https://www.welt.de/motor/article167053492/Elektro-Scooter-machen-mobil-in-der-Stadt.html

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Comparison of the Life Cycle of different scooters used in Berlin

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cc	cubic centimeter
cm^3	cubic centimeter
p*km	person-kilometer
km	kilometer
kg	kilogram
V	Volts
Ah	Ampere hour
kWh	kilowatt-hour

mg	milligram
m^3	cubic meter
g	gram
L	liter

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1. Introduction

The use of two-wheel vehicles is attractive in big cities due to the small size, that helps in the mobility, and also due to reduced costs compared to cars or other means of transport (European Commission, 2020). One of the most popular variants in urban centers are scooters with 50 cc engines (European Commission, 2020).

Despite the advantages for the users, some concerns regarding the use of these vehicles are constantly being discussed (Vasic and Weilenmann, 2006). Vehicles are reported as one of the main sources of urban pollution, that, besides the environmental impacts, can also result in health problems. One study performed in Berlin and Potsdam in Germany showed that the groups of vehicles which included mopeds demonstrated an increase in the amount of particulates between 30 and 40% compared to the reference values (von Schneidemesser *et al.*, 2019).

These mopeds or scooters are available in different models around the world. The oldest versions are usually two-stroke engines, that are often related to high emission of pollutants due to the fuel and oil mixture applied (Potera, 2004). There are several studies that relate the high pollution levels in big city centers to the use of this type of equipment (Platt *et al.*, 2014). An incremental improvement was the development of four-stroke engine scooters (Potera, 2004). During the use phase, four-stroke engines emit less hydrocarbons, carbon oxides, and particulates, but they cause higher emissions of nitrogen oxide than vehicles with two-stroke engines, according to the Manufacturers of Emission Controls Association (MECA, 2014). More recently, electric scooters are also being applied, and despite the reduced emissions in the use phase, the electricity production needs to be considered when evaluating the environmental impact of these models. Consequently, comparing the environmental impacts of each model and understanding the hotspots of the life cycle represent one way to identify how to reduce the problems caused by scooters and how to understand better the challenges of urban mobility.

2. Goal and Scope definition

The goal of this work is to compare the environmental impacts from the production until the end of life (from cradle to grave) of three different scooters (50 cm^3) used in Berlin, Germany. The first model is an electric scooter, the second model is a two-stroke engine scooter, and the third model is a four-stroke engine scooter. For the motor scooters, while possible and to maintain the coherence, references according to EURO2 are selected, considering direct injection and catalyst.

In order to compare the different models, Life Cycle Assessment is applied, using the software openLCA, and the database ecoinvent 3.6. The Functional Unit defined is 1 p*km (person-kilometer). In an attempt to evaluate and quantify the impacts of the production of the raw materials, production of the scooter, transportation, use and dismantling of the different scooters, ReCiPe 2016 Midpoint (H) is selected and all the impact categories available in this method are considered in this study.

Figure 1 and Figure 2 represent the system boundaries of the process implemented. Figure 1 represents the electric scooter, and Figure 2 the motor scooters.

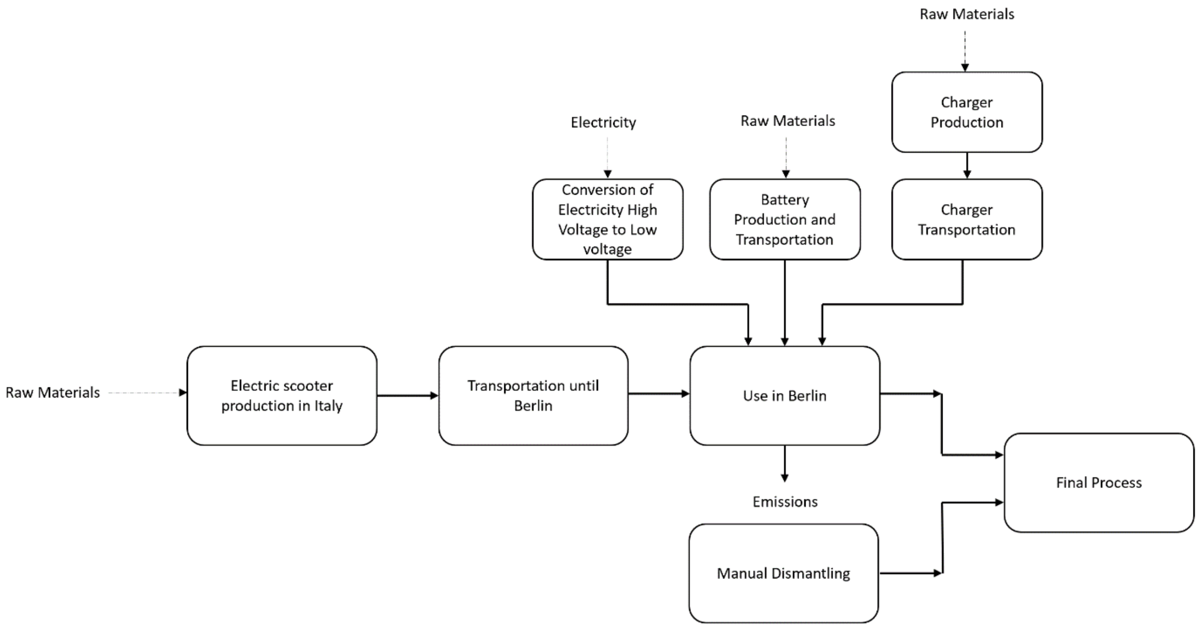


Figure 1: System Boundaries of the Electric Scooter

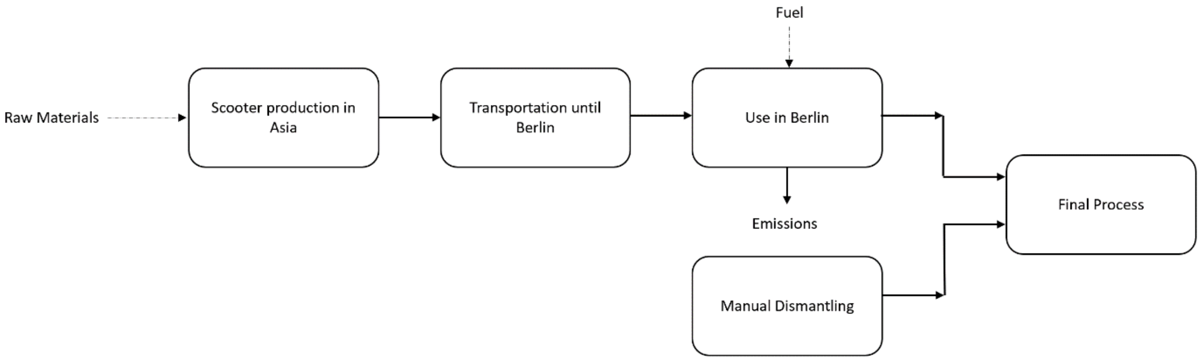


Figure 2: System Boundaries of the Motor Scooter (Two-stroke and Four-Stroke)

2.1. Assumptions

Some assumptions are defined with the aim to simplify the modeling process. The life expectancy for all three scooter models is estimated at 50,000 km (Leuenberger and Büsser, 2010). The number of passengers considered, also referred to as average occupancy, is 1.1 passenger for each model, due to the extra seat available in all the models (Leuenberger and Büsser, 2010). Therefore, the total life expectancy of each scooter considered is 55000 p*km.

Even if all scooters considered in this work are used in Berlin, they are produced in other countries. It is defined that the three different models are produced in different regions of the world, due to the different technologies employed for each of them. It is assumed that the electric scooter is produced in Italy, in reference to the production of the model Vespa Elletrica (Vespa, 2018a), while the motor scooters are produced in Asia. The four-stroke scooter considered comes from Japan (Yamaha, 2018) to Europe and the other model (two-stroke) is manufactured in China. For the transportation from Asia, it is considered first a transportation by ship until Rotterdam, then by train until Berlin city center, and, lastly, by lorry. For the transportation of the Italian model, it is assumed a first step by lorry until Milan, then by train until Berlin, and again by lorry until the Berlin city center.

Despite all the scooter models considered have the same capacity (50 cm^3) and also the same production process (for motor scooters) in the database is considered, the models and their weight are still different. Fuel consumption and other parameters are also modified. Table 1 summarizes the different parameters of the scooters. The models of reference considered are applied to estimate the place of production and the weight of the model. The fuel consumption/ electricity consumption is used according to the information provided by the supplier for the electric scooter and for the four-stroke scooter models. As this data could not be obtained for the other scooter (two-stroke), a value from a similar model is applied. Other parameters, unless when specified, are not defined considering these models, due to the lack of the data available, such as the materials used in the production of each model.

Model	**Electric Scooter**	**Two-stroke Scooter**	**Four-stroke Scooter**
Source	(Vespa, 2018b)	(Genuine Scooter Company, 2020)	(Yamaha, 2018)
Capacity (cm^3)	-	50	50
Model of Reference	Vespa Elettrica	Buddy 50	Yamaha Aerox 4
Weight of the model (kg)	105	89.81	97
Place of Production	Europe (Italy)	Asia (China)	Asia (Japan)

TABLE 1: DETAILS OF THE THREE DIFFERENT SCOOTERS CONSIDERED

For all the phases of the life cycle, secondary data (obtained from papers or suppliers) are preferentially used. However, when data are difficult to be obtained, datasets from the ecoinvent database are also applied.

For modelling the use phase, the emissions of organic compounds, carbon monoxide, carbon dioxide and nitrogen oxides are obtained from literature for the two-stroke scooter model for a direct injection technology with oxidation catalyst (Martini *et al.*, 2009). For the metal's emissions, the literature applied considers the use of two-stroke engine but from a chainsaw with a similar size (46 cm^3), that uses the mixture of gasoline and mineral lubricating oil, and use of catalyst is also considered (Ålander *et al.*, 2005).

Subsequently, most of the emissions calculated for the two-stroke are applied to calculate the equivalent emission for the four-stroke model, considering the modifications in the emissions that occur between these two options, according to some authors (MECA, 2014; Stutzer, 2017; Keita *et al.*, 2018). For the particulate emissions (according to the size), the emission factors considered are calculated based on the ecoinvent Process.

In the use phase of the electric scooter, besides electricity, the battery and the charger should also be considered. Both battery and charger are assumed to be produced in China and used in Europe. Finally, for the end-of-life, it is assumed that all three scooters are manually dismantled. Transport to the dismantling facilities are not considered.

3. Life Cycle Inventory Analysis

openLCA software is applied to model and evaluate the life cycle of the scooters with ecoinvent 3.6 database. Based on the system boundaries (Figures 1 and 2) and on the assumptions previously explained, three different systems are modeled.

3.1. Production of the Scooters

For the production of the scooter, the ecoinvent processes "electric scooter production, without battery | electric scooter, without battery | APOS, U - GLO" and "motor scooter production | motor scooter, 50 cubic cm engine | APOS, U - RoW" are considered for the electric scooter and the motor scooter, respectively. The only modification is the removal of the waste flow, as this will be considered in the end of life process. These processes are selected according to the production facilities' location from Table 1. The quantitative reference is 1 item of scooter produced, the different weight of the models is not considered in this step for the motor scooters, since the output is in number of items and there is no weight of reference for the scooter considered by ecoinvent.

3.2. Transportation of the Scooter until Berlin

Since the two motor scooters are produced in Asia, the transportation to Berlin is divided in three steps. The first part consideres the transportation from Asia until Rotterdam by ship, and subsequently the transport from Rotterdam to Berlin by train. Finally, the scope includes the transport with lorry (EURO 5) from the train station until Berlin city center. For the electric scooter, the scooter is produced in a city close to Pisa, and then transferred by lorry (EURO5) to Milan. From Milan to Berlin, the transportation is done by train. Finally, lorry (EURO5) is applied to transport the product until the city center. Figure 3 summarizes the distance and the weight considered in each transportation step for each vehicle. The quantitative reference for the transportation is 1 item of scooter transported.

