

# **Life Cycle Assessment Methodology and Data**

**Estimated Greenhouse Gas Emissions,  
Air Pollutants and Primary Energy  
Demand of Passenger Vehicles**

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The forecast of electric energy supply for all European Countries and the corresponding air pollutant emission factors are kindly made available for free by Ricardo, under the condition that the data are used exclusively for the needs of Green NCAP LCA projects. Green NCAP highly values the provided data and appreciates RICARDO's gesture.

The **PAUL SCHERRER INSTITUTE** (PSI) in Switzerland reviewed the methodology, basic data and draft results [Bauer 2022] of the LCA Expert Tool 2.1 [Jungmeier et al. 2022], which is the basis for this document.

Ricardo reviewed document 'Life Cycle Assessment Methodology and Data (2nd edition)' and analysed some results for correctness and consistency. A summary of the findings was provided [Hill 2022], no issues were identified, several recommendations for improvement were made.

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<b>1.</b>	<b>INTRODUCTION</b>	<b>5</b>
1.1.	Background	5
1.2.	Project Aim	5
<b>2.</b>	<b>METHODOLOGY OF LIFE CYCLE ASSESSMENT (LCA)</b>	<b>7</b>
2.1.	Definition Life Cycle Assessment (LCA)	7
2.2.	System Boundaries	8
2.3.	Functional Unit	12
2.4.	Allocation	12
2.4.1.	GHG Emissions and Primary Energy	12
2.4.2.	Air Pollutants	13
2.5.	Consideration for End-of-Life	13
2.6.	Environmental Effects	13
2.6.1.	Greenhouse Gas Emissions	13
2.6.2.	Land Use Change and Biofuels	14
2.6.3.	Primary Energy Demand	16
2.6.4.	Air Pollutants	16
2.7.	Description of Terms for Communication	17
<b>3.</b>	<b>DATA BASE</b>	<b>18</b>
3.1.	Data Structure	18
3.2.	Foreground Data	19
3.2.1.	Vehicle Specification	20
3.2.2.	Biomass Resources	20
3.2.3.	Electricity Mix	21
3.2.3.1.	GHG Emissions and Primary Energy Demand	21
3.2.3.2.	Air Pollutants	21
3.3.	Background Data	22
3.3.1.	Vehicle	22
3.3.1.1.	Vehicle Production	22
3.3.1.2.	Battery Production	22
3.3.1.3.	Vehicle Operation	27
3.3.1.4.	Vehicle Maintenance	28
3.3.1.5.	Vehicle End-of-Life	28
3.3.2.	Supply of Fuels and Energy	28
3.3.2.1.	Hydrogen Production	28
3.3.2.2.	Biofuel Production	28
3.3.2.3.	Land Use Change of Biofuels	29
3.3.2.4.	Supply of Fuels and Electricity	29
<b>4.</b>	<b>MAIN FINDINGS AND CONCLUSIONS</b>	<b>30</b>

<b>ANNEX I: MAIN DATA</b>	31
<b>ANNEX II: ABBREVIATIONS</b>	66
<b>ANNEX III: REFERENCES</b>	67

# 1. INTRODUCTION

## 1.1. Background

There is international consensus that the environmental effects of transportation systems can only be analysed and compared on the basis of Life Cycle Assessment (LCA) including the production, operation and the end-of-life treatment of the various facilities.

Life cycle assessment is a method to estimate the material and energy flows of a product (e.g. transportation service) to analyse environmental effects over the entire lifetime of the product 'from cradle to grave'.

Based on the methodology of 'Life Cycle Assessment' (LCA) an LCA Expert Tool (Version 2.1) was developed and documented in a report and a handbook in 2022 to estimate the greenhouse gas (GHG) emissions and the primary energy demand (PED) of different transportation systems with a passenger vehicle using different fuels, propulsion systems and state of technologies in different countries [Jungmeier et al. 2022]. This tool was already used to calculate and publish the LCA based GHG emissions and primary energy demand of **61 vehicles tested in Green NCAP** in April 2022 [Jungmeier et al. 2022a]. Since then, Green NCAP tested vehicles have received a package of LCA calculations produced by the further developed versions of the tool. This document summarizes the methodology and data used in the 4<sup>th</sup> edition applicable as of September 2025. The 4<sup>th</sup> edition adds to the 3<sup>rd</sup> edition the explanations and data necessary for the calculation of air pollutant emissions, without introducing changes to the methodology or data for primary energy demand or greenhouse gas calculations.

The LCA Expert Tool (v2.1) is updated (v2.4) [Jungmeier et al. 2024] and is used to assess the life cycle based GHG emissions and primary energy demand of vehicles available on the current European market as a basis to provide this information to consumers.

## 1.2. Project Aim

The aim of the project is to provide the LCA data and results for an online life cycle based environmental information system of vehicles for European consumers and preparing to roll out this interactive tool internationally. For that purpose, the calculation methods and basic data from the LCA Expert Tool (v2.4) are used [Jungmeier et al. 2024] as input for the web pages of the different FIA mobility clubs and consumer organisations.

The goal of the Life Cycle Assessment (LCA) is to estimate the greenhouse gas emissions, the primary energy demand and selected air pollutants of vehicles currently available on the European market. The Life Cycle Assessment is done for generic global supply chains of vehicle production and energy supply in Europe between 2024 and 2039. The main focus is to estimate significant differences between the vehicles and the main influencing parameters among:

- › Propulsion system
- › Type of fuel
- › Energy demand
- › Vehicle mass
- › Battery capacity
- › CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM emissions from vehicles equipped with an ICE.

No brand specific calculations for the vehicle production are made. The calculation is done for different total lifetime mileages ranging up to maximum 240,000 km in maximum 16 years vehicle lifetime. The annual millage can be selected by the users of the online LCA Consumer Tool on [www.greenncap.com/lca-tool/](http://www.greenncap.com/lca-tool/), but the Consumer Tool results currently include PED and GHG and no air pollutant emissions.

The life cycle based environmental information about passenger vehicles include the GHG emissions in CO<sub>2</sub>-equivalent (sum of CO<sub>2</sub>, CH<sub>4</sub> und N<sub>2</sub>O), the total cumulated primary energy demand (PED) with its fossil and renewable shares and the air pollutants NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM<sub>2.5</sub> and PM<sub>10</sub>. This environmental information is estimated and documented per driven kilometre and in absolute values over the entire life cycle, using the shares of vehicle production, operation and end-of-life treatment in Europe. For the electric vehicles (BEV and PHEV) the current and future national electricity mixes for each of the 27 EU countries, Norway, the United Kingdom and Switzerland, average EU27 and a 100% renewable electricity mix from wind, photovoltaics and hydro power in Europe, are made available. For conventional ICE, HEV and PHEV vehicles using fossil fuel (with biofuel blending diesel B7 and petrol E10), for all countries, the same assumptions regarding the fuel supply are made as in the EU27 average situation. The approach is consistent with LCA Expert Tool 2.4 [Jungmeier et al. 2024].

## 2. METHODOLOGY OF LIFE CYCLE ASSESSMENT (LCA)

### 2.1. Definition Life Cycle Assessment (LCA)

*Life cycle assessment is a method to estimate the material and energy flows of a product (e.g. transportation service) to analyse environmental effects over the entire lifetime of the product ‘from cradle to grave’.*

The environmental effects of the various stages in the life cycle of the transportation systems with passenger vehicles are investigated. The stages include extraction of raw materials, manufacturing, distribution, product use, recycling and final disposal (from cradle to grave), (**Figure 1**). Life cycle assessment allows the comparison of different systems offering the same transportation service during the same time period and identifies those life cycle phases having the highest environmental effects.

The most important attribute in the LCA definition is ‘estimated’, so all environmental results based on LCA are an estimation, as it is not possible to identify all environmental contributions in the life cycle of a transportation system totally. However, due to the strong development of LCA and its databases in the last 15 years the most relevant influences on the GHG emissions, air pollutants and the primary energy demand of different transportation systems can be identified and calculated.

To reflect the LCA definition, all results are usually given in ranges, as by comparing different transportation systems it is only relevant if the ranges are significantly different. Partly overlapping ranges between two systems indicate that there is no significant difference between them in terms of the assessed environmental impacts.

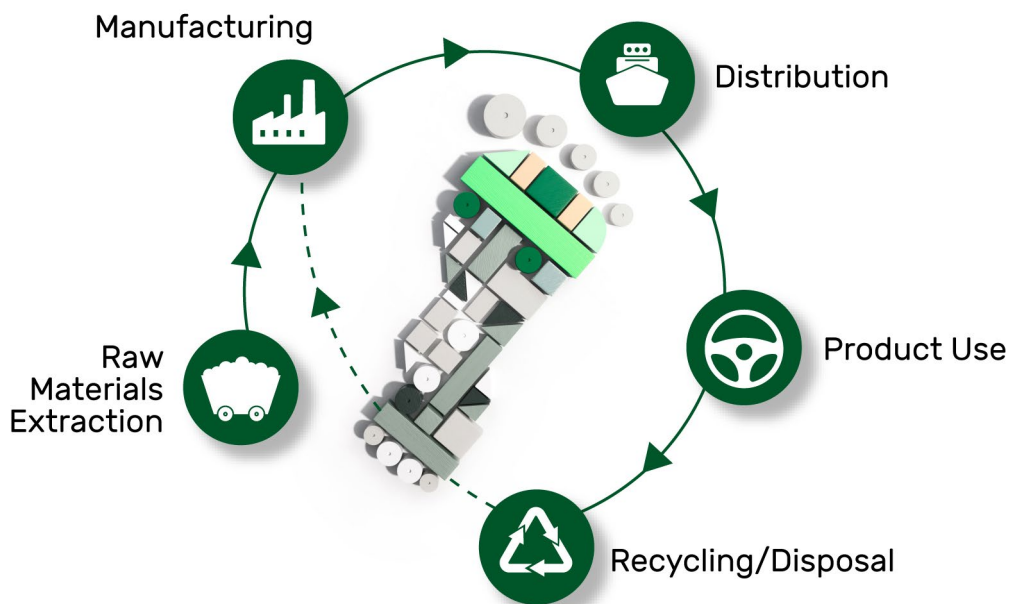


Figure 1 - Scheme of Life Cycle Assessment

According to ISO 14040, a LCA consists of the 4 following phases, which are closely linked during the whole process of applying LCA methodology (**Figure 2**):

- › Goal and scope definition,
- › Inventory analyses,
- › Impact assessment, and
- › Interpretation & documentation.

In the inventory analysis, the mass and energy balance is made along the whole process chain to calculate the physical (primary) energy demand and the physical emissions of each single greenhouse gas.

In the impact assessment the single energy inputs and emissions are aggregated to the primary energy demand and the global warming effects by applying the global warming potentials to the single emission species.

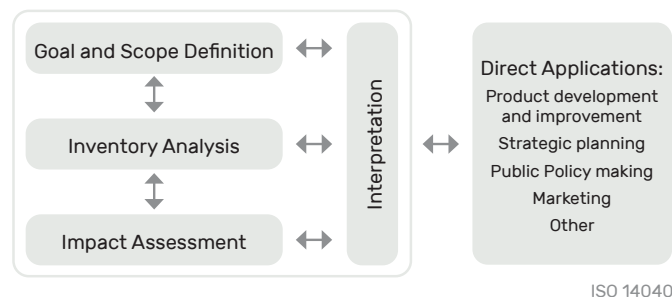


Figure 2 - Life Cycle Assessment framework according to ISO 1,4040

The LCA performed here is an ‘attributional LCA’, as an attributional life cycle assessment estimates what share of the global environmental burdens belongs to the transportation service and is based on average data. In contrast, a ‘consequential LCA’ gives an estimate of how the global environmental burdens are affected by the production and use of the product and ideally uses marginal data in many parts of the life cycle.

## 2.2. System Boundaries

For providing a transportation service, all processes must be analysed from raw material and resource extraction to the vehicle offering the transportation service. The elements and system boundaries of vehicle’s LCA include all technical systems using and converting primary energy and material resources to provide the transportation service and contributing to environmental effects.

In **Figure 3** the simplified scheme of the process chain exemplary for a battery electric vehicle is shown covering the production, the operation and the end-of-life phase of the system:

- › The production phase includes the production of the vehicle and the battery.
- › The operation phase offers the transportation service by driving the vehicle, charging & fueling infrastructure, electricity grid, electricity and fuel production, spare and maintenance parts and ends with the extraction of primary energy in nature.
- › The end-of-life phase includes the dismantling processes of the vehicle and sorting the materials for reuse, recycling and energy generation.

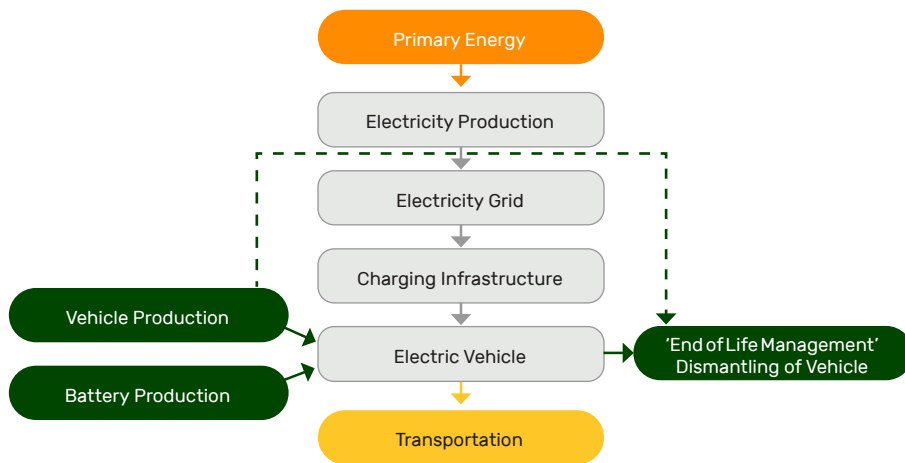


Figure 3 - Scope of life cycle assessment – example battery electric vehicle

Life cycle assessment of the three phases in the life cycle of a vehicle – production, operation (including fuel/energy supply) and end-of-life treatment – cumulates the environmental effects over the whole lifetime. In **Figure 4** this is shown for three hypothetical vehicle types. The cumulated effects over the entire lifetime are then distributed to the transportation service provided in the operation phase (e.g. 240,000 km in 16 years) to get the specific effects per driven kilometre (e.g. g CO<sub>2</sub>-eq./km). If the framework conditions are changing during the operation phase, e.g. changing electricity supply, the effects might be different for each year in the operation phase.

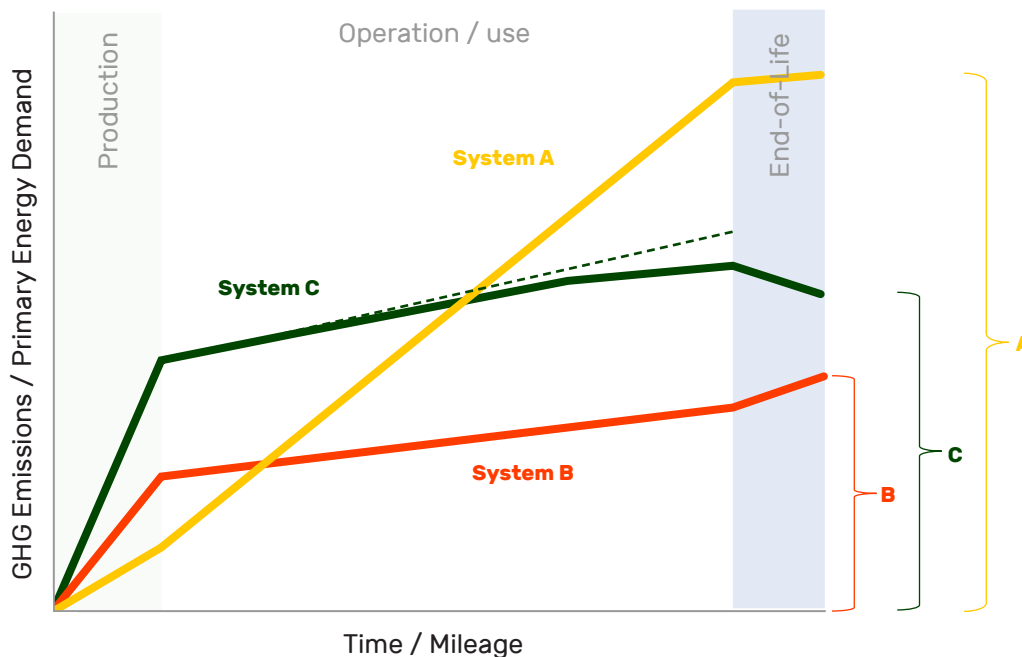


Figure 4 - The three phases in the life cycle of a vehicle – production, operation / use (including fuel/energy supply) and end-of-life treatment for 3 hypothetical vehicle types A, B and C

All GHG emissions, air pollutants and energy relevant processes to provide a transportation service with a passenger vehicle are considered in the process chain, in which possible co-products, e.g. animal feed from FAME production, district heat from electricity production, are also accounted for with their effects of substituting for other products and services.

As examples, in **Figure 5** the process chain for a diesel B7 ICE vehicle and in **Figure 6** the process chain for a battery electric vehicle are shown.

The schemes of the process chain show the most relevant processes in the LCA of a transportation system from main raw material in nature (on the top) to the provided transportation service (on the bottom).

The five most relevant process steps are:

1. Cultivation, collection or extraction of raw materials
2. Transportation of raw materials
3. Conversion of raw materials to transportation fuel and electricity, where other products might be co-produced, e.g. wind power plant, refinery, electrolysis
4. Distribution of transportation fuel/energy incl. filling/charging station and infrastructure
5. Vehicle using the transportation fuel.

The main inputs to the process steps are energy (e.g. electricity, fuels), auxiliary materials (e.g. fertilizer, chemicals) and materials for the production of the energy conversion and transportation facilities; e.g. the materials for the production of the vehicle also including the battery for BEV and the energy for manufacturing and assembling.

The main outputs of a process step are beside transportation fuels, GHG emissions, air pollutants and co-products (e.g. animal feed, chemicals, heat).

On the top of a process step the most important input into it (e.g. raw oil, hydrogen) is shown and an arrow links the process to the previous step in the process chain. On the bottom of the process step the most important output (e.g. diesel, electricity) is shown and an arrow links the process to the next step in the process chain.

On the left hand side, the input in terms of primary energy demand is shown, which is associated with the energy and material needed, and is calculated in the LCA.

On the right hand side, the output in terms of GHG emissions (covering CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) and air pollutants (NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>) is shown, which is associated with the energy and material needed, and is calculated in the LCA.

The GHG emissions and air pollutants cover:

- › Direct emissions from fuel combustion in the process step
- › Direct emissions from processing or losses (e.g. CH<sub>4</sub> from natural gas extraction, N<sub>2</sub>O from fertilization)
- › Indirect emissions from the supply of energy & materials and the production & end-of-life of the facilities for energy conversion and transportation.

In the Inventory Analysis of the LCA (see **Figure 2**) all physical mass and energy flows e.g. CO<sub>2</sub>, N<sub>2</sub>O, electricity are analysed or estimated in the process chains. In the Impact Assessment, the results of the inventory analysis of the process chains are assessed for the different impact categories, e.g. the single GHG emissions are added up using the global warming potential of the different gases to the global warming potential in CO<sub>2</sub>-equivalents (see also **chapter 2.6.**).

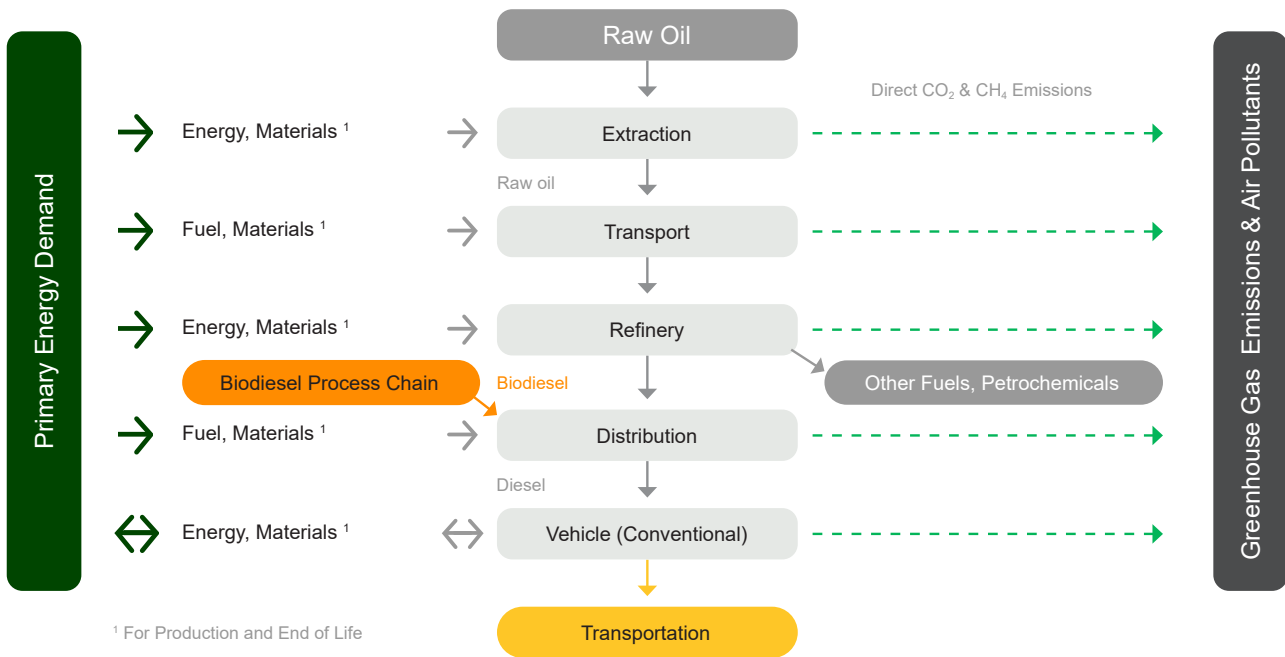


Figure 5 - Process chain for an internal combustion engine vehicle running on diesel B7

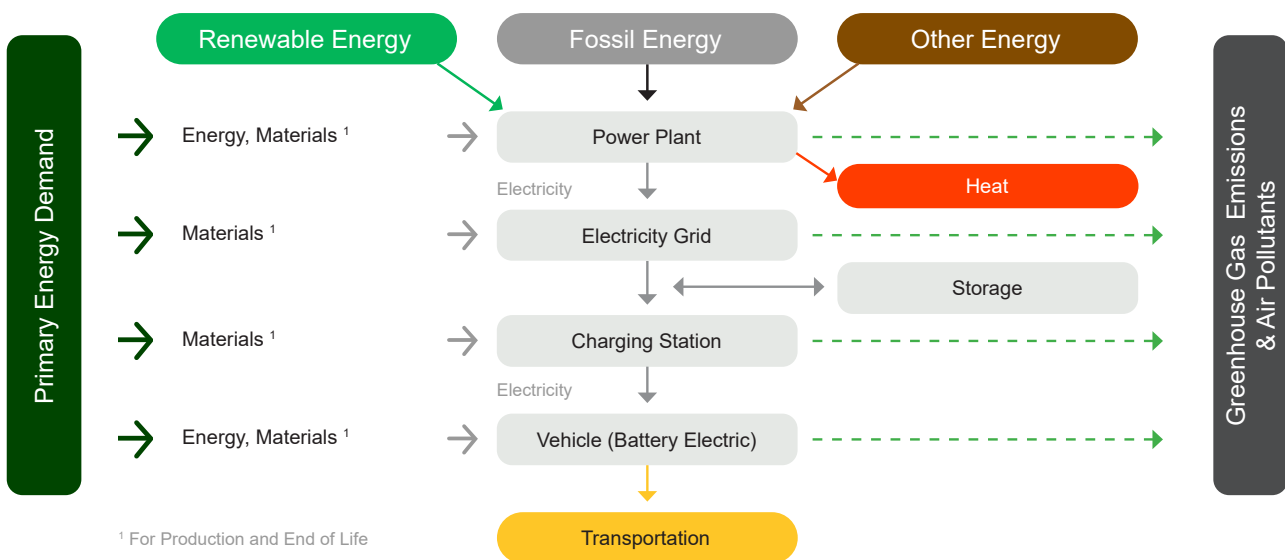


Figure 6 - Process chain for a battery electric vehicle using an electricity mix

Depending on the propulsion system and the energy carrier, the transportation systems have different GHG emissions, air pollutants and primary energy demand, which occur on different locations, at different phases and time in the life cycle. For example: an ICE vehicle using diesel has the highest CO<sub>2</sub> emissions from the stack of the vehicle operation, a biodiesel ICE vehicle has the highest N<sub>2</sub>O emissions from nitrogen fertilization of the raw material cultivation in agriculture and a current battery electric vehicle using renewable electricity has the highest CO<sub>2</sub> emissions deriving from the battery production.

