes from carbon monoxide. Sulphur dioxide and methane have the same score of 10%, while nitrogen dioxide has the lowest at 9%. Like new transmission, carbon dioxide is the enormous amount of gas emission produced. This result happens because of the material used to manufacture the transmissions.

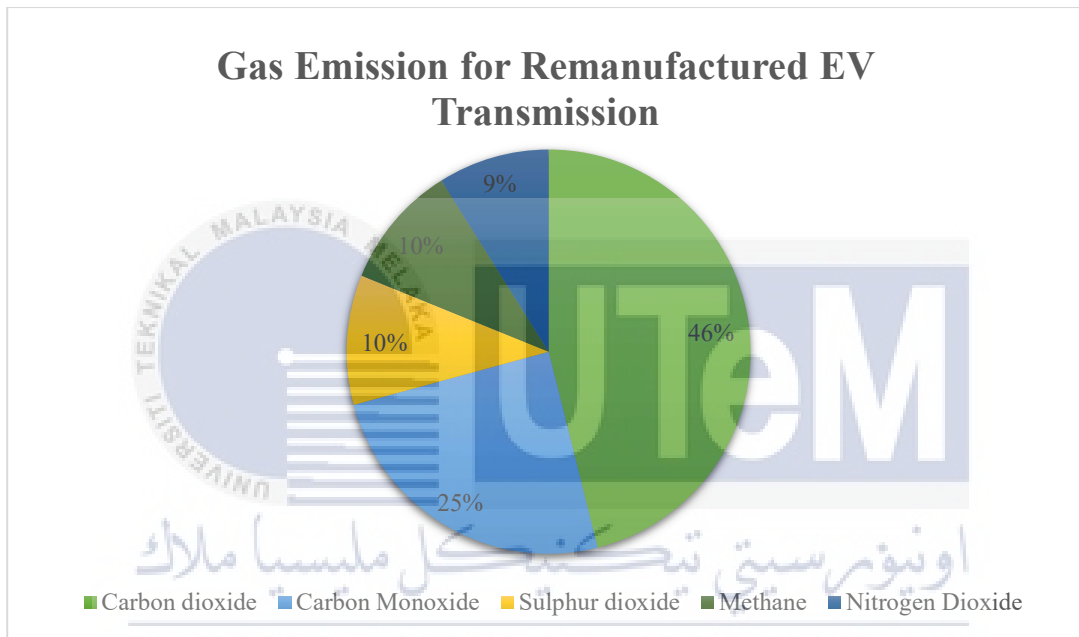


Figure 4.3: Percentage of gas emission released by manufacturing of remanufactured EV transmissions.

As stated before, the most significant gas emission is carbon dioxide. The main contributor to this emission is the production of steel and chromium-coated steel material, which is respected to $5.23\text{E}+04$ kg and $4.32\text{E}+04$ kg for both materials, respectively. Next, carbon monoxide is the second largest emission released. The main contributor to this emission is the production of chromium-coated steel and steel slab respected to 344.85 kg and 169.47 kg for both. The sulphur dioxide and methane emissions are relatively low, accounting for only 10% of the total. This places them third on the chart. The main cause of the release of sulphur dioxide (124.72 kg) and methane (118.24 kg) is the production of steel slabs. Finally, nitrogen dioxide has a 9%, with the primary source of this emission being the manufacturing of steel slabs with 95.31 kg. It has been identified, based on the findings

presented, that the production of steel slab has the most significant influence on the emission of greenhouse gases upon the production of EV remanufactured transmission.

4.3.4 Life Cycle Impact Assessment for Remanufactured Transmission

The Life Cycle Inventory data is used to create the Life Cycle Impact Assessment (LCIA) for various environmental impact categories. The Environment Footprint (EF) approach is used to analyse the interactions between all of the emissions that were recorded, and the results are used to determine the probable environmental implications.

Table 4.2: Environmental Impact for the remanufactured EV transmission.

Impact category	Unit	Impact result
Abiotic depletion	kg sb eq	1.25
Abiotic depletion (Fossil)	MJ	1.34E+06
Global warming	kgCO ₂ eq	1.05E+05
Ozone layer depletion (ODP)	kgCFC11 eq	0.13E-04
Photochemical ozone formation	kg NMVOC eq	255.90
Eutrophication (fresh water)	kgP eq	0.13
Eutrophication (marine)	kgN eq	79.38
Acidification	molH ⁺ eq	433.10

Table 4.2 shows the absolute environmental impact of the remanufactured EV transmission. According to the table, the value of abiotic depletion is 1.25 kg sb equivalent, which refers to the resource used in minerals and metals. Copper and manganese are the most commonly used materials, weighing 518.60 kg and 1550.73 kg, respectively. Copper and manganese are beneficial for chromium-coated steel and steel slab production.

It is essential to look at the energy resources for remanufactured products and the material resources. This is important not only for the environment but also for the security of the food supply. 1.34×10^6 MJ of fossil fuel are needed to make a new electric vehicle transmission. Natural gas is the result's main factor, with a total usage of 3.57×10^5 MJ, followed by hard coal (5.35×10^5 MJ) and uranium (2.45×10^5 MJ). All those three resources are used to make chromium-coated steel and steel slabs.

After that, the global warming potential is 1.05×10^5 kgCO₂ equivalent. The main gas impacting this result is the emission of carbon dioxide, with a value of 9.60×10^5 kg. Next, the total result for ozone layer depletion and photochemical ozone formation is 0.13×10^{-4} kgCFC11 equivalent and 255.9 kg NMVOC equivalent. After that, the eutrophication result is 0.13 kgP equivalent (freshwater) and 79.38 kgN equivalent (marine). Finally, the acidification potential is 433.2 molH⁺ equivalent, with the main contributor is from sulphur dioxide gas emission released into the air.

4.4 Comparison of New and Remanufactured Transmission

The comparison of life cycle between new transmission and remanufactured transmission is crucial to depict the percentage difference. Again, the life cycle assessment only focuses on cradle to gate, where the materials used to produce the product will be the leading role of this study.

4.4.1 Gas Emission

Figure 4.4 depict the gas emission released to produce the newly transmission and remanufactured transmission. The regulated emission compared in this study including carbon dioxide, carbon monoxide, sulphur dioxide, methane, and nitrogen oxide.

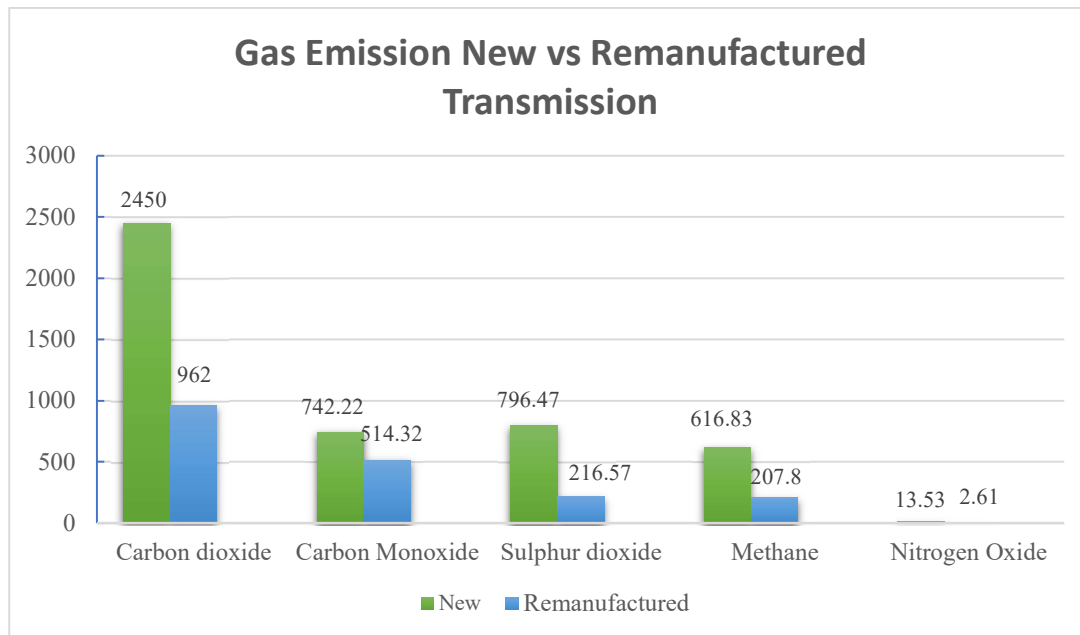


Figure 4.4: Gas emission released to produce the newly transmission versus remanufactured transmission.

Figure 4.4 shows that remanufactured transmissions emit fewer greenhouse gas emissions into the environment during the manufacturing process than newly manufactured transmissions. This is due to the fewer materials and fabrication processes to produce each component in the transmission to remanufacture the transmission. Remanufacturing use around 49% less materials compared to a new transmission (based on the current injection rate). This is because, during the remanufacturing process, only broken components will be replaced, while those that are not broken will be maintained and used again.