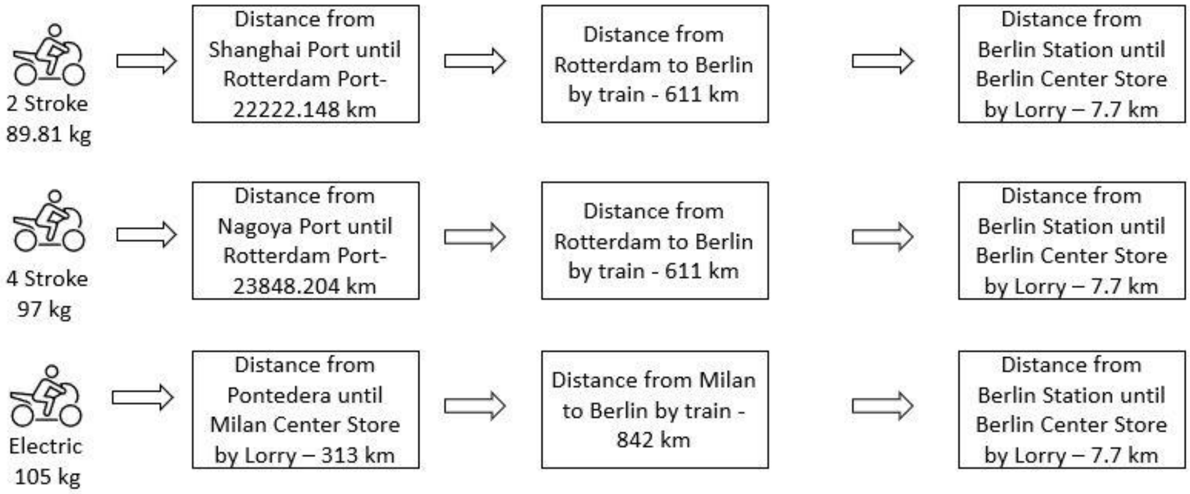


FIGURE 3: TRANSPORTATION DISTANCES CONSIDERED FOR EACH MOPED

3.3. Use of the scooters in Berlin

For all three scooters, the functional unit (in openLCA) of the product system of using the scooter is 55000 p*km, which corresponds to the 1.1 person times 50000 km ("expectancydurationescooter" or "lifeexpectancy"). Therefore, all the inputs and outputs included are calculated according to this number. Then, besides calculating the fuel consumption, electricity consumption, road use and maintenance, and the emissions for 50000 km, the number is also multiplied by the number of persons considered, in order to maintain the modeling logic. In the next paragraphs, details of the inventory of the use phase of each model are described.

- Fuel and Electricity Consumption of the Scooters

The motor scooters require fuels during the use phase. For the motor scooters, the fuels considered are the flows available on ecoInvent 3.6 database, which are “petrol, two-stroke blend” for the two-stroke model and “petrol, low sulfur” for the other model. The fuel consumption (“kmperliteroffuel”) for the two-stroke scooter considered is 40.8 km/L (Hirz, 2015), while for the four-stroke scooter the fuel consumption (“kmperliteroffuel”) considered is 45.45 km/L (Yamaha, 2018). The fuel consumption is multiplied by the number of persons, in order to reflect the quantitative reference of the process that is in p*km. For the electric scooter, electricity is required. In order to calculate the electricity consumption, the battery voltage (“batteryvoltage”) of 48 V and battery capacity (“batterycapacity”) of 86 Ah of the Vespa model are considered, which represents in total 4.128 KWh (Vespa, 2018b). During the entire life cycle of the scooter (50000 km), the battery should be charged 500 times (“numberofcharges”), considering that each cycle lasts 100 km. Therefore, the number of charges necessary during the life cycle multiplied by the consumption of the battery results in the electricity consumption of the scooter during the use phase. Since the output of the use is in p*km, the number of persons considered (“numberofperson” or “personpervehicle”) is also multiplied in the electricity consumption.

- Electricity Mix of the Electric Scooter

As the electric scooter requires electricity during the use phase, the electricity mix considered can influence the environmental impacts observed. In the present work, three different electricity mixes in Germany are compared. The first one is the average German mix available on ecoinvent 3.6 (“market for electricity, medium voltage | electricity, medium voltage | APOS, U - DE”). The second mix considered (Table 2) is the green mix available in Germany considering data from 2019 (Federal Ministry for Economic Affairs and Energy, 2020). The last mix (Table 3) is the conventional grid (including all types of energy) in Germany updated on 2020 (Bulach *et al.*, 2020).

Green Electricity	Share (%)
Hydropower	8%
Wind energy onshore	41%
Wind energy offshore	10%
Solar Photovoltaic	19%
Solid biofuels	4%
Liquid biofuels	0%
Biogas	12%
Biomethane	1%
Sewage gas	1%
Landfill gas	0%
Biogenic fraction of waste	2%
Geothermal energy	0%

TABLE 2: GERMAN GREEN ELECTRICITY MIX

(FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY, 2020)

Electricity	Share (%)
Lignite power plants	19.9
Wind power plants (onshore)	17.8
Hard coal power plants	13.3
Natural gas power plants	11.9
Photovoltaic systems	8.4
Nuclear power plants	8
Offshore wind turbines	5.1
Biogas combined heat and power plants	4.7
Hydropower plants	3.9
Wood-fired power stations	2.8
Furnace gas use	1.5
Waste incineration plants	1.3
Geothermal power plants	0.5
Oil-fired power plants	0.5
Coal gas use	0.4

TABLE 3: GERMAN ELECTRICITY MIX

(BULACH *ET AL.*, 2020)

Most of the flows considered are High voltage flows, therefore the electricity is converted to medium voltage and then to low voltage, considering the efficiency of these processes available on the ecoinvent Processes of conversion of electricity. The transmission of the electricity (in high and medium voltage) is also considered based on the database. It is important to highlight that some of the flows are already available in ecoinvent in medium or low voltage, in these cases, the share of the electricity is corrected, since not all the flows are available in the same voltage.

Regarding Table 2, the providers are defined according to the most suitable conditions for Germany. For instance, for the hydropower a mix of 16% from reservoir and 84% from run-of-river is considered (Itten, Frischknecht and Stucki, 2014). Some of the electricity conditions of Table 2 are not identified as providers in the ecoinvent, consequently biomethane, landfill gas and biogas are considered together in the provider "heat and power co-generation, biogas, gas engine | electricity, high voltage | APOS, U – DE". In the same way, Sewage and biogenic waste are also considered together in the provider "electricity, from municipal waste incineration to generic market for electricity, medium voltage | electricity, medium voltage | APOS, U – DE".

For Table 3, the providers and the mixes considered are defined according to the reference applied (Bulach *et al.*, 2020). For the hydropower, the same share considered in the previous mix of run-of-river and from reservoir is applied (Itten, Frischknecht and Stucki, 2014). For the electricity produced by nuclear power plants, the share of 78% boiling water reactor and 22% pressure water reactor is considered (Itten, Frischknecht and Stucki, 2014). In both Tables (2 and 3), the provider "electricity production, photovoltaic, 570kWp open ground installation, multi-Si | electricity, low voltage | APOS, U – DE" is considered for solar energy.

After all the flows (in three electricity mix applied) are converted to low voltage (in each case), the distribution network of Germany is considered and also the use and emission of sulfur hexafluoride in the process of distribution of electricity low voltage. The distribution is based on the process "market for electricity, low voltage | electricity, low voltage | APOS, U - DE" from ecoinvent.

- Battery and Charger of Electric Scooter

During the life cycle of the electric scooter, one battery is required. According to the suppliers of the battery, the battery can last for 1000 cycles, and each cycle lasts 100 km (Vespa, 2018b). Therefore, the battery can be applied for 10^5 km. As mentioned, it is assumed that the expected duration of the scooter is 50000 km (Leuenberger and Büsser, 2010). With regard to these conditions, the battery lasts longer than the scooter itself. Nevertheless, the possibility that more recent models have a higher duration than the scooter considered in this report justifies the use of one battery only. Besides that, the data of the duration of the battery are obtained from the supplier's information, and they are calculated considering perfect use conditions, which is not always true. Then, both the duration of the battery and the duration of the scooter can lead to an underestimation of the amount of the battery considered in the life cycle of one scooter. In order to assure a more conservative approach, only one battery is required. In addition to the battery, one charger is considered, the charger is produced by the ecoinvent process "charger production, for electric scooter | charger, for electric scooter | APOS, U - GLO".

Two different processes for battery production are considered in this report. In both cases, the same weight of the battery ("weightbattery") is considered (25 kg) (Vespa, 2018b). The first option is the battery for electric vehicles available on ecoinvent, the global process "battery production, Li-ion, rechargeable, prismatic | battery, Li-ion, rechargeable, prismatic | APOS, U - GLO" is selected since it already contains details of production in Asia and transportation until Europe.

The second model considers the description of battery applied in Frankfurt International Airport for electric bus used in the airport (Bulach *et al.*, 2020). Table 4 summarizes the inputs and outputs of the production of the battery considering the process proposed by Bulach *et al.* (2020) based on secondary information (from literature).

Input Flows	Amount	Unit
aluminium, wrought alloy	0.5*0.5	kg
Electrolyte Battery Airport	0.1	kg
LCO cathode airport	0.06	kg
LTO anode airport	0.14	kg
Separator airport	0.2	kg
sheet rolling, aluminium	0.5*0.5	kg
transport, freight train	distancerotterdam_berlin	kg*km
transport, freight, lorry 16-32 metric ton, EURO5	distanceberlin_citycenter	kg*km
transport, freight, sea, container ship	distancechina_rotterdam	kg*km
Output Flow	**Amount**	**Unit**
Battery airport	1.0	kg

TABLE 4: PRODUCTION DETAILS BASED ON BATTERY OF FRANKFURT INTERNATIONAL AIRPORT (BULACH *ET AL.*, 2020)

The input flows “Electrolyte Battery Airport”, “ LCO cathode airport”, “LTO anode airport” and “Separator airport” are modeled according to the references on Bulach *et al.* (2020). However, some modifications during the transportation phase of the battery are considered, since not all the inputs of Table 4 considered the transportation steps. Consequently, in order to assure that all the components are considered in the same location, the transportation steps proposed for the separator and electrolyte (Majeau-Bettez, Hawkins and StrØmman, 2011) are not considered. Alternatively, the transportation phase (from Asia to Europe) is only considered for the final battery obtained. The distance by sea from China to Rotterdam considered (“distancechina_rotterdam”) is 22222.15 km. The distance from Rotterdam to berlin (“distancerotterdam_berlin”) is 611 km, from berlin until the city center (“distanceberlin_citycenter”) is 7.7 km. Besides that, in Bulach *et al.* (2020) , it says that wrought alloy and sheet rolling aluminum are used, but the proportion is not defined. Therefore, it is considered 50% for each.

- Emissions of the scooters

The emissions are also considered in the use phase. The emissions for the electric scooter are based on the ecoinvent Process “transport, passenger, electric scooter | transport, passenger, electric scooter | APOS, U - GLO”, they are only corrected to the quantitative reference of the use phase. In this way, for the electric scooter, only brake wear, road wear and tyre wear emissions are considered. For the two-stroke model, the data of the emissions of ecoinvent are not applied since they consider a mix of the two different motor models and not the models individually. The emissions for the motor scooters will be described in the next paragraphs.

The emissions of the volatile organic compounds (VOCs), carbon monoxide, carbon dioxide and nitrogen oxide from two-stroke scooter are obtained from Martini *et al.* (2009), considering the model "MOPED PO003", which is a two-stroke moped, 50 cc, with direct injection (EURO2). In this reference, the VOCs are obtained over an ECE cycle. And the other emissions are obtained considering also the cold part of the cycle, with a weighted average of 30 and 70% (Martini *et al.*, 2009).

For the emission of metals, specific data for each metal for two-stroke scooter is not identified, then it is applied data of the emissions from two-stroke professional chainsaw device (46 cm^3), obtained from Ålander *et al.* (2005). The system considers the use of a reference gasoline fuel with mineral lubricating oil and the system (carburetor) is equipped with catalyst. The reference fuel applied by this reference (Ålander *et al.*, 2005) has low sulfur content, in agreement with the flow selected in ecoinvent database. It is important to highlight that even if the metals emissions obtained in literature are not specific for two-stroke scooters and are referred to carburetor technology and not direct injection, these emissions come from the lubricant oil (that is used mixed with the gasoline) in this type of engine. Therefore, the use of the data from metallic emissions from other technology of two-stroke engine does not seem to be a problem to this study.

There are references that considers the metal emissions for European vehicles (Pulles *et al.*, 2012), however the results for different vehicles categories are presented together, therefore this study is not considered in this report. Regarding the European standards, lead is one of the metals that has regulated emissions by the EU, and the value calculated according to the adopted literature (Ålander *et al.*, 2005) is below the lead limit even for EURO5 vehicles (Transport Policy, 2020).

Another emission that can be obtained is the sulfur dioxide emission. In this report, the emissions are calculated according the sulfur content of the fuel. It is considered that the fuel has 20 mg/kg of sulfur content in both cases, which is above the regulation of EURO5 (10 mg/kg), but it is still below the regulation EURO2, that is the focus of this report. For the two different motor scooters, 20 ppm is considered, and the sulfur dioxide emission is calculated according to Equation 1. This equation is applied for two and four-stroke scooters and the result is multiplied by 50000 km and 1.1 person.

$$SO_2\left(\frac{kg}{km}\right) = 20\left(\frac{mg\ S}{kg\ fuel}\right)\ x\ density\left(\frac{kg}{m^3}\right)\ x\ 1\left(\frac{m^3}{1000\ L}\right) x\,\frac{1}{fuel}\left(\frac{L}{km}\right) x\,\frac{64}{32}\left(\frac{g\ SO_2}{g\ S}\right)\ x\ 10^{-6}\left(\frac{kg}{mg}\right) \tag{01}$$

For using Equation 01, some unit conversions are required and the density of the fuel applied in both scooters are considered the same 0.754 kg/L. This value is obtained for fuel of two-stroke engine from Ålander *et al.* (2005). For the two-stroke, the gasoline is used with an oil (2% v/v), and for the four-stroke only the fuel is used. Therefore, since the difference is only of 2% and the density adopted is inside the range regulated for gasoline, this density is adopted for both cases. The fuel consumption, that also appears in Equation 1, was previously detailed.

