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Environmental Evaluation of Individual Road Transport in Carinthia

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Environmental Evaluation of Individual Road Transport in Carinthia

commissioned by:

Entwicklungsagentur Kärnten GMBH

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Abstract

This study evaluates certain environmental impacts of individual passenger transport (car, motorcycle, scooter, etc.) in Carinthia, in order to get a general idea about environmental aspects associated with the current transportation system and assess possible effects of different e-mobility alternatives. The four calculated e-mobility scenarios reflect different shares of e-mobility, different efficiencies of the vehicles and different ways of electricity production. Five environmental indicators (CML-method) have been evaluated, in order to reveal a meaningful environmental profile of the analysed transportation system.

As expected, the results show, that currently fossil fuelled cars are predominantly responsible for the environmental effects of individual passenger transport (~97%) in Carinthia. Electro mobility only plays an insignificant role.

Increasing the e-mobility share up to 5% only leads to a small reduction in environmental impacts. Compared to the status quo, the reduction of impacts is around 2%. If the e-mobility share is increased up to 75%, this would lead to a significant reduction in environmental impacts of up to 45% (photochemical oxidation; compared to status quo). In case of such a high share of e-mobility, the shift to 100% renewable electricity leads to a further significant reduction in environmental impacts of up to 57% (for global warming; compared to status quo). If efficiencies in car operation (fuel/electricity consumption, etc.) are improved and more resource efficient car designs (e.g. lightweight city cars) are implemented, this could lead to a further reduction of the environmental impacts of up to 79% (for global warming; compared to status quo).

The results show that vehicle manufacturing becomes increasingly important as electricity moves to renewable sources. While currently vehicle production is responsible for around 13% of the environmental impacts, it is responsible for up to 34% in scenario SZ4. From the fact that battery production and disposal plays a major role in the lifecycle of an electric car (Figure 3-32), it can thus be concluded, that finding more resource efficient ways for battery design and disposal (e.g. recycling) is increasingly important for improving our future mobility system.

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1 Methodology

1.1 Goal and Scope

The goal of the study is to roughly evaluate certain environmental impacts of the Carinthian road transport system and possible e-mobility scenarios in order to get a general idea about environmental aspects associated with the current transportation system and assess possible effects of different e-mobility alternatives.

Since this study strongly focuses on e-mobility options, the scope of the evaluation is limited to individual motor traffic (car, motorcycle, scooter, etc.), which is seen as one mayor field of application for e-mobility solutions.

According to the basic idea of lifecycle thinking, this analysis does not only consider the direct environmental effects of mobility, but also effects in earlier or later stages of the lifecycle.

operation: contains all processes that are directly connected with the operation of the vehicle, such as fuel consumption and emissions (e.g. tailpipe emissions, emissions due to tire abrasion).

maintenance: contains all processes that are connected with the maintenance of the vehicle, such as cleaning, lubrication, replacement parts, etc.

production: contains all processes that are connected with the production and assembly of the vehicle and vehicle parts, such as auto body, motor, batteries, tires, automobile electronics, etc.

disposal: contains all processes that are connected with the disassembly and disposal of the vehicle and vehicle parts

The environmental effects of the transport infrastructure (e.g. constructing and maintaining of roads, bridges, tunnels, etc.) have not been considered in this study, since the basic road infrastructure for both, conventional and electrical mobility, is essentially the same.

The methods used for this environmental analysis are largely based on the acknowledged methods for life cycle assessment, but this study does NOT claim to be a lifecycle analysis according to ISO standards.

1.2 Data

Data on the vehicle fleet and average vehicle kilometres mainly comes from official statistics (Statistics Austria). The data represent the situation in Carinthia in the years 2011 to 2013.

Generic lifecycle inventory data for the considered transportation, infrastructure and energy processes comes from Ecoinvent database, version 2.2. The reference year of the LCI-datasets is between 2000 and 2010.

Other data and modelling assumptions are based on literature and expert knowledge.

1.3 Environmental Indicators

Several environmental indicators have been evaluated, in order to reveal an environmental profile of the analysed transportation system. Lifecycle impact assessment has been carried out, applying the CML 2001 method [Hischier et al., 2010]. The CML method has been developed by the Centre of Environmental Science of Leiden University and is one of the most acknowledged methods for impact assessment. ([Guinée et al., 2001], [Frischknecht et al., 2004a])

Global warming (GWP)
Anthropogenic emissions of greenhouse gases enforce the natural greenhouse effect and contribute to a global climate change. Consequences of the greenhouse effect include an increase of the temperature level, melting of polar ice caps, elevated sea levels and regional climate changes. The contribution of different gases is given by their global warming potential (GWP), expressed in CO_2-equivalent. The “Intergovernmental Panel on Climate Change” (IPCC) developed global warming potentials for a number of substances. Global warming potentials are based on models of the greenhouse effect and are quantified for different time horizons, typically 100 years. ([Hauschild et al., 2009], [Frischknecht et al., 2004], [Jensen et al., 1997])

Acidification (AP)
The release of protons into terrestrial or aquatic ecosystems causes a decrease in the pH (Acidification). Anthropogenically derived pollutant deposition enhances the rates of acidification, which may then exceed the natural neutralising capacity of the ecosystems. Acidification has various effects on ecosystems (nutrient deficiencies and imbalances, decline in growth, forest dieback, formation of acid lakes, etc.) and on man-made systems (damage of buildings by acid rain, etc.). Substances are considered to have an acidification effect if they supply hydrogen cations to the system or leach the corresponding anions from the system. The acidification potential (AP) can be expressed as SO_2-equivalents. ([Hauschild et al., 2009], [Frischknecht et al., 2004], [Jensen et al., 1997])

Abiotic resource depletion (ADP)

The earth contains a finite amount of abiotic resources, like minerals, metals and fuels. Several different methods for the environmental assessment of resource depletion exist, which mainly differ in the definition of the environmental problem. The method used in this study is based on [Oers et al., 2002] .This method considers the decrease of the resource itself as the key problem. Thus the characterisation model considers the natural reserves (ultimate reserves) of the resources and the rates of their extraction. Abiotic resources typically contain different concentrations of individual elements. The method used in this study weights on the basis of individual chemical elements and not on the level of minerals. The characterisation factor is the Abiotic Depletion Potential (ADP), which has the depletion of “antimony” as a reference and thus is expressed as antimony-equivalent. ([Hauschild et al., 2009], [Frischknecht et al., 2004], [Oers et al., 2002], [Jensen et al., 1997])

Photochemical oxidant formation (POCP)

The phenomenon of photochemical oxidant (photochemical smog) formation is caused by the degradation of certain organic compounds in the presence of light and nitrogen oxide (NO_x). The most relevant product of that photochemical reaction is ozone. Ozone may cause eye irritation, respiratory problems, and chronic damage of the respiratory system. Ozone also may have various effects on plants, like damage of the leaf surface, damage of the photosynthetic function, dieback of leaves or the whole plant. The photochemical ozone formation can be quantified by the photochemical ozone creation potential (POCP), which is expressed in ethylene (C_2H_4) equivalents. Since different background concentrations of NO_x lead to different rates of ozone formation, different POCP values for high (high NO_x POCP) and low background concentrations (low NO_x POCP) are used for LCA. In most situations the high NO_x POCPs, are the more relevant ones. ([Hauschild et al., 2009], [Frischknecht et al., 2004], [Jensen et al., 1997])

Cumulative Energy Demand (CED)

The cumulative energy demand (CED) accounts for the primary energy consumption throughout the life cycle of a good or a service. CED_{re} accounts for renewable energy sources (biomass, wind, solar geothermal, water), CED_{nre} accounts for non-renewable energy sources (fossil and nuclear sources). The cumulative energy demand is not an impact category, but it is widely used as an important indicator for environmental assessment. The cumulative energy demand is expressed in Megajoule equivalent [MJ-Eq]. [Hischier et al., 2010]

2 Data and Modelling Assumptions

This section describes the considered process modules and the corresponding modelling assumptions

2.1 Status Quo

The following data on the vehicle fleet, average vehicle miles and fuel consumption is mainly based on official statistics.

