Tampere University of Applied Sciences

Comparative Study of Environmental Impact of Biofuel, Electric and Conventional Passenger Cars in the Context of Finland

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ABSTRACT

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The purpose of the thesis was to compare the environmental impact of mid-range cars; Toyota corolla as a conventional car, Nissan leaf 40kWh as an electric car and a Toyota corolla modified as a Flexible Fuel Vehicle (FFV). Petrol, electricity and ethanol were the fuel types considered for these cars respectively. The environmental impact was analyzed based on greenhouse gases (GHGs) emitted during their whole life cycle. The emissions during the production phase of fuel, vehicle manufacturing, battery manufacturing and usage phase were considered. The research was conducted through literature review. Likewise, the data of emission was analyzed from the LIPASTO Traffic Emission, JEC Well to Tank report v5 and from the company's sustainability reports.

The results were presented in the form of bar diagrams to compare the overall emissions of each vehicle and their emissions at different stages. The alternative fuel-based cars seemed to have less emissions than a conventional car. The overall emissions of both Nissan leaf and FFV were around 15 thousand kilograms of CO_2eq, whereas the overall emission from Toyota corolla was around 35 thousand kilograms of CO_2eq. The emissions from the Toyota corolla were about twice the emissions from Nissan leaf and FFV.

Thus, it can be concluded that the electrification of fleets and use of the biofuel cars should be promoted to meet the EU and national targets. Purchasing of electric passenger cars and conversion of conventional cars into flexible fuel vehicles can be effective measures for a significant reduction of overall emissions from passenger cars.

Key words: conventional vehicle, electric vehicle, flexible fuel vehicle, greenhouse gases emissions, ethanol

CONTENTS

ABBREVIATIONS AND TERMS

GHG	Greenhouse Gas
FT	Fischer-Tropsch
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
BEV	Battery Electric Vehicle
EV	Electric Vehicle
FFV	Flexible Fuel Vehicle
TMC	Toyota Motor Corporation
EU	European Union
FFV	Flexible Fuel Vehicle
BFV	Biofuel Vehicle
WTW	Well to Wheel
WTT	Well to Tank
TTW	Tank to Wheel
NMC	Nickel Manganese Cobalt Oxide
PHEV	Plug in Hybrid Electric Vehicle
BMW	Bavarian Motor Works
LCA	Life Cycle Assessment
SUV	Sport Utility Vehicle
E85	Ethanol 85

1 INTRODUCTION

Currently, one of the major sources of total GHG (greenhouse gas) emissions is transportation. During the combustion of fossil fuel, it emits the gases like Carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O) which are capable of trapping heat on the earth's surface causing global warming and ultimately climate changes. The transportation sector alone contributes to 24% of total GHG emissions globally and 60% of which is contributed by combustion of passenger cars (Planète Énergies 2021). Additionally, the demand for commercial transporting vehicles is most likely to increase substantially. With the increase in the number of vehicles, the demand for fossil fuels increases simultaneously. Thus, it compels us to seek ways to minimize GHG emissions.

The share of GHG emission in Finland from fuel consumption in transport is 24% (Statista 2019). Finland has the target to be carbon neutral by 2035 along with achieving near to zero-emission by 2050 from the transportation sector. Finland also aims to have a share of 40% of renewable energy in transportation by 2030 (Jääskeläinen 2017). It has been found that electric cars emit zero GHG through tailpipes and biofuels emit 80 percent less GHG than fossil fuels (Car Emissions and Global Warming 2020). So, electric cars and biofuels can be a good possibility of meeting the targets. Thus, the study attempts to find the best alternative source of energy for vehicles in Finland by the comparative analysis of environmental impacts during the whole life of the chosen model of an electric car and biofuel sourced car.

The GHG emissions from electric cars and biofuel vehicles are compared to emissions made by the chosen conventional mode of transportation during their entire life. Consequently, the result of the difference in emissions might help to make a smart choice that is more environment friendly compared to other options. This study also attempts to find out if electric cars and biofuel sourced cars are as efficient in reducing GHG emissions as claimed by previous researches of Woods(2008), Samaras and Meisterling(2008), Kromer, M.A., Bandivadekar, A. and Evans, C(2010). Further, this research strives to acknowledge the present scenario of the electric cars and biofuel vehicles in Finland and their future on the Finnish roads.

2 LITERATURE REVIEW

In this section, a background study of fuel types and vehicle types will be carried out to provide comprehensive information and become familiar with the research and the frequently used terms. Various research and articles related to the topic were studied in order to gather the information provided in this section.

2.1 Bio-fuels

Biofuel is generally referred to as a liquid or gaseous fuel used in the transportation sector which is mostly produced from biomass. The biomass is collected from a wide variety of sources such as corn, cellulose, starch, vegetable waste and animal residues. Different types of biofuels are obtained from biomass resources including liquid fuel such as ethanol, biodiesel, FT diesel, methanol and gaseous fuels like hydrogen and methane. (Demirbas 2008)

There are three generations of biofuels: first, second and third generation. The generation of biofuel is defined on the basis of the source from which it is produced. The first generation of biofuels includes biodiesel, bioethanol and biogas. These are mainly produced from vegetable oils, sugar and starch, liquid manure and animal feedstocks. The first generation of biofuel mostly utilizes the crops that can be also used as food. So, it would be challenging to use these crops in the future as it may lead to scarcity of food. (Naik, Goud, Rout & Dalai, 2010)

The second generation of biofuel includes lignocellulosic technologies. They are found to be more water efficient and require much less arable land for production. Lignocellulose which is present in the plants can be used for the production of ethanol by the enzymatic reactions also called lignocellulosic process. The advantage of this method can be considered as the lignocellulosic ethanol which is a perfect blend component in the transportation sector. Their usage can prevent the usage of traditional crops for the production of fuels which would help to establish sustainability in the biofuel technology. (Schenk et al., 2008)

The third generation of biofuel refers to the production of biofuel from microalgae which is a plausible option for a sustainable mode of energy. Microalgae are known to be microscopic organisms that need solar energy, carbon dioxide and other nutrients from an aqueous zone. Microalgae can be used to produce sustainable biofuels in the form of bioethanol and biodiesel. The major advantage of using microalgae is the production of oil over 20 times the traditional ways of production. In addition to all the advantages, the high quality of agrarian land is not required to produce in high volume. In the present scenario, the rate of microalgae production is 10,000L per hectare per year which is higher than the production of oil from soybeans, canola, sunflower, palm and jatropha. Despite the numerous advantages over other generations of biofuel, the systematic review work has not been reported yet. (Chowdhury & Loganathan 2019)

2.1.1 Biofuel companies in Finland

Three big energy companies in Finland are involved in the production of biodiesel and bioethanol using renewable raw materials. These companies are the pioneers in the field of biofuel technology. Neste is an oil company that is the leading producer of biodiesel in the world. The Finnish forest-based company UPM, located in Lappeenranta produces biofuel using wood-based oils whereas St1 is an energy company that produces bioethanol mainly from the biowaste and residues. These companies support the agenda of the Finnish government to decrease greenhouse gas emissions and promote the decarbonization of road traffic using the concept of biofuel vehicles.

st1

According to the official website of st1, it is an energy company that has been challenging conventional forms of energy since its establishment. The company focuses on the development and refining of liquid fuels using renewable resources. It started as a Finnish petrol station chain and today it operates as a Nordic energy group in Finland, Sweden and Norway. There are 1300 St1 and Shell petrol stations in Finland which offer high quality fuels and services. (Areas of Operations-st1 2020)

The main goal of the company is to reduce the emission of carbon dioxide from traffic fuels by selling environment friendly fuels. The biofuel sold by the company fulfills both EU and national sustainability criteria. They also fulfill the minimum GHG reduction requirement of 50% set by the law. Along with the control of emissions, the company is also focused on the efficiency of these fuels so that they can also be used in ordinary combustion engines. 95 E10 Extra petrol and Shell FuelSave 95 are the two recently launched products which reduce the fuel combustion and thus are less expensive to use. (Smart Fuels for Nordic Drivers-st1 2020)

The company has also invested in renewable fuels such as advanced ethanol refined from feedstocks and waste-based ethanol used in RED95 ethanol diesel. Both these fuels reduce the CO2 emission from traffic by almost 80%. It is working to be at the forefront of the energy sector in the transition process. It is also investing in research and development to bring out new solutions for the use of renewable resources in a more cost-effective way than fossil fuels. (Renewable Energy-st1 2020)

2.1.2 Biofuel as a transportation fuel

The liquid biofuels like ethanol, biodiesel, green diesel and vegetable oils can be used in the transportation sector to power vehicles. The vehicles powered by biofuels are clean and energy efficient. Such vehicles play an important role in achieving the EU policies and objective of reducing energy consumption and emission of carbon. (European Commission 2020)

Ethanol and biodiesel are the two liquid biofuels that are widely used as a transport fuel in the present time. These fuels have a high blending quality which makes them suitable to be used along with conventional fuels. Ethanol effectively blends with petrol whereas biodiesel blends with petroleum-based diesel (Fuel Blend 2020). So, these biofuels can be readily used in existing vehicles. The biofuels can also be supplied from the stations which supply petroleum fuels.