## 2.3. Functional Unit

In LCA the cumulated environmental effects over the lifetime are attributed to the functional unit, which is the service of a system that is provided. In this analysis the considered transportation systems provide a transportation service with passenger vehicles. That means that the cumulated environmental effects of a passenger vehicle are attributed to the functional unit of driving:

- › 1 kilometre and
- › Max. 240,000 km in the total lifetime in max. 16 years.

These functional units are also used to compare the different transportation systems:

- › GHG emissions in g CO<sub>2</sub>-eq./km and tonnes CO<sub>2</sub>-eq./vehicle at the different stages in the life cycle, e.g. production, fuel/energy supply, operation and end-of-life
- › Primary energy demand in kWh<sub>total</sub>/km and MWh/vehicle with the %-share of renewable energy
- › Air pollutants in mg/km and kg/vehicle at the different stages in the life cycle, e.g. production, fuel/energy supply, operation and end-of-life.

The functional units are split up in the following contributions:

- › Vehicle production in absolute values (total, battery, fuel cell and H<sub>2</sub>-tank)
- › Fuel/energy supply per km for each year (1 to 16) separately
- › Maintenance per kilometre
- › Direct emissions of ICE, HEV and PHEV vehicle operation per kilometre
- › Vehicle end-of-life in absolute values.

The different possible driving ranges per filling or charging of an ICE, HEV, PHEV, BEV and FCV cannot be reflected in these functional units.

## 2.4. Allocation

An allocation of environmental effects in LCA is necessary, where a process produces more than one product, e.g. in an oil refinery: different energy carriers and raw materials for chemical industry, heat and electricity in a combined heat and power (CHP) plant, production of FAME with animal feed and glycerin as co-products.

### 2.4.1. GHG Emissions and Primary Energy

As this LCA focuses on energy systems, wherever reasonable, an allocation for energy carriers as co-product is done based on the energy content (lower heating value) of the products ('energy allocation'). For all other co-products e.g. animal feed in the value chain of FAME and bio-ethanol a credit for the substituted feed is given. Also for the glycerin and fertilizer coproduced with FAME a credit for the substituted synthetic glycerin and synthetic fertilizer is given.

A special case of allocation appears, when an automotive battery is also used in a 2<sup>nd</sup> life for a stationary application ('2<sup>nd</sup> stationary life') as modelled here (see [chapter 3.3.1.2](#)). In that case the GHG emissions, air pollutants and the primary energy demand from the battery production are allocated to the automotive and stationary use. The allocation is based on the share of total cumulated electricity stored in the 1<sup>st</sup> automotive life in the BEV and the 2<sup>nd</sup> stationary life. Here, the same amount of stored electricity in the automotive and stationary use is assumed.

## 2.4.2. Air Pollutants

For air pollutants the approach is the same as described above with one exception: air pollutants for the supply of fuels were calculated based on datasets provided by Ricardo [Ricardo 2023]. Following the recommendation from Ricardo, the dataset is used which uses an energy allocation methodology (FuelVariant 'Default') and not a substitution methodology.

## 2.5. Consideration For End-of-Life

The consideration of the environmental effects of the 'end-of-life' phase covers the following two aspects:

- › GHG emissions, air pollutants and primary energy demand for collection, dismantling and recycling of vehicles to secondary material
- › Credits for substitution of primary material by recovered secondary material.

The given credits for the secondary material recovered depend on the purity of the single materials or mix of materials. As the given credits are higher than the emissions and primary energy demand of the recovery processes for most of the considered vehicles, the end-of-life phase might have negative GHG emissions, negative air pollutants and a negative primary energy demand.

The influence of the end-of-life GHG emissions, air pollutants and primary energy demand in the total lifetime of the vehicle is relatively small, compared to the production and operation phase. For this reason, the end-of-life is calculated for the year 2039 and is independent from the calculated vehicle lifetime. The calculated vehicle lifetime is a result of the user selected annual mileage and the maximum of 240,000 km and 16 years.

## 2.6. Environmental Effects

Based on the inventory data two impact categories are assessed:

1. Global warming
2. Total primary energy demand, and
3. Air pollutants.

Additionally, the most relevant aspects of land use change for the raw material production for biofuels on GHG emissions are described. Other environmental effects like emissions to air NO<sub>x</sub>, SO<sub>2</sub>, PM and their consequential impacts like acidification, ozone formation, and human toxicity are not considered<sup>1</sup>.

Other environmental effects like the impact of the relevant emissions on acidification, ozone formation or human toxicity are not considered.

### 2.6.1. Greenhouse Gas Emissions

The greenhouse gas emissions – carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrogen oxide/laughing gas (N<sub>2</sub>O) – are considered.

As measure of the greenhouse effect of these gases the global warming potential (GWP) is used. This gives the contribution of the different gases to the possible global warming and is expressed in form of an equivalent amount of CO<sub>2</sub>. The concept of global warming potential was developed to compare the contribution of the different gases to global warming. The global warming effect of a kilogram gas

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<sup>1</sup> The Clean Air Index in Green NCAP's vehicle rating programme assesses the pollutants produced locally by a vehicle; see: [www.greenncap.com](http://www.greenncap.com)

is expressed with a multiple (“equivalent factor”) of the effect of one kilogram carbon dioxide. With the equivalent factors for 100 years (GWP 100) the amount of the gases is calculated in amount of CO<sub>2</sub>-equivalents (CO<sub>2</sub>-eq.) [IPCC 2019]:

- › 1 kg CO<sub>2</sub> = 1 kg CO<sub>2</sub>-eq.
- › 1 kg CH<sub>4</sub> = 34 kg CO<sub>2</sub>-eq.
- › 1 kg N<sub>2</sub>O = 298 kg CO<sub>2</sub>-eq.

## 2.6.2. Land Use Change and Biofuels

Biofuels (and E-fuels) contain carbon and its combustion in an ICE creates about the same CO<sub>2</sub> emissions like petrol, diesel or CNG per energy unit.

The biogenic CO<sub>2</sub> emissions to the atmosphere from the combustion of biofuels are calculated to be zero, as the same amount was fixed before in the biomass by photosynthesis taking CO<sub>2</sub> from the atmosphere (CO<sub>2</sub> uptake = CO<sub>2</sub> from combustion).

This accounting system for biogenic CO<sub>2</sub> is used also in the national GHG accounting system following the IPCC guideline for national inventories in the energy sector. Changes and dynamics in the carbon stocks, e.g. the carbon which is stored in plants, litter and soil, in agriculture and forestry are considered in the CO<sub>2</sub> emissions or CO<sub>2</sub> uptake caused by Land Use Changes (LUC) for biomass used for biofuels.

Analysing CO<sub>2</sub> effects from land use change two different types of LUC are relevant (**Figure 7**):

- › Direct Land Use Change (dLUC)
- › Indirect Land Use Change (iLUC)

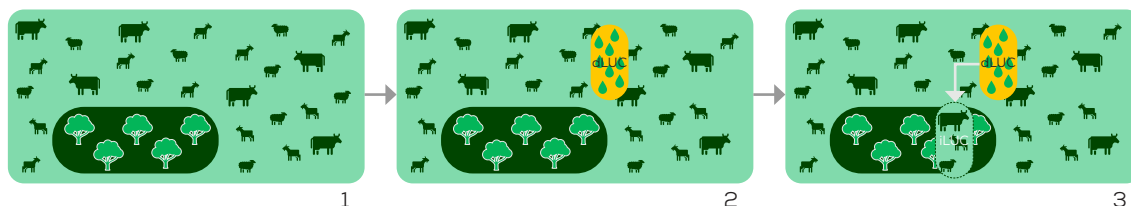


Figure 7 - Direct Land Use Change (dLUC) and Indirect Land Use Change (iLUC)

Direct Land Use Change (dLUC) occurs if for cultivation of energy crops a land use change takes place, e.g. from pasture to crop land. Direct effects can be calculated, e.g. change of carbon storage pools with the difference of carbon stocks from pasture and crop land per hectare. This initial effect, which occurs once, must be allocated to the biomass cultivated on the crop land, e.g. for biofuels.

Indirect Land Use Change (iLUC) occurs if existing crop land is now used for energy crops, which was used for other products before. The demand for these products remains and additional land is used causing land use change on global scale, e.g. conversion of natural forests into agricultural land. Indirect effects can be calculated after localization, which is difficult on a global level. The calculation of this initial effect is done on the difference of the carbon stock from forest and agricultural land. But on a physical level a direct allocation of these indirect effects to a specific agricultural crop, e.g. for biofuel or additional animal feed is not possible. The indirect effects are calculated by using economic models and methods. These models give broad ranges of possible iLUC effects of biomass cultivation for biofuels.

For the calculation of GHG emissions due to Land Use Change the European Commission uses the GLOBIOM-Modell - Global Biosphere Management Model ([Valin H. et al., 2015]; [www.globiom.org](http://www.globiom.org)). IIASA's Global Biosphere Management Model (GLOBIOM) is used to analyse the competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors. As such, the model can provide scientists and policymakers with the means to assess, on a global basis,

the rational production of food, forest fiber, and bioenergy, all of which contribute to human welfare. In GLOBIOM no distinction between iLUC and dLUC is possible, as iLUC cannot be allocated to certain agricultural activities.

Exemplary in **Figure 8** some results of possible LUC effects of biofuel from the GLOBIOM model are shown. The highest possible GHG emissions of LUC are calculated for FAME from palm oil with about 231 g CO<sub>2</sub>-eq./MJ and from soy oil with about 150 g CO<sub>2</sub>-eq./MJ, followed by FAME from rape seed oil with about 65 g CO<sub>2</sub>-eq./MJ. The possible GHG emissions of bio-ethanol from maize, wheat and sugar beet due to LUC effects are with 14 to 34 g CO<sub>2</sub>-eq./MJ significantly lower.

The main data for possible dLUC and iLUC effects on the GHG emissions are shown in **Table 16** in ANNEX I: MAIN DATA.

The calculation in the Tool only includes possible CO<sub>2</sub> emissions from dLUC; as it was decided among the stakeholder involved.

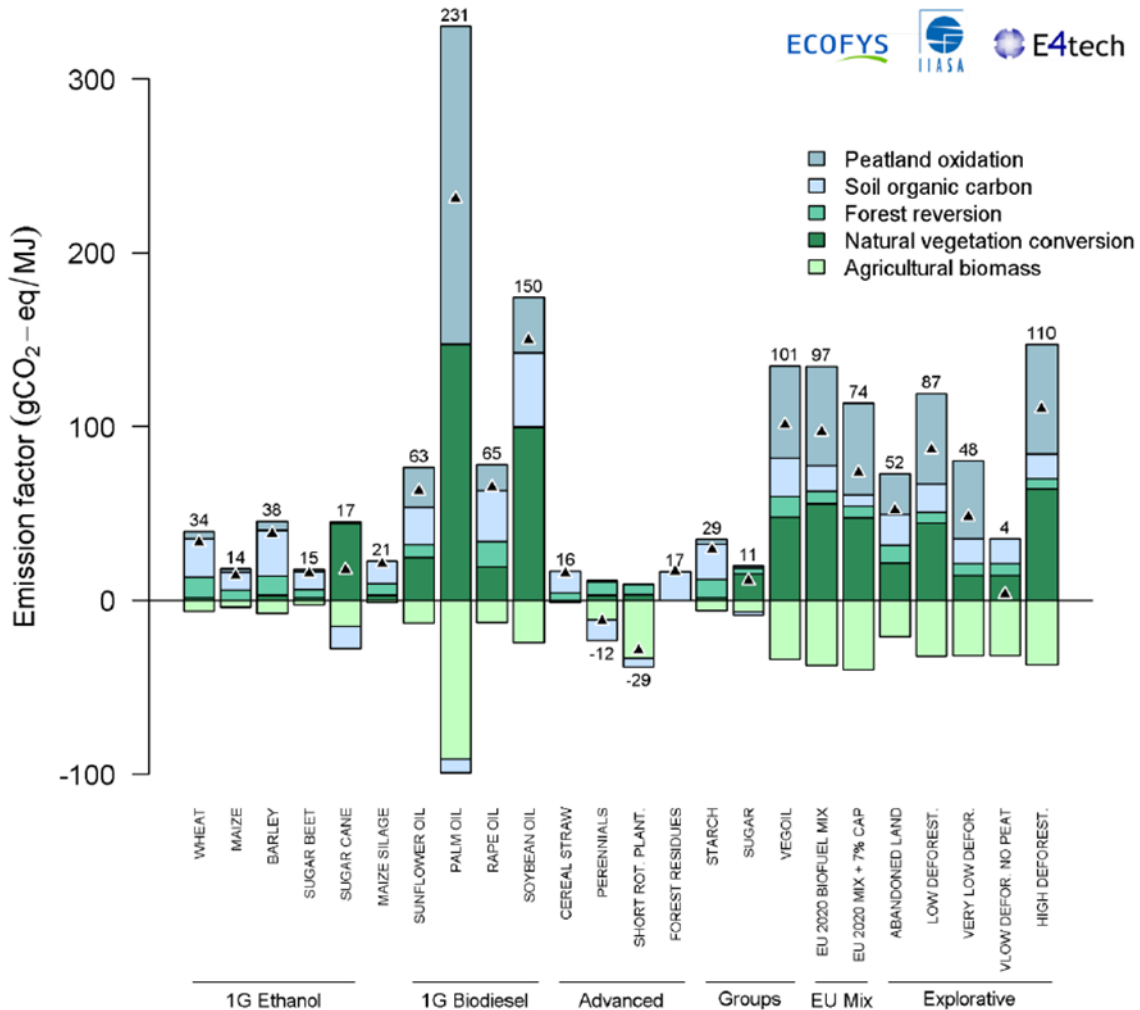


Figure 8 - Possible LUC effects on GHG emissions of biofuels [Valin H. et al., 2015]

Diesel B7 (7 vol.-% FAME) and petrol E10 (10 vol.-% EtOH) are used for ICE, HEV and PHEV, as biofuel blending is state of the art in Europe. Most of this biofuel used is produced in Europe with European feedstock, e.g. wheat, corn, rapeseed and waste cooking oil.

Based on the current legislation in Europe (RED-Renewable Energy Directive [EU 2018]) these biofuels fulfil relevant sustainability criteria e.g. minimum GHG reduction. The combustion of biofuels in ICE, HEV and PHEV is considered to be 'CO<sub>2</sub> neutral'. Therefore, the effect of CO<sub>2</sub> emissions of biofuel blending from ICE is less than 7% compared to pure diesel or petrol due to the lower volumetric heating value of biofuels.

The GHG emissions of biofuel production (e.g. N<sub>2</sub>O emissions from agricultural cultivation) are calculated based on LCA incl. possible direct land use change. Indirect land use change effects are not considered as they are out of the scope of the LCA applied here. In other studies addressing land use, possible indirect land use change effects are analysed based on global economic models, e.g. EtOH 43 – 61 g CO<sub>2</sub>/kWh and FAME 119 – 238 g CO<sub>2</sub>/kWh [EU 2015] for single feedstocks, which might lead to additional CO<sub>2</sub> emissions in the life cycle of 25 – 65 g CO<sub>2</sub>/km using pure biofuel with current feedstock mix; with E10 and B7 the effect is correspondingly much lower.

The European biofuel industry follows strict legislation and uses synergy effects (e.g. animal food production, starch products, glycerine). However, it shall be acknowledged that biofuel-production might conflict with food- and feedstock production globally, but these effects are difficult to quantify.

### 2.6.3. Primary Energy Demand

Based on the amount and type of final energy carriers e.g. fuels, electricity, the necessary amount of primary energy is calculated to supply the energy needed for the transportation systems. E.g. the electricity production in a coal power plant has an average annual efficiency of about 40%; that means that the primary energy demand to produce 1 kWh of electricity is 2.5 kWh of coal. For renewable electricity generation from wind, photovoltaics and hydro power the annual efficiency of the power plant is set per definition to 100%; that means that the primary energy demand to produce 1 kWh of electricity is 1 kWh of wind, solar or hydro power.

The following primary energy resources are considered:

- › Fossil resources: coal, oil and gas,
- › Renewable resources: hydro power, biomass, solar, wind
- › Other resources e.g. nuclear<sup>2</sup>, waste, residues.

The primary energy demand is calculated based on the lower heating values.

### 2.6.4. Air Pollutants

The following air pollutants are considered:

- › Nitrogen oxides (NO<sub>x</sub>)
- › Ammonia (NH<sub>3</sub>)
- › Non-methane volatile organic compounds (NMVOC)
- › Carbon monoxide (CO)
- › Sulfur oxides (SO<sub>x</sub>)
- › Particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub>)

The calculation is made for each emission separately. The impact of relevant emissions on acidification, ozone creation or eutrophication is not considered.

---

<sup>2</sup> Except for the electricity mixes, the nuclear primary energy is included in the fossil primary energy due to the used data source.

## 2.7. Description of Terms For Communication

For communication to a broader audience the most relevant terms are briefly described. The terms used are the following:

- › Life Cycle Assessment (LCA) is a method to estimate the overall environmental effects of a vehicle in its total lifecycle, covering vehicle production, vehicle operation and end-of-life of the vehicle
- › GHG emissions are given in CO<sub>2</sub>-equivalent (CO<sub>2</sub>-eq.) covering the sum of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) according to their contribution to global warming for a time horizon of 100 years (GWP 100). The unit is g CO<sub>2</sub>-eq. per kilometre driven
- › The Primary Energy Demand is the sum of all primary energy taken from nature to provide the transportation service covering coal, oil, natural gas, hydro, wind, solar and nuclear energy. The unit is kWh per kilometre driven
- › The renewable share of primary energy demand covers hydro, wind, solar energy and biomass
- › The considered air pollutants are Nitrogen oxides (NO<sub>x</sub>), Ammonia (NH<sub>3</sub>), Non-methane volatile organic compounds (NMVOC), Carbon monoxide (CO), Sulfur oxides (SO<sub>x</sub>) and Particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>).
- › The GHG emissions, air pollutants and the primary energy demand are given in:
  - › Total LCA and
  - › Contributions in the three phases of the life cycle
    - › Production
    - › Operation and
    - › End-of-life
- › Production covers the production of the total vehicle (incl. battery, fuel cell, H<sub>2</sub>-tank)
- › Operation covers the operation of the vehicle with the supply of energy, the use of energy and maintenance
- › End-of-life covers the recycling and waste treatment of used vehicles. As the recovered secondary material substitutes for primary material, the GHG emissions and the primary energy demand can be negative.

## 3. DATA BASE

### 3.1. Data Structure

Basically, in the LCA data are used that represent adequately the technical, geographical and timely framework condition to fulfil the goal and the scope of the LCA based estimation of GHG emissions, air pollutants and primary energy demand. In this assessment and in the LCA Expert Tool, the different transportation systems are compared to each other. The most important aspect of the basic data is to reflect the main differences (e.g. fuel demand per km) between the systems and the states of technology, in order to identify the most significant differences between the GHG emissions, air pollutants and the primary energy demand. The basic data are based on generic and global process chains, e.g. steel and aluminium.

So the main focus of the data collection and selection is on the main influences that effect the estimated overall GHG emissions, air pollutants and primary energy demand significantly.

By reflecting this, in the LCA two different types of data categories (see example [Figure 9](#)) are set up: the fore- and background data.

The foreground data, which have a significant influence on the total environmental effects considering the specific goal and scope, determine most of the differences between the considered vehicles and their technologies. The foreground data must be collected, assessed and documented explicitly in accordance to the goal and the scope of the LCA. The foreground data for this LCA are mainly the following vehicle data, received from the mobility clubs and Green NCAP:

- › Propulsion system
- › Type of fuel
- › Fuel/energy demand
- › Vehicle mass
- › Battery capacity
- › CH<sub>4</sub> and N<sub>2</sub>O emissions from vehicles equipped with an ICE Vehicle (where available from Green NCAP testing)
- › NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub> and PM<sub>10</sub> emissions from vehicles equipped with an ICE Vehicle (where available from Green NCAP testing), and
- › Average electricity mix for the considered countries and the EU27 mix.

The background data, which have a minor influence on the difference between the considered environmental effects of the compared vehicles, e.g. environmental effects of steel or petrol E10 supply, are taken and documented from adequate data bases, e.g. own JOANNEUM data, GEMIS 5.2 [GEMIS 2023], ecoinvent 3.4, ecoinvent 3.10 [Ecoinvent 2024]. The background data are used referring to the goal of this LCA, where the Life Cycle Assessment is performed for generic global supply chains of vehicle production and energy supply in Europe between 2024 and 2039.