Table 2-1: vehicle fleet in Carinthia (individual passenger transport), 2013

Federal state/district	vehicles (total)	passenger cars	motor-cycles	scooter
Carinthia	**395.821**	**338.445**	**34.700**	**22.676**
Klagenfurt (Stadt)	**67.063**	58.216	5.407	3.440
Villach (Stadt)	**40.616**	34.425	3.671	2.520
Hermagor	**12.769**	10.721	1.282	766
Klagenfurt Land	**44.150**	37.706	4.062	2.382
St. Veit an der Glan	**38.306**	32.927	3.251	2.128
Spittal an der Drau	**53.309**	45.722	4.606	2.981
Villach Land	**46.707**	39.383	4.647	2.677
Völkermarkt	**31.165**	26.806	2.512	1.847
Wolfsberg	**39.992**	33.905	3.415	2.672
Feldkirchen	**21.744**	18.634	1.847	1.263

Table 2-2: passenger cars in Carinthia, by fuel type, 2013

Fuel type	passenger cars	
Petrol	141.594	41,85%
Diesel	196.108	57,95%
Electric	203	0,04%
LPG	0	0,00%
Natural gas	36	0,01%
Petrol/LPG (bivalent)	7	0,00%
Petrol/Natural gas (bivalent)	19	0,01%
Petrol/Electric (hybrid)	460	0,14%
Diesel/Electric (hybrid)	18	0,01%
total	**338.445**	**100,00%**

Table 2-3: passenger cars in Carinthia, by fuel type, 2011/2012

fuel type	passenger cars (fleet)	vehicle kilometres per year	fuel consumption			average km per car and year
			total	per car	per 100 km	
			in liter			
petrol	116.221	1.240.289.274	91.170.573	784	7,4	10.672
diesel	170.812	2.675.997.950	181.244.647	1.061	6,8	15.666
other	2.089	36.201.019	3.242.596	1.552	9,0	17.332
total	289.122	3.952.488.243	275.657.816	953	7,0	13.671

The environmental effects of vehicle operation have been estimated based on the total vehicle kilometres in different vehicle categories. The vehicle kilometres of all "other" cars (not petrol or diesel) have been apportioned proportional to the fraction of non-petrol/diesel cars in Table 2-3. For motorcycles and scooters, vehicle kilometres per year have been estimated based on the e-mobility share (0,04%/1% for motorcycles/scooters) and estimations on average annual vehicle kilometres (3.500 km/a). Since no LCI-datasets on hybrid cars and motorcycles were available, these categories have been estimated with data for efficient petrol driven cars (EURO5) and motor scooter. Electric energy for vehicle operation was calculated with the Austrian electricity mix. Table 2-4 shows the resulting vehicle kilometres and the assigned LCI-dataset.

Table 2-4: total vehicle kilometres and assigned ecoinvent datasets

vehicle catagory	vehicle kilometers per year	assigned ecoinvent dataset
passenger car, diesel	2.675.997.950	operation, passenger car, diesel, fleet average 2010
passenger car, petrol	1.240.289.274	operation, passenger car, petrol, fleet average 2010
passenger car, natural gas	3.296.996	operation, passenger car, natural gas
passenger car, hybrid	23.606.493	operation, passenger car, petrol, EURO5
passenger car, electric	9.297.530	operation, passenger car, electric, LiMn2O4
total (cars)	**3.952.488.243**	
motorcycle, petrol	116.081.085	operation, scooter
scooter, petrol	81.167.625	operation, scooter
motorcycle, electric	48.915	operation, electric scooter
scooter, electric	819.875	operation, electric scooter
total (scooter, motorcycles)	**198.117.500**	

For the allocation of environmental effects of vehicle production and disposal, estimations on their lifetime-kilometres are necessary. Based on the considerations in [Spielmann et al.,2007] 150.000 km was chosen for all cars and 52.500 was chosen for motorcycles/scooter.

The tables in Annex 1 show the assigned datasets for vehicle production, maintenance and disposal.

2.2 E-Mobility Scenarios

Four scenarios have been defined, which reflect different shares of e-mobility, different efficiencies of the vehicles and different ways of electricity production (Table 2-5). The scenarios do not consider the effect of shifting to other modes of traveling (buses, bike, etc.) or traveling more or less (the total vehicle kilometres are the same in every scenario).

Table 2-5: e-mobility scenarios, basic assumptions

	e-mobility share	electricity mix	energy efficiency	material efficiency
status quo	0,04%	Austria	basis	basis
scenario SZ1	5%	Austria	basis	basis
scenario SZ2	75%	Austria	basis	basis
scenario SZ3	75%	100% renewable	basis	basis
scenario SZ4	75%	100% renewable	improved	improved

Scenario SZ1: shows the effect of an increased e-mobility share of 5%. All other parameters remaining unchanged.

Scenario SZ2: shows the effect of an increased e-mobility share of 75%. All other parameters remaining unchanged.

Scenario SZ3: shows the effect of using 100% renewable electricity (Table 2-6). All other parameters remaining unchanged.

Table 2-6: electricity mix "100% renewable"

electricity production	%
hydro-power	97,8 %
wind-power	0,9 %
biomass cogeneration	0,9 %
photovoltaic	0,4 %

Scenario SZ4: additionally assumes improved efficiencies in car operation (fuel/electricity consumption, etc.) and more resource efficient car designs (e.g. lightweight city cars).

3 Results

3.1 Status Quo

The Figure 3-1 Figure 3-5 show the LCIA-results for the current state of individual passenger transport in Carinthia. As expected, fossil fuelled cars are predominantly responsible for the environmental effects of individual passenger transport (~97%). The operation of the car causes the largest environmental effect (~85%), followed by vehicle production (~13%). The carbon footprint of individual passenger transport in Carinthia is 1.087.000 tons of CO_2-equivalent, which is approximately 1,95 tons per capita.

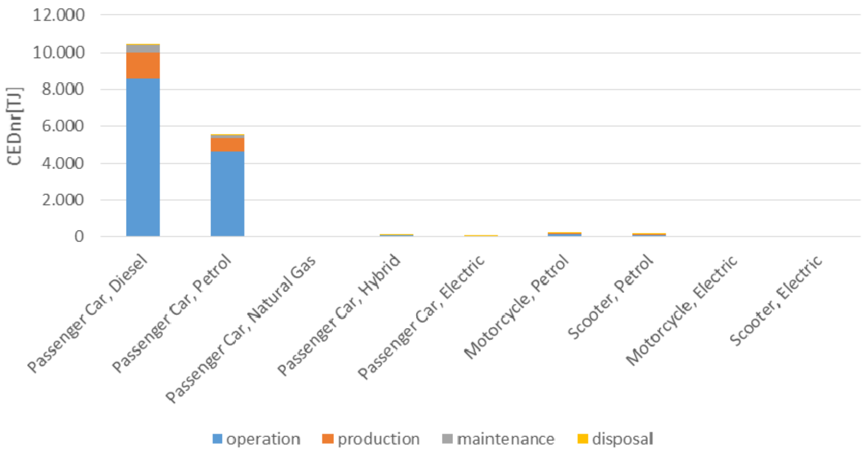

Figure 3-1: Individual passenger transport, Carinthia, Status Quo, Cumulative Energy Demand [TJ/a]

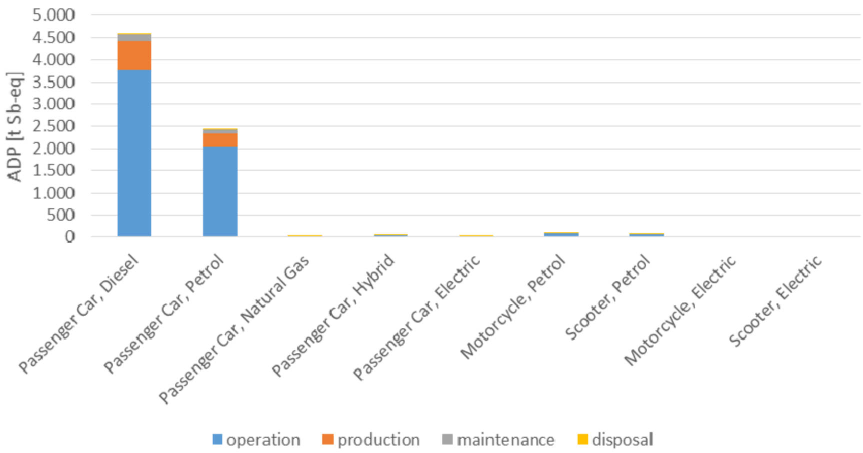

Figure 3-2: Individual passenger transport, Carinthia, Status Quo, Abiotic Depletion Potential [t Sb-eq/a]