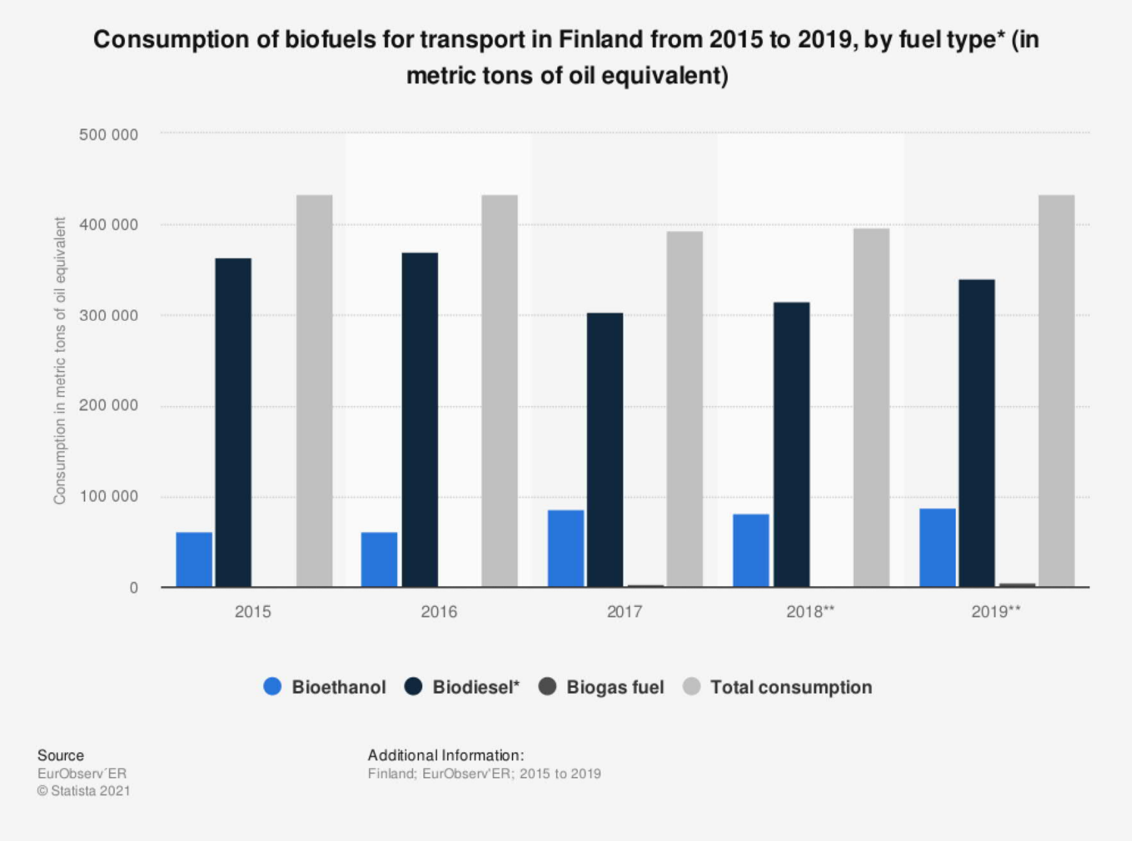

FIGURE 1. Consumption of biofuels for transport in Finland from 2015 to 2019 (Statista 2021)

From the graph above, it is clearly seen that the most used biofuel for transport in Finland from 2015 to 2017 was biogas fuel followed by biodiesel. Bioethanol has been least used as a transportation fuel in Finland. The trend of biofuel consumption is quite higher in 2018 in comparison to the previous year. Also, in 2019 the consumption is highest for all three kinds of biofuels compared to 2018. From this graph, it can be predicted that consumption will be even higher in coming years.

E85

E85 is an ethanol fuel type that can be used with FFV vehicles or the vehicle that has been later converted to FFV. In general, the range of ethanol content in E85 is 70 to 80% volume, however, in Finland, it is typically between 82 to 83 percent. (NEOT GROUP 2021)

In addition, RE85 is a specific ethanol biofuel produced by st1 company. The GHG emission from st1 was considered for this research to find out the production phase emission for E85, also known as Well to tank (WTT). According to st1, RE85 is a high alloy ethanol made from the bio waste collected in Finland which has a positive environmental effect despite the compromising in its efficiency because of its high-octane number. (st1 2021)

2.1.3 Flexible Fuel Vehicles (FFV)

Flexible fuel vehicles (FFV) can be known as a special kind of vehicle that can run on entire petrol or petrol blended with ethanol. However, at least 15 percent of gasoline blended with ethanol is recommended to ensure a start in cold weather. It is one of the vehicles that runs on alternative fuel and burns cleaner than other fossil fuels. These kinds of vehicles are equipped with the modified components so that they can operate with the blend of ethanol, otherwise, it is not possible in normal conventional vehicles. (US Department of Energy 2010)

In the context of Finland, traditional cars can be converted to FFV with few modifications in the engine. Smart fuel control E85 v7 and eFlexPro E85 are some of the examples of conversion kits that can upgrade most of the existing conventional cars to FFV. In this research, a conventional car upgraded to a FFV was chosen to compare with other vehicle types.

2.2 Electric batteries

An electric battery is a mechanical device that stores electrical energy in the form of chemical energy. A battery is composed of electrochemical cells and it has two terminals. The positive terminal is called cathode and the negative terminal is called anode. It is used to power different devices such as radio, tv remotes, torch light, mobile phones, electric cars, etc. Batteries have been around us for more than 200 years already. But most of the batteries were non-rechargeable and needed to be replaced after complete depletion. The first lead-acid rechargeable battery was invented in 1859 by Gaston Plante. (Battery university 2020)

The three most popular battery types are lead-acid, nickel based and lithium-based batteries. Due to the low specific energy, low energy density and limited life cycle of lead-acid batteries, they were replaced by nickel batteries. Nickel batteries are better than lead-acid batteries in terms of their rapid recharge rate, long life and availability in different sizes with different designs. However, it is difficult to manage the waste collected during the production of such batteries. So, lithium-ion based technology is most preferred in comparison to lead-acid and nickel-based batteries. They offer high energy density, long cycle life and are lighter in weight than the other batteries which make them most efficient to use. (Chodakowska 2018)

The variation that comes with the batteries is the size of fuel cells and cathode type used for it (Amsterdam Roundtables Foundation, 2014). Batteries used in the car determines the strength and flexibility for the users so most of the EV companies are having partnerships with different battery suppliers and looking for advanced battery pack development. Since batteries are the prime reason for the high price of EVs, the development of battery technology and the declining price of batteries might play a significant role in the overall growth of EVs users. (Muhonen 2016)

NMC (Lithium Nickel Manganese Cobalt Oxide)

NMC refers to the lithium battery which is a cathode combination of Nickel, Manganese and Cobalt. This kind of battery chemistry is widely used and famous for electric cells or as power cells. Nissan leaf 40kWh, a representative for an electric vehicle in this study, uses the NMC battery. Moreover, NMC is a popular choice as a power tool in electric bikes or other sorts of electric powertrains.

Nickel is renowned for its high specific energy, while manganese is known for achieving low internal resistance despite the low specific energy. The combination of these metals strengthen each other. The combination of cathode in general is one third of Nickel, another third of Manganese and the remaining third of Cobalt, however, the high price of cobalt is resulting in a reduction of cobalt content. Nickel content cathode is being used to reduce cobalt content because of its low price. In addition to lower cost of nickel-based systems, it has high energy density with a longer life cycle than the cobalt based system. In contrast, nickel based systems have a relatively lower voltage than cobalt based systems. Overall, NMC is economical with better performance and excellent specific energy. (Battery university 2021)

2.2.1 Electric Vehicle

Most of the electric vehicles today run on the lithium-ion batteries due to their high energy density and high capacity. They are the most essential source of power for these vehicles. These vehicles have become more popular due to zero emissions of greenhouse gases. There are three basic designs of electric cars namely series parallel hybrid car, plug-in series hybrid electric vehicle (PHEV) and battery-powered electric vehicle (BEV).