From the graph, carbon dioxide shows a major difference between the newly manufactured and the remanufactured transmission. The production of remanufacturing released 60.73% lesser carbon dioxide to the environment. Carbon dioxide illustrate the carbon footprint of the product. The decrease of carbon dioxide is due to less material usage, means less energy usage and lead to less fossil fuel combustion.

There isn't much difference in carbon monoxide; the percentage difference between remanufactured and newly transmission is only 30.71%. Carbon oxide is produced whenever there is burning to happen. In this context, it likely happened during the melting process for die casting. Apart from that, remanufacturing can also minimize sulphur dioxide emissions to the air. From the graph, it shows a significant different where remanufactured transmission released 72.81% lesser of sulphur dioxide compared to newly manufactured transmission. Sulphur dioxide, also known as SO₂, is an odorless gas but pungent and disagreeable smell. Again, the combustion of fossil fuels and the smelting of mineral ores that contain sulphur are the two leading causes of SO₂ emission. Lastly, remanufacturing can cut methane and nitrogen oxide emissions by 66.31 and 63.47%, respectively. From an overall view, it is shown that remanufacturing is slightly better than newly manufactured products when compared in terms of gas emission released at the same is more friendly to the environment.

4.4.2 Life Cycle Impact Assessment

The data from the Life Cycle Inventory are used to generate the Life Cycle Impact Assessment (LCIA) for each of the different environmental impact categories. The Environmental Footprint (EF) approach is used to analyse the interactions between all of the emissions that were recorded, and the results are used to determine the probable environmental impacts. The environmental impact indicators are considered to be at a "mid-point" rather than an "end-point" in the sense that, for instance, the amount of greenhouse gas (GHG) emission in kg of carbon dioxide equivalent (CO₂-eq) was provided rather than estimating end-points of global temperature or sea level increases (Birkeland, 2011).

Table 4.3: Comparison of environmental impact between newly manufactured EV transmission and Remanufactured EV transmission.

Impact category	Unit	Impact result	
		New	Remanufactured
Abiotic depletion	kg sb eq	6.72	1.25
Abiotic depletion (Fossil)	MJ	5.46E+06	1.34E+06
Global warming	kgCO2 eq	2.81E+05	1.05E+05
Ozone layer depletion (ODP)	kgCFC11 eq	2.80E-04	0.13E-04
Photochemical ozone formation	kg NMVOC eq	1726.47	255.90
Eutrophication (fresh water)	kgP eq	6.27	0.13
Eutrophication (marine)	kgN eq	236.77	79.38
Acidification	molH ⁺ eq	1525.47	433.10

Table 4.3 presents a comparison between the absolute environmental impacts that are created by the production of a new EV transmission and those that are caused by the remanufacturing of EV transmissions. There is also an indication of the relative reductions in emissions that are environmentally relevant, showed in Figure 4.5. The percentage difference has been normalised with respect to a newly manufactured transmission. The considered environmental impact categories are abiotic depletion potential (ADP), global warming potential (GWP), ozone layer depletion (OLD), photochemical ozone formation (POF), eutrophication potential (EP), and acidification potential (AP). The consumption of resources is represented by ADP, while the rest of the impact categories are used to describe environmental emissions.

From the result, it is clear that remanufacturing can minimize the environmental impact caused by the production of EV transmissions. The highest savings are in eutrophication potential (freshwater), at minus 97% contra with eutrophication potential (marine), where the weight is only 66% less than newly manufactured transmission. The term "eutrophication" refers to the process by which phosphorus, mono-nitrogen oxides (NO_x), nitrogen oxide, nitric oxide, and ammonia are released into the atmosphere, which can lead to the potential degradation of water bodies (including the growth of algae blooms and the consumption of dissolved oxygen).

The second-highest savings are for ozone layer depletion (ODP), at minus 95% and local air quality (measured by photochemical ozone production potential), at minus 41%. Depletion of the ozone layer refers to the process through which the ozone layer that is already present in the upper atmosphere becomes thinner. This occurs when the atoms of chlorine and bromine (outputs from the production of lubricating oil) that are present in the atmosphere interact with ozone and cause the ozone molecules to break down. One chlorine molecule is capable of destroying 100,000 ozone molecules, and it is destroyed faster than it is made, which is a paradox. Photochemical ozone production, on the other hand, is a mixture of pollutants that is made when nitrogen oxides and volatile organic compounds (VOCs) react with sunlight. This makes a brown haze above cities. It happens more frequently in hot and humid regions because they receive more sunlight.

The release of warming gases into the atmosphere is connected with global warming potential (GWP). It is computed in kilograms of CO₂ equivalents. The gas emissions released by newly manufactured and remanufactured transmissions is shown in Figure 4.4. Overall, remanufacturing was able to minimise the GWP to 63%. Greenhouse gases (GHGs) warm the Earth by absorbing energy and decreasing the rate at which it escapes to space; they act as an insulator, like a blanket. The Global Warming Potential (GWP) was created to facilitate comparisons of different gases' global warming consequences. It measures how much energy one tonne of a gas will absorb over a specific length of time compared to one tonne of carbon dioxide emissions (CO₂).

Next, remanufacturing will also be able to minimise the acidification potential to minus 72%. Acidification potential refers to the substances that contribute as acid rain's precursors. These include sulphur dioxide (SO₂), nitrogen oxides (NO_x), nitrogen monoxide (NO), nitrogen dioxide (N₂O), and several other compounds. Typically, SO₂-equivalence is used to characterise acidification potential. Most of the time, these acid gases are released into the environment when fuel is burned.

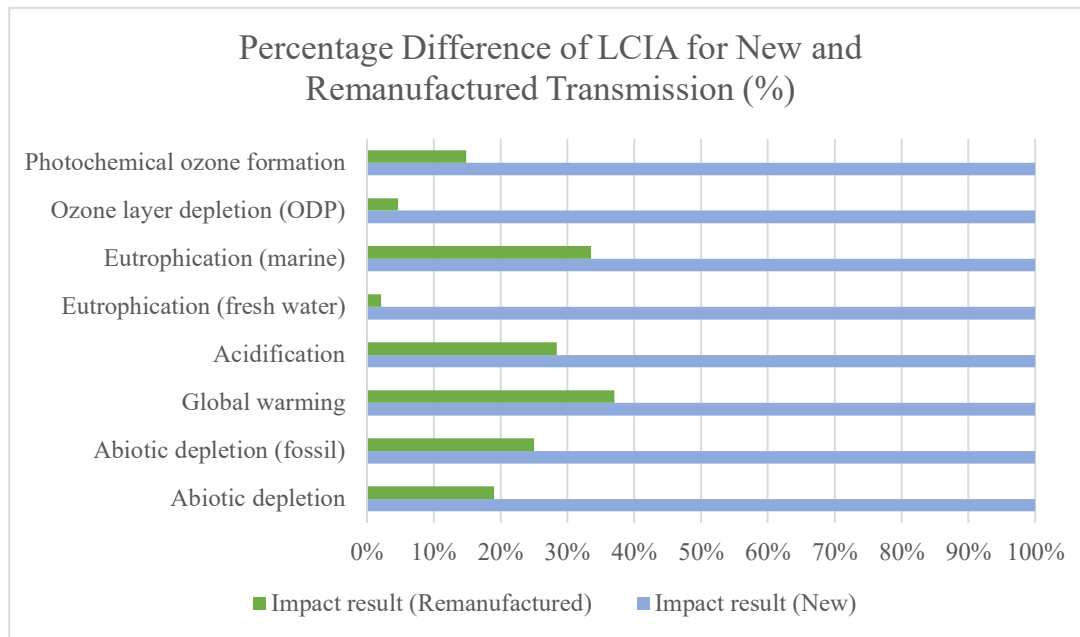


Figure 4.5: Percentage difference of LCIA for new and remanufactured transmission.

One of the primary benefits of utilising a transmission that has been remanufactured is the reduction in the quantity of raw material that is required. It is imperative that a look be taken at the usage of raw material extracted from the earth as the shortage of metals continues to increase on a daily basis (Liu et al., 2022). Looking at the abiotic depletion, it shows that remanufacturing able to minimise 81% the used of raw material compared to newly manufactured transmission in total.

The normalised comparison results for material usage are displayed in Figure 4.6. Again, the difference has been normalised respected to the newly manufactured transmission. Remanufacturing saves between 13 and 99% on raw materials for all materials (depending on current injection rates). The biggest saving is the consumption of bauxite, which commonly beneficial to made aluminium parts. For transmission, aluminium is used for casing and flange.