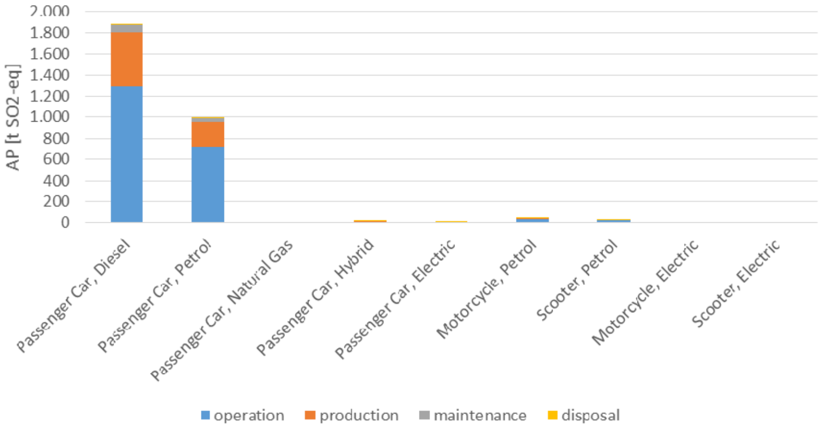

Figure 3-3: Individual passenger transport, Carinthia, Status Quo, Acidification Potential [t SO_2-eq/a]

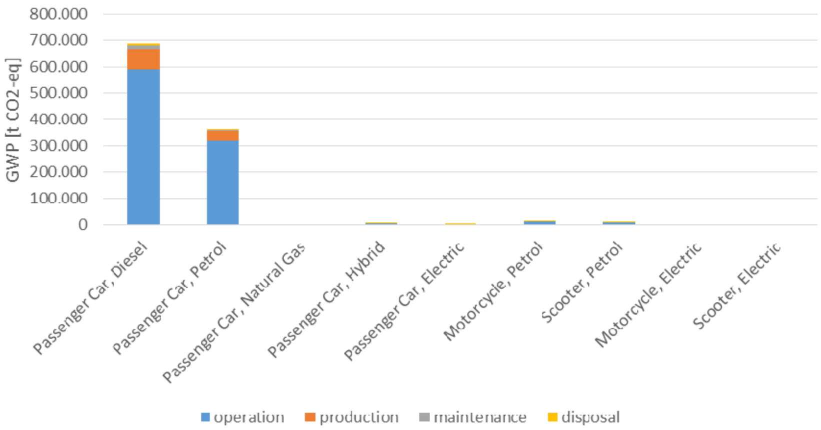

Figure 3-4: Individual passenger transport, Carinthia, Status Quo, Global Warming Potential [t CO_2-eq/a]

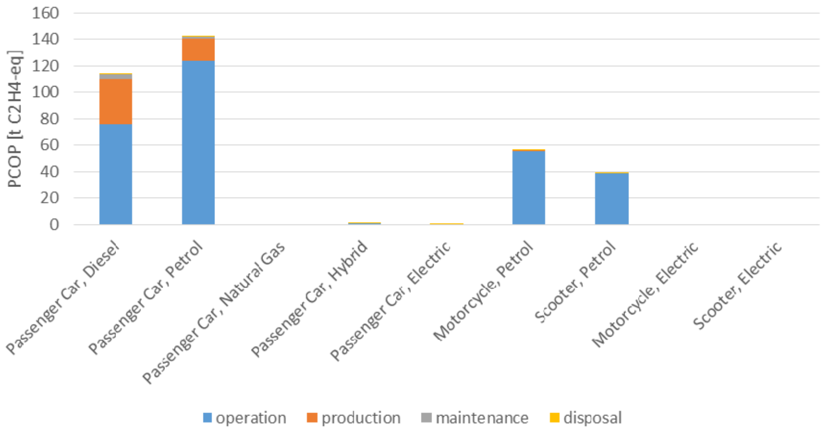

Figure 3-5: Individual passenger transport, Carinthia, Status Quo, Photochemical Oxidant formation Potential [t C_2H_4-eq/a]

3.2 Scenario SZ1

Increasing the e-mobility share up to 5%, leads to a small reduction in environmental impacts. Compared to the status quo, the reduction is between 0,7% (acidification) and 2,8% (photochemical oxidation). In scenario SZ1 the carbon footprint of individual passenger transport in Carinthia is 1.064.000 tons of CO_2- equivalent (-2,1%), which is approximately 1,91 tons per capita.

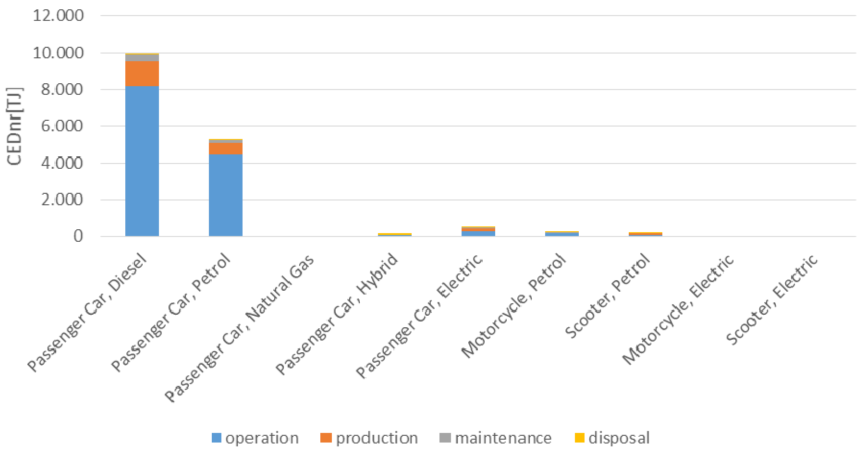

Figure 3-6: Individual passenger transport, Carinthia, Scenario SZ1, Cumulative Energy Demand [TJ/a]

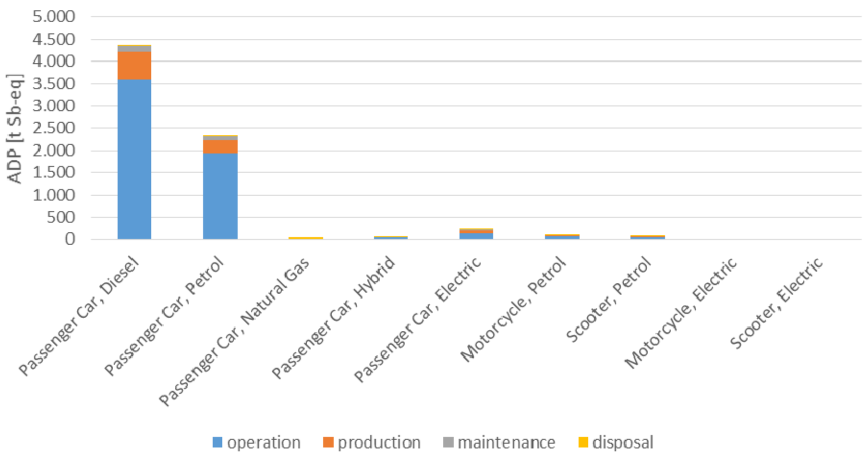

Figure 3-7: Individual passenger transport, Carinthia, Scenario SZ1, Abiotic Depletion Potential [t Sb-eq/a]