The series-parallel hybrid car consists of both the combustion engine and electric motor which supplement each other. The plug-in hybrid vehicle has an electric battery that can run up to 50 km and an engine that provides power for long distance driving. Finally, there are fully battery powered vehicles that have a large battery that can run up to 200 to 300km. PHEV and BPEV are getting more popular as compared to series-parallel hybrid cars which have been used for more than a decade already. These vehicles are quite costly due to their large batteries and charging system. (Van Vliet et al. 2011)

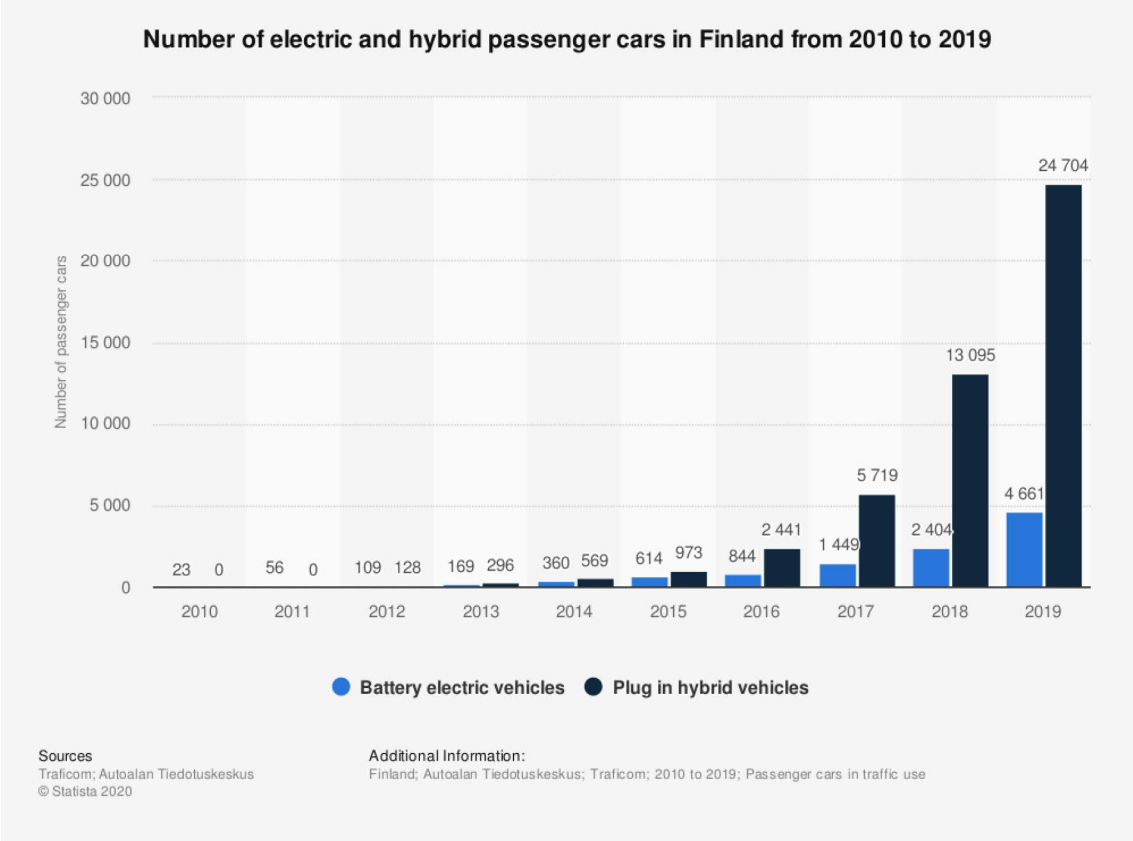

FIGURE 2. Number of electric and hybrid passenger cars in Finland from 2010 to 2019 (Statista 2019)

From the above graph, the growth in the adaptation of plug-in hybrid vehicles (PHEVs) and electric vehicles (EVs) can be clearly seen. The number of PHEV had increased by 88%, while the number of EVs by 93%. However, there is a huge difference in the total number of EVs and PHEVs which shows less preference of EVs over PHEVs.

2.2.2 Electric Vehicle in Finland

According to the statistics of 2019, Tesla Motors completely rules the Finnish roads. Out of the total of almost 4,700 electric cars in Finland, more than 2000 cars are manufactured by the company. Nissan is the second common brand in Finland with 973 passenger cars on road. It is then followed by Hyundai with 481 cars, Volkswagen with 313 cars, BMW I with 175 cars and Audi with 163 electric passenger cars on the road. (Statista 2020)

Just like conventional vehicles run on fuels, electric cars run on batteries which require charging from time to time. Earlier, there were very few charging points, but the numbers have increased with the growing number of electric vehicles. There were about 1109 charging stations in Finland as of June 2020 as shown in figure below. But they are mostly located in the major cities as the Uusimaa region possess about one-third of the total. There are few charging stations other than the main road networks but they are quite far from each other.

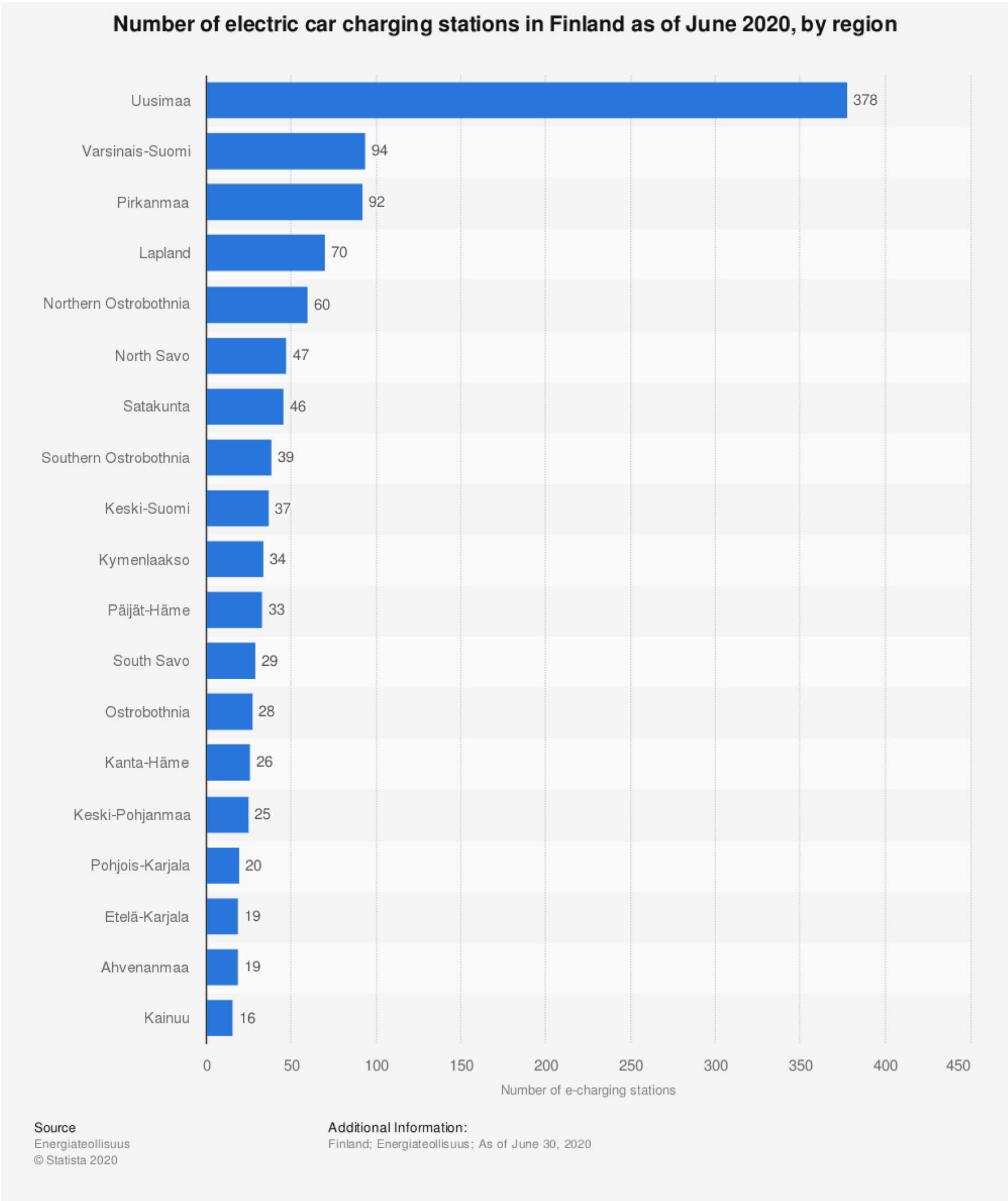

FIGURE3. Number of electric car charging stations in Finland by June 2020 (Statista 2020)