Manganese and iron ore had the least saving (13% and 52%), which are mainly use in the steel production and casting in the fabrication phase. The primary materials used in transmission are steel (hot-rolled and chromium) and aluminium. Bauxite and clay are primarily employed in the production of aluminium, which is used in the manufacture of the transmission housing. Fortunately, the consumption of bauxite and clay in remanufacturing

is minimal because the transmission casing will not change. As a result, the use of certain materials is not critical, and the percentage difference is very low. Iron ore, chromium ore, copper ore, and nickel ore are primarily used to manufacture steel and chromium steel. These materials are used extensively in the shaft, gear train, and bearing.

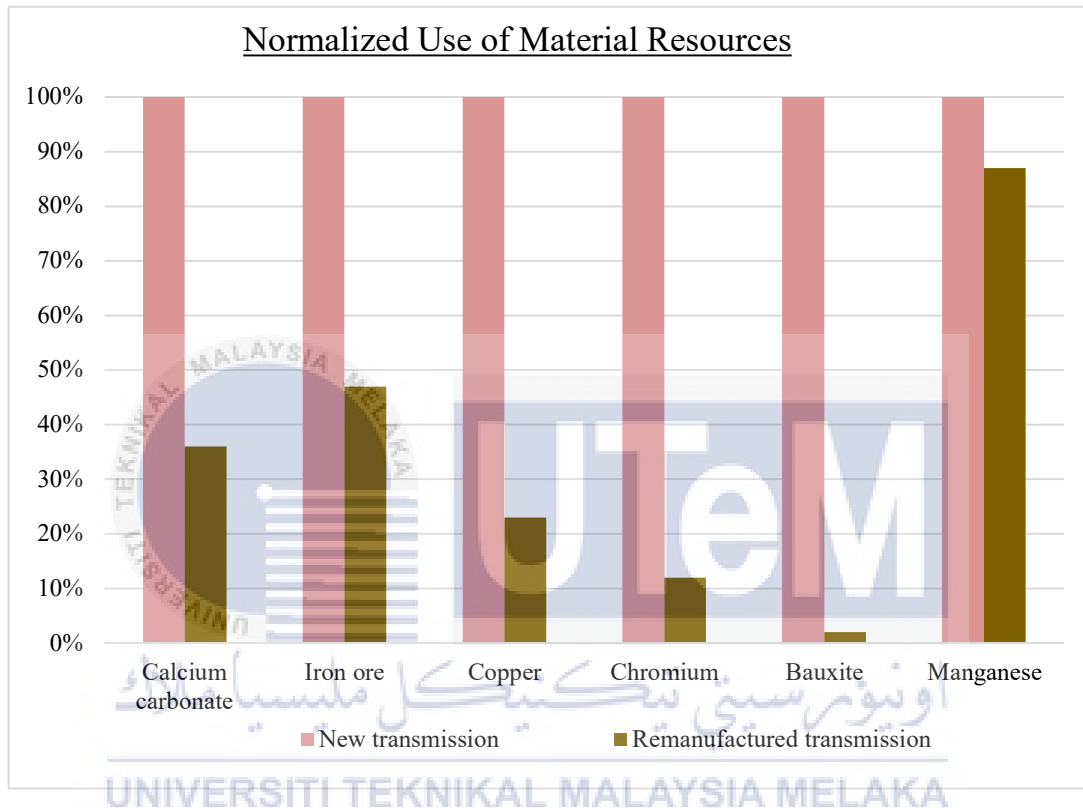


Figure 4.6: Normalized use of material resources in newly manufactured and remanufactured transmission over the cradle to gate phase.

As can be seen in Figure 4.6, the production process of materials has a major impact on the surrounding environment in terms of ADP, GWP, OLD, POF, EP, AP, HTP, and FEW. The manufacturing process has secondary effects on both the newly manufactured product and the previously manufactured product. So, if the environmental effects of a product's lifecycle need to be cut down, one of the first things to do should be to cut down on the environmental effects caused by the production of raw materials or components that come before the product. When it comes to remanufacturing, the fabrication of new components for replacement causes significant environmental impacts compared to other phases, such as collecting, disassembling, reconditioning, and so on (Zheng et al., 2019).

Therefore, to improve the positive effects of remanufacturing on the environment, it is essential to cut down on the number of replacement parts. On the one hand, more old or non-functional items or parts might be returned to a like-new condition, and fewer new parts are needed for replacement, which would result in fewer negative effects on the environment during the manufacture of raw materials or components. On the other hand, if the used parts are restored to a condition that is "better than new," the product will either have a longer service life or lower energy consumption, both of which will result in a reduction in the environmental effect that is caused during the usage phase.

4.5 Conclusion of Result and Discussion

A life cycle assessment comparison between newly manufactured and remanufactured EV transmissions has been made to identify the environmental impact projected from the production of the products. The analysis has been made using the openLCA software. The EV transmission prototype by (Carlos Daniel Pires, 2018) is the reference model used in this study. The targeted transmission per analysis is 10,000 units based on monthly transmission production.

Carbon dioxide, carbon monoxide, sulphur dioxide, methane, and nitrogen dioxide are the regulated emissions studied in this research. The most significant amount of gas emission for newly manufactured EV transmission is carbon dioxide. The main contributor of this emission is the production of stainless steel and steel material which are respected to $8.32\text{E}+04$ kg and $5.30\text{E}+04$ kg for both materials. On the other hand, the most significant amount of gas emission for remanufactured EV transmission is carbon dioxide. The main contributor to this emission is the production of steel and chromium-coated steel material, which is estimated at $5.23\text{E}+04$ kg and $4.32\text{E}+04$ kg for both materials. Carbon dioxide shows a major difference between the newly manufactured and the remanufactured transmission. The production of remanufacturing released 60.73% lesser carbon dioxide to the environment. Compared to a new transmission, remanufacturing uses around 49% fewer materials. This is due to the reduced number of materials utilised and the fabrication process used to build each component in the transmission to remanufacture it.

Next, the data from life cycle inventory are used to create LCIA's for each environmental impact category. The Environmental Footprint (EF) technique was used to analyse the relationships between all reported emissions to estimate their environmental impacts. To compare between new transmission between the remanufactured EV transmission, remanufacturing saves between 31 and 72% on raw materials used. The major saving is for the copper, chromium, and nickel ore. This is due to in remanufacturing, there is lesser number of new materials needed because the components that still in a perfect condition will remain and the broken components only will be change. Therefore, in order to improve the positive effects that remanufacturing has on the environment, it is essential to cut down on the quantity of replacement parts, so that less raw material will be used.



CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter is an important one since it gives an overall significance of the study and stresses the findings upon which conclusions are drawn to fulfil the said objectives in Chapter 1. It also acknowledges and suggests for further research which may be usefully carried out regarding the remanufacturing of EV transmission or any other relevant topic.

5.2 Conclusion

The main objectives of this research are to study the concept of electric vehicle transmission, to identify the main components for remanufactured EV transmission and finally to propose the environmental impact performance analysis of newly manufactured and remanufactured electric vehicle transmission. From the literature review, it is said that EV transmission has two common concept which is single-speed and multi-speed transmission. For this studies, the concept chosen is single-speed transmission and the prototype model by (Carlos Daniel Pires, 2018) are used as a reference. The injected material (material used) to run the analysis are referred from the studies while the injected material for the remanufactured transmission is based on the survey done to several automotive workshop. Based on the survey, all the automotive workshop said the components that required to be change in order to remanufacture the product is shaft, bearing and gear train.

Next, a comparison of life cycle assessment between newly manufactured and remanufactured EV transmission has been made to identify the environmental impact projected from the production of the products. The analysis has been made by using the openLCA software. The analysis is limited to cradle to gate phase and the LCA method used to run the life cycle impact assessment is based on Environmental Footprint (EF) methodology. Based on the LCA study and the inventory criteria specified, remanufacturing appears to be a better environmental choice for spare parts because it reduces regulated emissions across the transmission's life cycle and needs fewer material and energy resources. According to the EF impact assessment approach, the global warming potential (measured in kg CO₂-eq) has decreased by 45.6% by remanufacturing compared to newly manufactured transmission. To compare between new transmission between the remanufactured EV transmission, remanufacturing saves between 64 and 80% on raw materials used. The major saving is for the copper, chromium, and nickel ore. This is due to in remanufacturing, there is lesser number of new materials needed because the components that still in a perfect condition will remain and the broken components only will be change. Therefore, in order to improve the positive impact that remanufacturing has on the environment, it is essential to cut down on the quantity of replacement parts, so that less raw material will be used to remanufacture the transmission. Finally, the result had shown that the remanufactured transmission performs significantly better than the newly manufactured component in terms of all environmental impact categories considered. The savings are chiefly due to lower power consumption and material requirements as a result of the reuse of components and remanufacturing are able to minimise the exploitation of a new raw materials.