The other emissions of the four-stroke scooter are calculated relatively to the emissions of the two-stroke. In order to do so, the relation between the emissions of two-stroke scooters and the other model previously reported in literature is considered (MECA, 2014), which indicates that the hydrocarbons are reduced in 95%, the carbon monoxide is reduced in 30% and the particulates are reduced in 80% (MECA, 2014). In the present study, the conversion factor (from two-stroke to four-stroke) of emission of metals is considered as the particulates that are mentioned in literature. The nitrogen oxide emission increases 200% (MECA, 2014), which means it increases three times in relation to the two-stroke model.

Some specific volatile organic compounds and carbon dioxide are not converted to the value for four-stroke with the previous reference and correlations, since more specific data is available for them. For the specific hydrocarbons' emissions available on Keita *et al.* (2018), the relation between the emission of two wheeled two-stroke and four-stroke engine is calculated from literature, Table 5 (Keita *et al.*, 2018). For the carbon dioxide, the ratio from two-stroke and four-stroke emission from the HBEFA is also considered (two-stroke/four-stroke = 1.4379) (Stutzer, 2017). The emissions obtained from the references of these paragraphs are not considered directly to obtain the emissions for the four-stroke model (and also for the two-stroke), for two main reasons: (i) in some cases the size of the scooter is not specified in these references, (ii) in other cases the emission is referring to more than one size of scooter. However, since it is adopted the ratio between the two and four-stroke and then this ratio is used to correct the emissions for the two-stroke in the same size considered in this report, then it is possible to assume that the error is reduced.

Compound	**Two-Stroke / Four-Stroke**
n-heptane	34.52
Benzene	11.84
Toluene	11.93
m+p - Xylene	23.69
O – Xylene	31.72
Ethylbenzene	20.05
1,3,5 - trimethylbenzene	52.78
1,2,4 - trimethylbenzene	36.78
Isoprene	14.36

TABLE 5: COMPARISON OF EMISSION OF ORGANIC COMPOUNDS BASED ON KEITA ET AL. (2018)

Besides all these compounds, particles are also emitted in different sizes. These particles are calculated from ecoinvent Process "transport, passenger, motor scooter | transport, passenger, motor scooter | APOS, U - RoW", considering that the ecoinvent database is elaborated considering 45% two-stroke and 55% four-stroke. However, the particle emissions are not only proportional to that, then it is also considered that the emissions of particulates in four-stroke is 20% of the emission in two-stroke engine models.

Tables A.1 and A.2 (in the appendix) summarizes all the emissions considered for the motor scooters model.

- Road, Road Maintenance and Scooter Maintenance

The road maintenance, road and the maintenance of the scooter are calculated according to the reference process in ecoinvent "transport, passenger, electric scooter | transport, passenger, electric scooter | APOS, U - GLO" for the electric scooter and for the other scooters "transport, passenger, motor scooter | transport, passenger, motor scooter | APOS, U – RoW". The data for electric scooter does not contain information about the "road maintenance", it only contains the flow "road". For the motor scooter, "road" and "road maintenance" are available. So, the proportion of these two flows from the motor scooter process are applied to calculate the "road maintenance" for the electric scooter.

- Inputs and Outputs implemented

Tables A.3, A.4 and A.5 (in the Appendix) contain all the inputs and outputs of the use phase considered during the definition of the model in openLCA, according to the details previously explained.

The electric scooter calculation model considers more than one battery and more than one electricity mix. Therefore, some parameters are defined in order to be possible to define which system and which model are being evaluated by the user of the model. In order to work as an "on-off" parameter, the possible values inserted are 1 or 0. For Instance, when it is desired to evaluate the use of the battery produced according to the database, b1 should be one and b2 should be zero. All the parameters necessary to define the evaluated scenario are available on Table 6.

Parameter	Definition
b1	When equal to 1, it is used to select the battery production process from the database.
b2	When equal to 1, it is used to select the battery production process based on data from Frankfurt Airport (Bulach *et al.*, 2020).
d1	When equal to 1, it is used to select the electricity mix from ecoinvent.
d2	When equal to 1, it is used to select the green electricity mix from Germany (Federal Ministry for Economic Affairs and Energy, 2020).
d3	When equal to 1, it is used to select the electricity mix described in the report from Frankfurt Airport (Bulach *et al.*, 2020).

Table 6: Different Parameters applied to define the scenarios

3.4. Manual Dismantling of the Scooters

The three scooters are manually dismantled based on the process "manual dismantling of used electric scooter | manual dismantling of electric scooter | APOS, U - GLO". The same process is considered for the other scooters, since it is similar to the process proposed for the dismantling of used passenger car with internal combustion engine. In this step, the input and the outputs are referring to the quantitative reference, which is 1 p*km. The output of used items in the production of the scooter and the battery, that were removed in the previous steps, are included as an output of this process.

3.5. Final Process

The Final process receives as inputs the dismantled scooter and the used scooter.

3.6. Model Graphs

All the information explained from section 3.1. until 3.5 are applied to create the product systems and respective model graphs (Figures 4 – 6). The model graphs show the complete supply chain and the respective linkages. Figure 4 represents the model graph for the electric scooter. The graph visualizes the use of more than one type of battery and more than one type of electricity mix.

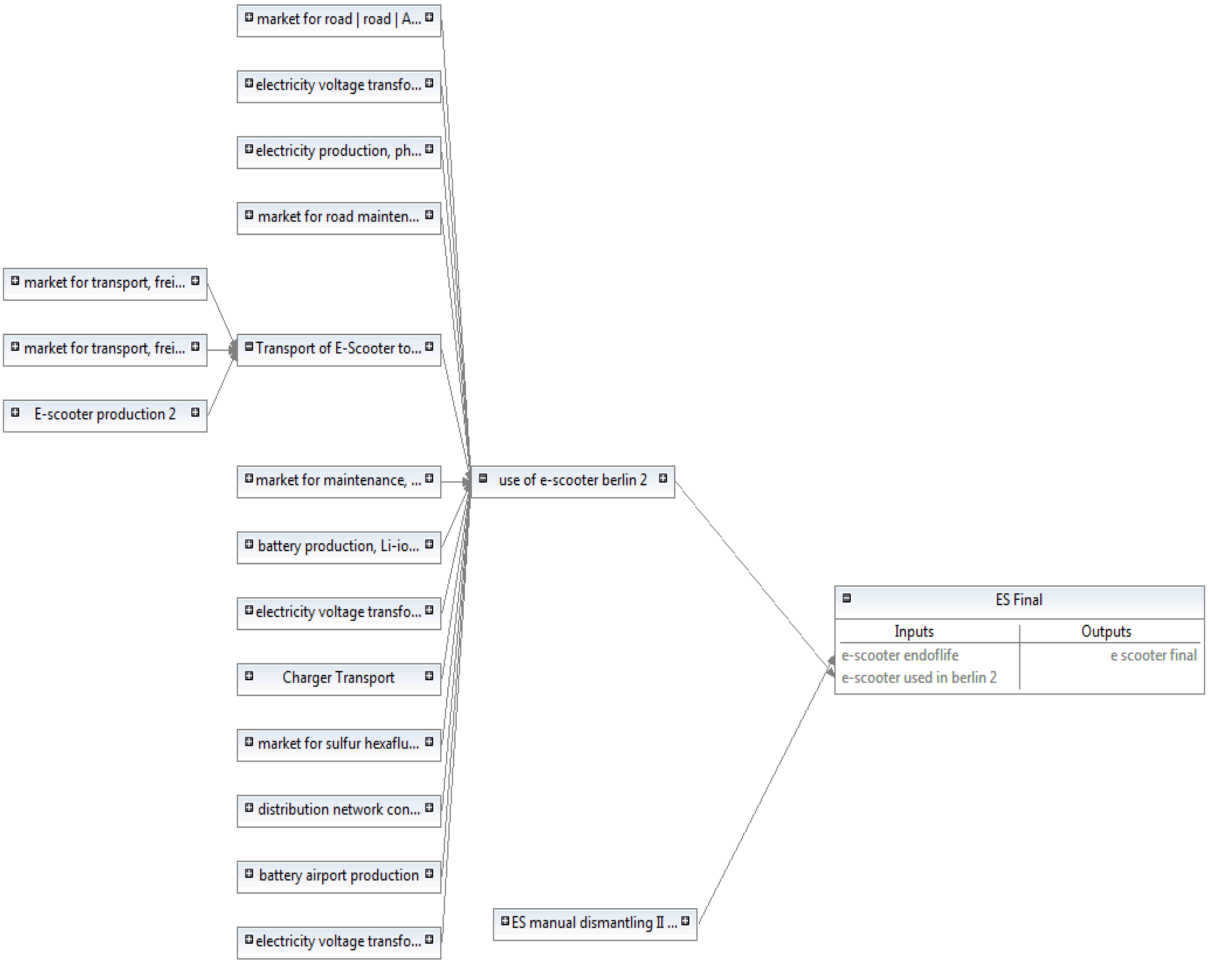


Figure 4: Model Graph for Electric Scooter.

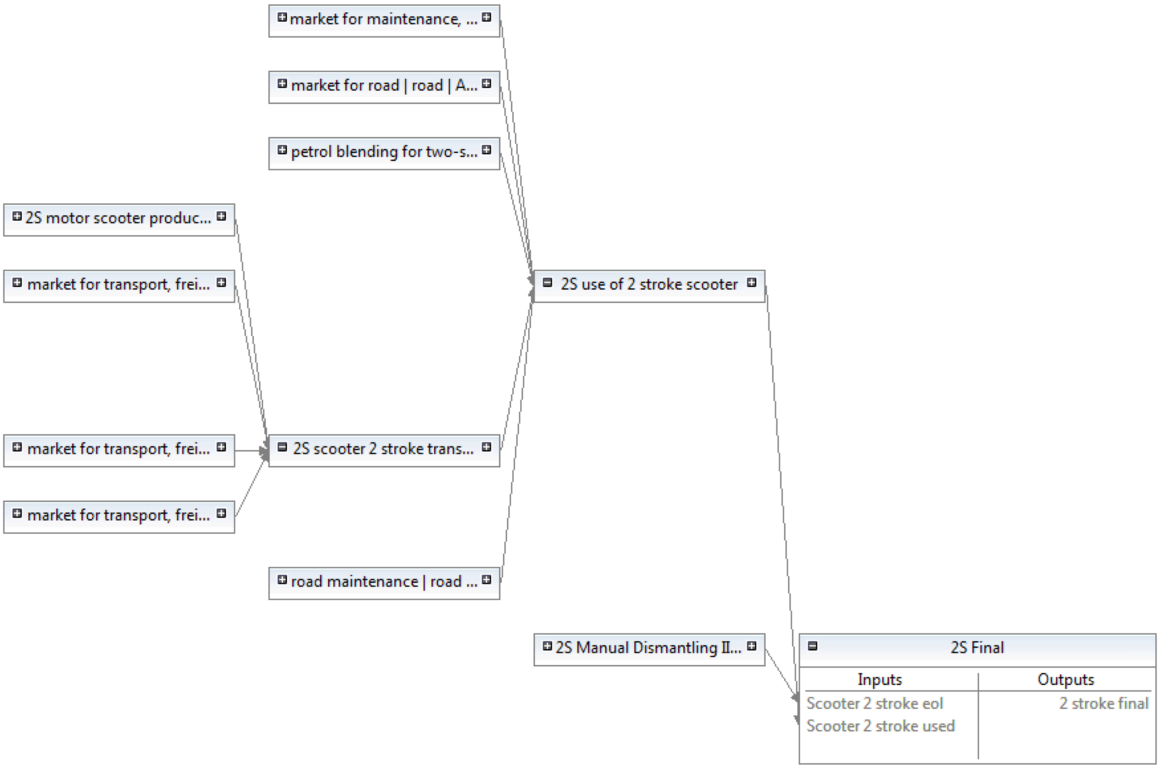


Figure 5: Model Graph for Two-stroke Scooter.