Nissan Leaf 40kWh

Nissan Leaf is one of the most popular electric cars on the Finnish road. It is the first mass market electric car that was manufactured in 2011. It is now in its second generation which came out in 2018. This car has 150 miles of an estimated range and a 40kWh electric battery. With a 40kWh battery, it has increased its performance to a 147-horsepower electric motor. (Edmunds 2021)

Nissan Leaf 40kWh, an electric car considered car for this research, is a midsize automatic car with front-wheel drive. Electricity is the only source of energy for this car. It takes about 8 hours at 240 V to charge its battery. It can be charged at any charging station in Finland. (Fueleconomy 2021)

2.3 Internal Combustion Engine

Even though ICE (Internal Combustion Engine) has led to numerous problems concerning the quality of the environment, it is one of the greatest achievements enumerated in human history. With petrol and diesel as the prime fuel, this engine is still the most popular and convenient way of transportation. It can be predicted that the ICEVs will dominate the automobile industry for many more years considering its advantage over biofuel and electric batteries in terms of price, range of mileage and efficiency. (ScienceDirect Topics 2011)

The conventional internal combustion engine is a type of heat engine where the hydrocarbon fuel is combusted in the presence of an oxidizer transferring chemical energy to mechanical energy. The process is accomplished under a high-pressure condition exerting force on a moving part which is mostly a piston, turbine or nozzle. The very first combustion engine was successfully developed by Étienne Lenoir in 1859. (Gusev 2016)

Toyota Corolla

Toyota is one of the most popular car brands in the world. It is a Japanese brand which is known as a well-designed vehicle. The Toyota Motors Corporation

(TMC) produces cars, minivans, trucks and SUVs. Toyota Corolla is an immensely popular car model launched during the ‘60s. (Edmunds 2021)

The 2019 Toyota Corolla Automatic (AV-S7) with a 1.8 L tank and 4 cycles has been chosen for this research. This car has an estimated range of 409 miles and runs on petrol. It is a midsize car with a front-wheel drive. (Fueleconomy 2021)

2.3.1 Fossil fuels in Finland

Fossil fuel generally refers to a source of energy that can be retained from biomass that has been formed and stored under the earth’s crust for billions of years. It collectively represents coal ignite, natural gas, fuel oils refined from crude oil. Even though peat is a younger phase of fuel, it is considered as a fossil fuel. However, diesel and petrol are the most popular form of fuel oil available all over the world.

Fossil fuels, traditional main sources of energy, have been responsible for air pollution and global warming which also causes negative effects in social and health aspects leading to low quality life of populations. In addition, it is important to understand that fossil fuel is a renewable source of energy and their depletion in the earth raises questions against the sustainable energy system and the availability for future generations. However, many European countries including Finland are still hugely dependent on fossil fuels. (Martins, Felgueiras & Smitková 2018)

Moreover, according to Statistics Finland, the share of energy production from fossil fuels and peat increased by 14 percent in 2018. Oil contributed 22% share in the total energy consumption in 2018, according to Statistics Finland. The consumption of petrol has been falling; however, the use of diesel has been still on the track of growing. The most notable use of diesel is in the sector of transport of trade and industry. In the case of Finland, the bioliquid component has been composed of petrol and diesel as a transport fuel. This renewable source of driving power in domestic roads is contributing 9.5 % share in total, whereas 9.2% is contributed by liquid biofuels, 0.1% by electricity and the remaining 0.3% by gaseous biofuel. (Statistics Finland 2018)

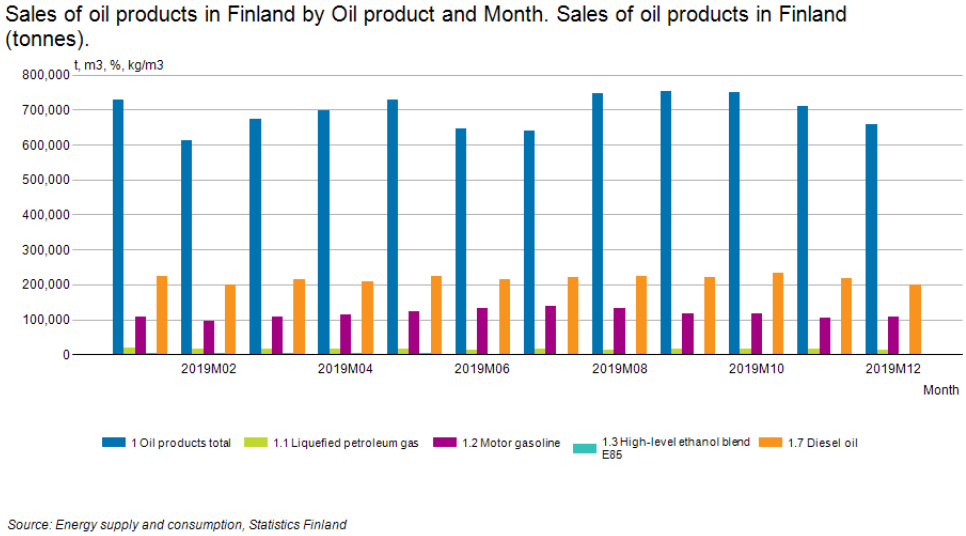

FIGURE4. Sales of oil product in Finland by oil product type (Statistics Finland)

3 METHODOLOGY

The research model includes the quantitative differences of GHG emissions of the three types of passenger cars. So, the three cars chosen differ in terms of their propulsion system. There has been a tremendous amount of research on this subject in different parts of the world. But this research is mainly focused on the Finnish transportation system.

Three different models of cars representing ICE, BEV and BFV that run on different fuel types were chosen and compared based on greenhouse gas emissions during their whole life from production to operation. To find out the differences in environmental impact with the different modes of vehicles and fuel types, the quantitative data of Life Cycle Assessment (LCA) were retrieved through the literature review. The results have been discussed based on relevant and existing literature, figures and tables. Detailed explanations for each of these processes are made available in their respective section down below.

3.1 Research question and objectives

The main objective of the research was to determine the vehicle type which would lead to lower GHG emissions. 'The lesser the emission, the better the vehicle' was the theme of this research. Even though there were several numbers of articles published in this topic, a research gap was observed that all the three modes of transportation have not been compared to each other in the case of Finland.

This research aimed to analyse the following research questions:

1. Which type of vehicle emits more GHGs among ICEV, BEV and FFVs?
2. Does the adaptation of electric cars and flexible fuel vehicles help to meet EU and national targets?

3.2 Research Design

The research was focused on the environmental impact of the three vehicles in the long run. Analyzing the emission during the whole life of vehicles helped to determine the better mode of sustainable transportation in the context of Finland. The assumption and data were taken considering the context of Finland.

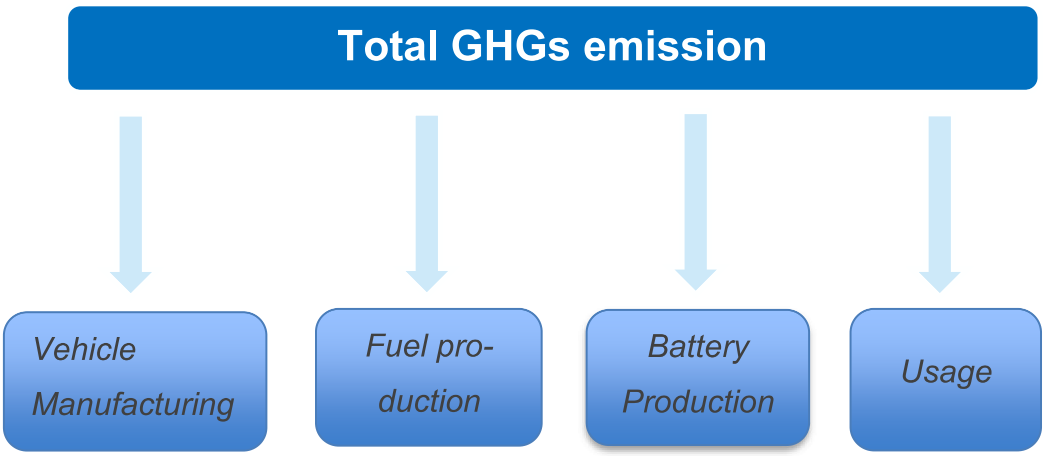

DIAGRAM 1. A conceptual model for calculation of total GHGs emission

The total GHG emission was determined by the results obtained from the study of previous existing research on life cycle assessment (LCA) of the vehicle and the well to tank (WTT) emission of fuel types. The following diagram explains the process of calculation of emissions in detail for each of the vehicles.