5.3 Recommendation

For future studies, the Design for Remanufacturing: A Study of Electric Vehicle Transmission could be enhanced by adding the route and transportation to collect the transmission to be remanufactured in the LCA analysis. It's important to find out how the used transmission get from one place to another before being remanufactured. It would also be helpful to know more about how the products are made in the factories in Malaysia and

where the raw materials come from. So, a better energy model and a better transportation model with information about how raw materials are moved would be on hand. Next, it is also recommended to include each part's different injection rate, such as a change from 100% to 0%, which couldn't be done this time due to a lack of time. Lastly, the life cycle cost assessment can be included in the future research to study if there is any significant impact regarding cost when implementing remanufacturing.

5.4 Sustainable Design and Development

This study indicates that the researcher is aware and conscious for the environment sustainability. This study shows how remanufacturing a product could minimise the use of new raw material. A study stated that significant energy consumption and emissions to air and water, such as carbon dioxide (CO₂) and sulphur dioxide (SO₂), can be reduced by extending the lifespan of components. Therefore, with remanufacturing the lifespan of a product can be extended because it uses cradle to cradle concept. It is hoped that this study is able to inspire other researchers to make more research regarding remanufacturing to aid minimise the use of new raw material and at the same time to reduce the harmful gasses emission to the environment.

5.5 Life Long Learning

It is suggested that there will be many automotive industries would like to participate in implementing remanufacturing product as their spare parts or maybe widen the scope of remanufacturing by adding it in a new car as well. Remanufacturing, if done properly, can boost the community's economy by creating new job opportunities, cheaper spare parts, and reduce the reliance on new raw materials.

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Gantt Chart

Month	MARCH				APRIL			MAY				JUNE		
Activity/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PSM 1														
Title and supervisor selection														
Identify problem statement														
Identify project methodology and working principle														
Project report writing (Draft: chapter1- chapter 3)														
Submission of project draft report														
Submission of video presentation														
PSM1 Q&A session														
Report submission														

Month	OCTOBER				NOVEMBER			DECEMBER				JANUARY			
Activity/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PSM 2															
Run analysis															
Result interpretation															
Project report writing (Chapter 4 - Chapter 5)															
Submission of project draft report															
Submission of draft presentation slide															
PSM 2 presentation															
Report submission															

Interview Questions

Workshop name: _____

1. Have you ever repaired an electric car transmission?

☐ YES

☐ NO

2. What components in the transmission are often damaged and need to be replaced?

☐ Housing + Flange

☐ Shaft

☐ Gear Train

☐ Bearing

☐ Fixtures

☐ Gasket

☐ Lubricant

3. How long is the lifespan of a transmission?

4. Do you familiar with remanufacturing or recond term?

☐ YES

☐ NO

5. What will you do with a transmission that has been salvage by customer?

☐ Try to repair & resell

☐ Send to factory for remanufacturing

☐ Sell at recycling centre

☐ Dispose of in a landfill

OpenLCA Input

Input parameter for new EV transmission

Inputs/Outputs: New EV Transmission

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided was...	Provider	Data quality ...	Description
Fe Aluminium DC cast ingot	Materials production/Metal...	7.29000	kg		none		P Aluminium...		Casing, Fla...
Fe Aluminium sheet	Materials production/Metal...	76.00000	g		none		P Aluminium...		Gasket
Fe lubricating oil	Organic chemicals/nan	4.70000	kg		none		P Lubricatin...		ATF
Fe Stainless steel (hot rolled)	Materials production/Metal...	0.08600	kg		none		P Stainless s...		Spring typ...
Fe Stainless steel (hot rolled)	Materials production/Metal...	1.20580	kg		none		P Stainless s...		Screws
Fe Steel billet (St)	Materials production/Metal...	13.83900	kg		none		P Secondar...		Gear Train
Fe Steel billet (St)	Materials production/Metal...	2.01900	kg		none		P Secondar...		Shaft
Fe Steel tin-free steel (Electrolytic chro...	Materials production/Metal...	1.60000	kg		none		P Electrolyti...		Bearing

Input parameter for remanufactured EV transmission

Inputs/Outputs: Remanufactured EV Transmission

Flow	Category	Amount	Unit	Costs/Reven...	Uncertainty	Avoided was...	Provider	Data quality ...	Description
Fe Steel billet (St)	Materials production/Metal...	2.01900	kg		none		P Secondar...		Shaft
Fe Steel billet (St)	Materials production/Metal...	13.83900	kg		none		P Secondar...		Gear Train
Fe Steel tin-free steel (Electrolytic chro...	Materials production/Metal...	1.60000	kg		none		P Electrolyti...		Bearing

Calculation properties used for LCA in this study

LCA Calculation properties

Calculation properties

Please select the properties for the calculation

Allocation method: **None**

Impact assessment method: **Environmental Footprint (Mid-point indicator)**

Normalization and weighting set: **PEF standard weighting and normalization factors**

Calculation type: ☐ Quick results ☒ Analysis ☐ Regionalized LCIA ☐ Monte Carlo Simulation

☒ Include cost calculation

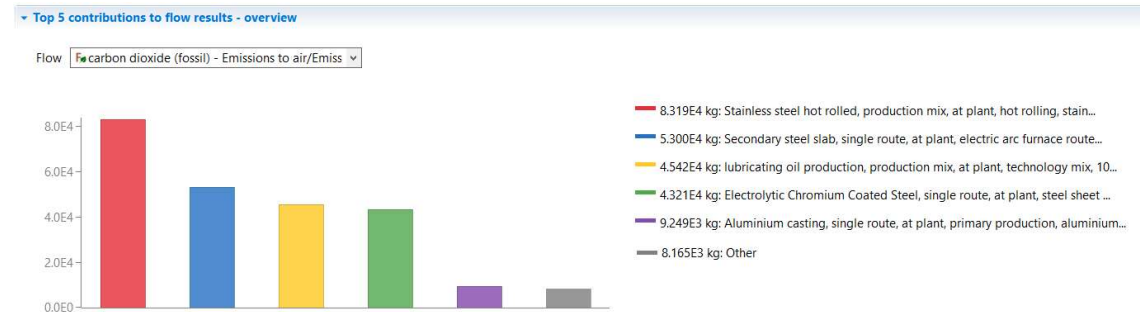
☒ Assess data quality

< Back Next > Finish Cancel

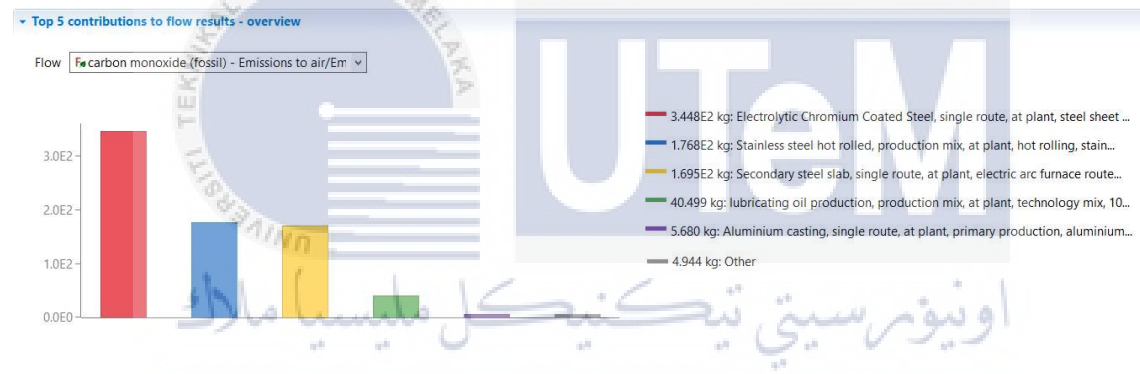
OpenLCA Result

Newly EV Transmission

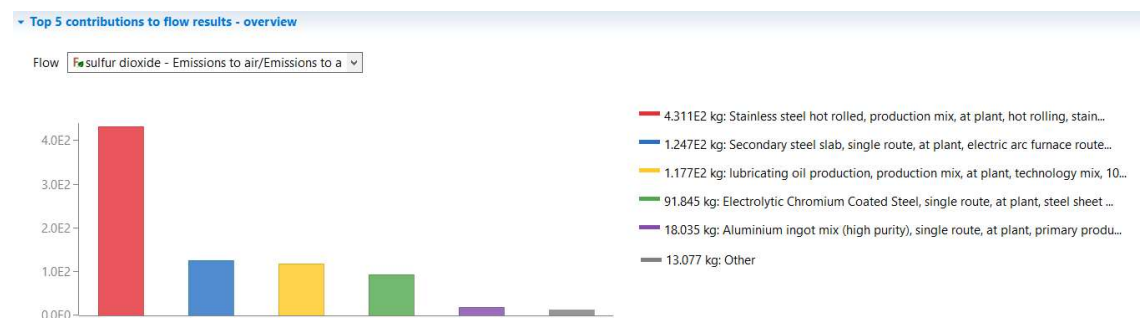
Top 5 contributors of carbon dioxide for new EV transmission production