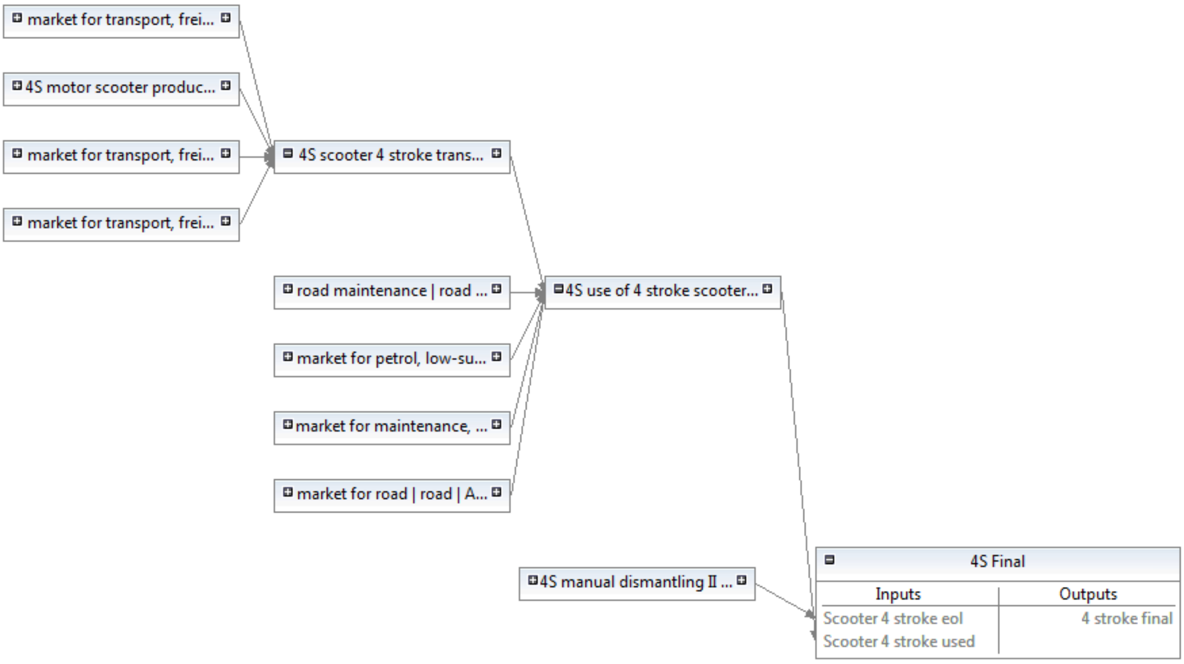


Figure 6: Model Graph for Four-stroke Scooter.

4. Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment of this work is divided in two different parts. The first part contains the results for the two-stroke scooter, four-stroke scooter and different possibilities for electric scooter. Subsequently, the results of a project comparing all combinations of battery production and electricity mix applied will be presented. In total, eight systems are evaluated, since six combinations are available for the electric scooter. Table 7 summarizes all the scenarios. As previously mentioned, the impact assessment method defined for all of them is ReCiPe Midpoint (H).

Scenario	Identification	Scooter	Battery	Electricity Mix
1	2S	Two-stroke	-	-
2	4S	Four-stroke	-	-
3	ES-1	Electric	ecoinvent	ecoinvent
4	ES-2	Electric	ecoinvent	Green Mix
5	ES-3	Electric	ecoinvent	(Bulach *et al.*, 2020)
6	ES-4	Electric	(Bulach *et al.*, 2020)	ecoinvent
7	ES-5	Electric	(Bulach *et al.*, 2020)	Green Mix
8	ES-6	Electric	(Bulach *et al.*, 2020)	(Bulach *et al.*, 2020)

TABLE 7: SCENARIOS EVALUATED IN THIS REPORT

- Impact Assessment for the scooter's models

For the **first scenario (Two-stroke Scooter)**, for almost all the impacts categories, the use phase accounts for the greatest share of the impacts (Table 8). The exceptions are Mineral resource scarcity, Human carcinogenic toxicity and Human non-carcinogenic toxicity.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	5,73%	2,02%	92,06%	0,19%	0,00037	kg NOx eq
Marine ecotoxicity	31,60%	0,16%	39,78%	28,46%	0,00508	kg 1,4-DCB
Fossil resource scarcity	7,54%	0,39%	91,96%	0,11%	0,02911	kg oil eq
Water consumption	21,93%	0,17%	77,45%	0,45%	0,00034	m3
Fine particulate matter formation	14,45%	1,89%	82,95%	0,71%	0,00013	kg PM2.5 eq
Terrestrial ecotoxicity	38,01%	0,66%	60,07%	1,26%	0,15182	kg 1,4-DCB
Land use	12,51%	0,27%	86,82%	0,40%	0,00138	m2a crop eq
Terrestrial acidification	15,60%	2,65%	81,50%	0,25%	0,00027	kg SO2 eq
Human non-carcinogenic toxicity	17,16%	0,09%	38,57%	44,18%	0,08828	kg 1,4-DCB
Global warming	8,16%	0,43%	90,87%	0,54%	0,09067	kg CO2 eq
Marine eutrophication	18,89%	0,18%	69,81%	11,12%	1,6E-06	kg N eq
Mineral resource scarcity	58,71%	0,23%	40,72%	0,34%	0,0005	kg Cu eq
Ozone formation, Terrestrial ecosystems	5,35%	1,79%	92,69%	0,17%	0,00042	kg NOx eq
Ionizing radiation	6,24%	0,17%	93,45%	0,14%	0,00629	kBq Co-60 eq
Stratospheric ozone depletion	9,98%	0,88%	88,60%	0,54%	3E-08	kg CFC11 eq
Freshwater eutrophication	22,70%	0,20%	76,85%	0,25%	1,6E-05	kg P eq
Freshwater ecotoxicity	33,43%	0,15%	39,10%	27,32%	0,00375	kg 1,4-DCB
Human carcinogenic toxicity	58,84%	0,41%	40,30%	0,45%	0,00285	kg 1,4-DCB

TABLE 8: RESULTS FOR TWO-STROKE SCOOTER

For the impact category Fossil resource scarcity, the petrol blending for two-stroke engines accounts for 74.97% of the impacts, followed by the road maintenance (9.90%) and the transportation of the scooter (7.93%). Another relevant category to be evaluated for the two-stroke scooters is Global warming. In the use phase, 12.87% of the impacts of this category are a result of the fuel applied. The flow of carbon dioxide emissions to air (high population density) contributes to 60.66% of the impact category, explaining why most of the impacts of Global warming are located in Europe (Figure 7). Mineral resource scarcity is one of the only categories whose hot spot is not the use phase. The highest share of the impacts is in the production, due to the "reinforcing steel" process (12.67%) and also production of aluminum and zinc, for instance.

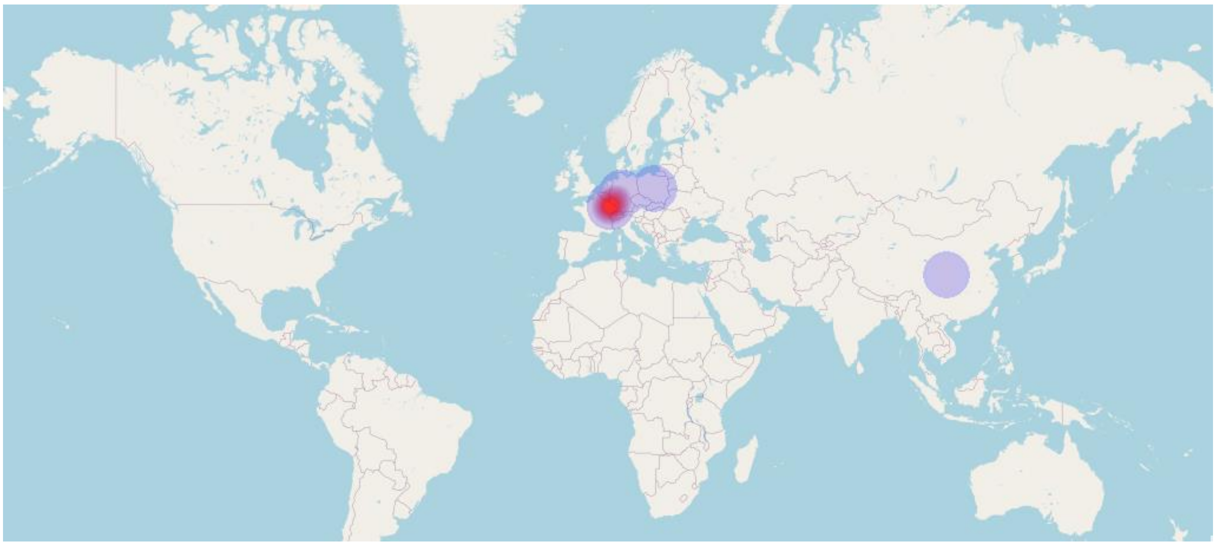


Figure 7: Two-Stroke Scooter - Global Warming Impact around the world

For the **second scenario** (Table 9), Mineral resource scarcity, Human carcinogenic toxicity and Human non-carcinogenic toxicity are the only categories whose top contribution in the four-stroke scooter life cycle is not the use phase. The reason for the Mineral resource scarcity is the same that was previously explained for the first scenario. The water consumption in the use phase results mainly from the road maintenance observed in this step. For the Global warming, in the use phase, the emission that is responsible for an important share of the impact category is again the carbon dioxide fossil.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	3,12%	1,27%	95,51%	0,10%	0,00068	kg NOx eq
Marine ecotoxicity	31,97%	0,18%	39,05%	28,80%	0,00502	kg 1,4-DCB
Fossil resource scarcity	8,16%	0,48%	91,24%	0,12%	0,02692	kg oil eq
Water consumption	22,15%	0,21%	77,18%	0,46%	0,00034	m3
Fine particulate matter formation	12,56%	1,89%	84,93%	0,62%	0,00014	kg PM2.5 eq
Terrestrial ecotoxicity	40,06%	0,81%	57,80%	1,33%	0,14403	kg 1,4-DCB
Land use	12,35%	0,30%	86,94%	0,41%	0,00139	m2a crop eq
Terrestrial acidification	10,56%	2,08%	87,19%	0,17%	0,0004	kg SO2 eq
Human non-carcinogenic toxicity	17,29%	0,10%	38,10%	44,51%	0,08762	kg 1,4-DCB
Global warming	10,14%	0,61%	88,58%	0,67%	0,07298	kg CO2 eq
Marine eutrophication	19,02%	0,21%	69,57%	11,20%	1,60E-06	kg N eq
Mineral resource scarcity	59,38%	0,26%	40,00%	0,36%	0,0005	kg Cu eq
Ozone formation, Terrestrial ecosystems	3,27%	1,26%	95,37%	0,10%	0,00069	kg NOx eq
Ionizing radiation	6,34%	0,19%	93,33%	0,14%	0,00619	kBq Co-60 eq
Stratospheric ozone depletion	10,59%	1,08%	87,76%	0,57%	2,80E-08	kg CFC11 eq
Freshwater eutrophication	22,87%	0,22%	76,65%	0,26%	1,60E-05	kg P eq
Freshwater ecotoxicity	33,80%	0,17%	38,40%	27,63%	0,0037	kg 1,4-DCB
Human carcinogenic toxicity	60,00%	0,47%	39,06%	0,47%	0,0028	kg 1,4-DCB

TABLE 9: RESULTS FOR FOUR-STROKE SCOOTER

For the **third scenario (ES-1)** of the electric scooter (Table 10), besides the scooter production, the production of the battery and the charger are also considered. But these contributions are combined in the use phase, as represented in Figure 1. The battery considered in this process is based on the model from ecoinvent and the electricity consumption is also based on the German Mix from the same database.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	29,44%	0,59%	69,18%	0,79%	0,00013	kg NOx eq
Marine ecotoxicity	45,97%	0,03%	53,67%	0,33%	0,02216	kg 1,4-DCB
Fossil resource scarcity	21,91%	0,23%	77,31%	0,55%	0,01723	kg oil eq
Water consumption	18,69%	0,07%	80,58%	0,66%	0,00088	m3
Fine particulate matter formation	35,04%	0,22%	63,62%	1,12%	9,96E-05	kg PM2.5 eq
Terrestrial ecotoxicity	38,42%	0,24%	61,03%	0,31%	0,52422	kg 1,4-DCB
Land use	13,08%	0,28%	86,26%	0,38%	0,00292	m2a crop eq
Terrestrial acidification	32,10%	0,22%	66,76%	0,92%	0,00024	kg SO2 eq
Human non-carcinogenic toxicity	27,91%	0,04%	71,74%	0,31%	0,18336	kg 1,4-DCB
Global warming	22,05%	0,20%	77,08%	0,67%	0,06454	kg CO2 eq
Marine eutrophication	16,96%	0,05%	82,26%	0,73%	5,05E-06	kg N eq
Mineral resource scarcity	56,12%	0,07%	43,30%	0,51%	0,00092	kg Cu eq
Ozone formation, Terrestrial ecosystems	29,88%	0,58%	68,78%	0,76%	0,00014	kg NOx eq
Ionizing radiation	7,16%	0,09%	92,47%	0,28%	0,01388	kBq Co-60 eq
Stratospheric ozone depletion	16,52%	0,20%	82,54%	0,74%	3,85E-08	kg CFC11 eq
Freshwater eutrophication	13,57%	0,05%	86,11%	0,27%	6,75E-05	kg P eq
Freshwater ecotoxicity	46,96%	0,02%	52,68%	0,34%	0,01748	kg 1,4-DCB
Human carcinogenic toxicity	41,66%	0,12%	57,71%	0,51%	0,00633	kg 1,4-DCB

TABLE 10: RESULTS FOR ELECTRIC SCOOTER (ES-1)

According to Table 10, again, the use phase is responsible by the biggest share of the impacts in almost all categories. But now, this results also from the production of electricity required to charge the battery. In the Global warming category, 40.55% of the impacts come from the electricity production and conversion to low voltage. In the Mineral resource scarcity, besides the contribution of the production of the scooter (56.12%), 14.15% are from the battery production that is only considered for the electric model.