In general, the use of different background data sources might lead to methodological inconsistencies (e.g. allocation, state of technology etc.) and to some extent might lead to arbitrary results. For this reason, priority is given in using the different databases. For the background data, JOANNEUM data sets are of highest priority and the missing data are added from GEMIS and from ecoinvent. All relevant data are explicitly documented in the following chapters.

Typical background data for the LCA are about:

- › Electricity mix for auxiliary processes
- › Production of materials for vehicles
- › Auxiliary material and energy for processes
- › Distribution infrastructure (e.g. electricity, hydrogen, liquid and gaseous fuels).

The background data are interpolated between 2020, 2030, 2040 and 2050, where necessary.

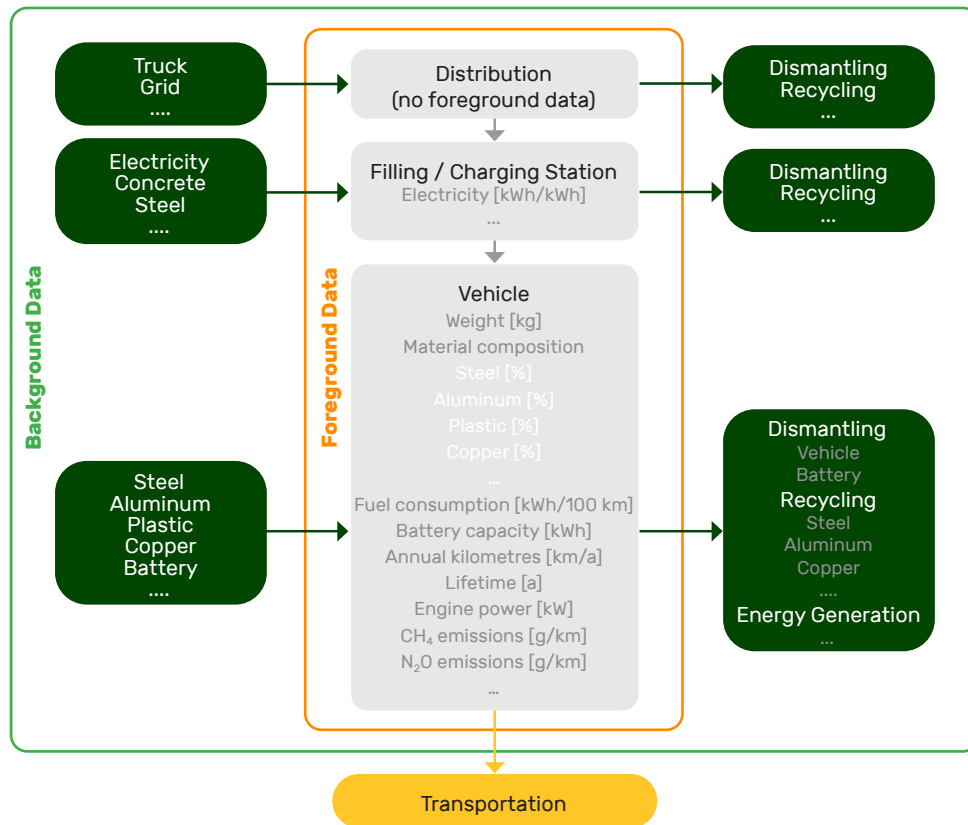


Figure 9 - Examples of foreground data ('Vehicle', 'Filling/charging station',) and background data ('Material and component production', 'Dismantling, recycling and energy generation')

In the initial state of the LCA it is not always entirely clear, which data are explicitly foreground data and which are the background data, e.g. charging infrastructure for electric vehicles, as this depends on the specific aim and goal of the LCA. This is also in accordance to the iteration processes according to ISO 1,4040 (see [Figure 2](#)). For this purpose also relevant inputs and clarification from the continuous stakeholder process, as well as requirements from the future usage of the Tool are used to finally set the foreground data explicitly.

All basic data are documented and integrated in the LCA Expert Tool v2.4 [Jungmeier et al. 2024], and the most relevant data are also given in this report. The foreground data and selected background data were discussed among the stakeholders.

### 3.2. Foreground Data

There are three groups of foreground data specified:

1. Specification of the vehicle
2. Resources and processes used to produce the energy carrier for the vehicle

### 3. Possible future developments.

#### 3.2.1. Vehicle Specification

The foreground data for the specification of the vehicle are:

- › Vehicle data
  - › Mass
  - › Annual kilometres [km/a]: defined by user with max 240,000 km in lifetime
  - › Lifetime: maximum 16 years
  - › Energy demand
  - › CH<sub>4</sub> and N<sub>2</sub>O emissions: if not available, default data are used [Jungmeier et al 2024]
  - › NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub> and PM<sub>10</sub> emissions (data from tests performed by Green NCAP)
- › Battery and charging
  - › Capacity [kWh]
  - › Lifetime: same as vehicle based on stakeholder decision: max. 240,000 km
  - › Charging losses [%]: 2% charging losses outside the vehicle are considered [Green NCAP 2022]
  - › Location of battery production [%] (interpolated for 2024 based on [McKinsey 2024 and Schade 2022])
    - › China: 78%
    - › Europe: 14%
    - › USA: 8%
  - › End-of-life [%]
    - › Material recycling: 97%
    - › 2<sup>nd</sup> stationary life: 3%.

#### 3.2.2. Biomass Resources

The foreground data for the biogenic resources to produce and supply the energy carrier for the vehicle are:

- › Land use change (LUC) (**Table 1** in ANNEX I: MAIN DATA), considers: sugar cane from pasture, soy beans from pasture, palm oil from tropical forest.
- › Share of biofuel blending – biodiesel (FAME) in diesel: 7 vol.-%, bioethanol (EtOH) in petrol: 10 vol.-% in E10; 85 vol.-% in E85.
- › Biomass mix (**Table 2** in ANNEX I: MAIN DATA) ([JRC 2020], [IEA 2024], [OECD-FAO 2024], [Rangaraju 2021] and [JOANNEUM RESEARCH 2024])
  - › FAME – rape seed oil, cooking oil and animal fat, palm oil, soya oil
  - › EtOH – wheat and maize, sugar beet, sugar cane, wood, straw.

### 3.2.3. Electricity Mix

#### 3.2.3.1. GHG Emissions and Primary Energy Demand

For the European countries the national consumption electricity mix, its GHG emissions and primary energy demand were kindly provided by Ricardo [Ricardo 2023] solely for the use in Green NCAP LCA Projects. For the years 2020, 2030 and 2040. The values for 2050 were extrapolated. The data were supplied for two different scenarios:

- › Baseline is based on REF2020 for EU countries (further updated also to include actual year 2020 data from Eurostat statistics on electricity production by fuel),
- › Tech1.5 has been further updated for 2030 based on the MIX scenario from the Fit-for-55 package (see here: Policy scenarios for delivering the European Green Deal from modelling files for EU), with projections for 2040 based on the Tech1.5 scenario from the EU's Long-Term Strategy to reach a climate-neutral Europe by 2050.

However, most of the policy proposals for Fit-for-55 have now been formally adopted (status: Fit for 55 - The EU's plan for a green transition - Consilium (europa.eu)), which suggests that values closer to the MIX/Tech1.5 scenario present the 'current' policy expectation. Crucially, a couple of policies that are contributing to the future FF55 package for electricity have not yet been agreed on (e.g. 'The proposal for a revision of the Council directive on the taxation of energy products and electricity'). The limitation is given by the fact that the EU27+UK data is not perfectly consistent with the updated UK-only data. Therefore, conservatively an average of the two scenarios is reasonable to represent current policy in place (until new EC reference scenario becomes available).

For Germany, the GHG emissions in 2024 are not based on this electricity mix, as it was decided in the stakeholder consultations based on an explicit wish of the ADAC. The ADAC prefers using the published GHG emissions of the German electricity mix in 2024 by the Environmental Agency [Bundesanzeiger 2023].

Non-EU countries were calculated with the specified foreground data using LCA, using also the GHG emissions from upstream emission from IEA [IEA 2023 a].

The shares of the electricity mix of the different countries are shown in the **Table 3** in ANNEX I: MAIN DATA. Between 2020, 2030 and 2050, the foreground data are interpolated for the 16 years of lifetime of the vehicles.

It is important to notice that in the calculations of the operation phase of the vehicle, the changes of the energy/electricity supply in the lifetime of the vehicle are considered.

#### 3.2.3.2. Air Pollutants

Also the emission factors for the air pollutants of the national electricity mixes of the European countries were kindly provided by Ricardo [Ricardo 2024] solely for the use in Green NCAP LCA Projects. As air pollutants were added later the updated Ricardo data contained the years 2020, 2030, 2040 and 2050. Again the data were supplied for two different scenarios « Baseline » and « Tech1.5 ». To be in line with GHG emissions and primary energy demand, again an average of the two scenarios was used for the investigated air pollutants.

### 3.3. Background Data

The background data cover all other data that are necessary to estimate the LCA based GHG emissions, air pollutants and the primary energy demand of the transportation systems with passenger vehicles. These data derive from different data bases (e.g. GEMIS 5.2, ecoinvent 3.4 and 3.10) and own data. In the following section the most relevant background data, which are necessary to assess and discuss the main results of the LCA, are shown.

The background data are grouped as follows:

- › Vehicle covering production, operation, maintenance and end-of-life
- › Supply of energy carriers to the vehicle also covering production of hydrogen, electricity supply and biofuels as well as their possible land use change effects.

#### 3.3.1. Vehicle

##### 3.3.1.1. Vehicle Production

The estimation of the vehicle material composition (except battery, see [chapter 3.3.1.2](#) and [Table 4](#) in ANNEX I: MAIN DATA) is mainly based on work from Graz University of Technology [Hausberger et al. 2018] and own work at JOANNEUM RESEARCH, especially on hydrogen storage tanks and electronics in vehicles [JOANNEUM RESEARCH 2024].

The energy demand for the basic vehicle manufacturing in a vehicle factory is estimated based on the VW Sustainability report [VW 2021]:

- › Electricity: 1,060 kWh/vehicle
- › Heat: 590 kWh/vehicle
- › Natural gas: 420 kWh/vehicle.

The background data for vehicle production cover

- › Share of material mix for vehicles ([Table 4](#) in ANNEX I: MAIN DATA) and hydrogen fuel cell & tank production ([Table 5](#) ANNEX I: MAIN DATA) to calculate the environmental effects of vehicle production. The H<sub>2</sub> pressure is 700 bar, the mass of the H<sub>2</sub>-tank and-of-the fuel cell system is 276 kg.
- › Materials ([Table 6](#) in ANNEX I: MAIN DATA) and primary energy for vehicle production.

##### 3.3.1.2. Battery Production

On the basis of a literature review on environmental life cycle impacts of automotive batteries, the calculation of GHG emissions from battery manufacturing is done with the JOANNEUM RESEARCH in-house “JR Battery LCA-Tool” [Aichberger et al. 2020a], [Pucker-Singer et al. 2021].

The main processes in the LCA of automotive batteries are ([Figure 10](#)):

- › Raw material mining and refining
- › Grade material production
- › Battery system manufacturing
- › Battery use
- › Reuse
- › Recycling and 2<sup>nd</sup> life (Reuse)
- › Transports.

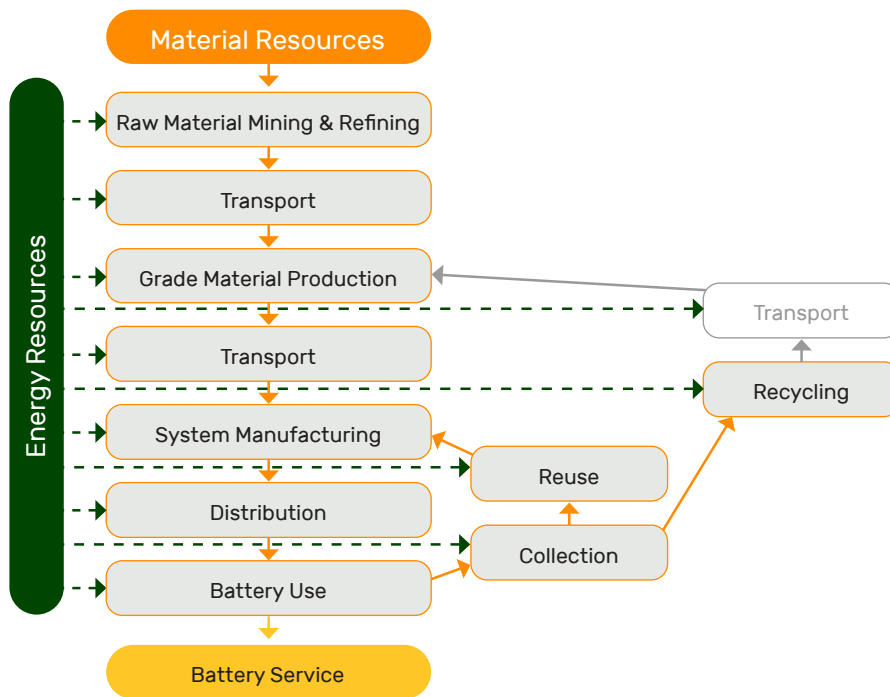


Figure 10 - System boundaries for automotive battery systems

The LCA for automotive battery system is calculated in the in-house battery LCA-Tool for the following two functional units

- › Per kWh battery capacity, e.g. kg CO<sub>2</sub>-eq./kWh
- › Per km driven (assuming e.g. 57 kWh battery capacity and 240,000 km lifetime mileage), e.g. g CO<sub>2</sub>-eq./km with a passenger vehicle

The modelling of the automotive battery system is done for the following seven main components **Figure 11**:

1. Cathode
2. Anode
3. Electrolyte
4. Separator
5. Module and battery packaging (pack, module and cell case)
6. Battery-Management-System (BMS)
7. Cooling (thermal) system.

The distribution of the mass to these components is shown in **Figure 12**.

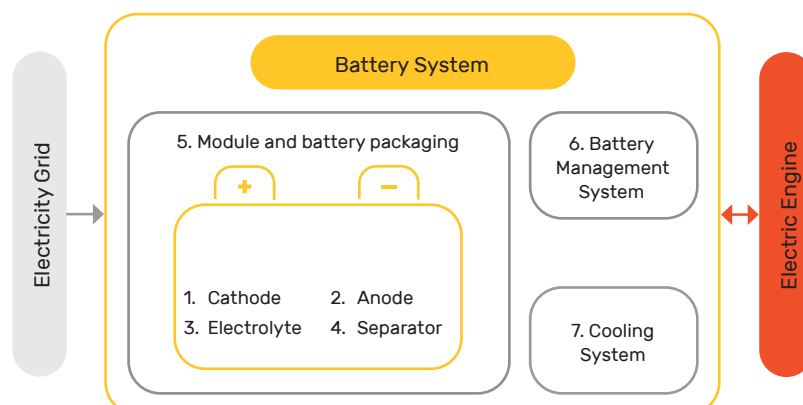


Figure 11 - Main components of the automotive battery system

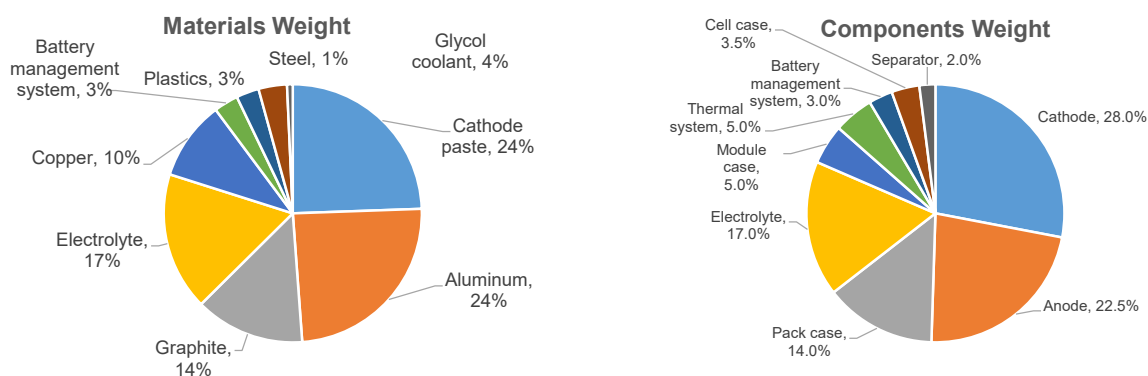


Figure 12 - Estimated average distribution of the mass of these components in the automotive battery system [JOANNEUM RESEARCH 2024]

The following main materials of the automotive battery system are considered in the LCA:

- › Positive active material (incl. Lithium, Nickel and Cobalt)
- › Aluminum
- › Graphite
- › Copper
- › Lithium hexafluorophosphate (Electrolyte)
- › Steel
- › Polymer.

The LCA is done for batteries produced in Europe, USA and China separately, mainly based on the different electricity generation mix.

For the end-of-life phase of automotive batteries – material recycling or reuse as stationary application in a 2<sup>nd</sup> life – less data are available. The battery recycling is currently tested in pilot and demo plants as a combination of mechanical and pyro- and hydrometallurgical processes. For the LCA modelling the following assumptions are made:

- › Dismantling of the battery module with use of aluminium and plastics
- › Dismantling of the battery cells with use of copper and aluminium
- › Dismantling of the cathode with use of aluminium and
- › Hydrometallurgical recycling of cobalt and nickel.

In the following Figures (**Figure 13**, **Figure 14** and **Figure 15**) the main inputs and results from the LCA of automotive batteries produced in Europe, USA and China for 2020, 2030 and 2050 are shown.

In **Table 7** in ANNEX I: MAIN DATA the background data for batteries used in the tool are shown based on the LCA battery modelling for 2020, 2030 and 2050. The data used for the calculations are for 2024, which are based on the interpolation between 2020 and 2030. Data were derived from two main sources [McKinsey 2024] and [Schade, 2022]. It is expected that the European OEMs will further integrate the battery upstream value chain. Recycling activities are expected to take place in the countries where the vehicles are disposed.

DESCRIPTION

The life cycle itself starts with the mining and refining of raw materials, followed by the material processing for battery grade materials, the production of the batteries, the use and at the end the reuse respectively recycling of batteries, which represents a circular process back to the battery production or material processing step. Between the different steps, transportation is necessary from one step to the next.

BATTERY CHARACTERISTICS			Location material production		KEY FACTORS END-OF-LIFE	
Battery chemistry	NMC 811		Aluminum reduction	Europe	Share of reuse and recycling	
Weight [kg]	6		Battery management	Europe	Reuse rate	3%
Capacity [kWh]	1		Synthetic graphite	China	Recycling rate	100%
Specific energy battery pack [Wh/kg]	174		Nickel refining	China	Location	
Depth of discharge	80%		Cobalt sulfate	China	Reuse	Europe
Battery total lifetime [cycles]	3,000		Cathode paste	Europe	Recycling	Europe
Battery lifetime in car [a]	12		Cell production		Reuse	
Battery lifetime in car [vehicle-km]	240,000		Cell production	Europe	Remaining capacity [kWh]	0.8
Remaining life cycle [cycles]	0		Heat + electricity [kWh/kWh]	47	Recycling	
KEY FACTORS PRODUCTION			Heat demand [kWh/kWh]	23.5	Pyrometallurgy	0%
Lithium and Nickel			Heat source	Natural Gas	Hydrometallurgy	100%
Lithium source	Brine		Electricity demand [kWh/kWh]	23.5	Direct physical	0%
Nickel SO2 capture	yes		Local renewable electricity	0%		

LCA RESULTS

per kWh							
	kg CO2-eq/kWh			kWh Primary Energy Demand/kWh	g SO2-eq/kWh	g Ozone-eq/kWh	g Particulate Matter (PM10)/kWh
	2020	2030	2050				
Battery materials	34 to 46	23 to 35	6 to 19	135 to 206	221 to 394	93 to 126	9 to 43
Battery production	14 to 19	9 to 14	2 to 6	58 to 89	23 to 40	30 to 40	0 to 2
Transports	0.4 to 0.6	0.2 to 0.3	0.1 to 0.2	1.7 to 2.6	1 to 2	2 to 3	0 to 0.1
Reuse	0 to 0	0 to 0	0 to 0	0 to 0	0 to 0	0 to 0	0 to 0
Recycling	-9 to -13	-7 to -10	-2 to -5	-43 to -65	-117 to -208	-38 to -51	-4 to -21
Total	39 to 53	25 to 39	6 to 20	152 to 232	128 to 228	87 to 117	5 to 24

Total Battery Pack							
	kg CO2-eq			kWh Primary Energy Demand	g SO2-eq	g Ozone-eq	g Particulate Matter (PM10)
	2020	2030	2050				
Battery total	39 to 53	25 to 39	6 to 20	152 to 232	128 to 228	87 to 117	5 to 24

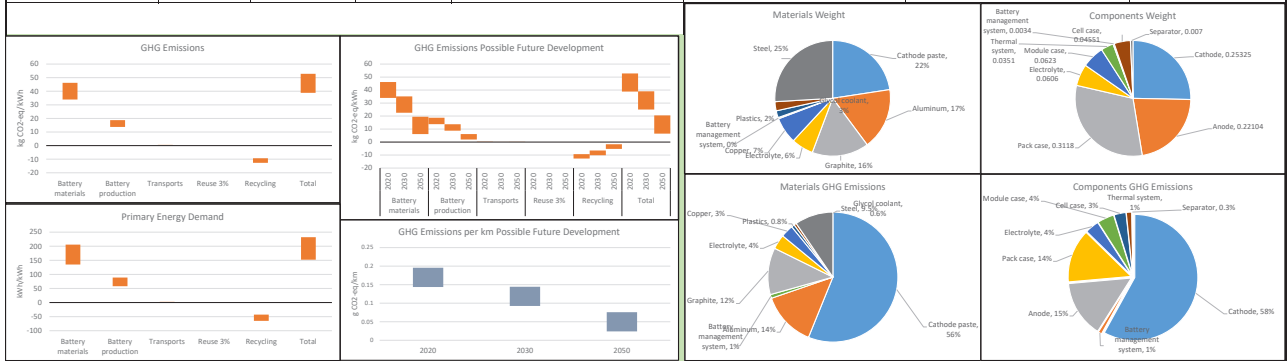


Figure 13 - LCA data and results of 'JR Battery LCA-Tool' for automotive batteries produced in Europe [JOANNEUM RESEARCH 2024]