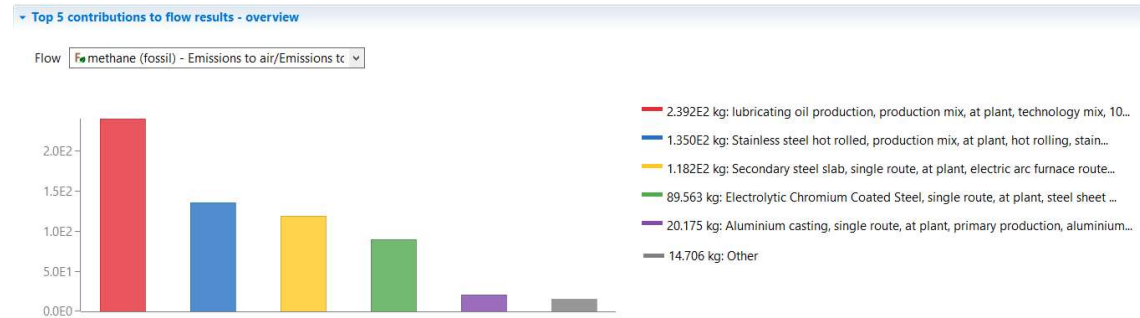
Top 5 contributors of carbon monoxide for new EV transmission production



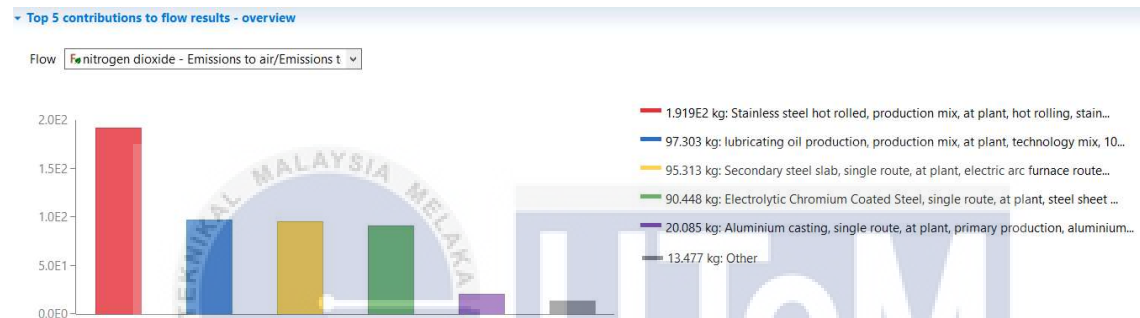
Top 5 contributors of sulphur dioxide for new EV transmission production



Top 5 contributors of methane for new EV transmission production



Top 5 contributors of nitrogen dioxide for new EV transmission production



Resource used (Abiotic depletion) from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.02257	disease...
> Resource use, minerals and metals				6.72127	kg Sb eq
▼ P Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			4.93251	kg Sb eq
F copper	Resources from ground / Non-renewa...	1733.47916 kg	0.00137 kg Sb eq/...	2.37487	kg Sb eq
F chromium	Resources from ground / Non-renewa...	3196.87179 kg	0.00044 kg Sb eq/...	1.41621	kg Sb eq
F molybdenum	Resources from ground / Non-renewa...	55.12514 kg	0.01780 kg Sb eq/...	0.98123	kg Sb eq
F nickel	Resources from ground / Non-renewa...	1465.72723 kg	6.53000E-5 kg Sb ...	0.09571	kg Sb eq
▼ P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			1.23784	kg Sb eq
F copper	Resources from ground / Non-renewa...	515.87027 kg	0.00137 kg Sb eq/...	0.70674	kg Sb eq
F molybdenum	Resources from ground / Non-renewa...	15.78570 kg	0.01780 kg Sb eq/...	0.28099	kg Sb eq
F lead	Resources from ground / Non-renewa...	20.34933 kg	0.00634 kg Sb eq/...	0.12901	kg Sb eq
F silver	Resources from ground / Non-renewa...	0.05685 kg	1.18000 kg Sb eq/...	0.06709	kg Sb eq
F zinc	Resources from ground / Non-renewa...	37.61111 kg	0.00054 kg Sb eq/...	0.02023	kg Sb eq
F chromium	Resources from ground / Non-renewa...	40.58802 kg	0.00044 kg Sb eq/...	0.01798	kg Sb eq
F gold	Resources from ground / Non-renewa...	0.00026 kg	52.00000 kg Sb e...	0.01362	kg Sb eq
▼ P lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			0.53261	kg Sb eq
F cadmium	Resources from ground / Non-renewa...	0.91033 kg	0.15700 kg Sb eq/...	0.14292	kg Sb eq
F gold	Resources from ground / Non-renewa...	0.00244 kg	52.00000 kg Sb e...	0.12712	kg Sb eq
F lead	Resources from ground / Non-renewa...	16.81839 kg	0.00634 kg Sb eq/...	0.10663	kg Sb eq
F copper	Resources from ground / Non-renewa...	33.24061 kg	0.00137 kg Sb eq/...	0.04554	kg Sb eq
F silver	Resources from ground / Non-renewa...	0.03662 kg	1.18000 kg Sb eq/...	0.04321	kg Sb eq
F sulfur	Resources from ground / Non-renewa...	140.25301 kg	0.00019 kg Sb eq/...	0.02707	kg Sb eq
F zinc	Resources from ground / Non-renewa...	29.39208 kg	0.00054 kg Sb eq/...	0.01581	kg Sb eq
F chromium	Resources from ground / Non-renewa...	22.77079 kg	0.00044 kg Sb eq/...	0.01009	kg Sb eq
F molybdenum	Resources from ground / Non-renewa...	0.52551 kg	0.01780 kg Sb eq/...	0.00935	kg Sb eq

Fossil resource used (Abiotic depletion) from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
Resource use, fossils				5.45945E6	MJ
lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			2.85307E6	MJ
crude oil	Resources from ground / Non-renewa...	2.12422E6 MJ	1.00000 MJ/MJ	2.12422E6	MJ
natural gas	Resources from ground / Non-renewa...	4.78580E5 MJ	1.00000 MJ/MJ	4.78580E5	MJ
hard coal	Resources from ground / Non-renewa...	1.25168E5 MJ	1.00000 MJ/MJ	1.25168E5	MJ
uranium	Resources from ground / Non-renewa...	9.08780E4 MJ	1.00000 MJ/MJ	9.08780E4	MJ
brown coal	Resources from ground / Non-renewa...	3.38106E4 MJ	1.00000 MJ/MJ	3.38106E4	MJ
Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			9.76327E5	MJ
hard coal	Resources from ground / Non-renewa...	5.37081E5 MJ	1.00000 MJ/MJ	5.37081E5	MJ
natural gas	Resources from ground / Non-renewa...	2.24067E5 MJ	1.00000 MJ/MJ	2.24067E5	MJ
crude oil	Resources from ground / Non-renewa...	1.63294E5 MJ	1.00000 MJ/MJ	1.63294E5	MJ
brown coal	Resources from ground / Non-renewa...	2.62349E4 MJ	1.00000 MJ/MJ	2.62349E4	MJ
uranium	Resources from ground / Non-renewa...	2.56349E4 MJ	1.00000 MJ/MJ	2.56349E4	MJ
Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			9.29954E5	MJ
natural gas	Resources from ground / Non-renewa...	3.23127E5 MJ	1.00000 MJ/MJ	3.23127E5	MJ
uranium	Resources from ground / Non-renewa...	2.37850E5 MJ	1.00000 MJ/MJ	2.37850E5	MJ
hard coal	Resources from ground / Non-renewa...	2.16521E5 MJ	1.00000 MJ/MJ	2.16521E5	MJ
brown coal	Resources from ground / Non-renewa...	9.49024E4 MJ	1.00000 MJ/MJ	9.49024E4	MJ
crude oil	Resources from ground / Non-renewa...	5.62554E4 MJ	1.00000 MJ/MJ	5.62554E4	MJ
Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			4.10378E5	MJ
hard coal	Resources from ground / Non-renewa...	3.21483E5 MJ	1.00000 MJ/MJ	3.21483E5	MJ
crude oil	Resources from ground / Non-renewa...	4.14231E4 MJ	1.00000 MJ/MJ	4.14231E4	MJ
natural gas	Resources from ground / Non-renewa...	3.40093E4 MJ	1.00000 MJ/MJ	3.40093E4	MJ
uranium	Resources from ground / Non-renewa...	7351.95522 MJ	1.00000 MJ/MJ	7351.95522	MJ
brown coal	Resources from ground / Non-renewa...	6093.70298 MJ	1.00000 MJ/MJ	6093.70298	MJ