Table 11 illustrates the results for the **fourth scenario (ES-2)**, the only difference from the previous scenario is the electricity grid applied. It is possible to notice that the percentage of Global warming that corresponds to the use phase (64.27%) is lower than in the previous scenario (77.08%). Now, only 5.46% of the Global warming impact category comes from the electricity consumption and conversion to low voltage.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	34,02%	0,69%	64,38%	0,91%	0,00011	kg NOx eq
Marine ecotoxicity	47,65%	0,02%	51,98%	0,35%	0,02138	kg 1,4-DCB
Fossil resource scarcity	32,96%	0,36%	65,85%	0,83%	0,01145	kg oil eq
Water consumption	17,68%	0,07%	81,62%	0,63%	0,00093	m3
Fine particulate matter formation	37,78%	0,24%	60,78%	1,20%	9,2E-05	kg PM2.5 eq
Terrestrial ecotoxicity	37,14%	0,23%	62,33%	0,30%	0,54234	kg 1,4-DCB
Land use	8,66%	0,19%	90,90%	0,25%	0,0044	m2a crop eq
Terrestrial acidification	35,24%	0,24%	63,51%	1,01%	0,00021	kg SO2 eq
Human non-carcinogenic toxicity	31,41%	0,05%	68,19%	0,35%	0,16294	kg 1,4-DCB
Global warming	34,37%	0,32%	64,27%	1,04%	0,0414	kg CO2 eq
Marine eutrophication	27,79%	0,09%	70,92%	1,20%	3,1E-06	kg N eq
Mineral resource scarcity	54,91%	0,07%	44,52%	0,50%	0,00094	kg Cu eq
Ozone formation, Terrestrial ecosystems	34,29%	0,66%	64,18%	0,87%	0,00012	kg NOx eq
Ionizing radiation	10,74%	0,14%	88,70%	0,42%	0,00925	kBq Co-60 eq
Stratospheric ozone depletion	17,55%	0,22%	81,44%	0,79%	3,6E-08	kg CFC11 eq
Freshwater eutrophication	27,96%	0,10%	71,39%	0,55%	3,3E-05	kg P eq
Freshwater ecotoxicity	48,48%	0,03%	51,14%	0,35%	0,01693	kg 1,4-DCB
Human carcinogenic toxicity	54,40%	0,16%	44,78%	0,66%	0,00484	kg 1,4-DCB

Table 11: Results for Electric scooter (ES-2)

Table 12 illustrates the results for the electric scooter considering the normal battery and the airport mix electricity (**Scenario 5, ES-3**). The use phase accounts for a higher share of Global warming impact category than the one available on Table 11. This illustrates that depending on the electricity mix applied, the impacts observed for the electric scooter can be modified. Consequently, this can indicate a possible alternative to the reduction of impacts (not only global warming) of the electric scooter according to the electricity matrix of the country. Among the electricity options, the lignite is the option that contributes most to Global warming (17.05%).

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	29,99%	0,60%	68,61%	0,80%	0,00013	kg NOx eq
Marine ecotoxicity	46,54%	0,03%	53,09%	0,34%	0,02189	kg 1,4-DCB
Fossil resource scarcity	22,93%	0,25%	76,25%	0,57%	0,01647	kg oil eq
Water consumption	21,06%	0,09%	78,10%	0,75%	0,00078	m3
Fine particulate matter formation	35,51%	0,23%	63,13%	1,13%	9,8E-05	kg PM2.5 eq
Terrestrial ecotoxicity	38,00%	0,24%	61,45%	0,31%	0,53001	kg 1,4-DCB
Land use	11,26%	0,25%	88,16%	0,33%	0,00339	m2a crop eq
Terrestrial acidification	32,93%	0,22%	65,91%	0,94%	0,00023	kg SO2 eq
Human non-carcinogenic toxicity	28,81%	0,05%	70,82%	0,32%	0,17763	kg 1,4-DCB
Global warming	23,62%	0,22%	75,45%	0,71%	0,06024	kg CO2 eq
Marine eutrophication	19,24%	0,07%	79,86%	0,83%	4,5E-06	kg N eq
Mineral resource scarcity	55,02%	0,06%	44,42%	0,50%	0,00094	kg Cu eq
Ozone formation, Terrestrial ecosystems	30,38%	0,59%	68,26%	0,77%	0,00014	kg NOx eq
Ionizing radiation	8,56%	0,11%	90,99%	0,34%	0,0116	kBq Co-60 eq
Stratospheric ozone depletion	17,71%	0,21%	81,29%	0,79%	3,6E-08	kg CFC11 eq
Freshwater eutrophication	15,61%	0,05%	84,03%	0,31%	5,9E-05	kg P eq
Freshwater ecotoxicity	47,51%	0,03%	52,12%	0,34%	0,01728	kg 1,4-DCB
Human carcinogenic toxicity	43,93%	0,13%	55,41%	0,53%	0,006	kg 1,4-DCB

Table 12: Results for Electric scooter (ES-3)

For the **sixth scenario (ES-4)**, the battery from airport and the electricity grid mix from ecoinvent are considered. The results are presented in Table 13. From this scenario on, the results will not be described in detail anymore, since the only difference from the previous scenarios with electric scooter is the battery considered.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	28,25%	0,57%	70,42%	0,76%	0,00014	kg NOx eq
Marine ecotoxicity	57,76%	0,03%	41,79%	0,42%	0,01764	kg 1,4-DCB
Fossil resource scarcity	21,38%	0,23%	77,85%	0,54%	0,01766	kg oil eq
Water consumption	18,67%	0,08%	80,59%	0,66%	0,00088	m3
Fine particulate matter formation	36,59%	0,24%	62,00%	1,17%	9,5E-05	kg PM2.5 eq
Terrestrial ecotoxicity	58,44%	0,35%	40,73%	0,48%	0,34468	kg 1,4-DCB
Land use	13,47%	0,29%	85,85%	0,39%	0,00283	m2a crop eq
Terrestrial acidification	34,01%	0,23%	64,79%	0,97%	0,00022	kg SO2 eq
Human non-carcinogenic toxicity	34,56%	0,05%	65,01%	0,38%	0,14811	kg 1,4-DCB
Global warming	21,38%	0,19%	77,78%	0,65%	0,06656	kg CO2 eq
Marine eutrophication	16,97%	0,06%	82,24%	0,73%	5E-06	kg N eq
Mineral resource scarcity	42,25%	0,05%	57,32%	0,38%	0,00122	kg Cu eq
Ozone formation, Terrestrial ecosystems	28,74%	0,56%	69,97%	0,73%	0,00014	kg NOx eq
Ionizing radiation	7,24%	0,10%	92,37%	0,29%	0,01371	kBq Co-60 eq
Stratospheric ozone depletion	16,67%	0,21%	82,37%	0,75%	3,8E-08	kg CFC11 eq
Freshwater eutrophication	14,40%	0,06%	85,26%	0,28%	6,4E-05	kg P eq
Freshwater ecotoxicity	59,07%	0,03%	40,48%	0,42%	0,01389	kg 1,4-DCB
Human carcinogenic toxicity	41,46%	0,12%	57,92%	0,50%	0,00636	kg 1,4-DCB

Table 13: Results for Electric scooter (ES-4)

For the **seventh scenario (ES-5)**, the battery from airport is considered and the green electricity grid mix is considered. The results are represented on Table 14.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	32,44%	0,66%	66,03%	0,87%	0,00012	kg NOx eq
Marine ecotoxicity	60,43%	0,03%	39,10%	0,44%	0,01686	kg 1,4-DCB
Fossil resource scarcity	31,78%	0,34%	67,08%	0,80%	0,01188	kg oil eq
Water consumption	17,67%	0,07%	81,63%	0,63%	0,00093	m3
Fine particulate matter formation	39,60%	0,25%	58,89%	1,26%	8,8E-05	kg PM2.5 eq
Terrestrial ecotoxicity	55,52%	0,34%	43,69%	0,45%	0,3628	kg 1,4-DCB
Land use	8,83%	0,20%	90,71%	0,26%	0,00432	m2a crop eq
Terrestrial acidification	37,56%	0,26%	61,11%	1,07%	0,0002	kg SO2 eq
Human non-carcinogenic toxicity	40,08%	0,06%	59,41%	0,45%	0,12769	kg 1,4-DCB
Global warming	32,77%	0,30%	65,94%	0,99%	0,04342	kg CO2 eq
Marine eutrophication	27,82%	0,09%	70,89%	1,20%	3,1E-06	kg N eq
Mineral resource scarcity	41,56%	0,05%	58,01%	0,38%	0,00124	kg Cu eq
Ozone formation, Terrestrial ecosystems	32,80%	0,63%	65,73%	0,84%	0,00013	kg NOx eq
Ionizing radiation	10,94%	0,14%	88,49%	0,43%	0,00908	kBq Co-60 eq
Stratospheric ozone depletion	17,72%	0,22%	81,27%	0,79%	3,6E-08	kg CFC11 eq
Freshwater eutrophication	31,74%	0,12%	67,51%	0,63%	2,9E-05	kg P eq
Freshwater ecotoxicity	61,50%	0,03%	38,03%	0,44%	0,01335	kg 1,4-DCB
Human carcinogenic toxicity	54,05%	0,16%	45,13%	0,66%	0,00488	kg 1,4-DCB

TABLE 14: RESULTS FOR ELECTRIC SCOOTER (ES-5)

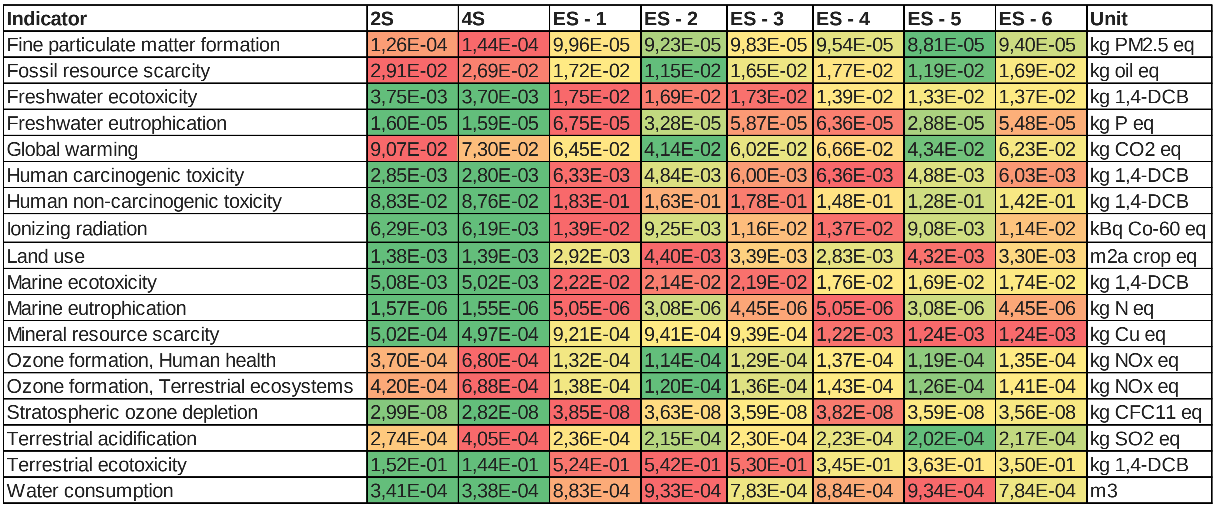
For the **eighth scenario (ES-6)**, the battery from airport is considered and the electricity grid mix available on literature (Bulach *et al.*, 2020) is considered. The results are represented on Table 15.

Impact category	Production	Transport	Use	EOL	Total	Unit
Ozone formation, Human health	28,75%	0,58%	69,90%	0,77%	0,00013	kg NOx eq
Marine ecotoxicity	58,66%	0,03%	40,88%	0,43%	0,01737	kg 1,4-DCB
Fossil resource scarcity	22,35%	0,24%	76,85%	0,56%	0,01689	kg oil eq
Water consumption	21,05%	0,08%	78,12%	0,75%	0,00078	m3
Fine particulate matter formation	37,11%	0,24%	61,47%	1,18%	9,4E-05	kg PM2.5 eq
Terrestrial ecotoxicity	57,47%	0,35%	41,71%	0,47%	0,35047	kg 1,4-DCB
Land use	11,55%	0,25%	87,86%	0,34%	0,0033	m2a crop eq
Terrestrial acidification	34,94%	0,24%	63,82%	1,00%	0,00022	kg SO2 eq
Human non-carcinogenic toxicity	35,95%	0,05%	63,60%	0,40%	0,14238	kg 1,4-DCB
Global warming	22,85%	0,21%	76,25%	0,69%	0,06227	kg CO2 eq
Marine eutrophication	19,26%	0,06%	79,85%	0,83%	4,4E-06	kg N eq
Mineral resource scarcity	41,62%	0,05%	57,95%	0,38%	0,00124	kg Cu eq
Ozone formation, Terrestrial ecosystems	29,21%	0,56%	69,49%	0,74%	0,00014	kg NOx eq
Ionizing radiation	8,68%	0,11%	90,87%	0,34%	0,01144	kBq Co-60 eq
Stratospheric ozone depletion	17,88%	0,22%	81,10%	0,80%	3,6E-08	kg CFC11 eq
Freshwater eutrophication	16,72%	0,06%	82,89%	0,33%	5,5E-05	kg P eq
Freshwater ecotoxicity	59,95%	0,03%	39,59%	0,43%	0,01369	kg 1,4-DCB
Human carcinogenic toxicity	43,71%	0,12%	55,64%	0,53%	0,00603	kg 1,4-DCB

TABLE 15: RESULTS FOR ELECTRIC SCOOTER (ES-6)

- Comparison of different scooters

A project is applied to compare the eight scenarios of life cycle for the three scooters. Table 16 shows that any scooter model is predominantly the best option in all the categories. These results will be discussed and explained in the interpretation section.