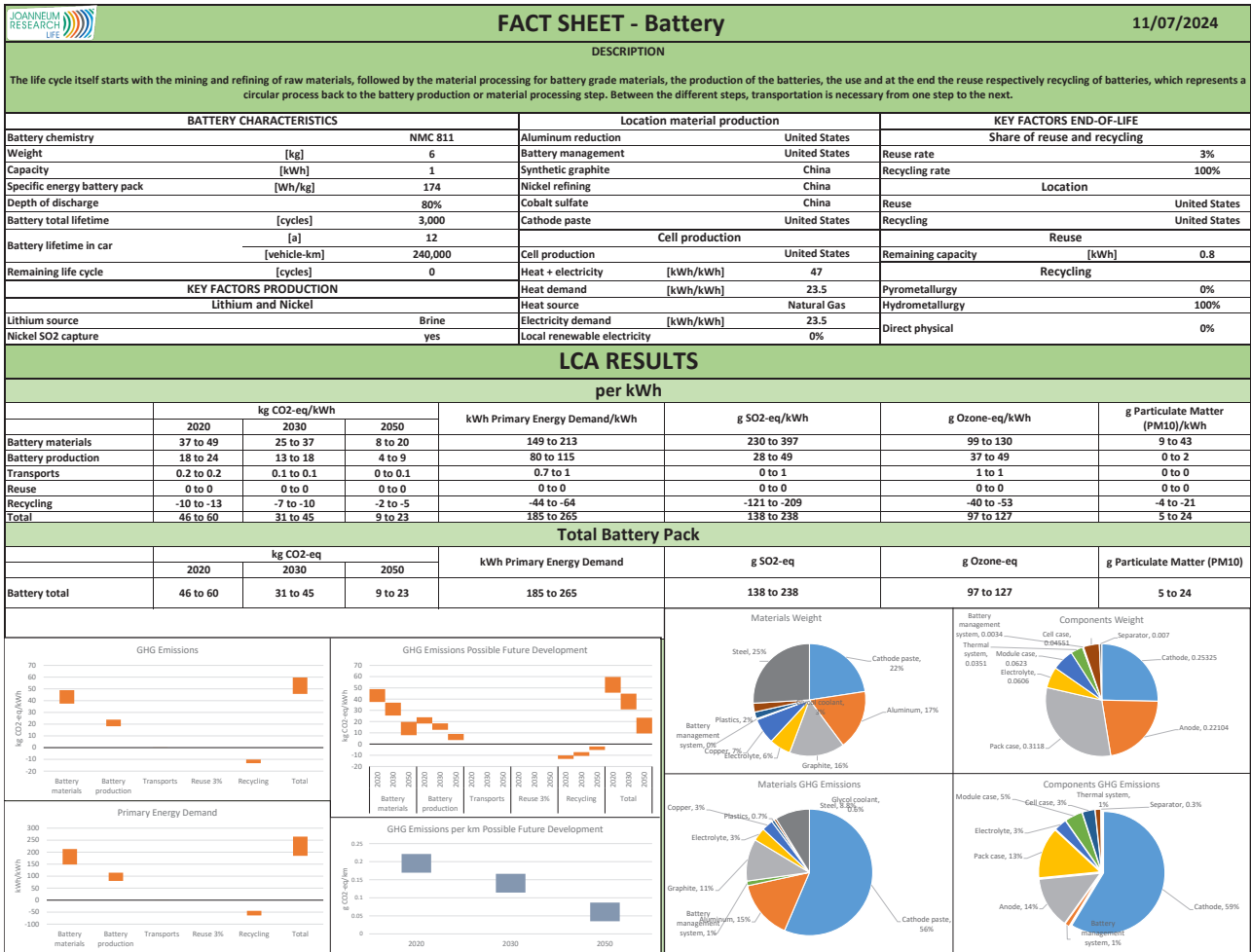


Figure 14 - LCA data and results of 'JR Battery LCA-Tool' for automotive batteries produced in USA [JOANNEUM RESEARCH 2024]

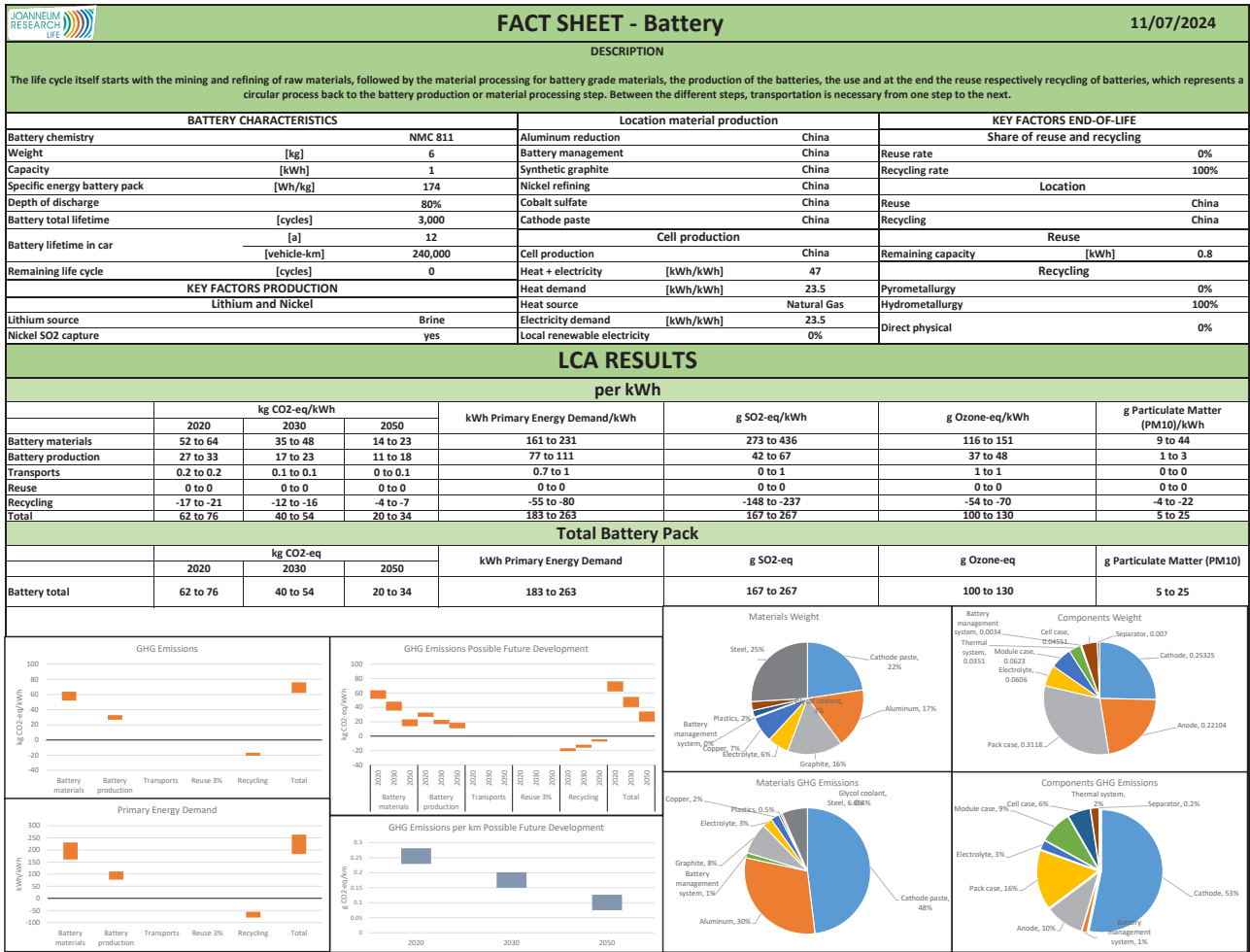


Figure 15 - LCA data and results of 'JR Battery LCA-Tool' for automotive batteries produced in China [JOANNEUM RESEARCH 2024]

As the JR Battery LCA-Tool does not include all investigated air pollutants, emission factors for NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> emissions factors were taken from [Ecoinvent 2024]. From the available datasets on battery production 'market for battery, Li-ion, LiMn<sub>2</sub>O<sub>4</sub>, rechargeable, prismatic | battery, Li-ion, LiMn<sub>2</sub>O<sub>4</sub>, rechargeable, prismatic | APOS, U', was chosen. It shows very similar results for the GWP100 as the JR Battery LCA-Tool for a production mix from China (78%), Europe (14%) and US (8%). Due to licensing reasons the emission factors cannot be published in this paper.

Emission factors for NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> for the end-of-life of batteries were estimated by scaling these emissions from battery production using the relation of CO<sub>2</sub> of battery production and battery recycling calculated with the JR Battery LCA-Tool.

### 3.3.1.3. Vehicle Operation

The energy consumption values for vehicle operation are provided by the stakeholders ADAC, ÖAMTC and Green NCAP. In cases where no CH<sub>4</sub> and N<sub>2</sub>O emissions for HEV, ICE and PHEV are provided, the default data from the LCA Expert Tool 2.4 [Jungmeier et al 2024] are used. NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM emissions for vehicle operation are provided by Green NCAP. As vehicle emissions measurement uses gravimetric method to determine the total amount of particle mass, no statements can be made about the size of the particles. Therefore, vehicle exhaust PM is counted together with PM<sub>2.5</sub> emissions from the other lifecycle phases and processes.

### 3.3.1.4. Vehicle Maintenance

The environmental effects from the maintenance of the vehicle during operation are considered ([Table 8](#) in ANNEX I: MAIN DATA), which are

- › Tyres
- › Spare/replacement parts (assumption: annually 0.5% of vehicle mass per year)
- › Combustion engine motor oil for ICE, HEV and PHEV and
- › Urea (diesel exhaust fluid) for diesel ICE.

[Table 9](#) in ANNEX I: MAIN DATA shows the GHG emissions and PED relevant for maintenance and [Table 10](#) shows the air pollutants relevant for maintenance. The resulting GHG emissions, air pollutants and PED are then converted into a specific factor per kg of vehicle mass using the standard mass of a generic vehicle depending on the propulsion system. The resulting factors used by the tool are shown in [Table 11](#).

### 3.3.1.5. Vehicle End-of-Life

For the environmental effects in the end-of-life phase of the vehicles the following issues are considered:

- › The energy demand for recycling to recover the secondary material is assumed to be about 20% of the energy demand of the vehicle manufacturing
- › A credit for the substitution of the materials: in average for all materials it is assumed that 1 t of secondary material substitutes for 0.15 t of primary material, e.g. for steel this is significantly higher and for electronics significantly lower
- › The GHG emissions, air pollutants and primary energy demand of end-of-life are not depending on the year, they are estimated for the years between 2030 - 2035.

Greenhouse gas emissions and primary energy demand for the end-of-life of batteries is calculated in much greater detail, directly sourced from the 'JR Battery LCA-Tool' [Aichberger et al. 2020] (see [chapter 3.3.1.2](#)).

## 3.3.2. Supply of Fuels and Energy

### 3.3.2.1. Hydrogen Production

In [Table 12](#) in ANNEX I: MAIN DATA the main data for hydrogen production via electrolysis and natural gas steam reforming are shown. The oxygen and heat from electrolysis are not used. The electricity demand for the compression from 30 bar to 800 bar and cooling of hydrogen is 2.7 kWh/kg H<sub>2</sub>, which is based on the ionic compressor IC 90 of Linde Gas. This data was used for the calculation of GHG emission and primary energy demand of hydrogen production. Air pollutants for hydrogen production are taken from [Ricardo 2023].

### 3.3.2.2. Biofuel Production

In [Table 13](#) in ANNEX I: MAIN DATA the main data for vegetable oil production are given. The co-produced animal feed substitutes soy feed. In [Table 14](#) in ANNEX I: MAIN DATA the main data for FAME (biodiesel) production are shown. The coproduced glycerin substitutes synthetically produced glycerin and the coproduced potassium substitutes for synthetic fertilizer. In [Table 15](#) in ANNEX I: MAIN DATA the main data for bio-ethanol production are shown. The coproduced animal feed substitutes soy feed. This data

was used for the calculation of GHG emission and primary energy demand of biofuel production. Air pollutants for biofuel production for different feedstocks (ethanol from wheat, sugarbeet<sup>3</sup>, sugarcane, wood and straw and FAME from rapeseed, used cooking oil and palm oil are taken from [Ricardo 2023].

### 3.3.2.3. Land Use Change of Biofuels

The background data for land use change for biomass resources are shown in [Table 16](#) in ANNEX I: MAIN DATA. The possible CO<sub>2</sub> emissions of iLUC are not considered in the analysis (see also [chapter 2.6.2.](#)), but for transport systems using biofuels an additional information on GHG emissions from iLUC is given in the Fact Sheet of LCA Tool 2.4 [Jungmeier et al. 2024].

### 3.3.2.4. Supply of Fuels and Electricity

The background data for the calculation of GHG emissions, primary demand and air pollutants for the supply of energy carriers to the vehicle are:

- › Heating values of fossil and biogenic resources ([Table 17](#) in ANNEX I: MAIN DATA)
- › Heating values of fuels ([Table 18](#) in ANNEX I: MAIN DATA)
- › Supply of fuels to the filling station ([Table 19](#), [Table 20](#), [Table 21](#) and [Table 22](#) in ANNEX I: MAIN DATA).
- › PED and GHG of the supply of electricity to the charging station incl. distribution ([Table 23](#) and [Table 24](#) in ANNEX I: MAIN DATA)<sup>4</sup>, where 'electr. / RES EU' is 25% hydro, 50% wind and 25% PV. [Table 25](#) lists the emissions factors for the supply to the filling station and electricity for NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, CO, SO<sub>x</sub>, PM<sub>2.5</sub> and PM<sub>10</sub>, which are used in the LCA tool
- › Supply of hydrogen to the filling station ([Table 26](#) and [Table 27](#) in ANNEX I: MAIN DATA).

For the air pollutants emission factors for the supply of fuels and electricity were taken directly from [Ricardo 2023 and Ricardo 2024]. The average of the two scenarios Baseline and Tech1.5 is used (see also 3.2.3 for more information on the scenarios).

Newly added fuels are E85 and LPG.

The characteristics of LPG (80% Propane) are

- › Heating value: 12.8 kWh/kg and 7.1 kWh/l
- › CO<sub>2</sub> emissions from combustion: 237 g CO<sub>2</sub>/kWh
- › Supply of LPG is like petrol (GREET 2023))

The characteristics of E85 are

- › Heating value: 6.29 kWh/l
- › CO<sub>2</sub> emissions from combustion: 56 g CO<sub>2</sub>/kWh
- › Supply of E85 is a mixture of gasoline and EtOH based on energy content.

The charging losses (outside of the vehicle) for charging of BEV and PHEV are assumed with 2% [Green NCAP 2022].

These background data are calculated with the specified foreground data using LCA [JOANNEUM RESEARCH 2024], [Jungmeier et al. 2024].

<sup>3</sup> For the NH<sub>3</sub> emissions of sugarbeet data from ecoinvent [Ecoinvent 2024] is used.

<sup>4</sup> 'Nuclear' primary energy is included here under 'fossil' primary energy, based on the source used [Ricardo 2023]

## 4. MAIN FINDINGS AND CONCLUSIONS

The main findings of the environmental assessment using LCA applied on the about 30,000 different vehicles available on the European market are:

- › The main differences between the vehicles are due to
  - › The mass of the vehicle
  - › The battery capacity
  - › The energy demand per driven kilometre.
- › The environmental effects of BEV and PHEV depend on the electricity mix of the considered country.
- › The production of the battery has a significant influence on the GHG emissions and primary energy demand of the BEV and PHEV.
- › The GHG emissions and primary energy demand of ICE are dominated by the operation of the vehicle.
- › In general, the GHG emissions and primary energy savings from substituting for secondary materials at the end-of-life are quite small in the overall life cycle. However, due to the future recycling of batteries, BEV and PHEV are able to provide more secondary material than ICE.

## ANNEX I: MAIN DATA

Table 1 Foreground data for land use change for biofuels

[JOANNEUM RESEARCH 2024]

Share of direct land use change (LUC) for biofuels	2021	2030	2050
Sugar cane (from pasture)	0%	0%	0%
Soja beans (from pasture)	0%	0%	0%
Palm oil (from trop. forest)	0%	0%	0%

Table 2 Foreground data for biomass mix for biofuels

[JRC 2020], [IEA 2024], [Rangaraju 2021] and [JOANNEUM RESEARCH 2024]

Country (EU27, CH, NO, UK)	2024	2030	2050
<b>FAME</b>			
Rape seed oil	35%	55%	55%
Used cooking oil	32%	32%	35%
Palm oil	27%	7%	4%
Soja oil	6%	6%	6%
<b>HVO</b>			
Rape seed oil	15%	15%	15%
Used cooking oil	38%	41%	43%
Palm oil	45%	42%	40%
Soja oil	2%	2%	2%
<b>EtOH</b>			
Wheat & maize	68%	60%	54%
Sugar beet	21%	21%	21%
Sugar cane	7%	6%	5%
Wood	2%	7%	10%
Straw	2%	7%	10%
<b>FT-diesel</b>			
Wood	50%	50%	50%
Straw	50%	50%	50%
<b>CRG</b>			
From fermentation			
Maize silage & manure	68%	61%	54%
Residues	32%	29%	26%
From gasification			
Wood	0%	5%	10%
Straw	0%	5%	10%

Table 3 Foreground data for electricity mixes 2024, 2030 and 2050

[Ricardo 2023], [Bundesanzeiger 2024] for Germany, [JOANNEUM RESEARCH 2024]

2024	Europe 27	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Germany	Denmark	Estonia	Spain	Finland	France	Greece	Croatia	Hungary	Ireland	Italy	Lithuania	Luxembourg	Latvia	Malta	Netherlands	Poland	Portugal	Romania	Sweden	Slovenia	Slovakia	Switzerland	Norway	United Kingdom
	EU27	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	CH	NO	UK
Coal	11.6%	0.9%	0.6%	27.3%	0.0%	31.4%	20.7%	8.0%	35.1%	1.4%	2.5%	0.6%	8.2%	5.5%	6.6%	1.8%	3.4%	0.8%	1.9%	0.0%	0.0%	4.6%	58.0%	3.0%	12.1%	0.6%	20.8%	4.0%	0.0%	0.1%	1.1%
Oil	0.7%	0.7%	0.3%	0.1%	52.6%	0.1%	0.7%	0.3%	0.2%	2.5%	0.3%	0.7%	5.4%	0.2%	0.3%	0.8%	2.1%	1.7%	0.0%	0.0%	1.7%	0.0%	0.7%	1.6%	0.0%	0.1%	0.1%	0.9%	0.0%	0.2%	0.2%
Natural gas	16.8%	11.4%	39.0%	9.4%	26.3%	7.9%	16.3%	3.1%	10.5%	19.0%	6.6%	4.7%	37.5%	19.4%	18.8%	40.9%	41.6%	25.2%	5.0%	34.5%	83.1%	47.6%	14.8%	21.1%	16.9%	0.5%	9.6%	11.2%	1.3%	0.4%	30.1%
Nuclear	22.1%	0.0%	23.2%	38.6%	0.0%	40.6%	6.8%	0.0%	0.0%	16.5%	36.4%	60.6%	0.0%	0.0%	54.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%	0.0%	0.0%	23.6%	28.8%	33.7%	58.2%	33.5%	0.0%	16.5%
Biomass	6.2%	6.0%	4.5%	3.7%	1.3%	5.7%	7.6%	16.4%	23.4%	2.3%	17.5%	1.6%	0.9%	6.6%	5.8%	3.8%	6.8%	13.4%	12.0%	13.9%	0.2%	3.9%	5.2%	6.2%	1.3%	7.2%	1.6%	5.3%	0.9%	0.0%	10.4%
Hydro	12.4%	58.1%	1.1%	9.5%	0.0%	4.0%	3.4%	0.1%	0.5%	12.0%	19.9%	12.2%	8.5%	45.1%	0.6%	3.0%	17.5%	14.6%	30.7%	39.8%	0.0%	0.0%	1.7%	26.5%	25.9%	42.5%	28.4%	15.6%	53.8%	77.3%	2.0%
Wind	21.6%	15.0%	22.8%	4.6%	5.2%	6.0%	28.4%	63.8%	26.8%	33.9%	15.7%	14.5%	25.5%	19.0%	2.8%	48.5%	10.7%	36.9%	21.7%	11.5%	0.1%	29.8%	16.1%	30.4%	14.4%	18.9%	1.2%	1.5%	0.5%	19.9%	35.4%
PV	8.3%	7.6%	7.8%	6.8%	14.6%	4.4%	11.8%	6.5%	2.7%	12.3%	0.7%	4.7%	14.0%	3.3%	10.4%	0.7%	15.3%	6.7%	27.5%	0.2%	14.9%	10.1%	3.5%	10.5%	5.9%	0.9%	4.6%	3.4%	4.9%	1.9%	4.4%
Waste	0.3%	0.3%	0.7%	0.0%	0.0%	0.1%	1.0%	2.0%	0.8%	0.2%	0.4%	0.3%	0.0%	1.1%	0.3%	0.6%	2.6%	0.8%	1.2%	0.0%	0.0%	1.1%	0.1%	0.8%	0.0%	0.6%	0.0%	0.1%	3.4%	0.1%	0.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.1%	0.0%	
<b>SUM</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

2030	EU27	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	CH	NO	UK
Coal	6.7%	0.1%	0.0%	17.9%	0.0%	21.2%	16.3%	0.0%	29.8%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	42.6%	0.0%	4.7%	0.0%	14.0%	0.0%	0.0%	0.0%	0.0%
Oil	0.2%	0.3%	0.0%	0.0%	0.0%	0.2%	0.5%	0.0%	0.0%	0.3%	0.2%	0.2%	0.6%	0.2%	0.0%	0.1%	0.8%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	1.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Natural gas	14.2%	3.9%	49.1%	14.6%	65.8%	3.9%	16.7%	0.8%	6.6%	7.1%	6.3%	1.2%	32.0%	9.7%	7.2%	26.7%	30.5%	13.8%	0.2%	31.9%	79.0%	25.7%	18.7%	2.5%	15.3%	0.6%	18.9%	7.4%	2.0%	0.6%	17.5%
Nuclear	16.8%	0.0%	0.0%	35.3%	0.0%	46.0%	0.0%	0.0%	0.0%	8.1%	40.3%	51.5%	0.0%	0.0%	66.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	28.2%	27.1%	28.9%	65.1%	30.0%	0.0%	16.9%
Biomass	5.5%	6.1%	3.8%	3.1%	1.4%	4.8%	7.1%	14.9%	13.5%	2.5%	14.9%	2.1%	0.9%	5.5%	5.8%	2.3%	7.9%	18.6%	7.8%	12.2%	0.2%	1.6%	5.2%	5.7%	1.8%	9.1%	1.6%	4.7%	0.8%	0.0%	7.0%
Hydro	11.8%	51.5%	0.4%	11.5%	0.0%	3.6%	3.6%	0.0%	0.5%	10.6%	15.0%	11.8%	10.5%	47.6%	0.5%	1.7%	17.1%	6.0%	3.3%	31.3%	0.0%	0.1%	1.4%	27.8%	22.6%	39.9%	25.5%	13.9%	51.0%	56.1%	1.8%
Wind	31.7%	23.4%	35.4%	6.0%	5.5%	13.7%	36.6%	74.2%	45.8%	52.5%	21.9%	25.0%	34.9%	28.1%	4.2%	67.6%	16.6%	48.3%	30.7%	24.1%	0.2%	55.7%	25.2%	41.2%	17.3%	22.0%	2.8%	3.6%	1.0%	38.6%	52.1%
PV	12.7%	14.7%	10.9%	11.7%	27.3%	6.7%	16.2%	10.0%	3.7%	18.9%	1.2%	8.1%	21.2%	7.1%	15.3%	1.6%	24.9%	13.2%	57.9%	0.5%	20.7%	14.6%	6.8%	21.4%	10.0%	1.3%	8.3%	5.1%	8.0%	4.6%	4.6%
Waste	0.2%	0.0%	0.3%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	1.8%	0.1%	0.0%	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	3.1%	0.0%	0.0%	
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.1%	0.0%	0.0%	
<b>SUM</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