Climate change (global warming) from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
Climate change				2.80988E5	kg CO2...
Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			8.89470E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	8.31883E4 kg	1.00000 kg CO2 e...	8.31883E4	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	134.96884 kg	36.80000 kg CO2 ...	4966.85320	kg CO2...
lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			6.76845E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	4.54159E4 kg	1.00000 kg CO2 e...	4.54159E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to urban ai...	8906.37478 kg	1.00000 kg CO2 e...	8906.37478	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	239.17912 kg	36.80000 kg CO2 ...	8801.79174	kg CO2...
methane (fossil)	Emissions to air / Emissions to urban ai...	53.19906 kg	36.80000 kg CO2 ...	1957.72536	kg CO2...
Carbon dioxide (land use change)	Emissions to air / Emissions to air, uns...	994.48121 kg	1.00000 kg CO2 e...	994.48121	kg CO2...
nitrous oxide	Emissions to air / Emissions to air, uns...	3.29470 kg	298.00000 kg CO2 ...	981.81972	kg CO2...
Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			5.81133E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	5.29958E4 kg	1.00000 kg CO2 e...	5.29958E4	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	118.23973 kg	36.80000 kg CO2 ...	4351.22213	kg CO2...
Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			4.71722E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	4.32113E4 kg	1.00000 kg CO2 e...	4.32113E4	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	89.56321 kg	36.80000 kg CO2 ...	3295.92601	kg CO2...
carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	344.84992 kg	1.57000 kg CO2 e...	541.41437	kg CO2...
Aluminium casting, single route, at plant, primary production, a	Systems / Unspecific parts			1.00822E4	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	9249.05915 kg	1.00000 kg CO2 e...	9249.05915	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	20.17485 kg	36.80000 kg CO2 ...	742.43449	kg CO2...
Aluminium ingot mix (high purity), single route, at plant, prima	Materials production / Metals and sem...			8592.58421	kg CO2...
carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	7810.16649 kg	1.00000 kg CO2 e...	7810.16649	kg CO2...
methane (fossil)	Emissions to air / Emissions to air, uns...	13.69793 kg	36.80000 kg CO2 ...	504.08396	kg CO2...
FC-14	Emissions to air / Emissions to air, uns...	0.02683 kg	7350.00000 kg CO...	197.17832	kg CO2...

Ozone depletion from new EV transmission production

▼ Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.02257	disease...
> Resource use, minerals and metals				6.72127	kg Sb eq
> Human toxicity, cancer				0.00294	CTUh
> Eutrophication marine				236.76978	kg N eq
> Climate change-Fossil				2.79345E5	kg CO2...
> Land use				1.67902E6	Pt
> Ecotoxicity, freshwater				1.20290E5	CTUe
> Eutrophication, freshwater				6.26977	kg P eq
> Ionising radiation, human health				2.49483E4	kBq U-...
> Climate change				2.80988E5	kg CO2...
▼ Ozone depletion				0.00028	kg CFC...
▼ P Lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			0.00026	kg CFC...
F CFC-10	Emissions to air / Emissions to urban al...	0.00030	0.72000 kg CFC11 ...	0.00022	kg CFC...
F HCFC-22	Emissions to air / Emissions to non-urb...	0.00104	kg 0.03400 kg CFC11 ...	3.52226E-5	kg CFC...
F CFC-114	Emissions to air / Emissions to air, uns...	8.80704E-6	kg 0.50000 kg CFC11 ...	4.40352E-6	kg CFC...
F 1,1,2-trichlorotrifluoroethane	Emissions to air / Emissions to air, uns...	5.19526E-6	kg 0.81000 kg CFC11 ...	4.20816E-6	kg CFC...
▼ P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			1.29242E-5	kg CFC...
F CFC-114	Emissions to air / Emissions to air, uns...	2.57126E-5	kg 0.50000 kg CFC11 ...	1.28563E-5	kg CFC...

Photochemical ozone formation from new EV transmission production

▼ Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
▼ Photochemical ozone formation - human health				1726.46895	kg NM...
▼ P Lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			1183.45557	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to urban al...	1003.37435	kg 1.00000 kg NMVO...	1003.37435	kg NM...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	97.30314	kg 1.00000 kg NMVO...	97.30314	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	22.57191	kg 1.00000 kg NMVO...	22.57191	kg NM...
F Nitrogen oxides	Emissions to air / Emissions to urban al...	17.53167	kg 1.00000 kg NMVO...	17.53167	kg NM...
▼ P Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			245.34866	kg NM...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	191.94992	kg 1.00000 kg NMVO...	191.94992	kg NM...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	431.11674	kg 0.08110 kg NMVO...	34.96357	kg NM...
F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	176.77518	kg 0.04560 kg NMVO...	8.06095	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	6.27409	kg 1.00000 kg NMVO...	6.27409	kg NM...
▼ P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			134.29543	kg NM...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309	kg 1.00000 kg NMVO...	95.31309	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	12.53024	kg 1.00000 kg NMVO...	12.53024	kg NM...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	124.72047	kg 0.08110 kg NMVO...	10.11483	kg NM...
F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	169.47322	kg 0.04560 kg NMVO...	7.72798	kg NM...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759	kg 1.00000 kg NMVO...	4.79759	kg NM...
▼ P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			121.60595	kg NM...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795	kg 1.00000 kg NMVO...	90.44795	kg NM...
F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	344.84992	kg 0.04560 kg NMVO...	15.72516	kg NM...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	91.84500	kg 0.08110 kg NMVO...	7.44863	kg NM...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115	kg 1.00000 kg NMVO...	3.61115	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	2.91286	kg 1.00000 kg NMVO...	2.91286	kg NM...
▼ P Aluminium casting, single route, at plant, primary production, a	Systems / Unspecific parts			25.19623	kg NM...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	20.08476	kg 1.00000 kg NMVO...	20.08476	kg NM...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	2.07120	kg 1.00000 kg NMVO...	2.07120	kg NM...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	12.71090	kg 0.08110 kg NMVO...	1.03085	kg NM...
F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	0.85136	kg 1.00000 kg NMVO...	0.85136	kg NM...
F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	5.68047	kg 0.04560 kg NMVO...	0.25903	kg NM...

Eutrophication potential (fresh water) from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.02257	disease...
> Resource use, minerals and metals				6.72127	kg Sb eq
> Human toxicity, cancer				0.00294	CTUh
> Eutrophication marine				236.76978	kg N eq
> Climate change-Fossil				2.79345E5	kg CO2...
> Land use				1.67902E6	Pt
> Ecotoxicity, freshwater				1.20290E5	CTUe
> Eutrophication, freshwater				6.26977	kg P eq
P Lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			6.01447	kg P eq
F phosphate	Emissions to water / Emissions to wate...	9.51027 kg	0.33000 kg P eq/kg	3.13839	kg P eq
F phosphate	Emissions to water / Emissions to fresh...	8.64295 kg	0.33000 kg P eq/kg	2.85217	kg P eq
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			0.09478	kg P eq
F phosphate	Emissions to water / Emissions to fresh...	0.18855 kg	0.33000 kg P eq/kg	0.06222	kg P eq
F Phosphorus	Emissions to water / Emissions to fresh...	0.03256 kg	1.00000 kg P eq/kg	0.03256	kg P eq
P Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			0.08429	kg P eq
F phosphate	Emissions to water / Emissions to fresh...	0.14677 kg	0.33000 kg P eq/kg	0.04844	kg P eq
F Phosphorus	Emissions to water / Emissions to fresh...	0.03585 kg	1.00000 kg P eq/kg	0.03585	kg P eq

Eutrophication potential (marine) from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.02257	disease...
> Resource use, minerals and metals				6.72127	kg Sb eq
> Human toxicity, cancer				0.00294	CTUh
> Eutrophication marine				236.76978	kg N eq
P Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			78.34475	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	191.94992 kg	0.38900 kg N eq/kg	74.66852	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	10.94247 kg	0.22600 kg N eq/kg	2.47300	kg N eq
P Lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			64.25215	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	97.30314 kg	0.38900 kg N eq/kg	37.85092	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	65.38701 kg	0.22600 kg N eq/kg	14.77746	kg N eq
F Nitrogen oxides	Emissions to air / Emissions to urban ai...	17.53167 kg	0.38900 kg N eq/kg	6.81982	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	2.62938 kg	0.59600 kg N eq/kg	1.56711	kg N eq
F Nitrogen oxides	Emissions to air / Emissions to air, uns...	8.53376 kg	0.38900 kg N eq/kg	1.37463	kg N eq
F ammonia	Emissions to air / Emissions to air, uns...	8.37733 kg	0.09200 kg N eq/kg	0.77071	kg N eq
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			41.56373	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309 kg	0.38900 kg N eq/kg	37.07679	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	0.59600 kg N eq/kg	2.85937	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	5.80198 kg	0.22600 kg N eq/kg	1.31125	kg N eq
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			37.81337	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	0.38900 kg N eq/kg	35.18425	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	0.59600 kg N eq/kg	2.15225	kg N eq
P Aluminium casting, single route, at plant, primary production, a	Systems / Unspecific parts			9.29381	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	20.08476 kg	0.38900 kg N eq/kg	7.81297	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	2.07120 kg	0.59600 kg N eq/kg	1.23443	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	0.79827 kg	0.22600 kg N eq/kg	0.18041	kg N eq
P Aluminium ingot mix (high purity), single route, at plant, prima	Materials production / Metals and sem...			5.19893	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	12.74819 kg	0.38900 kg N eq/kg	4.95905	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	0.78308 kg	0.22600 kg N eq/kg	0.17698	kg N eq