Indicator	2S	4S	ES - 1	ES - 2	ES - 3	ES - 4	ES - 5	ES - 6	Unit
Fine particulate matter formation	1,26E-04	1,44E-04	9,96E-05	9,23E-05	9,83E-05	9,54E-05	8,81E-05	9,40E-05	kg PM2.5 eq
Fossil resource scarcity	2,91E-02	2,69E-02	1,72E-02	1,15E-02	1,65E-02	1,77E-02	1,19E-02	1,69E-02	kg oil eq
Freshwater ecotoxicity	3,75E-03	3,70E-03	1,75E-02	1,69E-02	1,73E-02	1,39E-02	1,33E-02	1,37E-02	kg 1,4-DCB
Freshwater eutrophication	1,60E-05	1,59E-05	6,75E-05	3,28E-05	5,87E-05	6,36E-05	2,88E-05	5,48E-05	kg P eq
Global warming	9,07E-02	7,30E-02	6,45E-02	4,14E-02	6,02E-02	6,66E-02	4,34E-02	6,23E-02	kg CO2 eq
Human carcinogenic toxicity	2,85E-03	2,80E-03	6,33E-03	4,84E-03	6,00E-03	6,36E-03	4,88E-03	6,03E-03	kg 1,4-DCB
Human non-carcinogenic toxicity	8,83E-02	8,76E-02	1,83E-01	1,63E-01	1,78E-01	1,48E-01	1,28E-01	1,42E-01	kg 1,4-DCB
Ionizing radiation	6,29E-03	6,19E-03	1,39E-02	9,25E-03	1,16E-02	1,37E-02	9,08E-03	1,14E-02	kBq Co-60 eq
Land use	1,38E-03	1,39E-03	2,92E-03	4,40E-03	3,39E-03	2,83E-03	4,32E-03	3,30E-03	m2a crop eq
Marine ecotoxicity	5,08E-03	5,02E-03	2,22E-02	2,14E-02	2,19E-02	1,76E-02	1,69E-02	1,74E-02	kg 1,4-DCB
Marine eutrophication	1,57E-06	1,55E-06	5,05E-06	3,08E-06	4,45E-06	5,05E-06	3,08E-06	4,45E-06	kg N eq
Mineral resource scarcity	5,02E-04	4,97E-04	9,21E-04	9,41E-04	9,39E-04	1,22E-03	1,24E-03	1,24E-03	kg Cu eq
Ozone formation, Human health	3,70E-04	6,80E-04	1,32E-04	1,14E-04	1,29E-04	1,37E-04	1,19E-04	1,35E-04	kg NOx eq
Ozone formation, Terrestrial ecosystems	4,20E-04	6,88E-04	1,38E-04	1,20E-04	1,36E-04	1,43E-04	1,26E-04	1,41E-04	kg NOx eq
Stratospheric ozone depletion	2,99E-08	2,82E-08	3,85E-08	3,63E-08	3,59E-08	3,82E-08	3,59E-08	3,56E-08	kg CFC11 eq
Terrestrial acidification	2,74E-04	4,05E-04	2,36E-04	2,15E-04	2,30E-04	2,23E-04	2,02E-04	2,17E-04	kg SO2 eq
Terrestrial ecotoxicity	1,52E-01	1,44E-01	5,24E-01	5,42E-01	5,30E-01	3,45E-01	3,63E-01	3,50E-01	kg 1,4-DCB
Water consumption	3,41E-04	3,38E-04	8,83E-04	9,33E-04	7,83E-04	8,84E-04	9,34E-04	7,84E-04	m3

TABLE 16: COMPARISON OF ALL 8 SCENARIOS

The results of Table 15 are plotted in a bar graph (Figure 8), that illustrates how the impacts between the different models and different alternatives in the life cycle evaluated modify the results for each impact category.

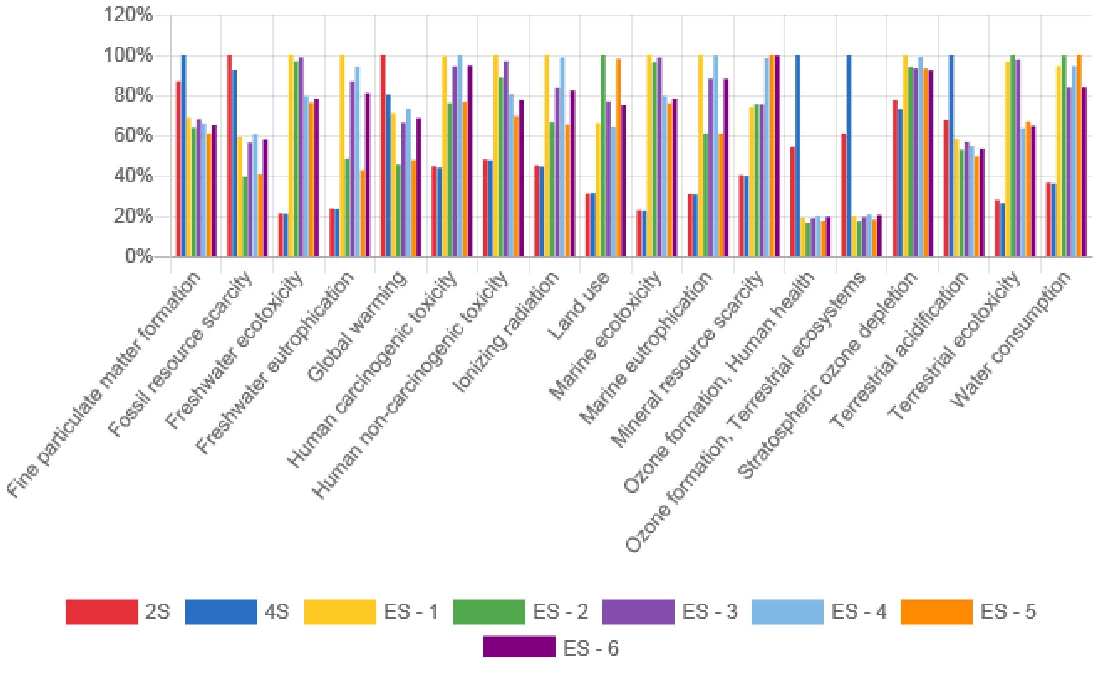


FIGURE 8: COMPARISON OF THE RESULTS OF EIGHT DIFFERENT SCENARIOS

5. Interpretation

The results obtained for the eight scenarios, summarized on Table 16 and Figure 8, shows that the comparison between the scooters is not straightforward and the results for the impact categories can lead to different conclusions depending on the scenarios compared.

The "incremental" modifications from the two-stroke engine to the four-stroke engine has several advantages such as higher fuel economy, decrease of emission of some specific compounds and modification of the fuel applied (Ålander *et al.*, 2005). However, the nitrogen oxide emissions are higher for four-stroke, according to Ålander *et al.* (2005). In the two-stroke engine, the formation of nitrogen oxide is limited due to the presence of an overlap of intake and exhaust of the cycle, resulting in a special type of gas recirculation (MECA, 2014).

In this way, the comparison of the impact of these two models shows that for both of them (for almost all impact categories) the hotspot of the process is the use phase, and the model that has the lowest environmental impacts varies according to the category. Compared to the two-stroke model, it is possible to notice that the four-stroke scooter has the lowest results for several impact categories, the main exceptions are: Fine particulate matter formation, Ozone formation and Terrestrial acidification. For the electric scooter, the results depend on the electricity mix and the battery considered. All these higher results for the four-stroke are a consequence of the higher nitrogen oxide emission, even if the particulates, metals, and organic compounds emitted are lower than in the other model.

Comparing these two system with the electric scooter using the ecoinvent mix for electricity in Germany and the battery from ecoinvent database (Scenario ES-1), Figure 9, it is possible to observe that despite the reduction in the emissions during the use phase (compared to the motor scooters), the impacts of the electric scooter are also high in some impact categories due to the energy consumed by the scooter.

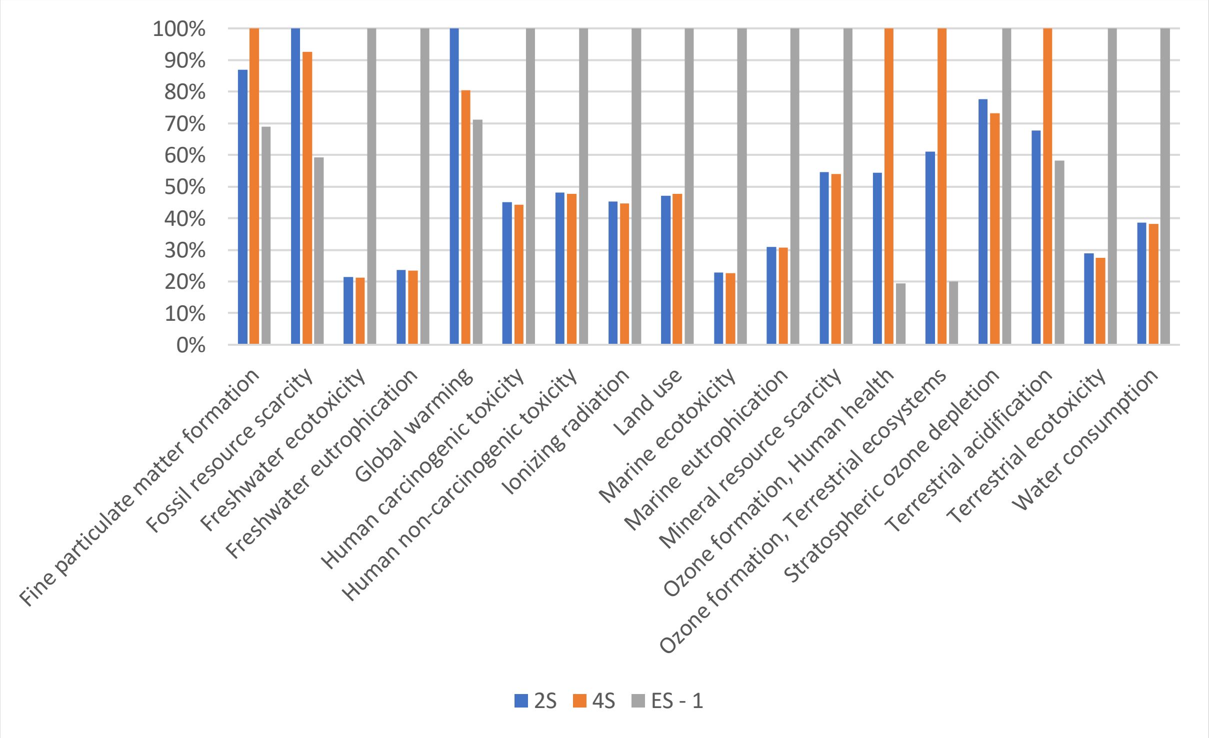


Figure 9: Comparison of the results of Scenarios 1 (2S), 2 (4S) and 3 (ES-1)

Figure 9 illustrates that two-stroke scooter has the highest impacts (among the three options) for the Fossil resource scarcity and the Global warming. According to the contribution tree of the Fossil resource scarcity, the impacts observed for the Fossil resource scarcity are a consequence of the flow "petrol, two-stroke blend", while the Global warming is a consequence of the higher carbon dioxide emission for the two-stroke. The four-stroke scooter has the worst impacts for Fine particulate matter formation, Ozone formation and Terrestrial acidification, due to the higher emission of nitrogen oxides. For all the other categories, the electric scooter (Scenario ES-1) is the scenario with highest impacts, when compared only with the scenarios of Figure 9. Despite having the worst results for some scenarios, in the category Global warming the impacts of the electric scooter are the lowest. This represents a possibility for electric scooters to solve some issues that are constantly related to the use of two-wheeled vehicles.