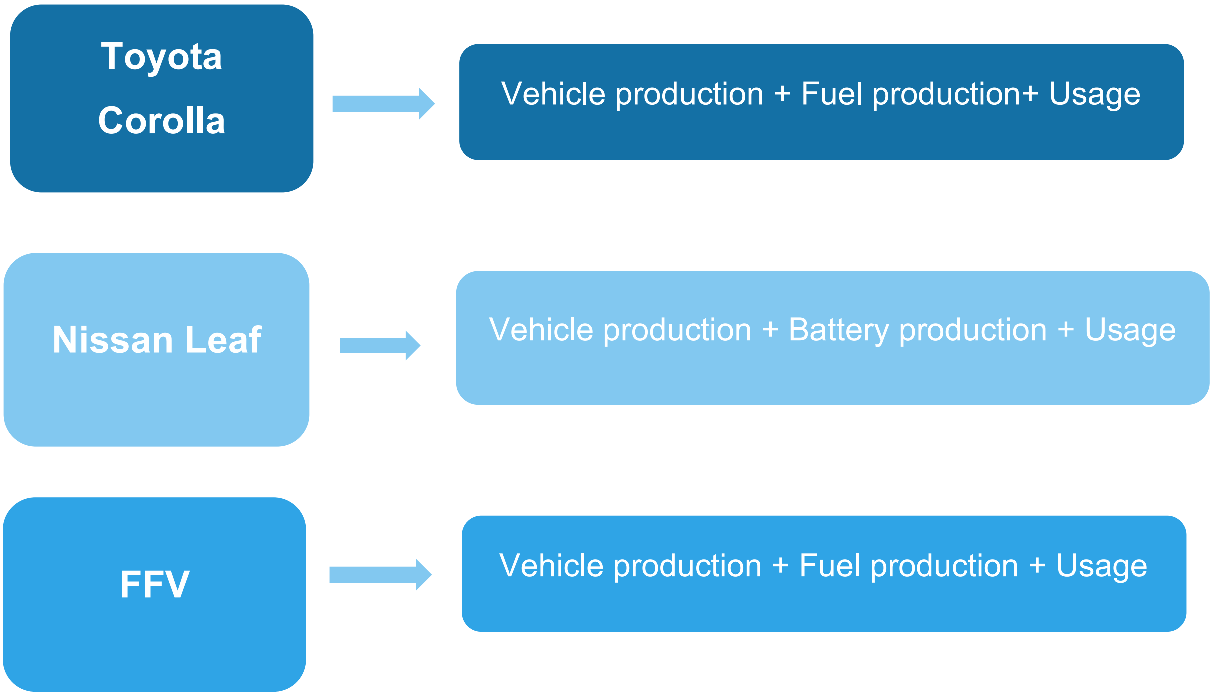

DIAGRAM 2. A conceptual model for calculation of total GHGs for each vehicle types

Two mid-range passenger cars, Toyota Corolla and Nissan Leaf were taken as representatives for three vehicle types. The GHG emission of ICEV (Toyota Corolla) and FFV comes from vehicle production, WTT emission and usage whereas the emission of BEV comes from vehicle production, battery production and usage.

3.3 Analysis of Environmental Aspect

It is important to understand the term “Life cycle Assessment (LCA)”. LCA of a vehicle is defined as a comprehensive technique to assess a vehicle's impact on the environment throughout their whole life from the manufacturing of raw materials to the vehicle scrapyard, by quantifying the impact of each stage (WorldAutoSteel 2021). However, in this case study, the emission during the end-of-life treatment was not considered which mostly refers to the vehicle dismantling and recycling of the material associated.

WTW (Well to Wheel) represents the emission involved from the production phase of oil to the combustion which can be subcategorized into two parts, ‘Well to Tank (WTT)’ and ‘Tank to Wheel (TTW)’. Well to tank is also known as indirect emission which represents the emission from the production phase of oil and tank to wheel is the direct emission from the vehicles, also known as tailpipe emission.

3.4 Scope

Three different vehicles running on each of the fuel types - gasoline, electric battery and bioethanol were chosen. The cars were selected according to their popularity in each category in the Finnish context. These cars differ in their propulsion system. All of the cars have been popular on the Finnish road as of 2019.

According to the statistics Finland 2019, Toyota Corolla was one of the most registered passenger cars in Finland. So, the Toyota Corolla was represented as an internal combustion engine vehicle. Petrol is the source of energy for this type of vehicle.

In the same way, Nissan Leaf was selected to represent the BEV as over nine hundred electric passenger cars on the road in Finland were from the Nissan brand in the year 2019. It has been one of the most used electric cars in the country.

Biofuel vehicles were also an important part of our study, however, there was no comprehensive information on originally developed mid-range passenger cars which would run on biofuels. So, flexible fuel vehicles (FFV) were considered for the research by the assumption that an ICEV could be converted to FFV. The Toyota Corolla model used to represent ICEV was considered as a flexible fuel vehicle that runs on biofuel, ethanol (E85). There has been a trend in Finland of converting old traditional vehicles into FFVs. So, the Toyota Corolla was assumed to be a FFV.

3.5 Sources of Data Collection

A website “fueleconomy.gov” was used to figure out the tailpipe emissions from petrol for the Toyota corolla and Nissan Leaf. Another website “lipasta.fi” was used to find out the tailpipe emissions for ethanol. Along with that, the sustainability report from the car companies and energy company st1 were analyzed to collect the data related to the GHG emissions during the vehicle manufacturing, battery production and WTT emissions. Likewise, a website “carbonfootprint.com” was used to calculate the emission factor of electricity in Finnish mix to calculate the emissions during the usage phase of Nissan leaf 40kWh. Mentioned sources of data have been listed below:

1. Lipasto.vtt.fi
2. https://www.fueleconomy.gov/feg/findacar.shtml
3. Sustainability Report 2020 Nissan Global
4. Sustainability Data Book 2019 TMC (Toyota Motor Corporation)
5. Sustainability Report St1
6. Carbonfootprint.com
7. Statistics Finland

4 RESULTS

4.1 GHG emissions during the vehicle production

When comparing the GHG emissions, it is not enough to consider only the emissions during the use of the vehicles. A significant amount of GHG is emitted during the production of the vehicles as well. To carry out this operation, the environmental reports published by each company were analyzed.

Toyota Corolla

According to the Sustainability Data Book 2019 published by Toyota Motor Corporation (TMC), the total amount of CO_2 produced during the manufacturing of Toyota cars was 1.11 million tons for the year 2019. The CO2 emission per unit produced was 0.387 tons which is 1.8% less than that of the previous year. The TMC calculated the emissions by conducting an LCA on five new and redesigned models (Century, Corolla Sport, Crown, and Lexus ES and UX) and one partially redesigned model (Probox/Succeed). So, this value of 0.387 ton was considered as the CO_2 emission during vehicle production for the Corolla model chosen for the research.

Nissan Leaf

Nissan Leaf is one of the models of the electric cars manufactured by Nissan Global. The environmental data by Nissan Motor Corporation for the year 2020 indicates that the total CO2 emissions from manufacturing processes were 2.408 million tons for the fiscal year 2019. And, the manufacturing CO2 emissions per vehicle produced was 0.51 tons which is about 30.1% less than the emissions in fiscal year 2005. The company produces both ICEVs and BEVs so this figure represents an overall average value of CO2 emitted during the production of the vehicle body.

TABLE 1. Average emission of each vehicle types during vehicle production

Model	Average Emission (Ton)
Toyota	0,387
Nissan Leaf	0,51
FFV	0,387

4.2 GHG emissions during battery production

The emissions during the battery production is a crucial factor to determine if an electric car is a sustainable mode of transportation compared to others. Many research and studies have been done all over the world concerning the emission issue of batteries. Among all of these articles, the four most relevant research on the electric batteries were selected and suitable data was processed.

This section focuses on the GHG emission due to the 40 kWh battery used in the Nissan Leaf passenger car which is a representative of an electric vehicle (EV). NMC is one of the widely popular electric batteries that is used in this particular model of Nissan and this section has been focused on finding the emission data for this specific battery type.

According to Massagie (2017), who compared the emissions from different types of battery chemistry constructed in Europe, the emission for NMC type was 160 kg CO_2 eq/kWh. LCO chemistry type had a low emission of 56 kg Co2 eq/kWh whereas LFP battery had a high emission of 161 kg CO_2 eq/kWh. The key parameters to determine the environmental effects from the production of batteries were cycle life, calendric life and depth of discharge.

According to Hao et al. (2017), the emission from electricity during the production phase was around 40%. In addition, the emission associated with electricity production in China is twice as much as in the USA. In this research, the three most commonly used lithium-ion batteries, LMO, NMC and LFP were studied. A case study was performed using a 28 kWh battery and the GHG emission values were found to be 2705 kg CO_2eq/kWh, 2912 kg CO_2eq/kWh and 3061 kg CO_2eq/kWh respectively for the three battery types mentioned above.