Acidification potential from new EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Eutrophication, terrestrial				2505.27919	mol N ...
> Acidification				1525.46776	mol H+...
P Stainless steel hot rolled, production mix, at plant, hot rolling, s	Materials production / Metals and sem...			709.50814	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	431.11674 kg	1.31000 mol H+ e...	564.76293	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	191.94992 kg	0.74000 mol H+ e...	142.04294	mol H+...
P lubricating oil production, production mix, at plant, technology	Materials production / Organic chemi...			314.09087	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	117.67804 kg	1.31000 mol H+ e...	154.15823	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	97.30314 kg	0.74000 mol H+ e...	72.00432	mol H+...
F sulfur dioxide	Emissions to air / Emissions to urban al...	20.07456 kg	1.31000 mol H+ e...	26.29767	mol H+...
F ammonia	Emissions to air / Emissions to air, uns...	8.37733 kg	3.02000 mol H+ e...	25.29953	mol H+...
F sulfur dioxide	Emissions to air / Emissions to non-urb...	12.87646 kg	1.31000 mol H+ e...	16.86816	mol H+...
F Nitrogen oxides	Emissions to air / Emissions to urban al...	17.53167 kg	0.74000 mol H+ e...	12.97344	mol H+...
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			241.21716	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	124.72047 kg	1.31000 mol H+ e...	163.38382	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309 kg	0.74000 mol H+ e...	70.53169	mol H+...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	1.13467 mol H+ e...	5.44367	mol H+...
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			191.88756	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	91.84500 kg	1.31000 mol H+ e...	120.31695	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	0.74000 mol H+ e...	66.93148	mol H+...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	1.13467 mol H+ e...	4.09746	mol H+...
P Aluminium casting, single route, at plant, primary production, a	Systems / Unspecific parts			34.31547	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	12.71090 kg	1.31000 mol H+ e...	16.65128	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	20.08476 kg	0.74000 mol H+ e...	14.86272	mol H+...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	2.07120 kg	1.13467 mol H+ e...	2.35012	mol H+...
F ammonia	Emissions to air / Emissions to air, uns...	0.14927 kg	3.02000 mol H+ e...	0.45079	mol H+...
P Aluminium ingot mix (high purity), single route, at plant, primar	Materials production / Metals and sem...			33.39670	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	18.03533 kg	1.31000 mol H+ e...	23.62629	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	12.74819 kg	0.74000 mol H+ e...	9.43366	mol H+...
> Water use				6.65422E4	m3 dep...

Remanufactured EV Transmission

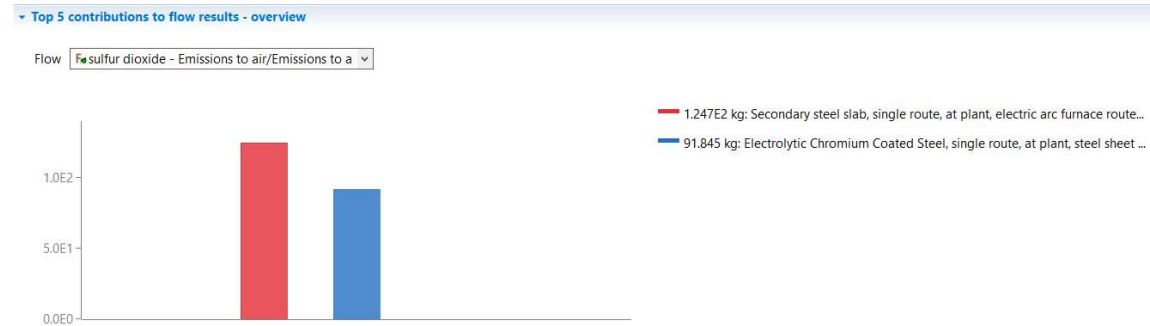
Top 5 contributors of carbon dioxide for remanufactured EV transmission production



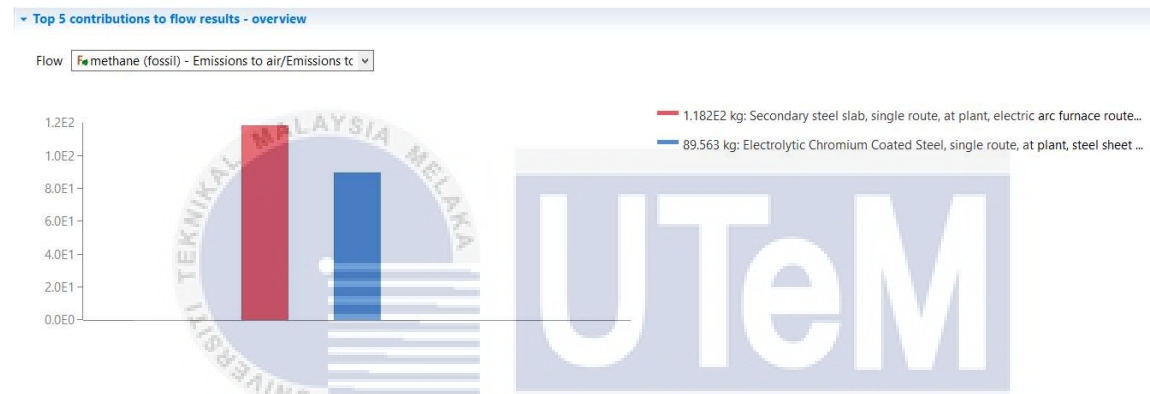
Top 5 contributors of carbon monoxide for remanufactured EV transmission production



Top 5 contributors of sulphur dioxide for remanufactured EV transmission production



Top 5 contributors of methane for remanufactured EV transmission production



Top 5 contributors of nitrogen dioxide for remanufactured EV transmission production



Resource used (Abiotic depletion) from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point Indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			1.23784	kg Sb eq
F copper	Resources from ground / Non-renewa...	515.87027 kg	0.00137 kg Sb eq/...	0.70674	kg Sb eq
F molybdenum	Resources from ground / Non-renewa...	15.78570 kg	0.01780 kg Sb eq/...	0.28099	kg Sb eq
F lead	Resources from ground / Non-renewa...	20.34933 kg	0.00634 kg Sb eq/...	0.12901	kg Sb eq
F silver	Resources from ground / Non-renewa...	0.05685 kg	1.18000 kg Sb eq/...	0.06709	kg Sb eq
F zinc	Resources from ground / Non-renewa...	37.61111 kg	0.00054 kg Sb eq/...	0.02023	kg Sb eq
F chromium	Resources from ground / Non-renewa...	40.58802 kg	0.00044 kg Sb eq/...	0.01798	kg Sb eq
F gold	Resources from ground / Non-renewa...	0.00026 kg	52.00000 kg Sb e...	0.01362	kg Sb eq
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			0.01479	kg Sb eq
F copper	Resources from ground / Non-renewa...	2.72510 kg	0.00137 kg Sb eq/...	0.00373	kg Sb eq
F manganese	Resources from ground / Non-renewa...	1183.46165 kg	2.54000E-6 kg Sb ...	0.00301	kg Sb eq
F lead	Resources from ground / Non-renewa...	0.37367 kg	0.00634 kg Sb eq/...	0.00237	kg Sb eq
F silver	Resources from ground / Non-renewa...	0.00179 kg	1.18000 kg Sb eq/...	0.00211	kg Sb eq
F gold	Resources from ground / Non-renewa...	2.22124E-5 kg	52.00000 kg Sb e...	0.00116	kg Sb eq
F molybdenum	Resources from ground / Non-renewa...	0.05278 kg	0.01780 kg Sb eq/...	0.00094	kg Sb eq
F sulfur	Resources from ground / Non-renewa...	3.28508 kg	0.00019 kg Sb eq/...	0.00063	kg Sb eq
F zinc	Resources from ground / Non-renewa...	1.13891 kg	0.00054 kg Sb eq/...	0.00061	kg Sb eq
F chromium	Resources from ground / Non-renewa...	0.40056 kg	0.00044 kg Sb eq/...	0.00018	kg Sb eq