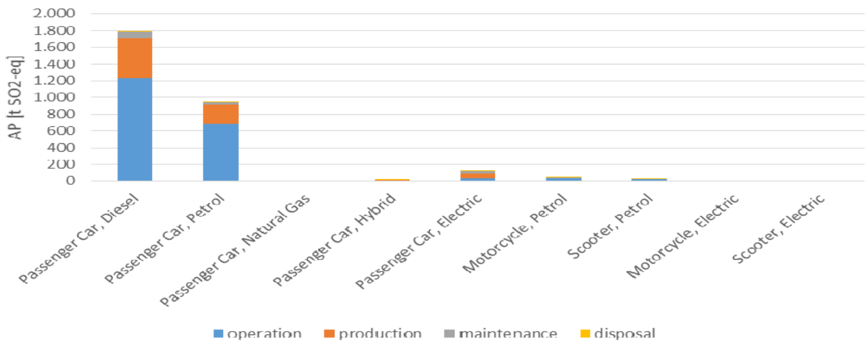

Figure 3-8: Individual passenger transport, Carinthia, Scenario SZ1, Acidification Potential [t SO_2-eq/a]

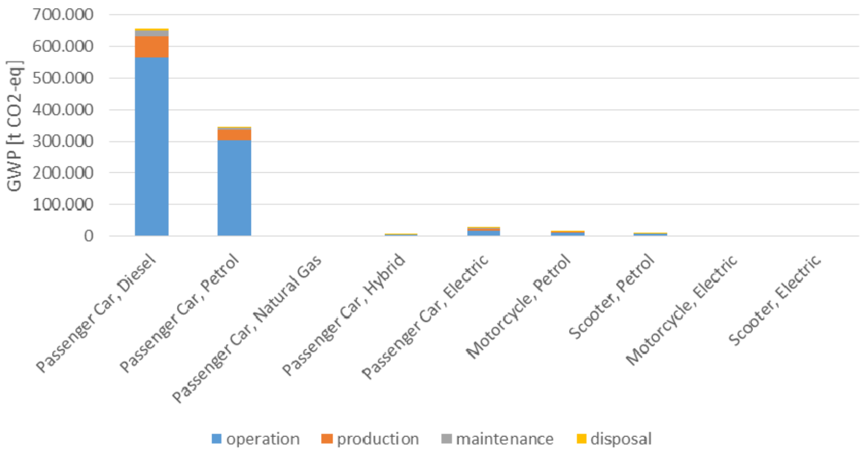

Figure 3-9: Individual passenger transport, Carinthia, Scenario SZ1, Global Warming Potential [t CO_2-eq/a]

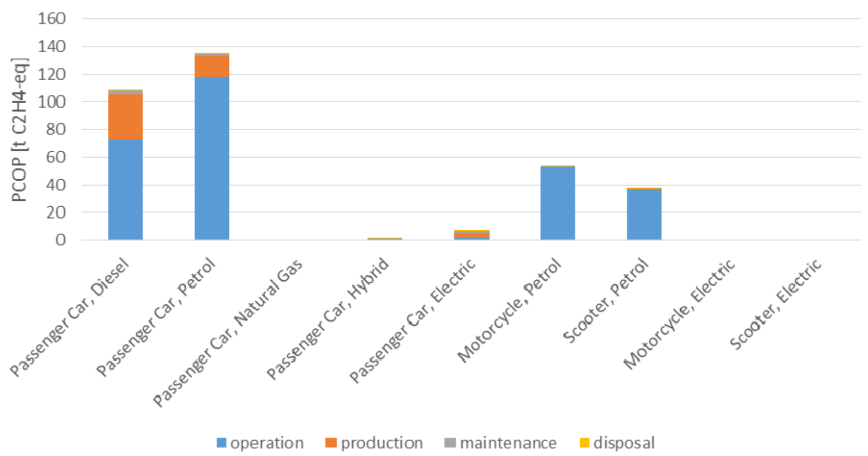

Figure 3-10: Individual passenger transport, Carinthia, Scenario SZ1, Photochemical Oxidant formation Potential [t C_2H_4-eq/a]

3.3 Scenario SZ2

Increasing the e-mobility share up to 75%, leads to a significant reduction in environmental impacts. Compared to the status quo, the reduction is between 11% (acidification) and 45% (photochemical oxidation). Electric cars are now predominantly responsible for the environmental effects of individual passenger transport (~63%), followed by diesel cars (~23%) and petrol cars (~11%). In scenario SZ2 the carbon footprint of individual passenger transport in Carinthia is 720.715 tons of CO_2- equivalent (-34%), which is approximately 1,30 tons per capita.

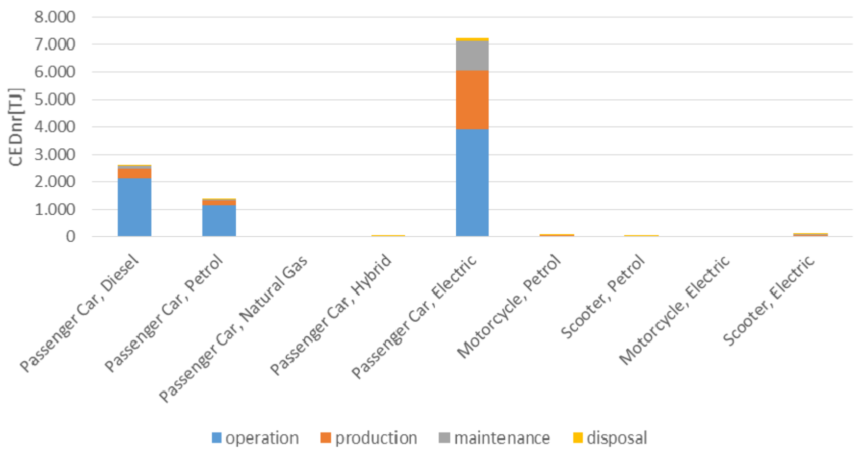

Figure 3-11: Individual passenger transport, Carinthia, Scenario SZ2, Cumulative Energy Demand [TJ/a]

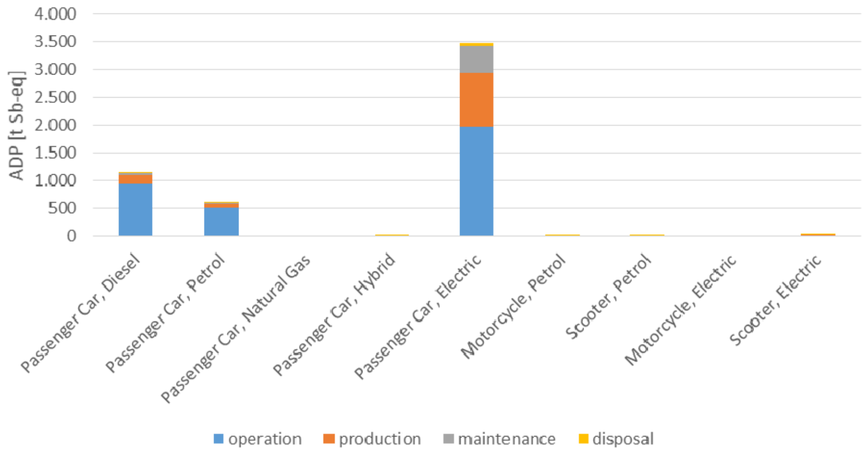

Figure 3-12: Individual passenger transport, Carinthia, Scenario SZ2, Abiotic Depletion Potential [t Sb-eq/a]

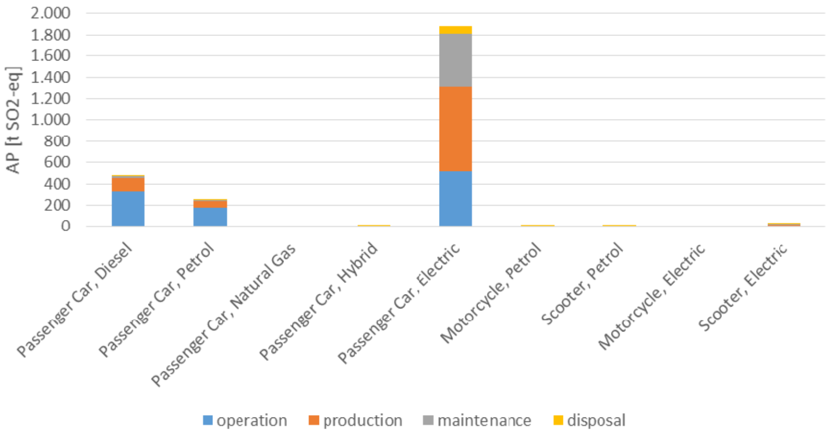

Figure 3-13: Individual passenger transport, Carinthia, Scenario SZ2, Acidification Potential [t SO_2-eq/a]