However, the impacts observed for the electric scooter depends on the electricity mix applied. The electricity mix in Germany includes coal for instance, which is commonly related as a source of pollutants. In this way, if the person using the scooter charges the equipment with a green electricity mix (Scenario ES-2), a lower environmental impact, at least in some categories, it is expected. Figure 10 shows that the use of green electricity mix , Scenario 4 (ES-2), reduces the environmental impact of almost all the impact categories compared to Scenario 3 (ES-1). The exceptions are Land use, Mineral resource scarcity, Terrestrial ecotoxicity and Water consumption. For instance, for the water consumption (in ES-2), 29.24% comes from the high voltage electricity production using biogas.

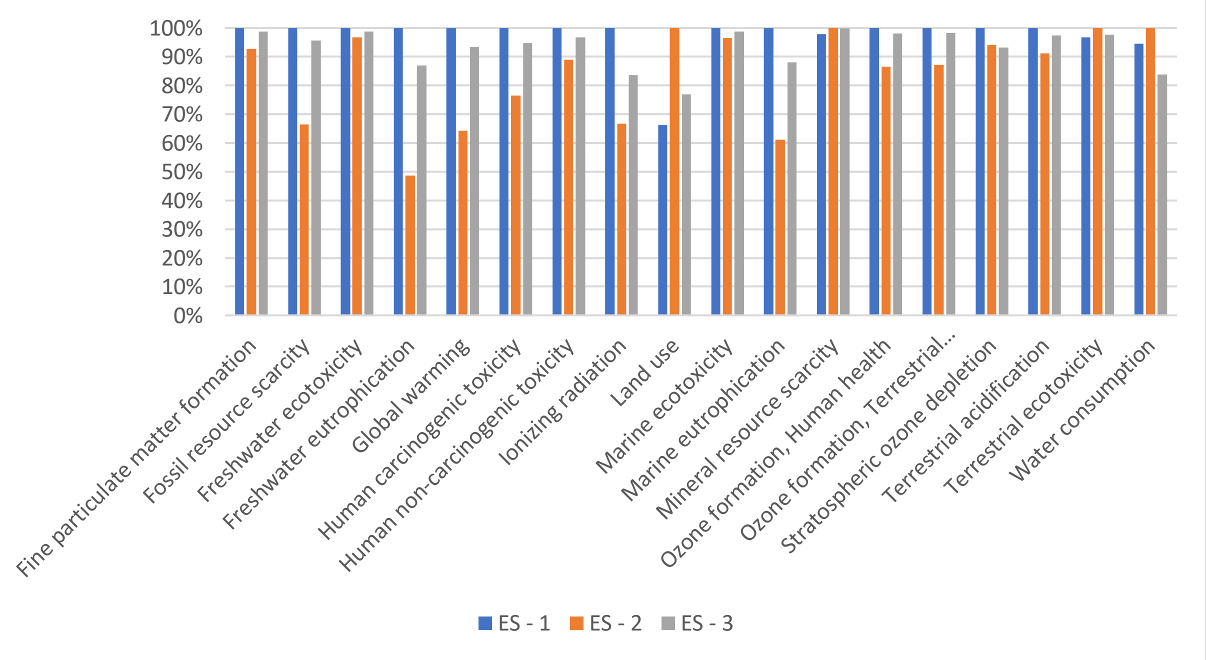


FIGURE 10: COMPARISON OF THE ELECTRICITY MIX APPLIED

Comparing the results of the scenarios ES-1 and ES-2, it is possible to notice the potential of the reduction in the Global warming impacts in more than 30% (due to the use of green energy). This is relevant since most of the Global warming impacts, even with the green electricity mix, are concentrated in one place (Europe), as observed in Figure 11. There is also an important contribution for the Global warming in Asia.

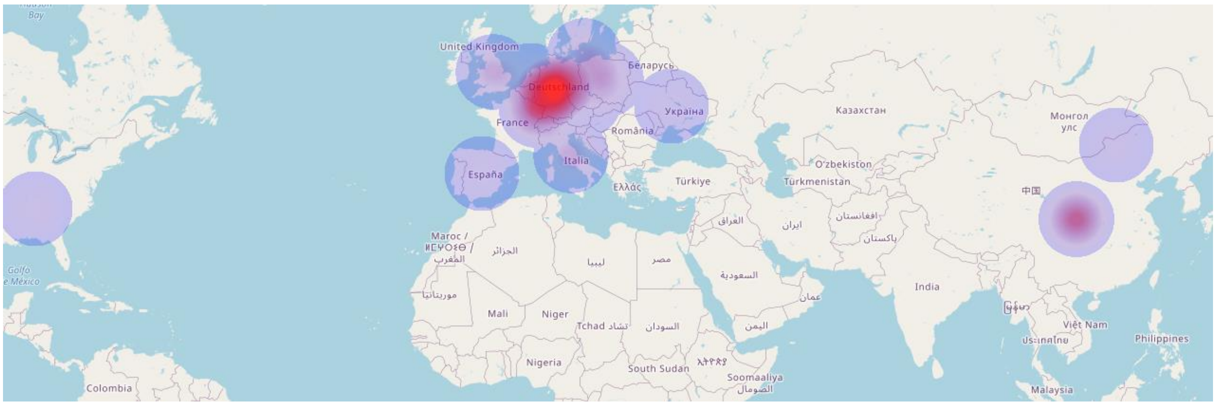


Figure 11: E-Scooter (Green Electricity Mix) - Locations of Global Warming Impact Category

It is not the aim of this work to identify the best scenario among the 8 possible options, however, considering all the discussed aspects and the results of Table 16, it is possible to observe that the scenarios with green electricity seems a promising alternative. The electric scooter solves the emissions issues of the motor scooter, and if a green electricity mix is applied, some of the impacts of the electricity production are reduced.

Figure 10 also contains the electricity mix obtained from literature (Scenario 5 – ES-3). As observed, the results for this electricity mix are similar to the results observed for the electricity mix of ecoinvent (Scenario 3 – ES-1). This happens because both of them contains the data about the complete German Electricity mix, the only difference is that one is already available in the database and the other is modeled according to the Inventory information. For 13 impact categories, the difference in the results between ES-1 and ES-3 are lower than +/- 10%, for 5 other categories the difference is between (+/-) 11% and 16%.

If scenarios 3 (ES-1) and 6 (ES-4) are compared, the only difference between these scenarios is the battery system considered for the battery production. Therefore it is possible to compare the environmental impacts of two processes considered for the battery (Figure 12).

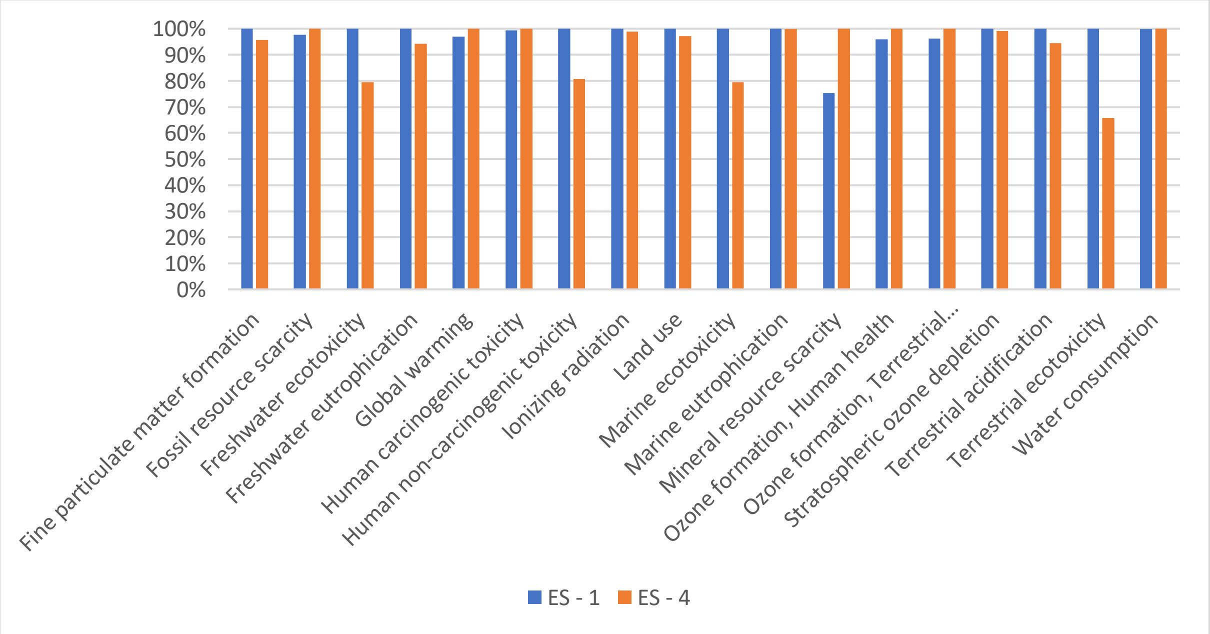


Figure 12: Comparison of two different battery options (ES-1 and ES-4)

Figure 12 shows that for many impact categories, the results of two batteries considered are similar. Nevertheless, for Freshwater ecotoxicity, Human non-carcinogenic toxicity, Marine ecotoxicity, Mineral resource scarcity and Terrestrial ecotoxicity, the differences are relevant. However, it is not possible to conclude which option is the best, because for both cases the battery is not specific for electric scooters. In the scenario ES-1, the battery considered in ecoinvent has a cathode of $LiMn_2O_4$, electrolyte of $LiPF_6$ in ethylenecarbonate, and the anode is lithium ion intercalation. The ecoinvent process can be used for any "mechanical drive of an electrical vehicle". While for ES-4, the battery model is also not specific for electric scooter and considers Lithium Cobalt Oxide (LCO) for Cathode and Lithium titanate (LTO) as anode. Therefore, the technologies of both batteries are not the same.

- Limitations

Some other limitations of this study can be highlighted. The production of motor scooter of the two-stroke and four-stroke scooter is considered the same process in ecoinvent. Probably, in industries, these processes are different, then the obtention of primary data collected from the industries can indicate some differences in the impacts during the production of the scooter that are not observed in this work. The difference considered between these two models after the production is the weight of the scooter, fuel, place of production and emissions. For the electric scooter, since the process from ecoinvent is also considered, more specific data could contribute to more precise results.

During the modeling of the use phase, most of the emissions for the four-stroke are calculated in reference to the emissions of two-stroke. Then, the results and conclusions of this work can be altered if more precise data about the emissions of the two different models are obtained. Also regarding the emissions of the motor scooters, only the compounds mentioned in this report are considered. If more compounds are considered, maybe the comparison of motor scooters and electric scooter could result in different conclusions. Besides that, due to some lack of data, as mentioned, the emissions of metals from two-stroke scooter are obtained from two-stroke engine with different application, but since the fuel is similar, the emissions expected are also the same.

There is one specific study in literature that compares two and four-stroke motorcycles and has several emissions details, however this study is not considered in this report because the data are from 1999, and even includes emissions data from a motorcycle that was produced in 1982(Tsai *et al.*, 2000). Then, since the data are not recent, they are not considered in this report. However, this reference (Tsai *et al.*, 2000) is important to demonstrate one important limitation of the present report. The report is not considering aspects related to the years of use of the motorcycle, e.g if the emissions will increase or decrease according to the number of kilometers that the scooter was already used. Besides that, the different driving cycles are not the focus of this report.

During the implementation of the modeling in openLCA, using ecoinvent Database, not all the flows are available. Then, some assumptions are made as explained in the inventory. Some examples are the consideration of two different green energy types as the same, due to the lack of specific flow identified.

In general, the expectancy of duration of the three scooters is considered the same for all the three scooters, but this is not necessarily accurate, because different models with different technologies can have a different duration. Besides that, the impacts over the life cycle of the electric scooter can be altered depending on the battery duration and the electricity consumption. If the battery lasts more than the scooter, then a second use for the battery can be defined by an allocation method, that will reduce the environmental impact. However, if the duration of the battery is lower, then more than one battery will be required and then the impacts will increase.

Despite all the limitations presented, the analyses performed in this work contributes to the challenge of rethink urban mobility in order to understand the sources of problems that are affecting society. The identification of hotspots is essential to illustrate the need of technologies to reduce the emissions of the motor scooters, while moving for greener electricity sources, that can contribute for the decrease in the electric scooters' impacts.