According to the research on lithium-ion batteries by Emilsson and Dallöf (2019), an emission of 61-106 kg CO_2eq/kWh of battery capacity was estimated for the most common NMC battery chemistry. According to the authors, the estimation was based on new and transparent data. In contrast, the estimated emission was 150-200 kg of CO_2 per kWh for an earlier article in 2007.

Using a probability approach by taking 24 of the hypothetical vehicle models based on the current market of the USA, Ambrose and Kendall (2016) have compared LCA GHG emission for lithium-based traction batteries. The LCA emission has been stimulated from five of the commercial batteries' chemistry. Among all of the five commercial batteries, the emission during the production of NMC batteries was 254 kg CO_2eq per Kwh. However, the result from this analysis is far more distant than the previous studies.

TABLE 2. Emission during production of batteries from different authors

	Articles	*Battery production emission ($KgCO_2eq/kWh$)*	*Average*
NMC Battery Chemistry	Massagie (2017)	160	158 (Kg CO_2eq per kWh)
	Hao, et al. (2017)	104	
	Emilsson and Dallöf (2019)	61-106	
	Ambrose and Kendall, (2016)	254	

4.3 GHG emissions during Well to tank (WTT)

In this section, WTT (Well to tank) emission will be discussed and literature review was done to figure out the appropriate data.

According to Autoalan Tiedotuskeskus (2019), the average age of passenger cars in Finland is 12,2 years. The average distance travelled by the passenger cars in Finland in 2019 is 13,600 km per car. (Statistics Finland) Then, the total distance travelled by a car in its total lifetime is about 13,600*12,2 = 165920 km. The consumption rate of E85(High blend ethanol) is 6 litres per 100km, as per the data from LIPASTO (VTT Technical Research Centre of Finland Ltd). So, the total amount of ethanol consumed during the whole life of FFV is about 6 ltr/100 km x 165920 km = 9955,2 litres.

Ethanol(E85)

As stated by the Sustainability Report 2019 of ST1 company, the table below is discussed.

TABLE 3. Emission and production of ethanol for st1 company

Total Production	Amount
Ethanol	8662 Tons
Emission	6848 Tons

About 8662 tons of ethanol was produced by St1 company in 2019 which led to an emission of about 6848 tons of GHG. 8662000 kg of ethanol is equal to 11032989,4 litres, assuming a conversion factor of 0,7851, using the website "endmemo.com". So, the GHG emission rate of the ethanol is 0,62 kg CO_2e/litre. At this rate, the total emission from the use of ethanol (E85) during the lifetime of FFV is 6172,224 kg CO_2 eq. It was assumed that the WTT emission from the pure ethanol of St1 was the emission for E85 which is composed of 80% ethanol and 20% petrol. The emission due to the petrol was ignored to avoid the possible complications during the calculation process.

Petrol

In this section, JEC well to tank report V5 will be analysed and followed. The report is a well to wheel analysis for the future automotive fuels and powertrains in the context of Europe. The result from this study was a consequential approach, aimed relevant for policy making. The study has figured out a minimum and a maximum value for the total well to tank emission in the case of petrol. The maximum value stands for 17 kg of CO_2 per GJ, whereas the minimum stands for 13,1 kg CO_2 eq per GJ. Assuming the average from the range helps to figure out the estimation of emission for this study which is 15,05 kg CO_2 eq per GJ.

The energy consumption of gasoline is 1,9 MJ/km, according to the LIPASTO. At this rate, the total energy consumed during the lifetime of a passenger car in Finland is 1,9 MJ/km x 165920 km = 315248 MJ. Using this data, the GHG WTT emission from gasoline is about 315,248 GJ x 15,05 kg CO_2 eq/GJ = 4744,5 kg CO_2 eq.

TABLE 4. Emission during production phase for petrol and E85

Fuel type	WTT emissions Kg
Petrol	4744,5
E85	6172,224

4.4 GHG emissions during the operation of vehicle

The GHG emission during the operation of a vehicle is the tailpipe emissions also known as Tank to Wheel (TTW) emission. It covers the main part of the emission during the life cycle of a vehicle. The emission from all three types of vehicles are as follows:

Toyota Corolla

At 286 grams of GHG emission per mile that translates to 178,75 gm/km, GHG emissions over the lifetime of Toyota Corolla in Finland when the regular gasoline used is calculated as follows: 165920 km x 178,75 gm/km = 29658200 gm = 29658,2 kg

Nissan Leaf

The Nissan Leaf uses about 30 kWh of electricity per 100 miles which translates to 0,186 kWh/km. At this rate, it consumes a total amount of 165920 x 0,186 = 30929,45 kWh electricity over a lifetime of 12,2 years. According to Carbonfoot-print.com, it translates to 4212,59 kg of CO_2 in the Finnish electricity mix where the conversion factor is 0,1362 kg CO_2eq per kWh.

Flexible Fuel Vehicle (Toyota Corolla)

The tailpipe emission of GHG due to high blend ethanol (E85) which has 85% of ethanol mixed with 15% petrol is 27 gm/km. At this rate, the total emission during the lifetime of Toyota Corolla due to the use of ethanol is about 27 gm/km x 165920 km = 4479840 gm = 4479.84 kg.

TABLE 5. Emission during usage phase for each vehicle types

Vehicle Model	Usage emission (Kg)
Toyota Corolla	29658,2
Nissan Leaf	4212,59
Flexible Fuel vehicle	4479,84

4.5 Comparison of emissions from the early stage

The GHG emission during the early stage includes the WTT emission of the fuels and the emission from the battery production process. From the graph, it is seen that the WTT emission of petrol is 4744,5 kg CO_2 eq and that of ethanol (E85) is 6172,224 kg CO_2 eq. And the emission during the production of the battery of an electric car is 6320 kg CO_2 eq. It can be clearly observed that the emission from E85 and battery production is almost the same and both emissions are more than that of petrol.

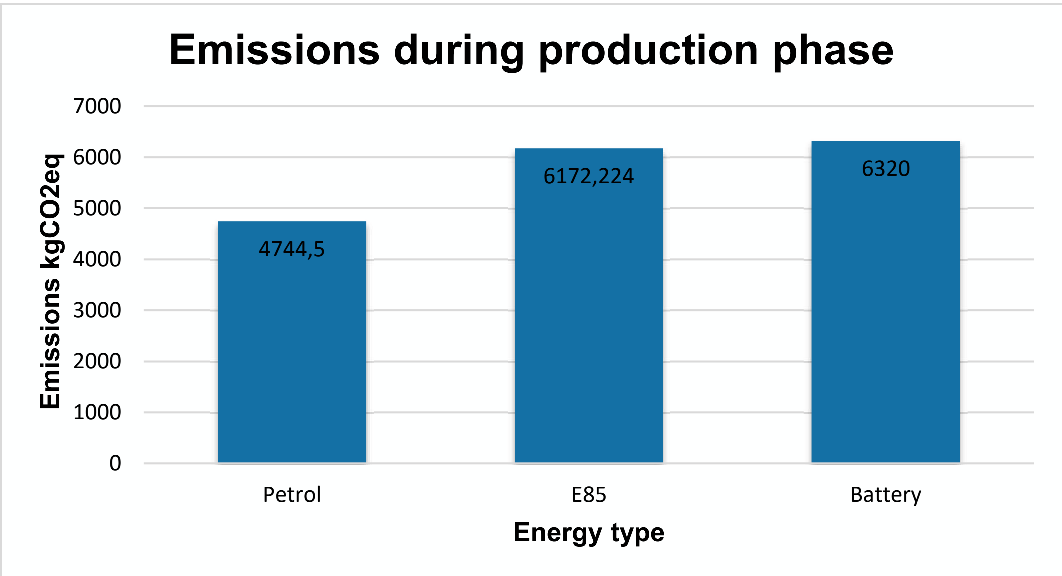

FIGURE 5. Emission from the production phase for each energy types

4.6 Comparison of emissions from the vehicle manufacturing

The GHG emission during the vehicle manufacturing phase shows that the electric car has the highest amount of emission in comparison to ICEV and FFV. Nissan Leaf has an emission of 510 kg CO_2 eq whereas the Toyota Corolla has an emission of 387 kg CO_s eq. In comparison, the emission of Nissan Leaf is about 32% more than that of Toyota Corolla. The emission of both ICEV and FFV remains the same as the Toyota Corolla was assumed to be converted into FFV.