2050	Europe 27	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Germany	Denmark	Estonia	Spain	Finland	France	Greece	Croatia	Hungary	Ireland	Italy	Lithuania	Luxembourg	Latvia	Malta	Netherlands	Poland	Portugal	Romania	Sweden	Slovenia	Slovakia	Switzerland	Norway	United Kingdom	
	EU27	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	CH	NO	UK	
Coal	0.7%	0.0%	0.0%	0.2%	0.0%	2.9%	0.0%	0.0%	6.5%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	7.9%	0.0%	0.5%	0.0%	2.7%	0.0%	0.0%	0.0%	0.0%	0.0%
Oil	0.1%	0.1%	0.0%	0.0%	0.2%	0.1%	0.1%	0.1%	0.0%	0.2%	0.1%	0.1%	0.2%	0.2%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
Natural gas	9.6%	2.9%	30.3%	13.3%	31.9%	11.0%	2.4%	4.0%	4.1%	3.6%	4.5%	1.5%	13.7%	8.5%	9.7%	14.3%	18.0%	6.8%	19.0%	14.2%	73.0%	17.2%	13.5%	1.0%	10.6%	2.9%	15.0%	6.2%	2.0%	0.3%	13.2%	
Nuclear	14.6%	0.0%	0.0%	27.0%	0.0%	51.3%	0.0%	0.0%	0.0%	5.2%	42.5%	38.9%	0.0%	0.0%	49.8%	0.0%	0.0%	15.5%	0.0%	0.0%	0.0%	1.5%	18.4%	0.0%	20.8%	25.0%	24.1%	60.6%	30.0%	0.0%	23.1%	
Biomass	8.3%	10.1%	10.5%	7.9%	3.0%	10.3%	4.5%	16.6%	10.3%	6.6%	18.8%	3.1%	2.5%	5.3%	10.3%	4.2%	13.8%	14.9%	9.5%	12.7%	4.5%	6.2%	9.1%	8.5%	5.8%	10.6%	6.8%	8.5%	1.2%	0.0%	4.1%	
Hydro	9.6%	45.6%	0.5%	8.4%	0.0%	2.9%	2.7%	0.0%	0.7%	7.8%	13.8%	10.3%	8.3%	35.1%	0.9%	1.5%	12.5%	4.6%	2.9%	26.1%	0.0%	0.1%	1.5%	24.1%	16.8%	33.1%	21.4%	10.1%	50.0%	37.2%	1.3%	
Wind	40.9%	24.9%	36.6%	26.2%	19.5%	10.6%	64.9%	73.3%	69.4%	48.5%	19.5%	35.5%	48.3%	29.9%	10.3%	74.8%	24.2%	40.0%	28.8%	42.9%	4.9%	62.2%	42.1%	51.0%	29.3%	27.3%	7.3%	8.3%	3.0%	59.1%	51.9%	
PV	16.0%	16.4%	22.0%	16.7%	44.5%	10.8%	24.0%	5.9%	9.0%	28.1%	0.9%	10.1%	25.9%	19.0%	18.9%	5.2%	30.2%	18.1%	39.7%	4.1%	17.7%	12.1%	7.2%	14.9%	16.2%	1.1%	22.8%	6.2%	10.0%	3.5%	6.5%	
Waste	0.3%	0.0%	0.1%	0.1%	1.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.4%	1.0%	0.8%	0.0%	0.0%	1.1%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	0.0%	0.0%	
<b>SUM</b>	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

Table 4 Background data for material mix of vehicles (without battery and fuel cell)

based on [Hausberger et al. 2018] and [JOANNEUM RESEARCH 2024]

Propulsion	ICE			PHEV			BEV	HFC
Fuel	Petrol & blending, bio-ethanol	Diesel & blending, biodiesel	CNG & blending, CRG	Petrol & electricity	Diesel & electricity	CNG & electricity	Electricity	Hydrogen (H <sub>2</sub> )
Steel	50.4%	49.4%	52.1%	50.3%	49.4%	51.7%	44.6%	44.4%
Cast iron	8.0%	9.4%	7.9%	9.8%	11.1%	9.7%	5.4%	5.3%
Aluminium	10.6%	11.9%	10.5%	9.7%	10.9%	9.6%	16.1%	16.1%
Glas	2.4%	2.2%	2.3%	2.2%	2.0%	2.1%	2.4%	2.4%
Paint	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%
Plastic	12.1%	11.0%	10.8%	11.0%	10.0%	10.1%	11.6%	12.0%
Rubber	3.9%	3.7%	3.9%	3.6%	3.4%	3.5%	4.0%	4.0%
Oil	0.8%	0.9%	0.8%	0.8%	0.9%	0.8%	0.4%	0.4%
Copper	2.3%	2.3%	2.3%	2.9%	2.9%	2.9%	3.7%	3.6%
Non ferrous metals	0.3%	0.4%	0.3%	1.1%	1.2%	1.1%	1.6%	1.6%
Electronic	4.9%	4.7%	4.9%	4.7%	4.4%	4.6%	5.7%	5.7%
Textiles	3.9%	3.7%	3.9%	3.6%	3.4%	3.5%	4.1%	4.0%
Carbon fiber	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SUM	100%	100%	100%	100%	100%	100%	100%	100%

Table 5 Background data for hydrogen fuel cell (HFC) and H<sub>2</sub> tank system

[JOANNEUM RESEARCH 2024]

	Tank & HFC
Steel	19.6%
Aluminium	8.9%
Plastic	7.5%
Electronic	0.9%
Copper	5.3%
Graphit	6.2%
CFK	51.5%
SUM	100.0%

Table 6 Background data for materials for vehicle production<sup>5</sup>

[JOANNEUM RESEARCH 2024]

<b>Materials for vehicle production 2024</b>	<b>GHG</b> [g CO <sub>2</sub> -eq./kg]	<b>PED</b> [kWh/kg]	<b>PED<sub>fos</sub></b> [kWh/kg]
Steel	2,470	8.9	7.8
Cast iron	900	3.5	3.2
Aluminium	12,050	53.2	47.6
Glas	1,130	3.3	3.2
Paint	5,680	28.0	21.5
Plastic	3,610	8.6	7.8
Rubber	3,300	9.9	9.5
Oil	1,420	13.3	13.1
Copper	3,610	11.9	11.0
Non ferrous metals	7,670	30.3	26.3
Electronic	36,630	133.4	120.2
Textiles	24,250	75.2	69.2
Carbon fiber	18,940	90.2	83.1

Table 7 Background data for batteries interpolated for 2024 based on 2020 and 2030

[JOANNEUM RESEARCH 2024]

<b>Li-Ion battery 2024</b>	<b>Greenhouse Gas Emissions</b>				<b>Primary Energy Demand</b>				<b>Share</b>	<b>Energy density</b> [Wh/kg]
	<b>CO<sub>2</sub></b> [kg/kWh]	<b>CH<sub>4</sub></b> [kg/kWh]	<b>N<sub>2</sub>O</b> [kg/kWh]	<b>CO<sub>2</sub>-eq.</b> [kg/kWh]	<b>Fossil</b> [kWh/kWh]	<b>Renew.</b> [kWh/kWh]	<b>Other</b> [kWh/kWh]	<b>Sum</b> [kWh/kWh]		
<b>Production</b>										
CN	72	0.131	0.003	77	249	4	2	255	78%	150
EU	45	0.115	0.002	50	198	11	7	216	14%	
US	52	0.124	0.002	57	231	10	6	247	8%	
<b>MIX</b>	<b>67</b>	<b>0.128</b>	<b>0.002</b>	<b>71</b>	<b>240</b>	<b>5</b>	<b>3</b>	<b>249</b>		
<b>Recycling</b>										
CN	-16	-0.016	-0.001	-17	-59	-1	0	-61	78%	150
EU	-10	-0.007	0.000	-10	-40	-5	-4	-49	14%	
US	-10	-0.009	0.000	-11	-42	-4	-3	-49	8%	
<b>MIX</b>	<b>-15</b>	<b>-0.014</b>	<b>-0.001</b>	<b>-15</b>	<b>-55</b>	<b>-2</b>	<b>-1</b>	<b>-58</b>		
<b>Total</b>	<b>52</b>	<b>0.114</b>	<b>0.002</b>	<b>56</b>	<b>185</b>	<b>4</b>	<b>2</b>	<b>191</b>		

<sup>5</sup> Emission factors for air pollutants were taken from [ecoinvent 2024] and cannot be published due to licensing reasons.

Table 8 Background data for operation

[HEV values represented by ICE]

Operation	ICE			PHEV		BEV	HFC
	Petrol	Diesel	CNG	Petrol & electricity	Diesel & electricity	Electricity	Hydrogen (H <sub>2</sub> )
Tyres [kg/KFZ a]	19.2	19.2	19.2	19.2	19.2	19.2	19.2
Engine oil [kg/1,000 km]	0.5	0.5	0.5	0.5	0.5		
Spare parts [kg/KFZ a]	6.4	6.8	6.4	7.0	7.4	8.0	7.0
Urea [kg/1,000 km]		1.5			0.8		

Table 9 Background data for maintenance - GHG emission and primary energy

[JOANNEUM RESEARCH 2024]

Maintenance	GHG	PED <sub>tot</sub>	PED <sub>fos</sub>
	[g CO <sub>2</sub> -eq./kg]	[kWh/kg]	[kWh/kg]
Tyres	3,300	9.9	9.5
Engine oil production	1,417	13.3	13.1
Engine oil use	3,172		
Spare/replacement parts	5,038	19.7	17.6
Urea production	278	2.3	2.2
Urea use (CO <sub>2</sub> only)	250		

Table 10 Background data for maintenance - air pollutants

[JOANNEUM RESEARCH 2024]

Maintenance [g/kg]	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>
Tyres	Ecoinvent 3.10: market for synthetic rubber   synthetic rubber   APOS, U						
Engine oil production	Ecoinvent 3.10: market for lubricating oil   lubricating oil   APOS, U						
Engine oil use	Neglected						
Spare/replacement parts	11	0.3	5	34	17	3	6
Urea production	Ecoinvent 3.10: market for urea   urea   APOS, U						
Urea use	Neglected						

Table 11 Emission factors used in the tool for maintenance

[JOANNEUM RESEARCH 2024]

<b>Spare parts &amp; tyres</b>	<b>CO<sub>2</sub></b> [g/kg a]	<b>CH<sub>4</sub></b> [g/kg a]	<b>N<sub>2</sub>O</b> [g/kg a]	<b>GHG</b> [g CO <sub>2</sub> -eq./kg a]	<b>PED<sub>fos</sub></b> [kWh/kg a]	<b>PED<sub>tot</sub></b> [kWh/kg a]	<b>NO<sub>x</sub></b> [g/kg a]	<b>NH<sub>3</sub></b> [g/kg a]	<b>NMVOC</b> [g/kg a]	<b>CO</b> [g/kg a]	<b>SO<sub>x</sub></b> [g/kg a]	<b>PM<sub>2.5</sub></b> [g/kg a]	<b>PM<sub>10</sub></b> [g/kg a]
Petrol ICE	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068
Petrol PHEV	66.6	0.087	0.003	70.6	0.22	0.23	0.14	0.003	0.178	0.218	0.186	0.042	0.065
Diesel ICE	67.9	0.088	0.004	72.0	0.22	0.24	0.14	0.001	0.160	0.048	0.103	0.027	0.037
Diesel PHEV	64.2	0.085	0.003	68.1	0.21	0.23	0.14	0.003	0.169	0.215	0.180	0.040	0.063
CNG ICE	70.3	0.090	0.004	74.5	0.23	0.25	0.15	0.003	0.193	0.238	0.203	0.045	0.070
Petrol E5 ICE	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068
Petrol E5 PHEV	66.6	0.087	0.003	70.6	0.22	0.23	0.14	0.003	0.178	0.218	0.186	0.042	0.065
Petrol E10 ICE	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068
Petrol E10 HEV	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068
Petrol E10 PHEV	66.6	0.087	0.003	70.6	0.22	0.23	0.14	0.003	0.178	0.218	0.186	0.042	0.065
Petrol E85 ICE	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068
Petrol E85 PHEV	66.6	0.087	0.003	70.6	0.22	0.23	0.14	0.003	0.178	0.218	0.186	0.042	0.065
Diesel B7 ICE	67.9	0.088	0.004	72.0	0.22	0.24	0.14	0.001	0.160	0.048	0.103	0.027	0.037
Diesel B7 HEV	67.9	0.088	0.004	72.0	0.22	0.24	0.14	0.001	0.160	0.048	0.103	0.027	0.037
Diesel B7 PHEV	64.2	0.085	0.003	68.1	0.21	0.23	0.14	0.003	0.169	0.215	0.180	0.040	0.063
CNG CRG5 ICE	70.3	0.090	0.004	74.5	0.23	0.25	0.15	0.003	0.193	0.238	0.203	0.045	0.070
CRG ICE	70.3	0.090	0.004	74.5	0.23	0.25	0.15	0.003	0.193	0.238	0.203	0.045	0.070
Electricity BEV	79.2	0.107	0.004	84.1	0.26	0.28	0.17	0.003	0.205	0.276	0.225	0.050	0.078
Gaseous hydrogen HFCV	74.9	0.098	0.004	79.4	0.25	0.26	0.16	0.003	0.200	0.245	0.209	0.047	0.073
LPG ICE	70.7	0.090	0.004	74.9	0.23	0.25	0.15	0.003	0.192	0.222	0.195	0.044	0.068

<b>Engine oil</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>GHG</b>	<b>PED<sub>fos</sub></b>	<b>PED<sub>tot</sub></b>	<b>NO<sub>x</sub></b>	<b>NH<sub>3</sub></b>	<b>NMVOC</b>	<b>CO</b>	<b>SO<sub>x</sub></b>	<b>PM<sub>2.5</sub></b>	<b>PM<sub>10</sub></b>
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[g/1,000 km & kg Car]

[kWh/1,000 km & kg Car]

[g/1,000 km & kg Car]

<b>Urea</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>GHG</b>	<b>PED<sub>fos</sub></b>	<b>PED<sub>tot</sub></b>	<b>NO<sub>x</sub></b>	<b>NH<sub>3</sub></b>	<b>NMVOC</b>	<b>CO</b>	<b>SO<sub>x</sub></b>	<b>PM<sub>2.5</sub></b>	<b>PM<sub>10</sub></b>
	[g/1,000 km & kg Car & kWh]			[kWh/1,000 km & kg Car & kWh]			[g/1,000 km & kg Car & kWh]						

Table 12 Background data for hydrogen production via low temperature electrolysis (PEM or alkaline) and natural gas steam reforming

based on [JOANNEUM RESEARCH 2024] and [BioGrace 2015]

	<b>Electrolyses</b>	<b>Steam reforming</b>
<b>Output</b>		
H <sub>2</sub> 30 bar [MWh]	1	1
<b>Input</b>		
Electricity [MWh]	1.43	
Natural gas [t]		0.107

Table 13 Background data for vegetable oil production for GHG emissions and primary energy  
based on [JOANNEUM RESEARCH 2024] and [BioGrace 2015]

		Rape seed	Soy bean	Palm oil
<b>Output</b>				
Vegetable oil	[MWh]	1	1	1
Animal feed	[t]	0.13	0.22	
<b>Input</b>				
Raw material	[t]	0.25	0.32	0.65
Electricity	[MWh]	11.10	33	0*
Heat	[MWh]	50	160	0*
Fuller's earth	[kg]	0.59	0.59	0.002
Phosphoric acid	[kg]	0.10	0.11	0.001
Hexane	[kg]	0.25	0.11	0

\* Provided internally by CHP plant from processing residues

Table 14 Background data for FAME (biodiesel) production for GHG emissions and primary energy  
based on [JOANNEUM RESEARCH 2024] and [BioGrace 2015]

	Amount
<b>Output</b>	
FAME	[MWh] 1.00
Glycerine	[kg] 10.00
Potassium (as fertilizer)	[kg] 0.64
<b>Input</b>	
Vegetable oil	[t] 0.10
Electricity	[kWh] 8.10
Heat	[kWh] 66.10
Methanol	[kg] 11.40
Potassium hydroxide	[kg] 1.00
Sulfuric acid	[kg] 1.00
Phosphoric acid	[kg] 0.30
NaOH	[kg] 0.70
Activated carbon	[kg] 0.10
N <sub>2</sub> (liquid)	[kg] 0.20

Table 15 Background data for bioethanol production for GHG emissions and primary energy  
 based on [JOANNEUM RESEARCH 2024], [BioGrace 2015]

		Wheat	Maize (corn)	Sugar beet	Sugar cane	Wood	Straw
<b>Output</b>							
Bio-ethanol	[MWh]	1.00	1.00	1.00	1.00	1.00	1.00
Animal feed (DDGS)	[kg]	131.00	121.00	78.00			
<b>Input</b>							
Raw material	[t]	0.42	0.55	1.62	1.97		0.63
Electricity	[kWh]	64.00	62.00	47.00			
Heat	[kWh]	450.00	436.00	614.00			
NaOH	[kg]	0.30	0.30	0.30			
Ammonia (25%)	[kg]	0.90	0.90	1.10		19.00	12.00
Sulfuric acid	[kg]	0.30	0.30	0.40		13.00	5.00
Urea	[kg]	0.10	0.10	0.10			
Molasses 880% (DM)	[kg]					9.00	6.00
Corn Steep Liquor (CSL)	[kg]					25.00	22.00
Diammoniahosphate (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	[kg]					3.00	3.00

Table 16 Background data for direct and indirect land use change (LUC) for biomass resources  
 (based on [EU 2009] and [EU 2015])

iLUC*	[g CO <sub>2</sub> /MJ]	[g CO <sub>2</sub> /kWh]
Bio-ethanol (wheat, maize)	12	43
Bio-ethanol (sugar beet)	13	47
Bio-ethanol (sugar cane)	17	61
FAME/HVO (rape seeds)	33	119
FAME/HVO (soja beans)	55	198
FAME/HVO (palm oil)	66	238

dLUC*	[kg CO <sub>2</sub> /ha]	[g CO <sub>2</sub> /kWh]
Sugar cane (grassland)	2,576	
Soja beans (grassland)	2,825	
Palm oil (trop. forest)	28,441	
EtOH / sugar cane		68
FAME / palm oil		804
FAME / soja oil		330
HVO / palm oil		805
HVO / soja oil		331

\* in brackets is the previous use of the land

Table 17 Background data for lower heating values of fossil and biogenic resources

[JOANNEUM RESEARCH 2024]

<b>Fossil Resources</b>	<b>[kWh/kg]</b>	<b>[g CO<sub>2</sub>/kWh]</b>
Coal	7.6	
Raw oil	11.1	
Natural gas		10.0

<b>Biomass resourcees</b>	<b>[kWh/kg]</b>	<b>Water content</b>
Wood	3.7	25%
Maize	2.8	35%
Wheat	3.9	14%
Sugar beet	0.8	73%
Rape seeds	6.8	9%
Soy beans	4.7	13%
Palm oil fruits	6.2	9%
Sugar cane	2.5	40%
Maize sillage	1.5	64%
Straw	3.9	14%
Waste cooking oil	10.3	0%
Bio-waste (DM)	2.2	69%
Manure (DM)	3.0	0%

Table 18 Background data for heating values of fuels

[JOANNEUM RESEARCH 2024] comparable to [EU 2018]

	<b>[kWh/kg]</b>	<b>[kWh/l]</b>	<b>[kWh/Nm<sup>3</sup>]</b>
Diesel	11.8	9.8	
Petrol	11.9	8.8	
CNG	13.9		10.0
Diesel B7		9.7	
Petrol E5		8.7	
Petrol E10		8.5	
FAME	10.3	9.1	
HVO	12.2	9.5	
FT-diesel	12.2	10.2	
EtOH	7.4	5.8	
CRG	13.9		10.0
H <sub>2</sub>	33.3		
E-fuel FT-diesel	12.2	10.2	
E-fuel CRG	13.9		10.0
LPG	12.8	7.1	

Table 19 Background data for the supply of fossil fuels to the filling station

[JOANNEUM RESEARCH 2024]

Supply to filling station Fuels	g CO <sub>2</sub> -eq./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	58.3	58.3	58.4	58.4	58.5	58.6	58.6	59.6	60.6	61.5	62.5	63.5	64.5	65.4	66.4	67.4
Diesel B7	63.9	63.9	63.8	63.7	63.6	63.5	63.4	64.3	65.1	66.0	66.8	67.7	68.5	69.4	70.3	71.1
Petrol	75.8	75.7	75.6	75.5	75.4	75.3	75.2	76.1	77.0	78.0	78.9	79.8	80.7	81.6	82.5	83.4
Petrol E5	80.8	80.5	80.2	79.9	79.7	79.4	79.1	79.8	80.6	81.4	82.2	83.0	83.8	84.5	85.3	86.1
Petrol E10	86.1	85.6	85.1	84.6	84.0	83.5	83.0	83.7	84.3	85.0	85.6	86.3	86.9	87.6	88.2	88.9
Petrol E85	194.5	189.6	184.6	179.7	174.7	169.8	164.8	162.8	160.7	158.6	156.6	154.5	152.5	150.4	148.3	146.3
CNG	40.7	40.8	41.0	41.2	41.3	41.5	41.7	42.5	43.3	44.2	45.0	45.8	46.6	47.5	48.3	49.1
CNG CRG5	44.1	44.2	44.2	44.3	44.3	44.4	44.4	45.2	45.9	46.7	47.4	48.2	48.9	49.6	50.4	51.1
LPG	75.8	75.7	75.6	75.5	75.4	75.3	75.2	76.1	77.0	78.0	78.9	79.8	80.7	81.6	82.5	83.4