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7. Feedback & Contact

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8. Appendix

A. 1: Compounds Emissions for two-stroke and four-stroke models

Description	**Two - Stroke**	**Four - Stroke**	**Unit**
Ethane	11.9	0.595	mg/km
Ethene	30.9	1.545	mg/km
Propane	0.9	0.045	mg/km
Propene	22.1	1.105	mg/km
Acetylene	40.2	2.01	mg/km
Isobutene	30.2	1.51	mg/km
n-butane	10.3	0.515	mg/km
trans-2-butene	3	0.15	mg/km
1- butene	4.7	0.235	mg/km
cis-2-butene	2.3	0.115	mg/km
Propyne	1.9	0.095	mg/km
Isopentane	95.2	4.76	mg/km
1,3-butadiene	3.8	0.19	mg/km
n-pentane	16.6	0.83	mg/km
trans-2-pentene	2.1	0.105	mg/km
cis-2-pentene	1	0.05	mg/km
methylpentanes	29.6	1.48	mg/km
Isoprene	2.1	0.15	mg/km
n-hexane	3.1	0.155	mg/km
n-heptane	6.1	0.18	mg/km
Benzene	6.9	0.58	mg/km
Toluene	27.4	2.30	mg/km
Ethylbenzene	10	0.50	mg/km
M+p-xylene	24.2	1.02	mg/km
o-xylene	11.2	0.35	mg/km
1,3,5- trimethylbenzene	3.4	0.06	mg/km
1,2,4- trimethylbenzene	2.6	0.07	mg/km
CO	1.05	0.735	g/km
CO_2	55	38.25	g/km
NO_X	0.19	0.57	g/km

TABLE A. 1: *COMPOUNDS EMISSIONS FOR TWO-STROKE AND FOUR-STROKE MODELS*

A. 2: Metal Emissions for two-stroke and four-stroke models

Description	Two - Stroke	Four - Stroke	Unit
Ag	6.01276E-09	1.2026E-09	kg/L fuel
Al	4.54565E-06	9.0913E-07	kg/L fuel
B	1.20255E-07	2.4051E-08	kg/L fuel
Ba	2.4051E-08	4.8102E-09	kg/L fuel
Bi	9.62041E-09	1.9241E-09	kg/L fuel
Ca	8.70648E-06	1.7413E-06	kg/L fuel
Co*	6.01276E-09	1.2026E-09	kg/L fuel
Cr*	8.41786E-08	1.6836E-08	kg/L fuel
Cu	6.01276E-08	1.2026E-08	kg/L fuel
Fe	1.90003E-06	3.8001E-07	kg/L fuel
Mg	1.04622E-06	2.0924E-07	kg/L fuel
Mn	3.60766E-08	7.2153E-09	kg/L fuel
Mo*	1.20255E-08	2.4051E-09	kg/L fuel
Na	1.28673E-06	2.5735E-07	kg/L fuel
Ni	1.44306E-07	2.8861E-08	kg/L fuel
Pb*	1.20255E-08	2.4051E-09	kg/L fuel
Rb (not included)	2.4051E-09	4.8102E-10	kg/L fuel
Sr*	2.4051E-08	4.8102E-09	kg/L fuel
Ti	5.77225E-07	1.1544E-07	kg/L fuel
V*	9.62041E-09	1.9241E-09	kg/L fuel
Zn	1.44306E-07	2.8861E-08	kg/L fuel

TABLE A. 2: *METAL EMISSIONS FOR TWO-STROKE AND FOUR-STROKE MODELS*

(*) Detected below the detection limit. The limit is considered as emission.

A. 3: Electric Scooter – Use Phase Inputs and Outputs

Input Flows	Amount	Unit
Battery airport	b2*weightbattery	kg
battery, Li-ion, rechargeable, prismatic	b1*weightbattery	kg
charger transported	1.0	Item(s)
distribution network, electricity, low voltage	numberofperson *(8.74049*10^-8)*batterycapacity*batteryvoltage *numberofcharges /1000	km
e-scooter new in Berlin	1.0	Item(s)
Electricity low voltage conventional 2	numberofperson *d1*batterycapacity*batteryvoltage *numberofcharges /1000	kWh
Electricity low voltage TVB	numberofperson *d2*batterycapacity*batteryvoltage *nonsolar *numberofcharges /1000	kWh
electricity mix airport lv	numberofperson *d3*(1-solarfactor_airport) *batterycapacity*batteryvoltage *numberofcharges /1000	kWh
electricity, low voltage	numberofperson *d3*(solarfactor_airport) *batterycapacity*batteryvoltage *numberofcharges /1000	kWh
electricity, low voltage	numberofperson *d2*batterycapacity*batteryvoltage *solarfactor *numberofcharges /1000	kWh
maintenance, electric scooter, without battery	1.0	Item(s)
road	7.02882	m*a
road maintenance	7.02882*14.01	m*a
sulfur hexafluoride, liquid	numberofperson * (6.27*10^-9)*batterycapacity*batteryvoltage *numberofcharges /1000	kg
Output Flows	**Amount**	**Unit**
brake wear emissions, passenger car	0.006972928	kg

e-scooter used in berlin 2	**expectancydurationescooter*numberofperson**	**p*km**
road wear emissions, passenger car	0.07671526	kg
Sulfur hexafluoride	(6.27*10^-9)*batterycapacity*batteryvoltage *numberofcharges /1000	kg
tyre wear emissions, passenger car	0.448539438	kg

Table A. 3: Electric Scooter – Use Phase Inputs and Outputs

A. 4: Two-stroke Scooter – Use Phase Inputs and Outputs

Input Flows	**Amount**	**Unit**
maintenance, motor scooter	1.0	Item(s)
petrol, two-stroke blend	(lifeexpectancy /kmperliteroffuel)*densityfuel *personpervehicle	kg
road	4.61	m*a
road maintenance	64.6	m*a
Scooter 2 stroke transported	1.0	Item(s)
Output Flows	**Amount**	**Unit**
1-Butene	4.7*lifeexpectancy *personpervehicle	mg
Aluminium	((4.54E-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Barium	((2.4E-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Benzene	6.9*lifeexpectancy *personpervehicle	mg
Benzene, 1,2,4-trimethyl-	2.6*lifeexpectancy *personpervehicle	mg
Benzene, 1,3,5-trimethyl-	3.4*lifeexpectancy *personpervehicle	mg
Benzene, ethyl-	10*lifeexpectancy *personpervehicle	mg
Bismuth dimethyldithiocarbamate *	((9.62*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Boron	((1.2*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Butadiene	3.8*lifeexpectancy *personpervehicle	mg
Butane	10.3*lifeexpectancy *personpervehicle	mg
Calcium	((8.7*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Carbon dioxide, fossil	55*lifeexpectancy *personpervehicle	g
Carbon monoxide, fossil	1.05*lifeexpectancy *personpervehicle	g
Chromium	((8.41*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
cis-2-Butene	2.3*lifeexpectancy *personpervehicle	mg
cis-2-Pentene	1*lifeexpectancy *personpervehicle	mg
Cobalt	((6.01*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Copper	((6.013*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Ethane	11.9*lifeexpectancy*personpervehicle	mg
Ethene	30.9*lifeexpectancy *personpervehicle	mg
Ethyne	40.2*lifeexpectancy *personpervehicle	mg

Heptane	6.1*lifeexpectancy *personpervehicle	mg
Hexane	3.1*lifeexpectancy *personpervehicle	mg
Iron	((1.9*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
isobutene	30.2*lifeexpectancy *personpervehicle	mg
isopentane	95.2*lifeexpectancy *personpervehicle	mg
Isoprene	2.1*lifeexpectancy *personpervehicle	mg
Lead	((1.20*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
m-Xylene	0.5*24.2*lifeexpectancy *personpervehicle	mg
Magnesium	((1.04*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Manganese	((3.61*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Methyl pentane	29.6*lifeexpectancy *personpervehicle	mg
Molybdenum	((1.20*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Nickel	((1.44*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Nitrogen oxides, DE	0.19*lifeexpectancy *personpervehicle	g
o-Xylene	11.2*lifeexpectancy *personpervehicle	mg
para-Xylene	0.5*24.2*lifeexpectancy *personpervehicle	mg
Particulates, < 2.5 um	((1.451544003E-5)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle	kg
Particulates, > 10 um	((6.810811371E-6)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle	kg
Particulates, > 2.5 um, and < 10um	((7.68544686E-6)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle	kg
Pentane	16.6*lifeexpectancy *personpervehicle	mg
Propane	0.9*lifeexpectancy *personpervehicle	mg
Propene	22.1*lifeexpectancy *personpervehicle	mg
Propyne	1.9*lifeexpectancy *personpervehicle	mg
Scooter 2 stroke used	**lifeexpectancy *personpervehicle**	**p*km**
Silver	((6.013*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Sodium	((1.29*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Strontium	((2.4*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Sulfur dioxide, DE	((20*densityfuel*1000/(1000*kmperliteroffuel))*(64/32)*10^-6)*personpervehicle *lifeexpectancy	kg

Titanium	((5.77*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Toluene	27.4*lifeexpectancy *personpervehicle	mg
trans-2-Butene	3*lifeexpectancy *personpervehicle	mg
trans-2-Pentene	2.1*lifeexpectancy *personpervehicle	mg
Vanadium	((9.62*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg
Zinc	((1.44*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle	kg

Table A. 4: Two-stroke Scooter – Use Phase Inputs and Outputs

(*) The original reference mentioned only bismuth, but this is not identified in the database.

A. 5: Four-stroke Scooter – Use Phase Inputs and Outputs

Input Flows	Amount	Unit
maintenance, motor scooter	1.0	Item(s)
petrol, low-sulfur	(lifeexpectancy /kmperliteroffuel)*densityfuel *personpervehicle	kg
road	4.61	m*a
road maintenance	64.6	m*a
Scooter 4 stroke transported	1.0	Item(s)
Output Flows	**Amount**	**Unit**
1-Butene	4.7*lifeexpectancy *personpervehicle *0.05	mg
Aluminium	((4.54E-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Barium	((2.4E-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Benzene	6.9*lifeexpectancy *personpervehicle /11.84375	mg
Benzene, 1,2,4-trimethyl-	2.6*lifeexpectancy *personpervehicle /36.78688	mg
Benzene, 1,3,5-trimethyl-	3.4*lifeexpectancy *personpervehicle /52.78	mg
Benzene, ethyl-	10*lifeexpectancy *personpervehicle /20.05	mg
Bismuth dimethyldithiocarbamate *	((9.62*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Boron	((1.2*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Butadiene	3.8*lifeexpectancy *personpervehicle *0.05	mg
Butane	10.3*lifeexpectancy *personpervehicle *0.05	mg
Calcium	((8.7*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Carbon dioxide, fossil	(55/1.4379)*lifeexpectancy *personpervehicle	g
Carbon monoxide, fossil	(1.05*0.7)*lifeexpectancy *personpervehicle	g
Chromium	((8.41*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
cis-2-Butene	2.3*lifeexpectancy *personpervehicle *0.05	mg
cis-2-Pentene	1*lifeexpectancy *personpervehicle *0.05	mg
Cobalt	((6.01*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Copper	((6.013*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Ethane	11.9*lifeexpectancy*personpervehicle *0.05	mg
Ethene	30.9*lifeexpectancy *personpervehicle *0.05	mg
Ethyne	40.2*lifeexpectancy *personpervehicle *0.05	mg

Heptane	6.1*lifeexpectancy *personpervehicle /34.5255	mg
Hexane	3.1*lifeexpectancy *personpervehicle *0.05	mg
Iron	((1.9*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
isobutene	30.2*lifeexpectancy *personpervehicle *0.05	mg
isopentane	95.2*lifeexpectancy *personpervehicle *0.05	mg
Isoprene	2.1*lifeexpectancy *personpervehicle /14.36	mg
Lead	((1.20*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
m-Xylene	0.5*24.2*lifeexpectancy *personpervehicle /23.6944	mg
Magnesium	((1.04*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Manganese	((3.61*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Methyl pentane	29.6*lifeexpectancy *personpervehicle *0.05	mg
Molybdenum	((1.20*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Nickel	((1.44*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Nitrogen oxides, DE	0.19*3*lifeexpectancy *personpervehicle	g
o-Xylene	11.2*lifeexpectancy *personpervehicle /31.72	mg
para-Xylene	0.5*24.2*lifeexpectancy *personpervehicle /23.6944	mg
Particulates, < 2.5 um	((1.451544003E-5)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle *0.2	kg
Particulates, > 10 um	((6.810811371E-6)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle *0.2	kg
Particulates, > 2.5 um, and < 10um	((7.68544686E-6)/(0.45+0.2*0.55))*lifeexpectancy *personpervehicle *0.2	kg
Pentane	16.6*lifeexpectancy *personpervehicle *0.05	mg
Propane	0.9*lifeexpectancy *personpervehicle *0.05	mg
Propene	22.1*lifeexpectancy *personpervehicle *0.05	mg
Propyne	1.9*lifeexpectancy *personpervehicle *0.05	mg
Scooter 4 stroke used	**lifeexpectancy *personpervehicle**	**p*km**
Silver	((6.013*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Sodium	((1.29*10^-6)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Strontium	((2.4*10^-8)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Sulfur dioxide, DE	((20*densityfuel*1000/(1000*kmperliteroffuel))*(64/32)*10^-6)*lifeexpectancy *personpervehicle	kg

Titanium	((5.77*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Toluene	27.4*lifeexpectancy *personpervehicle /11.94	mg
trans-2-Butene	3*lifeexpectancy *personpervehicle *0.05	mg
trans-2-Pentene	2.1*lifeexpectancy *personpervehicle *0.05	mg
Vanadium	((9.62*10^-9)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg
Zinc	((1.44*10^-7)/kmperliteroffuel)*lifeexpectancy *personpervehicle *0.2	kg

TABLE A. 5: FOUR-STROKE SCOOTER – USE PHASE INPUTS AND OUTPUTS

(*) The original reference mentioned only bismuth, but this is not identified in the database.