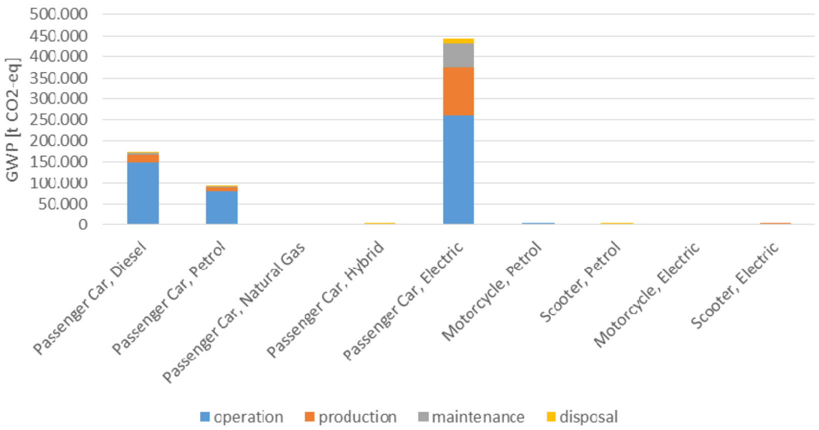

Figure 3-14: Individual passenger transport, Carinthia, Scenario SZ2, Global Warming Potential [t CO_2-eq/a]

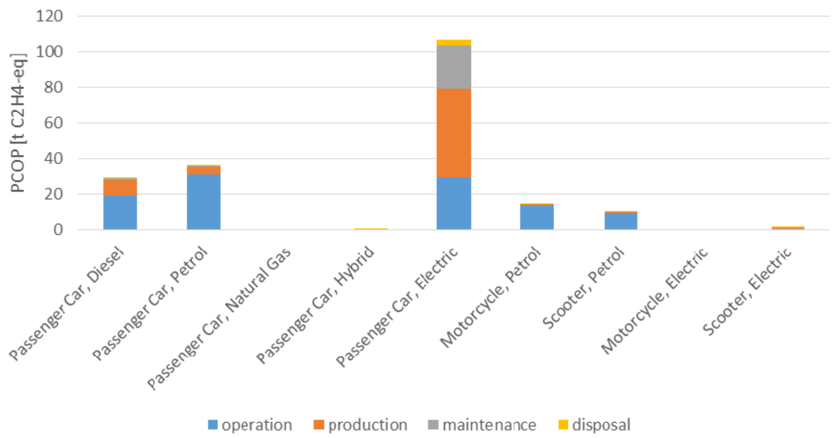

Figure 3-15: Individual passenger transport, Carinthia, Scenario SZ2, Photochemical Oxidant formation Potential [t C_2H_4-eq/a]

3.4 Scenario SZ3

Due to the high share of e-mobility (75%), the shift to 100% renewable electricity leads to a further significant reduction in environmental impacts. Compared to the status quo, the reduction is between 25% (acidification) and 57% (global warming). Electric cars still give the largest contribution to the environmental effects (~41%), closely followed by diesel cars (~37%) and petrol cars (~20%). The result of this scenario also shows that manufacturing becomes increasingly important as electricity moves to renewable sources. In this scenario vehicle production is responsible for more than 30% of the environmental impacts. In scenario SZ3 the carbon footprint of individual passenger transport in Carinthia is 466.244 tons of CO_2- equivalent (-57%), which is approximately 0,84 tons per capita.

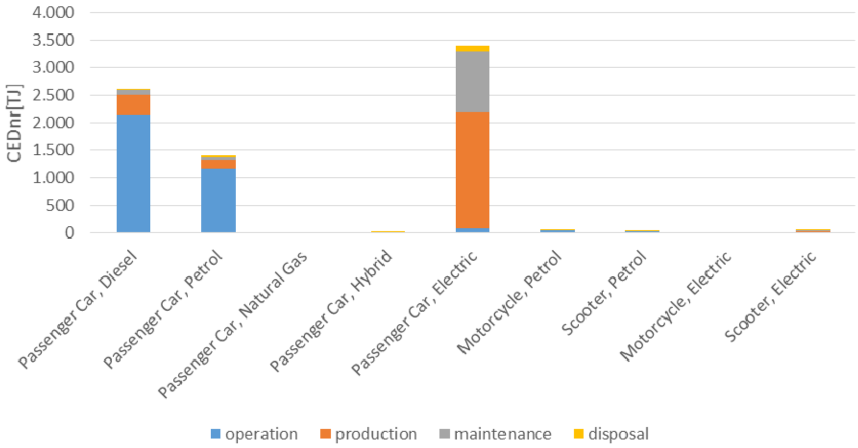

Figure 3-16: Individual passenger transport, Carinthia, Scenario SZ3, Cumulative Energy Demand [TJ/a]

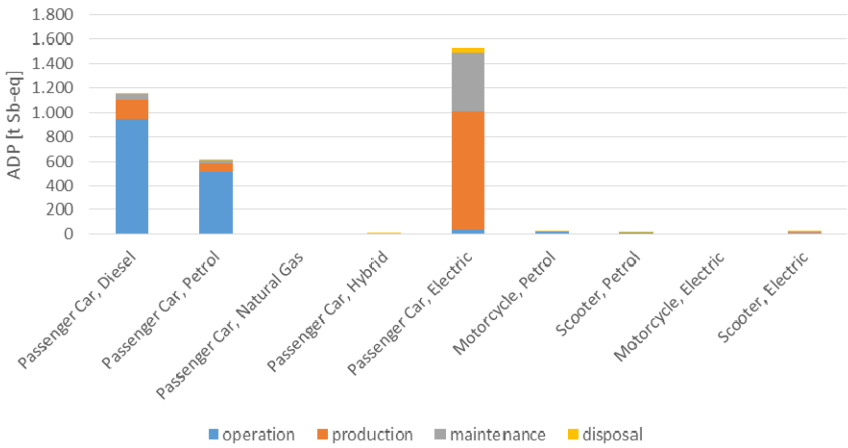

Figure 3-17: Individual passenger transport, Carinthia, Scenario SZ3, Abiotic Depletion Potential [t Sb-eq/a]

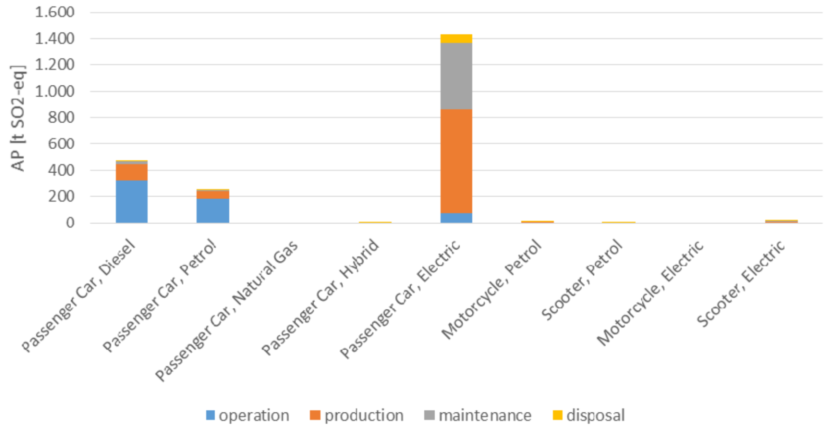

Figure 3-18: Individual passenger transport, Carinthia, Scenario SZ3, Acidification Potential [t SO_2-eq/a]