Supply to filling station Fuels	kWh fossil/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.19	1.19	1.19	1.20	1.20	1.20	1.21
Diesel B7	1.13	1.13	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.13	1.14	1.14	1.14	1.15	1.15
Petrol	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28
Petrol E5	1.24	1.24	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.25	1.25	1.25
Petrol E10	1.22	1.22	1.22	1.21	1.21	1.21	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22	1.22	1.22
Petrol E85	0.88	0.86	0.84	0.82	0.80	0.77	0.75	0.74	0.73	0.72	0.71	0.71	0.70	0.69	0.68	0.67
CNG	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.16	1.16	1.16	1.16	1.16
CNG CRG5	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13
LPG	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28

Supply to filling station	kWh renew./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel B7	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Petrol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petrol E5	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Petrol E10	0.13	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Petrol E85	1.48	1.49	1.50	1.51	1.52	1.52	1.53	1.54	1.54	1.54	1.55	1.55	1.55	1.56	1.56	1.57
CNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CNG CRG5	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
LPG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Supply to filling station	kWh total/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.19	1.19	1.19	1.20	1.20	1.20	1.21	1.21
Diesel B7	1.25	1.25	1.25	1.24	1.24	1.23	1.23	1.23	1.24	1.24	1.24	1.24	1.25	1.25	1.25	1.25
Petrol	1.26	1.26	1.26	1.25	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28	1.28
Petrol E5	1.31	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.31	1.31	1.31	1.32	1.32	1.32
Petrol E10	1.35	1.35	1.35	1.35	1.35	1.34	1.34	1.34	1.35	1.35	1.35	1.35	1.36	1.36	1.36	1.36
Petrol E85	2.37	2.36	2.35	2.33	2.32	2.30	2.29	2.28	2.28	2.27	2.27	2.26	2.26	2.25	2.24	2.24
CNG	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.16	1.16	1.16	1.16	1.16	1.17
CNG CRG5	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.19	1.19	1.19	1.19	1.19	1.19	1.19
LPG	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.16	1.16	1.16	1.16

Table 20 Background data for the supply of fossil fuels to the filling station - air pollutants

[JOANNEUM RESEARCH 2024] based on data from [RICARDO 2024]

Supply to filling station Fuels	NO <sub>x</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	201	201	201	201	201	201	201	201	201	201	200	200	200	200	200	200
Diesel B7	209	209	208	208	208	207	207	207	207	207	206	206	206	206	206	205
Petrol	203	202	202	202	202	202	202	202	202	202	202	202	202	202	202	201
Petrol E5	213	212	211	211	210	209	209	208	208	208	208	208	207	207	207	207
Petrol E10	223	222	221	219	218	217	215	215	215	214	214	213	213	213	212	212
Petrol E85	439	425	411	397	383	369	356	352	348	344	340	336	332	328	324	320
CNG	42	41	41	40	40	39	39	38	38	37	37	36	36	35	34	34
LPG	224	224	224	224	224	224	224	224	224	224	224	224	224	224	224	223

Supply to filling station Fuels	NH <sub>3</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Diesel B7	33	33	33	33	32	32	32	32	32	32	32	31	31	31	31	31
Petrol	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Petrol E5	31	30	28	27	26	24	23	23	22	22	22	21	21	20	20	20
Petrol E10	61	58	55	53	50	47	45	44	43	43	42	41	40	40	39	38
Petrol E85	677	647	616	585	555	524	493	485	477	468	460	452	443	435	427	418
CNG	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
LPG	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2

Supply to filling station	NMVOC [mg/kWh]																
	Fuels	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160
Diesel B7	153	153	153	153	153	153	153	153	153	153	153	153	153	153	153	153	153
Petrol	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151
Petrol E5	149	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148
Petrol E10	146	146	146	145	145	145	145	145	145	145	145	145	145	145	145	145	144
Petrol E85	94	92	90	88	86	84	82	81	80	80	79	79	78	78	77	76	76
CNG	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142
LPG	77	93	108	124	140	156	172	172	172	172	172	172	172	172	172	172	172

Supply to filling station	SO <sub>x</sub> [mg/kWh]																
	Fuels	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	411	411	411	411	410	410	410	410	410	410	410	410	410	410	410	410	410
Diesel B7	393	393	393	393	393	393	393	393	392	392	392	392	392	392	392	392	392
Petrol	415	415	415	415	415	415	415	415	415	415	415	415	414	414	414	414	414
Petrol E5	408	408	407	407	407	406	406	406	406	406	405	405	405	405	405	405	405
Petrol E10	400	400	399	398	398	397	397	396	396	396	396	396	396	395	395	395	395
Petrol E85	241	235	229	223	218	212	206	204	203	201	200	198	196	195	193	192	192
CNG	13	12	12	11	10	10	9	9	8	8	7	7	6	6	5	5	5
LPG	180	217	255	292	329	366	403	403	403	403	403	403	403	403	403	403	403

Supply to filling station	CO [mg/kWh]																
	Fuels	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	112	112	112	112	111	111	111	111	111	111	111	111	111	111	111	111	111
Diesel B7	123	123	122	121	121	120	120	119	119	119	119	119	119	119	119	119	118
Petrol	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114

Supply to filling station Fuels	CO [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Petrol E5	124	124	124	123	123	123	122	122	122	122	122	122	121	121	121	121
Petrol E10	135	134	134	133	132	132	131	131	130	130	130	130	129	129	129	129
Petrol E85	356	348	340	332	324	316	308	306	304	301	299	296	294	292	289	287
CNG	42	42	41	41	41	41	41	41	40	40	40	40	40	39	39	39
LPG	52	63	74	84	95	106	117	117	117	117	117	117	117	117	117	117

Supply to filling station Fuels	PM <sub>10</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	401	401	401	401	401	401	400	400	400	400	400	400	400	400	400	399
Diesel B7	378	378	378	378	378	378	377	377	377	377	377	377	377	377	376	376
Petrol	404	404	404	403	403	403	403	403	403	403	403	403	402	402	402	402
Petrol E5	393	393	393	393	392	392	392	392	392	392	391	391	391	391	391	391
Petrol E10	383	382	382	382	381	381	380	380	380	380	380	380	379	379	379	379
Petrol E85	162	159	156	153	150	146	143	142	141	141	140	139	138	137	136	135
CNG	25	25	24	23	22	22	21	20	19	18	18	17	16	15	14	14
LPG	177	214	251	287	324	360	397	397	397	397	397	397	397	397	396	396

Supply to filling station Fuels	PM <sub>2.5</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Diesel	403	403	402	402	402	402	402	402	402	402	402	402	401	401	401	401
Diesel B7	380	380	380	380	379	379	379	379	379	379	379	379	378	378	378	378
Petrol	405	405	405	405	405	405	405	404	404	404	404	404	404	404	404	404
Petrol E5	395	395	394	394	394	394	393	393	393	393	393	393	393	393	392	392
Petrol E10	384	384	383	383	383	382	382	382	382	381	381	381	381	381	381	380
Petrol E85	162	159	156	154	151	148	145	144	143	142	141	140	139	139	138	137

Supply to filling station	PM <sub>2.5</sub> [mg/kWh]															
	Fuels	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
CNG	26	26	25	24	23	22	22	21	20	19	19	18	17	16	15	15
LPG	400	400	399	399	399	399	399	399	399	399	399	399	399	399	398	398

Table 21 Background data for the supply of biofuels to the filling station [JOANNEUM RESEARCH 2024] for Europe without direct land use change

Supply to the filling station	2024			2030			2050		
	Biofuels	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]	PED <sub>fos</sub> [kWh/kWh]	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]	PED <sub>fos</sub> [kWh/kWh]	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]
EtOH / wheat & maize	257	2.6	0.91	203	2.4	0.66	144	2.2	0.39
EtOH / sugar beet	292	2.4	1.12	224	2.3	0.80	149	2.1	0.46
EtOH / sugar cane	171	5.3	0.50	165	5.1	0.48	160	5.0	0.46
EtOH / wood	57	2.8	0.17	56	2.7	0.17	56	2.6	0.16
EtOH / straw	97	2.7	0.22	94	2.6	0.21	92	2.5	0.21
FAME / rape seed oil	215	2.2	0.47	199	2.1	0.41	189	2.1	0.37
FAME / waste cooking oil	16	1.1	0.13	8	1.0	0.09	0	1.0	0.05
FAME / palm oil	261	4.8	0.64	247	4.6	0.59	239	4.6	0.55
FAME / soja oil	64	1.9	0.39	49	1.8	0.33	35	1.8	0.27
HVO / rape seed oil	249	2.4	0.57	235	2.3	0.52	227	2.3	0.48
HVO / waste cooking oil	49	1.3	0.23	44	1.2	0.20	39	1.2	0.17
HVO / palm oil	296	5.0	0.74	282	4.8	0.69	278	4.8	0.67
HVO / soja oil	98	2.1	0.50	85	2.0	0.44	74	2.0	0.39
CRG / maize silage & manure	145	2.0	0.66	127	1.9	0.58	111	1.8	0.51
CRG / residues	61	1.7	0.26	54	1.6	0.23	46	1.5	0.20
CRG / wood	23	1.8	0.07	23	1.7	0.07	22	1.6	0.07
CRG / straw	55	1.8	0.12	53	1.7	0.11	51	1.7	0.11

Supply to the filling station Biofuels	2024			2030			2050		
	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]	PED <sub>fos</sub> [kWh/kWh]	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]	PED <sub>fos</sub> [kWh/kWh]	GHG [g CO <sub>2</sub> -eq./kWh]	PED [kWh/kWh]	PED <sub>fos</sub> [kWh/kWh]
FT-diesel / straw	85	2.2	0.21	82	2.1	0.20	79	2.1	0.19
FT-diesel / wood	47	2.2	0.16	46	2.1	0.15	44	2.0	0.14

Table 22 Background data for the supply of biofuels to the filling station for Europe - air pollutants

[JOANNEUM RESEARCH 2024] based on data from [Ricardo 2023] and for NH<sub>3</sub> from sugar beet from [ecoinvent 2024]

[mg/kWh]	2024							2030							2040						
	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>
EtOH / wheat	533	830	83	366	216	103	90	530	830	83	365	212	98	85	522	830	83	363	206	88	75
EtOH / sugar beet	494	1,155	64	304	143	75	69	491	1155	64	303	140	72	66	486	1,155	64	302	135	64	58
EtOH / sugar cane	293	691	80	1,243	168	121	283	293	691	80	1,243	168	121	283	292	691	79	1,243	167	121	283
EtOH / wood	469	55	79	644	184	77	49	468	55	79	644	184	76	48	467	55	79	643	183	75	47
EtOH / straw	301	5	59	395	101	100	72	296	5	59	393	95	92	64	284	5	58	390	85	76	48
FAME / rape seed oil <sup>6</sup>	478	771	78	360	233	81	76	477	771	78	359	231	79	74	474	771	77	358	228	75	70
FAME / used cooking oil	34	1	10	18	4	12	11	33	1	10	17	3	10	10	30	1	10	17	1	7	6
FAME / palm oil	423	594	56	513	132	67	61	422	594	56	512	130	65	60	420	594	56	512	129	62	57

<sup>6</sup> Emission factors for FAME from rape seed oil, were also used for FAME from soja oil as [Ricardo 2023] does not contain data on soja oil

Table 23 Background data for the supply of electricity to the charging station Part I [JOANNEUM RESEARCH 2022] based on [Ricardo 2023], [IEA 2023] and own calculations based on electricity mix defined in foreground data<sup>7</sup>

Supply to charging station	g CO <sub>2</sub> -eq./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	295.1	280.5	265.9	251.3	236.7	222.1	207.5	200.9	194.4	187.8	181.2	174.6	168.0	161.5	154.9	148.3
Austria	133.3	121.6	110.0	98.3	86.7	75.0	63.3	62.4	61.4	60.4	59.5	58.5	57.6	56.6	55.6	54.7
Belgium	258.4	259.4	260.3	261.3	262.2	263.2	264.1	258.3	252.5	246.7	240.9	235.1	229.3	223.6	217.8	212.0
Bulgaria	509.1	490.6	472.0	453.5	434.9	416.3	397.8	382.4	367.0	351.6	336.2	320.8	305.4	290.0	274.6	259.1
Cyprus	599.2	560.2	521.1	482.0	443.0	403.9	364.9	355.3	345.8	336.3	326.7	317.2	307.6	298.1	288.6	279.0
Czech Republic	653.6	614.2	574.9	535.6	496.3	456.9	417.6	403.0	388.5	373.9	359.4	344.8	330.2	315.7	301.1	286.6
Germany	496.8	458.7	420.6	382.6	344.5	306.5	268.4	256.6	244.8	233.0	221.2	209.4	197.6	185.8	174.0	162.2
Denmark	226.6	197.4	168.3	139.1	110.0	80.8	51.7	50.4	49.2	47.9	46.6	45.4	44.1	42.9	41.6	40.3
Estonia	853.0	821.0	789.0	756.9	724.9	692.9	660.9	638.4	616.0	593.6	571.1	548.7	526.3	503.8	481.4	459.0
Spain	188.2	169.0	149.9	130.7	111.6	92.4	73.3	71.4	69.5	67.6	65.8	63.9	62.0	60.1	58.2	56.4
Finland	120.4	114.3	108.2	102.1	96.0	90.0	83.9	82.9	81.9	81.0	80.0	79.1	78.1	77.1	76.2	75.2
France	66.6	60.9	55.2	49.5	43.8	38.1	32.4	32.2	32.1	31.9	31.7	31.5	31.3	31.1	30.9	30.7
Greece	400.5	369.9	339.3	308.7	278.1	247.5	216.9	211.1	205.4	199.6	193.8	188.0	182.2	176.5	170.7	164.9
Croatia	220.6	199.3	178.0	156.7	135.4	114.1	92.8	92.4	92.0	91.6	91.2	90.8	90.4	90.0	89.6	89.2
Hungary	255.1	227.7	200.2	172.8	145.4	117.9	90.5	89.4	88.3	87.2	86.1	85.0	83.9	82.9	81.8	80.7
Ireland	286.8	269.2	251.6	234.0	216.5	198.9	181.3	177.0	172.7	168.4	164.2	159.9	155.6	151.3	147.0	142.8
Italy	342.6	321.8	301.1	280.3	259.6	238.8	218.1	212.6	207.0	201.5	196.0	190.5	184.9	179.4	173.9	168.4
Lithuania	248.9	232.1	215.3	198.5	181.7	164.9	148.1	144.2	140.2	136.3	132.3	128.4	124.4	120.5	116.5	112.6
Luxembourg	210.7	198.7	186.7	174.7	162.7	150.7	138.7	135.7	132.8	129.8	126.8	123.8	120.8	117.8	114.8	111.8
Latvia	267.4	261.6	255.9	250.1	244.3	238.5	232.7	226.4	220.1	213.8	207.5	201.2	194.9	188.5	182.2	175.9
Malta	476.4	466.0	455.6	445.3	434.9	424.5	414.1	411.2	408.3	405.3	402.4	399.4	396.5	393.5	390.6	387.7
Netherlands	363.8	332.9	302.0	271.1	240.2	209.3	178.4	174.6	170.8	167.0	163.2	159.4	155.6	151.8	148.0	144.3
Poland	959.9	921.9	883.9	845.9	807.9	769.9	731.9	704.9	677.9	650.9	623.9	596.8	569.8	542.8	515.8	488.8
Portugal	215.2	190.1	164.9	139.8	114.6	89.5	64.4	63.0	61.7	60.4	59.1	57.7	56.4	55.1	53.8	52.4
Romania	326.4	304.3	282.2	260.1	238.0	215.9	193.8	188.5	183.1	177.8	172.5	167.1	161.8	156.4	151.1	145.7
Sweden	41.8	40.5	39.1	37.8	36.5	35.2	33.9	33.3	32.7	32.1	31.5	30.9	30.3	29.7	29.1	28.5
Slovenia	419.3	414.3	409.3	404.4	399.4	394.4	389.4	376.7	363.9	351.2	338.4	325.6	312.9	300.1	287.4	274.6
Slovakia	193.4	174.2	155.0	135.9	116.7	97.5	78.4	77.0	75.7	74.4	73.0	71.7	70.3	69.0	67.6	66.3
Switzerland	54.1	54.7	55.4	56.1	56.8	57.5	58.2	57.2	56.2	55.2	54.2	53.2	52.2	51.2	50.2	49.2
Norway	11.8	12.1	12.3	12.5	12.8	13.0	13.2	13.1	13.1	13.0	12.9	12.8	12.7	12.6	12.5	12.4
United Kingdom	231.7	214.6	197.5	180.4	163.3	146.2	129.1	126.5	123.9	121.2	118.6	116.0	113.4	110.7	108.1	105.5

<sup>7</sup> For DE in 2023 the GHG emission are based on an official document of the Environmental Agency (Bundesanzeiger 2023).

Supply to charging station	g CO <sub>2</sub> -eq./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Electricity																
Ren. electr.	29.6	29.4	29.1	28.9	28.6	28.4	28.2	27.9	27.7	27.5	27.3	27.0	26.8	26.6	26.4	26.1
Hydro	6.3	6.3	6.3	6.2	6.2	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.0	6.0	6.0	6.0
Wind	22.5	22.4	22.3	22.2	22.0	21.9	21.8	21.6	21.5	21.3	21.1	21.0	20.8	20.6	20.4	20.3
PV	67.1	66.4	65.7	65.0	64.3	63.6	62.8	62.3	61.8	61.2	60.7	60.1	59.6	59.1	58.5	58.0
Nuclear energy	18.6	18.4	18.2	18.0	17.8	17.6	17.4	17.3	17.2	17.1	17.0	16.9	16.8	16.7	16.6	16.5
Natural gas	633.4	628.4	623.3	618.2	613.1	608.1	603.0	599.1	595.1	591.2	587.2	583.3	579.3	575.4	571.4	567.5

Supply to charging station	kWh fossil/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	1.69	1.62	1.55	1.48	1.42	1.35	1.28	1.26	1.23	1.20	1.18	1.15	1.12	1.10	1.07	1.04
Austria	0.57	0.53	0.49	0.45	0.41	0.37	0.33	0.33	0.32	0.32	0.32	0.31	0.31	0.30	0.30	0.30
Belgium	1.77	1.67	1.58	1.48	1.38	1.28	1.18	1.16	1.13	1.11	1.09	1.07	1.04	1.02	1.00	0.98
Bulgaria	2.68	2.63	2.58	2.53	2.48	2.43	2.37	2.32	2.26	2.21	2.15	2.10	2.04	1.99	1.93	1.88
Cyprus	2.16	2.04	1.92	1.80	1.68	1.56	1.44	1.41	1.38	1.34	1.31	1.28	1.24	1.21	1.18	1.15
Czech Republic	3.15	3.07	2.99	2.91	2.83	2.75	2.67	2.63	2.59	2.55	2.51	2.46	2.42	2.38	2.34	2.30
Germany	1.23	1.16	1.09	1.02	0.95	0.88	0.81	0.77	0.74	0.70	0.66	0.63	0.59	0.55	0.52	0.48
Denmark	0.95	0.84	0.73	0.62	0.51	0.40	0.29	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.26
Estonia	2.52	2.41	2.31	2.21	2.11	2.01	1.90	1.85	1.79	1.74	1.68	1.63	1.57	1.51	1.46	1.40
Spain	1.43	1.32	1.22	1.11	1.00	0.90	0.79	0.78	0.76	0.74	0.73	0.71	0.69	0.68	0.66	0.65
Finland	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.56	1.54	1.53	1.51	1.50	1.49	1.47	1.46	1.44
France	2.34	2.27	2.20	2.13	2.06	1.99	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65
Greece	1.49	1.40	1.31	1.22	1.13	1.04	0.95	0.94	0.92	0.90	0.88	0.86	0.84	0.82	0.80	0.78
Croatia	1.05	0.98	0.92	0.86	0.79	0.73	0.66	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.60	0.59
Hungary	2.50	2.48	2.46	2.44	2.41	2.39	2.37	2.33	2.30	2.26	2.22	2.19	2.15	2.12	2.08	2.04
Ireland	1.20	1.13	1.06	0.98	0.91	0.84	0.77	0.75	0.74	0.72	0.70	0.68	0.67	0.65	0.63	0.62
Italy	1.56	1.49	1.41	1.34	1.27	1.19	1.12	1.09	1.07	1.04	1.01	0.99	0.96	0.93	0.91	0.88
Lithuania	1.27	1.18	1.09	1.01	0.92	0.83	0.75	0.74	0.74	0.74	0.73	0.73	0.73	0.73	0.72	0.72
Luxembourg	1.22	1.16	1.11	1.05	1.00	0.94	0.89	0.87	0.86	0.85	0.84	0.82	0.81	0.80	0.79	0.77
Latvia	1.10	1.07	1.04	1.02	0.99	0.96	0.93	0.91	0.89	0.86	0.84	0.82	0.79	0.77	0.75	0.72
Malta	1.90	1.86	1.82	1.78	1.74	1.70	1.66	1.65	1.64	1.63	1.62	1.61	1.60	1.58	1.57	1.56
Netherlands	1.55	1.43	1.31	1.19	1.07	0.95	0.83	0.81	0.80	0.78	0.77	0.75	0.73	0.72	0.70	0.69
Poland	2.55	2.45	2.36	2.27	2.18	2.09	2.00	1.96	1.91	1.87	1.83	1.78	1.74	1.69	1.65	1.61

Supply to charging station	kWh fossil/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Portugal	0.98	0.89	0.80	0.71	0.62	0.53	0.44	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.37
Romania	1.89	1.86	1.83	1.81	1.78	1.75	1.72	1.69	1.66	1.63	1.60	1.57	1.54	1.51	1.48	1.45
Sweden	1.24	1.22	1.20	1.17	1.15	1.13	1.11	1.10	1.09	1.08	1.07	1.07	1.06	1.05	1.04	1.03
Slovenia	2.27	2.25	2.23	2.21	2.19	2.18	2.16	2.11	2.06	2.01	1.96	1.91	1.86	1.81	1.76	1.72
Slovakia	2.54	2.52	2.50	2.48	2.46	2.44	2.42	2.39	2.37	2.34	2.31	2.29	2.26	2.24	2.21	2.18
Switzerland	1.20	1.18	1.17	1.15	1.13	1.11	1.09	1.08	1.07	1.07	1.06	1.05	1.04	1.03	1.02	1.02
Norway	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
United Kingdom	1.35	1.27	1.20	1.12	1.04	0.97	0.89	0.88	0.87	0.87	0.86	0.85	0.84	0.83	0.82	0.82
Ren. electr.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Hydro	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wind	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
PV	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Nuclear energy	3.18	3.18	3.18	3.18	3.18	3.17	3.17	3.15	3.14	3.12	3.10	3.08	3.07	3.05	3.03	3.01
Natural gas	2.51	2.49	2.47	2.45	2.43	2.41	2.39	2.37	2.36	2.34	2.33	2.31	2.29	2.28	2.26	2.24