Fossil resource used (Abiotic depletion) from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point Indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
> Human toxicity, cancer				0.00028	CTUh
> Eutrophication marine				79.37710	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
> Ionising radiation, human health				1.53305E4	kBq U-...
> Climate change				1.05286E5	kg CO2...
> Ozone depletion				1.30961E-5	kg CFC...
> Resource use, fossils				1.34033E6	MJ
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			9.29954E5	MJ
F natural gas	Resources from ground / Non-renewa...	3.23127E5 MJ	1.00000 MJ/MJ	3.23127E5	MJ
F uranium	Resources from ground / Non-renewa...	2.37850E5 MJ	1.00000 MJ/MJ	2.37850E5	MJ
F hard coal	Resources from ground / Non-renewa...	2.16521E5 MJ	1.00000 MJ/MJ	2.16521E5	MJ
F brown coal	Resources from ground / Non-renewa...	9.49024E4 MJ	1.00000 MJ/MJ	9.49024E4	MJ
F crude oil	Resources from ground / Non-renewa...	5.62554E4 MJ	1.00000 MJ/MJ	5.62554E4	MJ
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			4.10378E5	MJ
F hard coal	Resources from ground / Non-renewa...	3.21483E5 MJ	1.00000 MJ/MJ	3.21483E5	MJ
F crude oil	Resources from ground / Non-renewa...	4.14231E4 MJ	1.00000 MJ/MJ	4.14231E4	MJ
F natural gas	Resources from ground / Non-renewa...	3.40093E4 MJ	1.00000 MJ/MJ	3.40093E4	MJ
F uranium	Resources from ground / Non-renewa...	7351.95522 MJ	1.00000 MJ/MJ	7351.95522	MJ
F brown coal	Resources from ground / Non-renewa...	6093.70298 MJ	1.00000 MJ/MJ	6093.70298	MJ

Climate change (global warming) from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
> Human toxicity, cancer				0.00028	CTUh
> Eutrophication marine				79.37710	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
> Ionising radiation, human health				1.53305E4	kBq U-...
> Climate change				1.05286E5	kg CO2...
> P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			5.81133E4	kg CO2...
> F carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	5.29958E4 kg	1.00000 kg CO2 e...	5.29958E4	kg CO2...
> F methane (fossil)	Emissions to air / Emissions to air, uns...	118.23973 kg	36.80000 kg CO2 ...	4351.22213	kg CO2...
> P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			4.71722E4	kg CO2...
> F carbon dioxide (fossil)	Emissions to air / Emissions to air, uns...	4.32113E4 kg	1.00000 kg CO2 e...	4.32113E4	kg CO2...
> F methane (fossil)	Emissions to air / Emissions to air, uns...	89.56321 kg	36.80000 kg CO2 ...	3295.92601	kg CO2...
> F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	344.84992 kg	1.57000 kg CO2 e...	541.41437	kg CO2...

Ozone depletion from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
> Human toxicity, cancer				0.00028	CTUh
> Eutrophication marine				79.37710	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
> Ionising radiation, human health				1.53305E4	kBq U-...
> Climate change				1.05286E5	kg CO2...
> Ozone depletion				1.30961E-5	kg CFC...
> P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			1.29242E-5	kg CFC...
> F CFC-114	Emissions to air / Emissions to air, uns...	2.57126E-5 kg	0.50000 kg CFC11 ...	1.28563E-5	kg CFC...
> P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			1.71902E-7	kg CFC...
> F CFC-114	Emissions to air / Emissions to air, uns...	3.38892E-7 kg	0.50000 kg CFC11 ...	1.69446E-7	kg CFC...
> F HCFC-22	Emissions to air / Emissions to air, uns...	7.10675E-8 kg	0.03400 kg CFC11 ...	2.41630E-9	kg CFC...

Photochemical ozone formation from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Eutrophication marine				79.37710	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
> Ionising radiation, human health				1.53305E4	kBq U-...
> Climate change				1.05286E5	kg CO2...
> Ozone depletion				1.30961E-5	kg CFC...
> Resource use, fossils				1.34033E6	MJ
> Climate change-Land use and land use change				44.03382	kg CO2...
> Human toxicity, non-cancer				0.01456	CTUh
> Photochemical ozone formation - human health				255.90138	kg NM...
> P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			134.29543	kg NM...
> F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309 kg	1.00000 kg NMVO...	95.31309	kg NM...
> F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	12.53024 kg	1.00000 kg NMVO...	12.53024	kg NM...
> F sulfur dioxide	Emissions to air / Emissions to air, uns...	124.72047 kg	0.08110 kg NMVO...	10.11483	kg NM...
> F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	169.47322 kg	0.04560 kg NMVO...	7.72798	kg NM...
> F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	1.00000 kg NMVO...	4.79759	kg NM...
> P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			121.60595	kg NM...
> F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	1.00000 kg NMVO...	90.44795	kg NM...
> F carbon monoxide (fossil)	Emissions to air / Emissions to air, uns...	344.84992 kg	0.04560 kg NMVO...	15.72516	kg NM...
> F sulfur dioxide	Emissions to air / Emissions to air, uns...	91.84500 kg	0.08110 kg NMVO...	7.44863	kg NM...
> F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	1.00000 kg NMVO...	3.61115	kg NM...
> F non-methane volatile organic compounds	Emissions to air / Emissions to air, uns...	2.91286 kg	1.00000 kg NMVO...	2.91286	kg NM...

Eutrophication potential (fresh water) from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
> Human toxicity, cancer				0.00028	CTUh
> Eutrophication marine				79.37710	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			0.09478	kg P eq
F phosphate	Emissions to water / Emissions to fresh...	0.18855 kg	0.33000 kg P eq/kg	0.06222	kg P eq
F Phosphorus	Emissions to water / Emissions to fresh...	0.03256 kg	1.00000 kg P eq/kg	0.03256	kg P eq
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			0.03549	kg P eq
F Phosphorus	Emissions to water / Emissions to fresh...	0.02778 kg	1.00000 kg P eq/kg	0.02778	kg P eq
F phosphate	Emissions to water / Emissions to fresh...	0.02337 kg	0.33000 kg P eq/kg	0.00771	kg P eq

Eutrophication potential (marine) from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
> Particulate Matter				0.00758	disease...
> Resource use, minerals and metals				1.25263	kg Sb eq
> Human toxicity, cancer				0.00028	CTUh
> Eutrophication marine				79.37710	kg N eq
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			41.56373	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309 kg	0.38900 kg N eq/kg	37.07679	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	0.59600 kg N eq/kg	2.85937	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	5.80198 kg	0.22600 kg N eq/kg	1.31125	kg N eq
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			37.81337	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	0.38900 kg N eq/kg	35.18425	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	0.59600 kg N eq/kg	2.15225	kg N eq

Acidification potential from remanufactured EV transmission production

Impact analysis: Environmental Footprint (Mid-point indicator)

Subgroup by processes ☒ Don't show < 1 %

Name	Category	Inventory result	Impact factor	Impact result	Unit
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	0.59600 kg N eq/kg	2.85937	kg N eq
F nitrate	Emissions to water / Emissions to fresh...	5.80198 kg	0.22600 kg N eq/kg	1.31125	kg N eq
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			37.81337	kg N eq
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	0.38900 kg N eq/kg	35.18425	kg N eq
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	0.59600 kg N eq/kg	2.15225	kg N eq
> Climate change-Fossil				1.05110E5	kg CO2...
> Land use				3.71172E5	Pt
> Ecotoxicity, freshwater				1.34081E4	CTUe
> Eutrophication, freshwater				0.13028	kg P eq
> Ionising radiation, human health				1.53305E4	kBq U-...
> Climate change				1.05286E5	kg CO2...
> Ozone depletion				1.30961E-5	kg CFC...
> Resource use, fossils				1.34033E6	MJ
> Climate change-Land use and land use change				44.03382	kg CO2...
> Human toxicity, non-cancer				0.01456	CTUh
> Photochemical ozone formation - human health				255.90138	kg NM...
> Climate change-Biogenic				131.67379	kg CO2...
> Eutrophication, terrestrial				856.95211	mol N ...
> Acidification				433.10472	mol H+...
P Secondary steel slab, single route, at plant, electric arc furnace	Materials production / Metals and sem...			241.21716	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	124.72047 kg	1.31000 mol H+ e...	163.38382	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	95.31309 kg	0.74000 mol H+ e...	70.53169	mol H+...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	4.79759 kg	1.13467 mol H+ e...	5.44367	mol H+...
P Electrolytic Chromium Coated Steel, single route, at plant, steel	Materials production / Metals and sem...			191.88756	mol H+...
F sulfur dioxide	Emissions to air / Emissions to air, uns...	91.84500 kg	1.31000 mol H+ e...	120.31695	mol H+...
F nitrogen dioxide	Emissions to air / Emissions to air, uns...	90.44795 kg	0.74000 mol H+ e...	66.93148	mol H+...
F nitrogen monoxide	Emissions to air / Emissions to air, uns...	3.61115 kg	1.13467 mol H+ e...	4.09746	mol H+...