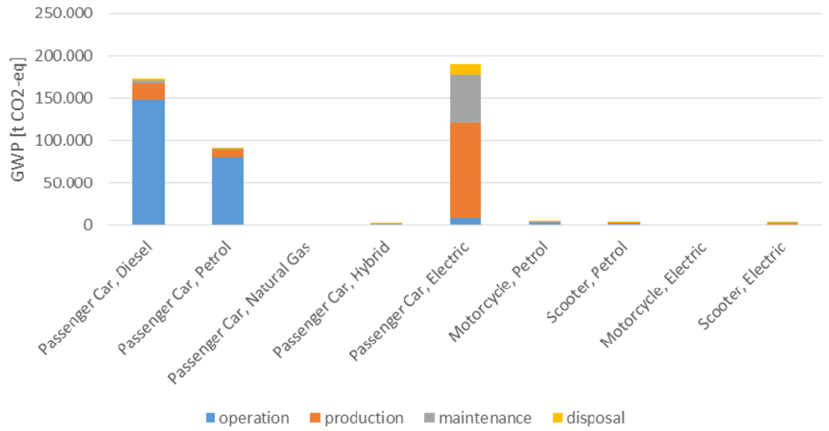

Figure 3-19: Individual passenger transport, Carinthia, Scenario SZ3, Global Warming Potential [t CO_2-eq/a]

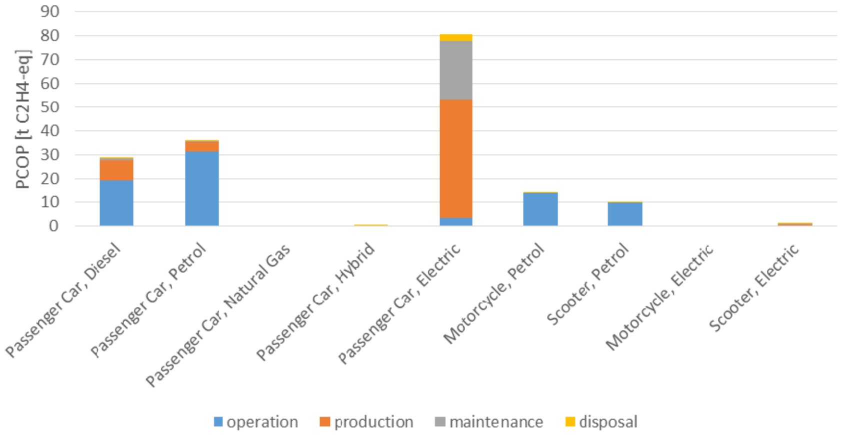

Figure 3-20: Individual passenger transport, Carinthia, Scenario SZ3, Photochemical Oxidant formation Potential [t C_2H_4-eq/a]

3.5 Scenario SZ4

Scenario SZ4 shows that improved efficiencies in car operation (fuel/electricity consumption, etc.) and more resource efficient car designs (e.g. lightweight city cars) could lead to a further significant reduction of the environmental impacts. Compared to the status quo, the reduction is between 70% (acidification) and 79% (global warming). In scenario SZ3 the carbon footprint of individual passenger transport in Carinthia is 234.087 tons of CO_2- equivalent (-79%), which is approximately 0,42 tons per capita.

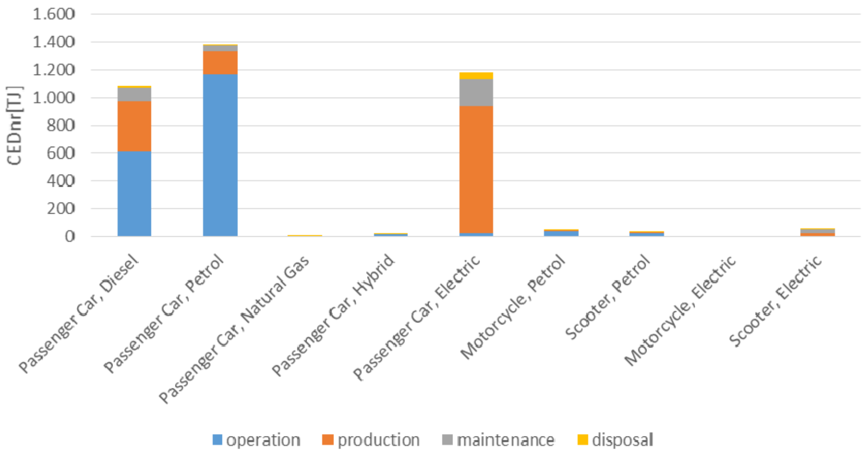

Figure 3-21: Individual passenger transport, Carinthia, Scenario SZ4, Cumulative Energy Demand [TJ/a]

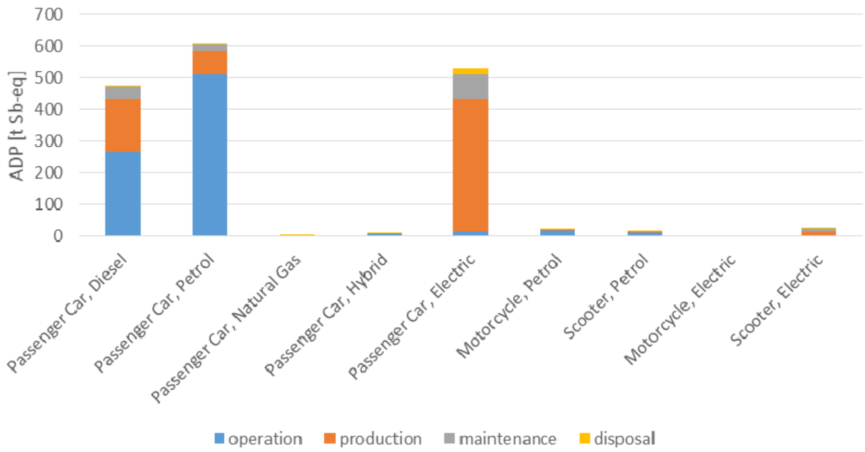

Figure 3-22: Individual passenger transport, Carinthia, Scenario SZ4, Abiotic Depletion Potential [t Sb-eq/a]

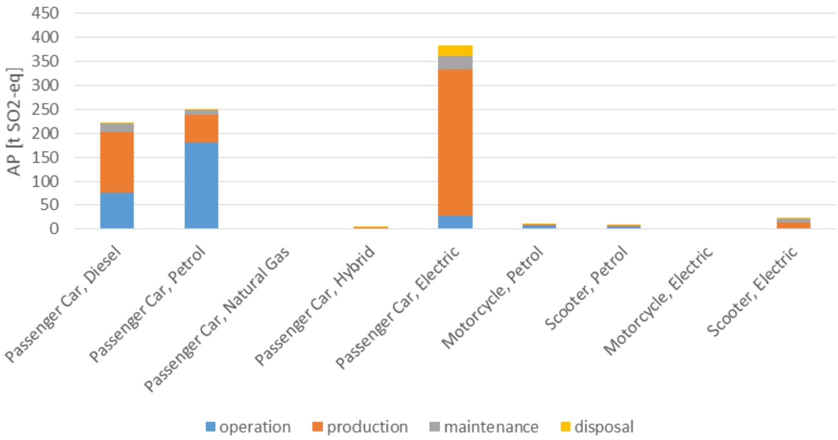

Figure 3-23: Individual passenger transport, Carinthia, Scenario SZ4, Acidification Potential [t SO_2-eq/a]

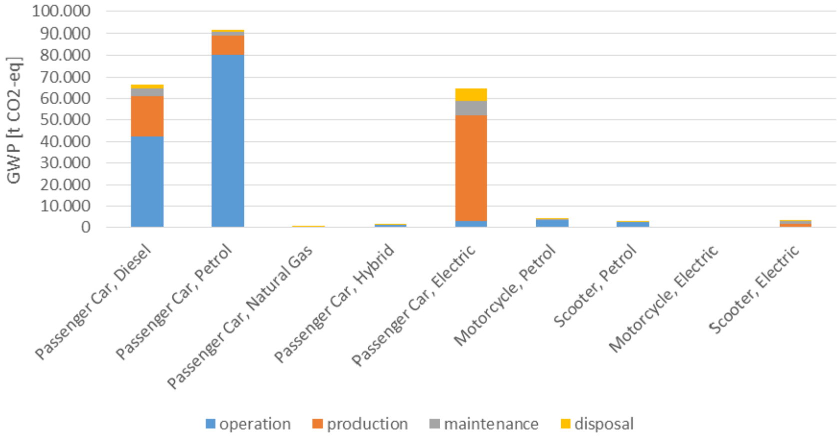

Figure 3-24: Individual passenger transport, Carinthia, Scenario SZ4, Global Warming Potential [t CO_2-eq/a]