Table 24 Background data for the supply of electricity to the charging station Part II [JOANNEUM RESEARCH 2024] based on [Ricardo 2023], [IEA 2023] and own calculations based on electricity mix defined in foreground data<sup>8</sup>

Supply to charging station Electricity	kWh renew./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	0.67	0.68	0.70	0.72	0.74	0.76	0.78	0.78	0.79	0.79	0.79	0.80	0.80	0.80	0.81	0.81
Austria	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.14	1.14	1.13	1.13	1.12	1.11	1.11	1.10	1.10
Belgium	0.55	0.57	0.59	0.61	0.63	0.65	0.66	0.67	0.68	0.68	0.69	0.70	0.70	0.71	0.71	0.72
Bulgaria	0.35	0.36	0.37	0.39	0.40	0.41	0.42	0.43	0.45	0.46	0.48	0.49	0.51	0.52	0.54	0.55
Cyprus	0.24	0.27	0.29	0.31	0.33	0.35	0.38	0.39	0.41	0.42	0.43	0.45	0.46	0.48	0.49	0.51
Czech Republic	0.34	0.35	0.36	0.38	0.39	0.40	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.43	0.43
Germany	0.90	0.91	0.92	0.92	0.93	0.94	0.95	0.96	0.97	0.99	1.00	1.01	1.02	1.03	1.05	1.06
Denmark	1.20	1.23	1.25	1.27	1.30	1.32	1.34	1.34	1.33	1.32	1.32	1.31	1.30	1.30	1.29	1.28
Estonia	1.18	1.17	1.16	1.15	1.14	1.13	1.12	1.11	1.11	1.11	1.10	1.10	1.09	1.09	1.08	1.08
Spain	0.70	0.75	0.79	0.84	0.88	0.92	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98
Finland	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
France	0.40	0.42	0.45	0.47	0.50	0.52	0.55	0.55	0.56	0.56	0.56	0.57	0.57	0.58	0.58	0.58
Greece	0.55	0.58	0.61	0.64	0.68	0.71	0.74	0.74	0.75	0.76	0.76	0.77	0.78	0.78	0.79	0.80
Croatia	0.90	0.93	0.96	1.00	1.03	1.06	1.10	1.09	1.08	1.08	1.07	1.06	1.05	1.05	1.04	1.03
Hungary	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.50	0.51	0.51	0.51	0.51	0.52	0.52	0.52	0.53
Ireland	0.68	0.70	0.73	0.75	0.78	0.81	0.83	0.83	0.84	0.84	0.84	0.85	0.85	0.85	0.85	0.86
Italy	0.69	0.73	0.76	0.79	0.83	0.86	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.92	0.92	0.92
Lithuania	0.93	0.98	1.02	1.06	1.10	1.14	1.19	1.18	1.17	1.17	1.16	1.15	1.15	1.14	1.13	1.13
Luxembourg	0.88	0.89	0.91	0.92	0.93	0.94	0.96	0.95	0.95	0.94	0.94	0.94	0.93	0.93	0.92	0.92
Latvia	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.07	1.07	1.07	1.07	1.06	1.06	1.06	1.06	1.06
Malta	0.22	0.23	0.24	0.26	0.27	0.28	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31	0.32	0.32
Netherlands	0.57	0.60	0.64	0.68	0.71	0.75	0.79	0.79	0.79	0.80	0.80	0.81	0.81	0.81	0.82	0.82
Poland	0.38	0.40	0.42	0.45	0.47	0.49	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60
Portugal	0.91	0.95	0.98	1.02	1.06	1.10	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12
Romania	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.62	0.63	0.64	0.65	0.65	0.66	0.67	0.68	0.68
Sweden	0.93	0.93	0.94	0.95	0.96	0.97	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.95	0.94	0.94
Slovenia	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54
Slovakia	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.39	0.39	0.39	0.40	0.40	0.41	0.41	0.41	0.42
Switzerland	0.90	0.94	0.99	1.03	1.07	1.11	1.15	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07	1.06
Norway	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
United Kingdom	0.82	0.85	0.89	0.92	0.95	0.99	1.02	1.02	1.01	1.01	1.01	1.00	1.00	0.99	0.99	0.99

<sup>8</sup> For DE in 2023 the GHG emission are based on an official document of the Environmental Agency (Bundesanzeiger 2023).

Supply to charging station	kWh renew./kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Electricity																
Ren. electr.	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Hydro	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Wind	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
PV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nuclear energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural gas	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05

Supply to charging station	kWh total/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Electricity																
Europe 27	2.37	2.32	2.27	2.23	2.18	2.13	2.08	2.06	2.03	2.01	1.99	1.96	1.94	1.91	1.89	1.87
Austria	1.60	1.58	1.56	1.54	1.52	1.50	1.48	1.48	1.47	1.46	1.45	1.44	1.43	1.42	1.41	1.40
Belgium	2.35	2.26	2.18	2.10	2.02	1.94	1.86	1.84	1.82	1.81	1.79	1.77	1.76	1.74	1.72	1.71
Bulgaria	3.07	3.03	2.99	2.95	2.91	2.86	2.82	2.78	2.74	2.70	2.66	2.62	2.58	2.54	2.50	2.46
Cyprus	2.43	2.33	2.23	2.13	2.03	1.94	1.84	1.82	1.80	1.78	1.76	1.74	1.72	1.70	1.68	1.66
Czech Republic	3.52	3.46	3.39	3.32	3.25	3.19	3.12	3.08	3.04	3.00	2.96	2.92	2.88	2.84	2.80	2.76
Germany	2.13	2.07	2.01	1.94	1.88	1.82	1.76	1.74	1.71	1.69	1.66	1.64	1.61	1.59	1.56	1.54
Denmark	2.16	2.08	1.99	1.90	1.81	1.72	1.64	1.63	1.62	1.61	1.59	1.58	1.57	1.56	1.55	1.54
Estonia	3.72	3.61	3.50	3.39	3.27	3.16	3.05	2.99	2.93	2.86	2.80	2.74	2.68	2.62	2.56	2.50
Spain	2.15	2.08	2.02	1.96	1.90	1.83	1.77	1.75	1.74	1.72	1.71	1.69	1.68	1.66	1.65	1.63
Finland	2.54	2.53	2.52	2.51	2.50	2.48	2.47	2.46	2.45	2.43	2.42	2.40	2.39	2.38	2.36	2.35
France	2.77	2.72	2.68	2.63	2.59	2.54	2.49	2.47	2.44	2.41	2.39	2.36	2.33	2.30	2.28	2.25
Greece	2.06	2.00	1.94	1.88	1.82	1.76	1.70	1.69	1.68	1.67	1.65	1.64	1.63	1.61	1.60	1.59
Croatia	1.96	1.93	1.90	1.86	1.83	1.80	1.77	1.75	1.74	1.72	1.71	1.69	1.67	1.66	1.64	1.63
Hungary	2.97	2.96	2.95	2.94	2.92	2.91	2.90	2.86	2.83	2.80	2.76	2.73	2.70	2.66	2.63	2.60
Ireland	1.89	1.84	1.80	1.75	1.70	1.66	1.61	1.60	1.58	1.57	1.55	1.54	1.52	1.51	1.50	1.48
Italy	2.27	2.23	2.19	2.15	2.11	2.07	2.03	2.00	1.98	1.96	1.93	1.91	1.89	1.86	1.84	1.81
Lithuania	2.22	2.17	2.13	2.08	2.03	1.99	1.94	1.93	1.92	1.91	1.90	1.89	1.88	1.87	1.86	1.86
Luxembourg	2.11	2.07	2.03	1.98	1.94	1.90	1.85	1.84	1.82	1.80	1.79	1.77	1.75	1.74	1.72	1.70
Latvia	2.12	2.10	2.08	2.07	2.05	2.03	2.01	1.99	1.97	1.94	1.92	1.89	1.87	1.84	1.82	1.80
Malta	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.96	1.96	1.95	1.94	1.93	1.93	1.92	1.91	1.90
Netherlands	2.14	2.05	1.97	1.88	1.80	1.71	1.63	1.61	1.60	1.59	1.58	1.56	1.55	1.54	1.53	1.51
Poland	2.96	2.89	2.82	2.75	2.68	2.61	2.54	2.50	2.47	2.43	2.40	2.36	2.33	2.29	2.26	2.22

Supply to charging station	kWh total/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Portugal	1.90	1.85	1.80	1.74	1.69	1.64	1.58	1.57	1.56	1.55	1.55	1.54	1.53	1.52	1.51	1.50
Romania	2.47	2.45	2.43	2.42	2.40	2.38	2.36	2.33	2.31	2.29	2.26	2.24	2.22	2.19	2.17	2.15
Sweden	2.18	2.17	2.15	2.14	2.13	2.11	2.10	2.09	2.08	2.06	2.05	2.04	2.02	2.01	2.00	1.99
Slovenia	2.71	2.70	2.68	2.67	2.66	2.65	2.63	2.59	2.55	2.52	2.48	2.44	2.40	2.36	2.32	2.28
Slovakia	2.95	2.93	2.91	2.89	2.87	2.85	2.83	2.81	2.79	2.76	2.74	2.72	2.70	2.67	2.65	2.63
Switzerland	2.11	2.13	2.15	2.17	2.19	2.22	2.24	2.22	2.20	2.18	2.17	2.15	2.13	2.11	2.10	2.08
Norway	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
United Kingdom	2.19	2.14	2.10	2.05	2.01	1.97	1.92	1.91	1.90	1.89	1.87	1.86	1.85	1.84	1.82	1.81
Ren. electr.	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
Hydro	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Wind	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
PV	1.12	1.12	1.12	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
Nuclear energy	3.19	3.18	3.18	3.18	3.18	3.18	3.17	3.16	3.14	3.12	3.10	3.09	3.07	3.05	3.03	3.01
Natural gas	2.51	2.49	2.47	2.45	2.43	2.41	2.39	2.38	2.36	2.34	2.33	2.31	2.29	2.28	2.26	2.24

Table 25 Background data for the supply of electricity to the charging station Part III - air pollutants

[JOANNEUM RESEARCH 2024] based on [Ricardo 2023], [IEA 2023] and own calculations based on electricity mix defined in foreground data

Supply to charging station Electricity	NO <sub>x</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	418	400	381	362	343	325	306	297	288	280	271	262	253	245	236	227
Austria	230	223	217	210	204	197	190	192	194	196	198	201	203	205	207	209
Belgium	301	294	288	281	275	268	261	260	260	259	258	257	257	256	255	254
Bulgaria	654	627	599	572	544	516	489	464	439	414	388	363	338	313	288	263
Cyprus	576	517	458	398	339	280	221	214	208	201	194	188	181	174	168	161
Czech Republic	826	787	748	709	670	631	592	561	530	498	467	436	404	373	342	311
Germany	641	615	588	562	536	510	484	456	428	400	372	344	316	288	260	232
Denmark	532	500	468	436	404	371	339	340	340	340	341	341	341	342	342	342
Estonia	1,332	1,277	1,222	1,167	1,112	1,058	1,003	942	881	820	759	698	637	576	515	454
Spain	205	192	179	166	153	140	127	132	137	142	146	151	156	161	166	171
Finland	415	408	400	393	386	379	371	378	384	391	398	404	411	417	424	430
France	123	120	116	113	109	105	102	103	105	106	108	109	110	112	113	115
Greece	363	329	295	261	227	193	159	157	154	152	150	147	145	143	141	138
Croatia	316	295	275	255	235	214	194	194	195	195	195	195	196	196	196	197
Hungary	386	361	336	311	286	261	236	237	237	238	239	239	240	240	241	241
Ireland	252	236	219	203	187	171	155	154	154	153	153	152	152	151	150	150
Italy	375	363	352	341	329	318	307	305	304	303	302	301	300	299	298	296
Lithuania	441	437	433	428	424	420	415	411	407	403	399	395	391	387	383	379
Luxembourg	382	365	348	331	315	298	281	275	269	264	258	252	246	240	235	229
Latvia	459	454	448	442	437	431	426	416	406	397	387	378	368	359	349	340
Malta	285	279	274	268	262	256	250	253	256	259	263	266	269	272	275	279
Netherlands	332	302	272	242	212	183	153	158	163	168	174	179	184	189	194	199
Poland	1,169	1,124	1,079	1,034	989	944	899	845	791	737	683	629	575	521	467	413
Portugal	293	274	256	238	219	201	182	187	192	196	201	206	210	215	220	224
Romania	369	347	324	302	280	257	235	233	230	227	225	222	220	217	214	212
Sweden	216	219	222	226	229	232	235	236	238	239	240	242	243	244	246	247
Slovenia	500	486	472	458	444	430	416	400	383	367	351	335	318	302	286	270
Slovakia	280	262	244	227	209	191	173	178	183	188	193	198	203	208	213	218
Switzerland	40	40	40	40	40	40	40	39	39	39	38	38	38	38	37	37
Norway	22	21	21	21	21	21	21	21	21	20	20	20	20	20	20	20
United Kingdom	408	406	404	402	400	399	397	385	373	362	350	338	326	314	303	291

Supply to charging station	NO <sub>x</sub> [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Ren. electr. <sup>9</sup>	78	77	77	76	75	75	74	73	73	72	71	71	70	69	69	68
Hydro	20	20	20	19	19	19	19	19	19	19	19	19	18	18	18	18
Wind	47	47	46	46	45	45	44	44	43	43	42	42	41	41	40	40
PV	198	196	195	193	192	190	189	187	185	184	182	181	179	177	176	174
Nuclear energy	66	66	66	66	66	66	66	65	65	64	64	63	63	62	62	61
Natural gas	344	345	345	345	345	345	345	344	342	341	339	338	336	335	333	332

Supply to charging station	NH <sub>3</sub> [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Europe 27	2.98	2.85	2.73	2.60	2.47	2.35	2.22	2.11	2.00	1.89	1.78	1.67	1.56	1.45	1.35	1.24
Austria	1.09	1.09	1.10	1.11	1.11	1.12	1.13	1.12	1.11	1.10	1.10	1.09	1.08	1.07	1.06	1.06
Belgium	1.41	1.37	1.33	1.29	1.25	1.22	1.18	1.16	1.14	1.12	1.10	1.09	1.07	1.05	1.03	1.01
Bulgaria	6.39	6.10	5.80	5.50	5.20	4.91	4.61	4.29	3.98	3.66	3.34	3.03	2.71	2.39	2.08	1.76
Cyprus	0.48	0.49	0.50	0.51	0.53	0.54	0.55	0.57	0.60	0.62	0.64	0.67	0.69	0.71	0.73	0.76
Czech Republic	7.48	7.18	6.87	6.57	6.27	5.97	5.66	5.25	4.84	4.42	4.01	3.59	3.18	2.76	2.35	1.93
Germany	4.58	4.40	4.23	4.06	3.88	3.71	3.53	3.30	3.07	2.84	2.62	2.39	2.16	1.93	1.70	1.47
Denmark	3.04	2.76	2.47	2.19	1.90	1.61	1.33	1.30	1.28	1.25	1.22	1.20	1.17	1.15	1.12	1.09
Estonia	8.02	7.81	7.60	7.39	7.18	6.97	6.76	6.31	5.87	5.42	4.97	4.53	4.08	3.63	3.19	2.74
Spain	1.79	1.81	1.83	1.85	1.87	1.89	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.68	1.65
Finland	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.18	1.17	1.15	1.14	1.12	1.10	1.09	1.07	1.05
France	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Greece	2.64	2.40	2.16	1.92	1.67	1.43	1.19	1.21	1.22	1.23	1.25	1.26	1.27	1.29	1.30	1.32
Croatia	2.10	1.97	1.85	1.73	1.60	1.48	1.35	1.36	1.36	1.36	1.36	1.37	1.37	1.37	1.37	1.38
Hungary	2.42	2.23	2.04	1.85	1.66	1.47	1.28	1.27	1.25	1.24	1.22	1.20	1.19	1.17	1.16	1.14
Ireland	1.17	1.14	1.12	1.09	1.06	1.04	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00
Italy	1.70	1.63	1.57	1.50	1.43	1.36	1.29	1.28	1.26	1.24	1.23	1.21	1.19	1.18	1.16	1.14
Lithuania	2.01	1.94	1.87	1.80	1.73	1.66	1.59	1.55	1.52	1.48	1.44	1.41	1.37	1.34	1.30	1.26
Luxembourg	2.20	2.15	2.10	2.05	2.00	1.94	1.89	1.82	1.75	1.67	1.60	1.53	1.46	1.38	1.31	1.24
Latvia	0.97	0.94	0.92	0.90	0.88	0.86	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.88	0.88	0.89
Malta	0.72	0.71	0.71	0.71	0.70	0.70	0.69	0.69	0.69	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Netherlands	1.72	1.64	1.57	1.50	1.42	1.35	1.27	1.27	1.26	1.26	1.25	1.24	1.24	1.23	1.23	1.22
Poland	11.47	11.01	10.56	10.10	9.64	9.19	8.73	8.12	7.50	6.89	6.28	5.66	5.05	4.44	3.82	3.21
Portugal	1.72	1.67	1.61	1.55	1.50	1.44	1.38	1.38	1.37	1.36	1.35	1.35	1.34	1.33	1.32	1.32

<sup>9</sup> 25% hydro, 50% wind, 25% PV

Supply to charging station	NH <sub>3</sub> [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Romania	3.84	3.60	3.36	3.12	2.89	2.65	2.41	2.34	2.28	2.21	2.15	2.08	2.02	1.95	1.89	1.82
Sweden	1.32	1.30	1.29	1.27	1.25	1.23	1.21	1.22	1.22	1.22	1.22	1.23	1.23	1.23	1.23	1.24
Slovenia	4.91	4.70	4.48	4.26	4.05	3.83	3.62	3.41	3.19	2.98	2.76	2.55	2.34	2.12	1.91	1.70
Slovakia	1.63	1.52	1.42	1.31	1.21	1.10	0.99	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.04
Switzerland	0.88	0.87	0.87	0.86	0.86	0.86	0.85	0.85	0.84	0.83	0.83	0.82	0.81	0.81	0.80	0.79
Norway	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.33	0.33
United Kingdom	1.32	1.34	1.35	1.37	1.39	1.40	1.42	1.42	1.42	1.41	1.41	1.41	1.41	1.41	1.40	1.40
Ren. electr. <sup>8</sup>	4.03	4.00	3.97	3.93	3.90	3.86	3.83	3.79	3.76	3.73	3.69	3.66	3.62	3.59	3.55	3.52
Hydro	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23
Wind	1.95	1.92	1.90	1.88	1.86	1.84	1.82	1.80	1.78	1.76	1.74	1.72	1.70	1.68	1.66	1.64
PV	12.00	11.90	11.81	11.71	11.62	11.52	11.43	11.33	11.24	11.14	11.04	10.95	10.85	10.75	10.66	10.56
Nuclear energy	1.10	1.10	1.09	1.09	1.09	1.09	1.09	1.08	1.07	1.07	1.06	1.05	1.04	1.03	1.02	1.02
Natural gas	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44	0.44	0.43

Supply to charging station	NMVOC [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Europe 27	41	40	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Austria	30	29	27	26	24	22	21	21	20	20	20	19	19	19	18	18
Belgium	51	52	52	52	53	53	53	52	50	49	47	46	44	43	41	39
Bulgaria	42	42	42	43	43	43	43	42	41	40	39	38	37	36	35	34
Cyprus	110	104	98	91	85	79	72	69	66	63	59	56	53	50	47	44
Czech Republic	59	55	52	48	45	42	38	38	37	36	36	35	34	34	33	32
Germany	50	49	48	47	46	45	44	42	40	38	36	35	33	31	29	27
Denmark	31	29	27	25	23	21	19	19	19	19	19	19	19	19	19	19
Estonia	91	87	83	80	76	73	69	66	64	61	58	55	53	50	47	44
Spain	43	40	37	35	32	29	26	26	25	25	24	24	23	23	22	21
Finland	28	28	28	28	28	28	28	28	27	27	27	27	27	26	26	26
France	23	22	21	20	19	18	18	18	17	17	17	17	17	17	17	17
Greece	64	61	58	56	53	51	48	46	44	43	41	39	37	35	33	31
Croatia	39	37	35	33	31	29	28	27	27	27	26	26	26	26	25	25
Hungary	42	39	37	34	32	29	27	27	27	27	27	27	27	27	27	27
Ireland	57	54	51	49	46	43	41	39	38	37	35	34	32	31	30	28
Italy	63	61	58	55	52	50	47	46	44	43	41	40	39	37	36	34

Supply to charging station	NMVOC [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Lithuania	46	45	43	41	39	37	36	35	34	32	31	30	29	28	27	26
Luxembourg	34	33	32	31	29	28	27	27	26	26	26	26	26	25	25	25
Latvia	54	53	53	52	52	51	50	48	46	44	42	40	38	36	34	32
Malta	92	90	88	86	84	82	81	80	80	80	80	80	80	80	80	79
Netherlands	67	63	59	54	50	45	41	40	39	38	37	36	35	34	33	32
Poland	66	64	63	61	59	58	56	54	52	49	47	45	43	40	38	36
Portugal	42	38	35	31	27	24	20	20	20	20	19	19	19	19	18	18
Romania	43	42	41	40	39	38	36	36	36	35	35	35	34	34	33	33
Sweden	18	18	19	19	19	19	19	19	19	20	20	20	20	21	21	21
Slovenia	39	41	43	44	46	48	49	47	45	44	42	40	38	36	34	32
Slovakia	38	36	34	32	30	28	26	26	26	26	26	26	25	25	25	25
Switzerland	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10
Norway	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
United Kingdom	49	47	44	42	39	37	34	33	31	30	28	27	25	23	22	20
Ren. electr. <sup>8</sup>	18	18	18	18	18	17	17	17	17	17	17	16	16	16	16	16
Hydro	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6
Wind	16	16	16	15	15	15	15	15	15	14	14	14	14	14	14	13
PV	35	34	34	34	33	33	33	33	32	32	32	32	31	31	31	30
Nuclear energy	17	17	17	16	16	16	16	16	16	16	16	16	16	16	15	15
Natural gas	126	126	126	126	126	126	126	126	125	125	124	124	123	122	122	121