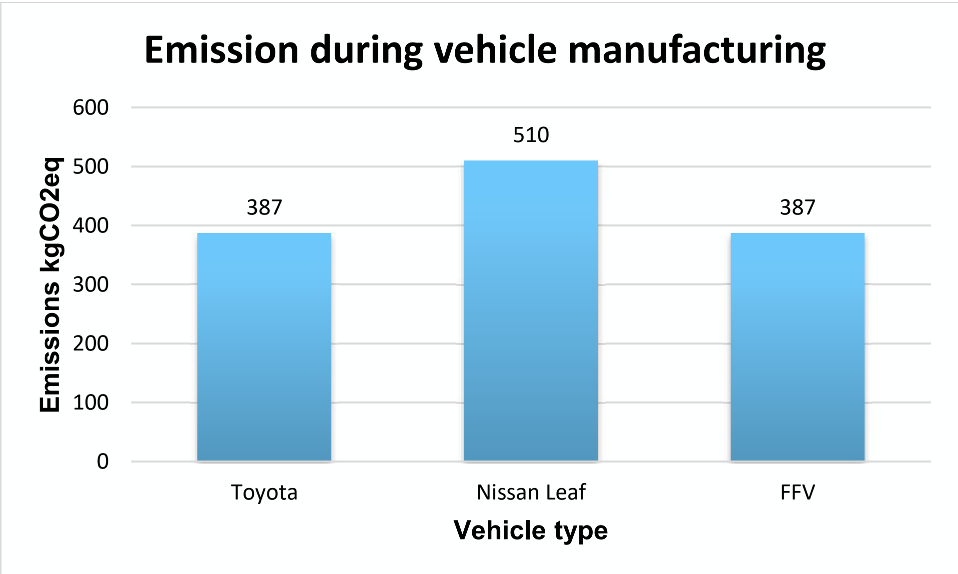

FIGURE 6. Emission from the production phase for each vehicle types

According to the result obtained from this methodology, it could be misleading as the emission from electric cars is noticeably higher than emission from Toyota corolla (ICE). However, the emission for each of the vehicle types is an overall average of GHG emission from both conventional and electric cars. In the case of Toyota, LCA of five new and redesigned models (Century, Corolla sport, Crown and Lexus ES and UX) and one partially redesigned model (Probox/Succeed) were taken into account. In the case of Nissan Leaf, the average emission of all the cars manufactured by the company was considered. So, it should be noted that the emission from vehicle production is one of the assumptions in the methodology and the results obtained may not represent the exact scenario. It would be quite interesting to find out the differences in the emission during the manufacturing of electric vehicles and conventional vehicles from each company despite not being included in this study.

According to the environmental report of Nissan (2020), a major part of this emission comes from the consumption of energy generated by fossil fuels. About 30% of the emission from the plants is due to the painting of vehicles. The cast iron melting, assembling of vehicle parts and transportation are also responsible for increasing the emission during production. Similarly, according to the sustainability report of Toyota Motor Corporation (2019), the total amount of CO2 emission during the production includes the emissions from material and parts manufacturing, vehicle assembly, upstream transportation and maintenance, etc.

4.7 Comparison of emissions from the usage phase

The GHG emission during the usage phase is the gas released by the cars in the form of tailpipe emission while driving. It has been observed that the emission from the Toyota Corolla which runs on gasoline is about 29660 kg CO2 eq. The GHG emitted by Nissan Leaf during the charging of its battery is 4212,59 kg CO2 eq and FFV which runs on ethanol (E85) is 4479,84 kg CO2 eq. So, the emission of Toyota Corolla is about 7 times more than that of Nissan Leaf and FFV. Meanwhile, the usage emissions difference between Nissan Leaf and FFV seems identical, however, FFV wins the battle.

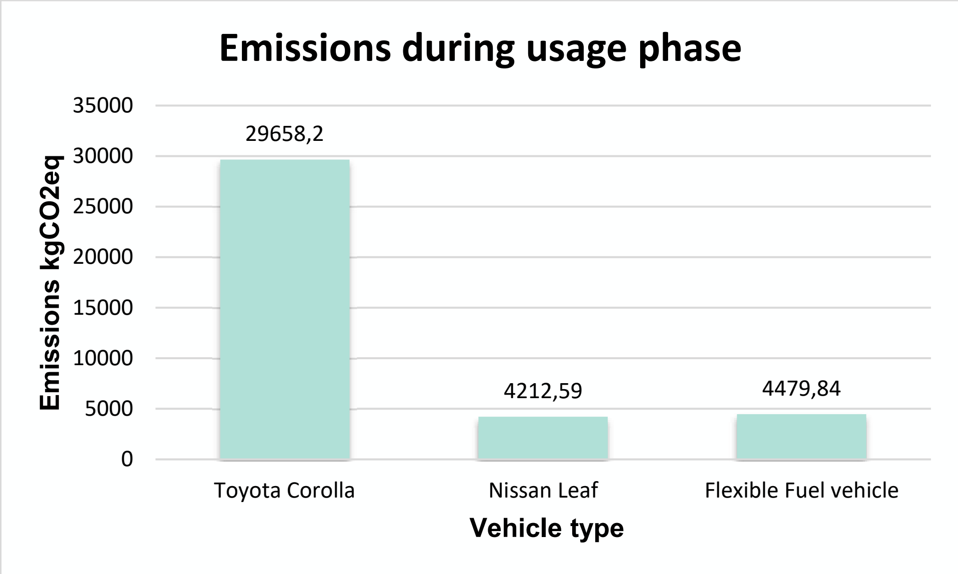

FIGURE 7. Emission from the usage phase for each vehicle types

4.8 Comparison of overall emissions

In the following graph, the emission of the three propulsion systems for various stages have been compared to each other in CO2 equivalent. At the early stage, the emission of Toyota Corolla is nearly 5000 kg. It is lower than the emissions from both Nissan Leaf and FFV. The emission of Nissan Leaf is about 6320kg and that of FFV is 6172kg. The next stage is the process of vehicle production which seems to emit the least amount of greenhouse gases. As seen from the graph, all three vehicles emit almost equal amounts of CO_2 in the production phase. The emission of Toyota Corolla and FFV remains the same at 387kg whereas the Nissan Leaf emits 510kg of CO_2 eq. Finally, it can be observed that a significant amount of CO_2 is released in the usage of the vehicles. The tailpipe emission is maximum for Toyota Corolla followed by FFV and Nissan Leaf. Nearly 30 thousand kg of CO_2 equivalent is released by Toyota Corolla, 4213 kg by Nissan Leaf and 4480 kg by FFV in the final stage.

The maximum amount of CO_2 is released by Toyota Corolla through the usage in the form of tailpipe emission. Nissan Leaf expels the most amount of emission during the early stage which includes the process of battery production. In FFVs, the highest CO_2 emission occurs in the early stage i.e., WTT emission.

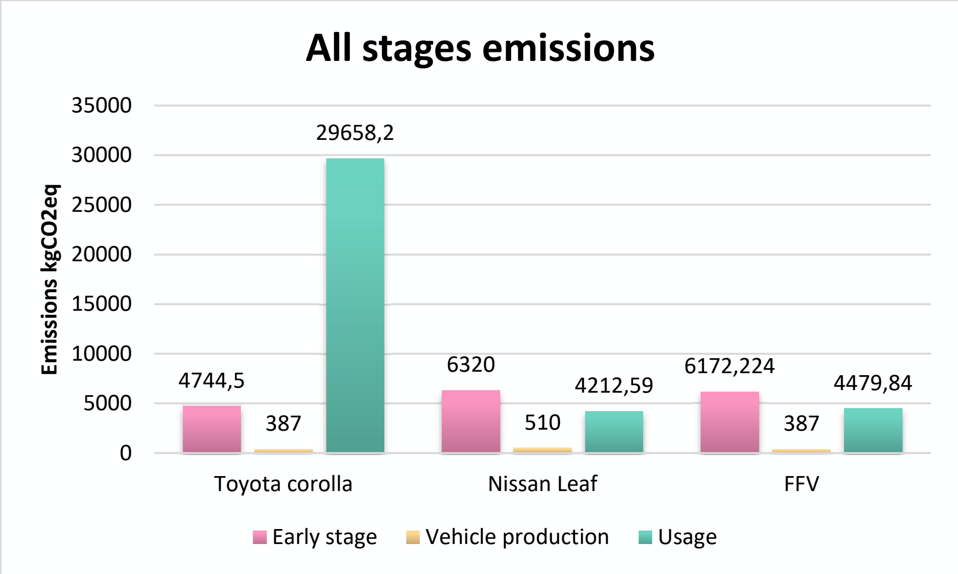

FIGURE 5. Emission from all stages for each vehicle types

The overall emission of the three vehicle types are also compared to each other. The graph clearly explains that the Toyota Corolla has the highest emission during its life cycle. It is then followed by Flexible Fuel Vehicle and Nissan Leaf. The Toyota Corolla emits a total of 34790 kg CO_2 equivalent from the process of fuel production to operation. FFV has an emission of about 15905 kg CO_2 equivalent which is almost as half as that of Toyota Corolla. Nissan Leaf has the least amount of total CO_2 emission which is 15765kg CO_2 equivalent. The electric car and FFV have a difference of nearly 140 kg CO_2 equivalent.