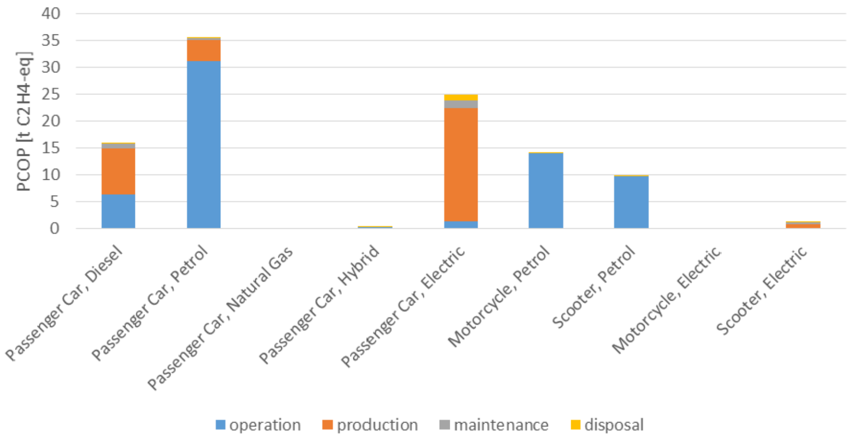

Figure 3-25: Individual passenger transport, Carinthia, Scenario SZ4, Photochemical Oxidant formation Potential [t C_2H_4-eq/a]

3.6 Comparison of Scenario Results

Figure 3-26 to Figure 3-30 directly compare the aggregated scenario results, which clearly illustrates the resulting improvements from scenario to scenario.

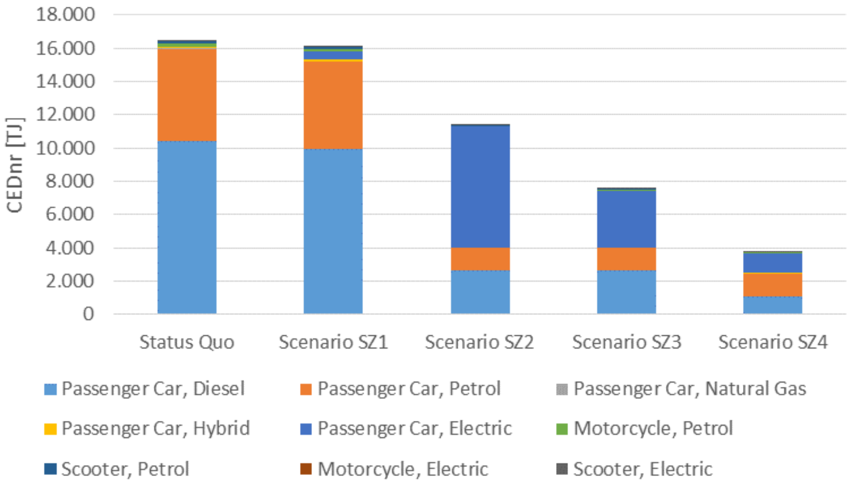

Figure 3-26: Individual passenger transport, Carinthia, scenarios SZ0-SZ4,Cumulative Energy Demand [TJ]

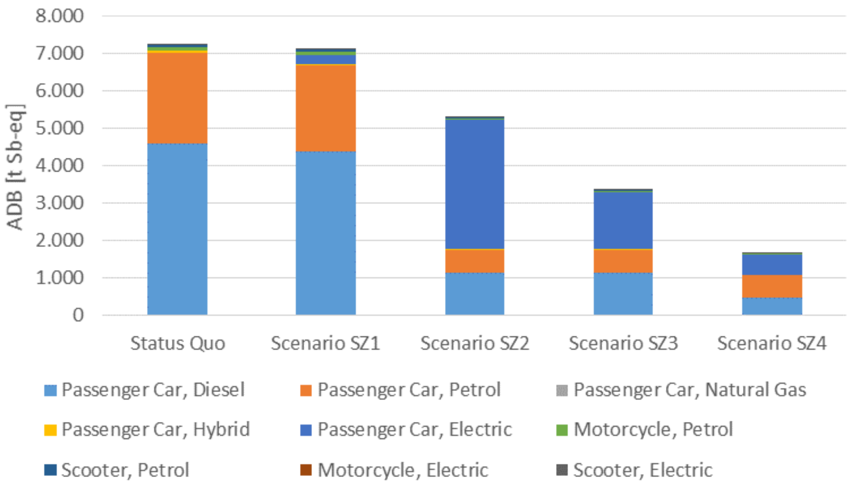

Figure 3-27: Individual passenger transport, Carinthia, scenarios SZ0-SZ4, Abiotic Depletion Potential [kt Sb-eq]

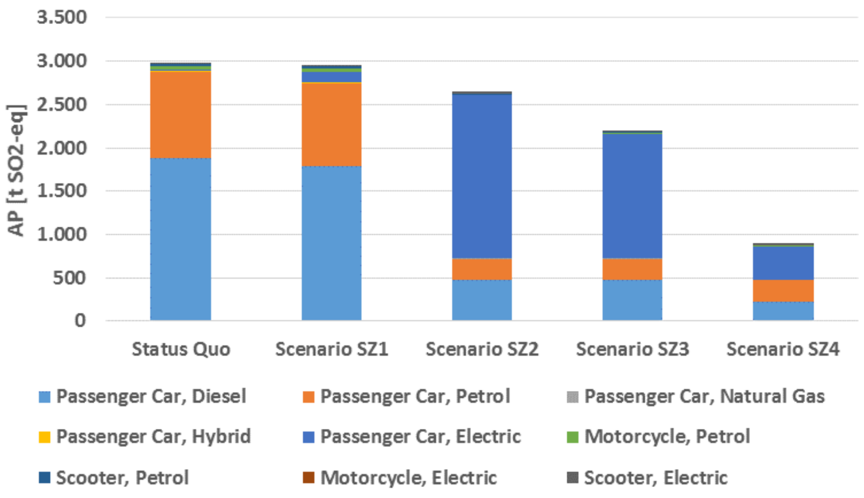

Figure 3-28: Individual passenger transport, Carinthia, scenarios SZ0-SZ4, Acidification Potential [t SO_2-eq]

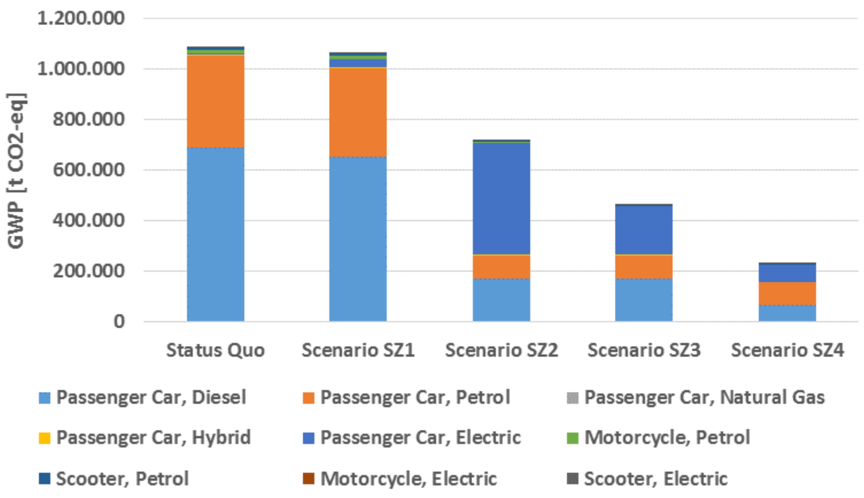

Figure 3-29: Individual passenger transport, Carinthia, scenarios SZ0-SZ4,Global Warming Potential [t CO_2-eq]