Supply to charging station	CO [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Europe 27	175	169	163	158	152	146	140	136	131	127	122	118	113	109	105	100
Austria	102	101	99	97	95	93	91	90	90	89	88	88	87	87	86	85
Belgium	146	144	142	140	138	136	134	132	129	126	124	121	118	115	113	110
Bulgaria	276	267	258	250	241	232	224	214	204	195	185	176	166	157	147	138
Cyprus	162	157	151	146	140	135	130	126	122	118	114	110	106	102	98	94
Czech Republic	334	321	308	295	282	268	255	243	230	217	204	191	179	166	153	140
Germany	237	230	222	215	207	200	192	183	174	164	155	146	137	127	118	109
Denmark	171	160	149	137	126	115	104	103	102	102	101	101	100	99	99	98
Estonia	415	402	389	376	364	351	338	320	302	285	267	249	231	213	196	178
Spain	147	144	141	138	135	132	129	127	125	123	121	119	117	115	113	111

Supply to charging station	CO [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Finland	124	125	125	126	127	128	129	128	128	127	126	126	125	124	124	123
France	109	108	106	105	104	102	101	100	100	99	99	99	98	98	98	97
Greece	186	175	165	155	144	134	124	122	120	118	116	114	112	110	108	106
Croatia	148	143	137	131	125	119	114	113	111	110	109	108	107	106	105	104
Hungary	169	160	151	143	134	126	117	116	115	115	114	113	112	112	111	110
Ireland	140	135	130	126	121	117	112	110	108	106	103	101	99	97	95	92
Italy	167	161	156	150	144	138	133	130	128	126	123	121	118	116	113	111
Lithuania	163	159	155	151	147	143	139	136	134	131	128	125	123	120	117	115
Luxembourg	143	139	135	130	126	122	117	115	113	110	108	106	103	101	99	97
Latvia	144	143	141	140	138	137	136	132	129	126	123	120	117	114	111	108
Malta	166	162	159	156	153	149	146	147	147	148	148	149	150	150	151	151
Netherlands	171	162	153	144	135	126	118	116	115	114	112	111	110	108	107	106
Poland	444	429	413	398	383	368	353	334	314	295	275	256	236	217	197	178
Portugal	139	132	125	118	111	104	97	97	97	97	98	98	98	98	98	98
Romania	205	197	189	181	173	165	157	155	153	151	149	147	145	143	141	139
Sweden	109	109	109	109	109	108	108	109	109	110	110	110	111	111	112	112
Slovenia	223	219	216	212	208	204	200	192	183	174	165	156	148	139	130	121
Slovakia	141	135	130	124	119	113	108	108	108	108	108	109	109	109	109	109
Switzerland	62	62	62	61	61	61	61	60	60	60	59	59	58	58	57	57
Norway	38	37	37	37	37	36	36	36	36	35	35	35	35	34	34	34
United Kingdom	147	144	141	139	136	133	130	128	125	123	121	118	116	113	111	109
Ren. electr. <sup>8</sup>	101	101	100	99	98	97	96	95	94	93	93	92	91	90	89	88
Hydro	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11
Wind	70	70	69	68	68	67	66	65	65	64	63	62	62	61	60	60
PV	252	250	248	246	244	242	240	238	236	234	232	230	228	226	224	222
Nuclear energy	60	60	59	59	59	59	59	59	58	58	57	57	57	56	56	55
Natural gas	224	224	224	224	224	224	224	223	222	221	220	219	218	217	216	215

Supply to charging station	SO <sub>x</sub> [mg/kWh]															
	Electricity	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Europe 27	295	280	264	248	232	216	200	188	177	165	153	142	130	118	106	95
Austria	111	104	98	91	85	78	72	71	70	68	67	66	65	64	62	61
Belgium	166	162	158	154	151	147	143	138	134	129	125	120	116	111	107	102
Bulgaria	600	573	545	517	490	462	434	401	367	333	299	265	231	198	164	130
Cyprus	978	839	699	560	421	281	142	138	134	129	125	121	117	113	109	105
Czech Republic	728	692	657	622	586	551	515	477	439	400	362	323	285	246	208	169
Germany	446	427	408	389	369	350	331	306	281	257	232	207	183	158	133	109
Denmark	261	229	198	166	135	103	71	70	69	68	67	66	65	64	63	62
Estonia	826	800	774	748	722	695	669	622	576	529	482	435	389	342	295	248
Spain	183	169	154	140	126	111	97	96	94	92	91	89	88	86	85	83
Finland	75	76	76	77	78	78	79	78	77	76	75	74	73	72	71	70
France	93	89	85	81	77	73	69	69	68	68	68	67	67	67	66	66
Greece	366	327	287	248	209	170	131	128	124	120	116	112	108	105	101	97
Croatia	192	174	157	139	121	103	85	86	87	88	89	90	92	93	94	95
Hungary	238	214	191	167	143	119	95	94	92	91	89	88	86	85	83	82
Ireland	159	148	138	127	117	107	96	94	91	89	86	84	81	79	76	74
Italy	237	221	206	190	175	159	144	139	134	129	123	118	113	108	103	98
Lithuania	211	196	181	166	150	135	120	116	111	107	103	99	94	90	86	81
Luxembourg	207	198	188	179	170	160	151	144	138	131	124	117	111	104	97	90
Latvia	140	135	131	127	122	118	114	110	106	102	98	94	90	86	82	78
Malta	190	186	183	179	175	172	168	167	166	165	164	163	162	160	159	158
Netherlands	211	194	178	161	144	128	111	110	108	107	105	104	102	101	100	98
Poland	1,129	1,080	1,032	983	935	886	838	776	714	652	590	528	466	405	343	281
Portugal	184	169	154	139	124	109	94	91	89	86	84	81	79	76	74	72
Romania	341	317	292	267	242	217	192	183	175	167	158	150	142	133	125	117
Sweden	71	69	67	65	63	61	58	59	59	60	61	61	62	62	63	63
Slovenia	473	455	437	419	401	383	366	342	319	295	272	248	225	201	178	155
Slovakia	178	161	144	127	109	92	75	75	74	74	74	74	73	73	73	72
Switzerland	36	35	35	35	35	35	35	35	34	34	34	34	33	33	33	33
Norway	17	17	16	16	16	16	16	16	16	16	16	15	15	15	15	15
United Kingdom	153	150	146	142	139	135	132	127	123	119	115	110	106	102	98	93
Ren. electr. <sup>8</sup>	131	130	129	128	127	125	124	123	122	121	120	118	117	116	115	114
Hydro	32	32	32	31	31	31	31	31	31	30	30	30	30	30	29	29
Wind	115	114	113	111	110	109	108	107	105	104	103	102	101	100	98	97
PV	263	261	259	257	255	252	250	248	246	244	242	240	238	236	233	231
Nuclear energy	102	102	102	102	102	102	102	101	100	100	99	98	97	96	96	95
Natural gas	213	213	213	213	214	214	214	213	212	211	210	209	208	207	206	205

Supply to charging station	PM <sub>10</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	559	532	506	479	452	425	398	383	368	353	338	323	308	293	278	263
Austria	284	273	263	252	241	231	220	221	222	223	224	225	226	227	228	229
Belgium	378	369	359	350	341	331	322	318	314	310	306	302	297	293	289	285
Bulgaria	956	914	872	831	789	747	706	663	621	579	536	494	452	410	367	325
Cyprus	1,095	958	821	684	547	410	273	265	256	247	238	229	221	212	203	194
Czech Republic	1,187	1,131	1,075	1,020	964	909	853	802	751	699	648	597	546	494	443	392
Germany	843	807	771	736	700	665	629	589	550	511	471	432	392	353	313	274
Denmark	637	589	541	493	445	397	349	349	349	349	349	349	349	349	349	349
Estonia	1,687	1,623	1,558	1,494	1,430	1,366	1,301	1,219	1,137	1,054	972	889	807	725	642	560
Spain	310	290	270	249	229	209	188	191	193	196	198	201	203	206	208	210
Finland	437	431	425	419	413	408	402	407	412	417	421	426	431	436	441	446
France	192	186	180	174	167	161	155	156	157	157	158	159	159	160	161	162
Greece	547	493	439	385	331	277	223	219	215	210	206	202	197	193	189	184
Croatia	414	386	357	329	300	271	243	243	242	242	241	241	241	240	240	239
Hungary	499	462	426	389	353	316	280	279	278	277	276	275	275	274	273	272
Ireland	333	312	292	271	251	230	210	207	205	202	200	197	195	192	190	187
Italy	482	462	441	421	400	380	359	355	350	346	341	337	332	328	323	319
Lithuania	530	516	502	488	474	460	446	439	432	426	419	413	406	399	393	386
Luxembourg	466	444	421	398	376	353	330	322	313	305	296	288	279	270	262	253
Latvia	506	498	491	483	475	468	460	449	438	427	416	405	393	382	371	360
Malta	363	355	346	338	330	322	313	316	319	322	325	328	330	333	336	339
Netherlands	425	388	351	314	277	240	203	207	211	215	219	223	227	231	235	239
Poland	1,722	1,652	1,583	1,514	1,445	1,375	1,306	1,222	1,138	1,054	969	885	801	717	633	548
Portugal	383	357	330	304	278	252	225	229	232	235	238	241	245	248	251	254
Romania	553	518	483	448	412	377	342	335	327	319	312	304	297	289	281	274
Sweden	263	265	266	267	269	270	271	273	274	276	277	279	280	282	283	285
Slovenia	743	719	695	671	648	624	600	570	541	511	481	451	422	392	362	332
Slovakia	378	352	326	300	274	248	222	226	230	234	238	242	246	250	254	258
Switzerland	82	82	82	82	81	81	81	80	80	79	79	78	78	77	77	76
Norway	49	48	48	48	47	47	47	47	46	46	46	46	46	45	45	45
United Kingdom	465	461	458	454	451	447	444	431	419	406	394	382	369	357	344	332
Ren. electr. <sup>8</sup>	169	167	166	164	163	162	160	159	157	156	154	153	151	150	149	147
Hydro	44	44	43	43	43	43	43	42	42	42	42	42	42	42	41	41
Wind	114	113	112	111	110	108	107	106	105	104	103	101	100	99	98	97
PV	402	399	396	393	389	386	383	380	377	373	370	367	364	360	357	354
Nuclear energy	129	129	129	129	129	129	129	128	127	126	125	124	123	122	121	120
Natural gas	452	452	452	452	453	453	453	451	449	447	445	443	441	439	437	435

Supply to charging station	PM <sub>2.5</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Europe 27	549	522	496	469	443	417	390	375	361	346	331	317	302	287	272	258
Austria	276	266	255	245	235	224	214	215	216	217	218	219	220	221	222	222
Belgium	370	361	352	343	334	325	316	312	309	305	301	297	293	289	285	281
Bulgaria	938	897	856	815	774	733	692	650	608	567	525	483	442	400	358	316
Cyprus	1,078	943	809	674	539	405	270	261	253	244	235	226	218	209	200	192
Czech Republic	1,166	1,111	1,056	1,001	946	891	836	786	736	685	635	584	534	484	433	383
Germany	830	795	760	725	690	654	619	580	541	502	464	425	386	347	308	269
Denmark	628	581	533	486	439	391	344	344	344	344	344	344	344	344	344	344
Estonia	1,666	1,602	1,538	1,475	1,411	1,347	1,284	1,202	1,121	1,039	958	877	795	714	633	551
Spain	301	281	261	240	220	200	180	183	186	188	191	193	196	199	201	204
Finland	428	422	416	410	404	399	393	398	403	408	413	418	423	427	432	437
France	182	176	170	164	158	152	146	147	148	149	150	151	151	152	153	154
Greece	537	484	430	377	324	271	217	213	209	205	200	196	192	188	183	179
Croatia	404	376	348	319	291	263	235	234	234	234	234	233	233	233	233	233
Hungary	489	452	416	380	344	308	272	271	270	270	269	268	267	267	266	265
Ireland	326	306	285	265	245	224	204	202	199	197	195	192	190	187	185	183
Italy	474	454	434	413	393	373	353	349	345	340	336	332	327	323	319	314
Lithuania	521	507	494	480	466	453	439	433	426	420	413	407	400	394	387	381
Luxembourg	458	436	414	392	370	347	325	317	308	300	291	283	274	266	258	249
Latvia	498	491	483	475	468	460	453	442	431	420	409	398	387	376	365	354
Malta	358	350	342	334	325	317	309	312	315	318	320	323	326	329	332	334
Netherlands	418	382	345	308	272	235	198	202	206	210	214	218	222	226	230	234
Poland	1,696	1,628	1,559	1,491	1,423	1,355	1,286	1,203	1,120	1,037	954	871	787	704	621	538
Portugal	375	349	323	297	271	245	219	222	225	229	232	235	238	241	245	248
Romania	539	505	470	435	401	366	332	324	317	309	302	295	287	280	272	265
Sweden	254	255	256	258	259	261	262	263	265	266	268	269	271	272	274	275
Slovenia	727	704	681	658	634	611	588	559	529	500	471	442	413	384	355	325
Slovakia	367	341	316	290	264	239	213	217	221	225	229	233	238	242	246	250
Switzerland	74	74	74	74	73	73	73	72	72	71	71	70	70	69	69	68
Norway	42	42	41	41	41	41	40	40	40	40	39	39	39	38	38	38
United Kingdom	458	454	451	447	444	440	436	424	412	399	387	375	362	350	338	325
Ren. electr. <sup>8</sup>	159	157	156	155	153	152	150	149	148	146	145	144	142	141	139	138
Hydro	37	37	37	37	36	36	36	36	36	35	35	35	35	35	34	34
Wind	106	105	104	103	102	101	100	98	97	96	95	94	93	92	91	90
PV	385	382	379	376	373	370	367	364	361	357	354	351	348	345	342	339
Nuclear energy	119	119	118	118	118	118	118	117	116	115	114	114	113	112	111	110
Natural gas	444	444	445	445	445	445	445	444	442	440	438	436	434	432	430	428

Table 26 Background data for the supply of hydrogen to the filling station

[JOANNEUM RESEARCH 2024]

<b>Supply to filling station</b>	<b>g CO<sub>2</sub>-eq./kWh</b>															
<b>Hydrogen</b>	<b>2024</b>	<b>2025</b>	<b>2026</b>	<b>2027</b>	<b>2028</b>	<b>2029</b>	<b>2030</b>	<b>2031</b>	<b>2032</b>	<b>2033</b>	<b>2034</b>	<b>2035</b>	<b>2036</b>	<b>2037</b>	<b>2038</b>	<b>2039</b>
H <sub>2</sub> natural gas	360.5	359.0	357.4	355.8	354.3	352.7	351.2	351.1	351.0	350.9	350.8	350.7	350.7	350.6	350.5	350.4
H <sub>2</sub> ee	46.8	46.4	45.9	45.5	45.1	44.6	44.2	43.8	43.4	42.9	42.5	42.1	41.7	41.3	40.8	40.4
H <sub>2</sub> hydro	10.8	10.7	10.6	10.6	10.5	10.4	10.4	10.3	10.3	10.2	10.2	10.1	10.1	10.1	10.0	10.0
H <sub>2</sub> wind	36.0	35.8	35.5	35.2	35.0	34.7	34.4	34.1	33.8	33.5	33.2	32.8	32.5	32.2	31.9	31.6
H <sub>2</sub> PV	104.3	103.2	102.1	100.9	99.8	98.7	97.5	96.5	95.5	94.6	93.6	92.6	91.6	90.6	89.6	88.6

<b>Supply to filling station</b>	<b>kWh fossil/kWh</b>															
<b>Hydrogen</b>	<b>2024</b>	<b>2025</b>	<b>2026</b>	<b>2027</b>	<b>2028</b>	<b>2029</b>	<b>2030</b>	<b>2031</b>	<b>2032</b>	<b>2033</b>	<b>2034</b>	<b>2035</b>	<b>2036</b>	<b>2037</b>	<b>2038</b>	<b>2039</b>
H <sub>2</sub> natural gas	1.74	1.73	1.71	1.70	1.69	1.67	1.66	1.65	1.65	1.65	1.64	1.64	1.63	1.63	1.62	1.62
H <sub>2</sub> ren.	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
H <sub>2</sub> hydro	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
H <sub>2</sub> wind	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
H <sub>2</sub> PV	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09

<b>Supply to filling station</b>	<b>kWh renew./kWh</b>															
<b>Hydrogen</b>	<b>2024</b>	<b>2025</b>	<b>2026</b>	<b>2027</b>	<b>2028</b>	<b>2029</b>	<b>2030</b>	<b>2031</b>	<b>2032</b>	<b>2033</b>	<b>2034</b>	<b>2035</b>	<b>2036</b>	<b>2037</b>	<b>2038</b>	<b>2039</b>
H <sub>2</sub> natural gas	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
H <sub>2</sub> ren.	1.66	1.65	1.64	1.64	1.63	1.62	1.61	1.61	1.61	1.60	1.60	1.60	1.60	1.59	1.59	1.59
H <sub>2</sub> hydro	1.66	1.65	1.64	1.64	1.63	1.62	1.61	1.61	1.61	1.60	1.60	1.60	1.60	1.59	1.59	1.59
H <sub>2</sub> wind	1.66	1.65	1.64	1.64	1.63	1.62	1.61	1.61	1.61	1.60	1.60	1.60	1.60	1.59	1.59	1.59
H <sub>2</sub> PV	1.66	1.65	1.64	1.64	1.63	1.62	1.61	1.61	1.61	1.60	1.60	1.60	1.60	1.59	1.59	1.59

Supply to filling station	kWh total/kWh															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Hydrogen																
H <sub>2</sub> natural gas	1.85	1.84	1.82	1.81	1.80	1.78	1.77	1.77	1.76	1.76	1.75	1.75	1.74	1.74	1.73	1.73
H <sub>2</sub> ren.	1.71	1.70	1.69	1.68	1.68	1.67	1.66	1.66	1.65	1.65	1.65	1.64	1.64	1.63	1.63	1.63
H <sub>2</sub> hydro	1.67	1.66	1.66	1.65	1.64	1.63	1.63	1.62	1.62	1.62	1.61	1.61	1.61	1.60	1.60	1.60
H <sub>2</sub> wind	1.70	1.69	1.68	1.67	1.66	1.66	1.65	1.65	1.64	1.64	1.64	1.63	1.63	1.62	1.62	1.62
H <sub>2</sub> PV	1.76	1.76	1.75	1.74	1.73	1.72	1.71	1.71	1.71	1.70	1.70	1.69	1.69	1.68	1.68	1.68

Table 27 Background data for the supply of hydrogen to the filling station

[JOANNEUM RESEARCH 2024] based on [Ricardo 2023]

Supply to filling station	NO <sub>x</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Hydrogen																
H <sub>2</sub> natural gas	149	147	145	142	140	137	135	132	129	127	124	121	118	115	112	110
H <sub>2</sub> ee	133	134	135	136	138	139	140	138	136	134	132	130	128	126	124	122

Supply to filling station	NH <sub>3</sub> [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Hydrogen																
H <sub>2</sub> natural gas	2.86	2.84	2.82	2.80	2.77	2.75	2.73	2.71	2.69	2.67	2.65	2.63	2.60	2.58	2.56	2.54
H <sub>2</sub> ee	5.49	5.62	5.74	5.87	5.99	6.12	6.25	6.17	6.09	6.01	5.93	5.85	5.77	5.70	5.62	5.54

Supply to filling station	NMVOC [mg/kWh]															
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Hydrogen																
H <sub>2</sub> natural gas	191	191	191	191	191	190	190	190	190	190	189	189	189	189	189	189
H <sub>2</sub> ee	30	30	30	31	31	31	31	31	31	32	32	32	31	31	31	30

Supply to filling station	SO <sub>x</sub> [mg/kWh]															
Hydrogen	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
H <sub>2</sub> natural gas	66	62	59	56	53	49	46	44	41	39	36	33	31	28	26	23
H <sub>2</sub> ee	153	155	157	159	161	163	165	163	161	159	157	155	153	151	149	147

Supply to filling station	CO [mg/kWh]															
Hydrogen	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
H <sub>2</sub> natural gas	100	99	98	97	96	95	94	93	92	91	91	90	89	88	87	86
H <sub>2</sub> ee	197	199	201	203	205	207	209	208	206	204	202	200	199	197	195	193

Supply to filling station	PM <sub>10</sub> [mg/kWh]															
Hydrogen	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
H <sub>2</sub> natural gas	127	123	119	115	111	107	103	99	95	91	87	83	79	75	71	67
H <sub>2</sub> ee	261	264	267	270	272	275	278	275	271	268	264	261	257	254	250	247

Supply to filling station	PM <sub>2.5</sub> [mg/kWh]															
Hydrogen	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
H <sub>2</sub> natural gas	129	125	121	117	113	109	105	101	97	93	89	86	82	78	74	70
H <sub>2</sub> ee	245	248	251	254	257	259	262	259	256	252	249	246	242	239	235	232

## ANNEX II: ABBREVIATIONS

BEV	Battery Electric Vehicle
bioCO <sub>2</sub>	Biogenic CO <sub>2</sub> from flue gas (12 - 15 vol.-%) of biomass combustion
CO <sub>2</sub> air	Capture of CO <sub>2</sub> from air (0.04 vol.-%)
CNG	Compressed natural gas
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CH <sub>4</sub>	Methane
CHP	Combined heat and power (plant)
CRG	Compressed renewable gas
dLUC	Direct land use change
E-fuel	Synthetic fuel, produced with electricity (Power-to-fuel) and CO <sub>2</sub> from air or sustainable biomass
EtOH	(Bio)Ethanol
FAME	Fatty acid methyl ester (biodiesel)
FT-diesel	Fischer-Tropsch diesel
GHG	Greenhouse gas emissions
H <sub>2</sub>	Hydrogen
HEV	Hybrid electric vehicle
HFCV	Hydrogen fuel cell vehicle
HFC	Hydrogen fuel cell
HVO	Hydrated vegetable oil
Hydro	Hydro power
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
iLUC	Indirect land use change
LCA	Life Cycle Assessment
LUC	Land use change
N <sub>2</sub> O	Nitrous oxide (laughing gas)
NH <sub>3</sub>	Ammonia
NMVOOC	Non-methane volatile organic compounds
NO <sub>x</sub>	Nitrogen oxides
PED	Primary energy demand
PHEV	Plug-In hybrid electric vehicle
PM <sub>10</sub>	Particulate matter with aerodynamic diameter < 10 µm
PM <sub>2.5</sub>	Particulate matter with aerodynamic diameter <2.5 µm
PV	Photovoltaics
SO <sub>x</sub>	Sulfur oxides

## ANNEX III: REFERENCES

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