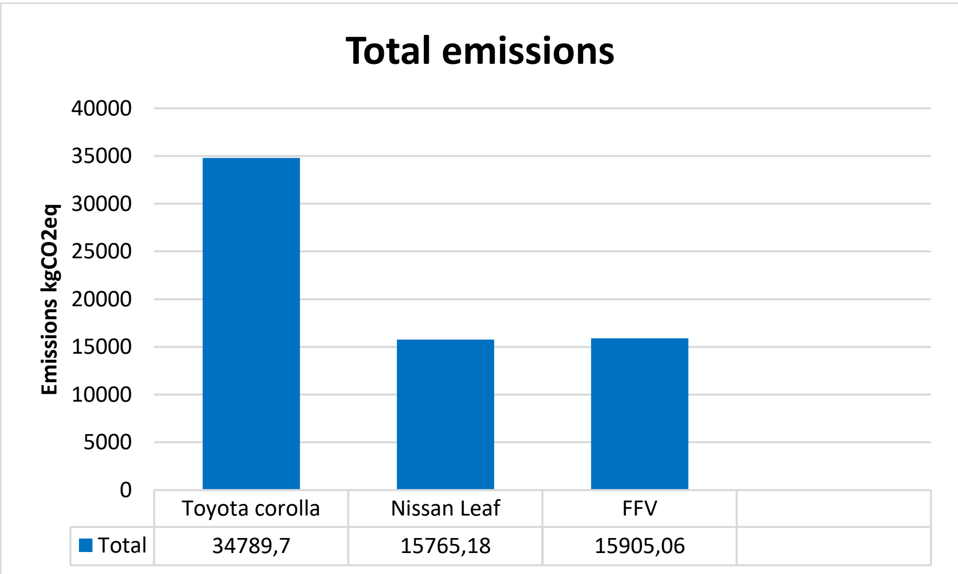

FIGURE 6. Emission in total for each vehicle types

5 DISCUSSION

The result clearly signifies that the adaptation of alternative vehicles contributes to the huge reduction in overall emission of GHGs. The emissions from the alternative fuel used in electric vehicles and flexible fuel are almost the same during their whole life. However, electric vehicles seem to be even more efficient in reducing the emissions. The emissions from electric vehicles and FFVs are at least five times lesser than the emissions from Internal Combustion Engine Vehicles (ICEV) during the usage phase.

It is important to understand how the electricity is generated during the production of electric vehicles. Even though the electricity itself is a clean energy, the emission during the production has a huge impact on overall emission made by a vehicle. After the review of articles by Massagie, Hao, Emilsson and Ambrose to calculate the average emission during the manufacturing of batteries, it can be concluded that the emissions during battery manufacturing highly depends on the electricity mix. Nearly 50% of emissions come from the electricity used during the process. The tailpipe emissions from electric cars cannot be considered zero until the electricity is fully generated using renewable fuels. Thus, with the increment in green electricity, we can lower the overall emission. According to the Finnish Energy (2019), the mix of renewable energy for the generation of electricity in Finland is 51%, which is relatively lower than many other European countries. Similarly, CO_2 neutral electricity is 85% for the year 2020.

According to IVL, a Swedish Environmental Research Institute 2019, there is an increasing supply chain risk for metals like lithium, cobalt and manganese. The cobalt is already scarce, so the content of cobalt is expected to decrease and the nickel content is expected to increase in newer batteries. This might lead to the supply chain risk for nickel, as well, in the near future. The recycling plays a very important role to conserve and maintain the supply chain of raw materials. In Europe, the recycling of cobalt, nickel and cobalt is progressing. However, this is not the case for lithium due to several factors. The relatively higher cost of recycling compared to the cost of raw materials along with the low volumes of battery collection is the main reason behind low scale recycling. In addition, according to the review article by Yang et. al., (2020), lithium battery industry has a high demand for mineral resources. In the year 2018, the global lithium production had increased by approximately 19% to 85 thousand tons. Also, the situation is the same for cobalt. An estimated amount of 200 to 500 million tons of used lithium-ion batteries were generated by the end of the year 2020. This situation has led to a threat to the environment and human health because of the use of many flammable organic and toxic compounds. So, the recycling of the used lithium batteries will help to reduce pollution in the environment.

Despite the less impact on the environment from the operation of electric vehicles, residents in Finland are not motivated to adopt it yet. The problem regarding the unavailability of enough charging stations is a key factor for the demotivation in purchasing electric vehicles. Most of the charging stations are located in major city areas, mostly in the Uusimaa region. This limits the passengers to make a long distance travel outside the city areas. According to the news article by “yle” published on 1st of August 2020, several housing companies in Finland have shown interest in installing charging stations. The Finnish government has also allocated 5,5 million euros for the installment of charging stations. The government plans to boost the number of electric vehicles by adding an extra number of 5500 charging stations at the residential areas. In contrast, according to the research done by Oksanen (2020) in his bachelor’s thesis, the major factor for the lack of motivation in the adaptation of electric vehicles is the high purchase price of electric vehicles in Finland. There seems to be a negligible role of other factors as a barrier of adopting electric vehicles.

According to the report published by “The Driven” (2019), the increase in battery production to meet the requirement of increasing electric vehicles has led to the reduction in the price of batteries. The batteries, whose prices were above 1100$ per kWh, had fallen to 156$ per kWh in 2019. It is also expected that the average price will be 100$ per kWh by 2023. This falling price of battery might have a positive impact on the electrification of vehicles since the price of battery is a prime factor for the higher cost of electric vehicles.

Since high blend ethanol helps to combust completely to burn cleaner, toxic tailpipe emission is reduced to a higher level. Emissions of toxic compounds like particulate matter (PM), carbon monoxide (CO), nitrous oxide (N_2O) from ethanol are significantly lower compared to petrol and diesel, according to the database of VTT Technical Research Centre of Finland.

According to statista (2019), new passenger cars registered in Finland with petrol engines is 82000 whereas diesel engines are 21000. However, passenger cars with diesel engines can take advantage of advanced diesel made of 100 percent renewable raw materials i.e., Neste My Renewable diesel. The diesel is a drop-in replacement fuel for conventional fossil fuel which can be used up to 100 percent as a neat biodiesel. This would facilitate the passenger to use biodiesel on existing infrastructure.

According to the article “Influence of Increasing Electrification of Passenger Vehicle Fleet on Carbon Dioxide Emissions in Finland” by Lajunen, A. et al (2020), adaptation of electric vehicles and increasing the mix of biofuels with fossil fuels are the prominent measures to lower the emission from the passenger vehicles. Additionally, the result from this research significantly predicts that the reduction in tailpipe emission is highly effective to meet the target set by the EU and the Finnish government. Moreover, the lowering of the average age of ICEVs would also be effective in the reduction of CO2 emissions.

6 CONCLUSION

From the aspect of environmental impact, electric cars and flexible fuel vehicles are the most suitable among these three cars in the context of Finland. Despite many reasons for the less adaptation of electric cars and flexible fuel vehicles, the continued use of existing conventional cars and purchasing new ones would not solve the existing problems related to GHG emissions. The residents of Finland have a great role to play to meet the EU targets and national targets. Choosing electric fleets over conventional cars that run on fossil fuels would certainly help to reduce the increasing rate of carbon emissions. Similarly, the conversion of old conventional cars into flexible fuel vehicles that run on high-blend ethanol will also contribute towards lesser emissions. In addition to that, the cars with existing diesel engines should be promoted to use drop-in biodiesel. The compatibility of biofuel with fossil fuel is a clear benefit of biofuels compared to electric cars. Moreover, the huge potential of Finland to produce biofuel proves to be an advantage over electric vehicles.

Even though the production and sales of electric vehicles compared to conventional cars are way behind, the increasing popularity of electric vehicles cannot be neglected. Advanced technology has made the price affordable compared to the past scenario, likewise, in the coming days, we can expect the price to lower with the advancement in technology. Despite the high cost of electric vehicles, there is a positive response from people towards these vehicles that contribute to achieve sustainability. However, there is still an effort required from the government to promote alternative fuels and vehicles.

Despite these assumptions and limitations, the result from the research showed that electric and flexible fuel vehicles are more eco-friendly compared to traditional conventional vehicles. However, further research needs to be carried out to obtain more precise results regarding the contribution of GHG emissions from each of the vehicle types.

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