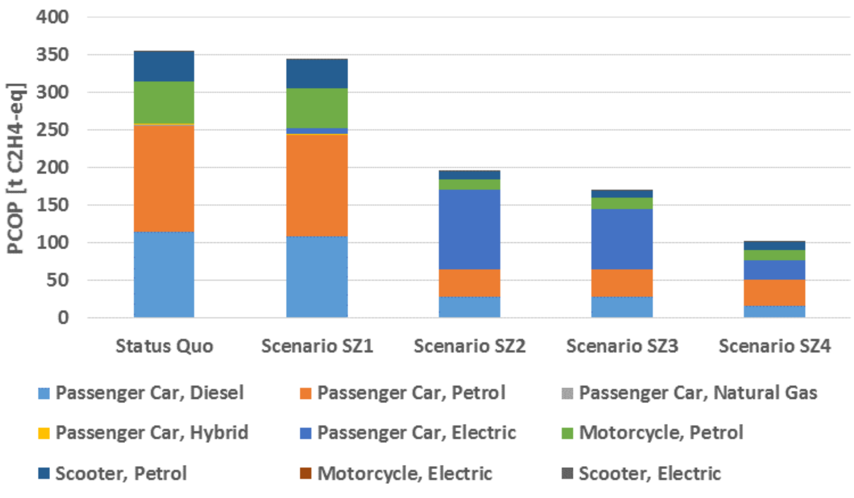

Figure 3-30: Individual passenger transport, Carinthia, scenarios SZ0-SZ4, Photochemical Oxidant formation Potential [t C_2H_4-eq]

3.7 Selected process results

In this section selected results of single processes are displayed and compared. Figure 3-31 shows the global warming potential (CO_2-equivalent) per vehicle kilometre.

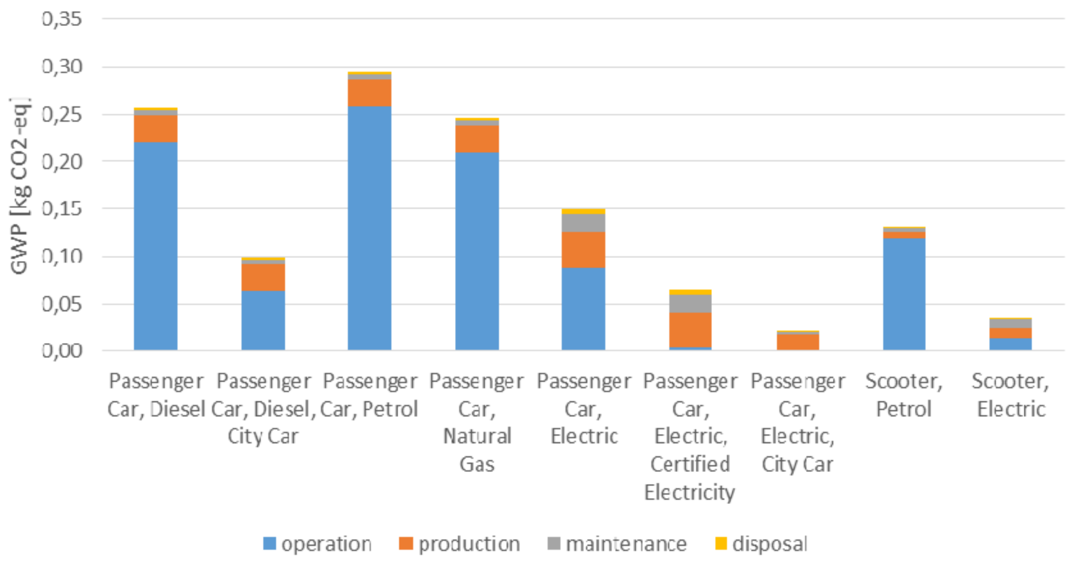

Figure 3-31: Global Warming Potential [kg CO_2-eq] per vehicle kilometre for different vehicle classes

Figure 3-32 shows how much certain materiel or functional groups contribute to the GWP-emissions for e-car production, maintenance and disposal. In each of the three categories, the largest contribution comes from the battery.

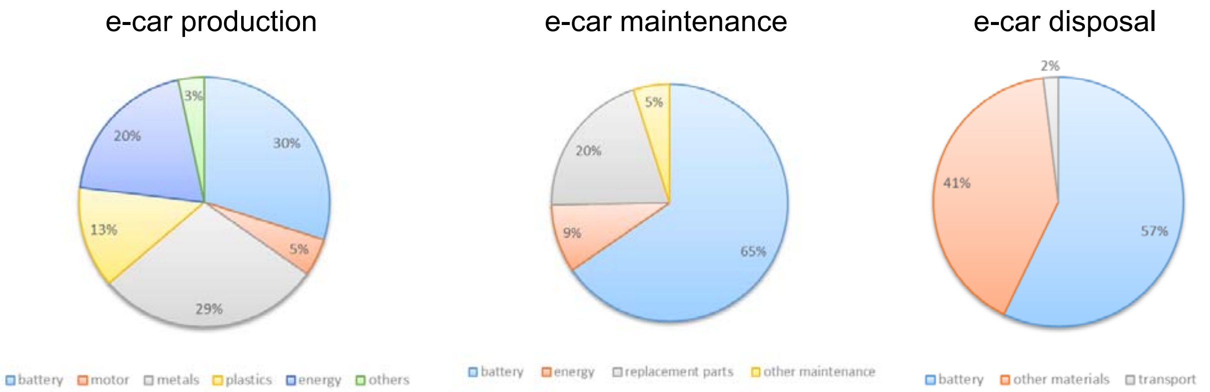

Figure 3-32: Distribution of GWP-emissions during e-car production, maintenance and disposal

3.8 Conclusion

As expected, currently fossil fuelled cars are predominantly responsible for the environmental effects of individual passenger transport (~97%) in Carinthia. Electro mobility only plays an insignificant role.

Increasing the e-mobility share up to 5% only leads to a small reduction in environmental impacts. Compared to the status quo, the reduction is around 2%. If the e-mobility share is increased up to 75%, this would lead to a significant reduction in environmental impacts of up to 45% (photochemical oxidation; compared to status quo). In case of such a high share of e-mobility, the shift to 100% renewable electricity leads to a further significant reduction in environmental impacts of up to 57% (for global warming; compared to status quo). If efficiencies in car operation (fuel/electricity consumption, etc.) are improved and more resource efficient car designs (e.g. lightweight city cars) are implemented, this could lead to a further reduction of the environmental impacts of up to 79% (for global warming; compared to status quo).

The results show that vehicle manufacturing becomes increasingly important as electricity moves to renewable sources. While currently vehicle production is responsible for around 13% of the environmental impacts, it is responsible for up to 34% in scenario SZ4. From the fact that battery production and disposal plays a major role in the lifecycle of an electric car (Figure 3-32), it can thus be concluded, that finding more resource efficient ways for battery design and disposal (e.g. recycling) is increasingly important for improving our future mobility system.

4 Literature

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Annex 1

Assigned datasets for vehicle production, maintenance and disposal

vehicle production

Vehicle category	assigned ecoinvent dataset
passenger car, diesel	passenger car
passenger car, petrol	passenger car
passenger car, natural gas	passenger car
passenger car, hybrid	passenger car
passenger car, electric	passenger car, electric, LiMn2O4, at plant
motorcycle, petrol	scooter, ICE, at regional storage
scooter, petrol	scooter, ICE, at regional storage
motorcycle, electric	electric scooter, at regional storage
scooter, electric	electric scooter, at regional storage

vehicle maintenance

Vehicle category	assigned ecoinvent dataset
passenger car, diesel	maintenance, passenger car
passenger car, petrol	maintenance, passenger car
passenger car, natural gas	maintenance, passenger car
passenger car, hybrid	maintenance, passenger car
passenger car, electric	maintenance, electric vehicle, LiMn2O4
motorcycle, petrol	maintenance, scooter
scooter, petrol	maintenance, scooter
motorcycle, electric	maintenance, electric scooter
scooter, electric	maintenance, electric scooter

vehicle disposal

Vehicle category	assigned ecoinvent dataset
passenger car, diesel	disposal, passenger car
passenger car, petrol	disposal, passenger car
passenger car, natural gas	disposal, passenger car
passenger car, hybrid	disposal, passenger car
passenger car, electric	disposal, electric vehicle, LiMn2O4
scooter, petrol	disposal, scooter
motorcycle, electric	disposal, electric scooter
scooter, electric	disposal, electric scooter